Annex A. Atmospheric Science

A.1. Air Particle Monitoring

A.1.1. Measurements and Analytical Specifications

Table A-1. Summary of integrated and continuous samplers included in the field comparison.

Abbreviation	Instrument	Manufacturer / Research Institute
INTEGRATED PARTICLE OR GAS/PARTICLE INSTRUMENTS		
Dichot	Dichotomous Sampler with Virtual Impactor	Andersen Instruments (Smyrna, GA)[a]
AND-241 Dichot	Thermo Andersen Series 241 Dichotomous Sampler	Andersen Instruments
AND-246 Dichot	Thermo Andersen SA-246B Dichotomous Sampler	Andersen Instruments
AND-HIVOL10 FRM	Thermo Andersen GMW-1200 HiVol PM_{10} FRM Sampler	Andersen Instruments
ARA-PCM	ARA Particle Composition Monitor	Atmospheric Research and Analysis Inc. (Plano, TX)
CMU	CMU Speciation Sampler	Carnegie Mellon University (CMU), (Pittsburgh, PA)
DRI-SFS	DRI Sequential Filter Sampler	Desert Research Institute (Reno, NV)
HEADS (or HI)	Harvard EPA Annular Denuder System (or Harvard Impactor)	Harvard School of Public Health (Boston, MA)
IMPROVE_SS[b]	IMPROVE Speciation Sampler	URG Corp. (Chapel Hill, NC)
URG-3000N[b]	Modified IMPROVE Module C Sampler for Carbon	URG Corp.
MASS-400[b]	URG Mass Aerosol Speciation Sampler Model 400	URG Corp.
MASS-450[b]	URG MASS Model 450	URG Corp.
MiniVol	Battery-Powered Portable Low-Volume Sampler	Air Metrics Inc. (Eugene, OR)
PC-BOSS	Particle Concentrator-Brigham Young University Organic	Brigham Young University (Provo, UT)
SAMPLING SYSTEM		
PQ-200 FRM	BGI PQ-200 FRM Sampler	BGI Inc. (Waltham, MA)
PQ-200 FRMA	BGI PQ-200A FRM Audit Sampler	BGI Inc.
R&P-ACCU	R&P-Automated Cartridge Collector Unit Sampler	Rupprecht & Patashnick, Co. (Albany, NY)[a]
R&P-2000 FRM	R&P Partisol-2000 FRM Sampler	Rupprecht & Patashnick, Co.
R&P-2000 FRMA	R&P Partisol-2000 FRM Audit Sampler	Rupprecht & Patashnick, Co.
R&P-2025 Dichot[b]	R&P Partisol 2025 Dichotomous Sequential Air Sampler	Rupprecht & Patashnick, Co.
R&P-2025 FRM	R&P Partisol-Plus Model 2025 $PM_{2.5}$ Sequential Samplers	Rupprecht & Patashnick, Co.
R&P-2300[b]	R&P Partisol 2300 Chemical Speciation Sampler	Rupprecht & Patashnick, Co.
RAAS-100 FRM	Thermo Andersen Reference Ambient Air Sampler Model 100	Andersen Instruments
FRM SAMPLER		
RAAS-200 FRM	Thermo Andersen RAAS Model 200 FRM Audit Sampler	Andersen Instruments
RAAS-300 FRM	Thermo Andersen RAAS Model 300 FRM Sampler	Andersen Instruments
RAAS-400[b]	Thermo Andersen RAAS Model 400 Speciation Sampler	Andersen Instruments
SASSb	MetOne Spiral Ambient Speciation Sampler	Met One Instruments (Grants Pass, OR)
SCS	$PM_{2.5}$ Sequential Cyclone Sampler	New York University (New York, NY)

Abbreviation	Instrument	Manufacturer / Research Institute
URG-PCM[b]	URG Particle Composition Monitor	URG Corp. (Chapel Hill, NC)
VAPS	URG Versatile Air Pollution Sampler	URG Corp.
CONTINUOUS MASS INSTRUMENTS		
BAM	β-Attenuation Monitor Model 1020	Met One Instruments
nano-BAM	Met One BAM Model 1020 with 150 nm impactor	Met One Instruments
CAMM	Continuous Ambient Mass Monitor	Developed by Harvard School of Public Health, comercialized by Thermo Andersen Instruments; now withdrawn from market
RAMS	Real-Time Ambient Mass Sampler (modified Tapered Element Oscillation Microbalance with diffusion denuder and Nafion dryer)	Brigham Young University
TEOM	Tapered Element Oscillating Microbalance	Rupprecht & Patashnick, Co.
30 °C-TEOM	TEOM operated at 30 °C	Rupprecht & Patashnick, Co.
50 °C-TEOM	TEOM operated at 50 °C	Rupprecht & Patashnick, Co.
SES-TEOM	TEOM 1400a Series with Sample Equilibration System	Rupprecht & Patashnick, Co.
D-TEOM	Differential TEOM	Rupprecht & Patashnick, Co.
FDMS-TEOM	Filter Dynamics Measurement System TEOM	Rupprecht & Patashnick, Co.
ACCU-TEOM	TEOM 1400 Series with an automated cartridge collection unit	Rupprecht & Patashnick, Co.
CONTINUOUS PARTICLE LIGHT SCATTERING INSTRUMENTS		
Dust Trak	Dust Trak nephelometer	TSI Inc. (Shoreview, MN)
EcoTech	EcoTech Model M9003 nephelometer	EcoTech Pty Ltd., Australia (American EcoTech, Warren, RI)
NGN	NGN-2 nephelometer	Optec Inc. (Lowell, MI)
RR-M903	Radiance Research Nephelometer Model M903	Radiance Research Inc. (Seattle, WA)
CONTINUOUS ELEMENT INSTRUMENTS		
GFAAS	Graphite Furnace Atomic Absorption Spectrometry—aerosol collection as preconcentrate slurry	University of Maryland (College Park, MD)
SEAS	Semicontinuous Elements in Aerosol Sampler	University of Maryland
CONTINUOUS NITRATE INSTRUMENTS		
ADI-N	Aerosol Dynamics Inc. flash volatilization analyzer	Aerosol Dynamics Inc. (Berkeley, CA)
ARA-N	Atmospheric Research and Analysis NO_3^- analyzer	Atmospheric Research and Analysis Inc.
R&P-8400N	R&P-8400N Flash Volatilization Continuous NO_3^- Analyzer	Rupprecht & Patashnick, Co.
CONTINUOUS SULFATE INSTRUMENTS		
ADI-S	Aerosol Dynamics Inc. Flash Volatilization Analyzer	Aerosol Dynamics Inc.
CASM	Continuous Ambient Sulfate Monitor (prototype of the TE-5020 by Thermo Electron [Franklin, MA])	Harvard School of Public Health
R&P-8400S	R&P-8400S Flash Volatilization Continuous SO_4^{2-} Analyzer	Rupprecht & Patashnick, Co.
TE-5020	Thermo Electron Model 5020 SO_4^{2-} Particulate Analyzer	Thermo Electron Corp. (Franklin, MA)
CONTINUOUS MULTI-ION INSTRUMENTS		
AIM	Ambient Ion Monitor Model 9000 (Cl^-,NO_2^-,NO_3^-,PO_4^{3-}, SO_4^{2-}, NH_4^+,Na^+,Mg^{2+},K^+,Ca^{2+})	URG Corp.
Dionex-IC	Dionex Ion Chromatograph (F^-, Cl^-, NO_2^-, Br^-,NO_3^-, PO_4^{3-}, SO_4^{2-}, Li^+, NH_4^+,Na^+,Mg^{2+},K^+,Ca^{2+})	Dionex Corp.
ECN	Energy Research Center of the Netherlands IC-based sampler (Cl^-, NO_3^-, SO_4^{2+},NH_4^+,Na^+, Mg^{2+},K^+,Ca^{2+})	Energy Research Center of the Netherlands (Petten, the Netherlands)c
PILS-IC	Particle into Liquid Sampler, coupled with IC (Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2+},NH_4^+,Na^+,Mg^{2+},K^+,Ca^{2+})	Georgia Institute of Technology (Atlanta, GA)
TT	Texas Tech IC-based sampler (NO_3^-, SO_4^{2+})	Texas Tech University (Lubbock, TX)

Abbreviation	Instrument	Manufacturer / Research Institute
CONTINUOUS CARBON INSTRUMENTS		
OC and EC		
ADI-C	ADI Flash Volatilization Carbon Analyzer	Aerosol Dynamics Inc.
RU-OGI	Rutgers University/Oregon Graduate Institute in-situ carbon analyzer (OC, EC)	Rutgers University (Camden, NJ)/Oregon Graduate Institute (Beaverton, OR)
R&P-5400	R&P-5400 continuous ambient carbon analyzer	Rupprecht & Patashnick, Co.
Sunset OCEC	Sunset Semi-Continuous Real-Time Carbon Aerosol Analysis Instrument	Sunset Laboratory, Inc. (Tigard, OR)
BC		
Aethalometer		Magee Scientific Co. (Berkeley, CA)
AE-16	Magee AE-16 aethalometer (BC)	Magee Scientific Co.
AE-20	Magee AE-20 dual wavelength aethalometer (BC)	Magee Scientific Co.
AE-21	Magee AE-21 dual-wavelength aethalometer (BC)	Magee Scientific Co.
AE-31	Magee AE-31 seven color aethalometer (BC)	Magee Scientific Co.
DRI-PA	DRI Photoacoustic Analyzer (BC)	Droplet Measurement Technologies, Inc. (Boulder, CO)
MAAP	Multi-Angle Absorption Photometer, Model 5012 (BC)	Thermo Scientific Corp. (Franklin, MA)
PSAP	Particle Soot Absorption Photometer (BC)	Radiance Research Inc. (Seattle, WA)
OTHER CARBON		
PAS-PAH	Photo-Ionization Monitor for PAHs (Model PAS 2000)	EcoChem Analytics (League City, TX)
PILS-WSOC	PILS-WSOC Analyzer, combination of PILS and total organic analyzer (TOA)	Georgia Institute of Technology
PARTICLE SIZING INSTRUMENTS FOR MASS AND CHEMICAL SPECIATION		
DRUM-3	Davis Rotating-Drum Uniform Size-Cut Monitor (0.1–2.5 µm in three stages)	University of California–Davis (Davis, CA)
DRUM-8	Davis Rotating-Drum Uniform Size-Cut Monitor (0.09- > 5.0 µm in eight stages)	University of California–Davis
ELPI	Electrical Low Pressure Impactor (0.007–10 µm in 12 stages)	Dekati (Tampere, Finland)
LPI	Low Pressure Impactor (0.03–10 µm in 13 stages)	Aerosol Dynamics, Inc.
MOUDI	Micro Orifice Uniform Deposit Impactor	MSP Corp. (Minneapolis, MN)
MOUDI-100	MOUDI Model 100 (0.18–18 µm in eight stages)	MSP Corp.
MOUDI-110	MOUDI Model 110 (0.056–18 µm in 10 stages)	MSP Corp.
Nano-MOUDI	Nano MOUDI (0.010–0.056 µm in three stages coupled to MOUDI Model 110)	MSP Corp.
PARTICLE NUMBER / VOLUME INSTRUMENTS		
APS	Aerodynamic Particle Sizer	TSI Inc.
APS-3320	TSI Model 3320 (0.5–20 µm)	TSI Inc.
APS-3321	TSI Model 3321 (0.5–20 µm; replaced TSI Model 3320)	TSI Inc.
DMA	Differential Mobility Analyzer	TSI Inc.
DMA-3081	TSI Model 3081 (0.01–1.0 m)	TSI Inc.
DMA-3085	TSI Model 3085 (0.002–0.15 µm)	TSI Inc.
EEPS	Engine Exhaust Particle Sizer (EEPS 0.056–0.56 µm)	TSI Inc.
FMPS	Fast Mobility Particle Sizer (FMPS 0.056–0.56 µm)	TSI Inc.
GRIMM-1108	Optical Particle Counter (OPC; 0.3–20 µm)	GRIMM Technologies, Inc. (Douglasville, GA)
SMPS	Scanning Mobility Particle Sizer	TSI Inc.
SMPS-3936	TSI Model 3936L (0.01–1.0 µm)	TSI Inc.
Nano-SMPS-3936	TSI Model 3936N (0.002–0.15 µm)	TSI Inc.

Abbreviation	Instrument	Manufacturer / Research Institute
SMPS + C	SMPS and Condensation Nucleus Counter (0.005–0.35 or 0.01–0.875 µm)	GRIMM Technologies, Inc.
SMPS-custom	DMA Model 3071 and CPC Model 3010	TSI Inc.
WPS	Wide-Range Particle Spectrometer (0.01–10.0 µm)	MSP Corp.

SINGLE PARTICLE INSTRUMENTS

AMS	Aerosol Mass Spectrometer (0.04–2 µm)	Aerodyne Research Inc. (Billerica, MA)
ATOFMS	Aerosol Time of Flight Mass Spectrometer (0.3–2.5 µm)	TSI Inc.
CNC, CPC	Condensation Nucleus Counters, Condensation Particle Counter	Various vendors
DAASS	Dry-Ambient Aerosol Size Spectrometer consisting of two SMPS and One APS (0.003–10 µm)	Carnegie Mellon University
LIBS	Laser-Induced Breakdown Spectroscopy	National Research Council, Industrial Materials Institute (Boucherville, Quebec, Canada)
PALMS	Particle Analysis by Laser Mass Spectrometer (0.22–2.5 µm)	NOAA (Boulder, CO)
RSMS-II	Rapid Single Particle Mass Spectrometer -II (0.035–1.1 µm)	University of Delaware (Newark, DE)
RSMS-III	Rapid Single Particle Mass Spectrometer RSMS-III (0.01–2.0 µm)	University of Delaware

LABORATORY INSTRUMENTS

DRI Model 2001	DRI Model 2001 Thermal/Optical Carbon Analyzer (OC, EC, Eight Carbon Fractions with reflectance and transmittance laser correction)	Atmoslytic, Inc. (Calabasas, CA)
SEM	Scanning Electron Microscopy	Various vendors

[a]Now with Thermo Scientific, Franklin, MA.
[b]EPA-approved speciation sampler used in the Speciation Trends Network (STN).
[c]Now commercialized by Applikon Analytical, the Netherlands, and marketed under the name "MARGA" (Monitor for Aerosols and Gases in Ambient Air).
[d]Not available.

Source: Chow et al. (2008)

Table A-2. Summary of PM$_{2.5}$ and PM$_{10}$ FRM and FEM samplers.

Manufacturer[a]	Sampler Name	Size Cut[b]	Description	FRM or FEM[c]	Designation #	FRN
BGI Inc.	PQ-100	PM$_{10}$	Louvered PM$_{10}$ inlet; operates at flow rate of 16.7 L/min; 24-h integrated sampler; uses a mass flow meter to adjust to equivalent volumetric flow at ambient temperature and pressure.	FRM	RFPS-1298-124	Vol. 63, p. 69625, 12/17/98
BGI Inc.	PQ-200	PM$_{10}$		FRM	RFPS-1298-125	Vol. 63, p. 69625, 12/17/98
BGI Inc.	PQ-200	PM$_{2.5}$	Identical to PM$_{10}$ sampler, but uses a WINS[e] impactor downstream of the PM$_{10}$ inlet for PM$_{2.5}$ fractionation at 16.7 L/min; 24-h integrated sampler.	FRM	RFPS-0498-116	Vol. 63, p. 18911, 04/16/98
						Vol. 63, p. 31993, 06/11/98
BGI Inc.	PQ-200VSCC or PQ-200AVSCC	PM$_{2.5}$	Same as BGI PQ200 PM$_{2.5}$ sampler, but with BGI VSCC instead of WINS impactor; PQ200A is a portable audit sampler, similar in design to PQ-200, but more compact in nature.	FEM (II)	EQPM-0202-142	Vol. 67, p. 15567, 04/02/02
R&P	R&P-2000	PM$_{10}$	R&P Partisol FRM Model 2000 PM$_{10}$ sampler with louvered PM$_{10}$ inlet; operates at flow rate of 16.7 L/min; 24-h integrated sampler; uses a mass flow meter to adjust to equivalent volumetric flow at ambient temperature and pressure; single-channel sampler.	FRM	RFPS-1298-126	Vol. 63, p. 69625, 12/17/98
R&P	R&P-2000	PM$_{2.5}$	R&P Partisol FRM Model 2000 PM$_{2.5}$ sampler, identical to PM$_{10}$ sampler, but uses a WINS impactor downstream of	FRM	RFPS-0498-117	Vol. 63, p. 18911, 04/16/98

Manufacturer[a]	Sampler Name	Size Cut[b]	Description	FRM or FEM[c]	Designation #	FRN
R&P	R&P2000A	$PM_{2.5}$	the PM_{10} inlet for $PM_{2.5}$ fractionation at 16.7 L/min; 24-h integrated sampler; R&P2000A is a portable audit sampler.	FRM	RFPS-0499-129	Vol. 64, p. 19153, 04/19/99
R&P	R&P-2025	PM_{10}	R&P Partisol-Plus Model 2025 PM_{10} sequential sampler with louvered PM_{10} inlet; operates at 16.7 L/min; 24-h integrated sampler; uses a mass flow meter to adjust to equivalent volumetric flow at ambient temperature and pressure; sequential sampler with a capacity of 16 filter cassettes, allowing for two weeks of unattended daily sampling; filter exchange is performed pneumatically.	FRM	RFPS-1298-127	Vol. 63, p. 69625, 12/17/98
R&P	R&P-2025	$PM_{2.5}$	R&P Partisol-Plus Model 2025 $PM_{2.5}$ sequential sampler, identical to R&P-2025 PM_{10} sampler, but uses a WINS impactor downstream of the PM_{10} inlet for $PM_{2.5}$ fractionation at 16.7 L/min.	FRM	RFPS-0498-118	Vol. 63, p. 18911, 04/16/98
R&P	R&P2000VSCC	$PM_{2.5}$	Same as R&P-2000 $PM_{2.5}$ sampler, but with BGI VSCC, instead of WINS impactor for $PM_{2.5}$ separation.	FEM (II)	EQPM-0202-143	Vol. 67, p. 15567, 04/02/02
R&P	R&P2000AVSCC	$PM_{2.5}$	Same as R&P-2000A $PM_{2.5}$ sampler, but with BGI VSCC instead of WINS impactor for $PM_{2.5}$ separation.	FEM (II)	EQPM-0202-144	Vol. 67, p. 5567, 04/02/02
R&P	R&P-2025-VSCC	$PM_{2.5}$	Same as R&P-2025 $PM_{2.5}$ sampler, but with BGI VSCC instead of WINS impactor, for $PM_{2.5}$ separation.	FEM (II)	EQPM-0202-145	Vol. 67, p. 15567, 04/02/02
Andersen	RAAS-100	PM_{10}	Andersen Instruments, Inc. Model RAAS10-100 PM_{10} sampler with louvered PM_{10} inlet; operates at flow rate of 16.7 L/min; 24-h integrated sampler; volumetric flow measured by dry test meter at pump outlet modulates pump speed to maintain flow rate; single-channel.	FRM	RFPS-0699-130	Vol. 64, p. 33481, 06/23/99
Andersen	RAAS-100	$PM_{2.5}$	Graseby Andersen Model RAAS2.5-100 $PM_{2.5}$ sampler, similar to RAAS-100 PM_{10} with a WINS impactor for $PM_{2.5}$ separation.	FRM	RFPS-0598-119	Vol 63, p. 31991, 06/11/98
Andersen	RAAS200A	PM_{10}	Andersen Instruments, Inc. Model RAAS10-200 and RAAS2.5-100 Audit Samplers, portable compact version; similar to RAAS-100.	FRM	RFPS-0699-131	Vol. 64, p. 33481, 06/23/99
Andersen	RAAS-200A	$PM_{2.5}$		FRM	RFPS-0299-128	Vol. 64, p. 12167, 03/11/99
Andersen	RAAS-300	PM_{10}	Andersen Instruments, Inc. Model RAAS10-300, sequential sampler with louvered PM_{10} inlet, operates at 16.7 L/min; capacity to hold eight filter-holders for multiple day operation.	FRM	RFPS-0699-132	Vol. 64, p. 33481, 06/23/99
Andersen	RAAS-300	$PM_{2.5}$	Graseby Andersen Model RAAS2.5-300 $PM_{2.5}$ sampler, similar to RAAS-300 PM_{10} sampler with a WINS impactor for $PM_{2.5}$ separation.	FRM	RFPS-0598-120	Vol. 63, p. 31991, 06/11/98
Thermo Scientific, Inc.	CAPS	$PM_{2.5}$	Model 605 Computer Assisted Particle Sampler (CAPS), 24-h integrated. Not available commercially.	FRM	RFPS-1098-123	Vol. 63, p. 8036, 10/29/98
Thermo Scientific, Inc.	RAAS 100-VSCC	$PM_{2.5}$	Same as RAAS-100 $PM_{2.5}$ sampler, but with BGI VSCC, instead of WINS impactor.	FEM (II)	EQPM-0804-153	Vol. 69, p. 47924, 08/06/04
Thermo Scientific, Inc.	RAAS 200-VSCC	$PM_{2.5}$	Same as RAAS-200 $PM_{2.5}$ sampler, but with BGI VSCC instead of WINS impactor.	FEM (II)	EQPM-0804-154	Vol. 69, p. 47924, 08/06/04
Thermo Scientific, Inc.	RAAS 300-VSCC	$PM_{2.5}$	Same as RAAS-300 $PM_{2.5}$ sampler, but with BGI VSCC instead of WINS impactor.	FEM (II)	EQPM-0804-155	Vol. 69, p. 47925, 08/06/04
URG Corp.	MASS-100	$PM_{2.5}$	Model MASS100 $PM_{2.5}$ sampler with louvered PM_{10} inlet followed by WINS impactor, operates at 16.7 L/min; 24-h integrated, volumetric flow measured by dry test meter at pump outlet modulates pump speed to maintain flow rate; single channel.	FRM	RFPS-0400-135	Vol. 65, p. 26603, 05/08/00
URG Corp.	MASS-300	$PM_{2.5}$	Model MASS300 $PM_{2.5}$ sampler with louvered PM_{10} inlet followed by WINS impactor, operates at 16.7 L/min; 24-h integrated, sequential sampler with circular tray holding six filters.	FRM	RFPS-0400-136	Vol. 65, p. 26603, 05/08/00
Tisch Environmental, Inc.	TE-6070 HiVol	PM_{10}	Model TE-6070 PM_{10} High-Volume Sampler, with TE-6001 PM_{10} size selective inlet; 8" x 10" filter holder.	FRM	RFPS-0202-141	Vol. 67, p. 15566, 04/02/02
Met One	BAM	PM_{10}	Models BAM 1020, GBAM 1020, BAM 1020-1, and GBAM 1020-1, with BX-802 inlet; glass-fiber filter tape with 1-h filter change frequency.	FEM	EQPM-0798-122	Vol. 63, p. 41253, 08/03/98

Manufacturer[a]	Sampler Name	Size Cut[b]	Description	FRM or FEM[c]	Designation #	FRN

[a] BGI Inc.: BGI Incorporated, Waltham, MA. R&P: Rupprecht & Patashnick Company, Inc., Albany, NY, now Thermo Scientific, Inc., Franklin, MA. Andersen: Graseby Andersen, later Andersen Instruments, Inc., Smyrna, GA, now Thermo Scientific, Inc., Franklin, MA. Thermo Environmental Instruments, Inc., now Thermo Scientific, Inc., Franklin, MA. URG Corp.: URG Corporation, Chapel Hill, NC. Tisch Environmental, Inc., Cleves, OH. Met One Instruments, Inc., Grants Pass, OR

[b] The efficiency of an inlet[3] is determined by its 50% cut-point (d50, the diameter at which half of the particles penetrate through the inlet, while the other half is retained by the inlet) and

[c] FRM: Federal Reference Method; FEM: Federal Equivalent Method. Roman numeral within parenthesis indicates FEM class.

[e] Particle separation in WINS is achieved by means of a single-jet round nozzle with flow directed into an impaction reservoir. The impaction surface consists of a Gelman Type A/E glass-fiber filter immersed in 1 mL of Dow Corning (Midland, MI) 704 diffusion pump oil housed in a reservoir.

Note: The geometric standard deviation (GSD, which is an indicator of the sharpness of the separation, and is derived by the square root of the ratio of particle diameters at penetrations of 16% and 84%, [d16/d84]0.5).

Source: Chow (1995); Watson and Chow (2001)

Table A-3.   Measurement and analytical specifications for filter analysis of mass, elements, ions, and carbon.

Observable	Analytical Accuracy[a]	Precision[b]	Minimum Detectable Limit (MDL)	Interferences	Comparability	Data Completeness
$PM_{2.5}$ mass	± 5% [4]	± 10% [4]	0.04 µg/m^3 c to ~1 µg/m^3 d [5,6]	Electrostatic charges need to be neutralized before measurement; positive (e.g., OC adsorption) and negative artifacts (e.g., nitrate volatilization)	Within 20% [4]	90 to 100% [6,7]
Elements	± 2 - 5% [4]	± 10% [4]	XRF: 0.4-30 ng/m^3 g [8] PIXE: 6-360 ng/m^3 d [9] ICP/MS: 0.004-25 ng/m^3 [10] 0.05-11.7 ng/m^3 [9,11] AAS: 0.02-7.15 ng/m^3 [12]	Volatile compounds may evaporate from filters due to vacuum in XRF and PIXE Potential contamination during extraction and incomplete extraction efficiency for ICP-MS and AAS Matrix interference and peak overlap may occur on heavily loaded samples.	10 to 30% depending on species [4]	90 to 100%h [6,7]
Nitrate	± 6% with spiked concentrations on Teflon[4] and ± 1-14% on nylon filters [13]	± 5 to 10% on replicate analysis [4,13,14] co-located precision ± 5-7%[14-16]	0.06 µg/m^3 e to 0.2 µg/m^3 d [1,6,17]	Subject to volatilization from Teflon or quartz-fiber filters	Within 35% and probably greater [4]	85 to 100% [6,7]
Sulfate	± 5% [4]	± 6 to 10% [4,14,15]	0.06 µg/m^3 e to 0.2 µg/m^3 d [1,6,13]	n/a	Typically within 10%; MOUDIs [13] to 20% lower than speciation samplers [4,17-19]	85 to 100% [6,7,20,21]
Ammonium	± 5% [4]	± 10% [4]	0.06 µg/m^3 e to 0.07 µg/m^3 d [1,6]	Subject to volatilization from Teflon or quartz-fiber filters	Within 30% [4]	86 to 100% [6,7]
OC, EC, TC	± 5% for TC and OC. No standard exists to determine EC accuracy	OC: ± 20%	OC: 0.1 µg/m^3 f to 0.8 µg/m^3 d	Subject to adsorption (positive artifact) and volatilization (negative artifact) of organic gases to and from quartz-fiber filters	OC: Within 20 to 50%	86 to 100% [6,7]
		EC: ± 20%	EC: 0.03 µg/m^3 d to 0.1 µg/m^3 f		EC: Within 20 to 200%	
		TC: ± 10% [4]	TC: 0.8 µg/m^3 d [1,6]		TC: Within 20% [4,17,22]	
Total mass of WSOC	DRI Model 2001 Carbon Analyzer: ± 5%[23] TOA: ± 3-7% [24,25]	DRI Model 2001 Carbon Analyzer: ± 10%[23] Sunset Carbon Analyzer: ± 3%[26] TOA: ± 5-10% [27]	DRI Model 2001 Carbon Analyzer: 0.1 - 0.23 µg C/m^3 [23] Sunset Carbon Analyzer: 0.05-0.22 µg C/m^3 [26,28] Elemental High TOC II: 0.05 µg C/m^3 [29] TOA: 0.12 µg C/m^3 [26]	Extraction efficiency and volume reduction steps	Within 17% [26]	n/a

Observable	Analytical Accuracy[a]	Precision[b]	Minimum Detectable Limit (MDL)	Interferences	Comparability	Data Completeness
Elements in water soluble matter: carbon, hydrogen, nitrogen, and sulfur	carbon: 1.5%; hydrogen: 3%; nitrogen: 3%; sulfur: 5% [30]	± 2%[30]	carbon: 0.3 µg/m³ hydrogen:0.09 µg/m³ nitrogen: 0.03 µg/m³ sulfur: 0.10 µg/m³ [30]	Contamination during sample drying step	n/a	n/a
Dissolved organic nitrogen	n/a	± 5-30%[31]	0.001µg N/m³ while inorganic nitrogen is low; ≥ 0.071µg N/m³ while inorganic nitrogen is high [31]	Concentration of inorganic nitrogen	Good correlation between UV and persulfate oxidation methods (R^2 = 0.87) [31]	n/a
Neutral polyols and polyether	GC/MS: ± 4-8% [32]	GC/MS: ± 23% [33,34] Typically ± 20%, ranged from ± 10 to ± 30% [i 32,35,36,37,38] HPLC/MS: ± 5-26%[39]	GC/MS: Levoglucosan: 10 ng/m³ [40] 2.08 ng/m³ [j 31] 0.01-0.03 ng/m³ [33,41] HPLC/MS: 9-648 pg/m³ [39]	GCMS: Extraction recovery interfered by sample matrix Derivatization efficiency IC/PAD: Overlapping peaks in chromatogram	IC/PAD: Good correlation (R^2 = 0.97) with HPLC/MS; and (R^2 = 0.89) with GC/MS Method [42]	n/a
Mono- and Di-carboxylic acids	n/a	GC/MS: ± 5-11% on 3 replicates, ± 8 % in avg [43,44] IC: ± 10-15%[45]	GC/MS: 0.04-1.12 ng/m³ [46] IC: 0.01-0.12 ng/m³ [47]	GC/MS: Extraction recovery interfered by sample matrix Derivatization efficiency IC: Overlapping peaks in chromatogram	GC/MS: Within 50% for less volatile compounds [46]	n/a
Amino acids	n/a	± 9% [48]	1.65-23.6 pg/m³ [k 48]	Derivatization efficiency Stability of derivatives Overlapping peaks in chromatogram	n/a	n/a
Mass of humic-like substances (HULIS)	n/a	n/a	0.083 ng/m³ [l 49]	Separation efficiency	n/a	n/a

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; it does not refer to measurement accuracy if no standards available.[50]
[b] Refers to precision of co-located measurements, unless specified otherwise
[c] Based on 1 µg/filter limit of detection for 24-h samples, assuming a flow rate of 16.7 L/min
[d] Based on field blanks collected with FRM samplers; µg/filter converted to µg/m³ basis assuming a flow rate of 16.7 L/min for 24-h
[e] Based on ½ of a 47-mm filter extracted in 15 mL deionized-distilled water (DDW) for 24-h samples, assuming a flow rate of 16.7 L/min
[f] Based on 0.2 µg/cm² detection limit and 13.8 cm² deposit area for a 47-mm filter, assuming a flow rate of 16.7 L/min for 24-h
[g] Based on 24-h samples at a flow rate of 16.7 L/min and analyzed by XRF
[h] Except for samples from one FRM sampler at Atlanta Supersite, for which data recovery was 50%[7]; reason not reported.
[i] Reported as uncertainty in literature
[j] Based on 24-h samples at a flow rate of 16.7 L/min
[k] Based on 13.8 cm² deposit area for a 47-mm filter and extracted into a final volume of 200 µL, assuming a flow rate of 16.7 L/min for 24-h and molecular weight of amino acid = 150
[l] Based on 13.8 cm² deposit area for a 47-mm filter and extracted into a final volume of 200 µL, assuming a flow rate of 16.7 L/min for 24-h
n/a: Not available

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989)

Table A-4.   Measurement and analytical specifications for filter analysis of organic species.

Organic Species	Analytical Accuracy		Precision		MDL		Interferences		Comparability
	TD	Solvent Extraction	TD	Solvent Extraction	TD	Solvent Extraction	TD	Solvent Extraction	

	Analytical Accuracy		Precision		MDL		Interferences		
PAHs	± 2.8-24.1%[51] ± 4.4-29.4%[52] 13.8-26.5%[53] ± 0.5-12.9%[54] 0.05-4.83%[55]	Z-score values 0 to -1.9 [56] ± 4-8%[32] ± 6.5-22%[57]	Avg ± 3.2%, ranged from ± 0.05 to ± 11.5%[55]	Avg ± 8%, ranged from ± 3.8 to ± 15%[56] ± 23%[56] Avg ± 2.6%, ranged from ± 0.6 to ± 9.5%[57] typically ± 20%, ranged from ± 10 to ± 30%c [32,35-37]	0.016-0.48 ng/m^3 a [58] 0.030-0.45 ng/m^3 a [55]	0.83-1.66 ng/m^3 b [38] 0.033-3.85 ng/m^3 b [56] 0.01-0.03 ng/m^3 [33,34,37] 0.76-276 pg/m^3 b [57]	Fragmentation of labile compounds	Possible contaminants from solvents and complicated extraction procedures Loss of volatile compounds during the extraction and pretreatment steps Possible carryover from injection port	R^{2}s for solvent extraction were 0.95 [58], 0.97 [55], and 0.98 [59]
n-Alkanes	n/a	± 4-8%[32]	Avg ± 3.2%, ranged from ± 0.05 to ± 11.5%[55]	± 23%[56] Typically ± 20%, from ± 10 to ± 30%c [32,35-37]	0.081-0.86 ng/m^3 a [58] 0.061-0.97 ng/m^3 a [55]	0.01-0.03 ng/m^3 [33,34,37]	Same as PAHs	Same as PAHs	R^{2}s for solvent extraction are 0.94 [58], and 0.98 [55,59]
Hopanes	n/a	n/a	Avg ± 3.2%, ranged from ± 0.05 to ± 11.5%[55]	± 23%[56] Typically ± 20%, from ± 10 to ± 30%c [32,35-37]	0.030-0.14 ng/m^3 a [55]	0.83-1.66 ng/m^3 b [38] 0.01-0.03 ng/m^3 [33,41] 0.01 ng/m^3 [37]	Same as PAHs	Same as PAHs	R^{2}s for solvent extraction are 0.99 [55] and 0.998 [59]
Steranes	n/a	n/a	Avg ± 3.2%, ranged from ± 0.05 to ± 11.5%[55]	n/a	0.018-0.063 ng/m^3 a [55]	0.83-1.66 ng/m^3 b [60]	Same as PAHs	Same as PAHs	R^{2}s for solvent extraction are 0.97 [55] and 0.998 [59]
Organic acids (including n-alkanoic acids, n-alkenoic acids, alkane dicarboxylic acids, aromatic carboxylic acids, resin acids)	n/a	± 4-8%[32]	± 10 to ± 29%[55]	± 24%[41] ± 23%[56] Typically ± 20%, from ± 10 to ± 30%c [32,35-37]	Mono-carboxylic acids (C8, C12, and C16): 0.79, 2.0, and 3.2 ng/m^3 a [54]	0.01-0.03 ng/m^3 [33,41]	Fragmentation of labile compounds Loss of polar species due to absorption onto the surface of the injector Improper stationary phase column used during TD analysis Incomplete thermal desorption of analytes because of strong affinity with filter matrix	Possible contaminants from solvents and complicated extraction procedures Loss of volatile compounds during the extraction and pretreatment steps Possible carryover from injection port Low derivatization efficiency	Correlation with solvent extraction method R^2 = 0.731 [59]
Polyols and sugars, including guaiacol and substituted guaiacols, syringol and substituted syringols, anhydrosugars	n/a	± 4-8%[32]	n/a	± 23%[56] Typically ± 20%, from ± 10 to ± 30%c [32,35-37]	n/a	Levoglucosa: 10 ng/m^3 [61] 2.08 ng/m^3 b [38] 0.01-0.03 ng/m^3 [33,41]	Same as organic acids	Same as organic acids	n/a

Analytical Accuracy	Precision	MDL	Interferences

[a] Assumes 2.9 cm^2 filter used in analysis from a deposit area of 13.8 cm^2, and sample collection at a flow rate of 16.7 L/min for 24-h

[b] Assumes sample collection at a flow rate of 16.7 L/min for 24-h.

[c] Reported as uncertainty in literature.

[d] Assumes a final extract volume of 1 mL and sample collection at a flow rate of 16.7 L/min for 24-h. n/a: Not available

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-5   Measurement and analytical specifications for continuous mass and mass surrogate instruments.

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness
INERTIA INSTRUMENTS							
TEOM Air is drawn through a size-selective inlet onto the filter mounted on an oscillating hollow tube. The oscillation frequency changes with mass loading on the filter, which is used to calculate mass concentration by calibrating measured frequency with standards.	10 min–24 h	± 0.75%[c]	± 5 µg/m^3 for 10-min avg[c,d] ± 1.5 µg/m^3 for 1-h avg[c,d]	0.01 µg, which is 0.06 µg/m^3 for 1-h avg[c]	Loses semi-volatile species at both 30°C and 50°C. SES-TEOM, while less sensitive to relative humidity, does not com-pletely eliminate loss of semi-volatile species	Underestimated FRM mass by 20 to 35% [62-64]	99% [65][87] to 92% [6]
FDMSTEOM. A self-referencing TEOM with a filter at 4 °C that accounts for volatile species. It is equipped with a diffusion Nafion dryer to remove particle-bound water. The Teflon (PTFE)-coated borosilicate glass-fiber filter that is main-tained at 4 °C removes particles during the reference flow cycle. The flow alternates between a base and reference flow every 6 min. If a negative mass is mea-sured during the reference flow, due to loss of volatiles from the filter, it is added to the mass made during the prior particle-laden samples to obtain total PM$_{2.5}$ concentration.	1-h - 24 h	± 0.75%[c]	< 10%[65]	0.01 µg, which is 0.06 µg/m^3 for 1-h avg[c]	n/a	9 to 30% higher than FRM mass Within 10% of mass by D-TEOM, PC-BOSS, RAMS and BAM [66,67]	95 to 99%[65,68] 57 to 65%[67]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness
Differential Tapered Element Oscillating Microbalance (D-TEOM) Similar to FDMS, but an electrostatic precipitator is used in place of the glass-fiber filter to remove particles during the 6 min reference flow cycle.	1-h - 24 h	± 0.75%[c]	< 10%[e 65,69,70]	0.01 µg, or 0.06 µg/m³ for 1-h avg[c]	n/a	Within 10% of FDMS-TEOM [65,66]	86%[65]
RAMS A TEOM with a cyclone inlet, diffusion denuders, and Nafion dryer. Particles are collected on a "sandwich" filter (Teflon followed by carbon-impregnated glass-fiber filter) on the tapered oscillating element. The various denuders remove gas phase organic compounds, nitric acid, sulfur dioxide, nitrogen dioxide, ammonia, and ozone, which could otherwise be adsorbed by the TEOM filter.	10 min - 24 h	n/a	< 10%f [71]	± 1 to 2 µg/m³ for 30-min avg [72]	n/a	10 to 20% higher than avg[g 72] FRM mass [73,74]	n/a

PRESSURE DROP INSTRUMENT

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness
Continuous Ambient Mass Monitor (CAMM) Air is drawn through a Teflon-membrane filter tape and the pressure drop across the filter is monitored continuously. The proportion of pressure drop to aerosol loading is related to the PM concentration. The filter tape advances every 30–60 min to minimize volatilization and adsorption artifacts during sampling.	1-h – 24 h	n/a	28.1% for 1-h avg 15.9% for 24-h avg (~3.5 µg/m³) [75]	< 5 µg/m³ for 1 h avg [75]	Needs effective sealing for good performance; even slight leaks may result in highly variable baseline. Probably less sensitive than D-TEOM or RAMS. [75,77]	Varied performance: within 2% of SES-TEOM and FRM at Houston, TX, while not correlated with D-TEOM or FRM at Rubidoux, CA.[76,77]	n/a

B-ATTENUATION INSTRUMENT

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness
β Attenuation Monitor (BAM) β rays electrons) are passed through a quartz-fiber filter tape on which particles are collected. The loss of electrons (β attenuation) caused by the particle loading on the filter is converted to mass concentration, after subtraction of blank filter attenuation.	1-h – 24 h	± 3 µg for 24-h avg concentrations < 100 µg/m³ and 2% for 100 to 1,000 µg/m³ ± 8 µg < 100 µg/m³ and 8% for 100 to 1000 µg/m³ (1-h)[c]	± 2 µg/m³ [c,h]	5 µg/m³ for 1-h avg[l]	Water absorption by particles may result in higher mass measurements; maybe important at RH >85%	Up to 30% higher than FRM mass and within 2% of FDMS-TEOM [63,67]	93 to 99%[6,65,67]

LIGHT-SCATTERING INSTRUMENT

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness
Nephelometers (including DustTrak) A light source illuminates the sample air and the scattered light is detected at an angle (usually 90°) relative to the source. The signal is related to the concentration of the particles giving an estimate of the particle light scattering coefficient. Zero air calibrations can be performed using particle-free air.	5 min – 24 h	n/a	Nephelometers: < 5% for TSI and NGNi nephelometers [78,79] DustTrak: Greater of 0.1% or 1 µg/m³ [c,h]	Nephelometer: < 1.5 Mm-1 DustTrak: ± 1 µg/m³ for 24-h avg[j]	Conversion factor to calculate mass concentration from bscat may vary depending on particle size, shape and composition. Light scattering by DustTrak proportional to dp [6] for dp < 0.25 µm [79]	Typically good correlation with SES-TEOM and D-TEOM (R² >0.80). Comparability depends on conversion factor used.	>80 to 98% for NGN2, RR-M903 and GreenTek Nephelometers [6] >80% for DustTrak [6 95] to 98% for GRIMM optical particle counter[65]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision[b]	MDL	Interferences	Comparability	Data Completeness

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards available.

[b] Refers to precision of co-located measurements, unless specified otherwise.

[c] Manufacturer-specified measurement parameter.

[d] Details not available on how the precision was obtained and whether it refers to co-located precision.

[e] Includes a combination of estimates: based on co-located precision and based on regression slopes.

[f] Co-located precision with respect to PC-BOSS reconstructed $PM_{2.5}$ mass.

[g] Using glass-fiber "sandwich" filter.

[h] Specified as "resolution" by the manufacturer.

[i] Co-located precision estimate based on regression slope for NGN nephelometer (slope = 1.01, intercept = -1.64 $\mu g/m^3$, R^2 = 0.99).

[j] Specified as "Zero stability" by the manufacturer.

n/a: Not available.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2003b); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2004); [45]Yao et al. (2004); [46]Li and Yu (2004); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005c); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a).

Table A-6. Measurement and analytical specifications for continuous elements.

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	MDL	Interferences	Comparability	Data Completeness
Semi-continuous Elements in Aerosol System (SEAS) Particles are collected at 30-min interval for subsequent laboratory atomic absorption analysis for elements. Aerosol collection is through condensational growth by direct steam injection. The grown particles are separated from the airstream using virtual impactor. The droplets accumulate in a slurry that is pumped to a separate sample vial for each time period.	15-30 min	± 10%[b] for Mn, Fe, Ni, Cu, Zn, Se, Cd, and Sb ± 20%[b] for Cr, As, and Pb [80]	20 to 43%[c] [80]	Al: 440 pg Cr: 6.7 pg Mn: 9.9 pg Fe: 85 pg Ni: 42 pg Cu: 26 pg Zn: 43 pg As: 27 pg Se: 33 pg Cd: 3.2 pg Sb 160 pg Pb: 31 pg[80]	Spectral interferences limit the number of elements detected simultaneously	n/a	n/a
Laser-Induced Breakdown Spectroscopy (LIBS) Used for in-situ single particle analysis. A high-power pulsed laser is projected into particles producing high-temperature plasma. Photons emission from relaxing atoms in the excited states provides characteristics of individual elements.	A few seconds	n/a	n/a	Na: 143 fg Mg: 53 fg Al: 184 fg Ca: 50 fg Cr: 166 fg Mn: 176 fg Cu: 15 fg[81]	n/a	n/a	n/a

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	MDL	Interferences	Comparability	Data Completeness

a Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards are available.
b Based on analysis of standard reference material (SRM) 1643d from National Institute of Standards and Technology (NIST).
c Based on error propagation.
n/a: Not available

Source: [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004).

Table A-7. Measurement and analytical specifications for continuous NO_3^-.

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy	Precision	MDL	Interferences	Comparability	Data Completion
FLASH VOLATIZATION INSTRUMENTS							
Aerosol Dynamics Inc. continuous nitrate analyzer (ADIN) Particle collection by humidification and impaction followed by flash volatilization and detection of the evolved gases in a chemiluminescent NO_X analyzer.	10 min	n/a	n/a	0.1 µg/m³ for 10-min avg [82]	n/a	Within 30% of filter and continuous NO_3^-. See Weber et al. [82] for details.	93%[7]
Rupprecht and Patashnick continuous nitrate analyzer (R&P-8400N) Particle collection by impaction followed by flash volatilization and detection of the evolved gases in a chemiluminescent NO_X analyzer. A carbon honeycomb denuder, installed at the inlet to the Nafion humidifier removes nitric acid and ammonia vapor.	10 min	n/a	6.3%-23%[b] [83]	0.17 to 0.3 µg/m³ for 24-h avg [83,84] 0.24 µg/m³ to 0.45 µg/m³ for 10-min avg [83,85]	Conversion and volatilization efficiency appears to depend on ambient composition; extent of underestimation increases with higher concentrations. [84,86]	20 to 45% lower than filter NO_3^- [20,82-85,87]	>80 to >94%[6,20,83-85]
DENUDER-DIFFERENCE INSTRUMENT							
Atmospheric Research and Analysis nitrate analyzer (ARAN) Sampled air passes through a 350ºC molybdenum (Mo) mesh that converts particulate nitrate into NO. A pre-split stream with a Teflon filter installed upstream of an identical converter (i.e., particle-free air) is used as a reference. NO in both streams is quantified by chemiluminescence and their difference determines the particulate nitrate concentration. The instrument inlet contains a potassium iodide- coated denuder to remove HNO_3 and NO_2.	30 sec	n/a	n/a	0.5 µg/m³ for 30-sec avg [82]	n/a	Within 30% of filter and continuous NO_3^-. See Weber et al. [82] for details.	76%[7]
SAMPLE DISSOLUTION FOLLOWED BY IC ANALYSIS INSTRUMENTS							
Energy Research Center of the Netherlands (ECN) IC-based ion analyzer Collects particles into water drops using a steam jet aerosol collector, via cyclone. The combined flow from collected droplets containing dissolved aerosol components and wall steam condensate is directed to an anion IC for analysis of nitrate. Interfering gases are pre-removed by a rotating wet annular denuder system.	1-h	n/a	n/a	0.1 µg/m³ [82]	n/a	Within 30% of filter and continuous NO_3^-. See Weber et al. [82] for details.	100%[7]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy	Precision	MDL	Interferences	Comparability	Data Completion
Texas Tech University (TT) ion analyzer Particles in the sample stream are processed through a cyclone and a parallel plate wet denuder, then collected alternatively on one of two 2.5 cm pre-washed glass fiber filters for a period of 15 min. The particles on the freshly sampled filter are automatically extracted for 6.5 min with water and analyzed for nitrate by IC.	15-30 min	n/a	n/a	0.010 µg/m^3 [82]	n/a	Within 30% of filter and continuous NO_3 -. See Weber et al. [82] for details.	97%[7]
Particle into Liquid Sampler-Ion Chromatography (PILS-IC) Ambient particles are mixed with saturated water vapor to produce droplets collected by impaction. The resulting liquid stream is analyzed with an IC to quantify aerosol ionic components.	1 h	n/a	10%-15%[c] [7,82,88]	0.05 to 0.1 µg/m^3 [20,82,88]	Consistent water quality is essential for good precision.	Within 10% of nylon-filter NO_3 - and 37% higher than R&P-8400N [20]	65 to 70%[20]
Dionex-IC The gas-denuded air stream enters the annular channel of a concentric nozzle, where deionized water generates a spray that entrains the particles. The flow is then drawn through a 0.5 µm pore size PTFE filter. The remaining solution is aspirated by a peristaltic pump and sent to IC for ion analysis.	1-h	n/a	14%[d 65]	n/a	Consistent water quality is essential for good precision.	Bias of < 10% relative to filter NO_3 -[65]	n/a
Ambient Ion Monitor (AIM; Model 9000) Air is drawn through a size-selective inlet into a liquid diffusion denuder where interfering gases are removed. The stream enters a supersaturation chamber where the resulting droplets are collected through impaction. The collected particles and a fraction of the condensed water are accumulated until the particles can be injected into IC for hourly analysis.	1-h	n/a	n/a	0.1 µg/m^3 for 1-h avg[e]	n/a	n/a	n/a

PARTICLE MASS SPECTROMETER INSTRUMENT

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy	Precision	MDL	Interferences	Comparability	Data Completion
Aerosol Mass Spectrometer (AMS) Air stream is drawn through an aerodynamic lens and focused into a beam in a vacuum chamber. This aerosol beam is chopped by a mechanical chopper and the flight time of the particles through a particle-sizing chamber is determined by the time-resolved mass spectrometer measurement. The particle impacts onto a 600 °C heated plate where it decomposes and is analyzed by a quadruple mass spectrometer. The nitrate ion, along with other ions, is detected by the mass spectrometer.	A few seconds	n/a	n/a	0.03 µg/m^3 [20]	Subject to interferences from fragments of other species with mass to charge ratio in the same range as fragments of nitrate. Highly refractory materials are not detected.	Within 10% of nylon-filter NO_3 -, and within 15% of PILS-IC and 30% of R&P8400N [20]	94 to 98%[20]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy	Precision	MDL	Interferences	Comparability	Data Completion

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards are available.

[b] Overall uncertainty estimated by error propagation.

[c] Uncertainty estimated from uncertainties in flow rates and calibrations; does not refer to co-located precision.

[d] Co-located precision with respect to PC-BOSS $PM_{2.5}$ total particulate NO_3 (the sum of the denuded front filter [non-volatilized NO_3-] and HNO_3-absorbing backup filter [volatilized NO_3]).

[e] Manufacturer specified measurement parameter

n/a: Not available.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-8.   Measurement and analytical specifications for continuous SO_4^{2-}.

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	MDL	Interferences	Comparability	Data Completeness
FLASH VOLATILIZATION INSTRUMENTS							
Aerosol Dynamics, Inc. continuous sulfate analyzer (ADIS) Particle collection by impaction followed by flash volatilization and detection of the evolved gases by a UV-fluorescence SO_2 analyzer.	10 min	n/a	n/a	0.4 µg/m³ [82]	n/a	Within 15% of filter and continuous SO_4^{2-} See Weber et al. [82] for details	100%[7]
Rupprecht and Patashnick continuous sulfate analyzer (R&P-8400S) Particle collection by impaction followed by flash volatilization and detection of the evolved gases by a UV-fluorescence SO_2 analyzer. An activated carbon denuder at the inlet to the Nafion humidifier removes SO_2.	10 min	n/a	25% on avg < 15% at conc. >9 µg/m³ and >30% at conc. < 2 µg/m³ [b] [84]	0.48 µg/m³ [85]	SO_4^{2-} to SO_2 conversion and volatilization efficiency appears to depend on ambient composition [84]	10 to 30% lower than filter SO_4^{2-} [20,21,84]	84 to 95%[6,20,21,84,85]
THERMAL REDUCTION INSTRUMENTS							
Continuous Ambient Sulfate Monitor (CASM) Sampled air passes through a $Na2CO_3$ coated annular denuder to remove ambient SO_2 and is subsequently split into independent sample and filter flows. The sample flow passes through a quartz tube containing a stainless steel rod maintained at 1000 °C that reduces sulfate to SO_2. The flow then passes through a PTFE filter and into a trace-level SO_2 fluorescence analyzer.	15 min	n/a	n/a	n/a	n/a	Up to 25% lower than filter SO_4^{2-} and within 6% of R&P8400S, PILS-IC and AMS [20,21]	80 to 98%[20,21]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	MDL	Interferences	Comparability	Data Completeness
Thermo Electron Model 5020 sulfate particulate analyzer (TE-5020) The commercial version of CASM, with slight changes in the sample flow path.	15 min	n/a	< 10%c [89]	0.3 $\mu g/m^3$ for 24-h avg [89] 0.5 $\mu g/m^3$ for 15-min avgd	SO_4^{2-} to SO_2 conversion efficiency depends on ambient composition [89]	~20% lower than filter SO_4^{2-} [89]	88 to 90%[89]
SAMPLE DISSOLUTION FOLLOWED BY IC ANALYSIS INSTRUMENTS							
Energy Research Center of the Netherlands (ECN) IC-based ion analyzer Entrains particles into water drops using the steam jet aerosol collector. The drops are collected using a cyclone and the combined flow from collected droplets containing dissolved aerosol components and wall steam condensate is directed to an anion IC for analysis of sulfate. Interfering gases are pre-removed by a rotating wet annular denuder system.	1-h	n/a	n/a	n/a	n/a	Within 15% of filter and continuous SO_4^{2-} See Weber et al. [82] for details.	100%[7]
Texas Tech University (TT) ion analyzer Particles in the sample stream, after being processed through a cyclone and a parallel plate wet denuder, are collected alternatively on one of two 2.5 cm pre-washed glass fiber filters for a period of 15 min. The particles on the freshly sampled filter are automatically extracted for 6.5 min with water and analyzed for sulfate by IC.	30 min	n/a	n/a	n/a	n/a	Within 15% of filter and continuous SO_4^{2-} See Weber et al. [82] for details.	100%[7]
Particle into Liquid Sampler-Ion Chromatography (PILS-IC) Ambient particles are mixed with saturated water vapor to produce droplets collected by impaction. The resulting liquid stream is analyzed with an IC to quantify aerosol ionic components.	1-h	n/a	10%-15%e [7,82,88]	0.1 to 0.18 $\mu g/m^3$ [82,88]	Consistent water quality is essential for good precision.	Within 30% of filter and other continuous SO_4^{2-} [20,21]	65 to 70%[20,21]
Dionex-IC The gas-denuded air stream enters the annular channel of a concentric nozzle, where deionized water generates a spray that entrains the particles. The flow is then drawn through a 0.5-μm pore size PTFE filter. The remaining solution is aspirated by a peristaltic pump and sent to IC for ion analysis.	1-h	n/a	11%f [65]	n/a	Consistent water quality is essential for good precision.	Within 10% of filter SO_4^{2-} [65]	n/a
Ambient Ion Monitor (AIM; Model 9000) Air is drawn through a size-selective inlet into a liquid diffusion denuder where interfering gases are removed. The stream enters a super saturation chamber where the resulting droplets are collected through impaction. The collected particles and a fraction of the condensed water are accumulated until the particles can be injected into IC for hourly analysis.	1-h	n/a	n/a	0.1 $\mu g/m^3$ for 1-h avgd	n/a	n/a	n/a
PARTICLE MASS SPECTROMETER							
Aerosol Mass Spectrometer (AMS) Airstream is drawn through an aerodynamic lens and focused into a beam in a vacuum chamber. This aerosol beam is chopped by a mechanical chopper and the flight time of the particles through a particle-sizing chamber is determined by the time-resolved mass spectrometer measurement. The particle impacts onto a 600 °C heated plate where it decomposes and is analyzed by a quadruple mass spectrometer. The sulfate ion, along with other ions, is detected by the mass spectrometer.	A few seconds	n/a	n/a	n/a	Subject to interferences from fragments of other species with mass to charge ratio in the same range as fragments of sulfate. Highly refractory materials are not detected.	Up to 30% lower than filter SO_4^{2-} and within 5% of R&P8400S, PILS-IC and CASM [20,21]	93 to 98%[20,21]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	MDL	Interferences	Comparability	Data Completeness

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards available.
[b] Overall uncertainty estimated by error propagation.
[c] Co-located precision estimate based on regression slope (slope = 0.95, intercept = 0.01 to 0.2, $R^2 > 0.98$).
[d] Manufacturer specified measurement parameter.
[e] Uncertainty estimated from uncertainties in flow rates and calibrations; does not refer to co-located precision.
[f] Co-located precision with respect to PC-BOSS $PM_{2.5}$ SO_4^{2-}.
n/a: Not available

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b); [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2007); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-9. Measurement and analytical specifications for ions other than NO_3^- and SO_4^{2-}.

Instrument & Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit (Mdl)	Interferences	Comparability	Data Completeness
SAMPLE DISSOLUTION FOLLOWED BY IC ANALYSIS INSTRUMENTS							
NO_2^- by Particle into Liquid Sampler-Ion Chromatography (PILS-IC) Ambient particles are mixed with saturated water vapor to produce droplets collected by impaction. The resulting liquid stream is analyzed with an IC to quantify aerosol ionic components.	1-h	n/a	10%[b 88]	0.14 µg/m^3 [20]	Consistent water quality is essential for good precision	n/a	n/a
NH_4^+ by Particle into Liquid Sampler-Ion Chromatography (PILS-IC) Ambient particles are mixed with saturated water vapor to produce droplets collected by impaction. The resulting liquid stream is analyzed with an IC to quantify aerosol ionic components.	1-h	n/a	10%[b 88]	0.05 µg/m^3 [88]	Consistent water quality is essential for good precision	~5% lower than all-sampler avg[c] at Atlanta [7]	n/a
Cl^-, Na^+, K^+, Ca^{++} by Particle into Liquid Sampler-Ion Chromatography (PILS-IC) Ambient particles are mixed with saturated water vapor to produce droplets collected by impaction. The resulting liquid stream is analyzed with an IC to quantify aerosol ionic components.	1-h	n/a	10%[b 88]	0.1 µg/m^3 [88]	Consistent water quality is essential for good precision	n/a	n/a

Instrument & Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit (Mdl)	Interferences	Comparability	Data Completeness
Cl$^-$, NO$_2^-$, NO$_3^-$, PO$_4^{3-}$, SO$_4^{2-}$, NH$_4^+$, Na$^+$, Mg^{++}, K$^+$, Ca^{++} by Ambient Ion Monitor (AIM; Model 9000) Air is drawn through a size-selective inlet into a liquid diffusion denuder where interfering gases are removed. The stream enters a super saturation chamber where the resulting droplets are collected through impaction. The collected particles and a fraction of the condensed water are accumulated until the particles can be injected into IC for hourly analysis.	1-h	n/a	n/a	0.1 µg/m^3 for 1-h avg[d]	n/a	n/a	n/a

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards are available.

[b] Uncertainty estimated from uncertainties in flow rates and calibrations; does not refer to co-located precision.

[c] All-sampler avg appears to include a combination of 10 integrated and 3 continuous samplers, although specific details are missing 7. Performance evaluations at sites dominated by semi-volatile ammonium nitrate are needed.

[d] Manufacturer specified measurement parameter

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005b); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-10. Measurement and analytical specifications for continuous carbon.

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit	Interferences	Comparability	Data Completeness
PARTICLE COLLECTION ON IMPACTOR FOLLOWED BY FLASH VOLATILIZATION INSTRUMENT							
Aerosol Dynamic Inc. continuous carbon analyzer (ADI-C) Particle collection by impaction followed by flash oxidation and detection of the evolved gases by a non-dispersive infrared CO_2 analyzer. OC is estimated as twice the oxidizable carbon. EC is not quantified.	10 min	n/a	n/a	OC: 2 µg/m^3 EC, TC: not applicable, since it measures only OC [90]	n/a	15 to 22% lower OC than that by R&P-5400 and RU-OGI	83%[7]

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit	Interferences	Comparability	Data Completeness
PARTICLE COLLECTION ON FILTER / IMPACTOR FOLLOWED BY HEATING/ANALYSIS INSTRUMENTS							
Rupprecht and Patashnick 5400 continuous ambient carbon analyzer (R&P-5400) Particles collected on an impactor, which is heated to 275 °C to 350 °C, then to 700 °C after sample collection is complete. Evolved CO_2 is measured by an infrared detector. OC is defined as the carbon measured at the lower temperature, and EC is the remaining carbon measured at the higher temperature.	1-h	n/a	n/a	OC: 0.5 µg/m^3 EC: 0.5 µg/m^3 TC: 0.5 µg/m^3 [90]	n/a	20 to 60% lower TC than filter TC by TOR or TOT.[91,92]	56 to 60%[6,91]
Rutgers University-Oregon Graduate Institute (RU-OGI) in-situ thermal/optical transmittance carbon analyzer. Air is sampled through a quartz-fiber filter for 1-h and then analyzed by heating through different temperature steps to determine OC and EC. Sample flow is pre-split into two identical systems that alternate every hour between sampling and analysis mode to achieve continuous measurements.	30 min	n/a	3%[b,7]	OC: 0.3 µg/m^3 EC: 0.5 µg/m^3 TC: 0.4 µg/m^3 [90]	n/a	8% higher OC and 20% lower EC than R&P-5400 [90]	86%[7]
Sunset semi-continuous realtime carbon aerosol analysis instrument (Sunset OCEC) Particles collected on a quartz-fiber filter are subject to heating temperature ramps following the NIOSH 5040 TOT protocol and the resulting CO_2 is analyzed by nondispersive infrared (NDIR) detector to quantify OC and EC. Instrument is alternated between sampling and analytical mode.	1-h	n/a	OC: 10%[c] EC: 20%[c] TC: 10%[c] [93,94]	OC: n/a EC: n/a TC: 0.4 µg/m^3 (1-h avg)[95]	n/a	Within 7 to 25% of filter OC and EC and within 15% for TC. Wide variation due to differences in temperature and analysis protocols. [92,95,96]	80 to 89%[6,95]
LIGHT ABSORPTION INSTRUMENTS							
Aethalometer (AE-16, AE-21, AE-31) Attenuation of light transmitted through a quartz-fiber filter tape that continuously samples aerosol is measured and converted to a BC mass concentration using σ_{abs} of 14625/λ (m^2/g).	5 min	n/a	5 to 10%[d,7,97]	BC [e]: 0.1 µg/m^3 [90]	Subject to multiple scattering effects by particle and filter matrix resulting in absorption enhancement. Empirical corrections have been proposed [98] that can correct for such effects.	Within ± 25% of RU-OGI, Sunset and filter EC by TOR/TOT.[90-92]	75 to 90%[6]
Particle Soot Absorption Photometer (PSAP) Attenuation of light transmitted through a glass-fiber filter that continuously samples aerosol is measured to quantify light absorption (b_{abs}).	1 min	n/a	6 to 8%[99,100]	BC [f]: 0.1 µg/m^3 [90]	Instrument includes an empirical correction for scattering and loading effects [99] and adjustments have been proposed for the three wavelength model [100]	~50% lower than AE-16, RU-OGI and R&P-5400 EC.[90]	n/a
Multi-Angle Absorption Photometer (MAAP) Light transmittance at 0° and reflectance from a glass-fiber filter at 130° and 165° from the illumination direction are used in a radiative transfer model to estimate b_{abs} and is converted to BC using σ_{abs} of 6.6 m^2/g.	1 min	n/a	12%[g,101]	BC [h]: 0.05 µg/m^3 (or b_{abs} = 0.33 Mm-1 for 10-min avg) 0.02 µg/m^3 (or b_{abs} = 0.13 Mm-1 for 30-min avg)[101]	The instrument is designed to minimize multiple scattering and loading effects by measuring both transmittance and reflectance and using a two-stream approximation radiative transfer model to calculate b_{abs}.	Within 18% of filter EC by IMPROVE_TOR (R^2 = 0.96) and up to 40% higher than Sunset EC. [102]	n/a

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit	Interferences	Comparability	Data Completeness
DRI Photoacoustic Analyzer (DRI-PA) Light absorption by particles in air results in a heating of the surrounding air. The expansion of the heated air produces an acoustic (sound wave) signal which is detected by a microphone to determine b_{abs}, which is converted to BC using $\sigma_{abs} = 5$ m2/g for the 1047 nm instrument and $\sigma_{abs} = 10$ m2/g for the 532 nm instrument.	5 sec	n/a	n/a	BC i: 0.04 µg/m3 (or $b_{abs} = 0.4$ Mm-1 for 10-min avg) at 532 nm[103]	At 532 nm, absorbance by NO_2 interferes with that by particles. Accounted by either removing NO_2 from sample line using denuders or by doing a periodic background (particle-free air) subtraction.	Good correlation ($R^2 >0.80$), but more than 40% lower than aethalometer, MAAP and filter IMPROVE_TOR EC. Suggests need for a different σ_{abs}. [102]	n/a

PHOTO-IONIZATION INSTRUMENTS

Instrument and Measurement Principle	Averaging Time	Analytical Accuracy[a]	Precision	Minimum Detectable Limit	Interferences	Comparability	Data Completeness
Photoionization monitor for 91%[6T] polycyclic aromatic hydrocarbons (PAS-PAH) The air stream is exposed to UV radiation, which ionizes the particle-bound PAH molecules. The charged particles are collected on a filter element and the piezoelectric current is proportional to the particle-bound PAH.	5 min	n/a	n/a	~3 ng/m3 [j,k]	n/a	n/a	>91%6t

[a] Accuracy is the ability of analytical methods to quantify the observable of a standard reference material correctly; does not refer to measurement accuracy, since no standards are available.
[b] No specific details on how the precision was estimated; appears to be based on replicate analysis, may not represent overall co-located measurement precision
[c] Co-located precision estimates based on variation in avg ratios of replicate analysis using laboratory instrument and regression slopes (Slopes for OC = 1.01, EC = 0.82, TC = 0.94; R2 = 0.97 - 0.99) of co-located field measurements.
[d] Estimated using co-located AE-21 and AE-31 BC measurements at Fresno, CA.97
[e] While the default manufacturer recommended conversion factor (or mass absorption efficiency, σabs) is 16.6 m2/g at 880 nm, Lim et al. (2003) assumed a value of 12.6 m2/g.
[f] Assuming a σabs of 10 m2/g.
[g] Co-located precision estimate based on the variability of the avg ratio (0.99 ± 0.12).
[h] Assuming a σabs of 6.5 m2/g.
[i] Assuming a σabs of 10 m2/g at 532 nm and 5 m2g at 1047 nm.
[j] Specified by manufacturer as "lower threshold"; needs to be calibrated with site-specific PAH. Typically used as a relative measure in terms of electrical output in femtoamps.
[k] Manufacturer specified measurement parameter
n/a: Not available.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19]Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2001); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-11. Summary of mass measurement comparisons.

Site / Period / Sampler / Configuration				Summary of Findings
1. Birmingham, AL (11/04/96 To 11/23/96) 2. Denver-Adams City, CO (12/11/96 To 1/7/97) 3. Bakersfield, CA (1/21/97 To 3/19/97) 4. Denver-Welby, Co (12/12/96 To 12/21/96) 5. Phoenix, AZ (12/06/96 To 12/21/96) 6. Azusa, CA (3/25/97 To 5/19/97) 7. Research Triangle Park (RTP), NC (1/17/97 To 8/14/97) 8. Rubidoux, Ca (1/6/99 To 2/26/99) 9. Atlanta, Ga (8/3/99 To 8/31/99)				Peters et al. [104]: Pitchford [105] dataset Co-located precision (CV) for the RAAS2.5-100 samplers ranged from 1.5% at Bakersfield to 6.2% at Birmingham. In Birmingham, CV for two co-located Harvard Impactor was 1% and for three Dichots was 6.2%. The IMPROVE samplers had greater variability, with a CV of 11.3% (Denver-Adam City) and 10.8% (Bakersfield).
SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[A]	DENUDER[B]	Partisol and RAAS showed the strongest pairwise comparison (slope = 1.0 ± 0.06,
RAAS2.5-100 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	intercept = 0.26 ± 1.81, and correlation = 1.0), within the EPA equivalency criteria. Strong relation-
RAAS2.5-300 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	ships (correlation >0.96; slope = 0.9 – 1.12, intercept < 3σ) were observed for other samplers in reference to the RAAS.
RAAS2.5-200 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	At Denver-Welby, 6 RAAS samplers were deployed (3 with and 3 without temperature compensation for
R&P Partisol 2000 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	flow control). The units with temperature compensation had a positive bias relative to the non-temperature compensated units.
R&P Partisol-plus 2025 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	Non-FRM samplers did not meet the EPA equivalency criteria, despite strong linear relationships with the FRM sampler.
BGI PQ200 PM$_{2.5}$ FRM	16.7	Teflon (n/a)	None	Peters et al.[104]: RTP 97 dataset
Sierra Instruments SA-244 Dichot	16.7	Teflon (n/a)	None	CV was 1.7%, 2.3%, 3.4%, 6.4% for the PQ200, Partisol 2000, RAAS2.5100, and Dichot,
IMPROVE PM$_{2.5}$	22.8	Teflon (n/a)	None	respectively. Dichot flows were valve controlled and set visually by the operator using rotameters.
Harvard PM$_{2.5}$ Impactor	10	Teflon (n/a)	None	Good one-to-one correspondence was observed for FRM comparisons. The FRM averages were within
Airmetrics battery powered PM$_{2.5}$ MiniVol	5	Teflon (n/a)	None	-1.2% to 3.2%, within the acceptable ± 10% range
				Peters et al. [104]: Rubidoux 99 and Atlanta 99 dataset
				In Rubidoux, the precision for PQ200 was 6.1%, higher than at RTP 97. In Atlanta, the grouped data from PQ200, RAAS2.5-300, and Partisol yielded a precision of 1.7%.
				Linear regression results met the EPA equivalency criteria for all FRMs.
ATLANTA SUPERSITE, GA: 8/3/99 TO 9/1/99 4 km NW of downtown, within 200 m of a bus maintenance yard and several warehouse facilities, representative of a mixed commercial-residential neighborhood.				Solomon et al. [17] PM$_{2.5}$ mass from individual samplers was compared to all-sampler avgs, called the filter relative reference (filter RR) value. Overall agreements were within ± 20% of filter RR.
Sampler	Flow Rate (L/Min)	Filter Type[a]	Denuder[b]	FRM samplers were within 3.5% of filter RR.
R&P-2000 FRM	16.7	Teflon (P)	None	Avg mass measured by RAAS-400, SASS and URG-PCM were within ± 10% of filter RR. Avg
RAAS-100 FRM	16.7	Teflon (P)	None	mass measured by MASS-400, R&P-2300 and
RAAS-400	24	Teflon (P)	None	R&P-2025 dichot were greater than filter RR but within ± 20%. Avg mass measured by PC-BOSS
SASS	6.7	Teflon (P)	None	(BYU) and ARA-PCM were lower than filter RR within ± 10%.
MASS-400	16.7	Teflon (P)	Na$_2$CO$_3$	All samplers except PC-BOSS (TVA) had R^2 >0.80,
R&P-2300	10	Teflon (P)	None	relative to filter RR.
R&P-2025 Dichot:				While avg mass for each sampler was within 20%, daily variability was >50% of filter RR.
PM$_{2.5}$	15	Teflon (P)	None	Glycerol in the Na2CO$_3$ denuder may have
PM$_{10-2.5}$	1.67	Polycarbonate	None Na$_2$CO$_3$/Citric	contaminated the filter in the MASS-400 sampler resulting in higher PM$_{2.5}$ values.
URG-PCM	16.7	Teflon (P)	Acid	PC-BOSS samplers removed particles < 0.1 μm
ARA-PCM	16.7	Teflon (n/a)	Na$_2$CO$_3$/Citric acid	aerodynamic diameter from PM$_{2.5}$ measurements.
PC-BOSS (operated by TVA)	105	Teflon (W)	CIF	Corrections were made using sulfate (SO$_4^{2-}$)

Site / Period / Sampler / Configuration				Summary of Findings

PC-BOSS (operated by BYU)	150	Teflon (W)	CIF

PM2.5 CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	30 °C	Nafion	PM2.5

Right column findings for this section:

concentrations in the major flow or immediately after the $PM_{2.5}$ inlet, but before the flow split-up. This was insufficient to bring PC-BOSS mass close to filter RR. PC-BOSS was also equipped with upstream denuders ahead of the filters, which may have enhanced loss of semi-volatile components, resulting in a lower mass on the filter.

Butler et al. [62]

The sum of individual species accounted for ~78% of the RAAS-100 FRM $PM_{2.5}$ mass concentration.

TEOM explained ~82 to 92% of the species sum of RAAS with $R^2 = 0.86$.

ATLANTA SUPERSITE, GA: 11/21/01 TO 12/23/01

PM2.5 SAMPLER	FLOW RATE (L/MIN)	FILTER TYPEa		DENUDERb
R&P-2025 FRM	16.7	Teflon (n/a)		None

PM2.5 CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	30 °C	Nafion	PM2.5
SES-TEOM	16.7	30 °C	Nafion	PM2.5
CAMM	0.3	n/a	Nafion	PM2.5
RAMS	16.7	30 °C	Nafion	PM2.5 TEA & CIF denuders With particle concentrator
Radiance Research M903	n/a	n/a	Nafion	bscat
Radiance Research M903	n/a	n/a	None	bscat

Right column findings for this section:

Lee et al. [73]

RAMS $PM_{2.5}$ adjusted using particle concentrator efficiency of 0.5.

Good correlation between SES-TEOM and Radiance Research M903s ($R^2 = 0.80$), while medium correlation was found between CAMM and Radiance Research M903 ($R^2 = 0.64$) or RAMS and Radiance Research M903 ($R^2 = 0.63$).

CAMM = (0.75 ± 0.03) SES-TEOM + (2.51 ± 0.51); $R^2 = 0.78$; N = 196

RAMS = (0.85 ± 0.06) SES-TEOM + (5.34 ± 1.04); $R^2 = 0.52$; N = 96

RAMS = (0.91 ± 0.07) CAMM + (5.71 ± 1.20); $R^2 = 0.43$; N = 196

Semi-volatile material explains the difference between RAMS and SES TEOM.

CAMM = (0.75 ± 0.08) R&P-2025 FRM + (2.47 ± 1.02); $R^2 = 0.76$; N = 31

RAMS = (0.97 ± 0.22) R&P-2025 FRM + (2.39 ± 3.42); $R^2 = 0.64$; N = 13

SES-TEOM = (1.07 ± 0.05) R&P-2025 FRM + (-1.34 ± 0.71); $R^2 = 0.95$; N = 26

CAMM vs. FRM yielded lower slopes (0.75) with high intercepts.

PITTSBURGH SUPERSITE, PA: 7/1/01 to 6/1/02 6 km east of downtown in a park on the top of a hill

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPEa		DENUDER
MOUDI-110	30	Teflon (P)c,d		None
And-241 Dichot	16.7	Teflon (P)c		None
R&P-2000 PM2.5 FRM	16.7	Teflon (W)		None

PM2.5 CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
SES-TEOM	16.7	30 °C	Nafion	PM2.5
DAASS	n/a	30 °C	Nafion or None	PM2.5

Right column findings for this section:

Cabada et al; [18]: Rees et al. [106]

$MOUDI\ PM_{10} = 0.80\ Dichot\ PM_{10}$, $R^2 = 0.85$

$MOUDI\ PM_{2.5} = 1.03\ Dichot\ PM_{2.5}$, $R^2 = 0.78$

$MOUDI\ PM_{2.5} = 1.01\ FRM\ PM_{2.5}$, $R^2 = 0.78$

$Dichot\ PM_{2.5} = 0.97\ FRM\ PM_{2.5} + 0.02$; $R^2 = 0.94$

Good agreement for $PM_{2.5}$ FRM, Dichot, and MOUDI. Lower slope for PM_{10} suggests loss of coarse particles in the MOUDI sampler.

Ultrafine (< 100 nm) mass (PM0.10) measurements had high uncertainties (~30%)

Ultrafine mass by MOUDI showed no correlation with ultrafine volume (V0.10) by DAASS. Ratio of PM0.10/$PM_{2.5}$ mass ratio showed reasonable agreement with volume ratio (V0.10/V2.5, $R^2 = 0.55$, slope = 0.76). Bounce of large particles to smaller stages in MOUDI was small, since mass

Site / Period / Sampler / Configuration				Summary of Findings

<table>
<tr><td colspan="4"></td><td>ratio (PM0.10/PM$_{2.5}$) did not exceed volume ratio (V0.10/V2.5). Low correlation between ultrafine mass and volume could be due to the ultrafine mass measurement uncertainty or due to fundamental differences in the measurement methods employed by MOUDI and DAASS. Ambient conditions and characteristics of the aerosols (such as non-spherical shapes of fresh particles) could also influence these estimates.</td></tr>
</table>

Rees et al. [106]

SES-TEOM PM$_{2.5}$ = 1.02 FRM PM$_{2.5}$ + 0.65; R^2 = 0.95

Volatilization did not affect SES-TEOM performance when PM$_{2.5}$ mass >20-30 µg/m^3. When ambient temperature was < -6 °C, and when mass was low, SES-TEOM was lower (up to 50%) than FRM or Dichot.

FRESNO SUPERSITE, CA and other CRPAQS sites; 12/2/99 to 2/3/01. Some comparisons included data till 12/29/03 . Fresno Supersite was located 5.5 km northeast of downtown in a mixed residential-commercial neighborhood. [107]

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPEa		DENUDER
RAAS-100 PM$_{2.5}$ FRM	16.7	Teflon (P)		None
RAAS-300 PM$_{2.5}$ FRM	16.7	Teflon (P)		None
R&P-2000 PM$_{2.5}$ FRM	16.7	Teflon (P)		None
R&P-2025 PM$_{2.5}$ FRM	16.7	Teflon (P)		None
RAAS-400 PM$_{2.5}$	24	Teflon (P)		None
SASS PM$_{2.5}$	6.7	Teflon (P)		None
And-246 Dichot				
PM$_{2.5}$	15	Teflon (P)		None
PM$_{10-2.5}$	1.67	Teflon (P)		None
DRI-SFS PM$_{2.5}$	113	Teflon (P)		None
MiniVol PM$_{2.5}$	5	Teflon (P)		None
MOUDI-100	30	FEPb Teflon (P)		None
And-HIVOL PM$_{10}$ FRM	1130	Teflon (P)		None

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	50 °C	None	PM$_{2.5}$ and PM$_{10}$
BAM	16.7	Ambient	None	PM$_{2.5}$ and PM$_{10}$

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPEa		DENUDERb
PC-BOSS PM$_{2.5}$	150	Teflon (W)		CIF

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	50 °C	None	PM$_{2.5}$
TEOM	16.7	30 °C	None	PM$_{2.5}$
FDMSTEOM	16.7	30 °C	Nafion	PM$_{2.5}$
D-TEOM	16.7	30 °C	Nafion	PM$_{2.5}$
GRIMM1100	1.2	Ambient	None	bscat

Summary of Findings (right column):

Chow et al. [63]

PM$_{2.5}$ measurements from the 11 filter samplers were within ~20% of each other, except for MiniVols, which were 20 to 30% lower than RAAS-300 FRM.

All the FRM samplers were within ± 10% of each other.

All the filter samplers were well correlated with each other (R^2 >0.90).e

DRI-SFS (with HNO$_3$ denuder) and And-246 Dichot PM$_{2.5}$ were lower (~5% and 7%, respectively, on avg) than FRM, possibly due to nitrate (NO$_3$-) volatilization.

Poor correlation (R^2) found between TEOM PM$_{2.5}$ concentrations and RAAS-100 FRM. TEOM PM$_{2.5}$ was lower than RAAS-100 FRM by 22%. Heating of TEOM inlet to 50 °C resulted in loss of semi-volatile components such as ammonium nitrate (NH$_4$NO$_3$) and possibly some semi-volatile organic compounds.

TEOM PM$_{10}$ concentrations were 28% lower than the And-HIVOL10 FRM on avg, ranging from 13% in summer to 43% in winter.

TEOM was neither equivalente nor comparablee to the FRM sampler for PM$_{2.5}$ or PM$_{10}$.

BAM PM$_{2.5}$ concentrations showed high correlation (R^2 >0.90) with the RAAS-100 and RAAS-300 FRM samplers, with slopes ranging from 0.92 to 0.97. BAM PM$_{2.5}$ was typically higher than FRM (17 to 30%) except at Bakersfield, CA, where it was 21% lower, suggesting a BAM calibration difference between Bakersfield and other sites.

BAM PM$_{10}$ concentrations were 26% higher than And-HIVOL PM$_{10}$ FRM concentration on avg (R^2 >0.92).

Higher BAM measurements were attributed to water absorption by hygroscopic particles. BAM PM$_{2.5}$ and PM$_{10}$ deviations were larger for concentrations < 25 µg/m^3.

Grover et al. [65]

PC-BOSS PM$_{2.5}$ = (0.88 ± 0.04) FDMS-TEOM + (6.7 ± 4.3); R^2 = 95; n = 29

PC-BOSS PM$_{2.5}$ = (1.11 ± 0.07) D-TEOM + (7.5 ± 6.1); R^2 = 0.90; n = 29

TEOM50C PM$_{2.5}$ = (0.80 ± 0.01) TEOm^{3}0C + (1.1 ± 3.1); R^2 = 0.91; n = 507

TEOm^{3}0C PM$_{2.5}$ = (0.50 ± 0.01) FDMS-TEOM - (1.7 ± 6.9); R^2 = 0.68; n = 516

Heated GRIMM PM concentrations were lower than FDMS-TEOM and ambient temperature GRIMM,

Site / Period / Sampler / Configuration					Summary of Findings
GRIMM1100	1.2	80 °C heater, resulting in aerosol temperature	Heater	bscat	suggesting loss of semi-volatile matter.
					Data recovery was greater than 95% for all continuous instruments, except for D-TEOM, which had 86% recovery.
BAM	16.7	Ambient	None	$PM_{2.5}$	Reasonable agreement was seen between FDMS-TEOM, D-TEOM, BAM, and GRIMM $PM_{2.5}$ when semi-volatile matter was dominated by NH_4NO_3. However, the FDMS-TEOM was higher than the other instruments during high concentration periods, associated with days with a high fraction of semi-volatile organic compounds (SVOCs). Possible differences in SVOCs may have contributed to the differences between FDMS and other instruments.

HOUSTON SUPERSITE, TX; 1/1/00 to 2/28/02
The Houston Supersite included three sites located in southeast Texas including one on the grounds of a municipal airport at the edge of a small community, one adjacent to the highly industrial ship channel and one on the grounds of a middle school in a suburban community.

Russell et al. [64]; Lee et al. [108]

Good correlations between 24-h SES-TEOM $PM_{2.5}$ and R&P-2025 FRM mass.

$PM_{2.5}$ SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER
R&P-2025 FRM	16.7	Teflon (n/a)		None

CAMM = (0.93 ± 0.03) RAMS + (3.14 ± 0.74); R^2 = 0.81

SES-TEOM = (0.92 ± 0.03) RAMS + (1.52 ± 0.77); R^2 = 0.80

SES-TEOM = (1.01 ± 0.03) CAMM + (-1.91 ± 0.79); R^2 = 0.83

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER[b]
TEOM	16.7	50 °C	None	$PM_{2.5}$
SES-TEOM	16.7	30 °C	Nafion	$PM_{2.5}$ Aug-Sep '00
CAMM	0.3	Ambient	Nafion	$PM_{2.5}$ Aug-Sep '00
RAMS	16.7	30 °C	Nafion	$PM_{2.5}$ TEA & CIF denuders; Aug-Sep '00
Radiance Research M903	n/a	n/a	Nafion	Bscat Aug-Sep '00

Correlation of Radiance Research M903 and SES-TEOM was good (R^2 = 0.95), while that of Radiance Research M903 with CAMM or RAMS was poor (R^2 ~ 0.4).

RAMS >SES-TEOM at high temperature and low RH (< 60%), suggesting loss of water and particulate NO_3^- from SES-TEOM.

CAMM = (1.02 ± 0.08) R&P-2025 + (1.62 ± 1.35); R^2 = 0.89

RAMS = (1.10 ± 0.08) R&P-2025 + (0.68 ± 1.28); R^2 = 0.89

SES-TEOM = (1.09 ± 0.07) R&P-2025 + (0.21 ± 1.27); R^2 = 0.94

Integrated mass < Continuous $PM_{2.5}$ mass. Difference possibly related to loss of SVOCs and NO_3^- from integrated sampler

LOS ANGELES SUPERSITE, CA; 9/01 to 8/02
The Los Angeles Supersite consisted of multiple sampling locations in the South Coast Air Basin to provide wide geographical and seasonal coverage, including urban "source" sites and downwind "receptor" sites.

Jaques et al. [69]; Hering et al. [109]

Dichot $PM_{2.5}$ = 0.83 MOUDI + 1.23; R^2 = 0.83 (n = 37)

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]
R&P-2025 Dichot				
$PM_{2.5}$	15	Teflon (P)		None
$PM_{10-2.5}$	16.7	n/a		None
MOUDI-110	30	Teflon (P)[d]		None
HEADS $PM_{2.5}$	10	Teflon (n/a)		$NaHCO_3$

Dichot $PM_{2.5}$ showed higher NO_3^- loss than MOUDI, consistent with anodized aluminum surfaces serving as efficient denuders that remove volatilized NO_3^-. [2,110].

D-TEOM $PM_{2.5}$ = 1.18 MOUDI – 1.28; R^2 = 0.86 (n = 20)

Over-estimation of D-TEOM may be due to particle losses in the MOUDI.

$PM_{2.5}$ by D-TEOM during ESP-off phase (net artifact effect) tracked well with the NO_3^- concentrations.

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
D-TEOM	16.7	30 °C	Nafion	$PM_{2.5}$
Nano-BAM (BAM-1020 with d50 148 ± 10 nm inlet)	16.7	Ambient	None	~150 nm cut-point at 16.7 L/min

NO_3^- vaporization from the TEOM was caused by the temperature of the TEOM filter (~30 – 50 °C) rather than the pressure drop across the filter.

Vaporization from the TEOM had a time constant between 10 to 100 min, depending on ambient and TEOM filter temperatures; the vapor pressure, and the extent of vapor saturation upstream and downstream of the TEOM filter. The mass

Site / Period / Sampler / Configuration					Summary of Findings
SMPS-3936	0.3	Ambient	None	Number to mass assuming spherical particles of 1.6 g/cc density	measured during 5 min periods (ESP-on and off cycle in D-TEOM) provides an estimate of the dynamic vaporization losses.

Chakrabarti et al. [111]

Good agreement between MOUDI PM0.15 and Nano-BAM PM0.15 (MOUDI PM0.15 = 0.97 Nano-BAM PM0.15 + 0.60; R^2 = 0.92; n = 24)

Nano-BAM captured peak PM0.15 concentrations not quantified by SMPS. Potential particle agglomeration (with resulting high surface areas) caused SMPS to include particles in the accumulation- rather than ultrafine-mode, since mobility diameter is a function of surface area.

RUBIDOUX, CA; 08/15/01 to 09/07/01, 07/01/03 to 07/31/03. Rubidoux is located in the eastern section of the South Coast Air Basin (SoCAB) in the north-west corner of Riverside County, 78 km downwind of the central Los Angeles metropolitan area and in the middle of the remaining agricultural production area in SoCAB.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]
PC-BOSS PM2.5	150	Teflon (W)		CIF
R&P-2025 PM2.5 FRM	16.7	Teflon (n/a)		None

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	50 °C	None	PM2.5
FDMS-TEOM	16.7	30 °C	Nafion	PM2.5
D-TEOM	16.7	30 °C	Nafion	PM2.5
RAMS	16.7	30 °C	Nafion	PM2.5 Denuders used
CAMM	0.3	n/a	None	PM2.5
Radiance Research M903	n/a	n/a	Nafion	bscat
Radiance Research M903	n/a	n/a	None	bscat

Grover et al. [66] (2003 measurements):

D-TEOM = (0.98 ± 0.02) FDMS-TEOM + (-0.6 ± 5.3); R^2=0.85; n = 426; excludes 38 data points when FDMS-TEOM PM2.5 was higher than D-TEOM PM2.5 by ~21 µg/m^3.

RAMS = (0.93 ± 0.02) FDMS-TEOM + (2.4 ± 8.2); R^2 = 0.81; n = 337

FDMS-TEOM = (0.96 ± 0.06) PC-BOSSconstructed mass + (-0.3 ± 3.9); R^2 = 0.90; n = 33

R&P-2025 FRM = (0.96 ± 0.06) FDMS-TEOM + (-9.3 ± 3.9); R^2 = 0.90; n = 29

The R&P-2025 FRM PM2.5 was, on avg, ~32% lower than FDMSTEOM. Losses of NH_4NO_3 and organics can account for the difference.

TEOM @ 50 °C PM2.5 was consistently lower than FDMS-TEOM, DTEOM or RAMS and was, on avg, ~ 50% lower than FDMS-TEOM. This difference is due to loss of semi-volatile NO_3^- and organics from the heated TEOM.

FDMS-TEOM and D-TEOM needed little attention from site operators.

Lee et al. [76] (2001 measurements)

D-TEOM PM2.5 and Radiance Research M903s light scattering (with and without dryers) showed good correlation.

D-TEOM = (3.69 ± 0.09) Radiance Research M903no-dryer + (2.74 ± 0.89); R^2 = 0.84; n = 299

D-TEOM = (3.79 ± 0.10) Radiance Research M903dryed + (4.08 ± 0.84); R^2 = 0.83; n = 312

Radiance Research M903no-dryer = (1.03 ± 0.01) Radiance Research M903dryed + (0.34 ± 0.05); R^2 = 0.98; n = 513; absorbed water did not affect relationship to PM2.5.

CAMM and RAMS compared poorly (R^2 = 0 to 0.25) with D-TEOM, Radiance Research M903s and among themselves.

RAMS correlated well with D-TEOM for PM2.5 >30 µg/m^3 due to RAMS's efficient particle collection of larger particle sizes (historically associated with high mass loadings at this site) in the PM2.5 size range.

D-TEOM PM2.5 correlated well with ADI-N sized NO_3 (R^2 = 0.62) and OC by Sunset OCEC (R^2 = 0.61) suggesting that D-TEOM measured PM2.5 mass with minimum loss of SVOCs. RAMS showed R^2 of 0.20 (NO_3^-) to 0.30 (OC), while CAMM showed no correlation.

LINDON, UT; 01/29/03 to 02/12/03

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]
PC-BOSS PM2.5	150	Teflon (W)		CIF

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER

Grover et al. [66]

RAMS required regular maintenance.

RAMS = (0.92 ± 0.03) FDMS-TEOM + (1.3 ± 3.9); R^2 = 0.69; n = 332

PC-BOSS constructed mass = (0.89 ± 0.21) FDMS-TEOM + (1.8 ± 2.8); R^2 = 0.66; n = 11

TEOM @ 30 °C PM2.5 was consistently lower than

Site / Period / Sampler / Configuration					Summary of Findings
TEOM	16.7	30 °C		None	$PM_{2.5}$	FDMS-TEOM and the difference was consistent with concentrations SVOCs and NH_4NO_3 measured by PC-BOSS.
FDMS-TEOM	16.7	30 °C		Nafion	$PM_{2.5}$	
RAMS	16.7	30 °C		Nafion	$PM_{2.5}$ Denuder used	

PHILADELPHIA, PA; 07/02/01 to 08/01/01 At water treatment center in a grassy field surrounded by mixed deciduous and pine trees on three sides and a river on the other. Within 0.5 km of Interstate I-95 and within 30 km from downtown Philadelphia.

Lee et al. [73]

Radiance Research M903dryer = (0.78 ± 0.01) Radiance Research M903no dryer + (0.30 ± 0.03); R^2 = 0.95

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]	
Harvard Impactor $PM_{2.5}$	10	Teflon (n/a)		n/a	

Radiance Research M903s vs. CAMM, R^2 = 0.78

Radiance Research M903s vs. RAMS, R^2 = 0.63

Radiance Research M903s vs. SES-TEOM, R^2 = 0.72

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER	
SES-TEOM	16.7	35 °C	Nafion	$PM_{2.5}$	
CAMM	0.3	n/a	Nafion	$PM_{2.5}$	
RAMS	16.7	30 °C	Nafion	$PM_{2.5}$ TEA & CIF denuders With particle concentrator	
Radiance Research M903	n/a	n/a	Nafion	bscat	
Radiance Research M903	n/a	n/a	None	bscat	

CAMM = (0.60 ± 0.03) SES-TEOM + (2.0 ± 0.42); R^2 = 0.71; N = 185

RAMS = (0.71 ± 0.04) SES-TEOM + (2.51 ± 0.59); R^2 = 0.63; N = 185

RAMS = (0.93 ± 0.06) CAMM + (2.44 ± 0.68); R^2 = 0.55; N = 185

Both RAMS and CAMM under-measured ambient $PM_{2.5}$.

CAMM = (0.70 ± 0.06) HI + (0.16 ± 0.96); R^2 = 0.87; N = 22

SES-TEOM = (1.0 ± 0.10) HI + (-0.68 ± 1.74); R^2 = 0.89; N = 15

BALTIMORE SUPERSITE, MD; 05/17/01 to 06/11/01. Located near a freeway and bus yard.

Lee et al. [73]

Radiance Research M903dried = (0.65 ± 0.02) Radiance Research M903no dryer + (1.80 ± 0.20); R^2 = 0.75, suggesting influence from particle-bound water.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE		DENUDER	
RAAS-100 $PM_{2.5}$ FRM	16.7	Teflon		None	

High correlation (R^2 = 0.75) between Radiance Research M903s.

Poor correlation among the continuous instruments.

Radiance Research M903s did not follow $PM_{2.5}$ concentrations measured by other continuous instruments.

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER	
SES-TEOM	16.7	35 °C	Nafion	$PM_{2.5}$	
CAMM	0.3	n/a	Nafion	$PM_{2.5}$	
RAMS	16.7	30 °C	Nafion	$PM_{2.5}$ TEA & CIF denuders; No particle	
Radiance Research M903	n/a	n/a	Nafion	bscat	
Radiance Research M903	n/a	n/a	None	bscat	

CAMM = (0.32 ± 0.07) SES-TEOM + (9.45 ± 1.61); R^2 = 0.14; N = 120

RAMS = (0.82 ± 0.10) SES-TEOM + (6.41 ± 2.09); R^2 = 0.38; N = 120

RAMS = (0.71 ± 0.12) CAMM + (11.3 ± 2.23); R^2 = 0.21; N = 120

CAMM = (0.80 ± 0.29) RAAS-100 FRM + (-0.83 ± 5.85); R^2 = 0.60; N = 7

RAMS = (1.05 ± 0.12) RAAS-100 FRM + (4.80 ± 2.60); R^2 = 0.90; N = 11

SES-TEOM = (0.86 ± 0.10) RAAS-100 FRM + (2.96 ± 1.99); R^2 = 0.90; N = 10

SEATTLE, WA; 01/28/01 to 02/21/01
Urban area near major highway and interstate, 8 km southeast of downtown.

Lee et al. [108]

Radiance Research M903dried = 0.94 ± 0.00 Radiance Research M903no dryer; R^2 = 1.0.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]	
MASS $PM_{2.5}$	16.7	Teflon (n/a)		Na_2CO_3 denuder	

Correlation of Radiance Research M903 vs. SES-TEOM, R^2 = 0.80, while that of Radiance Research M903 with CAMM was R^2 = 0.84 and with RAMS was R^2 = 0.72.

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER	
SES-TEOM	16.7	30 °C	Nafion	$PM_{2.5}$	
CAMM	0.3	Ambient	Nafion	$PM_{2.5}$	
RAMS	16.7	30 °C	Nafion	$PM_{2.5}$ TEA & CIF denuders	
Radiance Research M903	n/a	n/a	Nafion	bscat	

CAMM = (1.07 ± 0.05) RAMS + (1.03 ± 0.55); R^2 = 0.61

SES-TEOM = (0.95 ± 0.03) RAMS + (1.24 ± 0.38); R^2 = 0.72

SES-TEOM = (0.87 ± 0.03) CAMM + (0.55 ± 0.37); R^2 = 0.74

SES-TEOM likely lost semi-volatile organic matter.

Continuous $PM_{2.5}$ samplers were similar to filter

Site / Period / Sampler / Configuration				Summary of Findings
Radiance Research M903	n/a	n/a	None	bscat	PM$_{2.5}$ sampler. Number of samples was small (~7). Some SES-TEOM mass values were less than MASS filter values suggesting that loss of mass is likely for a SES-TEOM at 30 °C, particularly during the cold season.

NEW YORK SUPERSITE, NY; 01/01/03 to 12/31/04
Urban site located at Queens College, NY, about 14 km west of Manhattan, within 2 km of freeways, and within 12 km of international airports. A rural site was located at Pinnacle State Park surrounded by golf course, picnic areas, undeveloped forest lands, and no major cities within 15 km.

Schwab et al. [67]

FDMS-TEOM had operational difficulties resulting in low data capture (65% at urban site and 57% at rural site).

BAM had data captures greater than 95% at both sites.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]		DENUDER[b]
R&P-2025 PM$_{2.5}$ FRM	16.7	Teflon (n/a)		None
R&P-2300 PM$_{2.5}$	16.7	Teflon (n/a)		None

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	INLET TEMPERATURE	DRYER	OTHER
TEOM	16.7	50 °C	None	PM$_{2.5}$
FDMS-TEOM	16.7	30 °C	Nafion	PM$_{2.5}$
BAM	16.7	"smart" heater on @ RH >44%		PM$_{2.5}$

Urban site:

BAM = (1.02 ± 0.02) FDMS-TEOM + 1.72; R^2 = 0.93; n = 244

FDMS-TEOM = (1.25 ± 0.02) FRM – (0.63 ± 0.26); R^2 = 0.95; n = 238

BAM = (1.28 ± 0.03) FRM + (1.27 ± 0.38); R^2 = 0.88; n = 320

Rural site:

FDMS-TEOM = (1.09 ± 0.02) FRM – (0.004 ± 0.18); R^2 = 0.95; n = 349

PM$_{2.5}$ FDMS-TEOM >FRM >TEOM50°C, suggesting that FRM captured a fraction, but not all, of the volatile components. TEOM50°C volatilizes PM$_{2.5}$, particularly during winter.

[a]Filter Manufacturer in parentheses - W: Whatman, Clifton, NJ; P: Pall-Gelman, Ann Arbor, MI; S: Schleicher & Schnell. Keene, NH; n/a: not available or not reported.
[b]Na$_2$CO$_3$: Sodium carbonate; NaHCO$_3$: Sodium bicarbonate CIF: Charcoal Impregnated Filter; FEP: Fluorinated Ethylene Propylene copolymer; TEA: Triethanolamine; TSP: Total Suspended PM.
[c]37 mm filter.
[d]37-mm after-filter for stages smaller than 0.16 μm and 47-mm for higher stages.
[e]Equivalence requires correlation coefficient (r) ≥ 0.97, linear regression slope 1.0 ± 0.05 and an intercept 0 ± 1 μg/m^3; Comparability requires r>0.9 and linear regression slope equal 1 within 3 standard errors and intercept equal zero within 3 standard errors; Predictability requires r>0.9. 91, 112

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Xiao et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao et al. (2003); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-12. Summary of element and liquid water content measurement comparisons.

SITE / PERIOD / SAMPLER	SUMMARY OF FINDINGS
College Park, MD; 11/18/1999 to 11/19/1999, 11/22/1999 Adjacent to a parking lot in the University of Maryland campus, influenced by motor vehicles, coal-fired power plants and incinerators ~21 km southwest of site and regionally transported material. ***Concentrated Slurry/Graphite Furnace Atomic Absorption Spectrometry (GFAAS) (collectively known as Semi-Continuous Elements in Aerosol Sampler, SEAS)*** Ambient air is pulled in at a flow rate of 170 L/min. Particles are grown using steam injection to about 3 to 4 μm in diameter, which are then concentrated and separated from the air stream in the form of a slurry using impactors. The slurry is collected in glass sample vials, which are subsequently analyzed by GFAAS in the laboratory.	Kidwell and Ondov (2001, 2004) Overall collection efficiency (of the entire system) measured using latex particles was 40% for particles initially 0.1 to 0.5 μm in diameter, increasing with size to 68% for particles 3 μm in diameter. Major losses were in the virtual impactor major flow channel and in the condensers. Six elements were detected *simultaneously*, limited by spectral interference and the minimum detectable limit (MDL). Twelve elements (Al, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sb, and Pb) were measured. MDLs ranged from 3.2 picogram (pg = 10^{-12} gram) to 440 pg. Comparison with NIST standards showed good agreement, except for Al, Cr and Fe, due to poor atomization. The method was valid for dissolved solutions, but not for large particles (>10 μm). Overall avg relative standard deviation (RSD) was 20 to 43% by error propagation, mainly due to the collection and analytical efficiencies. There were possible memory effects due to particle adhesion to impactor collection surfaces. Lower MDLs may be possible through redesign and introduction of a wash cycle between samples. A 2.5 μm inlet might improve analytical efficiency by removing coarse particles.
Pittsburgh Supersite, PA; 08/26/2002 to 09/02/2002 6 km east of downtown in a park on the top of a hill. ***Laser Induced Breakdown Spectroscopy (LIBS)*** Ambient air was concentrated using a $PM_{2.5}$ inlet and a virtual impactor. The concentrated stream was transported through a Teflon tube to the sample cell of the LIBS system. The sample cell was excited using a Nd: YAG laser. The resulting plasma was collected and focused into a spectrometer, generating spectra characteristic of different elements.	Lithgow et al. (2004) Calibration was done by sampling particle-laden streams with known metal concentrations. Good linear fits with correlation coefficients 0.97 to 0.99 Seven metals (Na, Mg, Al, Ca, Cr, Mn, and Cu) were analyzed. The MDLs were in the order of femtograms (fg = 10^{-15} gram) per sample. This system has the capability of identifying the components, quantifying them and also giving a particle size distribution. Mass was underestimated because of missing small particles.
Pittsburgh Supersite, PA; 07/01/2001 to 08/31/2001, 01/01/2002 to 07/01/2002. 6 km east of downtown in a park on the top of a hill. ***Dry Ambient Aerosol Size Spectrometer (DAASS)*** Measures the aerosol size distribution (using nano-SMPS, SMPS and APS) alternatively, at ambient relative humidity (RH) (ambient channel) and at low RH (18 ± 6%) (dry channel). A comparison of the two size distributions provides information on the water absorption and change in size due to RH.	Stanier et al. (2004); Khlystov et al. (2005) Measured water content ranging from less than 1 μg/m³ to 30 μg/m³, constituting < 5% to 100% of the dry aerosol mass. Small differences between dry and ambient channels of the DAASS. Number concentrations were within 5% of each other. Additional sources of error are associated with temperature differences between measured outdoor ambient temperature and the temperature at which the ambient measurement channel was maintained. Although the measurement system was placed in a ventilated enclosure, it was ~4 °C higher than ambient temperature during July 2001. During winter, the system was maintained at a minimum temperature of 9 °C, while the outdoor temperature dropped to -5 °C. This caused differences in RH sensed by the system in the ambient channel versus the actual outdoor RH. RH differences cause underestimation of the particle number at sizes < 200 nm and an overestimation at sizes >200 nm. This causes the volume growth factor to be higher by 2 to 14%, with the highest bias occurring at high RH and low temperature (92% outside RH and -5 °C). The difference in temperature might also lead to evaporation of semi-volatile components such as NH_4NO_3. For the winter period, it was estimated that, for the worst case, the volume growth factor would be underestimated by about 10% for 60 - 90% RH. Insufficient purging of dry air between the dry and ambient cycles (implying the need for supplemental vacuum power during the vent stages) causes uncertainties in estimated growth factors. Correction factors were between 0.97 and 1.03. Water content estimated by DAASS can be used to evaluate the thermodynamic models. For the Pittsburgh study, the models underestimated the water content by 37%. Data from DAASS showed that the aerosol was wet even at ambient RH less than 30%.

Table A-13. Summary of PM$_{2.5}$ NO$_3^-$ measurement comparisons.

SITE / PERIOD / SAMPLER / CONFIGURATION				SUMMARY OF FINDINGS
ATLANTA SUPERSITE, GA: 8/3/99 to 9/1/99 4 km NW of downtown, within 200 m of a bus maintenance yard and several warehouse facilities, representative of a mixed commercial-residential neighborhood.				Solomon et al[17]
SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]	PM$_{2.5}$ NO$_3^-$ from each sampler was compared to the all-sampler avgs, called the filter relative reference (filter RR) value. Overall agreements were within 30-35% of filter RR.
R&P-2000 FRM	16.7	Quartz (P)	None	
RAAS-400	24	Nylon (P)	MgO	Wide scatter from paired comparisons, possibly due to volatilized NO$_3^-$, differences in denuder design and filter types, and low concentrations (close to analytical uncertainty).
SASS	6.7	Nylon (P)	MgO	
MASS-400	16.7	Teflon (P)-Nylon (P)[c]	Na$_2$CO$_3$	A small positive artifact (few tenths of µg/m^3) might be present when using Na$_2$CO$_3$ impregnated filters, due to possible collection (and subsequent oxidation) of HONO and NO$_2$ on carbonate-impregnated filters. In addition, glycerol in Na$_2$CO$_3$ coated denuders may contaminate the filters downstream.
MASS-450	16.7	Quartz (P)	None	
R&P-2300	10	Nylon (P)	Na$_2$CO$_3$	
VAPS	15	Polycarbonatec (front & back-up)	Na$_2$CO$_3$	
URG-PCM	16.7	Teflon (P)-Cellulose-fiber (W)[c]	Na$_2$CO$_3$	
ARA-PCM	16.7	Teflon (n/a)-Nylon (n/a)	Na$_2$CO$_3$/Citric acid	PM$_{2.5}$ NO$_3^-$ R&P-2000 FRM and MOUDI-100 samplers are consistently lower than other samplers.
PC-BOSS (TVA)	105	Teflon (W)-Nylon (P)	CIF	Weber et al. [82]
PC-BOSS (BYU)	150	Teflon (W)-Nylon (P)	CIF	Hourly PM$_{2.5}$ NO$_3^-$were compared to all-sampler averages (continuous RR), similar to the approach used for integrated filter samplers. Overall agreements were within ± 20-30% (or ± 0.2 µg/m^3) except for ARA-N.
PC-BOSS (BYU)	150	Quartz (P)-CIF (S)	CIF	
MOUDI-100	30	Teflon (n/a)[d]-Quartz (n/a)[d]	None	Except for ARA-N, good correlations (R^2 = 0.70 to 0.90) were found during the second half of the study. The poor performance of ARA-N was probably due to an inefficient denuder (25-60% efficient) resulting in high background.
CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	DENUDER	ANALYSIS METHOD[b]	
ADI-N	1	Activated Carbon	NO$_X$ Chemiluminescence	Large discrepancies between continuous and filter RR, probably due to low ambient concentrations (study avg = 0.5 µg/m^3) near the detection limit (~0.1 µg/m^3, except for ARA-N, which had 0.5 µg/m^3).
ARA-N	3	Potassium iodide (KI) and dual sodium chlorite (NaClO$_2$)	NO$_X$ Chemiluminescence	
PILS-IC	5	Two URG annular glass denuders in series containing citric acid and CaCO$_3$	IC	The ARA-N was within 13%, ADI-N, ECN and PILS-IC within 18% and TT within 26% of filter RR (all < 0.2 µg/m^3 difference).
ECN	16.7	Rotating annular wet denuder system	IC	Filter samples showed more variability (Relative Standard Deviation, RSD = 22%) than continuous measurements (RSD = 13%). This is probably due to sampling artifacts in filter samples; NO$_3^-$volatilization in continuous monitors is expected to be minimal due to shorter averaging times and rapid stabilization in solutions.
TT	5	Wet parallel plate denuder	IC	
PITTSBURGH SUPERSITE, PA; 7/1/01 to 8/1/02 6km east of downtown in a park on the top of a hill				Cabada et al. [18]; Takahama et al. [116]
SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]	More than 70% (~0.5 µg/m^3) of NO$_3$ mass was lost from MOUDI samplers during summer.
MOUDI-110	30	Teflon (W)[d] Teflon (W)-	None	MOUDI NO$_3$ = 0.27 CMU; R^2 = 0.40; Summer MOUDI NO$_3$ = 0.99 CMU; R^2 = 0.49; winter
CMU	16.7	Nylon (W)	MgO/Citric acid	Wittig et al.[85]
R&P-2000 FRM	16.7	Teflon (W)	None	Avg conversion efficiency to NO$_X$ (tested using

	NH_4NO_3 solution) was 0.85 ± 0.08. Gas analyzer efficiency was stable at 0.99 ± 0.04.
	Corrections were made for instrument offset, software calculation error, conversion efficiency, gas analyzer efficiency, vacuum drift, and sample flow drift. The overall avg correction was 8%, ranging from -62% to 93%.
	Data Recovery >80%. Data loss was associated with vacuum pump failures and excessive flash strip breakage.
	R&P-8400N = 0.83 CMU + 0.20 µg/m³; R^2 = 0.84
	Under-estimation in the R&P-8400N could be due to incomplete particle collection or incomplete conversion of various forms of NO_3^-.
	Used co-located filter measurements for final calibration.

FRESNO SUPERSITE, CA and other CRPAQS sites; 12/2/99 to 2/3/01
Located 5.5 km northeast of downtown in a mixed residential-commercial neighborhood. [107]

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER
DRI-SFS	113	Quartz (P)Cellulose	Al_2O_3
RAAS-400	24	Quartz (P)-Nylon (P)	Na_2CO_3
RAAS-400	24	Quartz (P)-Quartz (P)	None
RAAS-100 FRM	16.7	Quartz (P)	None

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	DENUDER	ANALYSIS METHOD[b]
R&P-8400N	5	Activated Carbon	NO_x Chemiluminescence

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER
PC-BOSS	150	Teflon (W)- Nylon (P)	CIF

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	DENUDER	ANALYSIS METHOD[b]
R&P-8400N	5	Activated Carbon	NO_x Chemiluminescence
Dionex-IC	5	Parallel plate wet denuder	IC

Summary of findings (Fresno):

Chow et al. [87]

Maximum NO_3^- volatilization was observed during summer (Jun - Aug), while the lowest volatilization was observed during winter (Dec-Feb).

Seasonal avg volatilized NO_3^- in particulate NO_3^- (PNO_3^-, the sum of non-volatilized and volatilized NO_3^-) ranged from less than 10% during winter to more than 80% during summer.

Volatilized NH_4NO_3 accounted for 44% of actual $PM_{2.5}$ mass (i.e., measured mass plus volatilized NH_4NO_3) in Fresno during summer.

Front-quartz non-volatilized NO_3^- concentrations were similar for DRISFS (0.52 ± 0.26 µg/m³) and RAAS-100 FRM (0.81 ± 0.33 µg/m³) for warm months (May-Sep). With preceding denuders, the DRI-SFS PNO_3 concentration (3 ± 1.9 µg/m³) was much higher than the RAAS100 FRM NO_3^-, suggesting that the FRM sampler removed gaseous nitric acid (HNO_3) resulting in NO_3^- volatilization. FRM Teflon-membrane filters are subject to similar NO_3^- losses.

Chow et al. [117]

High correlation (R^2 >0.90) between 24-h avg R&P-8400N NO_3 and SFS filter NO_3^- concentrations, but R&P-8400N NO_3^- was 7 to 25% lower than filter NO_3^-.

Limited comparison (n < 15) with filter samples at Bakersfield showed that the slopes were close to unity during early morning hours, while they decreased during the afternoon hours, indicating possible loss of $NO_3^-$by the R&P-8400N instrument.

The R&P-8400N required substantial maintenance and careful operation.

Grover et al. [65]

Dionex-IC NO_3 = (0.71 ± 0.04) PC-BOSS NO_3 + (3.2 ± 1.1); R^2 = 0.91; n = 29

R&P-8400N = (1.10 ± 0.06) PC-BOSS NO_3 - (0.8 ± 1.8); R^2 = 0.93; n = 29

R&P-8400N = (0.55 ± 0.01) Dionex-IC + (1.4 ± 1.8); R^2 = 0.75; n = 493

R&P-8400N measured less than DIONEX IC, particularly at high RH. R&P-8400N may suffer incomplete flash vaporization under conditions of high RH.

BALTIMORE SUPERSITE, MD; 2/14/02 to 11/30/02
Adjacent to a parking lot in the University of Maryland campus, influenced by motor vehicles, coal-fired power plants and incinerators ~21 km southwest of site and regionally transported material.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER
SASS	6.7	Nylon (n/a)	MgO

Summary of findings (Baltimore):

Harrison et al. [83]

Corrections were made to R&P-8400N data for software calculation error, conversion efficiency, gas analyzer efficiency, vacuum drift and sample flow drift.

SITE / PERIOD / SAMPLER / CONFIGURATION				SUMMARY OF FINDINGS
				The relative uncertainty of R&P-8400N measurements averaged 8.7%, ranging from 6.3% to 23%.
CONTINUOUS SAMPLER	**FLOW RATE (L/MIN)**	**DENUDER**	**ANALYSIS METHOD**[b]	
R&P-8400N	5	Activated Carbon	NO_X Chemiluminescence	Data capture >95%.
				R&P-8400N underestimated SASS filter NO_3^- by ~33%, attributed to variations in conversion efficiency, matrix effects, and impaction efficiency. This suggested a true conversion efficiency of 68% as compared to an avg conversion efficiency of R&P-8400N to NO_X (tested using potassium nitrate solution) of 0.90 ± 0.04.
				Large errors occurred when the concentrations were near the detection limit, when the temperature difference (between instrument and ambient) was large, and when the ambient relative humidity (RH) was < 40%. Ridged flash strips produced lower dissociation losses than flat strips.
				Reliable measurements were obtained when the instrument-outdoor temperature differences were minimal and when grooved/ridged flash strips were used. A co-located filter measurement was used for final corrections.

NEW YORK SUPERSITE, NY; 06/29/01 to 08/05/01 and 07/09/02 to 08/07/02
Urban site located at Queens College, NY, about 14 km west of Manhattan, within 2 km of freeways, and within 12 km of international airports. Rural site located at Whiteface mountain, 600 m above sea level, in a clearing surrounded by deciduous and evergreen trees and no major cities within 20 km of the site.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER	
R&P-2300	10	Nylon (n/a)	Na_2CO_3	

CONTINUOUS SAMPLER	**FLOW RATE (L/MIN)**	**DENUDER**	**ANALYSIS METHOD**[b]
R&P-8400N	5	Activated Carbon	NO_X Chemiluminescence
PILS-IC	5	Na_2CO_3 and citric acid	IC
AMS	0.1	None	Mass Spectrometry

Summary of findings for this section:

Hogrefe et al. [20]

Data completeness: 86 - 88% for R&P-8400N, 94 -98% for AMS, and 65 - 70% for PILS-IC.

Some PILS measurements were invalidated owing to larger aqueous flow caused by bigger tubing. Larger aqueous flow and inconsistent water quality affected NO_3^- concentrations.

R&P-8400N NO_3^- was lower than R&P-2300 filter NO_3^-. PILS-IC was within 5% of R&P-2300 filter NO_3^- concentrations.

At the urban site, AMS was within 10% of the filter NO_3 concentration. At the rural site, AMS had a slope of 0.51 and R^2 of 0.46, compared with filter NO_3^-.

NEW YORK SUPERSITE, NY; 10/01 to 07/05 (urban), 07/02 to 07/05 (rural) Urban site located at a school in South Bronx, NY in a residential area, within a few kilometers away from major highways and a freight yard (experiencing significant truck traffic). Rural site located at Whiteface mountain, 600 m above sea level, in a clearing surrounded by deciduous and evergreen trees and no major cities within 20 km of the site.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[A]	DENUDER[b]
R&P-2300	10	Nylon (n/a)	Na_2CO_3
TEOM-ACCU	16.7	Zefluor	None

CONTINUOUS SAMPLER	**FLOW RATE (L/MIN)**	**DENUDER**	**ANALYSIS METHOD**[b]
R&P-8400N	5	Activated Carbon	NO_X Chemiluminescence

Rattigan et al. [84]

Data capture was more than 94%.

Data were adjusted for span and zero drifts, conversion efficiency, flow drift, and blanks.

R&P-8400N NO_3^- was systematically lower than R&P-2300 filter NO_3 over all concentration ranges, except at < 1 µg/m³.

Urban: R&P-8400N = 0.59 R&P-2300 NO_3 + 0.28; R^2 = 0.88; n = 305

Rural: R&P-8400N = 0.73 R&P-2300 NO_3 + 0.01; R^2 = 0.90; n~161; however concentrations were low with 95% of data < 1 µg/m³.

Required weekly or biweekly maintenance by trained personnel.

LOS ANGELES SUPERSITE, CA; 7/13/01 to 9/15/01 (Rubidoux) and 9/15/01 to 2/10/02 (Claremont)
Multiple sampling locations in the South Coast Air Basin (SoCAB), including urban "source" sites and downwind "receptor" sites.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
MOUDI	30	Teflon (P)d	None
HEADS	10	Teflon (n/a) - GF-GF	Carbonate

CONTINUOUS SAMPLER	**FLOW RATE (L/MIN)**	**DENUDER**	**ANALYSIS METHOD**[b]
ADI-N Sized	0.9	Activated Carbon	NO_X Chemiluminescence

Fine et al. [19]

MOUDI = 0.68 HEADS; R^2 = 0.88

ADI-N Sized = 0.80 HEADS; R^2 = 0.79

ADI-N Sized = 1.12 MOUDI; R^2 = 0.53

ADI-N NO_3^- showed better agreement with HEADS at lower concentrations, the ADI-N deviated (biased low) from the HEADS concentrations at higher NO_3^- concentrations. This deviation was attributed to NO_3^- vaporization, loss of NO_3^- associated with particles less than 0.1 µm not collected by the ADI-N sampler, or loss of particles in the ADI-N inlet tubing.

SITE / PERIOD / SAMPLER / CONFIGURATION				SUMMARY OF FINDINGS
				The underestimation of NO_3^- by MOUDI compared to HEADS may be due to NO_3^- volatilization from MOUDI stages, since SO_4^{2-} comparisons showed MOUDI to explain 85% of HEADS SO_4^{2-}
				ADI-N and MOUDI showed better correlation ($R^2 = 0.67$) for the 1 to 2 μm size range NO_3 relative to other size ranges ($R^2 < = 0.56$). This is possibly due to NO_3^- in the form of non-volatilized sodium nitrate ($NaNO_3$) than volatilized NH_4NO_3 in the 1-2 μm size range. Single particle analysis also indicated this possibility of $NaNO_3$ in the 1 to 2 μm range.

RUBIDOUX, CA; 07/01/03 to 07/31/03
Located in the eastern section of SoCAB in the north-west corner of Riverside County, 78 km downwind of the central Los Angeles metropolitan area and in the middle of the remaining agricultural production area in SoCAB.

Grover et al. [66]

R&P-8400N = (0.65 ± 0.07) PC-BOSS + (3.3 ± 2.4); $R^2 = 0.73$; n = 31

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
PC-BOSS	150	Teflon (W)-Nylon (P)	CIF

At higher concentrations (No numerical value reported), R&P-8400N NO_3^- was lower than PC-BOSS NO_3^-, possibly due to incomplete volatilization of NH_4NO_3 in R&P-8400N at higher concentrations (and higher relative humidity).

CONTINUOUS SAMPLER	FLOW RATE (L/MIN)	DENUDER	ANALYSIS METHOD[b]
R&P-8400N	5	Activated Carbon	NO_X Chemiluminescence
R&P-8400N	5	Activated Carbon	NOx Chemiluminescence
PILS-IC	5	Na_2CO_3 and Citric acid	IC
AMS	0.1	None	Mass Spectrometry

At the urban site, the continuous instruments correlated well with filter NO_3 - measurements and among themselves ($R2 \geq 0.89$). At the rural site, R2 ranged from 0.61 to 0.83, except for the AMS versus R&P2300 comparison, with an R2 of 0.46.

[a]Filter Manufacturer in parenthesis - W: Whatman, Clifton, NJ; P: Pall-Gelman, Ann Arbor, MI; S: Schleicher & Schnell. Keene, NH; n/a: not available or not reported.
[b]Al_2O_3: Aluminum oxide; GF: Na_2CO_3 impregnated Glass Fiber Filters; IC: Ion chromatography; MgO: Magnesium oxide; Na_2CO_3: Sodium carbonate; $NaHCO_3$: Sodium bicarbonate NO_X: Oxides of nitrogen; CIF: Charcoal Impregnated Filter; FEP: Fluorinated Ethylene Propylene copolymer; TEA: Triethanolamine; TSP: Total Suspended PM.
[c]Na_2CO_3 impregnated.
[d]37-mm filter.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-14. Summary of PM$_{2.5}$ SO$_4^{2-}$ measurement comparisons

SITE/PERIOD/SAMPLER/ CONFIGURATION	SUMMARY OF FINDINGS
ATLANTA SUPERSITE, GA: 08/03/99 to 09/01/99 4 km NW of downtown, within 200 m of a bus maintenance yard and several warehouse facilities, representative of a mixed commercial-residential neighborhood.	Solomon et al. [17] PM$_{2.5}$ SO$_4^{2-}$ from each sampler was compared to all-sampler averages, called the filter relative reference (filter RR) value. The samplers agreed to within

SITE/PERIOD/SAMPLER/ CONFIGURATION				SUMMARY OF FINDINGS
				10% of filter RR, except for the PC-BOSS (TVA) and MOUDI-100.
SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]	While avg mass was within 10%, daily variability was >50% of filter RR.
R&P-2000 FRM	16.7	Quartz (P)	None	All samplers, except for the PC-BOSS (TVA), correlated well (R^2 >0.90) with daily filter RR.
RAAS-400	24	Teflon (P)	None	PC-BOSS (TVA) had instrument leaks.
SASS	6.7	Teflon (P)	None	The R&P-2000 FRM, on avg, agreed within 1% of filter RR.
MASS-450	16.7	Quartz (P)	None	MOUDI-100 was ~13% low compared to filter RR.
R&P-2300	10	Quartz (P)	NOne	Weber et al. [82]; Zhang et al. [118]
VAPS	15	Quartz (P)	XAD-4	Hourly $PM_{2.5}$ SO_4^{2-} were compared to all-sampler averages (continuous RR), similar to the approach used for filter samplers. Overall agreement was within 16% or 2 $\mu g/m^3$.
URG-PCM	16.7	Teflon (P)-Cellulose-fiber (W)[c]		Good correlations (R^2 = 0.76 to 0.94) were found during the second half of the study, except for TT versus ADI.
ARA-PCM	16.7	Teflon (n/a)	Na_2CO_3/Citric acid	Good correlation (R^2 = 0.84) was found between continuous and filter-based SO_4^{2-}. Continuous RR = (1.15 ± 0.15), Filter RR + (0.41 ± 1.73)
ARA-PCM	16.7	Nylon (n/a)	Na_2CO_3/Citric acid	Variability among continuous SO_4^{2-} instruments (RSD = 13%) was similar to that for NO_3 instruments. Filter sample variability was low (RSD = 8%) indicating more uniformity among samplers.
PC-BOSS (TVA)	105	Teflon (W)	CIF	The ECN and TT instruments were within 15%, PILS-IC was within 20% and ADI-S was within 26% of filter RR.
PC-BOSS (TVA)	105	Quartz (P)	CIF	
PC-BOSS (BYU)	150	Teflon (W)	CIF	
PC-BOSS (BYU)	150	Quartz (P)	CIF	
MOUDI-100	30	Teflon (n/a)[d]-Quartz (n/a)[d]	None	

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	ANALYSIS METHOD[b]
ADI-S	2.7	Activated Carbon	SO_2, UV Fluorescence
PILS-IC	5	Two URG annular glass denuders in series containing citric acid & $CaCO_3$	IC
ECN	16.7	Rotating annular wet denuder system	IC
TT	5	Wet parallel plate denuder	IC

PITTSBURGH SUPERSITE, PA; 070/1/01 to 08/01/02
6km east of downtown in a park on the top of a hill

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
MOUDI-110	30	Teflon (W)[d]	None
CMU	16.7	Teflon (W)	MgO/Citric acid
R&P-2000 FRM	16.7	Teflon (W)	None

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	ANALYSIS METHOD[b]
R&P-8400S	5	Activated Carbon	SO_2 UV Fluorescence

Cabada et al., [18]; Takahama et al., [116]

MOUDI SO_4^{2-} 0.80 CMU; R^2 = 0.95; Summer

MOUDI SO_4^{2-} 0.97 CMU; R^2 = 0.48; winter

Wittig et al. [85]

Avg conversion efficiency to SO_2 (tested using ammonium sulfate [$(NH_4)_2SO_4$] solution) was 0.65 ± 0.07. Gas analyzer efficiency was stable at 0.99 ± 0.06.

Corrections were made for instrument offset, software calculation error, conversion efficiency, gas analyzer efficiency, vacuum drift, and sample flow drift. The overall correction was, on avg, -1% and ranged from -90% to 100% for individual samples.

Data Recovery >90%. Data loss was associated with vacuum pump failures or excessive flash strip breakage.

R&P-8400S (SO_4^{2-}) = 0.71 CMU + 0.42 $\mu g/m^3$; R^2 = 0.83

Underestimation is attributed to incomplete particle collection or incomplete conversion of various forms of SO_4^{2-}.

Used co-located filter measurements for final calibration.

LOS ANGELES SUPERSITE, CA; 07/13/01 to 09/15/01 (Rubidoux) and 09/15/01 to 02/10/02 (Claremont)
Multiple sampling locations in the South Coast Air Basin (SoCAB), including urban "source" sites and downwind "receptor" sites.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER
MOUDI	30	Teflon (P)[d]	None

Fine et al. [19]

MOUDI explained 85% of HEADS SO_4^{2-} (R^2 = 0.89; n = 40)

SITE/PERIOD/SAMPLER/ CONFIGURATION				SUMMARY OF FINDINGS

HEADS	10	Teflon (n/a) -GF[c]-GF[c]	Carbonate	

NEW YORK SUPERSITE, NY; 06/29/01 to 08/05/01 and 07/09/02 to 08/07/02
Urban site located at Queens College, NY, about 14 km west of Manhattan, within 2 km of freeways, and within 12 km of international airports. Rural site located at Whiteface mountain, 600m above sea level, in a clearing surrounded by deciduous and evergreen trees and no major cities within 20 km of the site.

Drewnick et al. [21]; Hogrefe et al. [20]

Data completeness: 89 - 93% for R&P-8400S, 94 - 98% for AMS, 81-98% for CASM, and 65-70% for PILS-IC.

The urban site data showed good correlations (R^2 = 0.87 to 0.94) with slopes ranging from 0.97 to 1.01. At the rural site, the variability was large (R^2 = 0.73 to 0.91) with slopes ranging from 0.76 to 1.32. SO_4 from PILS-IC was overestimated by ~25% when compared to the AMS at the rural site.

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
R&P-2300	10	Nylon (n/a)	Na_2CO_3
SCS	42	Zefluor (n/a)	None
TEOM-ACCU	16.7	Zefluor (n/a)	None

Filter samples were within 5% of each other, except for comparison of ACCU with R&P-2300 at the rural site, with high correlations (R^2 = 0.97 to 1.0). ACCU underestimated SO_4^{2-} by ~15%.

Continuous versus six-h SCS filter comparisons showed high R^2 (0.91 to 0.95) at the urban site. Continuous instruments consistently measured lower SO_4^{2-} concentrations compared to the SCS filter measurements (slopes 0.68 to 0.73)

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	ANALYSIS METHOD[b]
R&P-8400S	5	Activated Carbon	SO_2 UV Fluorescence
PILS-IC	5	Na_2CO_3 and Citric acid	IC
AMS	0.1	None	Mass Spectrometry
CASM	5	Na_2CO_3 and Carbon and a Nafion dryer	SO_2 UV Fluorescence

On avg, 85% of the filter-based SO_4^{2-} was measured by the continuous instruments with consistent relationships. At the rural site, PILS-IC overestimated SO_4^{2-} concentrations (slopes 1.11 to 1.15), AMS and R&P-8400S showed slopes of 0.71-0.74 against SCS and ACCU, while it ranged from 0.53- 0.68 against R&P-2300.

Error estimates:

Sampling losses: 2-3% for AMS and PILS-IC, 5-10% for R&P-8400S and none for CASM.

Continuous instruments probably experienced more inlet transport losses (~ 25%) than filter samplers due to longer inlet lines.

Small (< 2%) positive artifact was found in filters.

NEWYORK SUPERSITE, NY; 10/01 to 07/05 (urban), 07/02 to 07/05 (rural)
Urban site located at a school in South Bronx, NY in a residential area, within a few kilometers from major highways and a freight yard (experiencing significant truck traffic). Rural site located at Whiteface mountain, 600m above sea level, in a clearing surrounded by deciduous and evergreen trees and no major cities within 20 km of the site. The study by Schwab et al.[89] was based at a rural site located at Pinnacle State Park surrounded by golf course, picnic areas and undeveloped forest lands and no major cities within 15 km.

Rattigan et al. [84]

Data capture was above 85%. Data loss was primarily due to frequent flash strip failures, every 2 weeks and without warning.

Data were adjusted for span and zero drifts, measured conversion efficiency, flow drift, and blanks.

Calibrations used aqueous standards of $(NH_4)_2SO_4$ and oxalic acid solution in 1: 4 ratio. Lower fractions of oxalic acid showed lower conversion efficiencies.

Urban South Bronx site:

R&P-8400S = 0.82 TEOM-ACCU + 1.15; R^2 = 0.84; n = 513

R&P-8400S = 0.74 R&P-2300 + 1.14; R^2 = 0.81; n = 322

Rural Whiteface mountain:

R&P-8400S = 0.75 TEOM-ACCU + 0.22; R^2 = 0.95; n = 207

R&P-8400S = 0.78 R&P-2300 + 0.17; R^2 = 0.85; n = 198

INTEGRATED SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
R&P-2300	10	Nylon (n/a)	Na_2CO_3
TEOM-ACCU	16.7	Zefluor	None

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	ANALYSIS METHOD[b]
R&P-8400S	5	Activated Carbon	SO_2 pulsed fluorescence
TE-5020 (07/14/04 to 11/01/04)	5	Na_2CO_3	SO_2 pulsed fluorescence

Required weekly or biweekly maintenance by trained personnel

Schwab et al. [89]

TE-5020 = 0.78 ACCU – 0.2; R^2 = 0.94

Similar studies at St. Louis, MO, show slopes near unity. This suggests that the instrument is sensitive to aerosol composition.

Low maintenance and calibration requirements for TE-5020 compared to PILS-IC and R&P-8400S.

FRESNO SUPERSITE,CA; 12/01/03 to 12/23/03
Located 5.5 km northeast of downtown in a mixed residential-commercial neighborhood. Flow Sampler (L/min) Filter Type Denuder

Grover et al. [65]

Dionex-IC SO_4^{2-} (1.03 ± 0.03) PC-BOSS SO_4 + (0.2 ± 0.3); R^2 = 0.98; n = 27

R&P-8400S SO_4^{2-} (0.95 ± 0.05) Dionex-IC SO_4 + (0.3 ± 0.6); R^2 = 0.68; n = 195

SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]
PC-BOSS	150	Teflon (W)- Nylon (P)	CIF

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	ANALYSIS METHOD[b]
R&P-8400S	5	Activated Carbon	SO_2 pulsed fluorescence
Dionex-IC	5	Parallel plate wet denuder	IC

[a]Filter Manufacturer in parentheses - W: Whatman, Clifton, NJ; P: Pall-Gelman, Ann Arbor, MI; S: Schleicher & Schnell. Keene, NH; n/a: not available.

[b]Al_2O_3: Aluminum oxide; IC: Ion chromatography; CIF: Charcoal Impregnated Filter; FEP: Fluorinated Ethylene Propylene copolymer; MgO: Magnesium oxide; Na_2CO_3: Sodium carbonate; $NaHCO_3$: Sodium bicarbonate NO_X: Oxides of nitrogen; SO_2: Sulfur dioxide; TEA: Triethanolamine; TSP: Total Suspended PM; UV: Ultraviolet; XAD-4: Hydrophobic, non-polar polyaromatic resin.

[c]Na_2CO_3 impregnated.

[d]37-mm filter.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19]Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-15. Summary of PM$_{2.5}$ carbon measurement comparisons.

SITE/PERIOD/SAMPLER/ CONFIGURATION					SUMMARY OF FINDINGS
ATLANTA SUPERSITE, GA: 08/03/99 to 09/01/99 4 km NW of downtown, within 200 m of a bus maintenance yard and several warehouse facilities, representative of a mixed commercial-residential neighborhood.					Solomon et al. [17] Organic Carbon (OC);
SAMPLER	FLOW RATE (L/MIN)	FILTER TYPE[a]	DENUDER[b]	ANALYSIS METHOD[c]	PM$_{2.5}$ OC from each sampler was compared to the all-sampler avg, called the relative reference (RR) value. The samplers agreed to within 20 to 50% of RR. Only front filter OC is reported without artifact correction.
R&P-2000 FRM	16.7	Quartz (P)	None	NIOSH 5040-TOT	Denuded samplers showed lower OC (20 to 35%) than RR, while non-denuded sampler OC was higher (5 to 35%).
RAAS-400	24	Quartz (P)	None	NIOSH 5040-TOT	
SASS	6.7	Quartz (P)-Quartz (P)	None	NIOSH 5040-TOT	Among non-denuded samplers, as filter face velocity decreased, OC increased, with the exception of R&P-2300.
MASS-450	16.7	Quartz (P)	None	NIOSH 5040-TOT	
R&P-2300	10	Quartz (P)-Quartz (P)	None	NIOSH 5040-TOT	OC positive artifacts ranged from 2 to 4 μg/m^3 EC:
VAPS	15	Quartz (P)	XAD-4	NIOSH 5040-TOT	PM$_{2.5}$ EC from each sampler was compared to the all-sampler avg, called the relative reference (RR) value. The samplers agreed to within 20 to 200% of RR.
URG-PCM	16.7	Quartz (P)-Quartz (P)	XAD-4	Front: NIOSH 5040-TOT; Backup: custom-TOT[d]	
ARA-PCM	16.7	Quartz (n/a)-Quartz (n/a)	CIF	IMPROVE_TOR	TOT samples showed less EC than RR by 15 to 30%, while TOR samples showed more EC than RR by 40 to 90%. PCBOSS (BYU) >RR value by 140%. EC by TOR is ~twice EC by TOT.
PC-BOSS (TVA)	150	Quartz (P)-CIF (n/a)	CIF	Front: IMPROVE_TOR; Backup: TPV	
PC-BOSS (BYU)	150	Quartz (P)-CIF (S)	CIF	TPB	Major difference in EC is due to the carbon analysis protocol and optical monitoring correction (i.e., transmittance, reflectance).
MOUDI-100	30	Al Foilf-Quartz (n/a)[f]	None	Custom-TOR to suit Al[c]	Lim et al. (2003) TC concentrations measured by the RU-OGI and R&P-5400 correlated reasonably well (R^2 = 0.83), with a slope of 0.96. The ratio of the

SITE/PERIOD/SAMPLER/ CONFIGURATION						SUMMARY OF FINDINGS
CONTINUOUS SAMPLER	**FLOW RATE (L/min)**	**DENUDER**	**OC**	**EC**	**COMMENTS**	
ADI-C	2.7	Activated Carbon	Not known	n/a	Part of SO_4^{2-} instrument w/CO_2 non-dispersive infrared (NDIR) analyzer; data corrected for avg field blank; OC = 2 oxidized OC	
RU-OGI	16.1	None	700 in He	850 in 2% O_2	TOT; Dynamic blank for adsorption correction	
R&P-5400	16.7	None	275 in air	750 in air	No pyrolysis correction	
PSAP	1.26	None		b_{abs}@ 565 nm	$10 m^2/g$ factor	
AE-16	4	None		b_{abs}@ 880 nm	$12.6 m^2/g$ factor	

PITTSBURGH SUPERSITE, PA; 06/01/01 to 07/31/02
Six km east of downtown in a park on the top of a hill.

SAMPLER	FLOW	FILTER TYPE / PACK[a]		DENUDER	ANALYSIS METHOD[c]
CMU Custom-1	16.7	*Non-denuded sample*	Teflon (P/W)-Quartz (P) (QBT)	None	NIOSH 5040-TOT
	16.7	*Non-denuded sample*	Quartz (P)-Quartz (P) (QBQ)	None	NIOSH 5040-TOT
CMU Custom-2	16.7	*Denuded sample*	Denuder-Quartz (P)-CIG (S)	Activated Carbon	NIOSH 5040-TOT
	16.7	*Dynamic blank (DYN)*	Teflon (P/W)-Denuder-Quartz (P)-CIG (S)	Activated Carbon	NIOSH 5040-TOT
	16.7	*Non-denuded blank (UDB)*	Teflon (P/W)-Quartz (P)-CIG (S)	None	NIOSH 5040-TOT

Subramanian et al. [119]

Particulate OC (POC) was estimated from denuded sample (Quartz OC + CIG OC) after subtracting DYN POC.

Denuder efficiency (1-DYN POC/UDB POC) was 94 ± 3%. No seasonal variability or deterioration in denuder performance was observed.

Positive artifact due to denuder breakthrough was 18.3 ± 12.5% of the denuded sample POC.

Negative artifact (CIGsample-CIGDYN) was, on avg, 6.3 ± 6.2% of POC.

Positive artifact was 34 ± 10% from QBT, and was 13 ± 5% from QBQ. QBT >>QBQ.

QBT over-corrected the positive artifact by 20%. OC volatilization from the front Teflon filter that subsequently-adsorbed on the back-up quartz filter, resulted in an overestimation of the positive artifact.

Non-denuded QBQ provided a more representative estimate of the positive artifact on the non-denuded front quartz filter for 24-h samples. However, it was not suitable for 4-6 h samples, because the filters were not in equilibrium with the air stream.

Positive artifact dominated when sampling with a non-denuded quartz filter.

Comparison of 24-h avg non-denuded front quartz OC versus denuded POC over the year showed an intercept of 0.53 µg/m³, indicative of a positive artifact on quartz filter samples.

The artifacts were higher in summer on an absolute basis; however, they showed no seasonal variation when expressed as a fraction of POC.

ST. LOUIS SUPERSITE, IL, MO; 01/01/02 to 12/31/02
Three km east of St. Louis, MO City center, also impacted by industrial sources, and located in a mixed residential light commercial neighborhood.

SAMPLER	FLOW RATE (Lmin)	FILTER TYPE/PACK[a]	DENUDER[b]	ANALYSIS METHOD[c]
University of Wisconsin Custom-1	24	Quartz (P)	None	ACE Asia TOT
		Denuder-Quartz (P)	CIF	ACE Asia TOT
University of Wisconsin Custom-2	24	Denuder-Quartz (P)	CIF	ACE Asia TOT
		Teflon (n/a)-Denuder-Quartz (P)	CIF	ACE Asia TOT

Bae et al. [93, 96]

Denuder breakthrough was 0.17 ± 0.15 µg/m³, and constituted less than 5% of annual avg OC concentration.

Non-denuded OC = (1.06 ± 0.02) × denuded OC + (0.34 ± 0.10)

Equivalence of OC intercept and denuder breakthrough implies that the low-level artifact is caused by denuder breakthrough.

Non-denuded EC = (1.04 ± 0.03) × denuded EC + (0.07 ± 0.03), indicating negligible EC artifact.

Results suggested higher summer-time OC artifact, on an absolute basis.

Comparison of continuous Sunset TC and OC with 24-h filter samples showed good correlations (R^2) of 0.89 and 0.90, respectively.

SITE/PERIOD/SAMPLER/ CONFIGURATION						SUMMARY OF FINDINGS
CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	OC	EC	COMMENTS	Continuous Sunset TC in $\mu g/m^3$ = (0.97 ± 0.02) × filter TC + (0.83 ± 0.11), indicating comparability with the filter measurements.
Sunset OCEC	8	CIF	340, 500, 615, 870 °C in 100% He	550, 625, 700, 775, 850, 900 °C in 2% O_2, 98% He	ACE Asia TOT; CH_4 FID detector	Continuous Sunset OC = (0.93 ± 0.02) × filter OC + (0.94 ± 0.09)
						Positive intercept was interpreted to be a blank correction for the continuous measurements.
						EC comparison was poor with large scatter in data (R^2 = 0.60), probably due to low EC concentrations (avg = 0.70 $\mu g/m^3$), close to the detection limit (0.5 $\mu g/m^3$).

FRESNO SUPERSITE, CA and other CRPAQS sites; 12/02/99 to 02/03/01, 12/1/03 to 11/30/04
Fresno Supersite was located 5.5 km northeast of downtown in a mixed residential-commercial neighborhood.

Watson and Chow [91]; Chow et al. [117]; Chow et al. [120]; Watson et al. [6]; Park et al. [102]

SAMPLER	FLOW RATE (Lmin)	FILTER TYPE/PACK[a]	DENUDER[b]	ANALYSIS METHOD[c]	SUMMARY OF FINDINGS
DRI-SFS	113	Quartz (P)	None	IMPROVE_TOR	Non-denuded RAAS-400 and RAAS-100 FRM measured equivalent TC. DRI-SFS, RAAS-400 and RAAS-100 FRM samplers showed comparability for front filter TC, OC and EC measurements.
		Teflon (P)-Quartz	None	IMPROVE_TOR	Positive OC artifact was 1.62 ± 0.58 $\mu g/m^3$ (~24% of non-denuded front quartz OC) from QBT, and 1.12 ± 0.91 $\mu g/m^3$ (~17% of non-denuded front quartz OC) from QBQ. QBT >>QBQ
RAAS-400	24	(P) (QBT) Quartz (P)-Quartz (P) (QBQ)	None	IMPROVE_TOR	
RAAS-400	24	Quartz (P)-Quartz (P) (QBQ)	XAD-4 / CIF	IMPROVE_TOR	Results from CRPAQS showed, on avg, a positive OC artifact of 34% (of the non-denuded front quartz OC) from QBT and 17.5% (of the non-denuded front quartz OC) from QBQ.
RAAS-100 FRM	16.7	Quartz (P)	None	IMPROVE_TOR	Positive artifact was higher during summer than winter.

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER	OC	EC	COMMENTS	
R&P-5400	16.7	None	275 °C in air	750 °C in air	No pyrolysis correction	Negative artifact was, on avg, 0.61 ± 0.58 $\mu g/m^3$ (~10% of POC) at Fresno. Over all the CRPAQS sites, it ranged from 2.3% in winter to 11% in summer, with an avg of 4.9%.
Sunset OCEC	8.5	CIG	250, 500, 650, 850 °C in He	650, 750, 850, 940 °C in 2% O_2 in He	Transmittance	Positive artifact is estimated to be 0.5 $\mu g/m^3$. No difference in denuded quartz backup OC was found between using XAD and CIF denuders. Comparison of R&P-5400 TC, OC, and EC against filter samples showed poor correlation (R^2 < 0.55).
MAAP	16.7	None		b_{abs} @ 670 nm	Transmittance 6.5 m^2/g factor	TC from R&P-5400 was 40–60% higher than filter TC by TOR. None of the R&P-5400 versus TOR filter comparisons were comparable or predictable, due to several frequent instrument malfunctions during the experiment and the small data set (~35 data points).
AE-16	6.8	None		b_{abs} @ 880 nm	Transmittance 14625/λ m^2/g factor, where λ is in nm	IMPROVE_TOR EC was consistently 20–25% higher than aethalometer BC.
AE-21	6.8	None		b_{abs} @ 370, 880 nm		IMPROVE_TOR EC was comparable to MAAP BC.
AE-31	6.8	None		b_{abs} @ 370, 470, 520, 590, 660, 880 and 950 nm		Comparison of light absorption (b_{abs}) from DRI-PA (1047 nm), MAAP (670 nm), and AE (880 nm) analyzers with the filter IMPROVE_TOR EC, gave a σ_{abs} of 2.3, 5.5 and 10 m^2/g, differing from the default conversion factors of 5, 6.5, and 16.6 m^2/g used for each instrument at the specified wavelength.
DRI-PA	3	None		b_{abs} @ 1047 nm	Absorption, 5 m^2/g factor	Grover et al. [65]

SAMPLER	FLOW RATE (L/min)	FILTER TYPE/PACK[a]	DENUDER[b]	ANALYSIS METHOD[c]	
					R&P-5400 TC = (0.50 ± 0.01) Sunset TC + (3.6 ± 1.5); R^2 = 0.73; n = 480
					Sunset TC = (0.63 ± 0.05) PC-BOSS TC + (4.1 ± 3.2); R^2 = 0.86; n = 29
PC-BOSS	150	Quartz (P)-CIG (S)[†]	CIF	TPV	R&P-5400 TC = (0.41 ± 0.02) PC-BOSS TC + (6.7 ± 1.6); R^2 = 0.91; n = 29

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER[b]	OC	EC	COMMENTS

SITE/PERIOD/SAMPLER/ CONFIGURATION						SUMMARY OF FINDINGS

R&P-5400	16.7	None	375 °C in air	750 °C in air	No pyrolysis	
Sunset OCEC	8.0	CIG	250, 500, 650, 850 °C in He	650, 750, 850 °C in 2% O_2 & 98% He	NIOSH 5040_TOT NDIR CO_2 detector	

BALTIMORE SUPERSITE, MD; 02/15/2002 to 11/30/2002
East of downtown in an urban residential area. Within 91 m of bus maintenance facility.

Park et al. [95]

Data capture 93.8%

Compared to SASS, Sunset underestimated OC and EC by 22% and ~11.5%, respectively.

SAMPLER	FLOW RATE (L/min)	FILTER TYPE/PACK[a]	DENUDER[b]		ANALYSIS METHOD[c]
SASS	6.7	Quartz (P)-Quartz (P)	None		STN_TOT

Higher OC in SASS was attributed to the absence of a denuder (i.e., positive artifact by gaseous adsorption) and to temperature differences between the STN_TOT and Sunset_TOT carbon analysis temperature protocols.

EC discrepancy was probably related to the differences in temperature protocol.

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER[b]	OC	EC	COMMENTS
Sunset OCEC	8	Carbon	600 °C, then 870 °C in He	870 °C in 2% O_2 in He	TOT; CH4 FID detector; Denuder breakthrough ~ 0.5 – 1 µg C/m³; Used 0.5 to correct OC concentrations

RUBIDOUX, CA; 07/13/03 to 07/26/03
Rubidoux is located in the eastern section of the South Coast Air Basin (SoCAB) in the north-west corner of Riverside County, 78 km downwind of the central Los Angeles metropolitan area and in the middle of the remaining agricultural production area in SoCAB.

Grover et al. [66]

Sunset OCEC TC = (0.90 ± 0.06) PC-BOSS + (2.0 ± 2.1);
R^2 = 0.93; n = 21

Sunset TC was adjusted for carbon artifacts measured by second (blank) instrument.

SAMPLER	FLOW RATE (L/min)	FILTER TYPE/PACK[a]	DENUDER[b]		ANALYSIS METHOD[c]
PC-BOSS	150	Quartz (P)-CIG (S)	CIF		TPB (CIG heated to 450 °C in N_2)

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER[b]	OC	EC	COMMENTS
Sunset OCEC	8	CIF	n/a	n/a	TOT; NDIR detector; NIOSH 5040 protocol
Sunset OCEC	8	CIF	n/a	Not measured	TOT; has blank quartz filter before entering analyzer. Used as "blank" stream for quantifying OC artifacts; 3-step analysis only in He.

NEW YORK SUPERSITE, NY; 01/12/04 to 02/05/04
Urban site located at Queens College, NY, about 14 km west of Manhattan, within 2 km of freeways, and within 12 km of international airports.

Venkatachari et al. [92]

Regression of OC from Sunset OCEC against PM2.5 mass concentration yielded an intercept of 1.14 µg/m³, which was used as a measure of the positive artifact on the Sunset data. The Sunset OC data was corrected for this artifact.

INTEGRATED SAMPLER	FLOW RATE (L/min)	FILTER TYPE/PACK[a]	DENUDER[b]		ANALYSIS METHOD[c]
R&P-2300	10	Quartz	None		STN_TOT

AE-20 BC concentrations were ~86% of Sunset EC and R&P2300 filter EC concentrations.

AE-20 versus R&P-5400 showed high scatter.

Sunset Optical EC = 0.58 ± 0.05 Sunset Thermal EC; R^2 = 0.86; n = 506

Sunset Optical EC = 0.62 ± 0.05 AE-20 BC; R^2 = 0.96; n = 539

R&P-5400 TC tracked filter TC closely, but differed widely for OC and EC.

Sunset OC = (0.75 ± 0.76) R&P-2300 OC + (0.08 ± 0.36); R^2 = 0.67; n = 16

Sunset OC = (0.98 ± 0.11) R&P-5400 OC - (0.47 ± 0.17); R^2 = 0.44; n = 327

R&P-5400 OC = (0.60 ± 0.47) R&P-2300 OC +

CONTINUOUS SAMPLER	FLOW RATE (L/min)	DENUDER[b]	OC	EC	COMMENTS
R&P-5400	16.7	None	340 °C in air	750 °C in air	No pyrolysis correction
Sunset OCEC	n/a	CIF	600, 870 °C in He	870 °C at 10% O_2 in He	Transmittance
AE-20	n/a	None		b_{abs} @ 370, 880 nm	Transmittance, 14625/λ m²/g factor, where λ is in nm
AMS	n/a	None	n/a	n/a	~ 1 µm cut-point

SITE/PERIOD/SAMPLER/ CONFIGURATION	SUMMARY OF FINDINGS
	(0.58 ± 0.82); $R^2 = 0.58$; $n = 17$
	Organic matter measurements by AMS showed reasonable correlation ($R^2 = 0.76$) with filter (R&P-2300) OC, while being poorly correlated with continuous OC by Sunset ($R^2 = 0.32$) and R&P-5400 ($R^2 = 0.36$)
	Sunset EC = (1.21 ± 0.44) R&P-2300 EC – (0.03 ± 0.13); $R^2 = 0.94$; $n = 16$
	Sunset EC = (1.35 ± 0.12) R&P-5400 EC + (0.06 ± 0.04); $R^2 = 0.61$; $n = 327$
	R&P-5400 EC = (0.49 ± 0.46) R&P-2300 EC + (0.09 ± 0.26); $R^2 = 0.77$; $n = 15$
	Sunset TC = (0.86 ± 0.39) R&P-2300 TC – (0.06 ± 0.69); $R^2 = 0.77$; $n = 16$
	Sunset TC = (1.31 ± 0.10) R&P-5400 TC – (1.15 ± 0.15); $R^2 = 0.59$; $n = 327$
	R&P-5400 TC = (0.77 ± 0.58) R&P-2300 TC + (0.35 ± 1.37); $R^2 = 0.83$; $n = 16$

[a]Filter Manufacturer in parentheses - W: Whatman, Clifton, NJ; P: Pall-Gelman, Ann Arbor, MI; S: Schleicher & Schnell. Keene, NH; n/a: not available. QBT: quartz backup filter behind Teflon front filter. QBQ: quartz backup filter behind Quartz front filter.

[b]Al_2O_3: Aluminum oxide; IC: Ion chromatography; CIF: Charcoal Impregnated Filter; CIG: Charcoal Impregnated Glass-Fiber Filter; FEP: Fluorinated Ethylene Propylene copolymer; MgO: Magnesium oxide; Na_2CO_3: Sodium carbonate; $NaHCO_3$: Sodium bicarbonate NO_X: Oxides of nitrogen; SO_2: Sulfur dioxide; TEA: Triethanolamine; TSP: Total Suspended PM; UV: Ultraviolet; XAD-4: (hydrophobic, non-polar polyaromatic resin.

[c]NIOSH 5040_TOT: National Institute of Occupational Safety and Health Method 5040 Thermal Optical Transmittance Protocol. [121, 122, 123, 124, 125] OC: 250, 500, 650, 850 °C for OC1, OC2, OC3, and OC4 fractions, respectively, for 60, 60, 60, 90 sec respectively, in 100% He atmosphere. EC: 650, 750, 850, 940 °C for EC1, EC2, EC3, and EC4 fractions, respectively, 30, 30, 30, >120 sec respectively, in 98% He and 2% O_2 atmosphere. OPT: Pyrolysis correction by transmittance. IMPROVE_TOR: Interagency Monitoring of Protected Visual Environments Thermal Optical Reflectance Protocol. [126] OC fractions: 120, 250, 450, 550 °C for OC1, OC2, OC3, and OC4 fractions, respectively, until a well defined peak has evolved at each step, with a time limit of min 80 sec and max of 580 sec, in 100% He atmosphere. EC fractions: 550, 700, 800 °C for EC1, EC2, and EC3 fractions, respectively, until a well defined peak has evolved at each step, with a time limit of min 80 sec and max of 580 sec, in 2% O_2 and 98% He atmosphere. OPR: Pyrolysis correction for pyrolyzed organic carbon (OP) by reflectance. OC = OC1+OC2+OC3+OC4+OP EC = EC1+EC2+EC3-OP TC = OC+EC. IMPROVE_A TOR: [127] Note that as of May, 2007, the U.S. EPA is switching samples from the Speciation Trends Network thermal optical transmittance protocol to the IMPROVE_A protocol. OC: 140, 280, 480, 580 °C for OC1, OC2, OC3, and OC4, fractions, respectively, until a well defined peak has evolved at each step, with a time limit of 80 sec and max of 580 sec, in 100% He atmosphere EC: 580, 740, 840 °C for EC1, EC2, and EC3 fractions, respectively, until a well defined peak has evolved at each step, with a time limit of min 80 sec and max of 580 sec, in 2% O_2 and 98% He atmosphere. OPR: Pyrolysis correction for pyrolyzed organic carbon (OP) by reflectance. OPT: Pyrolysis correction by transmittance. TPV: Temperature Programmed Volatilization. [17, 81, 128] For CIF Filters: Heated from 50 °C to 300 °C at a ramp rate of 10 °C/min in N_2. For Quartz filters: Heated from 50 °C to 800 °C at a ramp rate of 28 °C/min in 70% N_2 and 30% O_2; EC estimated from high temperature peak (>450 °C) on thermogram obtained from quartz-fiber filter analysis; No pyrolysis correction. STN_TOT: Speciation Trends Network Thermal Optical Transmittance Protocol.[129] OC: 310, 480, 615, 920 °C for 60, 60, 60, 90 sec respectively, in 100% He atmosphere. EC: 600, 675, 750, 825, 920 °C for 45, 45, 45, 45, 120 sec respectively, in 98% He and 2% O_2 atmosphere. ACE Asia TOT: Aerosol Characterization Experiments in Asia Thermal Optical Transmittance Protocol. [130] OC: 340, 500, 615, 870 °C for 60, 60, 60, 90 sec respectively, in 100% He atmosphere. EC: 550, 625, 700, 775, 850, 900 °C for45, 45, 45, 45, 45, 120 sec respectively, in 98% He, 2% O_2. Pyrolysis correction by transmittance.

[d]Custom TOT: XAD-4 impregnated quartz, analyzed in He-only atmosphere with a maximum temperature 176 °C; EC is not measured.

[e]Custom TOR to suit Al substrate; details not reported.

[f]37-mm filter

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005a); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2004); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-16. Summary of particle mass spectrometer measurement comparisons.

Spectrometer	Inlet Characteristics[a] (Flow Rate [L/Min] Size Inlet Dryer Aerodynamic Diameter, μm Particle Sizing Method)	Volatilization/ Ionization Method[a]	Hit Rates[b]	Mass Spectrometer[c]	Particle Analysis/ Classification	Other
PALMS	n/a PM$_{2.5}$ cyclone Nafion (17 days) / None (4 days) 0.35 - 2.5 Light scattering	LDI, ArF 193 nm 2x109 to 5x109 W/cm^2	14 to 100%, overall 87%	Single TOF reflectron; Ion polarity needs to be pre-selected	Peak ID/regression tree analysis	Pure sulfuric acid (H_2SO_4), (NH_4)$_2SO_4$, and water (H_2O) have relatively high ionization thresholds (i.e. difficult to ionize). Fraction of molecules ionized in the particles is on the order of 10^{-5} to 10^{-6}.
ATOFMS	1 None None 02 – 2.5 Aerosol TOF	LDI, Nd: YAG 266 nm laser ~ 1x108 W/cm^2	25-30%, occasionally as low as 5%	Dual TOF reflectron; Detects both positive and negative ions	Aerosol TOF	
RSMS-II	n/a None Nafion 0.015 - 1.3 Aerodynamic focusing Need to pre-select sizes to be analyzed	LDI, Arf laser, 193 nm 1x108 to 2x108 W/cm^2	n/a	Single linear TOF; Ion polarity needs to be pre-selected	Peak ID/artificial neural network	
AMS	n/a PM$_{2.5}$ cyclone None 0.05 - 2.5 Aerosol TOF	T~550 °C/ EI	n/a	Quadrupole; Mass weighted size distributions on pre-selected positive ions only.	ID using standard EI ionization databases	Does not detect/ analyze highly refractory materials such as metals, sea salt, soot etc. Fraction of molecules ionized in the particles is on the order of 10^{-6} to 10^{-7}

Middlebrook et al. [131]; Wenzel et al. [132]; Jimenez et al.[133]

Particle sizing is approximate in PALMS, while ATOFMS, RSMS-II and AMS provide relatively accurate particle sizing.

Particle transmission in AMS is ~100% (i.e., it uses all particles in the sampled air) between 60 and 600 nm, while that for PALMS, ATOFMS and RSMS-II range from 10^{-6} for submicron particles to 2% for supermicron (>0.8 μm) particles.

AMS has fewer matrix effects (due to separate volatilization and ionization steps) compared to single-step LDI instruments.

While four major particle classifications (organic/ SO_4^{2-}, sodium/potassium sulfate, soot/hydrocarbon and mineral) were observed by all three laser instruments, they differed in the classification frequencies. Differences in frequencies that are detected and grouped are related to the differences in the laser ionization conditions (e.g., wavelength), particle transmission, sizing method and the way the spectra were classified.

Shorter ionization wavelengths are able to produce ions more easily than longer ones.

Low hit rates in ATOFMS corresponded to periods of high SO_4^{2-} concentrations. Low hit rates in PALMS were related to a variety of factors including high SO_4^{2-} concentrations, differing laser fluence and laser position relative to particle beam. Use of a dryer in PALMS enhanced ionization of particles that were difficult to ionize at high ambient RH.

The RSMS-II and ATOFMS were less sensitive to SO_4^{2-} and hence may have fewer organic/SO_4^{2-} particles (i.e., underestimate SO_4^{2-}, pure sulfuric acid etc.).

The PALMS, ATOFMS and RSMS (laser based instruments) are qualitative, while the AMS can be quantitative. The relative ratio of ion intensities from the laser instruments, however, may be indicative of relative concentrations, thus giving semi-quantitative information.

Comparison of the ratio of NO_3 to SO_4 peaks with the results from the semi continuous instruments showed better correlation with the AMS (R^2 = 0.93) than PALMS (R^2 = 0.65 for non-dry particles to 0.70 for dry particles). While reasonable correlations between the PALMS and the composite semi-continuous data indicate the possibility for calibration of laser-based data for certain ions, the calibration factors may vary depending on the particle matrix, water content and laser ionization parameters, and averaging the spectra according to these factors may minimize these effects.

Comparison of AMS SO_4 with PILS SO_4 showed good correlation (R^2 = 0.79), and the data uniformly scattered around a 1: 1 line. NO_3 comparison was poor (R^2 = 0.49) because of the low signal to noise ratio at low concentrations

The continuum between particle classifications indicates that the particles were not adequately represented by non-overlapping classifications.

Spectrometer	Inlet Characteristics[a] (Flow Rate [L/Min] Size Inlet Dryer Aerodynamic Diameter, µm Particle Sizing Method)	Volatilization/ Ionization Method[a]	Hit Rates[b]	Mass Spectrometer[c]	Particle Analysis/ Classification	Other

HOUSTON SUPERSITE, TX; 08/23/00 to 09/18/00
Houston Regional Monitoring Site was located < 1.0 km north of the Houston ship channel, where chemical and other industries are present. The site was located between a railway to the south and a chemical plant to the north. Major freeways were located just to the north and east of the sampling site.

SPECTROMETER	INLET CHARACTERISTICS (FLOW RATE [L/MIN] SIZE INLET DRYER AERODYNAMIC DIAMETER, µM PARTICLE SIZING METHOD)	VOLATILIZATION/ IONIZATION METHOD[a]	HIT RATES[b]	MASS SPECTROMETER[c]	PARTICLE ANALYSIS/ CLASSIFICATION	OTHER
RSMS-II	n/a None Nafion 0.035 – 1.14 Aerodynamic focusing; Need to pre-select sizes to be analyzed	LDI, ArF laser, 193 nm	n/a	Single linear TOF; Ion polarity needs to be pre-selected	Peak ID/artificial neural network	At each size point, aerosol was sampled in each cycle for either 10 min or until mass spectra for 30 particles per major class were collected, whichever came first.

Phares et al. [134]

27,000 spectra were classified using a neural network into 15 particle types

Fifteen particle type mass spectra were presented along with their size distribution, avg time of day occurrence, and wind direction dependence

Major classes were a K^+ dominant, Si/Silicon Oxide, Carbon, Sea Salt, Fe, Zn, Amines, Lime, Vanadium, Organic Mineral, Pb and K, Al, and a Pb salt particle type.

FRESNO SUPERSITE, CA: 11/30/00 to 2/4/01
Urban location in a residential neighborhood.

SPECTROMETER	INLET CHARACTERISTICS (FLOW RATE [L/MIN] SIZE INLET DRYER AERODYNAMIC DIAMETER, µM PARTICLE SIZING METHOD)	VOLATILIZATION/ IONIZATION METHOD[a]	HIT RATES[b]	MASS SPECTROMETER[c]	PARTICLE ANALYSIS/ CLASSIFICATION	OTHER
ATOFMS	1 None None 0.3 – 2.5 Aerodynamic	LDI, ND: YAG 266 nm	n/a	Dual reflectron TOF	Peak ID/artificial neural network	ATOFMS unscaled detected particles tracked β attenuation monitor $PM_{2.5}$ mass concentration

Qin and Prather [135]

Biomass burning particles reached a maximum at night and a minimum during the day. These particles were less than 1 µm in diameter and accounted for more than 60% of the particles detected at night.

Another particle class characterized by high mass carbon fragments had a similar diurnal pattern. These particles were larger than 1 µm and were interpreted as biomass particles that have undergone gas to particle conversion of semi-volatile species followed by dissolution in a water droplet.

PITTSBURGH SUPERSITE, PA; 09/07/02 TO 09/22/02 FOR AMS; 09/20/01 to 09/26/02 for RSMS-III
6 km east of downtown in a park on the top of a hill

SPECTROMETER	INLET CHARACTERISTICS (FLOW RATE [L/MIN] SIZE INLET DRYER AERODYNAMIC DIAMETER, µM PARTICLE SIZING METHOD)	VOLATILIZATION/ IONIZATION METHOD[a]	MASS SPECTROMETER[c]	OTHER
AMS	1.4 cc/s $PM_{2.5}$ cyclone None 0.05 – 1.0 Aerosol TOF	T - 600 °C/ EI	Quadrupole; Mass weighted size distributions on pre-selected positive ions only.	Particle size-cut of ~1 µm

Spectrometer	Inlet Characteristics[a] (Flow Rate [L/Min] Size Inlet Dryer Aerodynamic Diameter, μm Particle Sizing Method)	Volatilization/ Ionization Method[a]	Hit Rates[b]	Mass Spectrometer[c]	Particle Analysis/ Classification	Other
RSMS-III	n/a None Nafion 0.03 – 1.1 Aerodynamic focusing; Need to pre-select sizes to be analyzed.	LDI, ArF laser, 193 nm		Dual TOF feflectron; Detects both positive and negative ions	At each size point, aerosol was sampled in each cycle for either 10 min or until mass spectra for 30 particles per major class were collected, whichever came first	

Zhang et al.[136]; Bein et al.[137]

The AMS observed 75% of the SO_4^{2-} measured by R&P-8400S ($R^2 = 0.69$).

Collection efficiency (CE) of 0.5 used for SO_4^{2-}, NO_3 and NH_4^+ and 0.7 for organics to correct mass concentrations for incomplete detection. Use of a constant CE irrespective of size and shape may overestimate accumulation mode (mostly, oxygenated) organics (true CE ~ 0.5) and underestimate smaller mode (primary) organics (true CE ~ 1.0).

Comparison of AMS organics (organic matter, OM) with OC measured by a continuous Sunset OCEC instrument showed good correlation ($R^2 = 0.88$) with a slope of 1.69. A 24-h avg comparison, showed a slope of 1.45. These values are in the typical range of 1.2 to 2.0 for OM/OC ratios.

AMS could be used along with the SMPS to estimate particle density. The AMS did not always agree with SMPS, probably due to non-spherical particles (irregular) such as soot from fresh traffic emissions, whose mass may be overestimated by the SMPS.

Comparison of AMS mass with the MOUDI, showed differences for aerodynamic diameters >600 nm, probably due to the AMS transmission being less than unity for particles larger than 600 nm.

For RSMS-III, 54% of the detected particles were assigned to one class (carbonaceous ammonium nitrate). This class was preferentially detected during the colder months and was detected from many different wind directions.

The next largest RSMS-III class was EC/OC/K class at 11%, and is believed to be from biomass burning.

An unidentified organic carbon RSMS-III class (3.3% of all detected particles) was seen to be highly dependent on wind direction dependence and was primarily detected during August and September of 2002. These particles likely originated from a landfill.

NEW YORK SUPERSITE; 06/30/01 to 08/05/01 (urban); 07/09/02 to 08/07/02: (rural)
Urban Site: Queens College, Queens, New York, located at the edge of a parking lot and within 1 km from expressways and highways in New York City Metropolitan area.
Rural Site: Whiteface Mountain, New York, located in a cleared area surrounded by mix of deciduous and evergreen trees, ~2 km away from the closest highway with no major cities within 20 km.

SPECTROMETER	INLET CHARACTERISTICS (FLOW RATE [L/MIN] SIZE INLET DRYER AERODYNAMIC DIAMETER, μM PARTICLE SIZING METHOD)	VOLATILIZATION/ IONIZATION METHOD[a]	MASS SPECTROMETER[c]	OTHER
AMS	0.1 PM$_{2.5}$ cyclone None 0.02 – 2.5 Aerosol TOF	T – 700 °C/ EI	Quadrupole; Mass weighted size distributions on pre-selected positive ions only.	Data are 10-min averages

Drewnick et al. [138, 139]; Hogrefe et al. [20]

Transport losses were 1.3% on avg.

Inlet losses (at the inlet of AMS) were 1.9%, on avg, ranging from 11% for a 20 nm particle to 9% for a 2.5 μm particle, with a minimum of 0.7% for a 350 nm particle

Overall measurement uncertainty of particle diameter was ~11%.

The AMS was reliable with proper calibration, care, and maintenance. Valid 10 min averages were obtained for all components more than 93% of the time.

The mass to charge ratios (m/z) of fragments from different components may overlap (e.g., NH^+, a fragment of NH_4^+ and CH_3^+, a fragment of organic species, have m/z = 15) resulting in an interference (called as isobaric interference) Interfering signals were not used to calculate concentrations. This loss in concentration was adjusted by applying a correction factor determined from laboratory studies.

Typical interferences were from fragments of organic species, water and oxygen.

With adjustments, the SO_4^{2-}, NO_3^-, and ammonium concentrations measured by the AMS were consistently lower than that measured by other co-located instruments, probably due to incomplete focusing of the $(NH_4)_2SO_4$ and NH_4NO_3 particles by the aerodynamic lens.

At the urban site, AMS NO_3 was within 10% of the filter NO_3 concentration. At the rural site, it had a slope of 0.51 and R^2 of 0.46.

AMS SO_4 showed good agreement with R&P-8400S at both the rural and urban locations ($R^2 = 0.89$ to 0.92, slope = 0.99, n = 407 to 695) and was within 70 to 85% of filter SO_4^{2-} concentration.

Comparison of the total non-refractory mass measured by the AMS with the PM$_{2.5}$ TEOM mass (operated at 50 °C or with dryer) at the urban location, showed good correlation ($R^2 = 0.91$) with near zero intercept (0.22 μg/m^3). On avg, the AMS observed 64% of the mass measured by the TEOM.

The unexplained mass (36%) was attributed to transport losses, transmission and optical losses, and refractory components in the aerosol sample (e.g., metals, EC). The mass closure was within the estimated uncertainty of the AMS mass measurements (5 to 10%).

Spectrometer	Inlet Characteristics[a] (Flow Rate [L/Min] Size Inlet Dryer Aerodynamic Diameter, µm Particle Sizing Method)	Volatilization/ Ionization Method[a]	Hit Rates[b]	Mass Spectrometer[c]	Particle Analysis/ Classification	Other

BALTIMORE SUPERSITE, MD; 04/01/02 to 11/30/02
East of downtown in an urban residential area. Within 91 m of a bus maintenance facility.

SPECTROMETER	INLET CHARACTERISTICS (FLOW RATE [L/MIN] SIZE INLET DRYER AERODYNAMIC DIAMETER, µM PARTICLE SIZING METHOD)	VOLATILIZATION/ IONIZATION METHOD[a]		MASS SPECTROMETER[c]		OTHER
RSMS-III	0.2 – 18, based on particle size chosen None Nafion 0.045 – 1.3 Aerodynamic focusing; Need to pre-select sizes to be analyzed	LDI, ArF laser, 193 nm		TOF with dual ion polarity		At each size set point, aerosol was sampled in each cycle for either 10 min or until mass spectra from 30 particles were collected, whichever came first.

Lake et al. [140, 141]

Utilizing both positive and negative ion detection enables detection of more species. However, detection efficiencies of negative ions decreased for smaller particles.

SO_4^+ concentration (number or mass) was not accurately quantified.

RSMS-III was most efficient in 0.050 to 0.77 µm range.

Particle compositions could be related to specific source categaories.

[a]EI: Electon Impact; LDI: Laser Desorption / Ionization
[b]Hit rate refers to the number of particles with a mass spectrum as a fraction of the number of particles detected. It does not apply to RSMS and AMS because there is no separate detection
[c]TOF: Time fo Flight
ATLANTA SUPERSITE, GA; 08/03/99 to 09/01/99
4 km NW of downtown, within 200 m of a bus maintenance yard and several warehouse facilities, representative of a mixed commercial-residential neighborhood.

Source: [1]Chow (1995); [2]Watson and Chow (2001); [3]Watson et al. (1983); [4]Fehsenfeld et al. (2004); [5]Solomon et al. (2001); [6]Mikel (2001); [7]Mikel (2001); [8]Watson et al. (1999); [9]Solomon and Sioutas (2006); [10]Graney et al.; [11]Tanaka et al. (1998); [12]Pancras et al. (2005); [13]John et al. (1988); [14]Hering and Cass (1999); [15]Fitz et al. (1989); [16]Hering et al. (1988); [17]Solomon et al. (2003); [18]Cabada et al. (2004); [19] Fine et al. (2003); [20]Hogrefe et al. (2004); [21]Drewnick et al. (2003); [22]Watson et al. (2005); [23]Ho et al. (2006); [24]Decesari et al. (2005); [25]Mayol-Bracero et al. (2002); [26]Yang et al. (2003); [27]Tursic et al. (2006); [28]Mader et al. (2004); [29]Xiao, et al. (2004); [30]Kiss et al. (2002); [31]Cornell et al. (1999); [32]Zheng et al. (2002); [33]Fraser et al. (2002); [34]Fraser et al. (2003b); [35]Schauer et al. (1996); [36]Fine et al. (2004); [37]Yue et al. (2004); [38]Rinehart et al. (2006); [39]Wan and Yu (2006); [40]Poore (2000); [41]Fraser et al. (2003a); [42]Engling et al. (2006); [43]Yu et al. (2005); [44]Tran et al. (2000); [45]Yao et al. (2004); [46]Li and Yu (2005); [47]Henning et al. (2003); [48]Zhang and Anastasio (2003); [49]Emmenegger et al. (2007); [50]Watson et al. (1989); [51]Greaves et al. (1985); [52]Waterman et al. (2000); [53]Waterman et al. (2001); [54]Falkovich and Rudich (2001); [55]Chow et al. (2007); [56]Miguel et al. (2004); [57]Crimmins and Baker (2006); [58]Ho and Yu (2004); [59]Jeon et al. (2001); [60]Mazzoleni et al. (2007); [61]Poore (2000); [62]Butler et al. (2003); [63]Chow et al. (2006c); [64]Russell et al. (2004); [65]Grover et al. (2006); [66]Grover et al. (2005); [67]Schwab et al. (2006b); [68]Hauck et al. (2004); [69]Jaques et al. (2004); [70]Rupprecht and Patashnick (2003); [71]Pang et al. (2002b) [72]Eatough et al. (2001); [73]Lee et al. (2005b); [74]Lee et al. (2005a); [75]Babich et al. (2000); [76]Lee et al. (2005c); [77]Lee et al. (2005b); [78]Anderson and Ogren (1998); [79]Chung et al. (2001); [80]Kidwell and Ondov (2004); [81]Lithgow et al. (2004); [82]Weber et al. (2003); [83]Harrison et al. (2004); [84]Rattigan et al. (2006); [85]Wittig et al. (2004); [86]Vaughn et al. (2005); [87]Chow et al. (2005b); [88]Weber et al. (2001); [89]Schwab et al. (2006a); [90]Lim et al. (2003); [91]Watson and Chow (2002); [92]Venkatachari et al. (2006); [93]Bae et al. (2004a); [94]Arhami et al. (2006); [95]Park et al. (2005a); [96]Bae et al. (2004b); [97]Chow et al. (2006a); [98]Arnott et al. (2005); [99]Bond et al. (1999); [100]Virkkula et al. (2005); [101]Petzold et al. (2002); [102]Park et al. (2006); [103]Arnott et al. (1999); [104]Peters et al. (2001); [105]Pitchford et al. (1997); [106]Rees et al. (2004); [107]Watson et al. (2000); [108]Lee et al. (2005a); [109]Hering et al. (2004); [110]Watson et al. (1998); [111]Chakrabarti et al. (2004); [112]Mathai et al. (1990); [113]Kidwell and Ondov (2001); [114]Stanier et al. (2004); [115]Khlystov et al. (2005); [116]Takahama et al. (2004); [117]Chow et al. (2005a); [118]Zhang et al. (2002); [119]Subramanian et al. (2004); [120]Chow et al. (2006b); [121]Birch and Cary (1996); [122]Birch (1998); [123]Birch and Cary (1996); [124]NIOSH (1996); [125]NIOSH (1999); [126]Chow et al. (1993); [127]Chow et al. (2007); [128]Ellis and Novakov (1982); [129]Peterson and Richards (2002); [130]Schauer et al. (2003); [131]Middlebrook et al. (2003); [132]Wenzel et al. (2003); [133]Jimenez et al. (2003); [134]Phares et al. (2003); [135]Qin and Prather (2006); [136]Zhang et al. (2005); [137]Bein et al. (2005); [138]Drewnick et al. (2004a); [139]Drewnick et al. (2004b); [140]Lake et al. (2003); [141]Lake et al. (2004)

Table A-17. Summary of key parameters for TD-GC/MS and pyrolysis-GC/MS.

Reference	Sample Type	TD Unit	Analytical Instrument	Total Analysis Time
TD-GC/MS WITH RESISTIVELY HEATED EXTERNAL OVEN				
Greaves et al. (1985; 1987); Veltkamp et al. (1996)	Aerosol sample and NIST SRM 1649	A cylindrical aluminum block containing a heating cartridge connected to a thermocouple	HP 5892A GC/MS in EI mode	ambient sample: 55.5 min NIST standard: 45.5 min
Waterman et al. (2000)	NIST SRM 1640a	External oven mounted on the top of the GC/MS system	HP 5890 GC/Fisons MD 800 MS, scan range: 40–520 amu	90 min
Waterman et al. (2001)	NIST SRM 1649a	Same as above	HP 5890 GC/Fisons MD 800 MS, scan range: m/z 40 to 520	90 mins
Sidhu et al. (2001)	Aerosol collected on glass fiber filters from combustion of alternative diesel fuel.	A stainless steel tube (0.635 cm O.D.)placed in a GC oven	Two GCs and one MS. The first GC is used as the TE unit. The second GC separates the desorbent.	U[a]
Hays et al. (2003; 2004); Dong et al. (2004)	Aerosol collected from residential wood combustion, residential oil furnace and fireplace appliance	A glass tube placed in an external oven (TDS2 Gerstel Inc.)	Aglient 6890 GC/5793 MSD, scan range: 50 to 500 amu	99 min
CURIE POINT TD-GC/MS				
Jeon et al. (2001)	High-volume PM_{10} ambient samples collected along the U.S./Mexico border	Curie point pyrolyzer	HP 5890 GC/5792 MSD	Ua
Neususs et al. (2000)	Ambient aerosol collected during the 2nd Aerosol Characterization Experiment	Curie point pyrolyzer	Fisons Trio 1000	35 min
IN-INJECTION PORT TED-GC/MS				
Helmig et al. (1990)	Aerosol samples collected on glass-fiber filters at a forest site	GC injector port, with modified septum cap	Carlo Erba Mega 5160 GC/VG 250/70 SE MS, scan range: 45-400 amu	47 min
Hall et al. (Hall et al., 1999)	NIST SRM 1649	Micro-scale sealed vessel placed inside the injector port	HP 5890 GC/Fisons MD 800 MS, scan range: 40-500 amu	82.5 min
Blanchard and Hopper (1997) Blanchard et al. (2002)	Aerosol samples collected on quartz-and-glass filters in Ontario	A GC injection port was added with three minor components, including a small T-connector, 3-way valve, and needle valve	HP 5892A GC/5972A MS in EI mode	71 min
Falkovich and Rudich (2001); Falkovich et al. (2004); Graham et al. (2004)	NIST SRM 1649a; urban aerosols collected with an 8-stage impactor in Tel-Aviv, Israel	Direct Sample Introduction (DSI) device (ChromatoProbe, Varian Co.)	Varian Saturn 3400 GC/MS	64.2 min
Ho and Yu (2004); Yang et al. (2005)	Ambient aerosol samples collected on Teflon-impregnated glass-fiber filters in Hong Kong and on quartz filters at Nanjing, China	Conventional GC injection port. No modification of GC injector and liner	HP 5890 GC/5791 MSD, scan range: 50-650 amu	41.5 min
TD-GC X GC-MS				
Welthagen et al. (2005); Schnelle-Kreis et al. (2005)	Ambient samples in Augsburg, Germany	Injection port Optic III with autoloader (ATAS-GL, Veldhoven, NL)	Agilent 6890 GC/LECO Pegasus III TOF/MS with a LECO Pegasus 4D GCxGC modulator	175 min
Hamilton et al. (2004)	$PM_{2.5}$ aerosol collected in London	Conventional GC injection port	The same as above, scan range: 20-350 amu	93.7 min
Hamilton et al. (Hamilton et al., 2005)	Secondary organic aerosol formed during the photo-oxidation of toluene with OH radicals	The same as above	The same above	102.5 min

Reference	Sample Type	TD Unit	Analytical Instrument	Total Analysis Time
IN SITU SEMI-CONTINUOUS AND CONTINUOUS TD SYSTEMS				
Williams et al. (2006)	In situ aerosol samples collected in Berkley, CA	Collection-TE cell with conventional GC injection port	Agilent 6890 GC/5793 MSD, scan range: 29-550 amu	59 min
PYROLYSIS TD-GC/MS				
Voorhees et al. (1991)	$PM_{0.6}$ and $PM_{>0.45}$ collected on quartz fiber in pristine regions of Colorado	A tube furnace directly interfaced to an GC/MS	Extrel Simulscan GC/MS, scan range: 35-450 amu	31.7 min
Subbalakshmi et al. (2000)	Ambient aerosol collected on glass-fiber filters in Jakarta, Indonesia	A pyroinjector	Agilent 6890 GC/5973 MS, scan range: 50-550 amu	63.5 min
Fabbri et al. (2002)	PM_{10} collected on glass-fiber filters in an industrial are of Italy	A pyrolyzer directly connected to the GC injector port through an interface heated at 250° C	Varian 3400 GC/Saturn II ion trap MS, scan range: 45-400 amu	57 min
Blazso et al. (2003)	$PM_{2.6}$ collected on quartz-fiber filters and size-segregated aerosol sampled collected on A1 foils in Brazil	A pyrolyzer	Agilent 6890 GC/5973 MS	30.3 min
Labban et al. (2006)	PM_{10} of re-suspended soil collected on quartz-fiber filters	Curie point pyrolyzer	HP 5890 GC/5972 MS	25.5. min

[a]Total analysis time could not be determined because of insufficient experimental details

A.1.2. Monitor Distribution with Respect to Population Density

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 230
- 231 - 459
- 460 - 2295
- 2296 - 4590
- 4591 - 11475
- 11476 - 45900
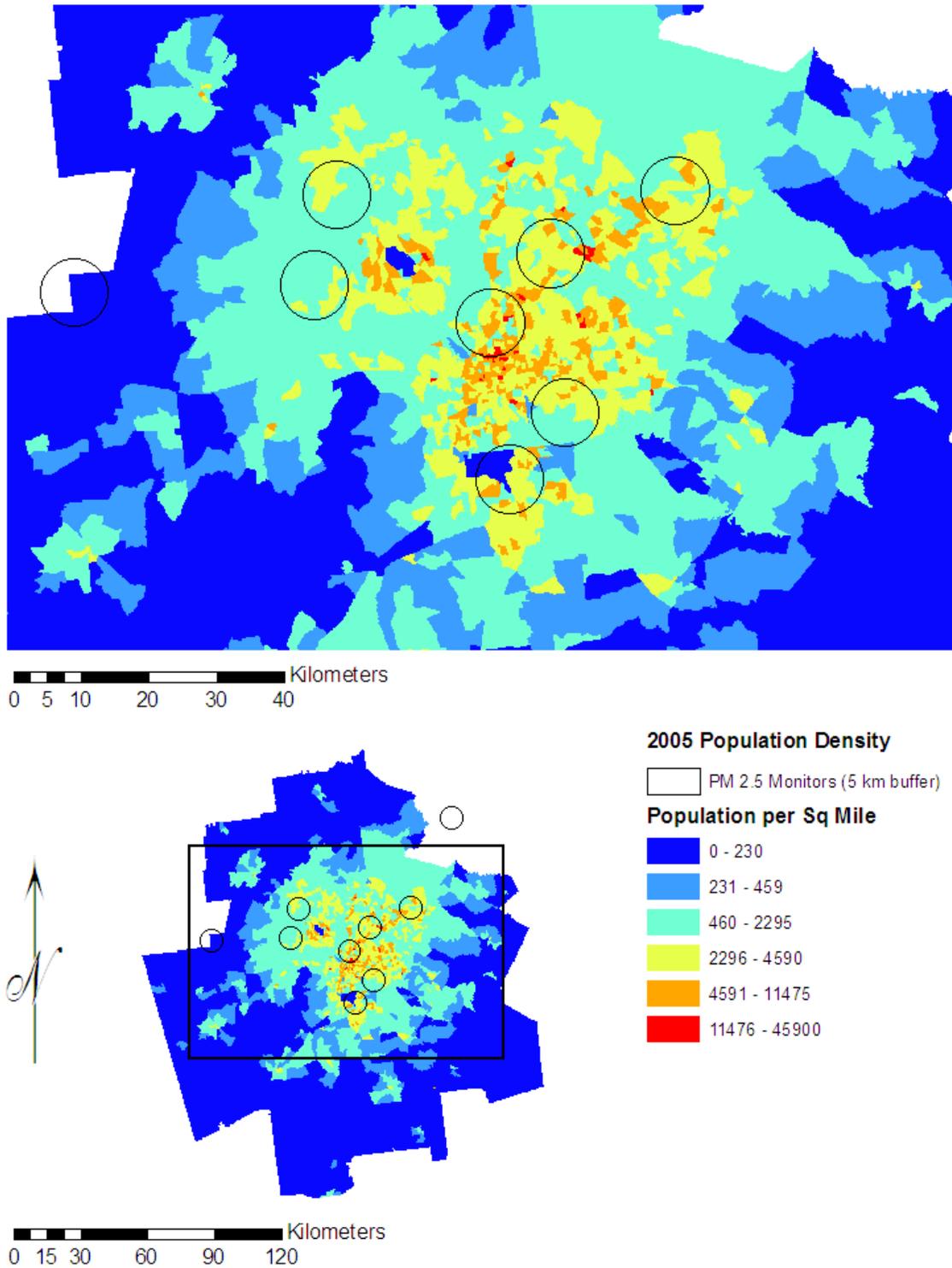
Figure A-1.   PM$_{2.5}$ monitor distribution in comparison with population density, Atlanta, GA.
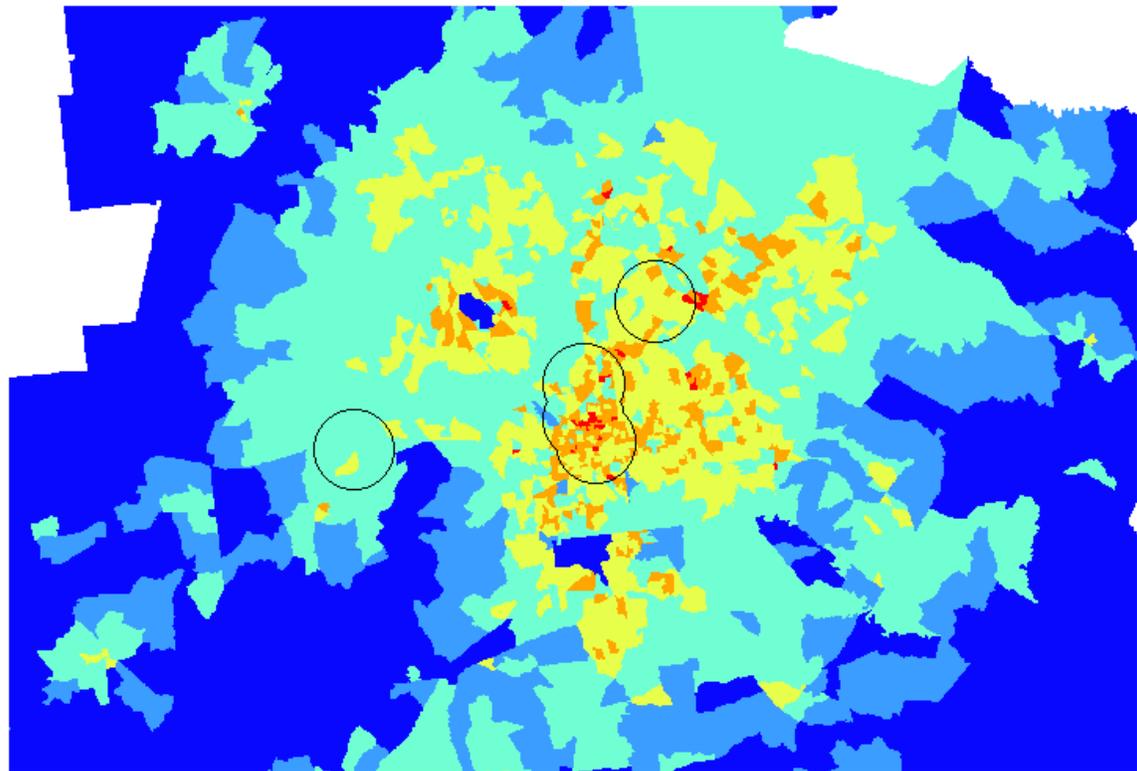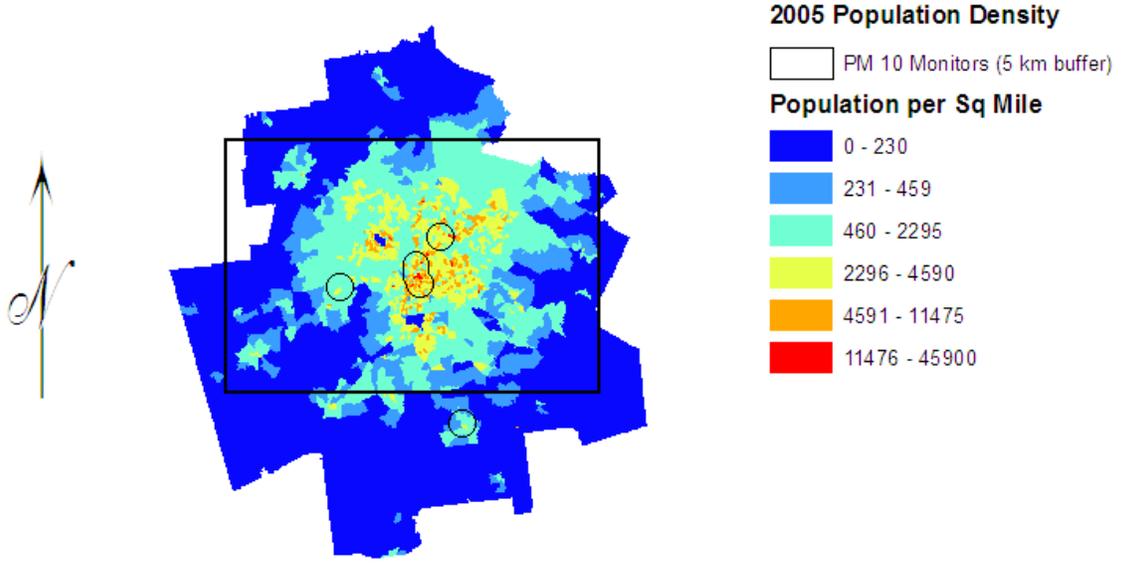
2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 230
- 231 - 459
- 460 - 2295
- 2296 - 4590
- 4591 - 11475
- 11476 - 45900

Figure A-2.   PM$_{10}$ monitor distribution in comparison with population density, Atlanta, GA.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 10 - 61
- 62 - 121
- 122 - 608
- 609 - 1215
- 1216 - 3038
- 3039 - 12153
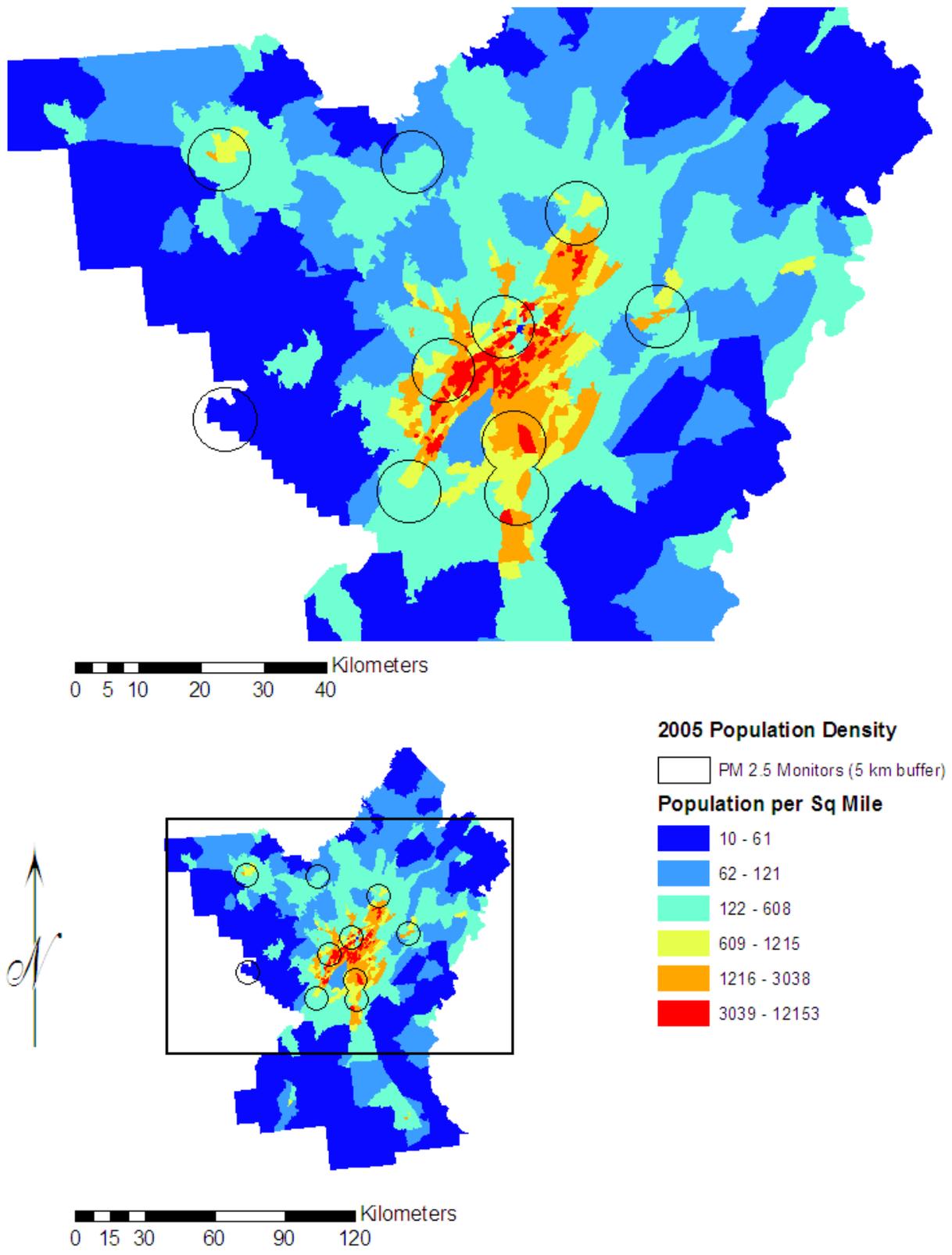
Figure A-3.   PM$_{2.5}$ monitor distribution in comparison with population density, Birmingham, AL.

2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 🟦 10 - 61
- 🟦 62 - 121
- 🟩 122 - 608
- 🟨 609 - 1215
- 🟧 1216 - 3038
- 🟥 3039 - 12153
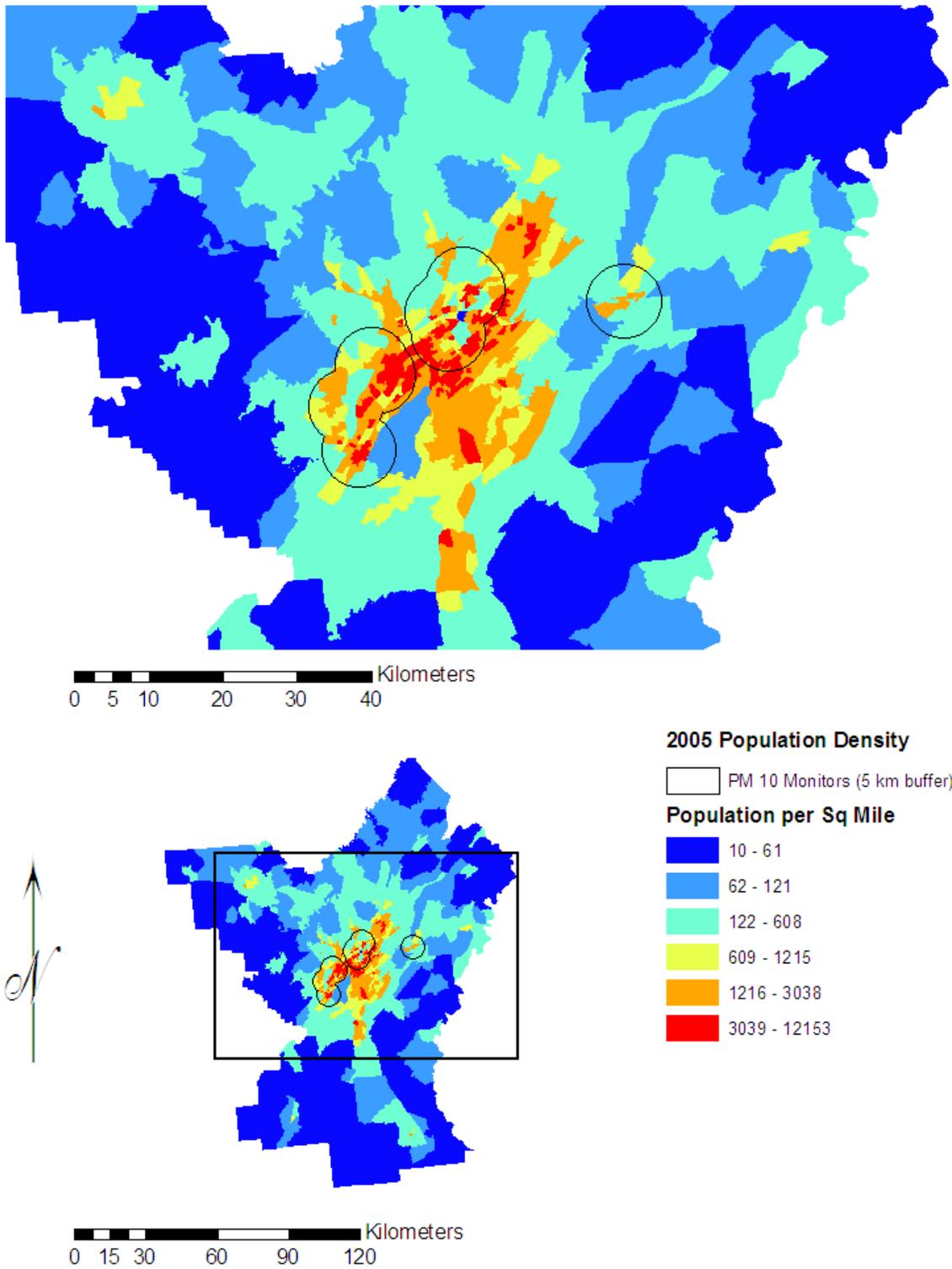
Figure A-4.   PM$_{10}$ monitor distribution in comparison with population density, Birmingham, AL.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- ▮ 0 - 650
- ▮ 651 - 1299
- ▮ 1300 - 6495
- ▮ 6496 - 12990
- ▮ 12991 - 32475
- ▮ 32476 - 129900
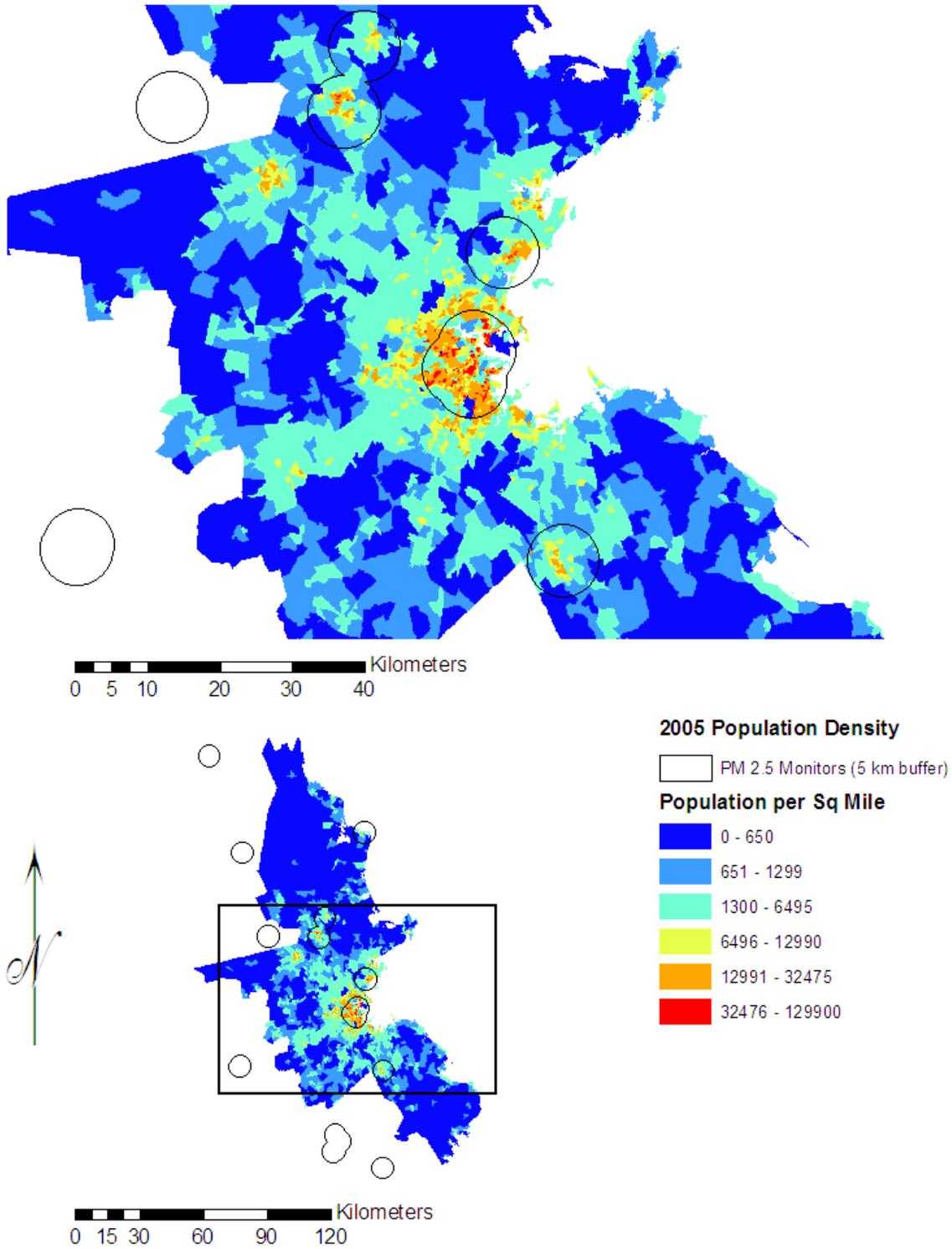
Figure A-5.   PM$_{2.5}$ monitor distribution in comparison with population density, Boston, MA.

2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 650
- 651 - 1299
- 1300 - 6495
- 6496 - 12990
- 12991 - 32475
- 32476 - 129900
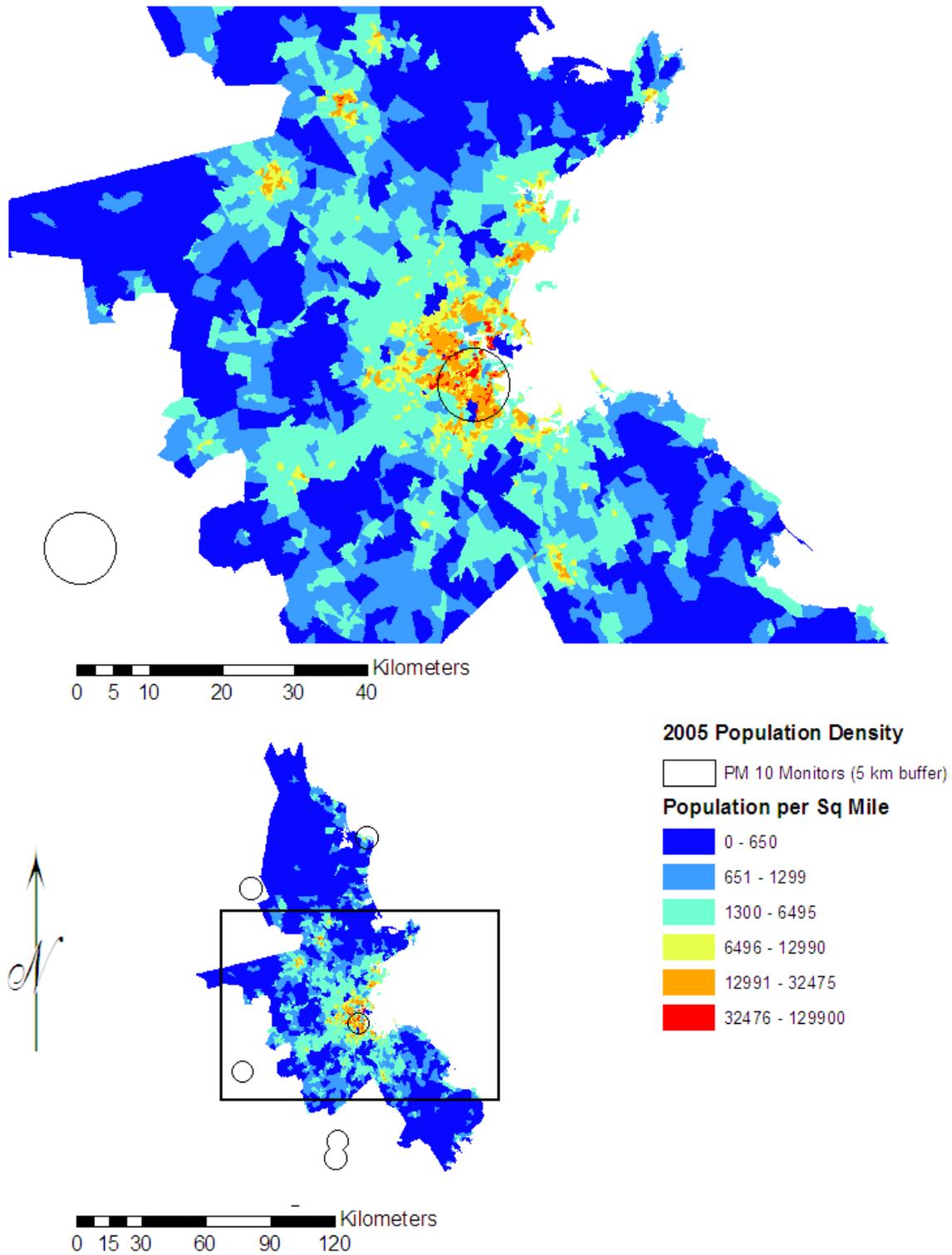
Figure A-6.　　PM$_{10}$ monitor distribution in comparison with population density, Boston, MA.
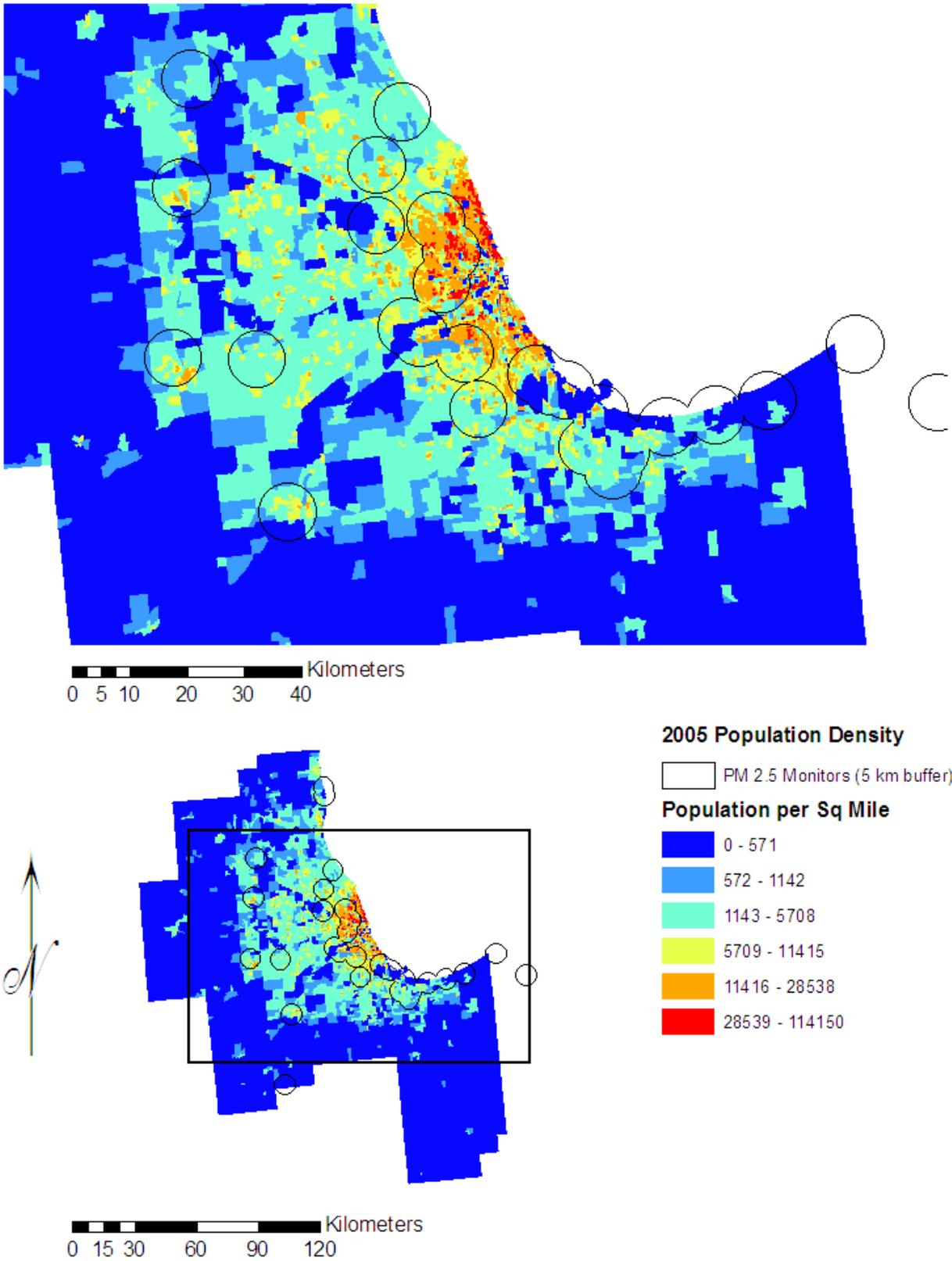
Figure A-7.   PM$_{2.5}$ monitor distribution in comparison with population density, Chicago, IL.
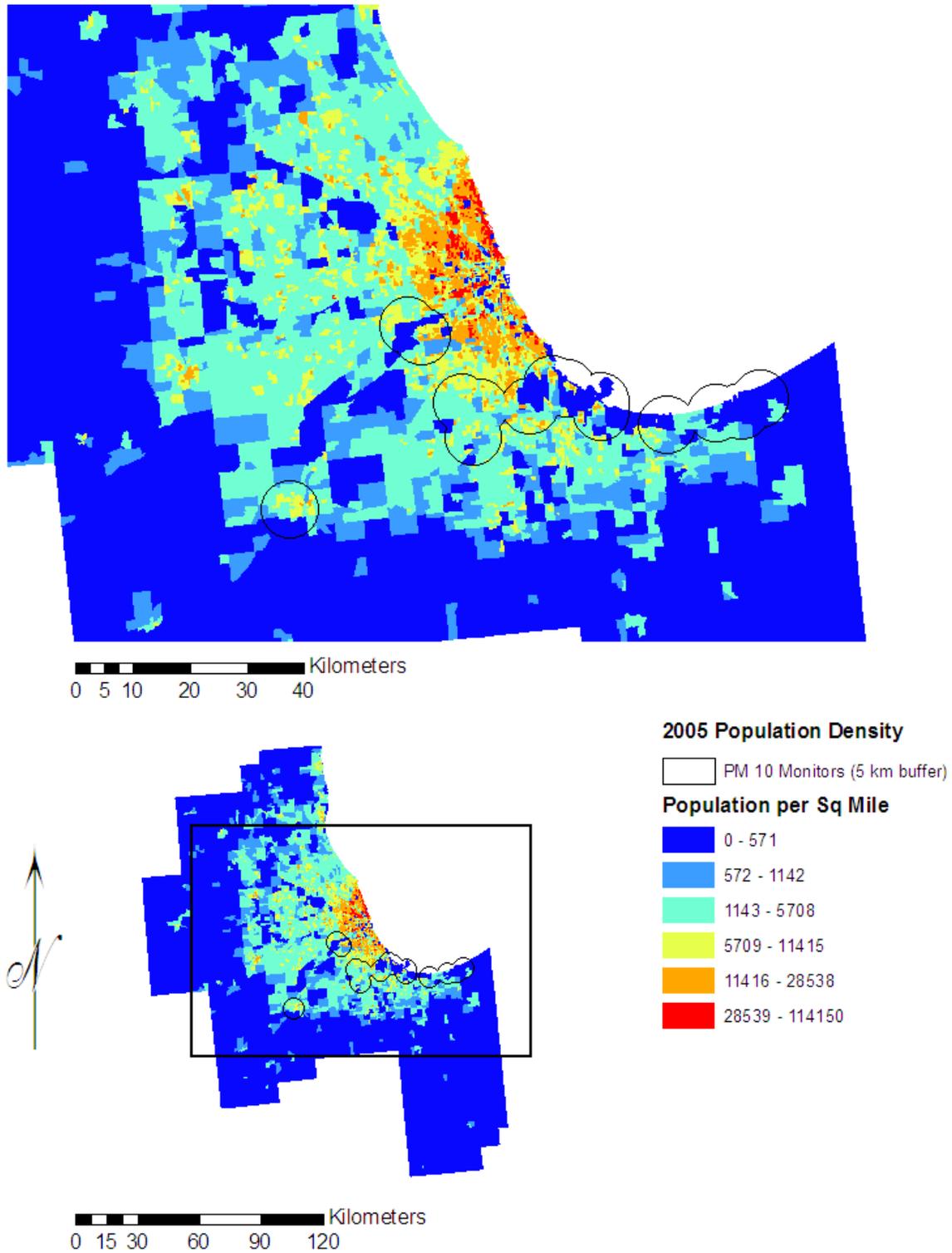
Figure A-8. PM$_{10}$ monitor distribution in comparison with population density, Chicago, IL.
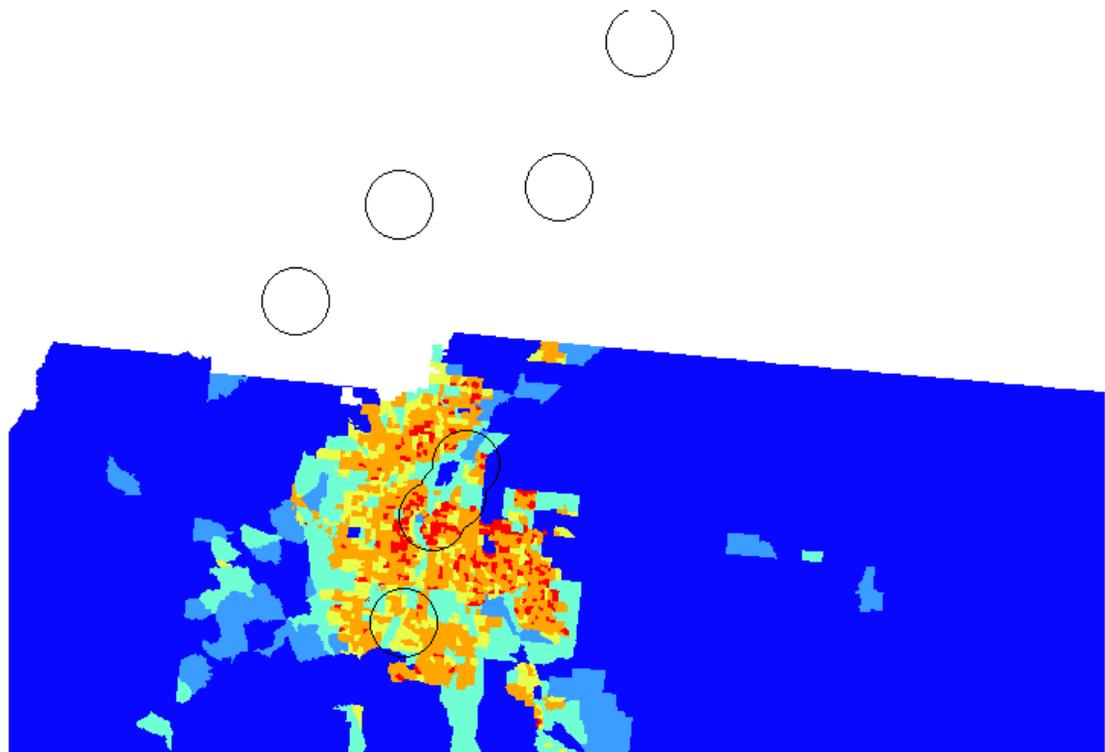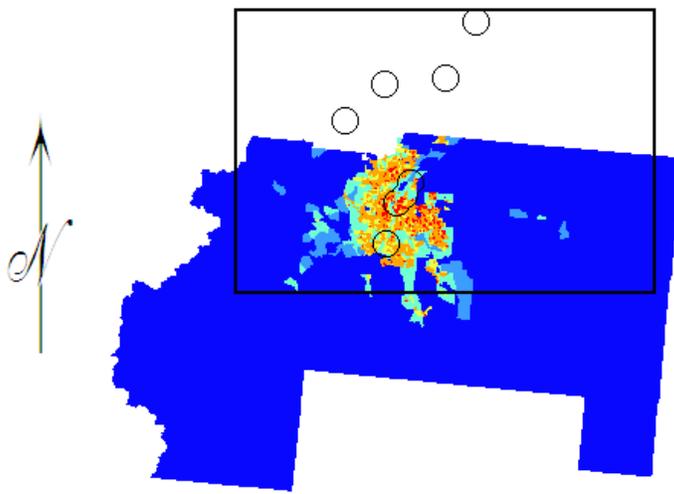
Figure A-9. PM$_{2.5}$ monitor distribution in comparison with population density, Denver, CO.
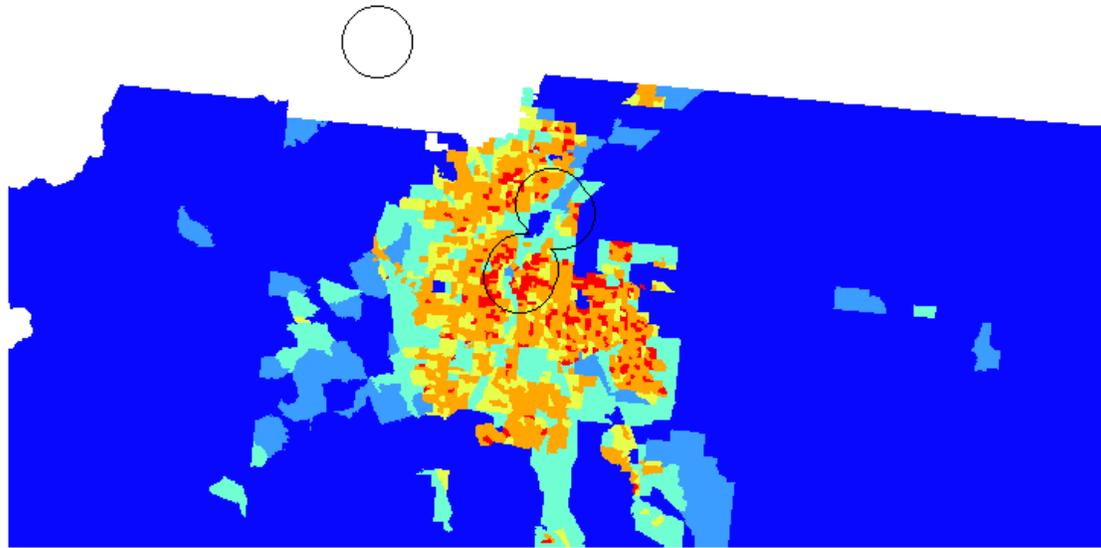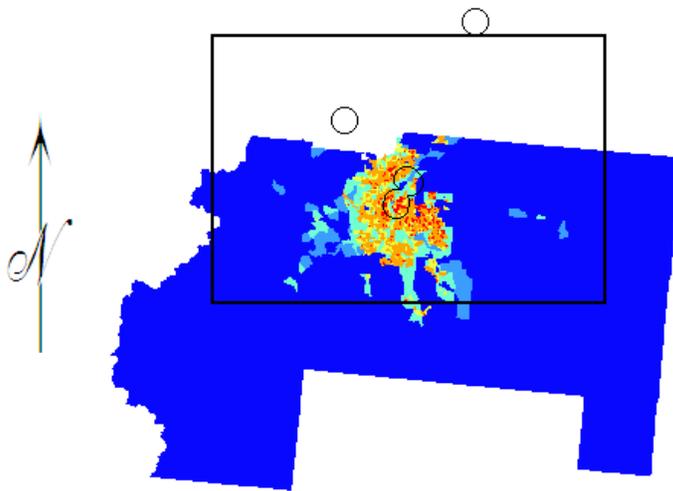
Figure A-10.   PM$_{10}$ monitor distribution in comparison with population density, Denver, CO.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- ■ 0 - 230
- ■ 231 - 461
- ■ 462 - 2303
- ■ 2304 - 4605
- ■ 4606 - 11513
- ■ 11514 - 46050
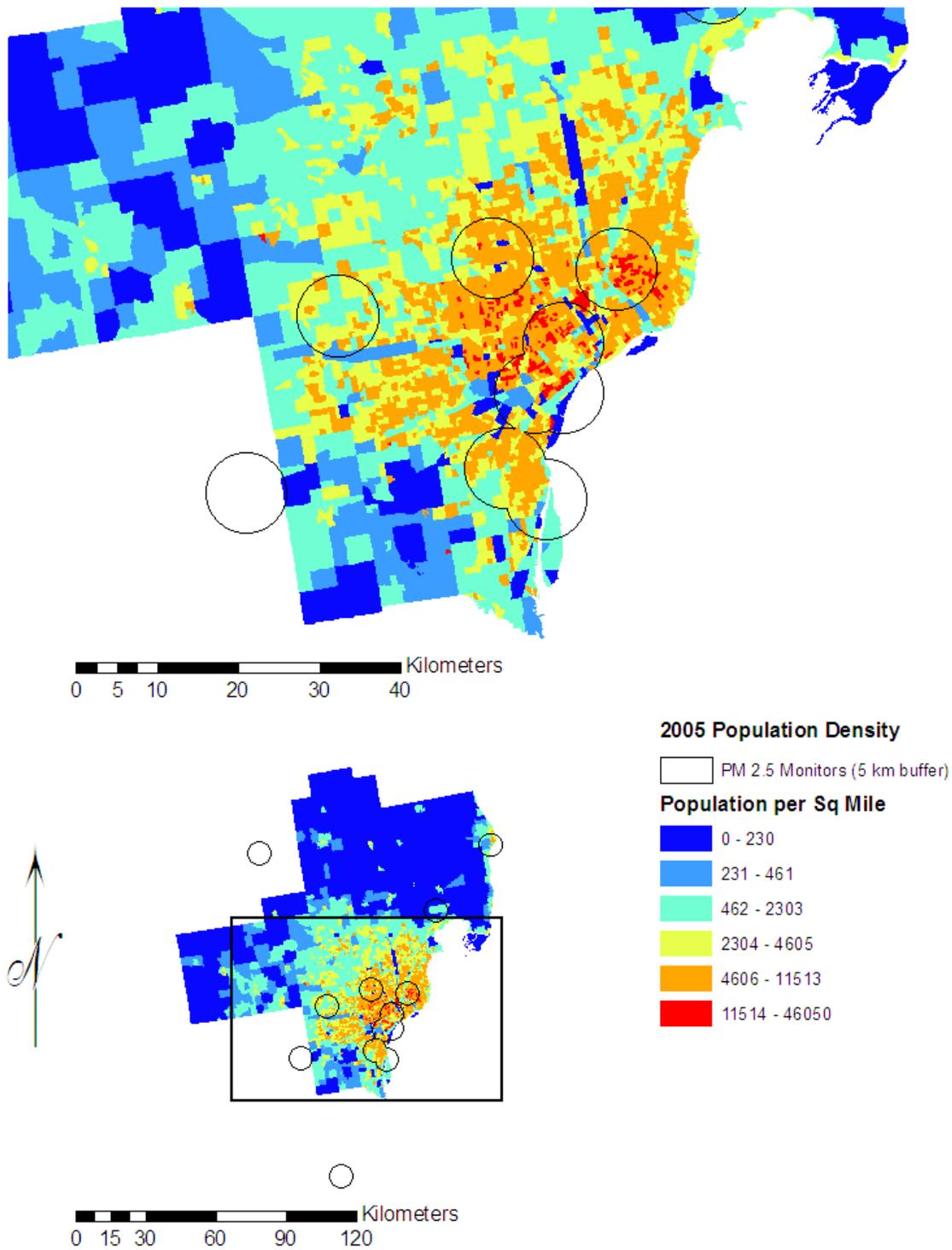
Figure A-11. PM$_{2.5}$ monitor distribution in comparison with population density, Detroit, MI.

2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 230
- 231 - 461
- 462 - 2303
- 2304 - 4605
- 4606 - 11513
- 11514 - 46050
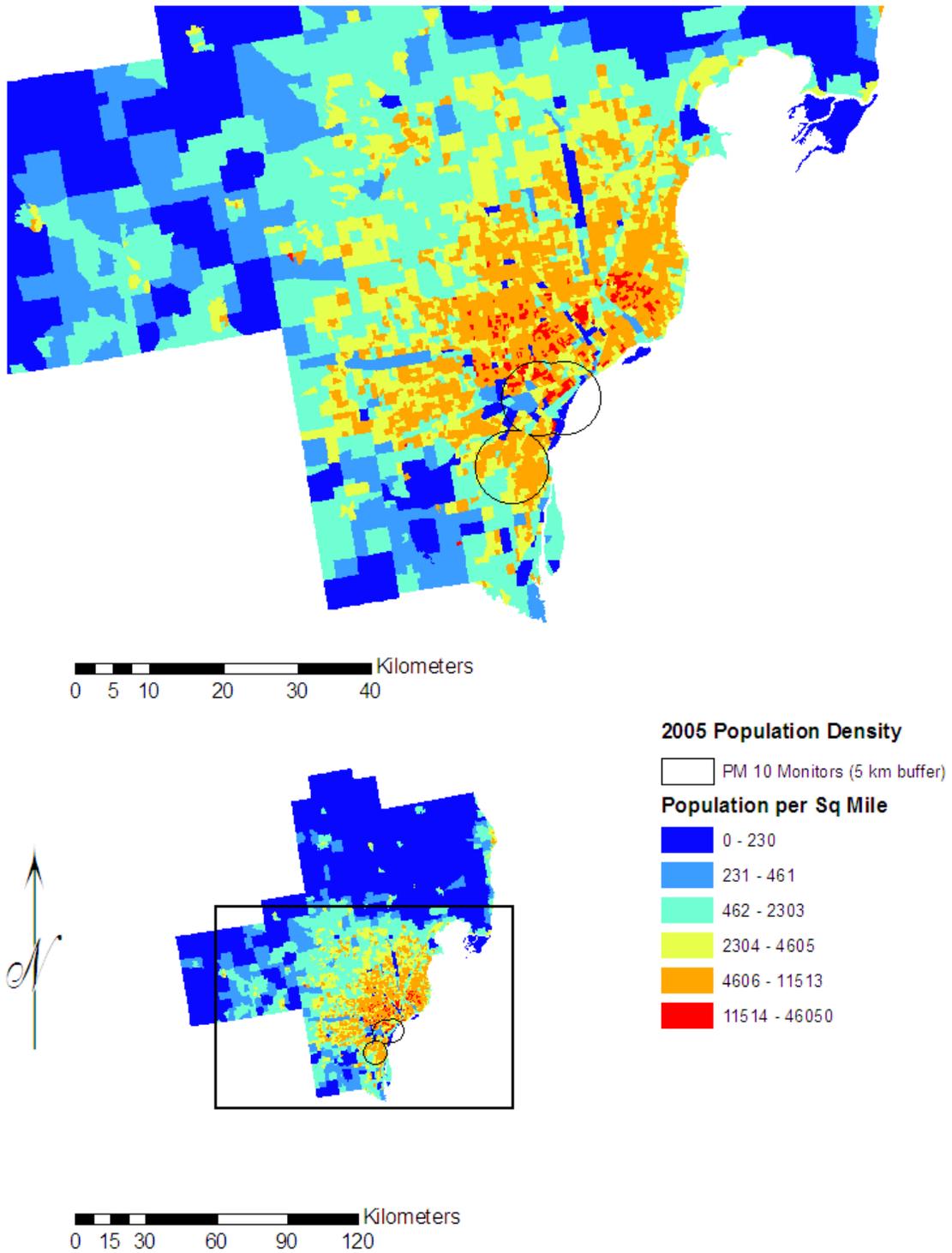
Figure A-12. PM_{10} monitor distribution in comparison with population density, Detroit, MI.
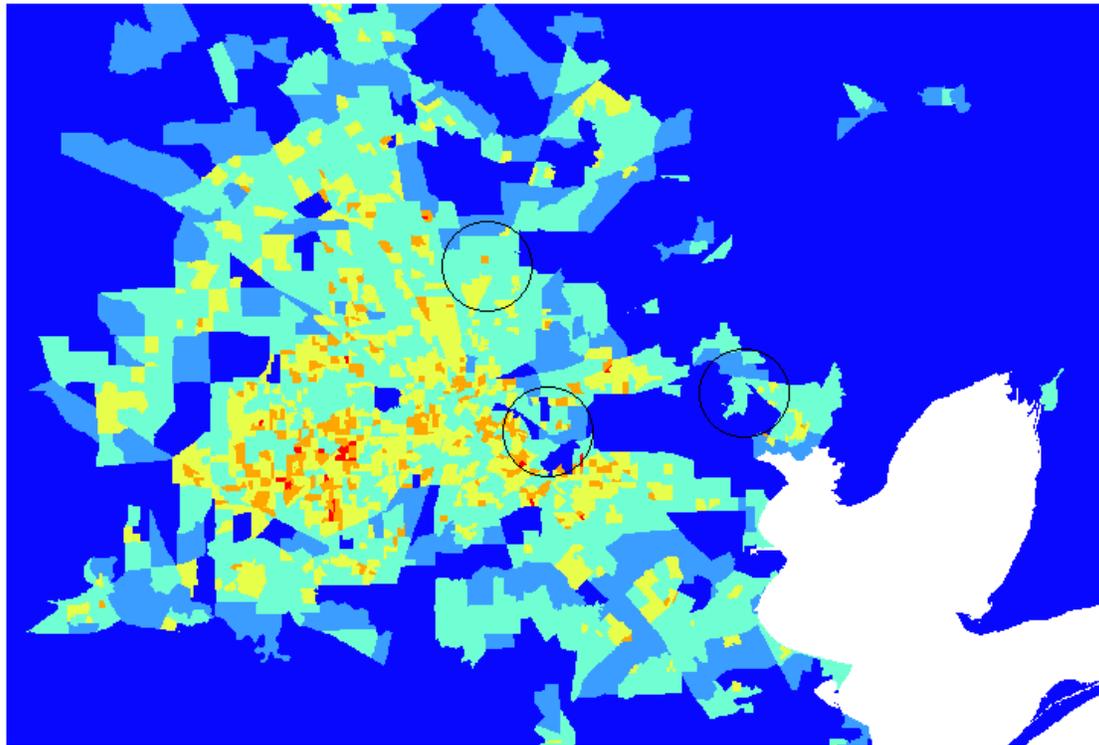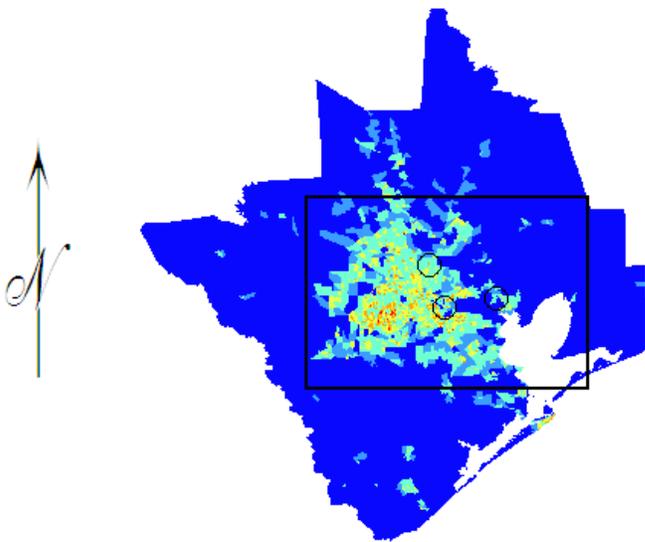
2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

■	0 - 472
■	473 - 944
■	945 - 4718
■	4719 - 9437
■	9438 - 23591
■	23592 - 94367

Figure A-13.   PM$_{2.5}$ monitor distribution in comparison with population density, Houston, TX.
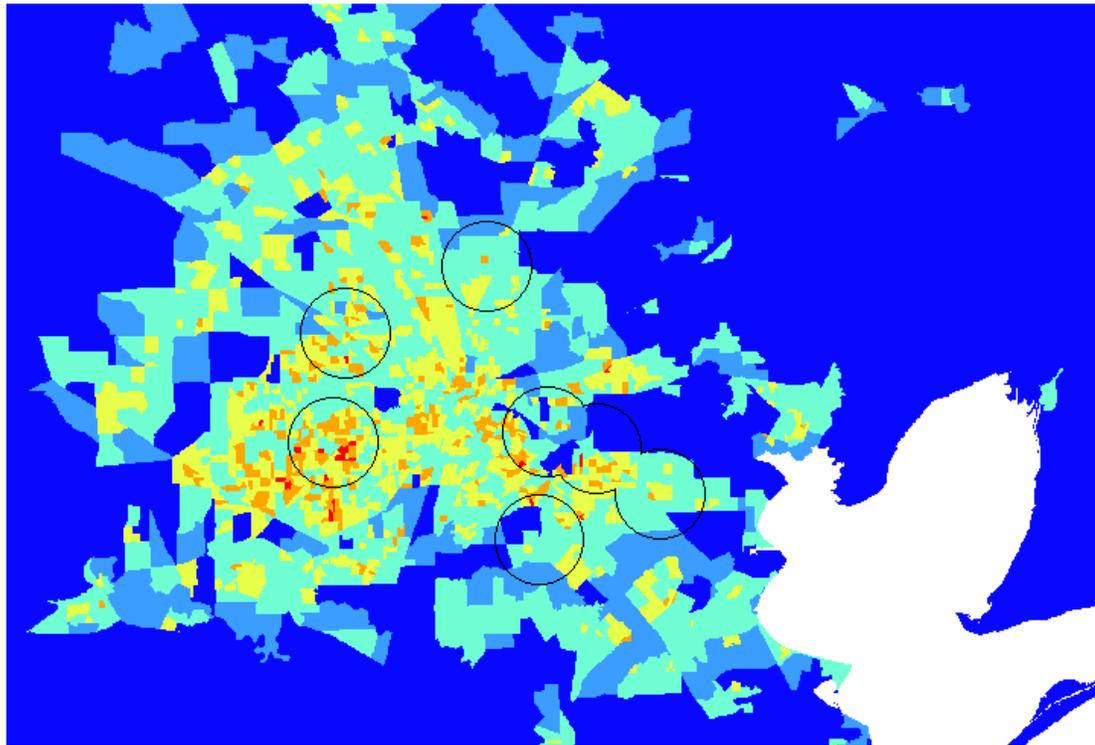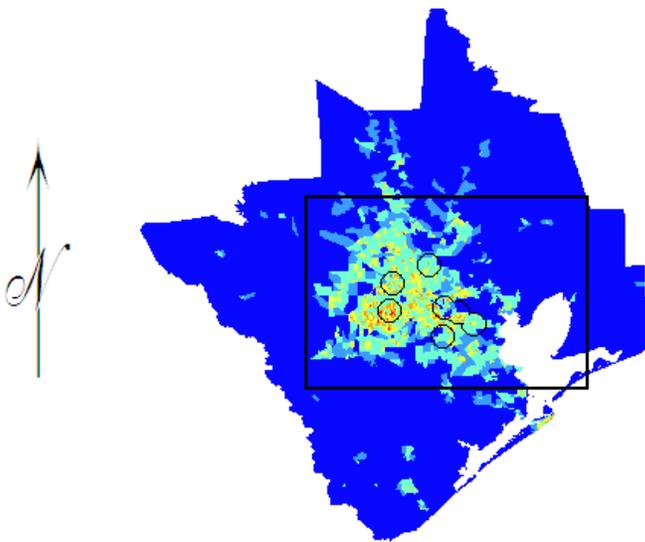
2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

■ 0 - 472
■ 473 - 944
■ 945 - 4718
■ 4719 - 9437
■ 9438 - 23591
■ 23592 - 94367

Figure A-14.   PM$_{10}$ monitor distribution in comparison with population density, Houston, TX.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

■ 0 - 702
■ 703 - 1404
■ 1405 - 7022
■ 7023 - 14043
■ 14044 - 35108
■ 35109 - 140433
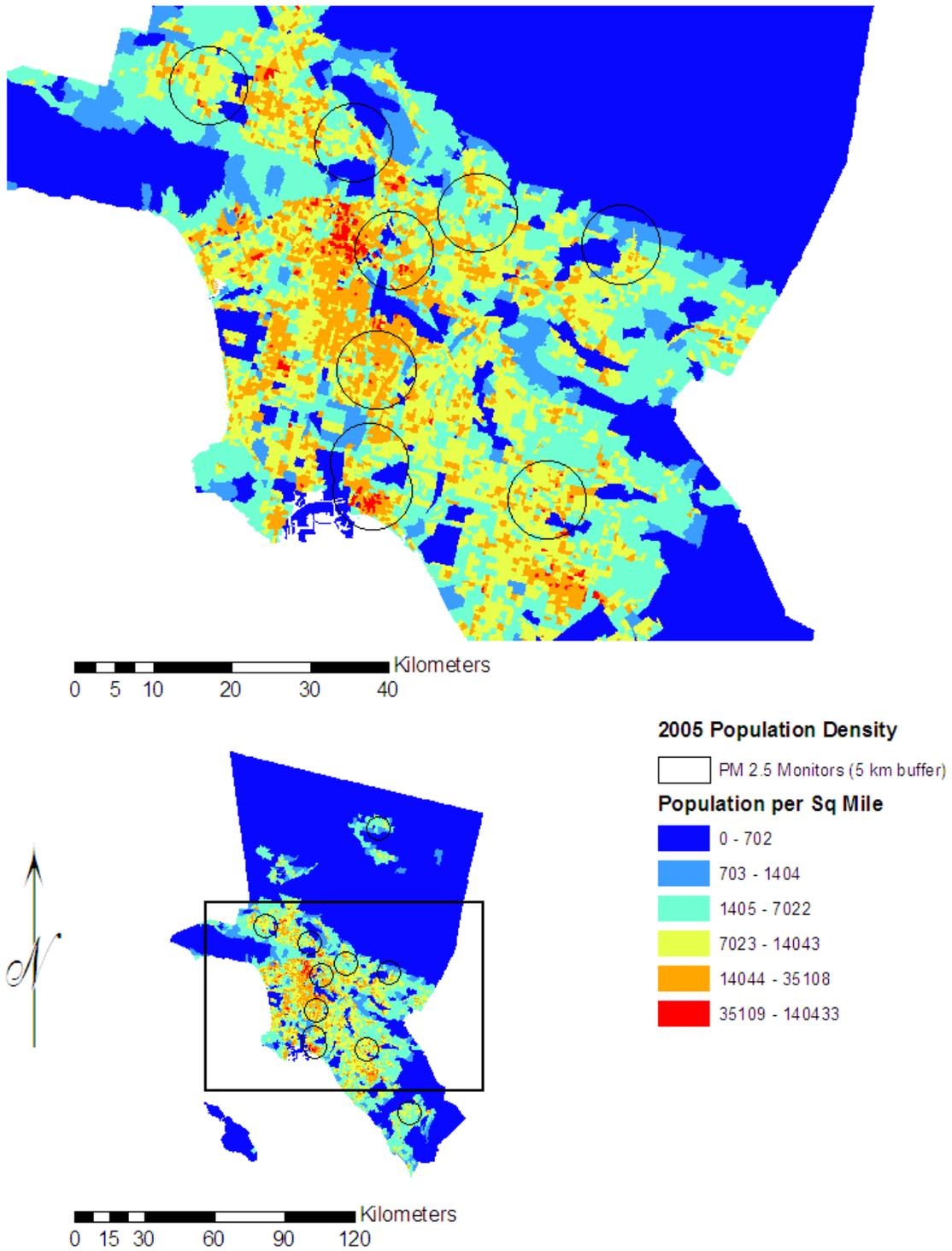
Figure A-15.   PM$_{2.5}$ monitor distribution in comparison with population density, Los Angeles, CA.
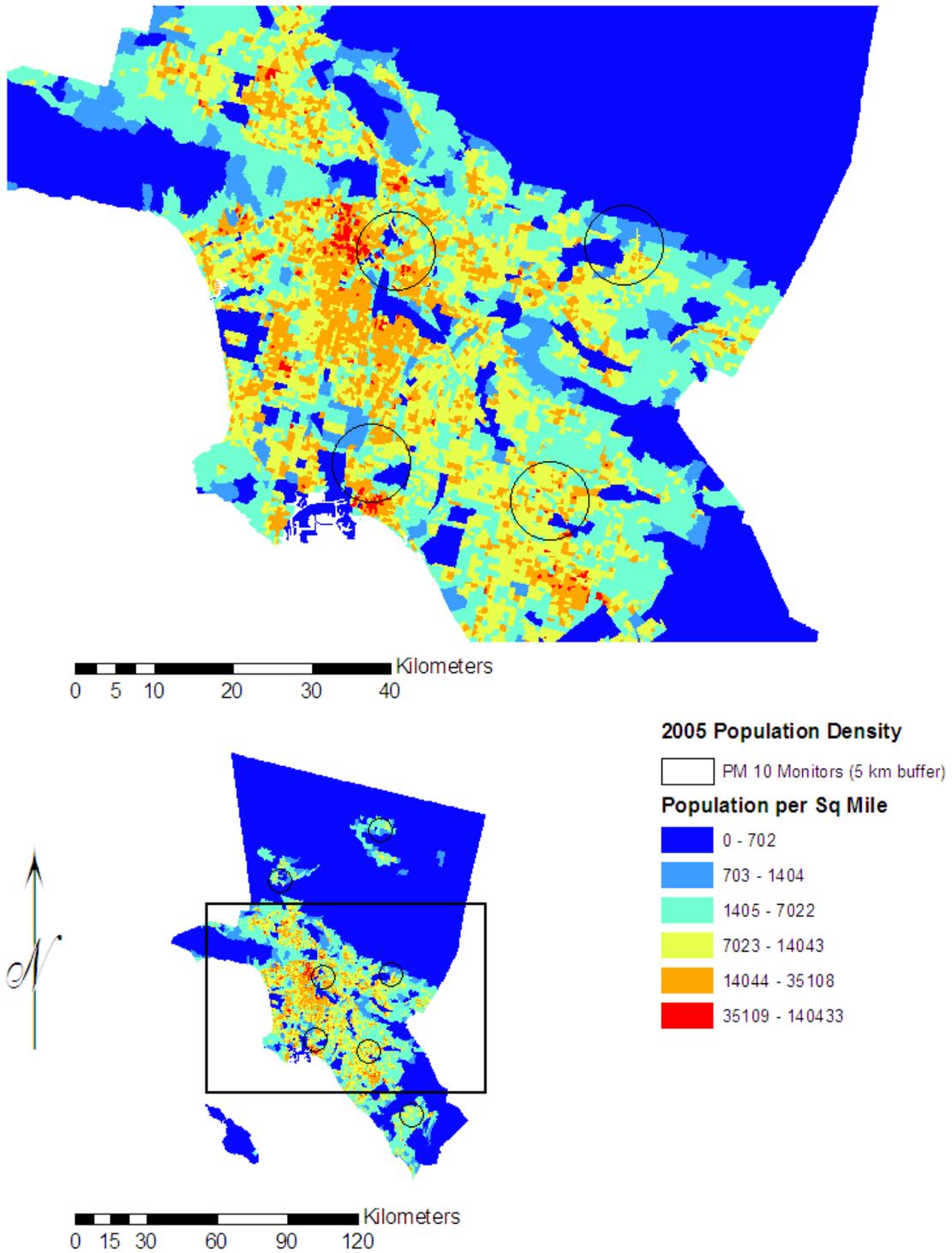
Figure A-16.   PM$_{10}$ monitor distribution in comparison with population density, Los Angeles, CA.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 2155
- 2156 - 4309
- 4310 - 21545
- 21546 - 43090
- 43091 - 107725
- 107726 - 430900
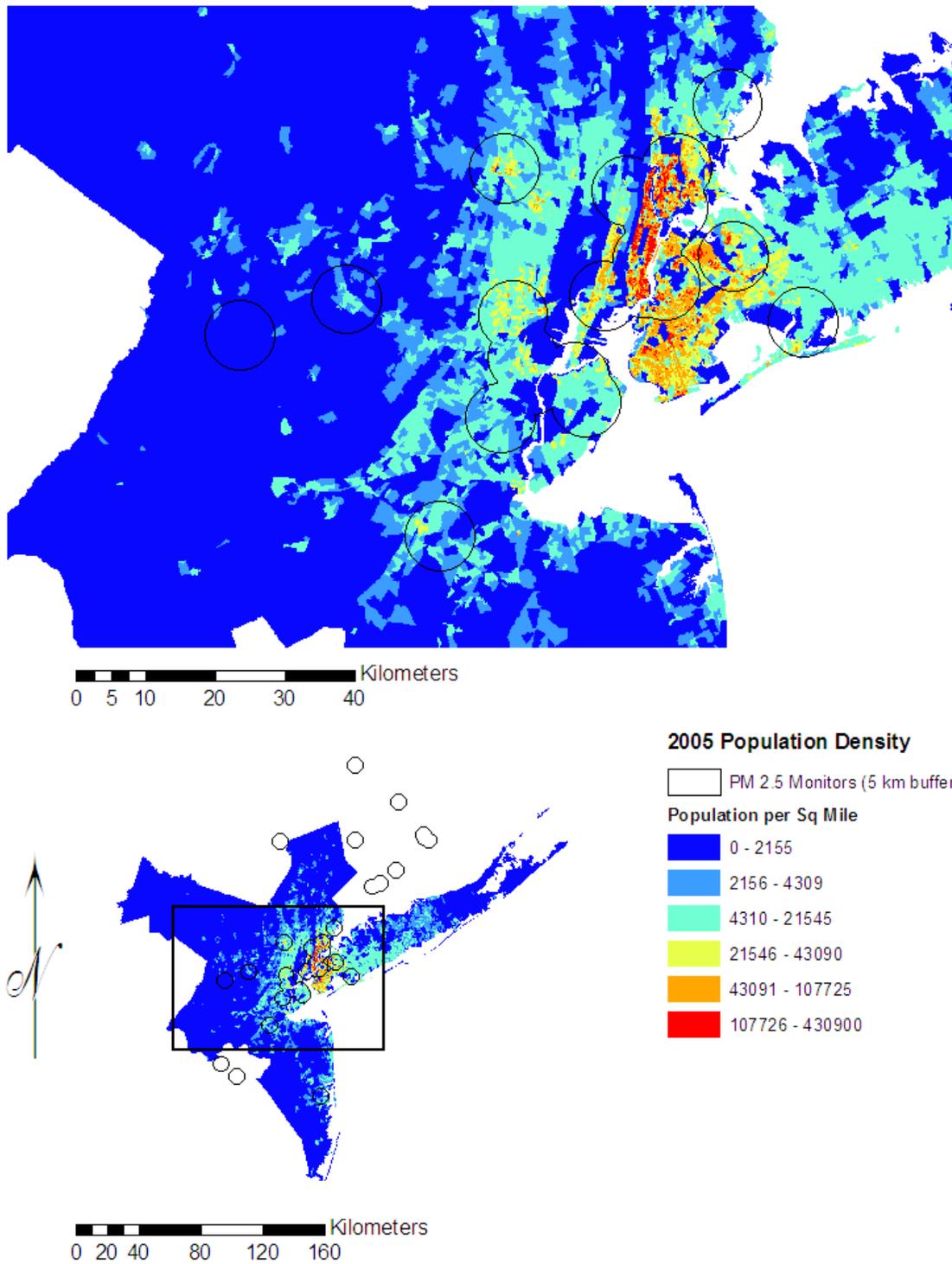
Figure A-17.   PM$_{2.5}$ monitor distribution in comparison with population density, New York City, NY.

2005 Population Density

▢ PM 10 Monitors (5 km buffer)

Population per Sq Mile

■ 0 - 2155
■ 2156 - 4309
■ 4310 - 21545
■ 21546 - 43090
■ 43091 - 107725
■ 107726 - 430900
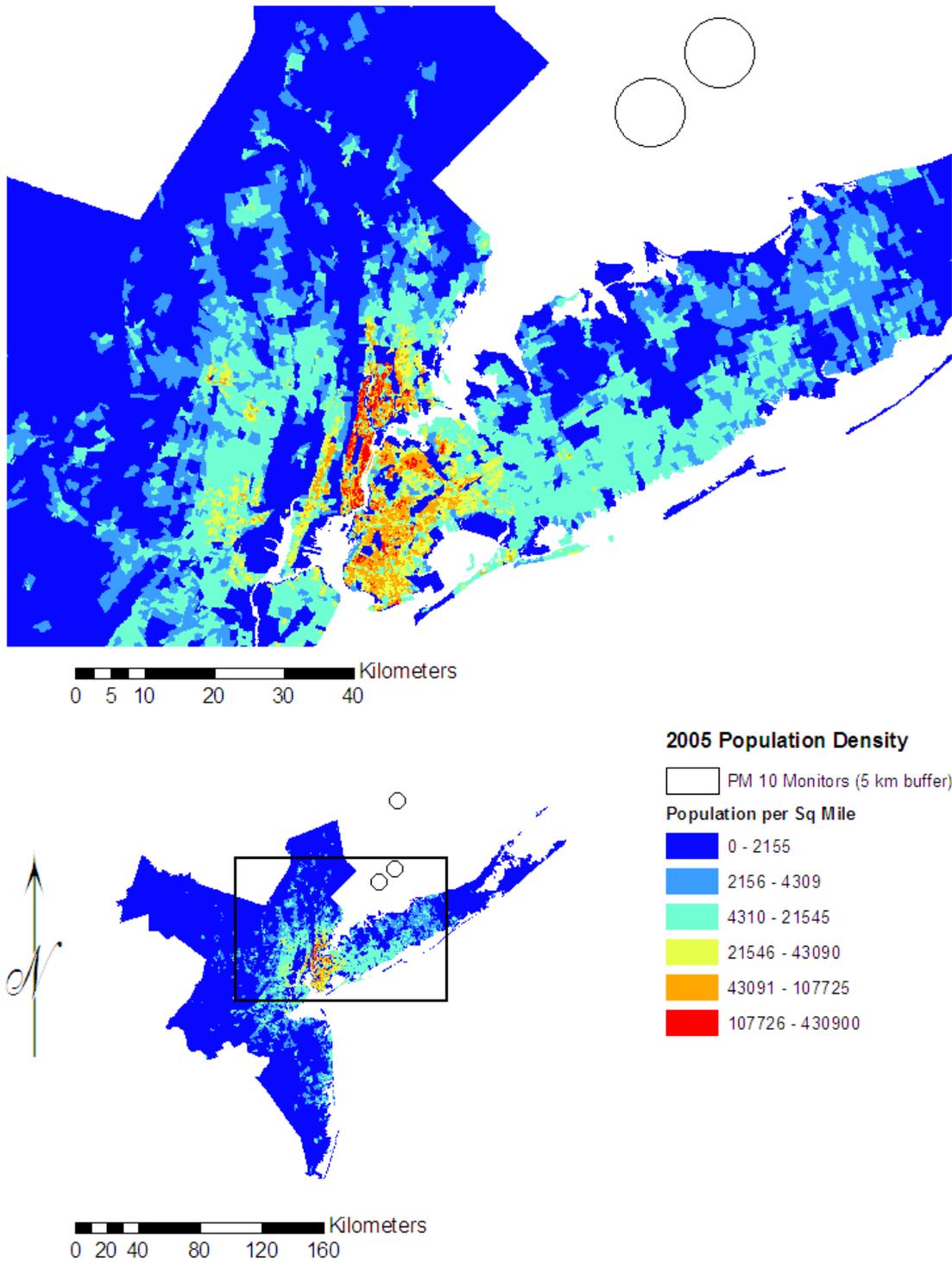
Figure A-18.   PM$_{10}$ monitor distribution in comparison with population density, New York City, NY.
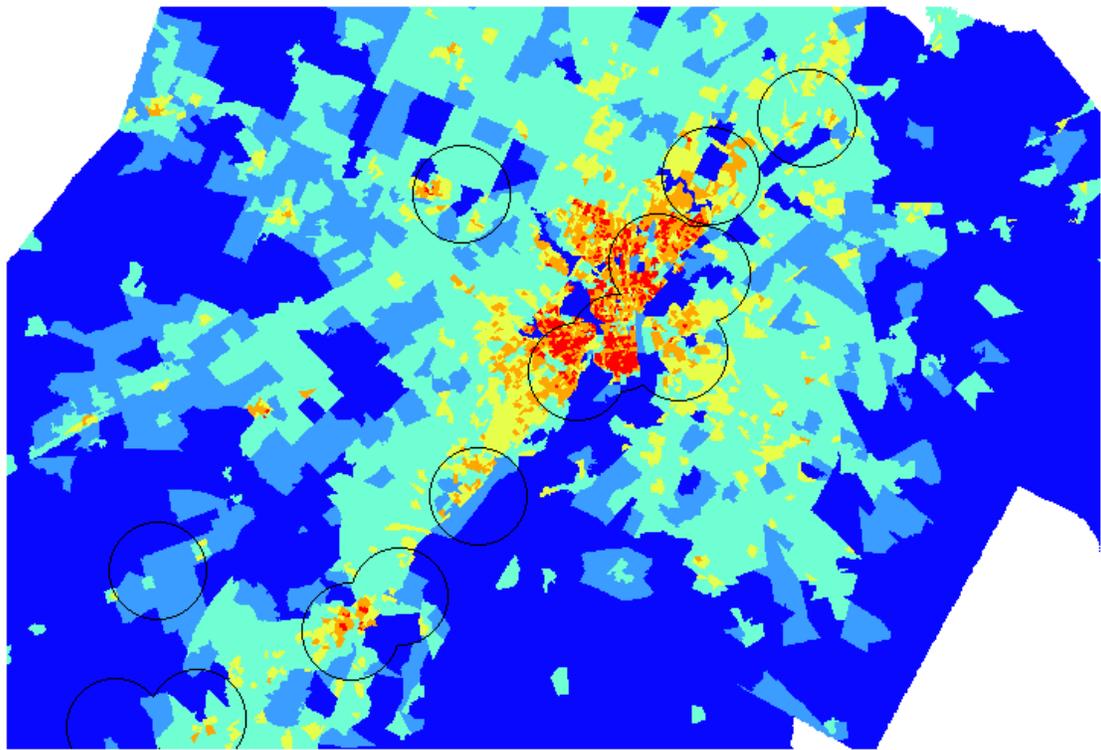
2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- ■ 0 - 474
- ■ 475 - 947
- ■ 948 - 4737
- ■ 4738 - 9773
- ■ 9774 - 23683
- ■ 23684 - 94733
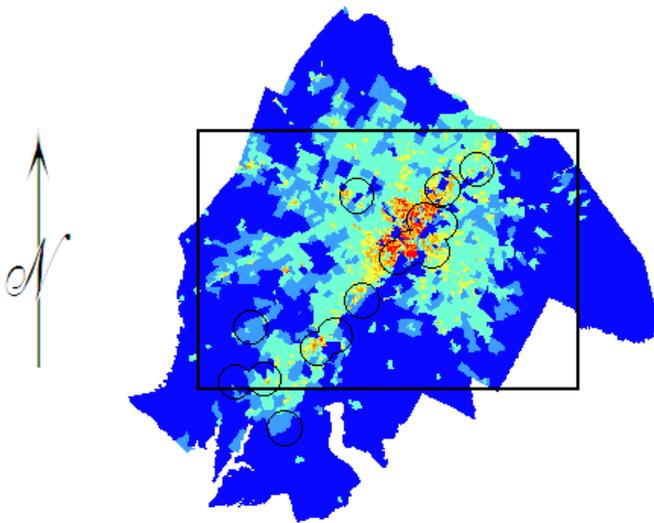
Figure A-19.   PM$_{2.5}$ monitor distribution in comparison with population density, Philadelphia, PA.
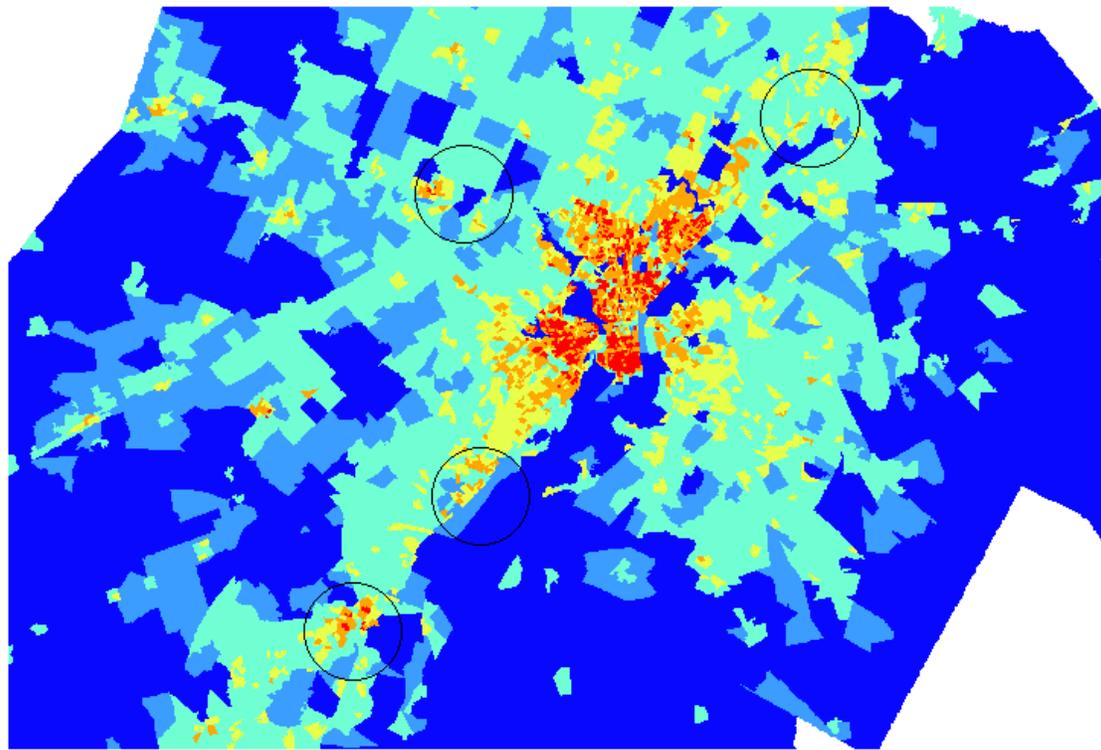
2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 474
- 475 - 947
- 948 - 4737
- 4738 - 9773
- 9774 - 23683
- 23684 - 94733
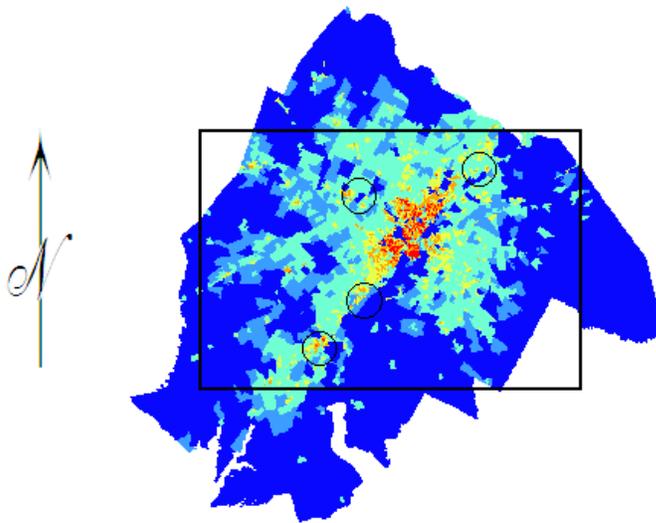
Figure A-20. PM_{10} monitor distribution in comparison with population density, Philadelphia, PA.
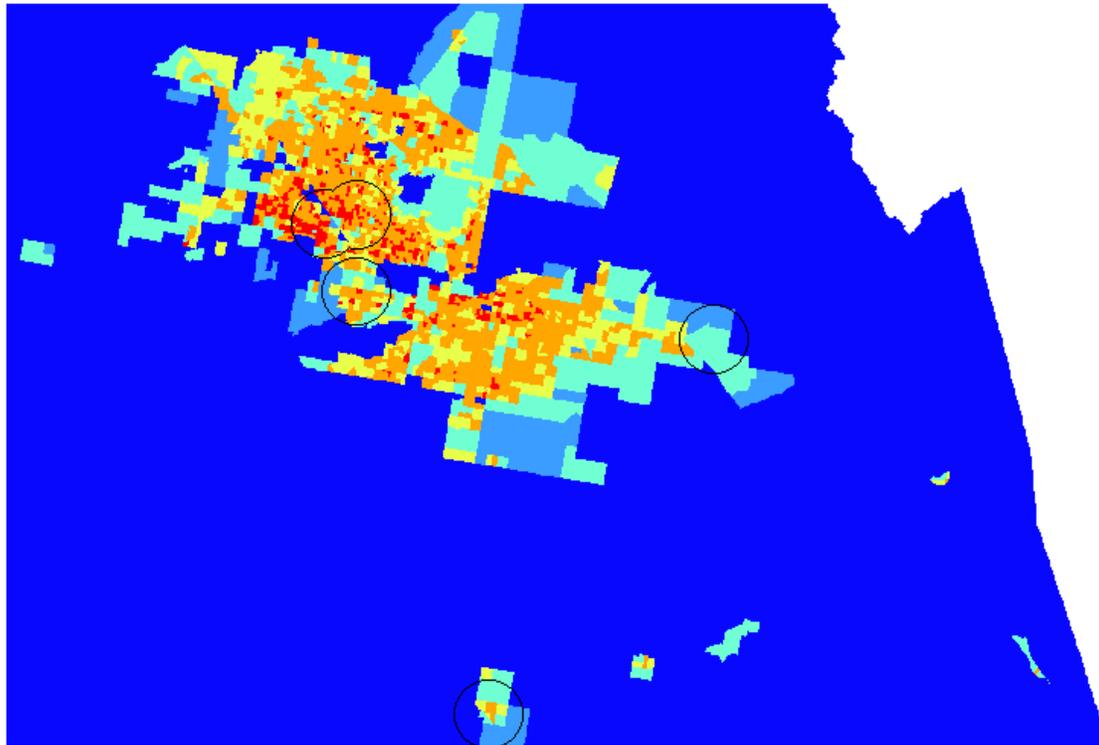
Figure A-21.   PM$_{2.5}$ monitor distribution in comparison with population density, Phoenix, AZ.
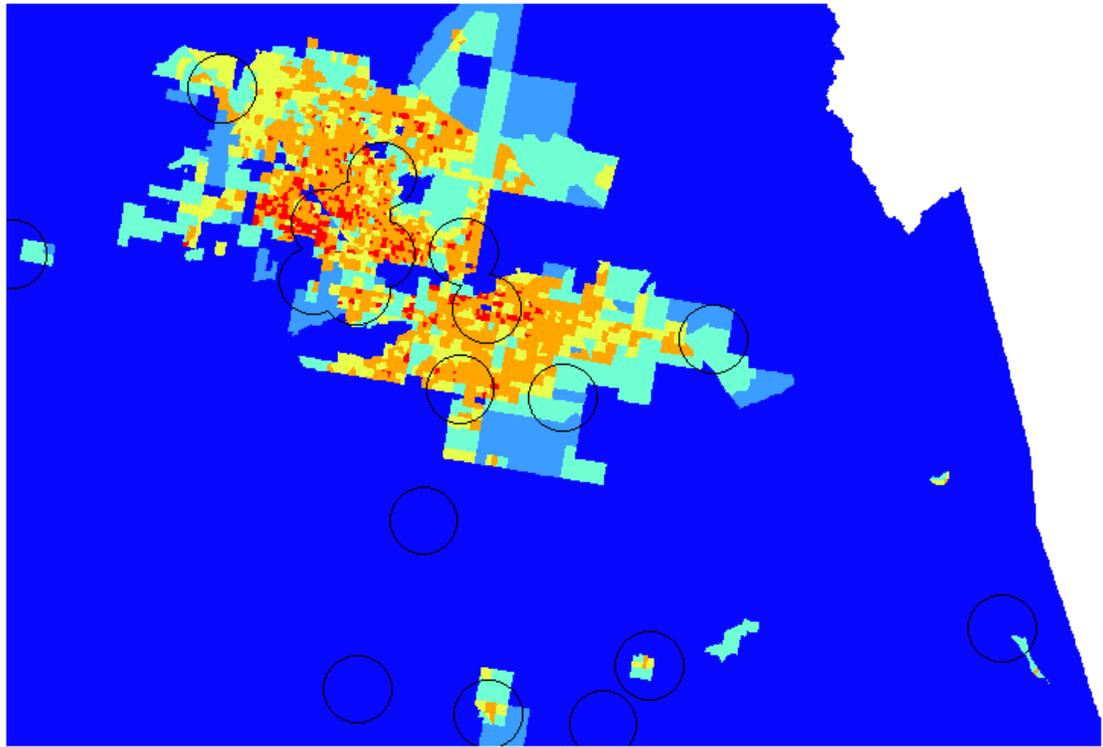
2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- ■ 0 - 206
- ■ 207 - 412
- ■ 413 - 2060
- ■ 2061 - 4120
- ■ 4121 - 10300
- ■ 10301 - 41200
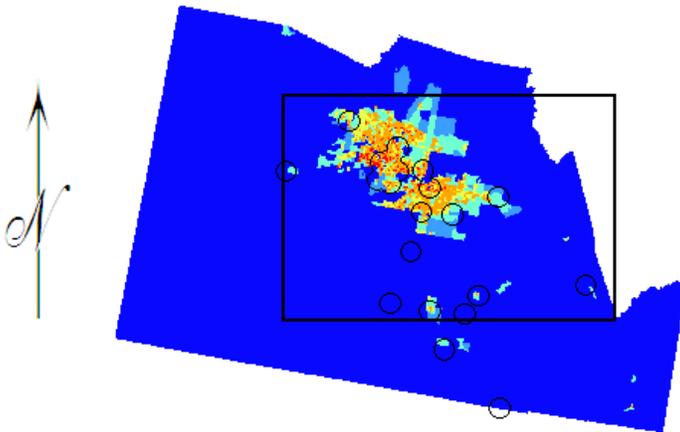
Figure A-22.   PM$_{10}$ monitor distribution in comparison with population density, Phoenix, AZ.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 16 - 530
- 531 - 1059
- 1060 - 5296
- 5297 - 10593
- 10594 - 26481
- 26482 - 105925
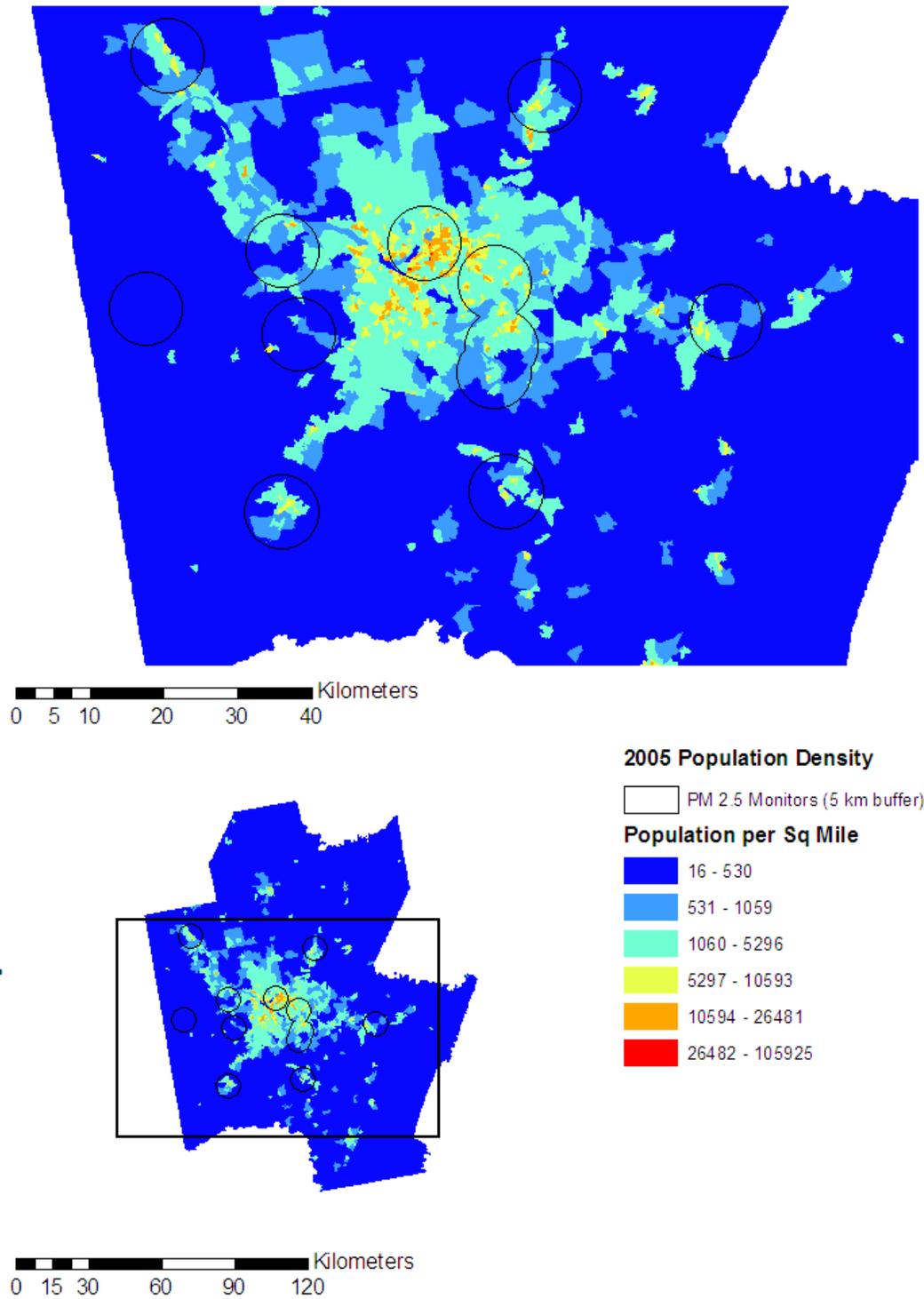
Figure A-23.   PM$_{2.5}$ monitor distribution in comparison with population density, Pittsburgh, PA.

2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 16 - 530
- 531 - 1059
- 1060 - 5296
- 5297 - 10593
- 10594 - 26481
- 26482 - 105925
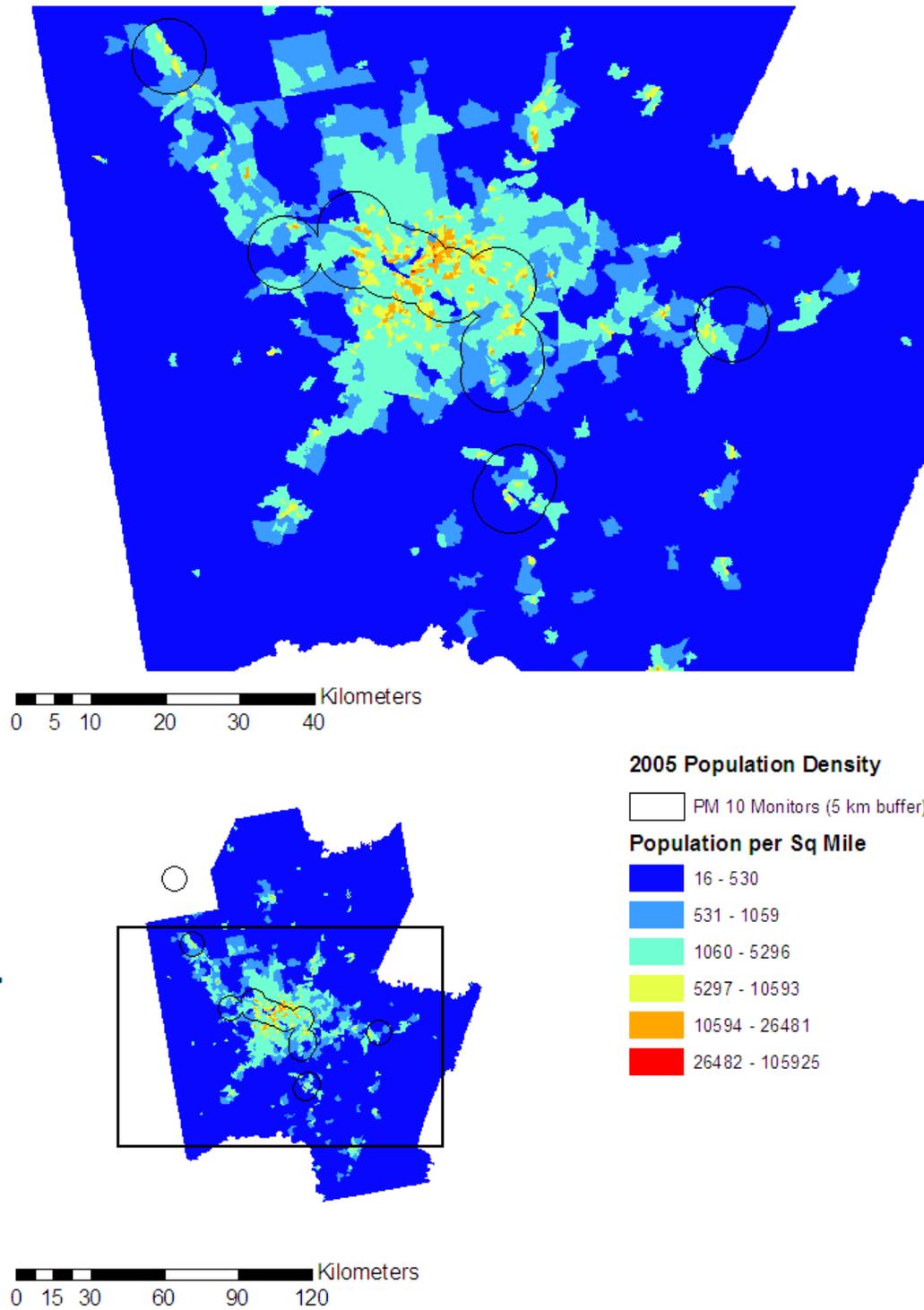
Figure A-24. PM$_{10}$ monitor distribution in comparison with population density, Pittsburgh, PA.

2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 231
- 232 - 462
- 463 - 2310
- 2311 - 4620
- 4621 - 11550
- 11551 - 46200
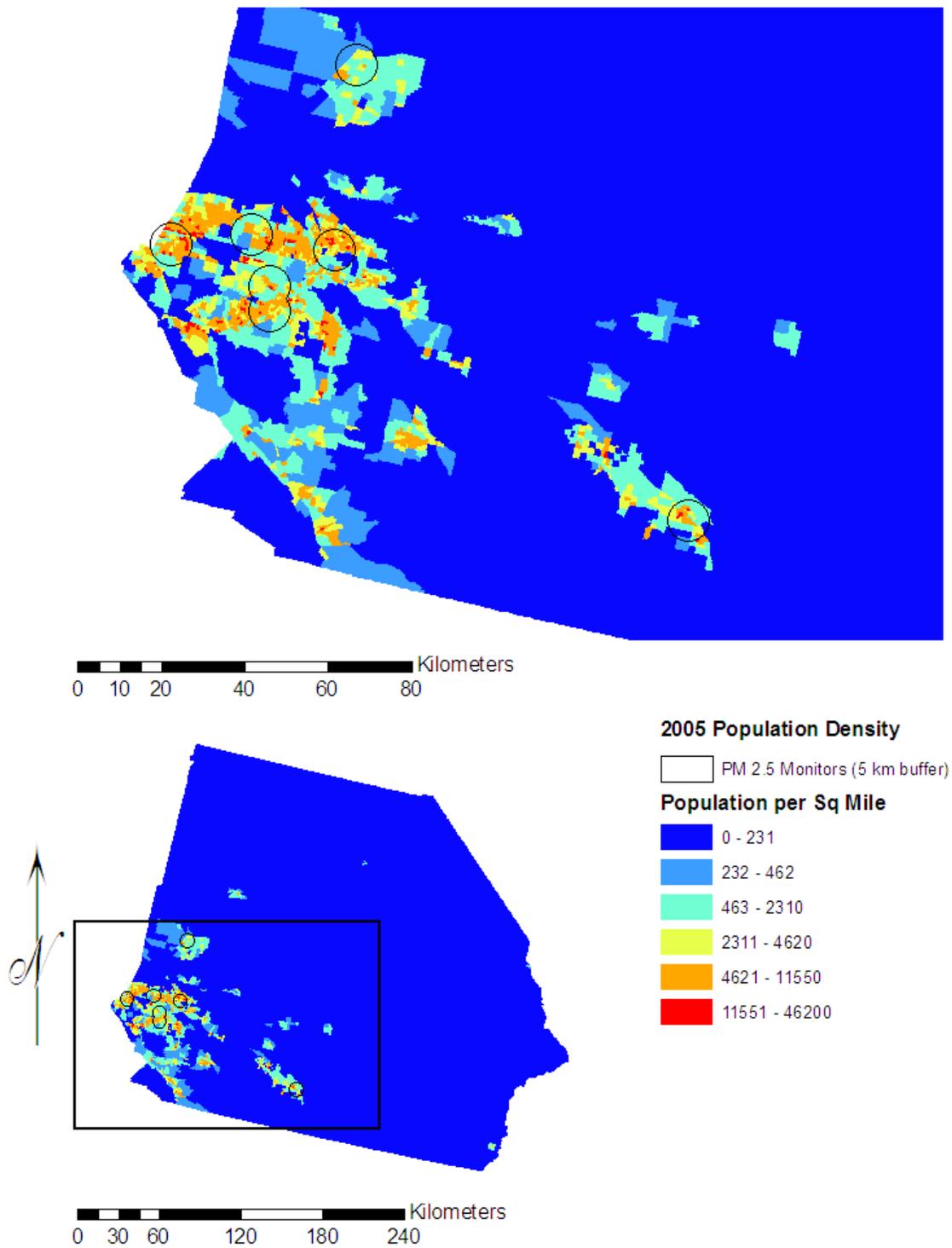
Figure A-25.   PM$_{2.5}$ monitor distribution in comparison with population density, Riverside, CA.

2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 231
- 232 - 462
- 463 - 2310
- 2311 - 4620
- 4621 - 11550
- 11551 - 46200
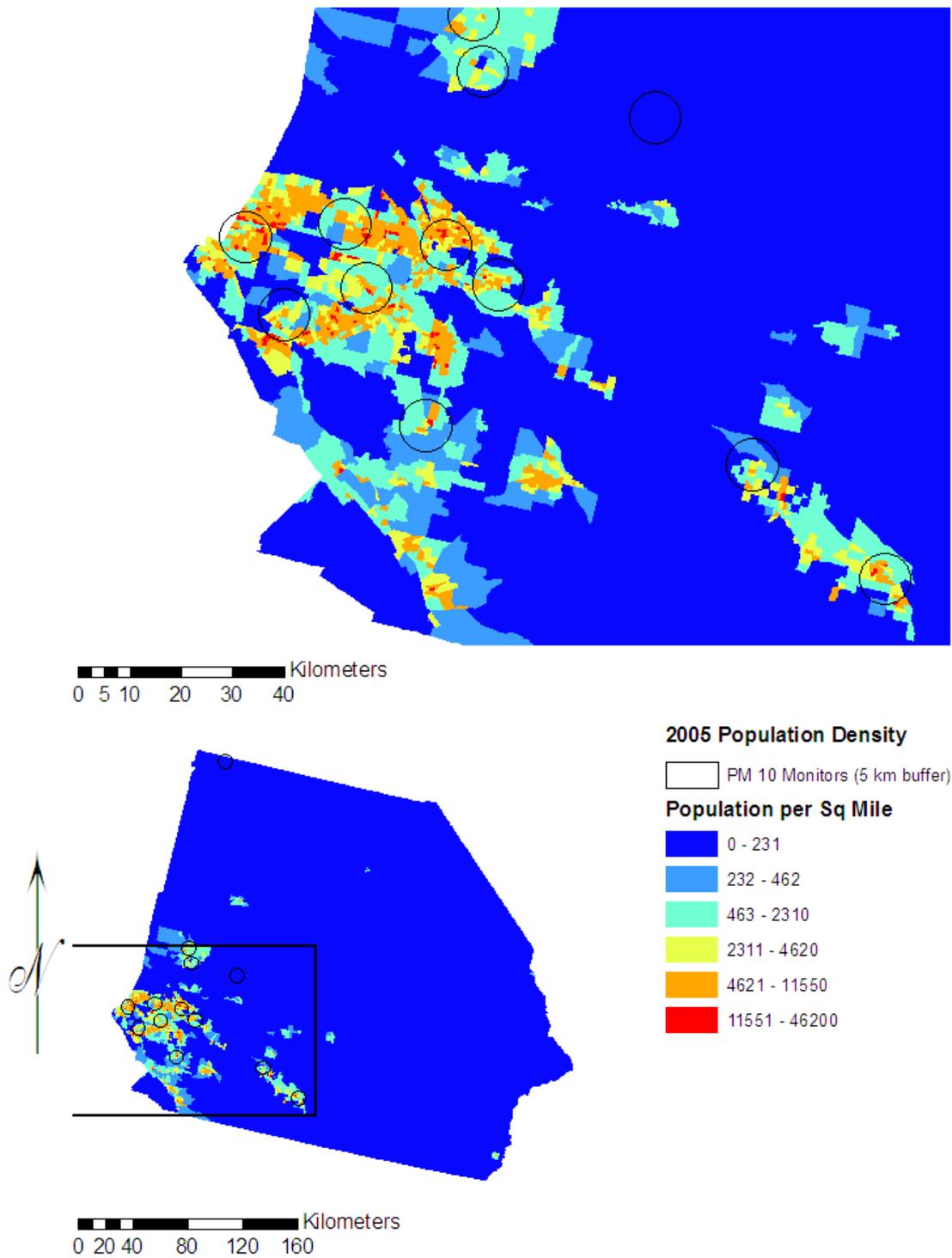
Figure A-26. PM$_{10}$ monitor distribution in comparison with population density, Riverside, CA.

2005 Population Density

PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 311
- 312 - 622
- 623 - 3111
- 3112 - 6222
- 6223 - 15554
- 15555 - 62217
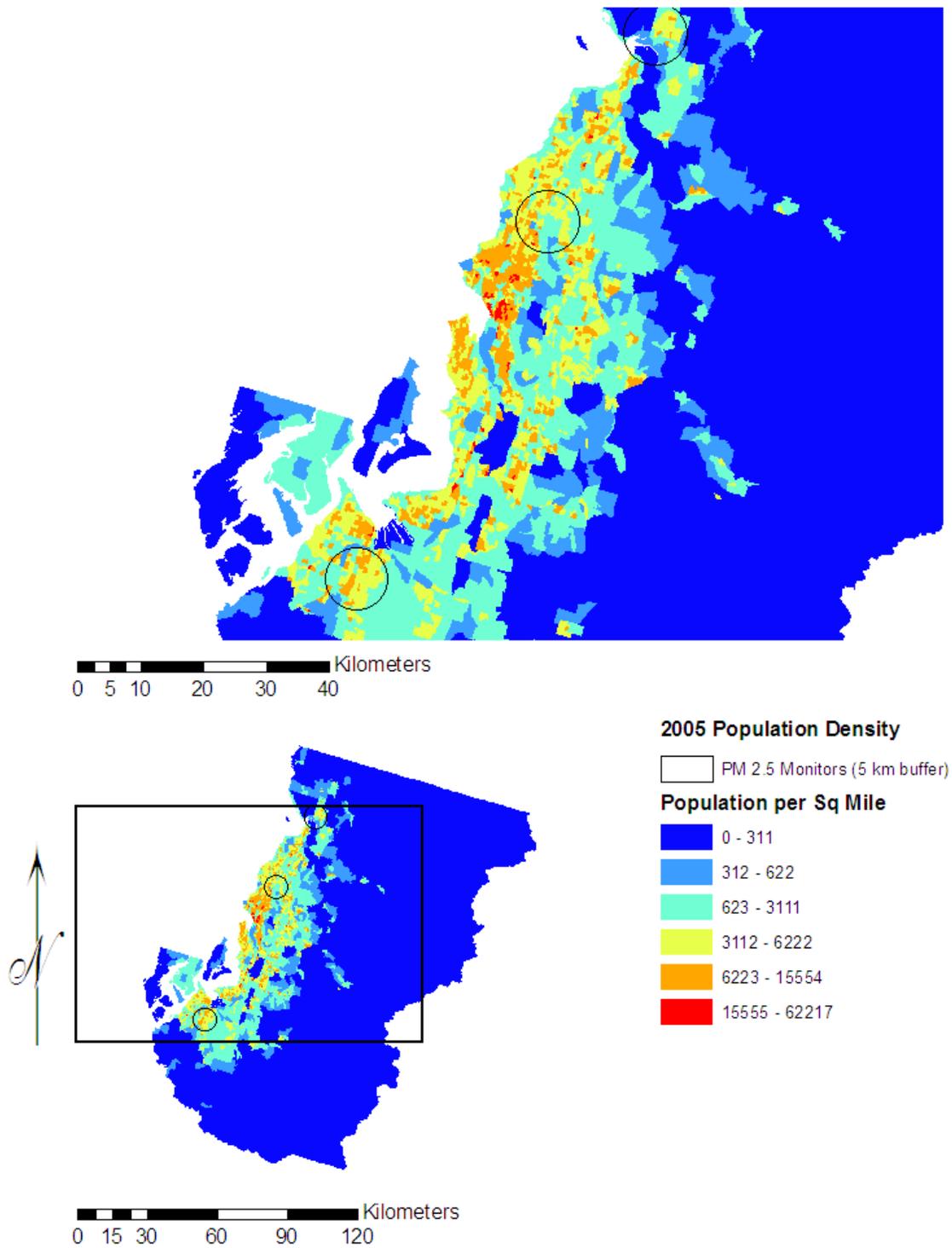
Figure A-27.   PM$_{2.5}$ monitor distribution in comparison with population density, Seattle, WA.
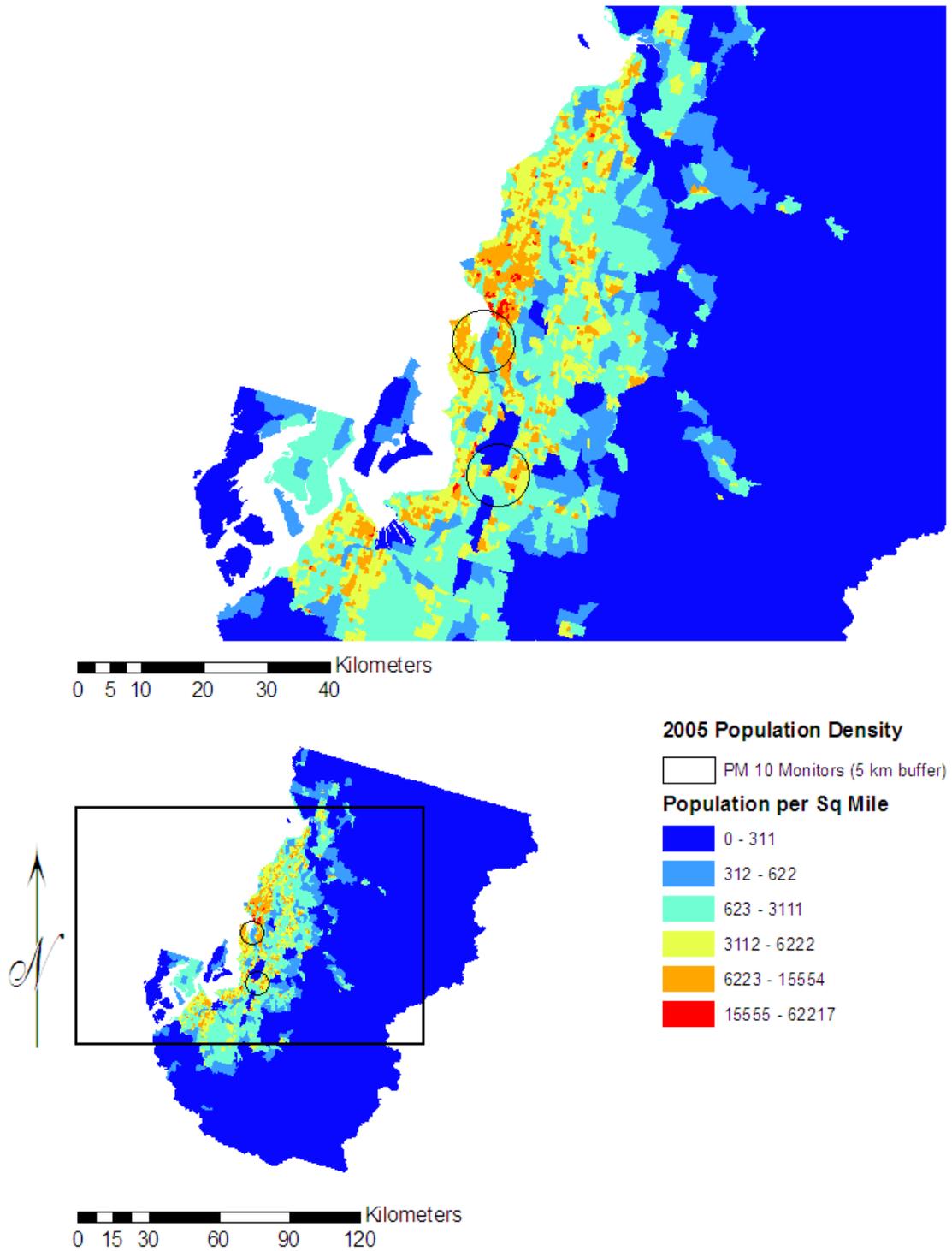
Figure A-28.   PM$_{10}$ monitor distribution in comparison with population density, Seattle, WA.
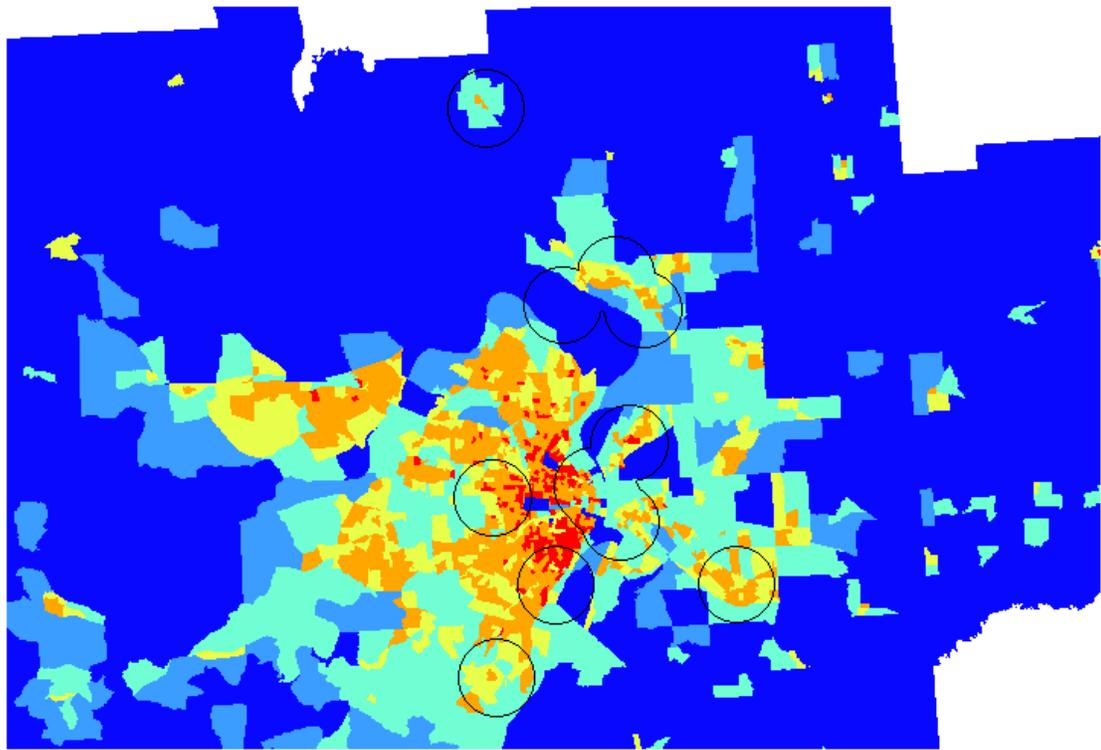
2005 Population Density

☐ PM 2.5 Monitors (5 km buffer)

Population per Sq Mile

- 🟦 0 - 141
- 🟦 142 - 282
- 🟩 283 - 1409
- 🟨 1410 - 2818
- 🟧 2819 - 7044
- 🟥 7045 - 28175
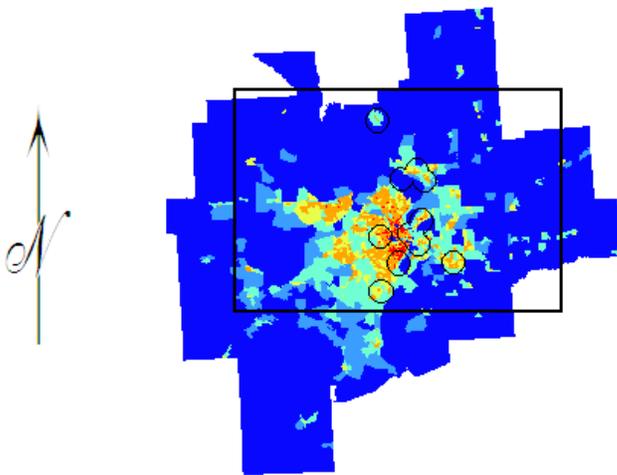
Figure A-29. PM$_{2.5}$ monitor distribution in comparison with population density, St. Louis, MO.
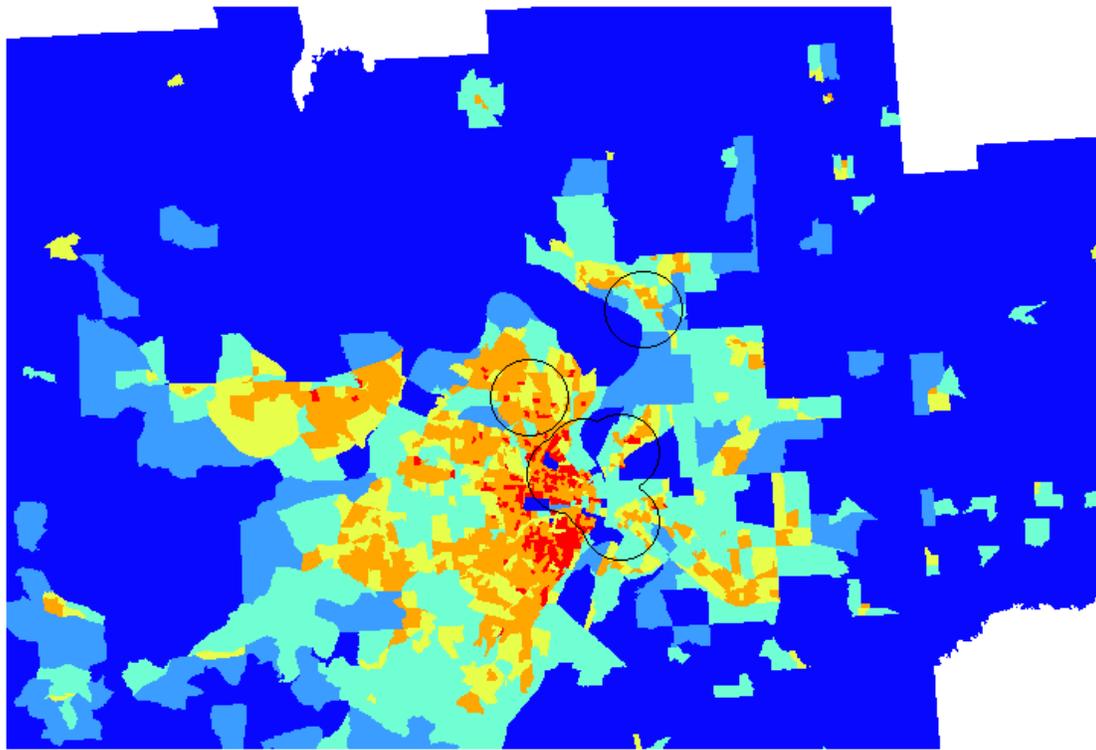
2005 Population Density

☐ PM 10 Monitors (5 km buffer)

Population per Sq Mile

- 0 - 141
- 142 - 282
- 283 - 1409
- 1410 - 2818
- 2819 - 7044
- 7045 - 28175
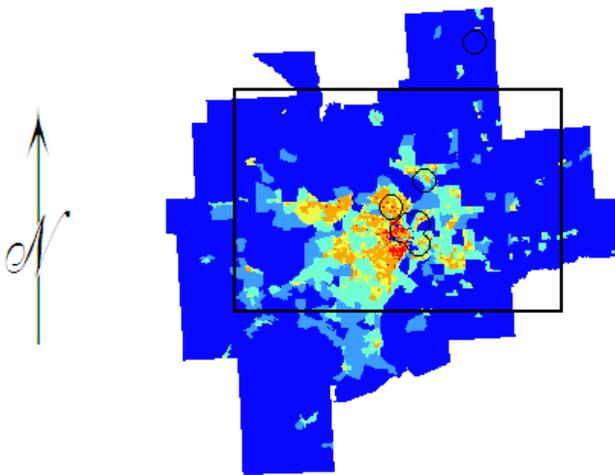
Figure A-30. PM_{10} monitor distribution in comparison with population density, St. Louis, MO.

A.2. Ambient PM Concentration

A.2.1. Speciation Trends Network Site Data

Figure A-31.   Cu concentrations measured at STN sites across the U.S.

Figure A-32. Fe concentrations measured at STN sites across the U.S.
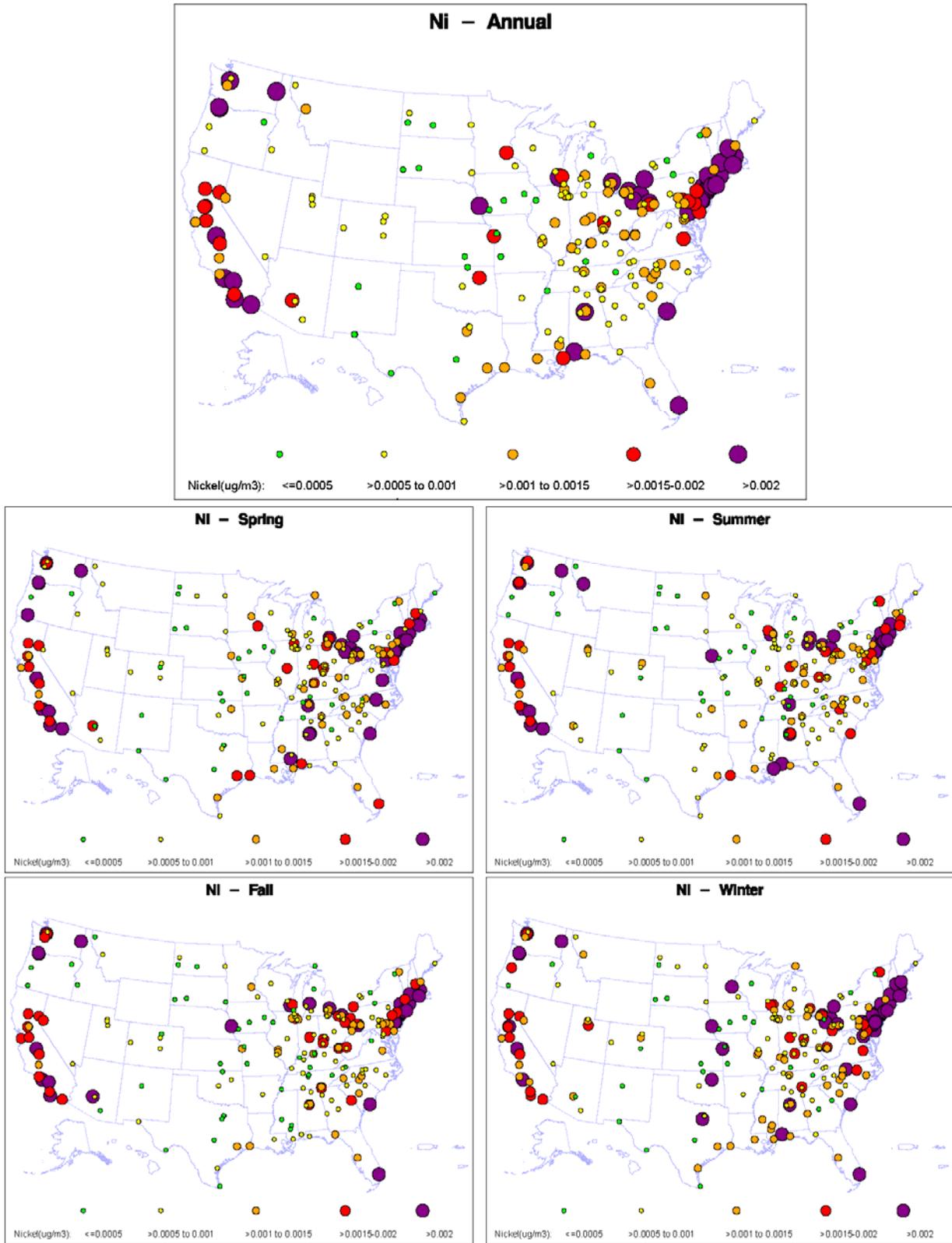
Figure A-33. Ni concentrations measured at STN sites across the U.S.
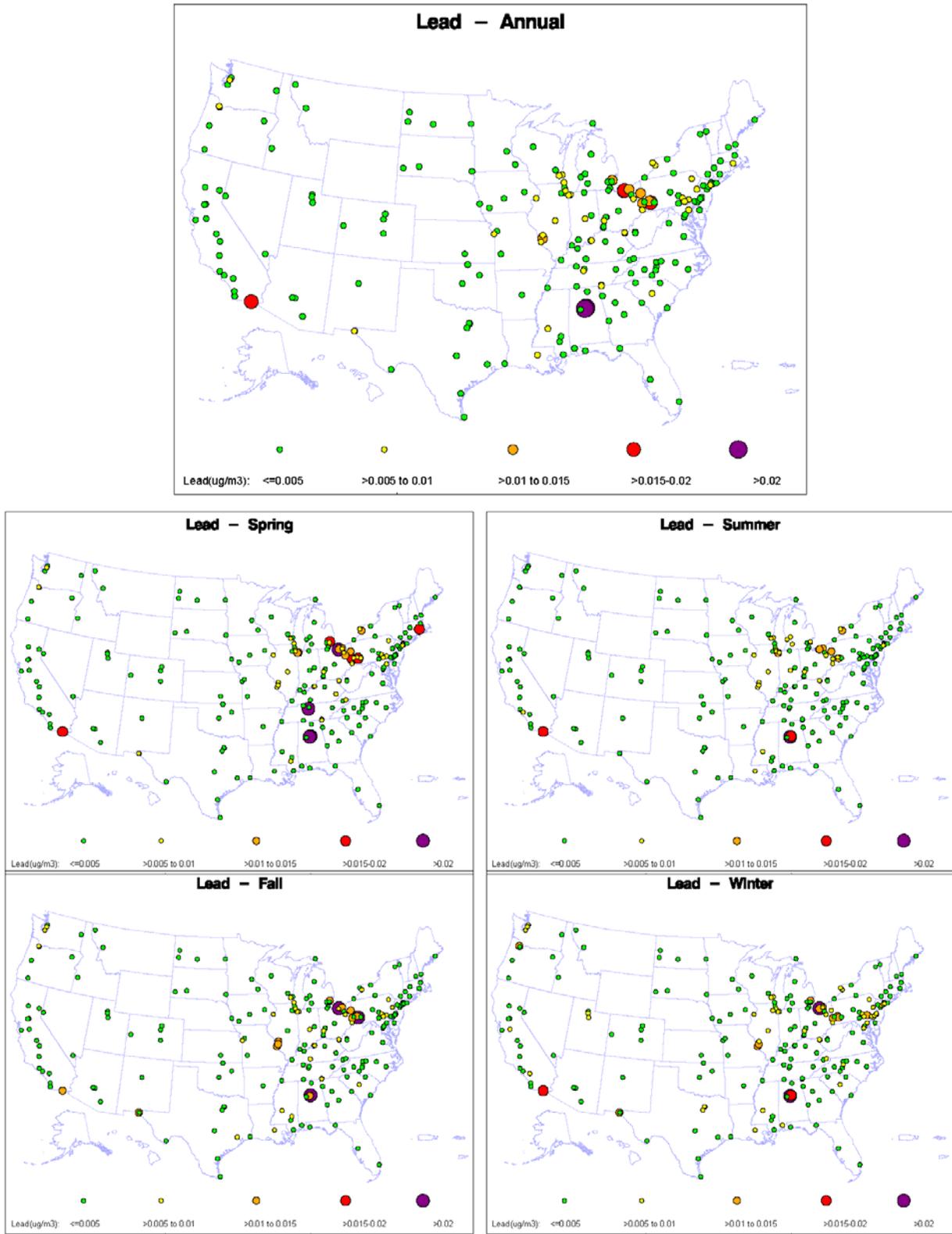
Figure A-34.   Pb concentrations measured at STN sites across the U.S.
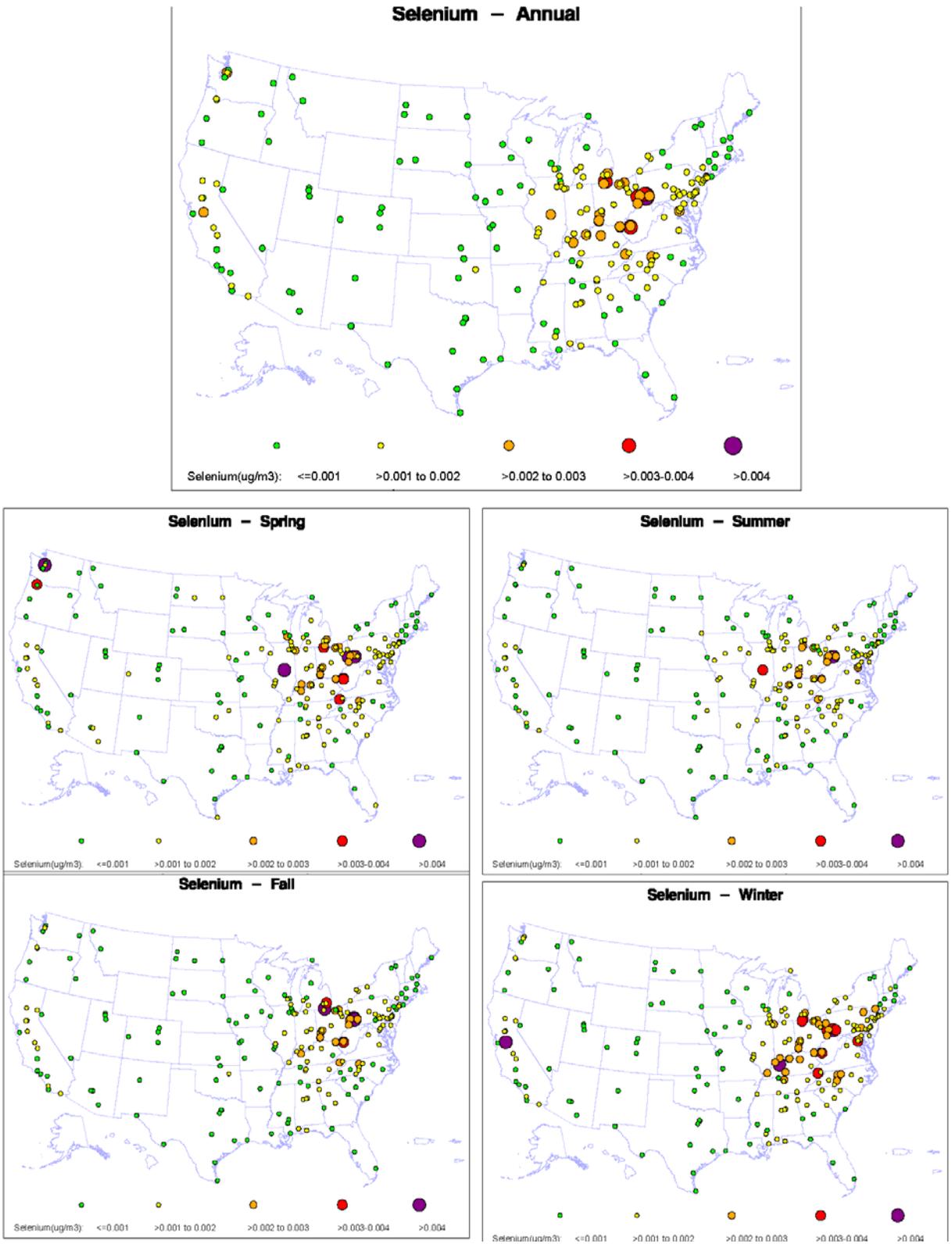
Figure A-35.   Se concentrations measured at STN sites across the U.S.
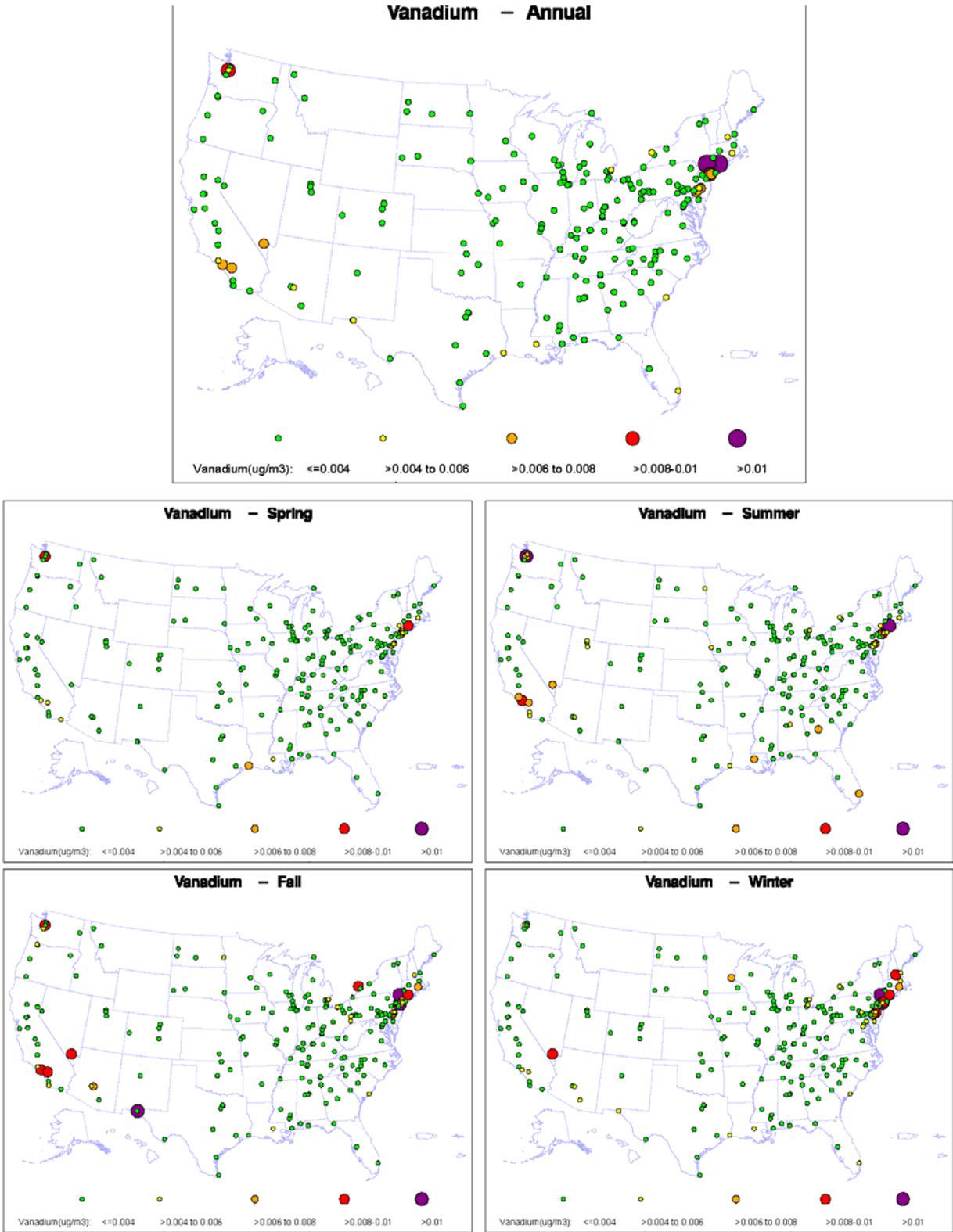
Figure A-36.   V concentrations measured at STN sites across the U.S.

A.2.2. Intraurban Variability

1   The following figures and tables exemplify the intraurban variability among measurements for 15

2   CSAs/CBSAs (2005-2007) through the use of inter-sampler correlations and seasonal box plots for PM_{10}

3   and $PM_{2.5}$. Maps show monitor locations; scatter plots of inter-sampler correlation vs. distance illustrate

4   differences in variability among each area. Box plots show the median and interquartile range with

5   whiskers extending to the 5th and 95th percentiles at each site during (1) winter (December-February); (2)

6   spring (March-May); (3) summer (June-August); and (4) fall (September-November).
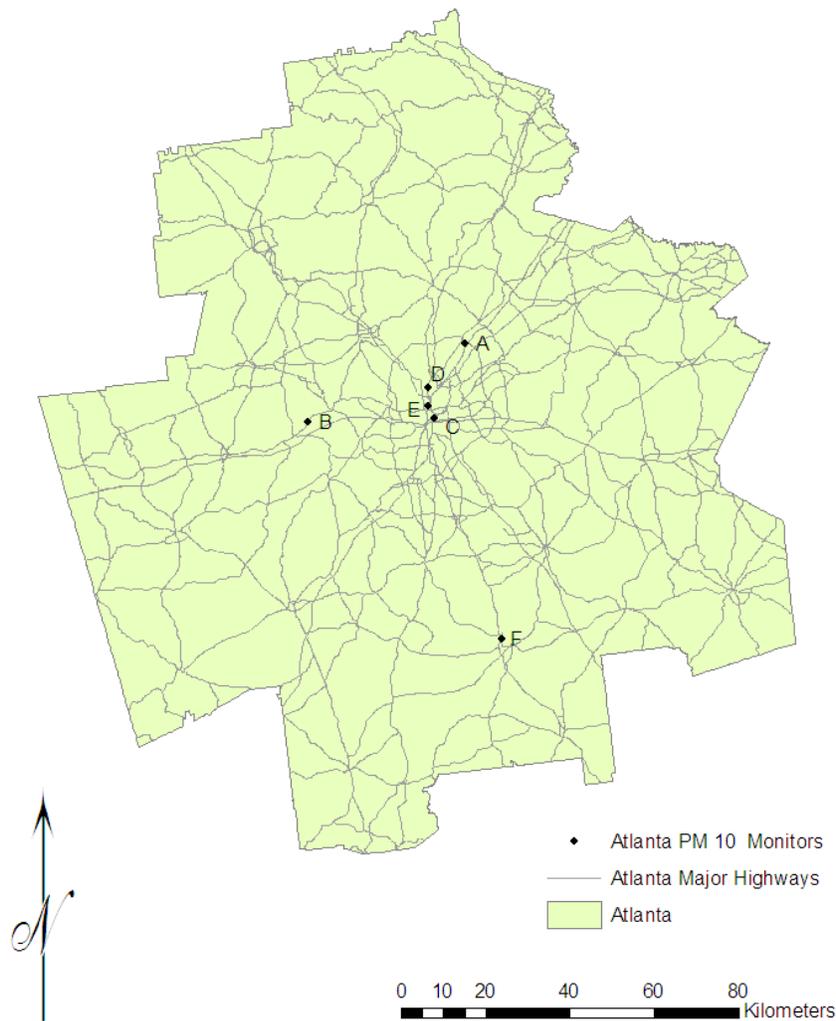
Figure A-37.   Map of PM_{10} FRM distribution with AQS Site IDs for Atlanta, GA.

AQS Site ID		A	B	C	D	E	F
	Mean	24.7	21.4	23.4	26.6	25.0	21.6
Site A 13-089-2001	Obs	172	178	171	174	995	178
Site B 13-097-0003	SD	13.0	9.3	9.5	11.8	11.5	9.7

Site C 13-121-0001
Site D 13-121-0032
Site E 13-121-0048
Site F 13-255-0002

1=winter
2=spring
3=summer
4=fall
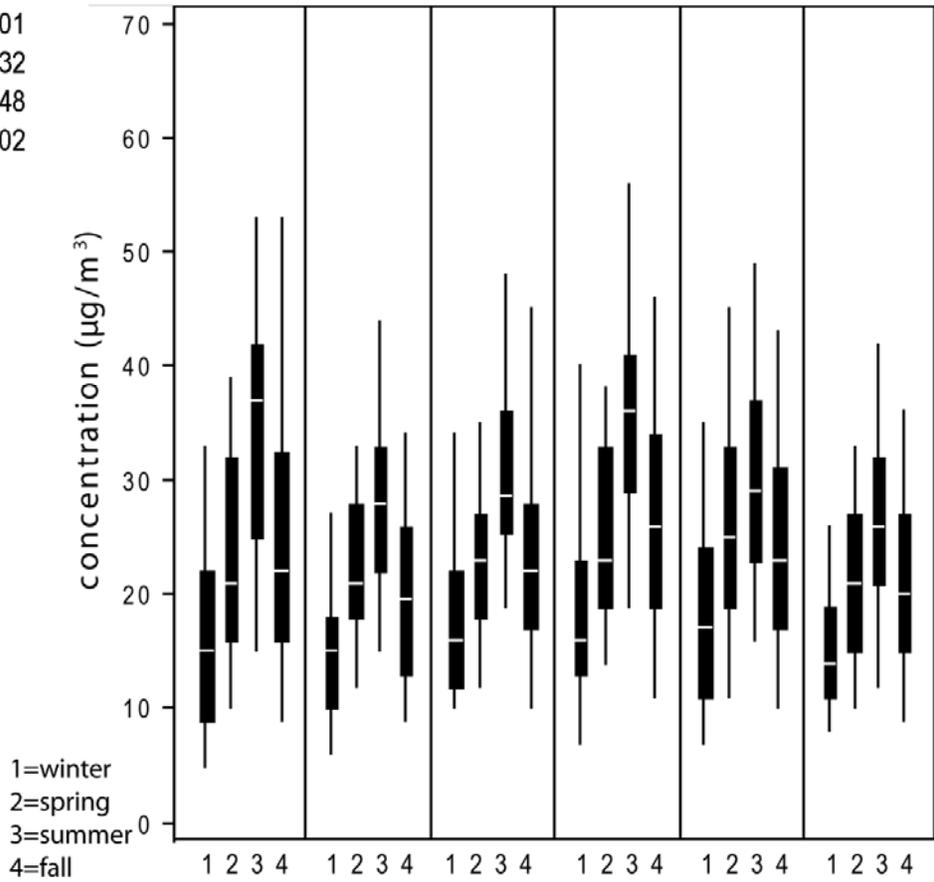
Figure A-38.   Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Atlanta, GA.

Table A-18. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Atlanta, GA.

Site	A	B	C	D	E	F
A	1.00	0.69	0.74	0.78	0.70	0.59
	(0.0, 0.00)	(18.0, 0.22)	(15.0, 0.20)	(13.0, 0.20)	(16.0, 0.22)	(20.0, 0.24)
	172	169	162	165	158	164
B		1.00	0.88	0.79	0.71	0.82
		(0.0, 0.00)	(6.0, 0.12)	(14.5, 0.17)	(16.0, 0.18)	(10.0, 0.14)
		178	167	170	162	169
C			1.00	0.88	0.84	0.82
			(0.0, 0.00)	(9.0, 0.13)	(10.0, 0.13)	(9.0, 0.15)
			171	162	155	161
D				1.00	0.75	0.74
	R			(0.0, 0.00)	(12.0, 0.15)	(15.0, 0.20)
	(P90, COD)			174	158	166
E	N				1.00	0.67
					(0.0, 0.00)	(17.0, 0.19)
					995	163
F						1.00
						(0.0, 0.00)
						178
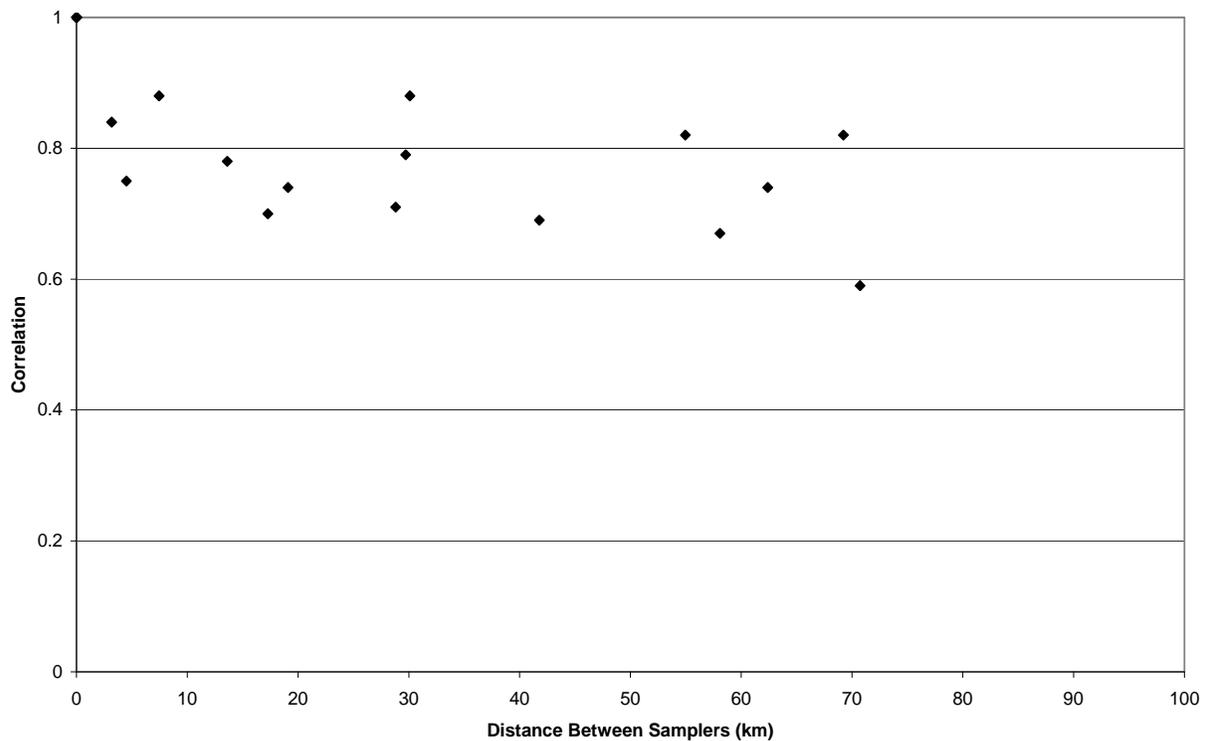
Figure A-39. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Atlanta, GA.
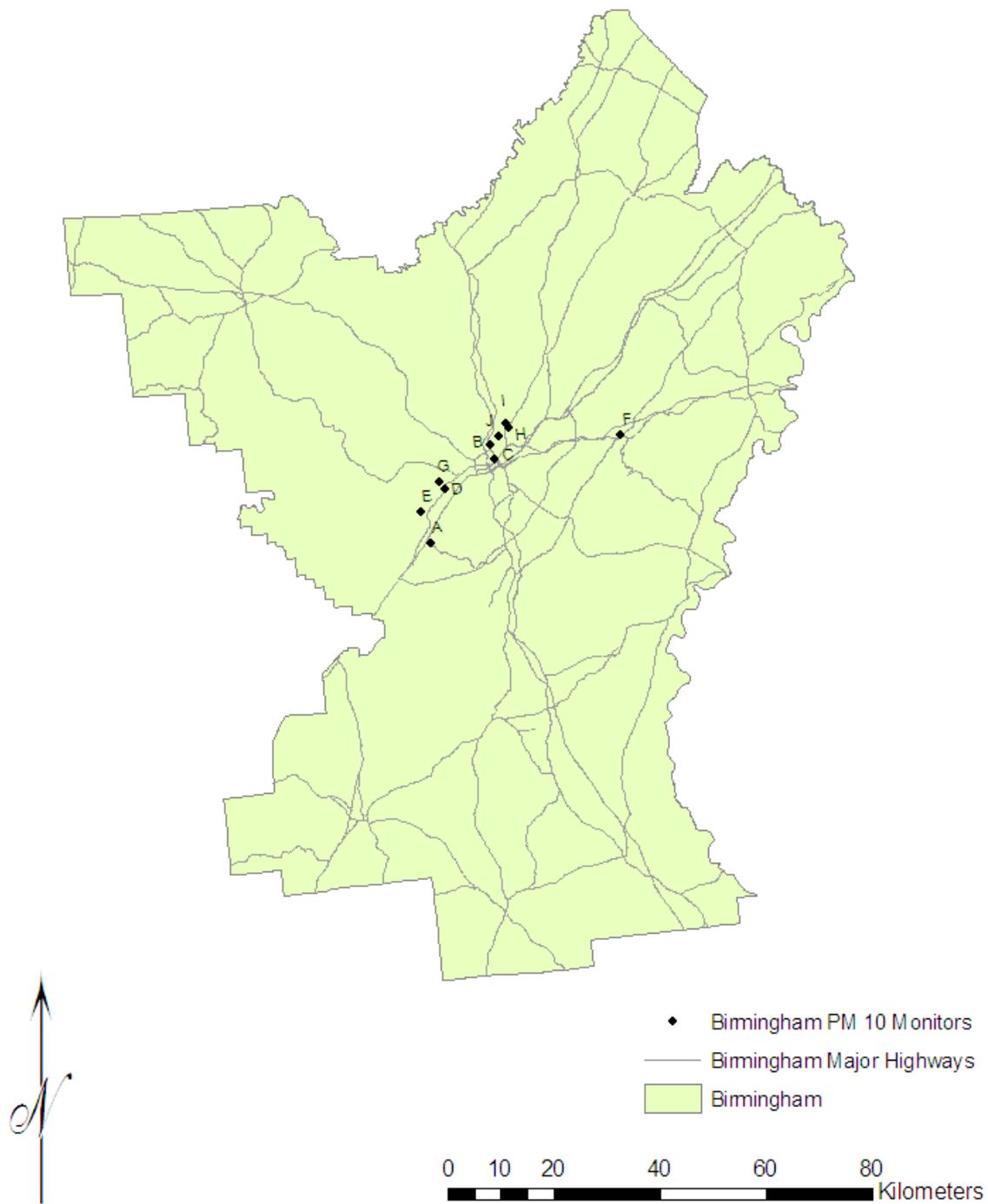
**Figure A-40.** Map of PM$_{10}$ FRM distribution with AQS Site IDs for Birmingham, AL.

AQS Site ID		A	B	C	D	E	F	G	H	I	J
Site A 01-073-0002	Mean	29.1	32.9	26.5	27.1	27.6	24.7	26.0	28.8	38.0	48.2
Site B 01-073-0023	Obs	180	1095	224	183	179	179	1090	181	1087	1080
Site C 01-073-0034	SD	12.6	20.0	11.4	11.8	14.3	11.0	14.0	12.6	29.5	30.0
Site D 01-073-1003											
Site E 01-073-1008											
Site F 01-073-1010											
Site G 01-073-2003											
Site H 01-073-6002											
Site I 01-073-6003											
Site J 01-073-6004											

1=winter
2=spring
3=summer
4=fall
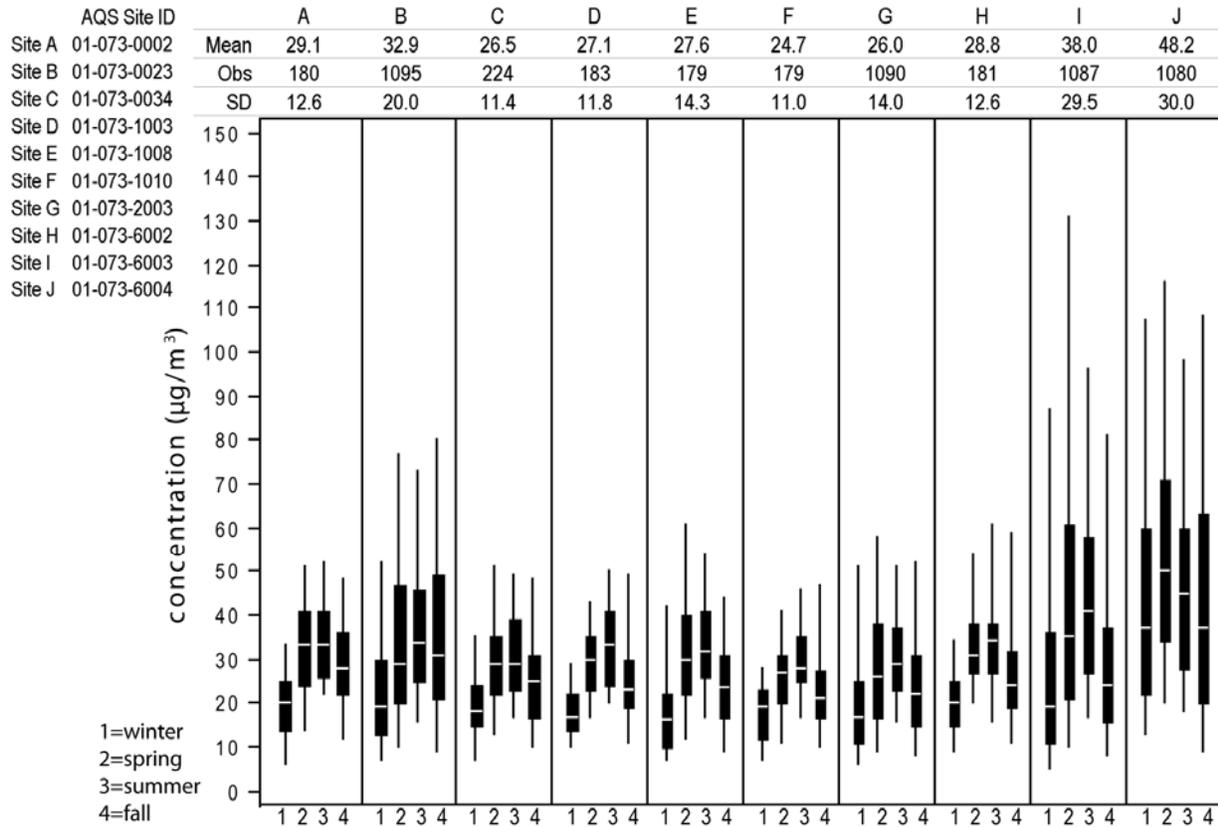
Figure A-41.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Birmingham, AL.

Table A-19.   Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Birmingham, AL.

Site	A	B	C	D	E	F	G	H	I	J
A	1.00	0.80	0.88	0.86	0.78	0.84	0.77	0.78	0.41	0.29
	(0.0, 0.00)	(23.0, 0.16)	(11.0, 0.11)	(12.0, 0.13)	(12.0, 0.14)	(13.0, 0.13)	(15.0, 0.18)	(14.0, 0.15)	(41.0, 0.30)	(68.0, 0.34)
	180	180	174	180	176	171	180	178	179	177
B		1.00	0.82	0.74	0.61	0.73	0.75	0.71	0.26	0.23
		(0.0, 0.00)	(23.0, 0.17)	(25.0, 0.21)	(26.0, 0.20)	(26.0, 0.19)	(25.0, 0.20)	(25.0, 0.22)	(51.0, 0.33)	(57.0, 0.36)
		1095	224	183	179	179	1090	181	1087	1080
C			1.00	0.84	0.66	0.78	0.74	0.80	0.33	0.41
			(0.0, 0.00)	(10.0, 0.12)	(15.0, 0.16)	(12.0, 0.14)	(14.0, 0.17)	(13.0, 0.15)	(43.0, 0.32)	(62.0, 0.34)
			224	175	171	168	224	173	222	221
D				1.00	0.67	0.79	0.76	0.84	0.45	0.41
				(0.0, 0.00)	(15.0, 0.17)	(12.0, 0.15)	(14.0, 0.17)	(11.0, 0.12)	(42.0, 0.30)	(65.5, 0.34)
				183	173	173	183	180	182	180
E					1.00	0.67	0.64	0.56	0.33	0.12
					(0.0, 0.00)	(16.0, 0.15)	(18.0, 0.18)	(19.0, 0.20)	(45.0, 0.32)	(71.0, 0.39)
					179	169	179	176	178	176
F						1.00	0.75	0.74	0.36	0.21
						(0.0, 0.00)	(14.0, 0.16)	(15.0, 0.17)	(43.0, 0.32)	(71.0, 0.38)
						179	179	171	178	177
G		R					1.00	0.76	0.59	0.15
		(P90, COD)					(0.0, 0.00)	(15.0, 0.19)	(43.0, 0.27)	(63.0, 0.39)
		N					1090	181	1083	1075
H								1.00	0.58	0.50
								(0.0, 0.00)	(38.0, 0.27)	(59.0, 0.31)
								181	180	178
I									1.00	0.05
									(0.0, 0.00)	(72.0, 0.40)
									1087	1072
J										1.00
										(0.0, 0.00)
										1080

Figure A-42   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Birmingham, AL.
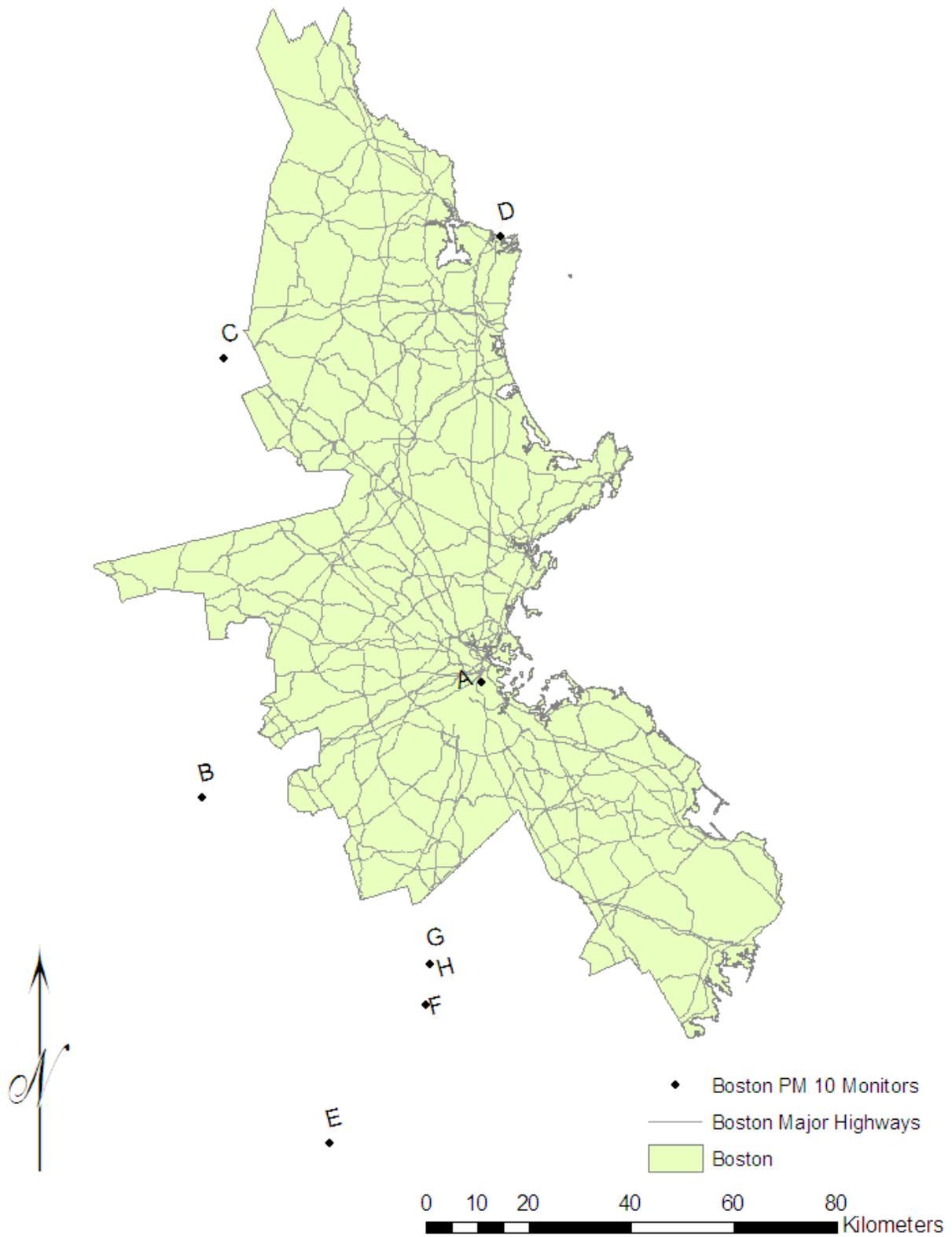
Figure A-43. Map of PM_{10} FRM distribution with AQS Site IDs for Boston, MA.

Boston - PM$_{10}$

	A	B	C	D	E	F	G	H
Mean	16.4	21.6	16.5	14.8	10.7	17.0	21.3	18.8
Obs	191	174	182	175	171	182	169	168
SD	7.7	11.9	9.2	8.2	7.0	8.7	10.8	9.4

AQS Site ID

Site A	25-025-0042
Site B	25-027-0023
Site C	33-011-0020
Site D	33-015-0014
Site E	44-003-0002
Site F	44-007-0022
Site G	44-007-0026
Site H	44-007-0027

concentration (µg/m³)

1=winter
2=spring
3=summer
4=fall

1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
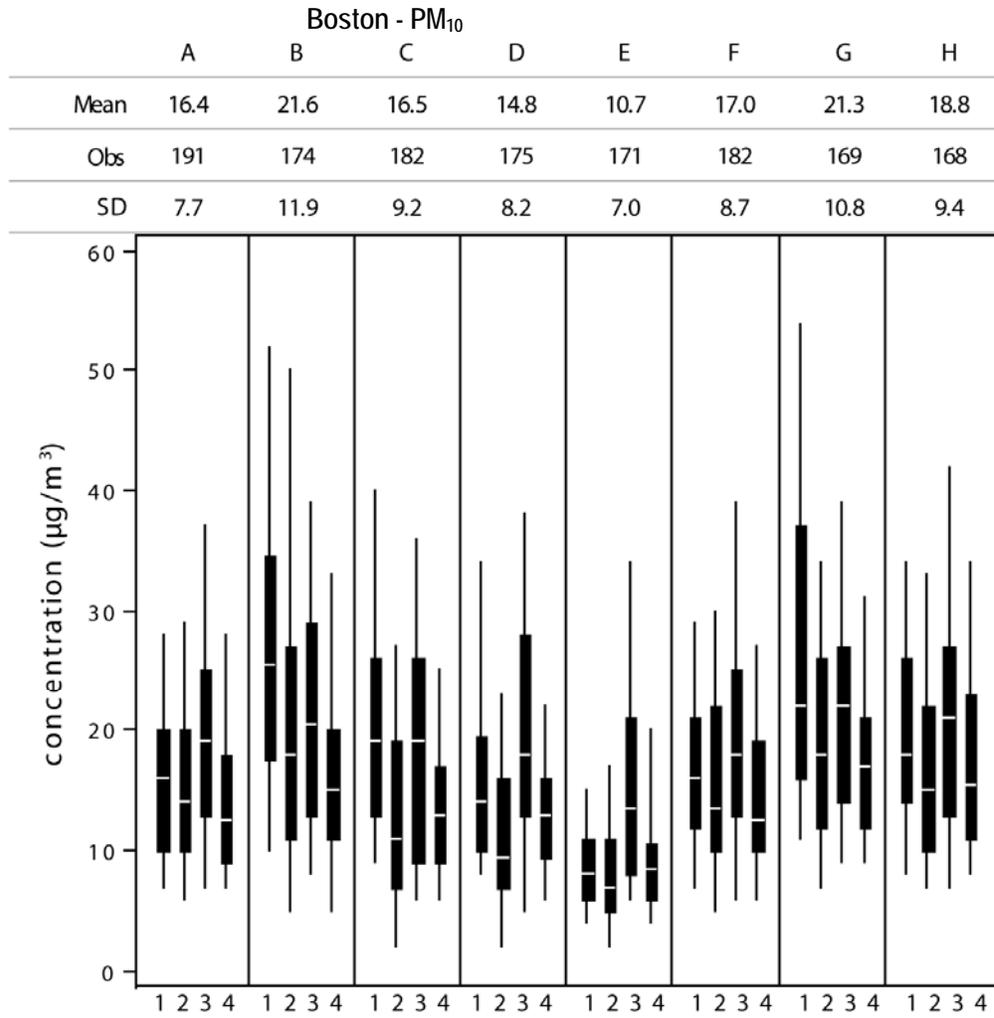
Figure A-44.   Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Boston, MA.

Table A-20.   Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Boston, MA.

Site	A	B	C	D	E	F	G	H
A	1.00	0.69	0.69	0.73	0.71	0.84	0.70	0.79
	(0.0, 0.00)	(15.0, 0.22)	(12.0, 0.20)	(10.0, 0.22)	(13.0, 0.30)	(8.0, 0.14)	(15.0, 0.20)	(10.0, 0.17)
	191	169	179	173	171	182	169	167
B		1.00	0.66	0.56	0.45	0.69	0.77	0.65
		(0.0, 0.00)	(17.0, 0.24)	(19.0, 0.28)	(24.0, 0.39)	(15.0, 0.21)	(12.0, 0.17)	(16.0, 0.20)
		174	167	161	158	169	156	154
C			1.00	0.72	0.47	0.62	0.64	0.59
			(0.0, 0.00)	(10.0, 0.22)	(17.0, 0.33)	(12.0, 0.21)	(16.0, 0.26)	(16.0, 0.24)
			182	170	168	179	166	164
D				1.00	0.63	0.68	0.59	0.69
				(0.0, 0.00)	(11.0, 0.29)	(10.0, 0.23)	(19.0, 0.30)	(13.0, 0.26)
				175	163	173	161	158
E					1.00	0.84	0.58	0.80
		R			(0.0, 0.00)	(13.0, 0.29)	(22.0, 0.38)	(15.0, 0.33)
		(P90, COD)			171	171	161	157
F			N			1.00	0.81	0.95
						(0.0, 0.00)	(11.0, 0.16)	(5.0, 0.11)
						182	169	167
G							1.00	0.79
							(0.0, 0.00)	(10.0, 0.13)
							169	154
H								1.00
								(0.0, 0.00)
								168
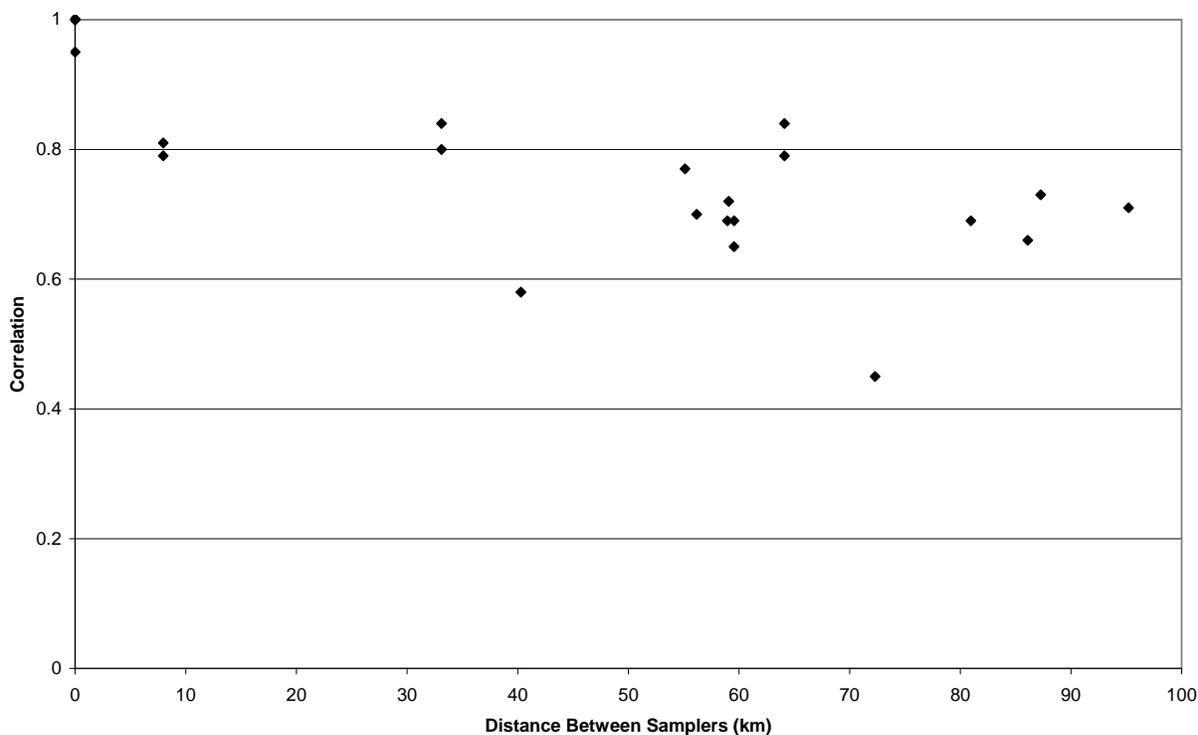
Figure A-45.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Boston, MA.
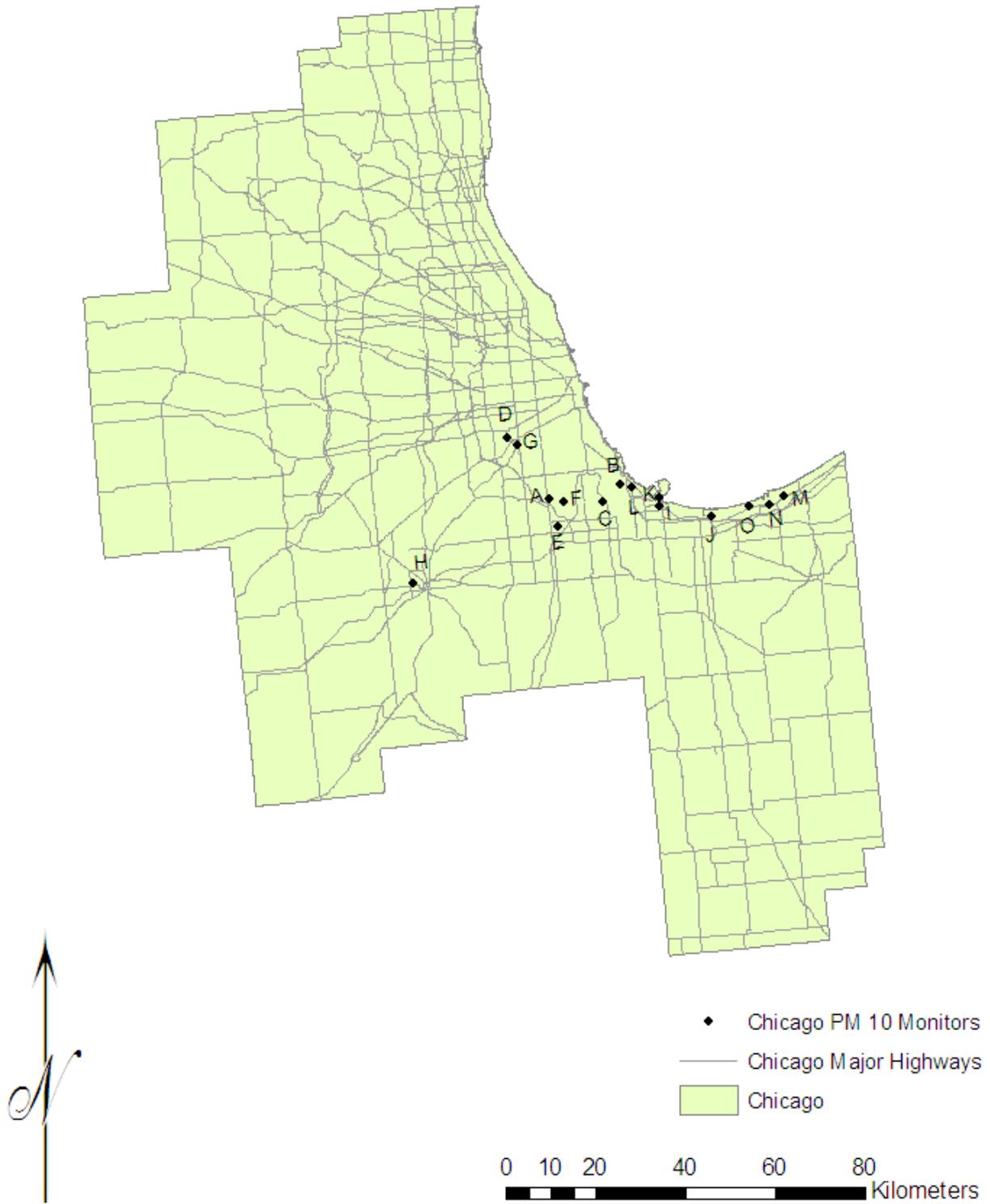
Figure A-46. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Chicago, IL.

AQS Site ID		A	B	C	D	E	F	G	H
Site A	17-031-0001	Mean	22.4	24.7	30.4	32.4	24.5	27.2	26.9	21.6
Site B	17-031-0022	Obs	179	1077	176	1058	174	176	174	176
Site C	17-031-0060	SD	10.9	13.1	15.1	17.3	11.9	13.4	12.3	12.3
Site D	17-031-1016									
Site E	17-031-1901									
Site F	17-031-2001									
Site G	17-031-3301									
Site H	17-197-1002									

1=winter
2=spring
3=summer
4=fall

AQS Site ID		I	J	K	L	M	N	O
Site I	18-089-0006	Mean	28.2	27.9	26.4	16.6	17.2	24.1	18.3
Site J	18-089-0022	Obs	182	1059	172	169	173	1051	169
Site K	18-089-0023	SD	13.8	18.1	9.5	9.8	11.2	15.1	10.7
Site L	18-089-2010								
Site M	18-127-0022								
Site N	18-127-0023								
Site O	18-127-0024								

1=winter
2=spring
3=summer
4=fall

Figure A-47.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Chicago, IL.

Table A-21. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Chicago, IL.

Legend for each cell: R / (P90, COD) / N

Site	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	1.00 (0.0, 0.00) 179	0.78 (15.0, 0.18) 176	0.68 (23.0, 0.24) 173	0.83 (25.0, 0.22) 174	0.93 (8.0, 0.10) 171	0.92 (11.0, 0.13) 173	0.86 (12.0, 0.17) 171	0.79 (12.0, 0.18) 167	0.75 (13.0, 0.18) 179	0.14 (22.0, 0.28) 173	0.69 (15.0, 0.21) 169	0.89 (13.0, 0.22) 166	0.55 (21.0, 0.30) 170	0.27 (16.0, 0.24) 171	0.75 (15.0, 0.23) 166
B		1.00 (0.0, 0.00) 1077	0.66 (23.0, 0.23) 173	0.74 (23.0, 0.21) 1040	0.76 (14.0, 0.17) 171	0.84 (12.0, 0.15) 173	0.79 (13.0, 0.18) 171	0.74 (17.0, 0.23) 173	0.68 (16.0, 0.19) 179	0.36 (22.0, 0.24) 1041	0.73 (16.0, 0.19) 169	0.81 (18.0, 0.27) 166	0.66 (23.0, 0.31) 170	0.33 (19.0, 0.25) 1033	0.77 (20.0, 0.26) 166
C			1.00 (0.0, 0.00) 176	0.63 (26.0, 0.23) 171	0.72 (21.0, 0.21) 169	0.74 (18.5, 0.19) 170	0.64 (19.0, 0.21) 168	0.62 (22.0, 0.27) 164	0.62 (23.0, 0.20) 176	0.19 (26.5, 0.28) 170	0.49 (24.0, 0.23) 166	0.66 (29.0, 0.37) 163	0.39 (33.0, 0.40) 167	0.27 (26.0, 0.26) 168	0.61 (31.0, 0.35) 163
D				1.00 (0.0, 0.00) 1058	0.79 (27.0, 0.21) 171	0.85 (19.0, 0.17) 171	0.79 (23.0, 0.19) 169	0.74 (27.0, 0.28) 171	0.70 (20.0, 0.19) 177	0.23 (32.0, 0.29) 1022	0.69 (24.0, 0.23) 168	0.82 (31.0, 0.36) 166	0.61 (36.0, 0.39) 168	0.29 (31.0, 0.29) 1020	0.76 (31.0, 0.33) 164
E					1.00 (0.0, 0.00) 174	0.93 (9.0, 0.10) 168	0.84 (13.0, 0.16) 166	0.86 (10.0, 0.16) 163	0.74 (13.0, 0.16) 174	0.17 (22.0, 0.26) 168	0.70 (15.0, 0.19) 164	0.89 (15.0, 0.25) 161	0.53 (22.0, 0.33) 166	0.34 (17.0, 0.22) 166	0.73 (18.0, 0.25) 163
F						1.00 (0.0, 0.00) 176	0.84 (12.0, 0.15) 169	0.86 (13.0, 0.19) 165	0.77 (12.0, 0.14) 176	0.21 (23.0, 0.25) 170	0.75 (16.0, 0.17) 166	0.89 (18.0, 0.28) 163	0.62 (25.0, 0.34) 167	0.32 (20.0, 0.23) 168	0.80 (20.0, 0.27) 163
G							1.00 (0.0, 0.00) 174	0.77 (15.0, 0.22) 162	0.69 (14.0, 0.18) 174	0.28 (23.0, 0.26) 168	0.74 (14.0, 0.18) 165	0.86 (19.0, 0.31) 161	0.52 (24.0, 0.36) 165	0.33 (19.0, 0.24) 166	0.70 (22.0, 0.30) 163
H								1.00 (0.0, 0.00) 176	0.71 (16.0, 0.23) 170	0.18 (27.0, 0.30) 169	0.66 (18.0, 0.25) 161	0.83 (13.0, 0.23) 157	0.59 (19.0, 0.29) 161	0.36 (17.0, 0.25) 168	0.76 (14.0, 0.22) 157
I									1.00 (0.0, 0.00) 182	0.24 (22.0, 0.24) 176	0.69 (12.0, 0.15) 172	0.75 (20.0, 0.32) 169	0.50 (26.0, 0.37) 173	0.39 (16.0, 0.21) 174	0.68 (21.0, 0.30) 169
J			R (P90, COD) N							1.00 (0.0, 0.00) 1059	0.49 (15.0, 0.20) 166	0.38 (25.0, 0.34) 163	0.22 (28.0, 0.36) 168	0.48 (22.0, 0.21) 1018	0.22 (27.0, 0.33) 164
K											1.00 (0.0, 0.00) 172	0.80 (17.0, 0.32) 161	0.54 (24.0, 0.35) 165	0.49 (14.0, 0.19) 164	0.65 (21.0, 0.31) 162
L												1.00 (0.0, 0.00) 169	0.60 (15.0, 0.26) 161	0.33 (19.0, 0.31) 161	0.78 (10.0, 0.20) 158
M													1.00 (0.0, 0.00) 173	0.24 (21.0, 0.35) 165	0.84 (8.0, 0.16) 161
N														1.00 (0.0, 0.00) 1051	0.31 (19.0, 0.29) 161
O															1.00 (0.0, 0.00) 169
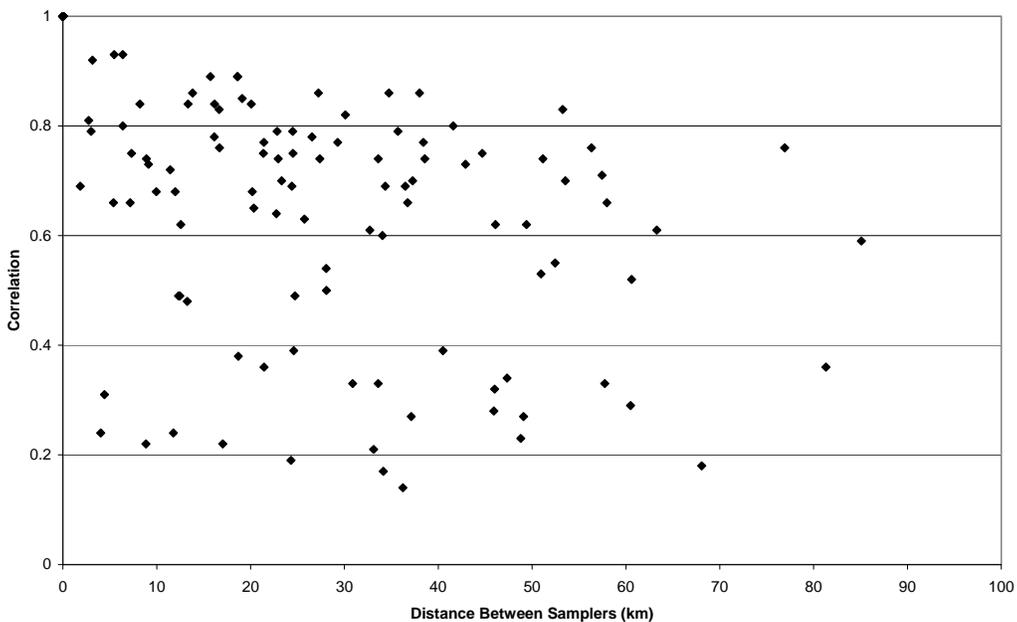
Figure A-48. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Chicago, IL.
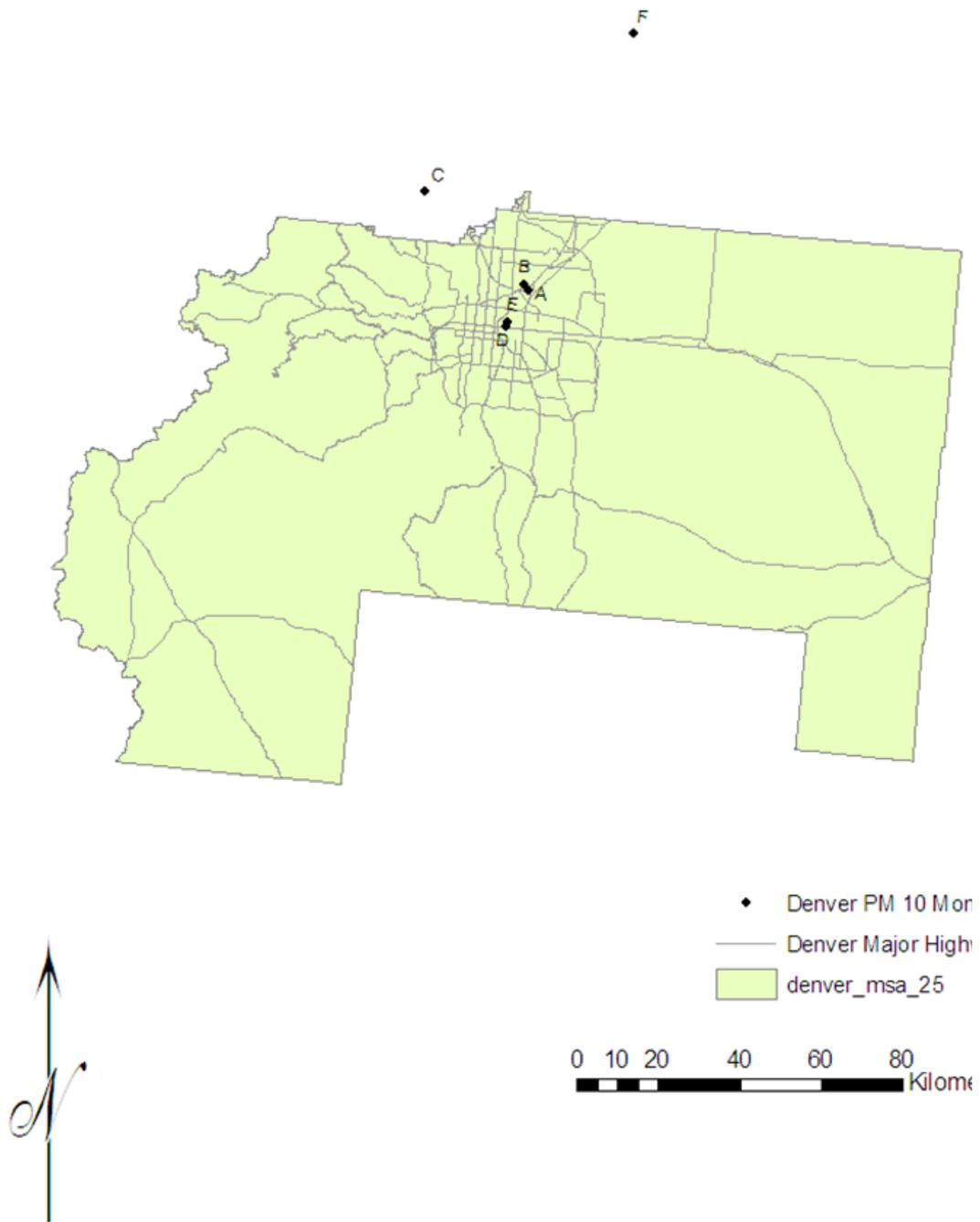
Figure A-49. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Denver, CO.

| AQS Site ID		A	B	C	D	E	F
Site A 08-001-0006	Mean	36.0	28.2	19.8	24.2	25.8	22.2
Site B 08-001-3001	Obs	1043	1074	169	1039	1028	353
Site C 08-013-0012	SD	18.3	13.2	9.7	10.6	11.5	11.2
Site D 08-031-0002							
Site E 08-031-0017							
Site F 08-123-0006							

1=winter
2=spring
3=summer
4=fall
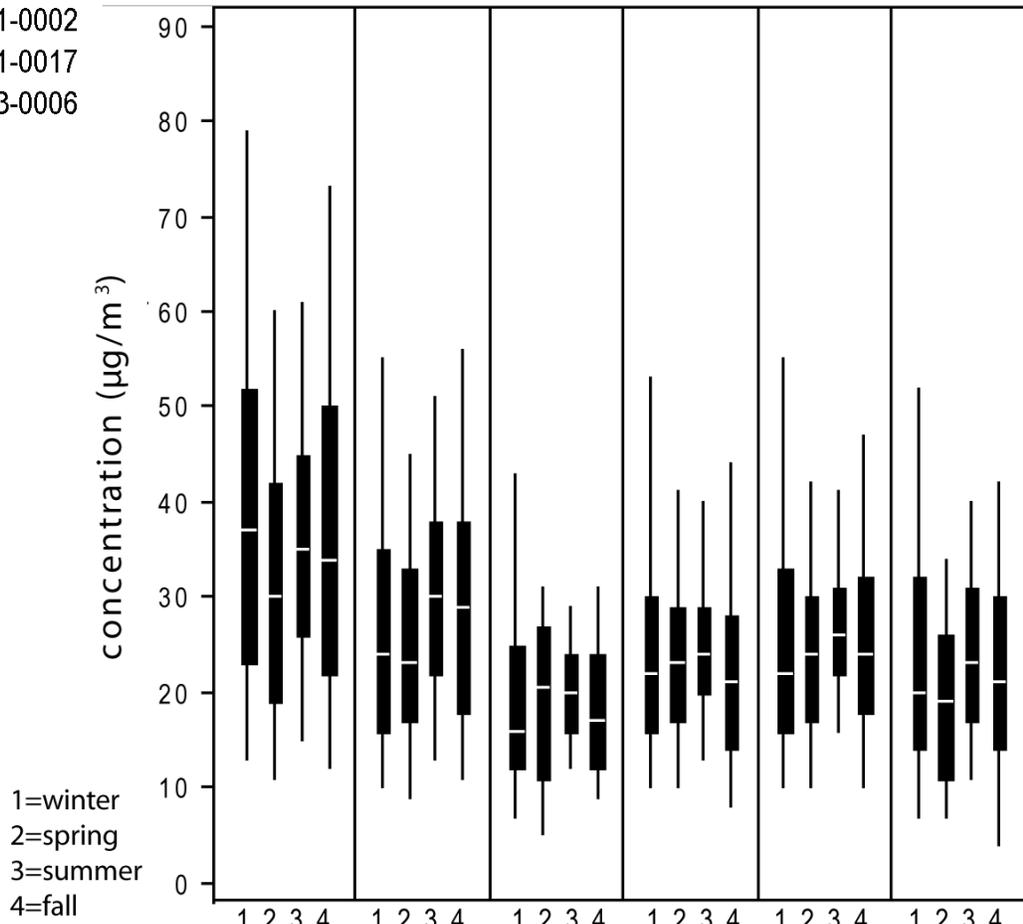
Figure A-50.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Denver, CO.

Table A-22. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Denver, CO.

Site	A	B	C	D	E	F
A	1.00	0.84	0.43	0.70	0.72	0.67
	(0.0, 0.00)	(20.0, 0.16)	(36.0, 0.34)	(29.0, 0.24)	(26.0, 0.21)	(27.0, 0.28)
	1043	1022	164	987	980	339
B		1.00	0.57	0.72	0.74	0.72
		(0.0, 0.00)	(28.0, 0.27)	(17.0, 0.18)	(15.0, 0.16)	(18.0, 0.22)
		1074	169	1019	1007	348
C			1.00	0.75	0.72	0.51
			(0.0, 0.00)	(17.0, 0.23)	(16.0, 0.23)	(16.0, 0.23)
			169	169	156	164
D	R			1.00	0.89	0.52
	(P90, COD)			(0.0, 0.00)	(9.0, 0.13)	(17.0, 0.22)
	N			1039	976	341
E					1.00	0.58
					(0.0, 0.00)	(17.0, 0.23)
					1028	330
F						1.00
						(0.0, 0.00)
						353

Figure A-51. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Denver, CO.
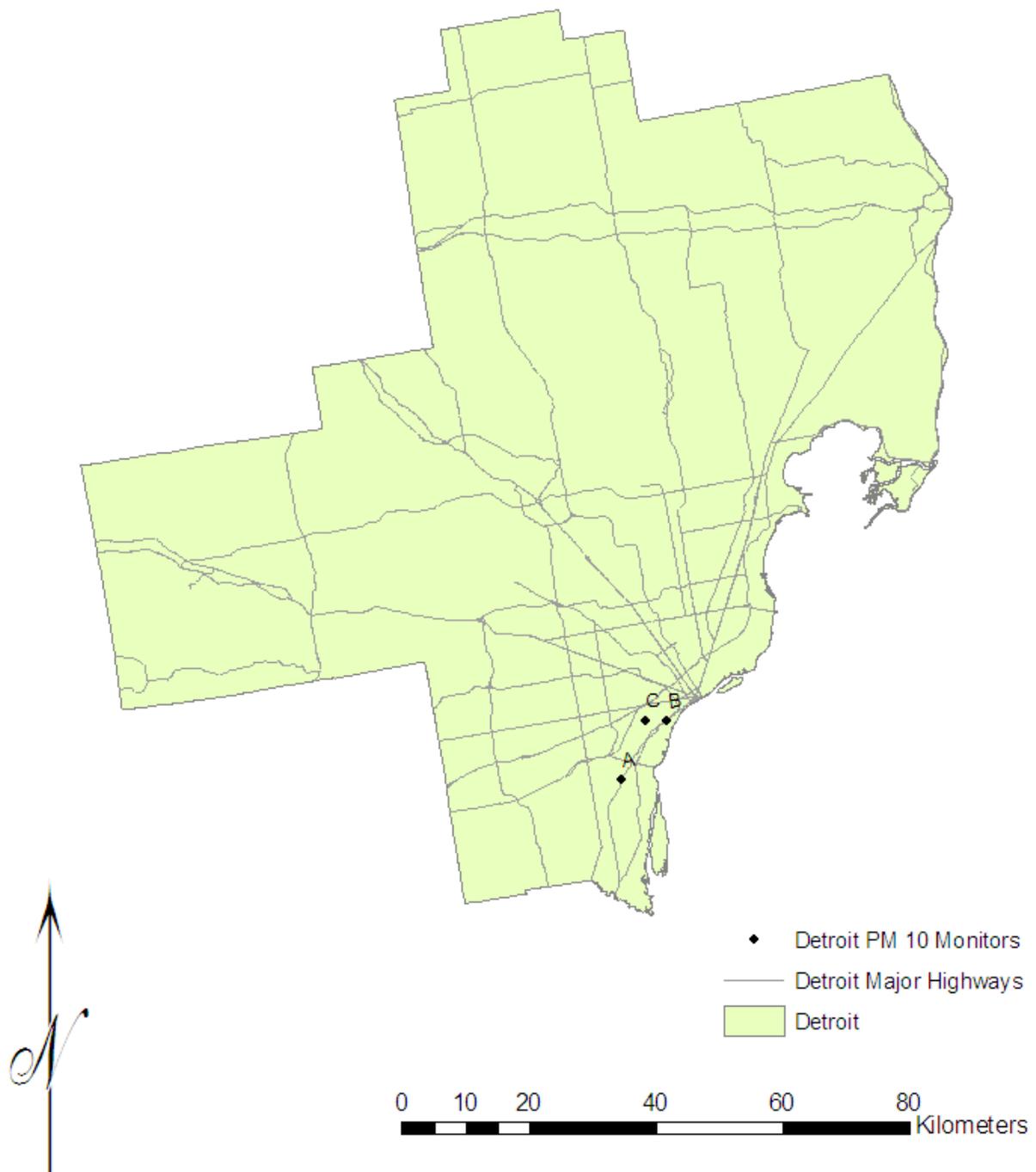
Figure A-52.   Map of PM$_{10}$ FRM distribution with AQS Site IDs for Detroit, MI.

AQS Site ID		A	B	C
Site A	26-163-0001			
Site B	26-163-0015			
Site C	26-163-0033			
	Mean	22.5	26.4	32.0
	Obs	174	176	1057
	SD	11.8	14.9	17.9

1=winter
2=spring
3=summer
4=fall
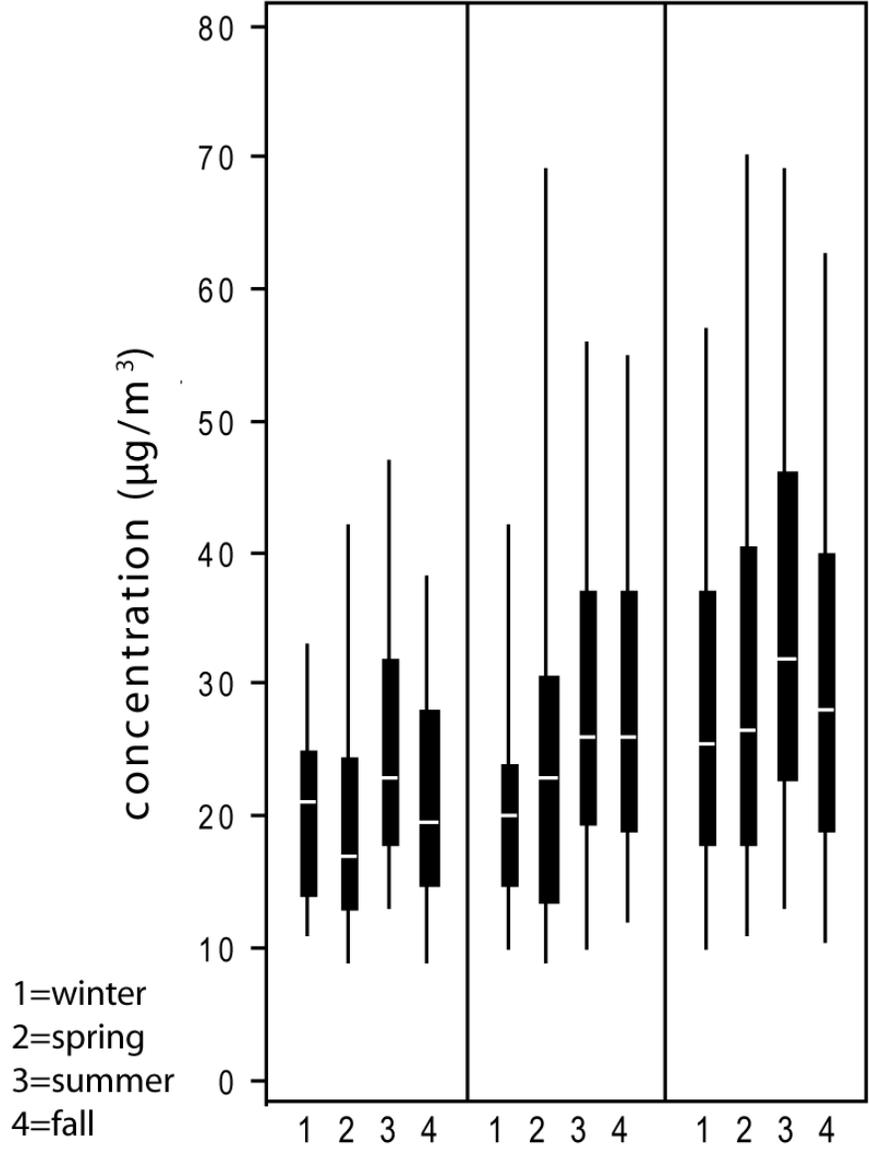
Figure A-53.   Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Detroit, MI.

Table A-23. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Detroit, MI.

Site	A	B	C
A	1.00	0.77	0.74
	(0.0, 0.00)	(14.0, 0.18)	(28.0, 0.26)
	174	169	172
B		1.00	0.79
		(0.0, 0.00)	(21.0, 0.21)
		176	174
C	R		1.00
	(P90, COD)		(0.0, 0.00)
	N		1057
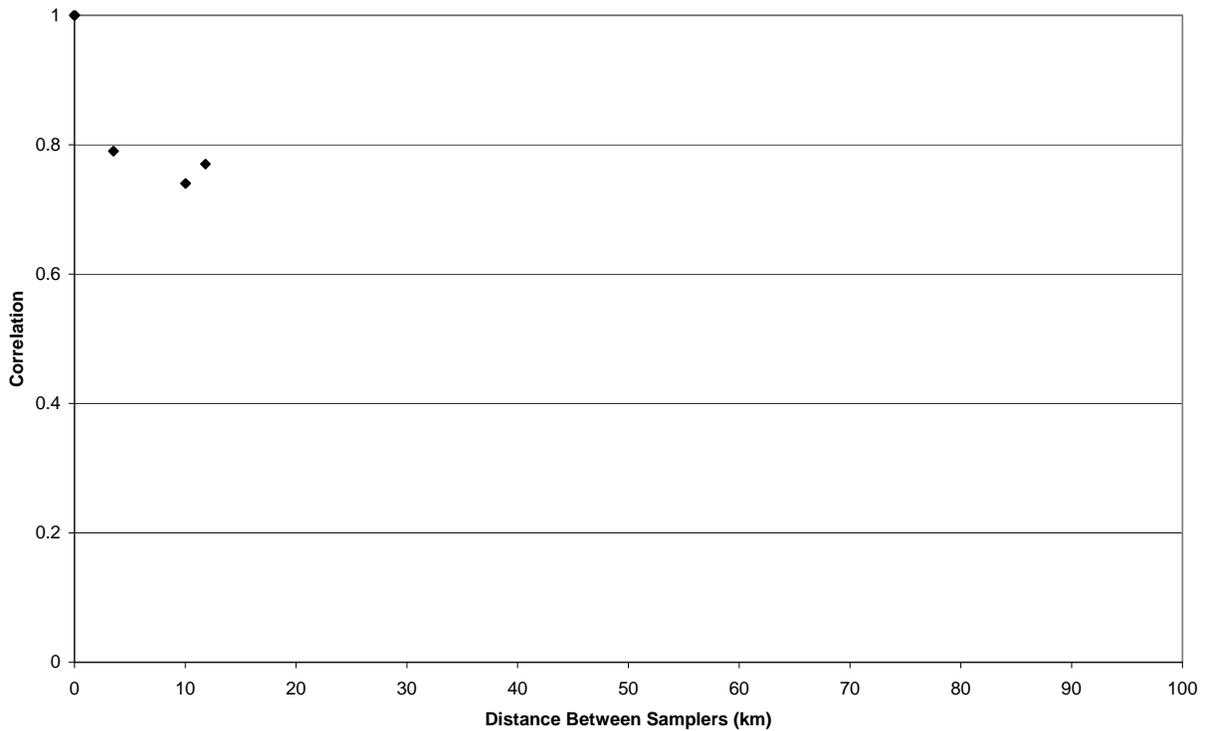
Figure A-54. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Detroit, MI.
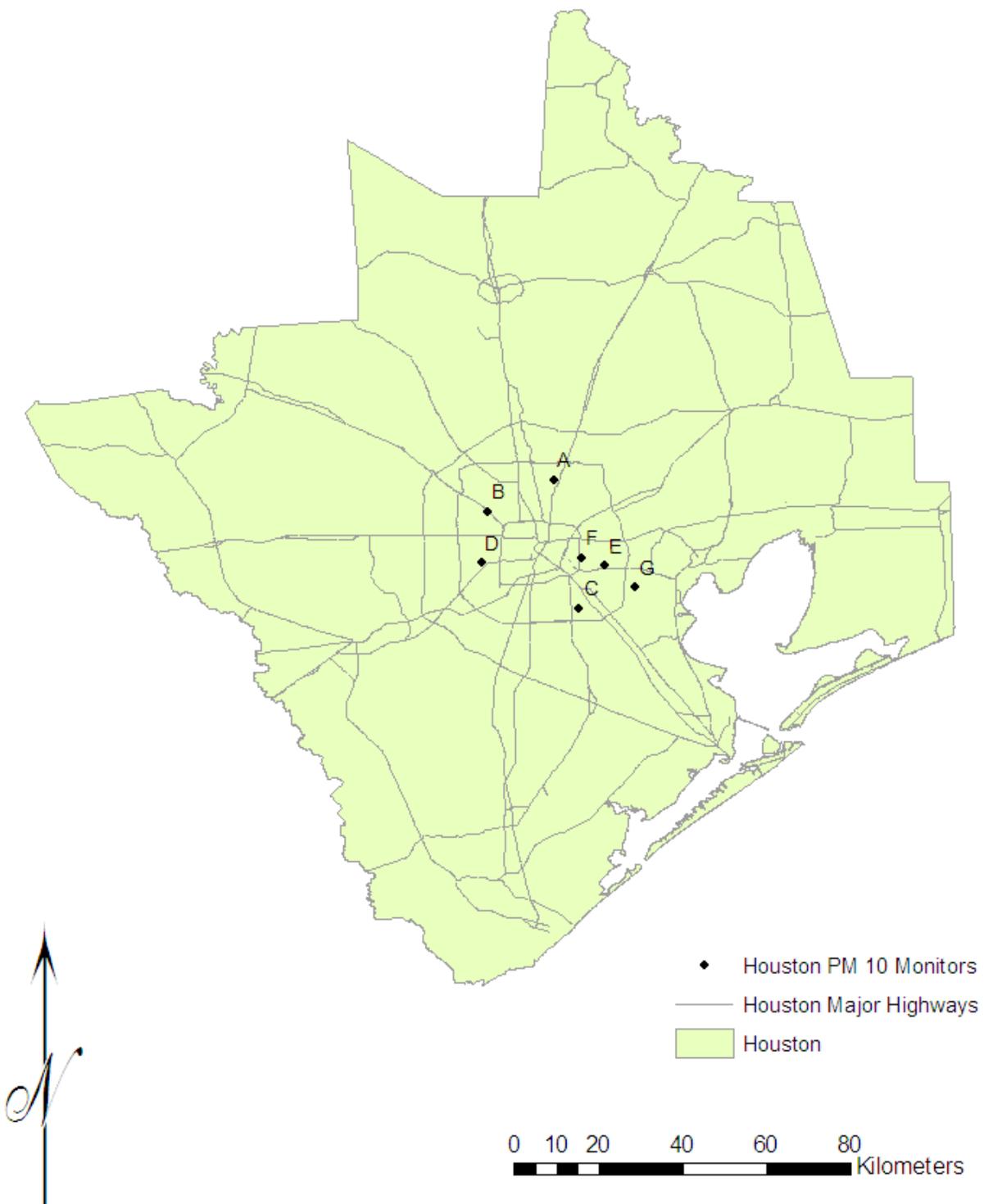
Figure A-55.   Map of PM$_{10}$ FRM distribution with AQS Site IDs for Houston, TX.

AQS Site ID		A	B	C	D	E	F	G
Site A 48-201-0024	Mean	24.5	24.0	23.4	22.3	22.7	54.8	15.8
Site B 48-201-0047	Obs	174	178	174	175	174	359	163
Site C 48-201-0062	SD	9.7	9.1	9.7	10.0	9.3	35.5	7.7

Site D 48-201-0066
Site E 48-201-0071
Site F 48-201-1035
Site G 48-201-1039

1=winter
2=spring
3=summer
4=fall
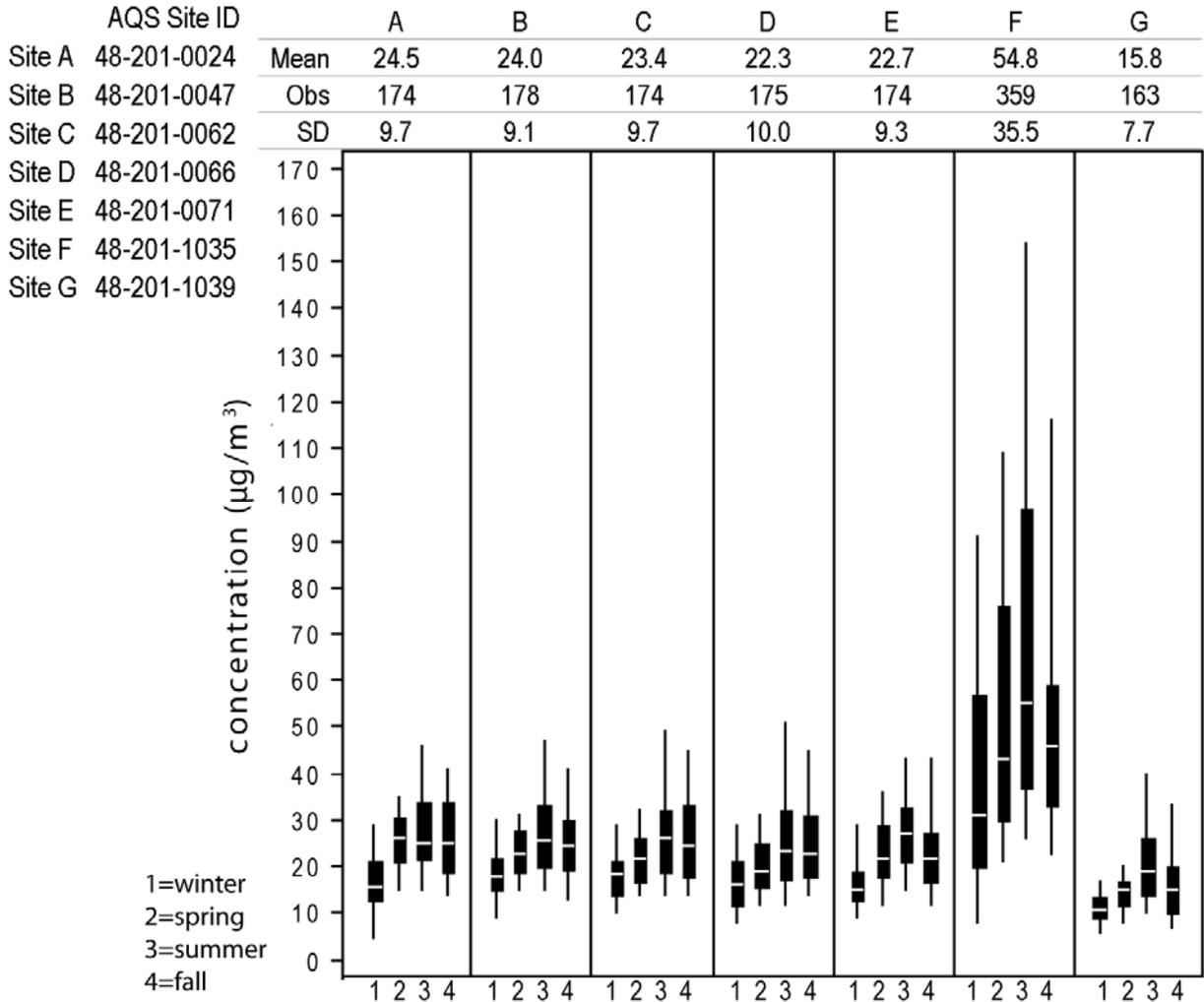
Figure A-56.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Houston, TX.

Table A-24. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Houston, TX.

SITE	A	B	C	D	E	F	G
A	1.00 (0.0, 0.00) 174	0.84 (9.0, 0.12) 163	0.78 (11.0, 0.16) 158	0.76 (12.0, 0.16) 165	0.43 (15.0, 0.20) 167	0.56 (77.0, 0.37) 159	0.75 (17.0, 0.28) 156
B		1.00 (0.0, 0.00) 178	0.86 (9.0, 0.11) 156	0.86 (9.0, 0.12) 160	0.38 (15.0, 0.19) 163	0.52 (74.0, 0.39) 158	0.79 (16.0, 0.26) 152
C			1.00 (0.0, 0.00) 174	0.83 (10.0, 0.14) 156	0.41 (17.0, 0.19) 159	0.38 (74.0, 0.40) 151	0.85 (14.5, 0.25) 150
D				1.00 (0.0, 0.00) 175	0.32 (18.0, 0.20) 163	0.43 (81.0, 0.43) 155	0.76 (16.0, 0.23) 154
E					1.00 (0.0, 0.00) 174	0.15 (78.0, 0.43) 158	0.38 (20.0, 0.28) 157
F	R (P90, COD) N					1.00 (0.0, 0.00) 359	0.37 (92.0, 0.54) 149
G							1.00 (0.0, 0.00) 163
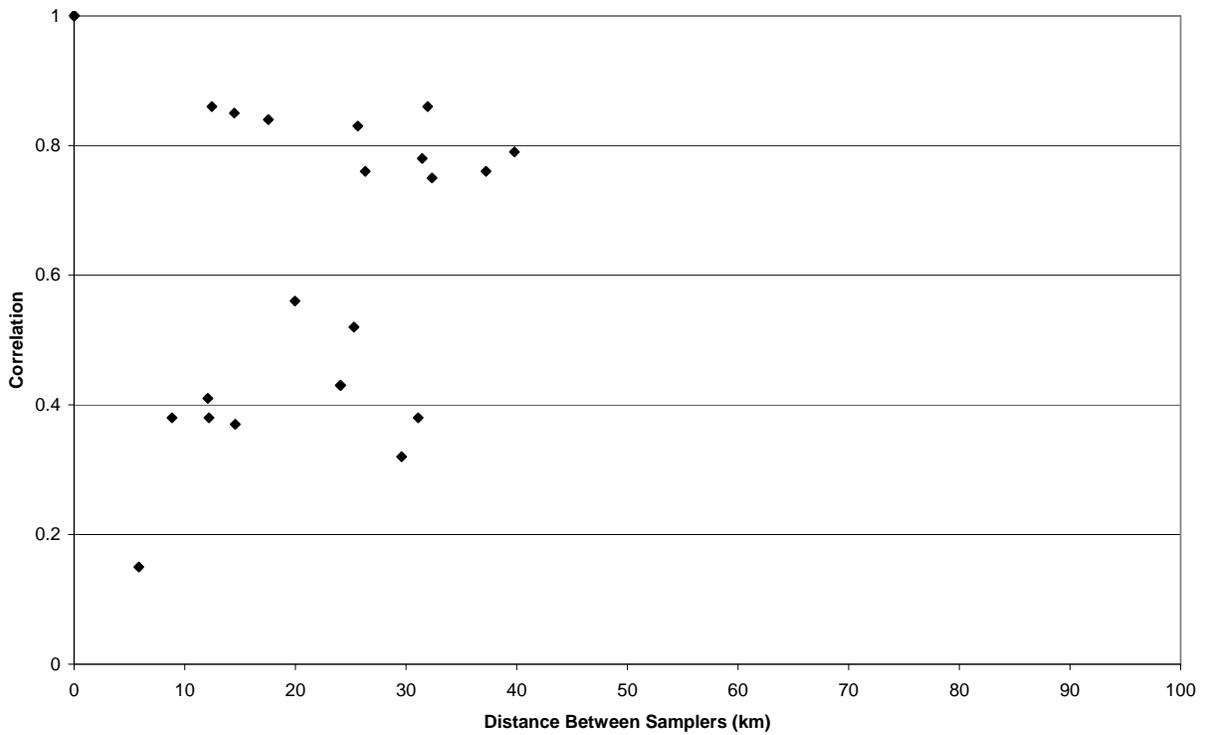
Figure A-57. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Houston, TX.
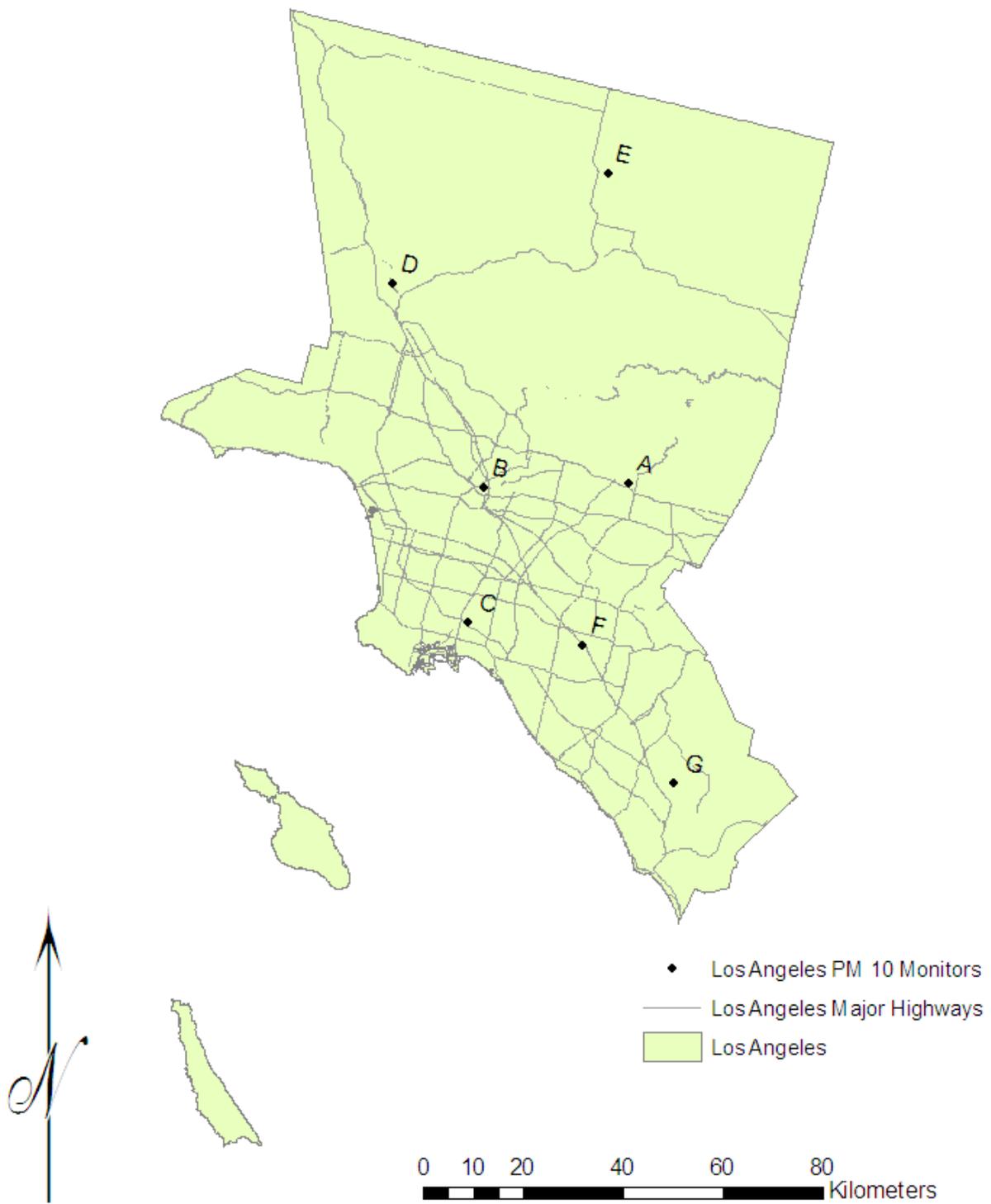
Figure A-58. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Los Angeles, CA.

	A	B	C	D	E	F	G
Mean	35.3	31.1	31.5	27.3	23.7	33.5	21.6
Obs	169	175	178	176	985	175	162
SD	19.8	13.3	19.6	18.1	12.1	37.6	9.4

AQS Site ID

Site A 06-037-0002
Site B 06-037-1103
Site C 06-037-4002
Site D 06-037-6012
Site E 06-037-9033
Site F 06-059-0007
Site G 06-059-2022

1=winter
2=spring
3=summer
4=fall
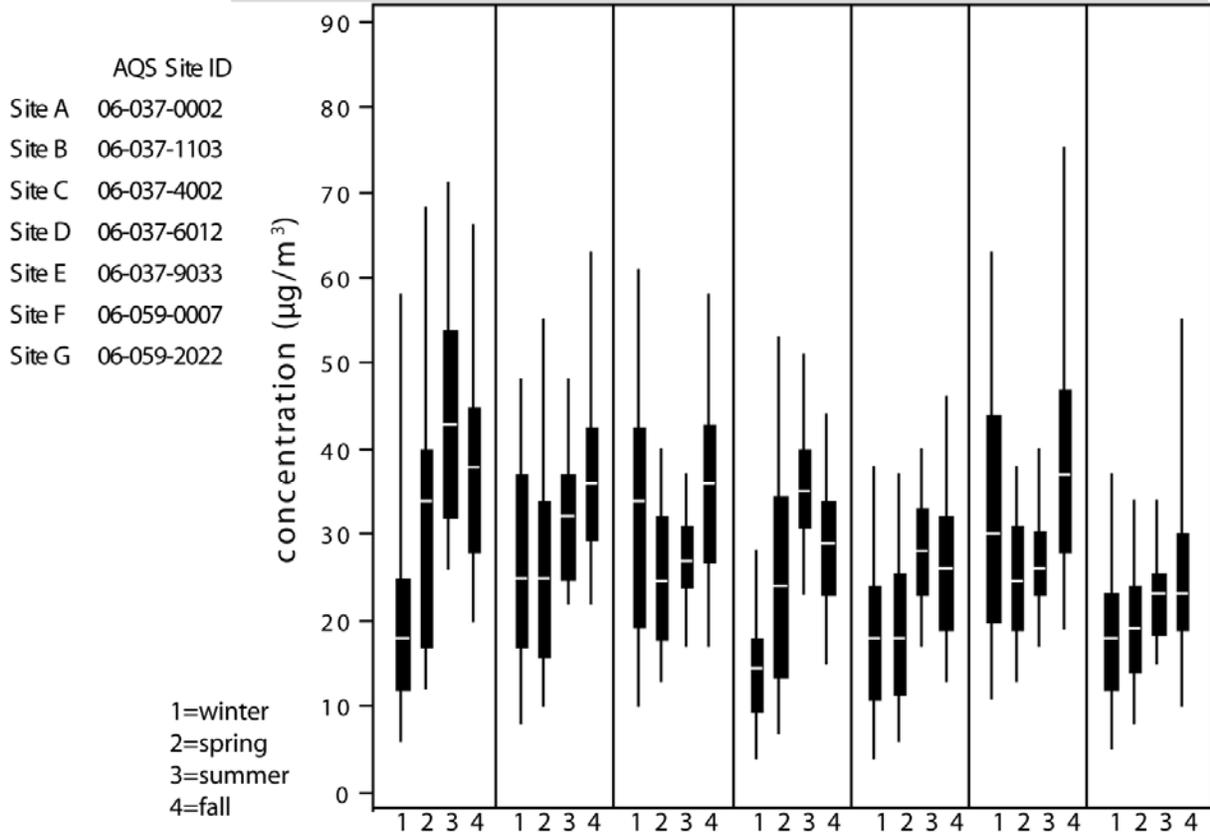
Figure A-59.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Los Angeles, CA.

Table A-25. Inter-sampler correlation statistics for each pair of PM_{10} AQS data for Los Angeles, CA.

Site	A	B	C	D	E	F	G
A	1.00 (0.0, 0.00) 169	0.73 (17.0, 0.17) 153	0.44 (27.0, 0.24) 154	0.73 (24.0, 0.22) 157	0.47 (28.0, 0.26) 169	0.41 (29.0, 0.24) 155	0.65 (30.0, 0.28) 143
B		1.00 (0.0, 0.00) 175	0.61 (14.0, 0.14) 159	0.57 (21.0, 0.24) 159	0.52 (23.0, 0.23) 173	0.42 (15.0, 0.16) 162	0.73 (20.0, 0.23) 149
C			1.00 (0.0, 0.00) 178	0.65 (27.0, 0.28) 158	0.43 (22.0, 0.24) 176	0.93 (11.0, 0.11) 159	0.73 (21.0, 0.22) 148
D				1.00 (0.0, 0.00) 176	0.70 (16.0, 0.20) 175	0.65 (26.0, 0.28) 161	0.57 (19.5, 0.24) 150
E					1.00 (0.0, 0.00) 985	0.29 (26.0, 0.25) 173	0.38 (20.0, 0.24) 159
F		R (P90, COD) N				1.00 (0.0, 0.00) 175	0.65 (21.5, 0.22) 150
G							1.00 (0.0, 0.00) 162
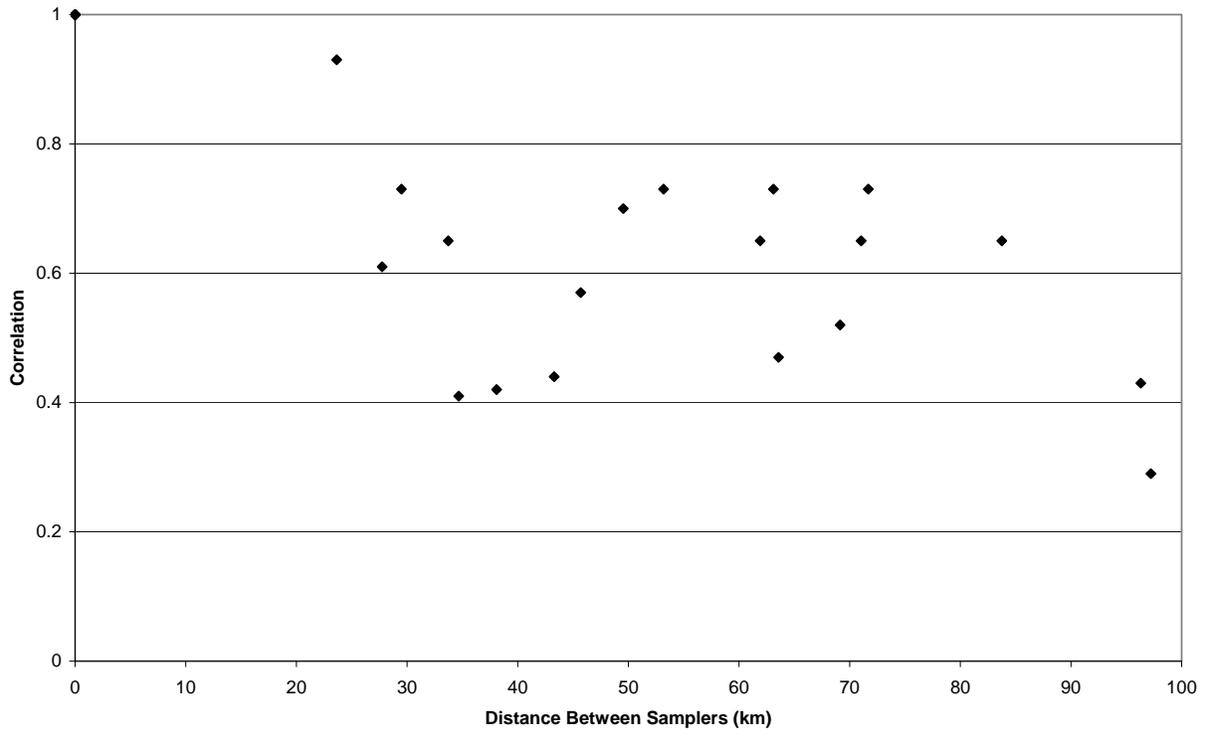
Figure A-60. PM_{10} inter-sampler correlations as a function of distance between monitors for Los Angeles, CA.
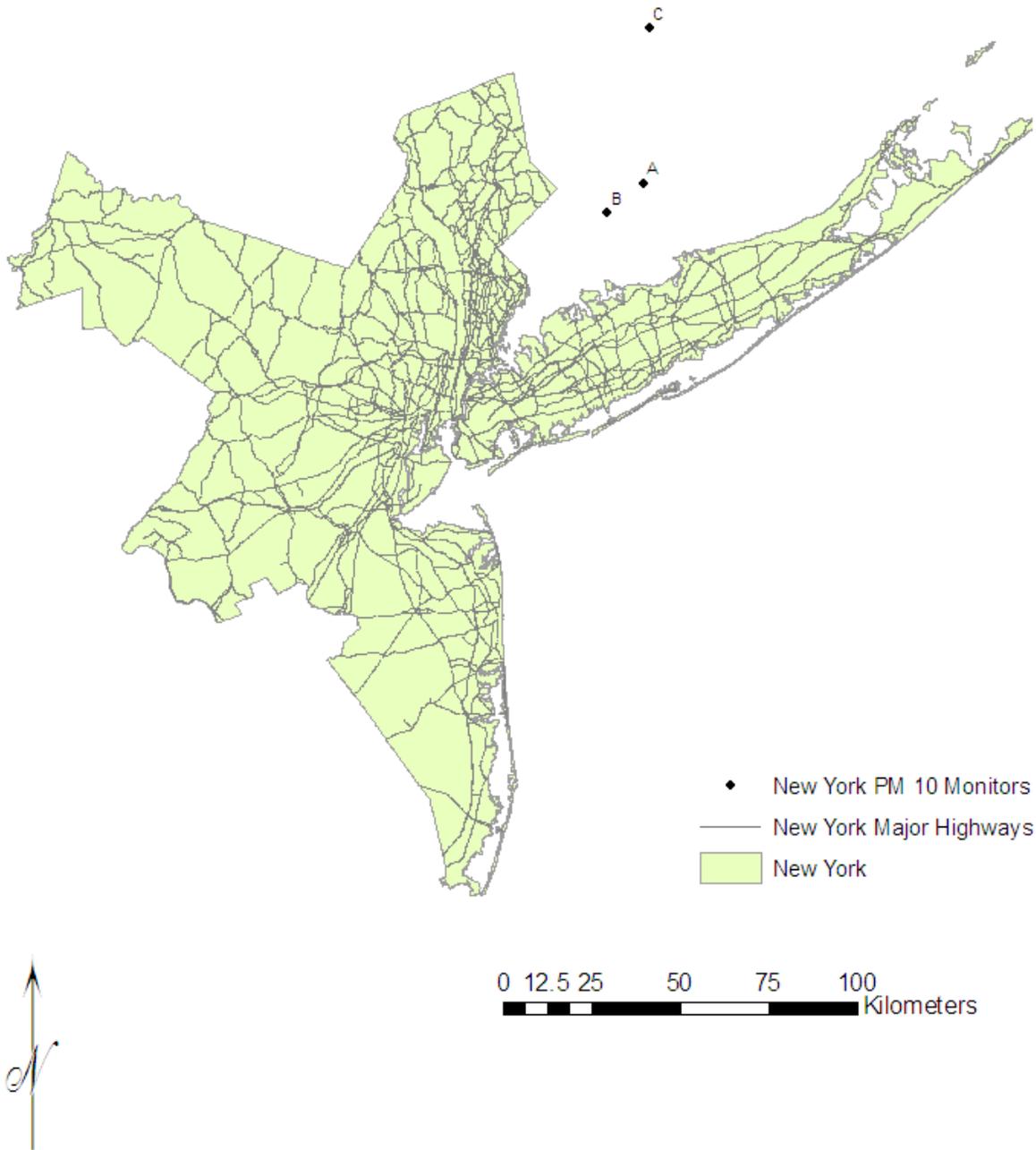
**Figure A-61.** Map of PM$_{10}$ FRM distribution with AQS Site IDs for New York City, NY.

AQS Site ID		A	B	C
Site A 09-001-0010	Mean	21.2	15.2	21.6
Site B 09-001-9003	Obs	167	169	178
Site C 09-009-2123	SD	11.3	8.4	12.3

concentration (µg/m³)

60

50

1=winter
2=spring
3=summer
4=fall

1 2 3 4   1 2 3 4   1 2 3 4
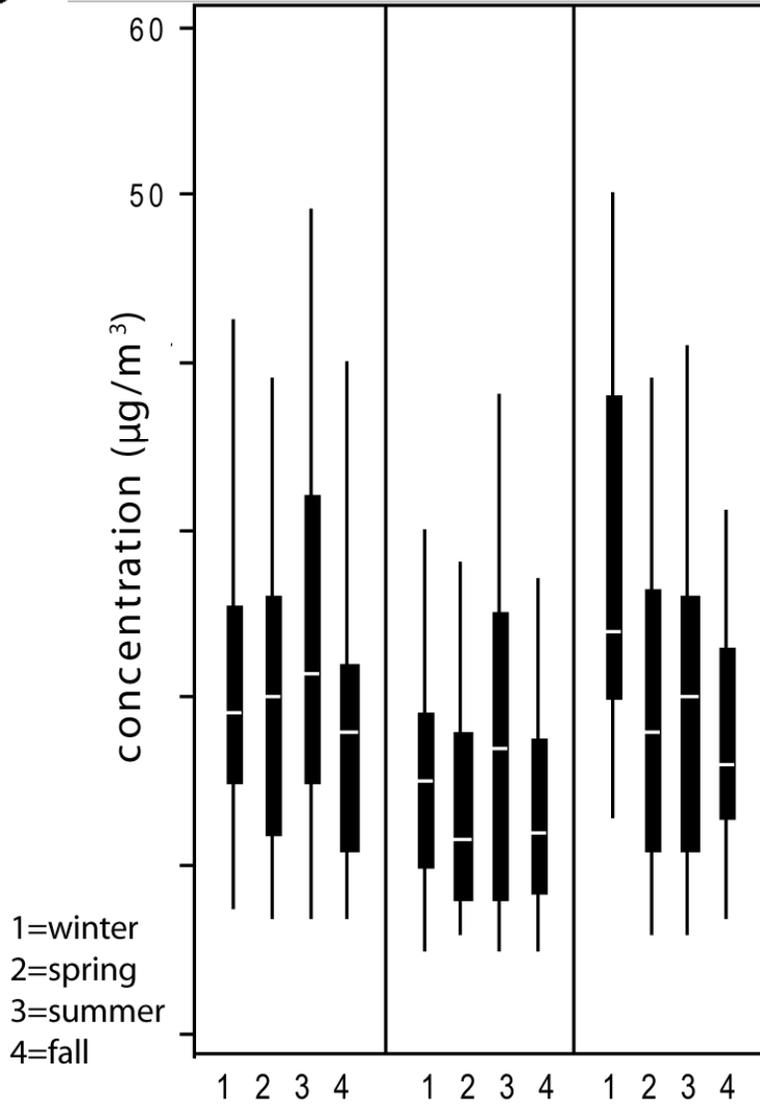
Figure A-62.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for New York City, NY.

Table A-26.   Inter-sampler correlation statistics for each pair of PM_{10} AQS data for New York City, NY.

Site	A	B	C
A	1.00	0.88	0.82
	(0.0, 0.00)	(11.0, 0.20)	(12.0, 0.16)
	167	156	164
B		1.00	0.74
		(0.0, 0.00)	(18.0, 0.25)
		169	166
C	R		1.00
	(P90, COD)		(0.0, 0.00)
	N		178
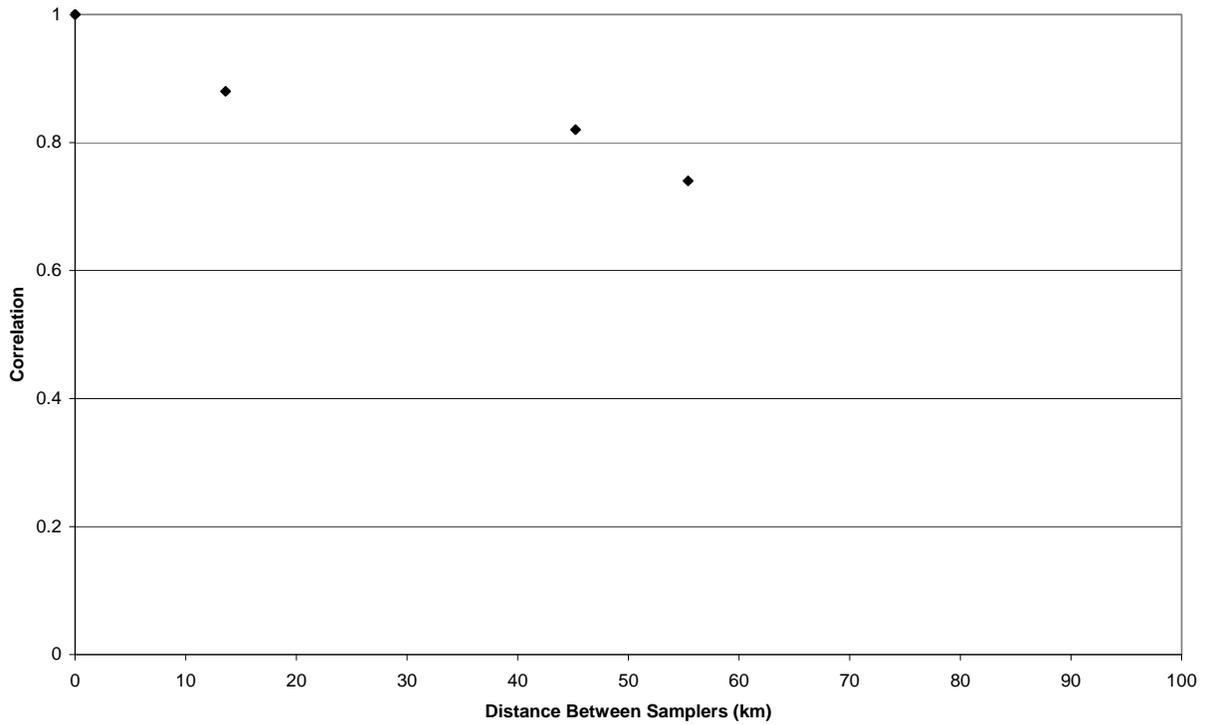
Figure A-63. PM_{10} inter-sampler correlations as a function of distance between monitors for New York City, NY.
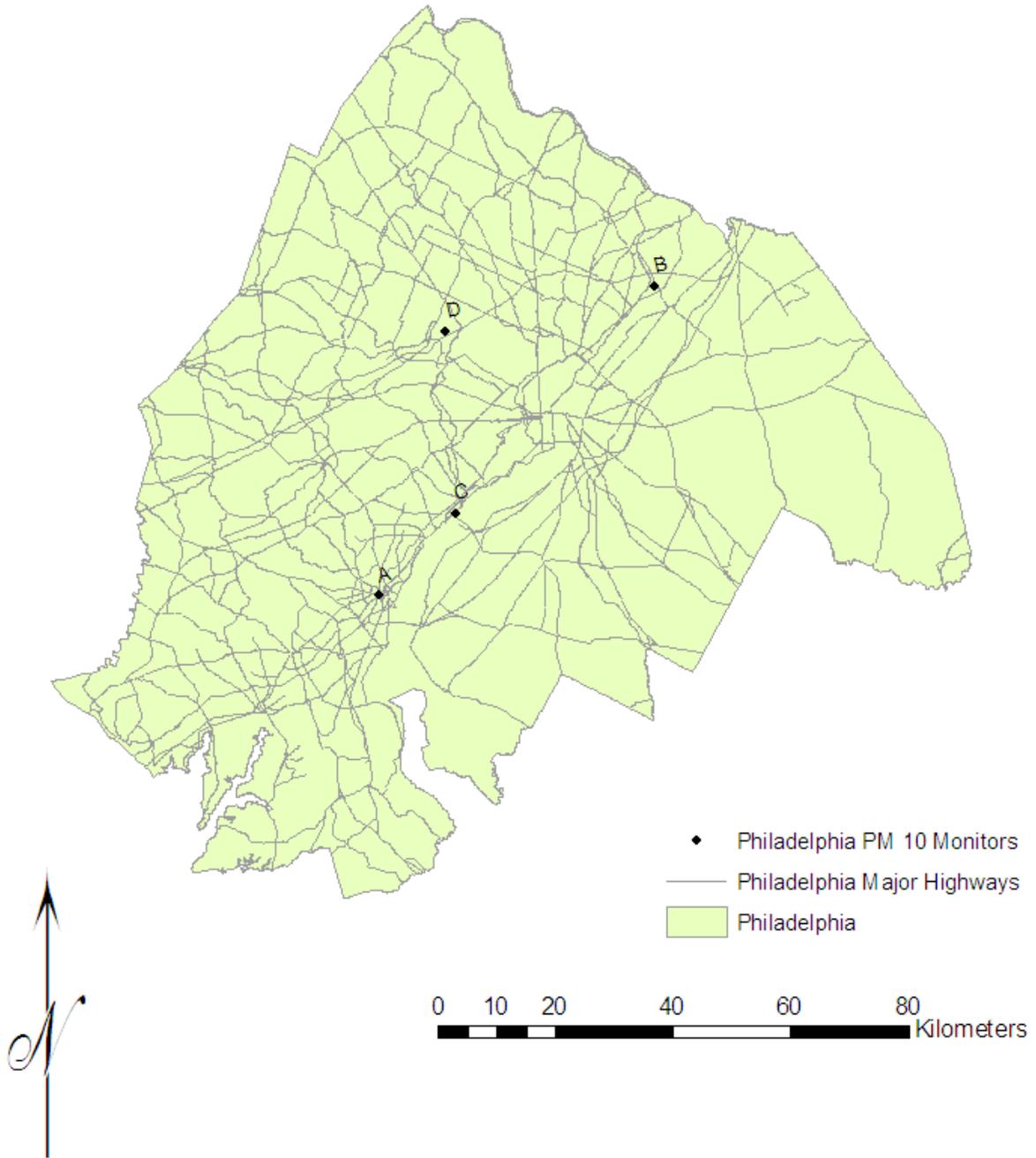
Figure A-64.   Map of PM$_{10}$ FRM distribution with AQS Site IDs for Philadelphia, PA.

AQS Site ID		A	B	C	D
Site A	10-003-2004	Mean	22.8	17.1	19.9	17.6
Site B	42-017-0012	Obs	1059	1040	1059	1049
Site C	42-045-0002	SD	11.7	9.3	9.4	9.8
Site D	42-091-0013					

1=winter
2=spring
3=summer
4=fall
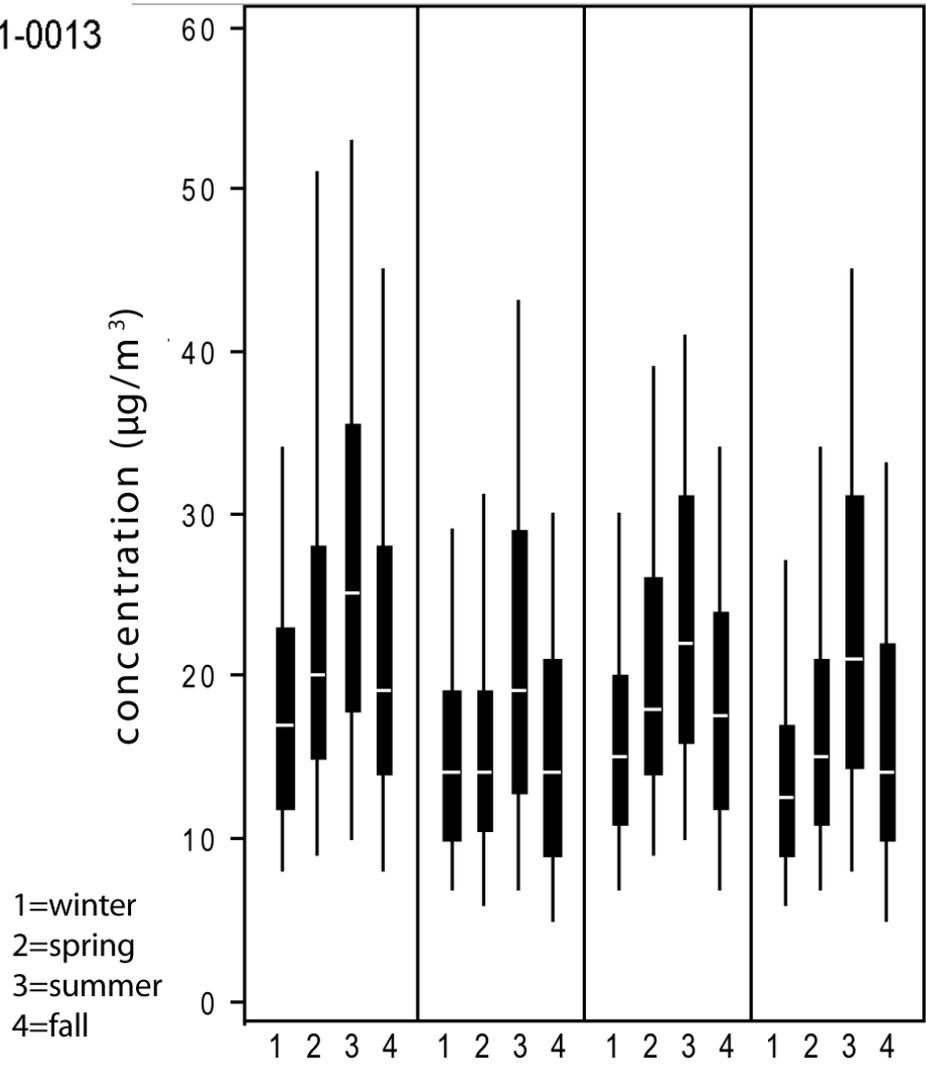
Figure A-65.   Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for Philadelphia, PA.

Table A-27.   Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Philadelphia, PA.

| Site	A	B	C	D
A	1.00	0.81	0.64	0.84
	(0.0, 0.00)	(13.0, 0.21)	(14.0, 0.19)	(12.0, 0.20)
	1059	1005	1025	1013
B		1.00	0.71	0.93
		(0.0, 0.00)	(11.0, 0.20)	(6.0, 0.12)
		1040	1006	994
C			1.00	0.73
			(0.0, 0.00)	(11.0, 0.19)
	R		1059	1014
D	(P90, COD)			1.00
	N			(0.0, 0.00)
				1049
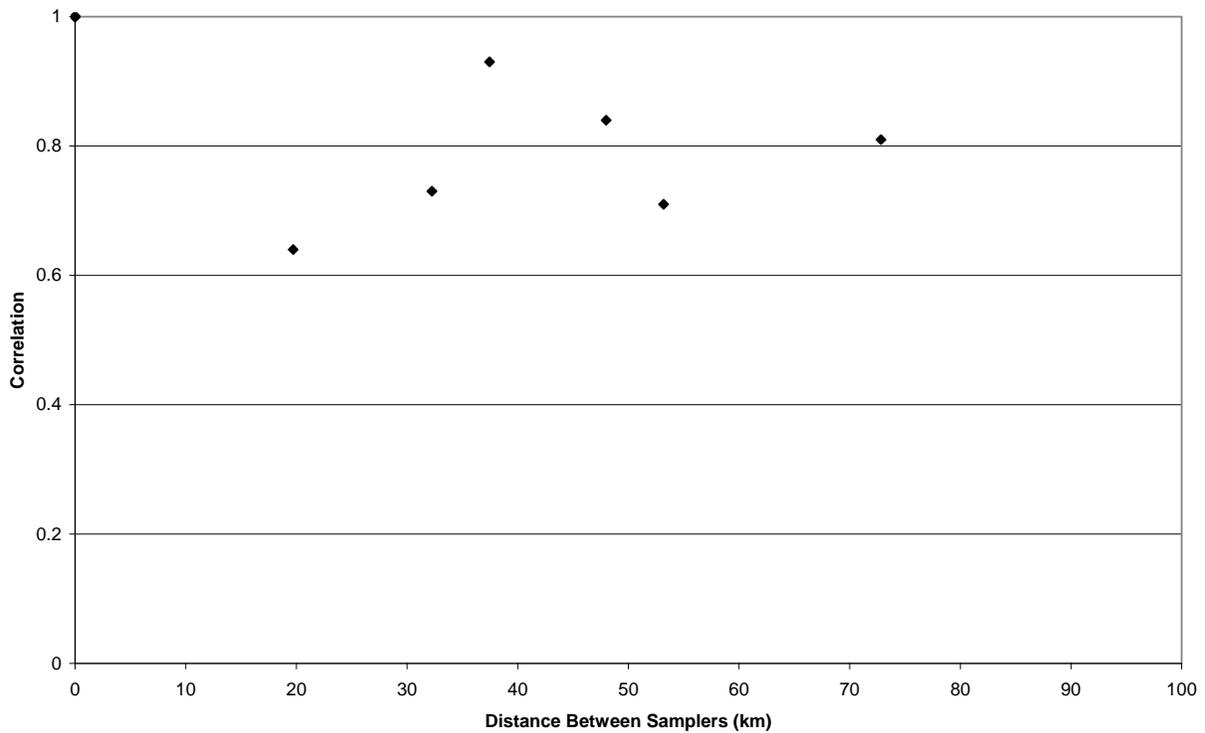
Figure A-66.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Philadelphia, PA.
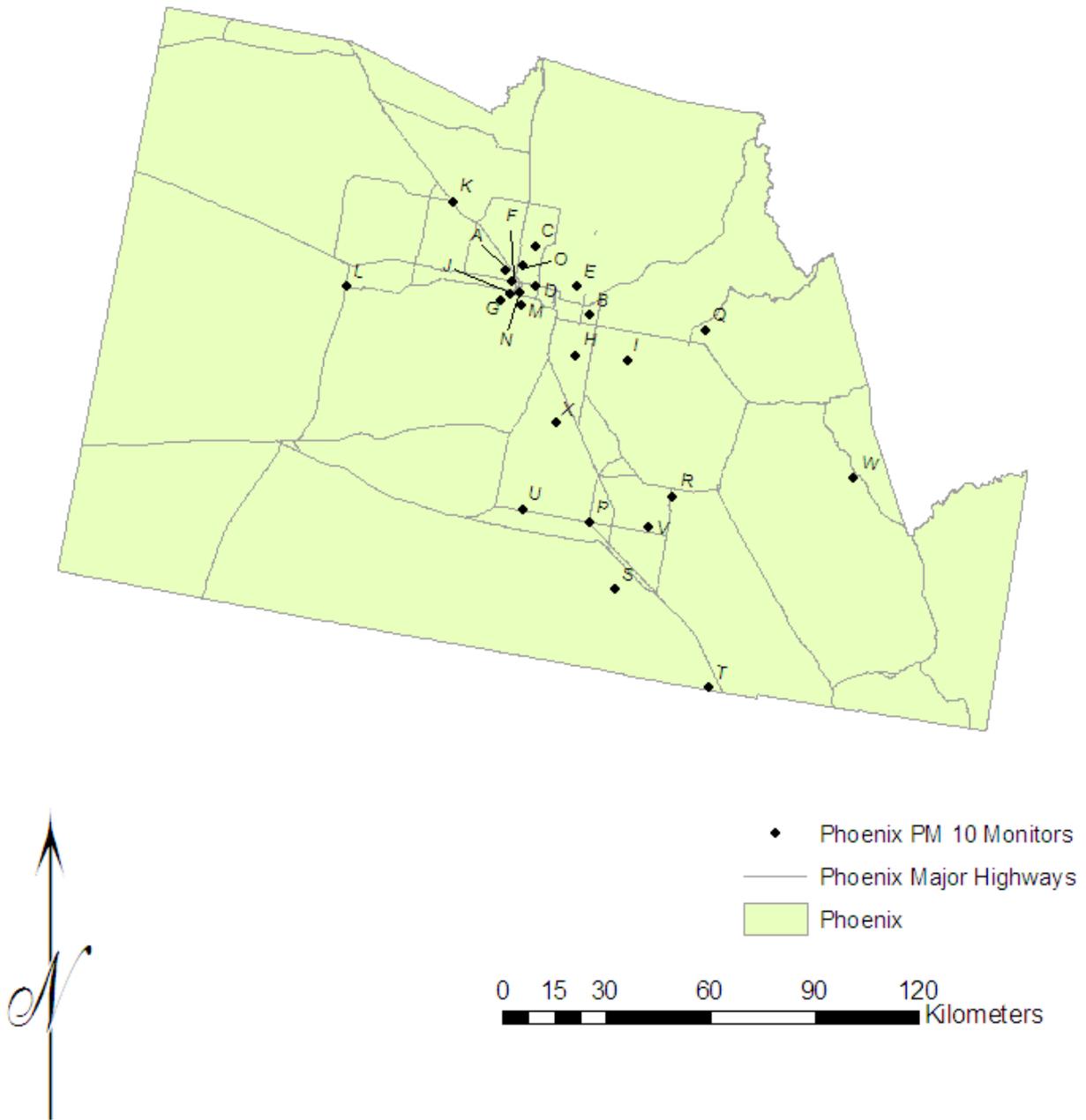
Figure A-67. Map of PM_{10} FRM distribution with AQS Site IDs for Phoenix, AZ.

AQS Site ID		A	B	C	D	E	F	G	H
Site A 04-013-0019	Mean	48.6	30.9	32.6	40.8	32.5	51.5	56.6	34.7
Site B 04-013-1003	Obs	790	179	182	1084	182	780	336	181
Site C 04-013-1004	SD	23.0	14.5	14.6	20.0	15.2	23.1	25.8	17.0
Site D 04-013-3002									
Site E 04-013-3003									
Site F 04-013-3010									
Site G 04-013-4003									
Site H 04-013-4004									

AQS Site ID		I	J	K	L	M	N	O	P
Site I 04-013-4006	Mean	55.6	75.6	32.5	53.0	58.4	65.5	34.3	49.7
Site J 04-013-4009	Obs	1073	1083	178	1090	174	1086	1067	407
Site K 04-013-4010	SD	30.6	39.5	16.1	27.8	30.9	34.9	21.3	54.2
Site L 04-013-4011									
Site M 04-013-8006									
Site N 04-013-9812									
Site O 04-013-9997									
Site P 04-021-0001									

Site Q 04-021-300
Site R 04-021-300
Site S 04-021-300
Site T 04-021-300/
Site U 04-021-3008
Site V 04-021-3011
Site W 04-021-3012
Site X 04-021-7004

	Q	R	S	T	U	V	W	X
Mean	20.8	38.8	13.7	27.0	80.6	74.7	21.5	54.3
Obs	172	171	172	175	476	475	170	322
SD	10.0	21.4	6.8	17.1	72.5	137.5	12.5	38.3

1=winter
2=spring
3=summer
4=fall

Figure A-68.   Box plots illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Phoenix, AZ.

Site	A	B	C	D	E	F	G	H	I	J	K	L	M
A	1.00	0.71	0.85	0.85	0.67	0.94	0.86	0.77	0.73	0.83	0.77	0.70	0.87
	(0.0, 0.00)	(38.0, 0.25)	(33.0, 0.21)	(21.0, 0.12)	(38.0, 0.23)	(14.0, 0.09)	(22.0, 0.13)	(34.0, 0.21)	(35.0, 0.18)	(59.0, 0.24)	(34.0, 0.24)	(30.0, 0.17)	(28.5, 0.16)
	790	178	181	788	181	779	335	180	772	781	177	789	170
B		1.00	0.84	0.82	0.85	0.67	0.74	0.81	0.67	0.68	0.75	0.60	0.63
		(0.0, 0.00)	(13.0, 0.12)	(23.0, 0.19)	(11.0, 0.11)	(37.0, 0.29)	(47.0, 0.30)	(13.0, 0.13)	(49.0, 0.30)	(84.0, 0.43)	(16.0, 0.15)	(51.0, 0.31)	(56.0, 0.32)
		179	179	177	179	175	179	178	175	176	175	178	164
C			1.00	0.88	0.81	0.78	0.80	0.81	0.70	0.73	0.81	0.63	0.75
			(0.0, 0.00)	(20.0, 0.16)	(12.0, 0.11)	(38.0, 0.27)	(44.0, 0.28)	(13.0, 0.13)	(48.0, 0.29)	(84.0, 0.41)	(15.0, 0.14)	(49.0, 0.29)	(55.0, 0.30)
			182	180	182	178	182	181	178	179	178	181	167
D				1.00	0.76	0.88	0.81	0.82	0.76	0.78	0.79	0.65	0.83
				(0.0, 0.00)	(23.0, 0.17)	(22.0, 0.14)	(29.0, 0.16)	(18.0, 0.17)	(39.0, 0.20)	(71.0, 0.31)	(22.0, 0.19)	(35.0, 0.20)	(42.0, 0.21)
				1084	180	778	334	179	1062	1072	176	1080	172
E					1.00	0.64	0.68	0.74	0.66	0.59	0.67	0.51	0.61
					(0.0, 0.00)	(40.0, 0.27)	(47.0, 0.29)	(16.0, 0.14)	(48.0, 0.29)	(88.0, 0.42)	(15.0, 0.15)	(49.0, 0.30)	(58.0, 0.31)
					182	178	182	181	178	179	178	181	167
F						1.00	0.83	0.76	0.75	0.86	0.74	0.69	0.87
						(0.0, 0.00)	(22.0, 0.13)	(36.0, 0.17)	(32.0, 0.17)	(54.0, 0.21)	(41.0, 0.28)	(30.0, 0.17)	(25.0, 0.15)
						780	331	177	762	772	175	779	167
G							1.00	0.77	0.65	0.78	0.71	0.65	0.80
							(0.0, 0.00)	(44.0, 0.26)	(38.0, 0.19)	(48.0, 0.30)	(46.0, 0.30)	(36.0, 0.19)	(33.0, 0.16)
							336	181	326	333	178	335	169
H								1.00	0.79	0.81	0.79	0.69	0.72
								(0.0, 0.00)	(47.0, 0.26)	(79.0, 0.39)	(16.0, 0.14)	(43.0, 0.27)	(53.0, 0.29)
								181	177	178	177	180	167
I			R (P90, COD) N						1.00	0.79	0.76	0.69	0.68
									(0.0, 0.00)	(52.0, 0.22)	(48.0, 0.29)	(33.0, 0.17)	(38.0, 0.20)
									1073	1061	174	1068	171
J										1.00	0.78	0.73	0.80
										(0.0, 0.00)	(83.0, 0.42)	(57.0, 0.23)	(51.0, 0.22)
										1083	175	1078	171
K											1.00	0.72	0.68
											(0.0, 0.00)	(45.0, 0.29)	(56.0, 0.32)
											178	177	164
L												1.00	0.63
												(0.0, 0.00)	(42.0, 0.20)
												1090	173
M													1.00
													(0.0, 0.00)
													174

Table A-28, continued

	N	O	P	Q	R	S	T	U	V	W	X
A	0.87	0.68	0.47	0.53	0.68	0.40	0.69	0.50	0.27	0.56	0.65
	(39.0, 0.18)	(28.0, 0.17)	(29.0, 0.19)	(49.0, 0.42)	(34.0, 0.27)	(64.0, 0.57)	(40.0, 0.34)	(82.0, 0.31)	(49.0, 0.27)	(48.0, 0.43)	(31.0, 0.20)
	784	783	406	171	171	171	174	475	474	169	262
B	0.59	0.75	0.75	0.73	0.63	0.55	0.59	0.53	0.66	0.65	0.64
	(67.0, 0.37)	(15.0, 0.15)	(22.0, 0.17)	(23.0, 0.27)	(30.0, 0.25)	(32.0, 0.43)	(21.0, 0.24)	(94.0, 0.41)	(62.0, 0.34)	(24.0, 0.30)	(46.0, 0.29)
	178	179	175	169	168	169	172	172	177	167	155
C	0.70	0.87	0.80	0.70	0.71	0.48	0.64	0.56	0.71	0.62	0.60
	(69.0, 0.35)	(11.0, 0.12)	(19.0, 0.15)	(24.0, 0.28)	(26.0, 0.24)	(36.0, 0.44)	(22.0, 0.24)	(91.0, 0.40)	(59.0, 0.32)	(28.0, 0.31)	(43.0, 0.28)
	181	182	178	172	171	172	175	175	180	170	157
D	0.78	0.86	0.73	0.63	0.68	0.49	0.65	0.66	0.45	0.58	0.70
	(57.0, 0.25)	(15.0, 0.12)	(30.0, 0.19)	(38.0, 0.38)	(27.0, 0.25)	(46.0, 0.53)	(31.0, 0.31)	(87.0, 0.34)	(59.0, 0.30)	(38.0, 0.39)	(32.0, 0.21)
	1075	1056	405	170	169	170	173	474	473	168	318
E	0.60	0.73	0.68	0.72	0.64	0.43	0.48	0.42	0.69	0.51	0.52
	(67.0, 0.35)	(14.0, 0.14)	(21.0, 0.17)	(21.0, 0.28)	(27.0, 0.24)	(33.0, 0.44)	(21.0, 0.25)	(93.0, 0.41)	(63.0, 0.32)	(25.0, 0.32)	(46.0, 0.28)
	181	182	178	172	171	172	175	175	180	170	157
F	0.91	0.68	0.46	0.48	0.63	0.38	0.63	0.47	0.28	0.42	0.66
	(35.0, 0.14)	(31.0, 0.21)	(30.0, 0.22)	(60.0, 0.46)	(37.0, 0.30)	(68.0, 0.60)	(45.0, 0.39)	(80.0, 0.31)	(50.0, 0.27)	(57.0, 0.47)	(34.0, 0.22)
	774	773	403	169	167	168	172	470	469	166	259
G	0.77	0.57	0.47	0.55	0.65	0.46	0.62	0.49	0.44	0.57	0.64
	(35.0, 0.16)	(41.0, 0.25)	(36.5, 0.24)	(61.0, 0.47)	(41.0, 0.30)	(73.0, 0.61)	(58.0, 0.41)	(78.0, 0.28)	(45.0, 0.24)	(59.0, 0.48)	(32.0, 0.22)
	332	336	330	172	171	172	175	329	334	170	185
H	0.70	0.75	0.82	0.63	0.74	0.55	0.62	0.60	0.76	0.64	0.76
	(66.0, 0.33)	(15.0, 0.14)	(18.0, 0.15)	(29.0, 0.31)	(24.5, 0.22)	(37.0, 0.46)	(24.0, 0.25)	(84.0, 0.38)	(58.0, 0.29)	(30.0, 0.33)	(39.0, 0.25)
	180	181	177	171	170	171	174	174	179	169	156
I	0.76	0.61	0.52	0.57	0.71	0.51	0.58	0.59	0.37	0.51	0.80
	(42.0, 0.18)	(49.0, 0.27)	(39.0, 0.22)	(66.0, 0.47)	(41.0, 0.27)	(77.0, 0.60)	(60.0, 0.40)	(72.0, 0.27)	(46.0, 0.23)	(63.0, 0.47)	(30.0, 0.16)
	1064	1045	397	169	168	168	171	461	461	167	314
J	0.91	0.58	0.41	0.48	0.65	0.48	0.65	0.51	0.28	0.46	0.74
	(29.0, 0.12)	(83.0, 0.38)	(68.0, 0.31)	(103.0, 0.58)	(75.0, 0.40)	(115.0, 0.69)	(92.0, 0.51)	(69.0, 0.26)	(59.0, 0.27)	(101.0, 0.58)	(62.0, 0.27)
	1074	1055	404	169	168	169	172	473	472	167	319
K	0.69	0.71	0.75	0.52	0.64	0.52	0.62	0.71	0.68	0.55	0.68
	(73.0, 0.36)	(16.0, 0.16)	(19.0, 0.18)	(28.0, 0.29)	(27.0, 0.23)	(34.0, 0.44)	(22.0, 0.24)	(89.0, 0.40)	(59.0, 0.33)	(28.0, 0.32)	(44.0, 0.29)
	177	178	174	168	167	168	171	171	176	166	153
L	0.68	0.55	0.51	0.47	0.57	0.48	0.49	0.59	0.33	0.50	0.68
	(48.0, 0.20)	(44.0, 0.26)	(37.0, 0.22)	(66.0, 0.47)	(44.5, 0.29)	(71.0, 0.60)	(62.0, 0.40)	(75.0, 0.27)	(53.0, 0.24)	(67.0, 0.48)	(29.0, 0.18)
	1081	1063	406	171	170	171	174	475	474	169	321
M	0.86	0.81	0.75	0.48	0.64	0.37	0.62	0.46	0.65	0.44	0.59
	(32.0, 0.16)	(53.0, 0.29)	(47.0, 0.30)	(74.0, 0.48)	(51.0, 0.32)	(80.0, 0.61)	(58.5, 0.41)	(62.0, 0.31)	(48.0, 0.26)	(68.0, 0.49)	(42.0, 0.24)
	173	174	165	157	158	158	160	165	168	156	145
N	1.00	0.58	0.41	0.48	0.67	0.42	0.63	0.42	0.26	0.40	0.60
	(0.0, 0.00)	(66.0, 0.32)	(51.0, 0.27)	(88.0, 0.53)	(62.5, 0.35)	(98.0, 0.65)	(75.0, 0.46)	(71.0, 0.29)	(55.0, 0.27)	(88.0, 0.54)	(48.0, 0.24)
	1086	1059	403	171	170	171	174	470	469	169	319
O		1.00	0.90	0.61	0.64	0.39	0.60	0.72	0.59	0.55	0.64
		(0.0, 0.00)	(35.0, 0.22)	(28.0, 0.31)	(25.0, 0.24)	(38.0, 0.47)	(22.0, 0.26)	(94.0, 0.39)	(69.0, 0.35)	(29.0, 0.33)	(44.0, 0.26)
		1067	407	172	171	172	175	475	473	170	317

|	N	O	P	Q	R	S	T	U	V	W	X
P			1.00	0.67	0.81	0.58	0.78	0.82	0.64	0.71	0.67
			(0.0, 0.00)	(32.0, 0.29)	(22.0, 0.19)	(44.0, 0.45)	(21.0, 0.21)	(80.0, 0.30)	(52.0, 0.23)	(32.0, 0.31)	(39.0, 0.24)
			407	169	170	169	172	400	404	167	197
Q				1.00	0.72	0.65	0.57	0.36	0.58	0.68	0.47
				(0.0, 0.00)	(40.0, 0.33)	(15.0, 0.28)	(23.0, 0.24)	(104.0, 0.53)	(78.0, 0.46)	(15.0, 0.22)	(62.0, 0.43)
				172	162	163	167	165	171	161	148
R					1.00	0.66	0.68	0.53	0.82	0.68	0.68
					(0.0, 0.00)	(55.0, 0.48)	(32.0, 0.27)	(75.0, 0.35)	(47.0, 0.25)	(40.0, 0.34)	(39.0, 0.24)
					171	162	165	164	171	160	148
S						1.00	0.60	0.46	0.59	0.72	0.52
						(0.0, 0.00)	(28.0, 0.35)	(115.0, 0.65)	(86.0, 0.59)	(19.0, 0.28)	(74.0, 0.58)
						172	167	165	171	162	149
T							1.00	0.56	0.66	0.68	0.61
							(0.0, 0.00)	(94.0, 0.47)	(71.0, 0.39)	(18.0, 0.24)	(51.5, 0.37)
							175	169	174	165	150
U								1.00	0.54	0.52	0.71
								(0.0, 0.00)	(66.0, 0.24)	(101.0, 0.53)	(61.0, 0.25)
								476	464	165	204
V									1.00	0.60	0.64
									(0.0, 0.00)	(78.0, 0.47)	(35.0, 0.20)
									475	169	206
W										1.00	0.56
										(0.0, 0.00)	(63.0, 0.44)
										170	145
											1.00
											(0.0, 0.00)
											322

Figure A-69. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Phoenix, AZ.
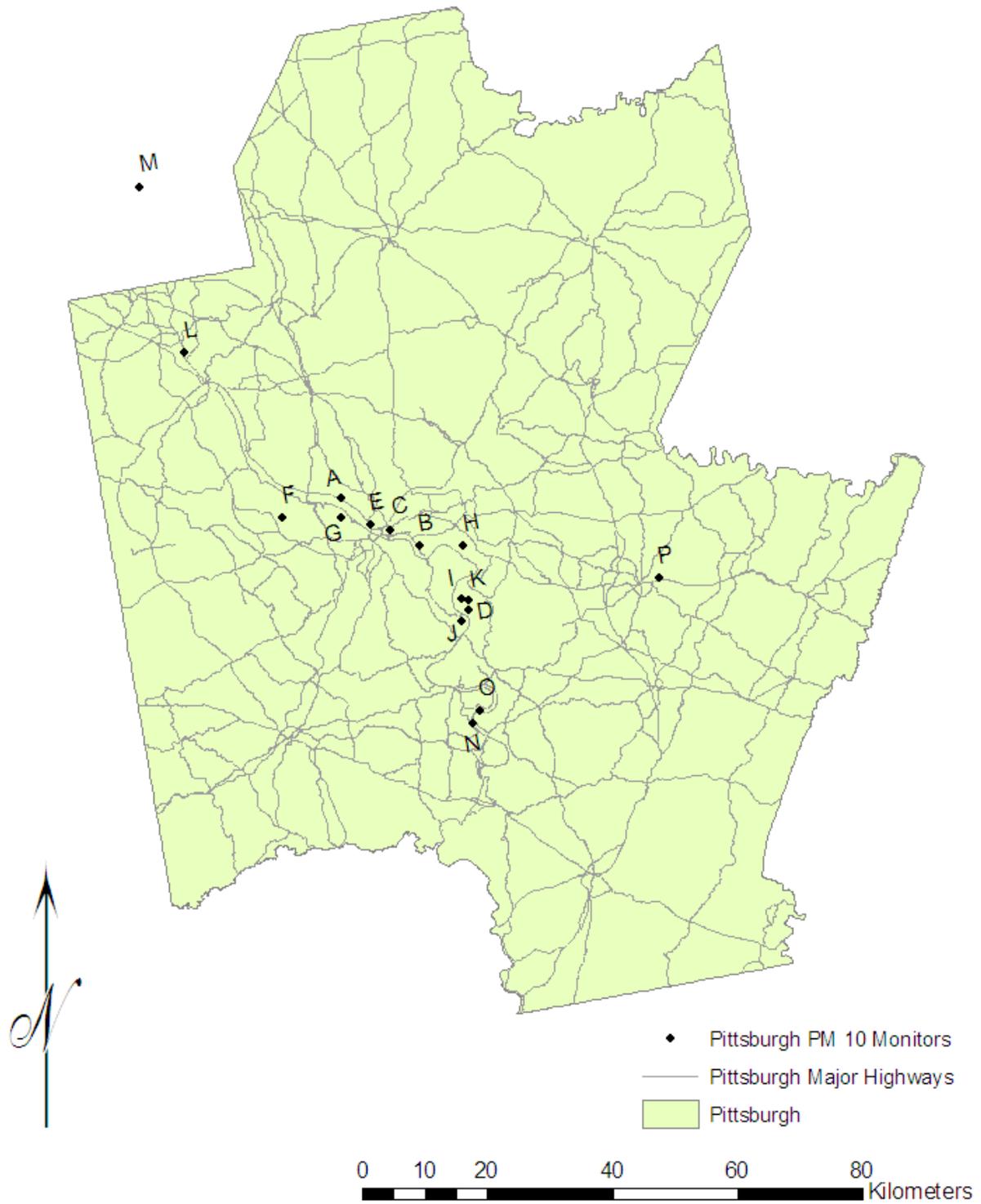
Figure A-70. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Pittsburgh, PA.

AQS Site ID		A	B	C	D	E	F	G	H	I
Site A 42-003-0002	Mean	21.2	18.2	21.8	27.7	23.4	19.6	18.4	29.7	25.2
Site B 42-003-0021	Obs	1077	1019	1083	1087	176	179	978	182	1022
Site C 42-003-0031	SD	12.9	11.4	12.3	20.3	11.1	9.9	11.7	16.8	19.3

Site D 42-003-0064
Site E 42-003-0092
Site F 42-003-0095
Site G 42-003-0116
Site H 42-003-1301
Site I 42-003-3006

1=winter
2=spring
3=summer
4=fall

	J	K	L	M	N	O	P	Q
Mean	20.1	36.5	26.3	26.4	21.7	19.7	27.3	21.1
Obs	177	1061	1051	1069	1092	167	178	1079
SD	10.3	26.7	16.3	15.0	12.4	11.0	12.0	11.4

AQS Site ID

Site I 42-003-3006
Site J 42-003-3007
Site K 42-003-7004
Site L 42-007-0014
Site M 42-073-0015
Site N 42-125-0005
Site O 42-125-5001
Site P 42-129-0007
Site Q 42-129-0008

1=winter
2=spring
3=summer
4=fall

Figure A-71.   Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Pittsburgh, PA.

Table A-29.   Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Pittsburgh, PA.

Site	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
A	1.00	0.93	0.93	0.80	0.92	0.89	0.93	0.79	0.86	0.84	0.76	0.88	0.85	0.86	0.77	0.78	0.86
	(0.0, 0.00)	(9.0, 0.15)	(8.0, 0.14)	(23.0, 0.21)	(8.0, 0.12)	(14.0, 0.18)	(8.0, 0.14)	(16.0, 0.17)	(18.0, 0.18)	(14.0, 0.20)	(40.0, 0.30)	(15.0, 0.18)	(16.0, 0.19)	(11.0, 0.16)	(16.0, 0.22)	(15.0, 0.19)	(11.0, 0.15)
	1077	1002	1065	1070	175	178	960	181	1005	176	1044	1033	1052	1074	166	177	1061
B		1.00	0.96	0.80	0.91	0.92	0.97	0.81	0.89	0.93	0.76	0.88	0.81	0.91	0.76	0.83	0.88
		(0.0, 0.00)	(8.0, 0.15)	(29.0, 0.24)	(11.0, 0.20)	(6.0, 0.16)	(5.0, 0.10)	(25.0, 0.29)	(22.0, 0.20)	(7.0, 0.16)	(43.0, 0.36)	(19.0, 0.23)	(20.0, 0.26)	(10.0, 0.16)	(12.0, 0.19)	(18.0, 0.28)	(10.0, 0.18)
		1019	1007	1012	163	166	911	169	954	164	986	982	994	1016	157	165	1003
C			1.00	0.81	0.94	0.94	0.94	0.77	0.87	0.90	0.75	0.88	0.83	0.89	0.78	0.88	0.90
			(0.0, 0.00)	(23.0, 0.20)	(6.0, 0.11)	(7.0, 0.12)	(8.0, 0.13)	(21.0, 0.22)	(19.0, 0.17)	(8.0, 0.13)	(39.0, 0.30)	(14.0, 0.17)	(15.0, 0.19)	(9.0, 0.12)	(12.0, 0.19)	(13.0, 0.19)	(9.0, 0.12)
			1083	1075	173	176	966	179	1010	174	1049	1039	1057	1080	164	175	1067
D				1.00	0.72	0.66	0.76	0.83	0.88	0.73	0.84	0.80	0.78	0.76	0.57	0.64	0.74
				(0.0, 0.00)	(21.0, 0.20)	(26.0, 0.24)	(27.0, 0.24)	(14.0, 0.18)	(16.0, 0.14)	(24.0, 0.22)	(24.0, 0.22)	(20.0, 0.20)	(20.0, 0.20)	(25.0, 0.20)	(28.0, 0.26)	(20.0, 0.25)	(26.0, 0.21)
				1087	176	179	970	182	1014	177	1055	1043	1061	1084	167	178	1071
E					1.00	0.90	0.90	0.78	0.77	0.86	0.65	0.83	0.80	0.84	0.77	0.84	0.85
					(0.0, 0.00)	(10.0, 0.14)	(10.0, 0.17)	(20.0, 0.20)	(20.0, 0.19)	(10.0, 0.16)	(36.0, 0.29)	(16.0, 0.17)	(14.0, 0.17)	(12.0, 0.14)	(14.0, 0.19)	(13.0, 0.16)	(11.0, 0.15)
					176	173	154	175	166	171	169	169	172	176	161	172	174
F						1.00	0.94	0.70	0.74	0.90	0.57	0.82	0.75	0.86	0.83	0.84	0.86
						(0.0, 0.00)	(7.0, 0.12)	(25.0, 0.27)	(25.0, 0.22)	(7.0, 0.12)	(41.0, 0.34)	(20.0, 0.20)	(19.0, 0.22)	(11.0, 0.14)	(9.0, 0.15)	(16.0, 0.22)	(9.0, 0.14)
						179	157	178	168	174	172	172	175	179	164	175	177
G							1.00	0.70	0.87	0.92	0.73	0.87	0.78	0.89	0.81	0.84	0.86
							(0.0, 0.00)	(22.0, 0.28)	(20.0, 0.19)	(7.0, 0.13)	(45.0, 0.35)	(18.0, 0.21)	(19.0, 0.24)	(9.0, 0.15)	(11.0, 0.17)	(17.0, 0.26)	(10.0, 0.16)
							978	160	910	156	955	938	952	975	146	157	967
H								1.00	0.76	0.74	0.68	0.77	0.78	0.74	0.60	0.65	0.76
								(0.0, 0.00)	(17.0, 0.20)	(23.0, 0.26)	(26.0, 0.22)	(15.0, 0.18)	(17.0, 0.18)	(21.0, 0.22)	(27.0, 0.29)	(19.0, 0.22)	(21.5, 0.24)

Site	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
								182	171	176	175	175	178	182	167	177	180
I									1.00	0.79	0.83	0.82	0.78	0.81	0.66	0.69	0.78
									(0.0, 0.00)	(22.0, 0.20)	(30.0, 0.25)	(16.0, 0.17)	(18.0, 0.20)	(20.0, 0.17)	(26.0, 0.24)	(21.0, 0.25)	(22.0, 0.19)
									1022	166	992	978	998	1019	158	167	1009
J										1.00	0.66	0.79	0.72	0.88	0.78	0.86	0.86
										(0.0, 0.00)	(44.5, 0.33)	(18.0, 0.20)	(18.0, 0.22)	(8.0, 0.13)	(11.0, 0.17)	(16.0, 0.21)	(8.0, 0.15)
										177	170	170	173	177	163	173	175
K											1.00	0.74	0.75	0.70	0.47	0.58	0.68
											(0.0, 0.00)	(31.0, 0.26)	(33.0, 0.24)	(40.0, 0.30)	(44.0, 0.36)	(34.0, 0.30)	(43.0, 0.30)
											1061	1017	1035	1058	160	171	1048
L			R									1.00	0.87	0.85	0.70	0.74	0.80
			(P90, COD)									(0.0, 0.00)	(13.0, 0.16)	(16.0, 0.17)	(22.0, 0.24)	(17.0, 0.21)	(18.0, 0.19)
			N									1051	1025	1048	160	171	1035
M													1.00	0.74	0.64	0.67	0.77
													(0.0, 0.00)	(18.0, 0.21)	(19.0, 0.26)	(17.0, 0.22)	(18.0, 0.19)
													1069	1067	163	174	1053
N														1.00	0.72	0.86	0.86
														(0.0, 0.00)	(13.0, 0.18)	(14.0, 0.20)	(10.0, 0.14)
														1092	167	178	1076
O															1.00	0.75	0.69
															(0.0, 0.00)	(18.0, 0.25)	(14.0, 0.19)
															167	163	165
P																1.00	0.84
																(0.0, 0.00)	(15.0, 0.21)
																178	176
Q																	1.00
																	(0.0, 0.00)
																	1079
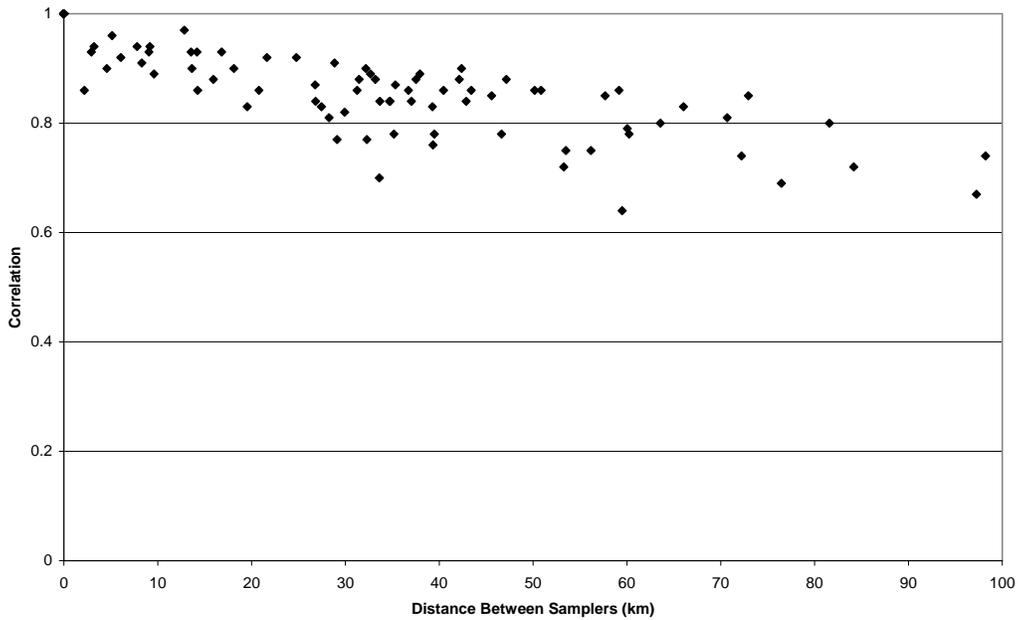
Figure A-72. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Pittsburgh, PA.
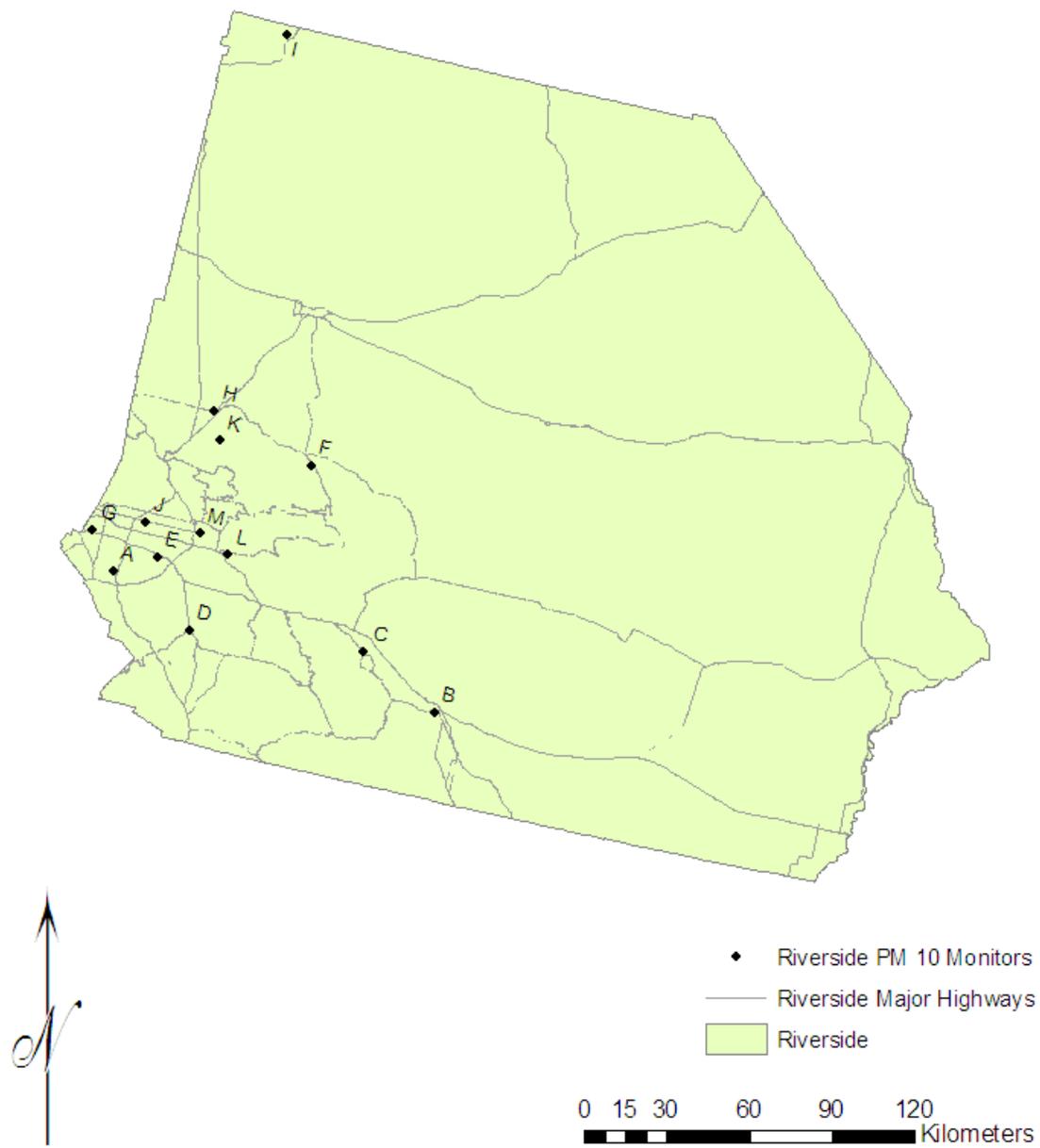
Figure A-73. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Riverside, CA.
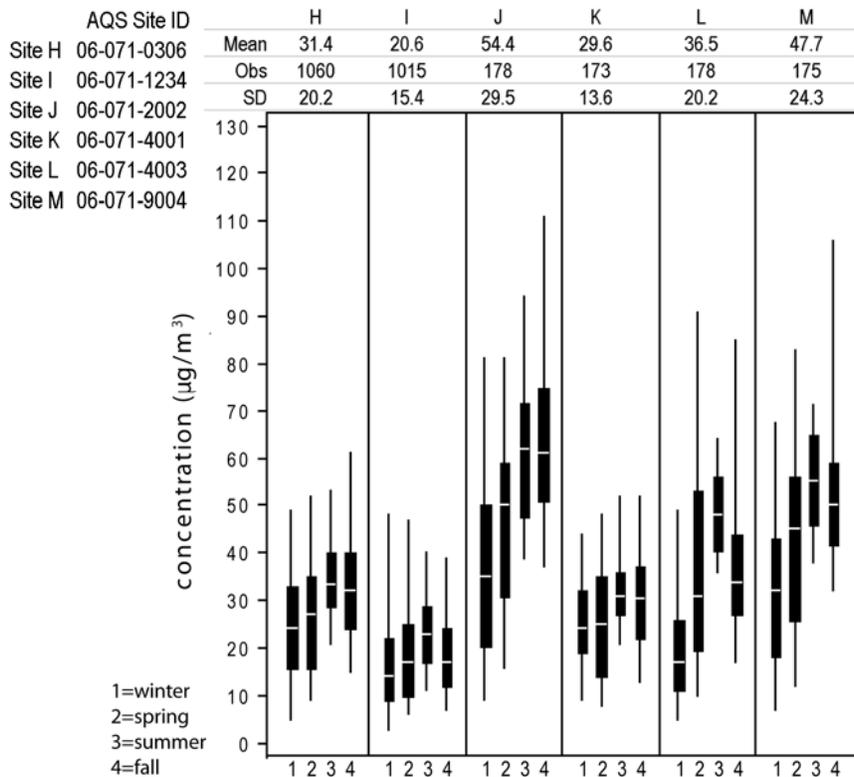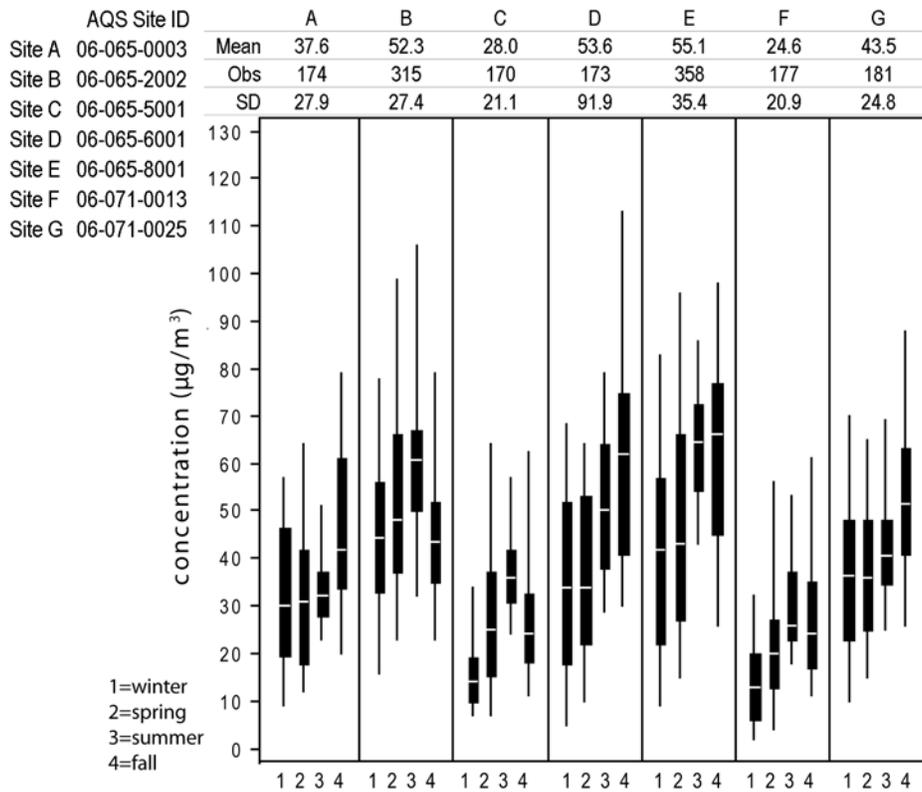
Figure A-74. Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Riverside, CA.

Table A-30. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Riverside, CA.

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	1.00	0.09	0.15	0.90	0.94	0.25	0.94	0.24	0.12	0.83	0.27	0.46	0.78
	(0.0, 0.00)	(50.0, 0.31)	(36.0, 0.32)	(33.0, 0.19)	(37.0, 0.24)	(41.0, 0.38)	(16.0, 0.13)	(25.0, 0.22)	(40.0, 0.39)	(38.5, 0.24)	(30.0, 0.23)	(32.0, 0.25)	(33.0, 0.21)
	174	170	155	165	172	169	171	174	173	160	158	169	164
B		1.00	0.86	0.07	0.13	0.31	0.12	0.32	0.29	0.13	0.31	0.35	0.29
		(0.0, 0.00)	(48.0, 0.37)	(47.0, 0.28)	(45.0, 0.27)	(57.0, 0.47)	(49.0, 0.26)	(48.0, 0.33)	(55.0, 0.49)	(51.0, 0.25)	(49.0, 0.35)	(51.0, 0.31)	(44.0, 0.24)
		315	161	167	298	173	176	309	302	172	163	173	168
C			1.00	0.13	0.21	0.36	0.20	0.34	0.36	0.23	0.38	0.50	0.40
			(0.0, 0.00)	(49.0, 0.37)	(58.0, 0.42)	(24.0, 0.31)	(40.0, 0.35)	(27.0, 0.28)	(24.0, 0.30)	(57.5, 0.41)	(24.0, 0.27)	(30.0, 0.25)	(41.0, 0.34)
			170	151	162	156	160	170	168	150	147	159	154
D				1.00	0.93	0.19	0.83	0.11	0.05	0.73	0.13	0.38	0.69
				(0.0, 0.00)	(29.0, 0.17)	(52.0, 0.43)	(23.0, 0.17)	(38.0, 0.27)	(52.0, 0.46)	(26.0, 0.18)	(43.0, 0.30)	(40.0, 0.26)	(24.5, 0.16)
				173	169	167	168	173	172	157	155	165	160
E					1.00	0.23	0.93	0.26	0.16	0.86	0.27	0.57	0.82
					(0.0, 0.00)	(63.0, 0.48)	(27.0, 0.17)	(46.0, 0.33)	(63.5, 0.51)	(18.0, 0.13)	(54.0, 0.36)	(40.0, 0.28)	(26.0, 0.15)
					358	174	179	351	340	175	165	175	171
F						1.00	0.27	0.73	0.32	0.35	0.43	0.44	0.48
						(0.0, 0.00)	(44.0, 0.41)	(28.0, 0.33)	(27.0, 0.32)	(57.0, 0.46)	(24.5, 0.32)	(35.0, 0.35)	(46.0, 0.43)
						177	173	177	176	162	160	170	164
G							1.00	0.27	0.20	0.90	0.35	0.58	0.85
							(0.0, 0.00)	(30.0, 0.25)	(46.5, 0.45)	(25.0, 0.16)	(34.0, 0.27)	(29.0, 0.24)	(24.0, 0.15)
							181	181	180	165	163	174	168
H								1.00	0.26	0.47	0.48	0.40	0.44
								(0.0, 0.00)	(27.0, 0.33)	(45.0, 0.32)	(18.0, 0.18)	(29.0, 0.25)	(34.0, 0.26)
								1060	983	178	172	178	175
I									1.00	0.20	0.45	0.38	0.35
									(0.0, 0.00)	(62.0, 0.51)	(25.0, 0.32)	(41.0, 0.39)	(48.0, 0.46)
									1015	177	172	177	173
J		R								1.00	0.42	0.70	0.85
		(P90, COD)								(0.0, 0.00)	(49.0, 0.35)	(37.0, 0.27)	(20.0, 0.15)
		N								178	155	163	157
K											1.00	0.49	0.48
											(0.0, 0.00)	(30.0, 0.26)	(38.0, 0.29)
											173	162	157
L												1.00	0.84
												(0.0, 0.00)	(24.0, 0.20)
												178	167
M													1.00
													(0.0, 0.00)
													175

Figure A-75.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Riverside, CA.

Figure A-76. Map of PM$_{10}$ FRM distribution with AQS Site IDs for Seattle, WA.
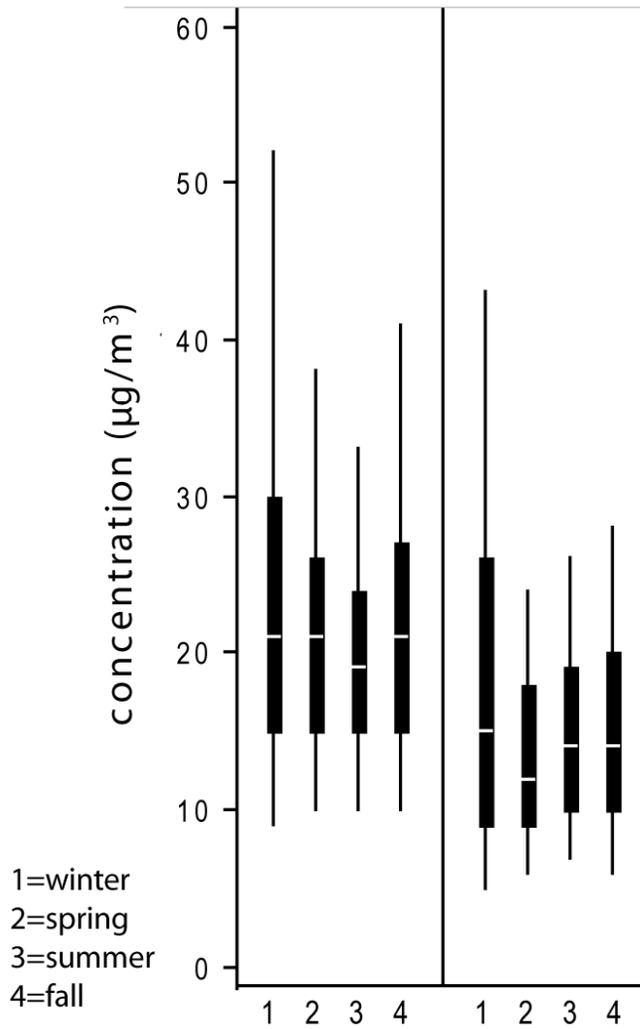
Figure A-77. Box plot illustrating the seasonal distribution of 24-h average PM$_{10}$ concentrations for Seattle, WA.

Table A-31. Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for Seattle, WA.

	A	B
A	1.00	0.77
	(0.0, 0.00)	(14.0, 0.24)
	1059	1041
B		1.00
R		(0.0, 0.00)
(P90, COD)		1077
N		
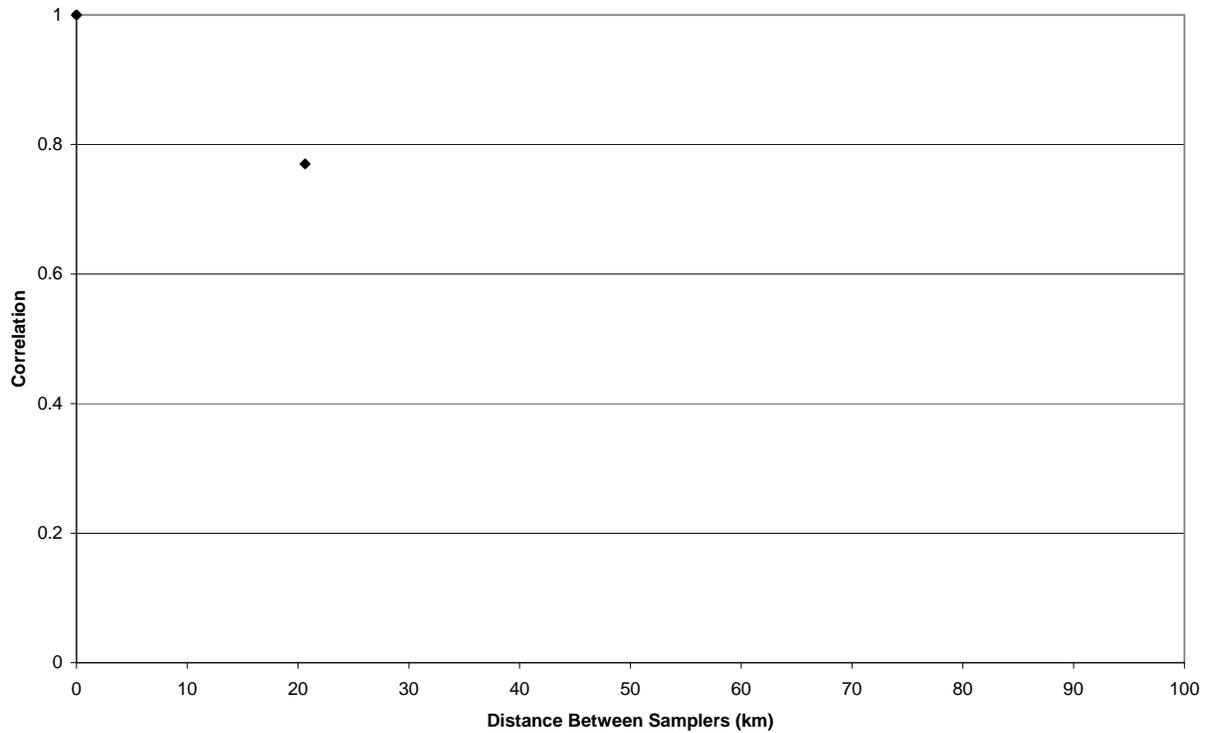
Figure A-78. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Seattle, WA.
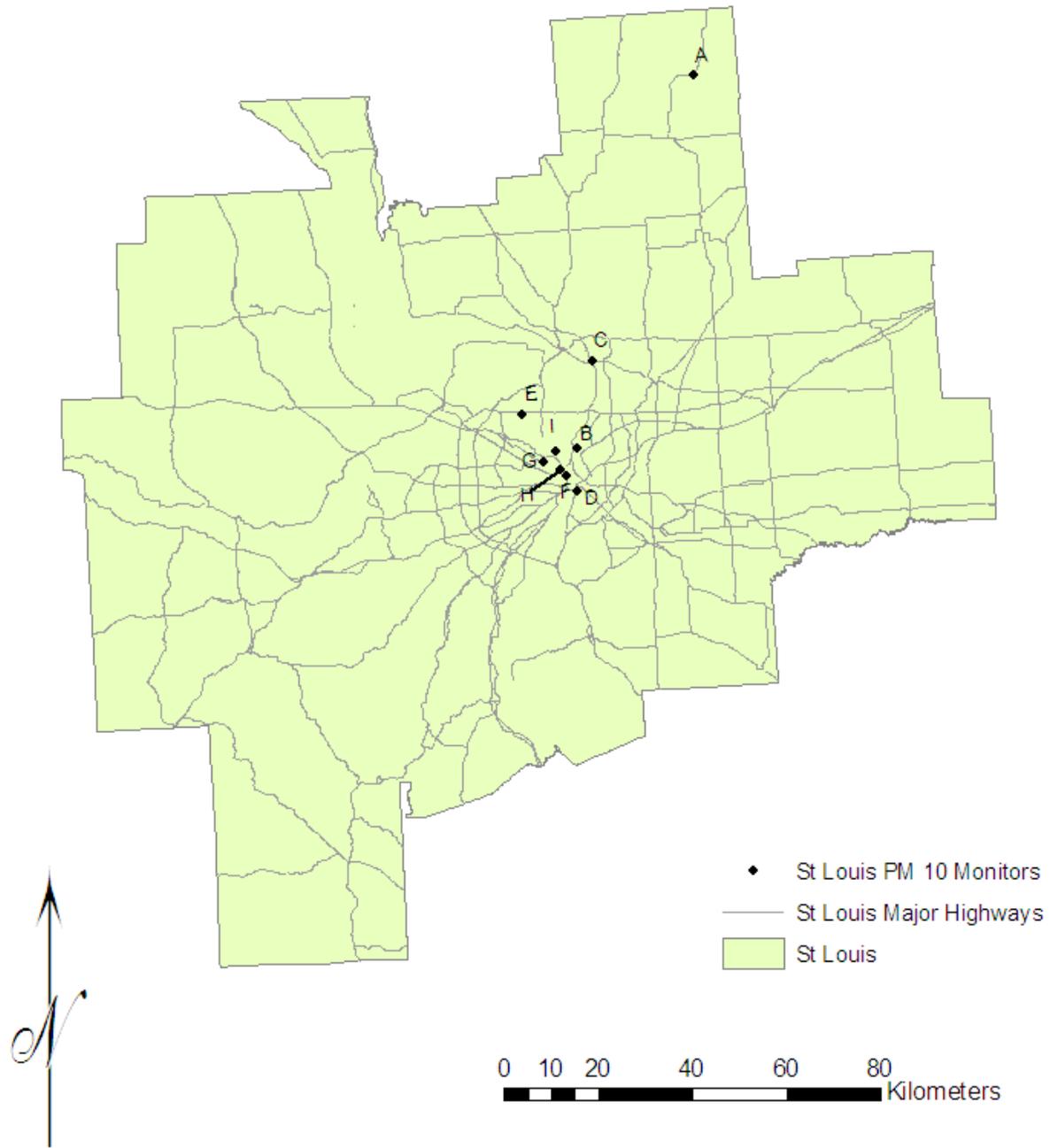
Figure A-79.   Map of PM$_{10}$ FRM distribution with AQS Site IDs for St. Louis, MO.

AQS Site ID		A	B	C	D	E	F	G	H	I
Site A 17-117-0002	Mean	22.8	35.4	28.3	34.0	20.5	28.2	22.7	29.5	40.3
Site B 17-119-0010	Obs	171	173	174	176	185	176	179	180	1050
Site C 17-119-3007	SD	9.4	15.5	12.2	14.7	14.4	11.7	10.4	12.8	28.5

Site D 17-163-0010
Site E 29-189-5001
Site F 29-510-0085
Site G 29-510-0086
Site H 29-510-0087
Site I 29-510-0088

1=winter
2=spring
3=summer
4=fall
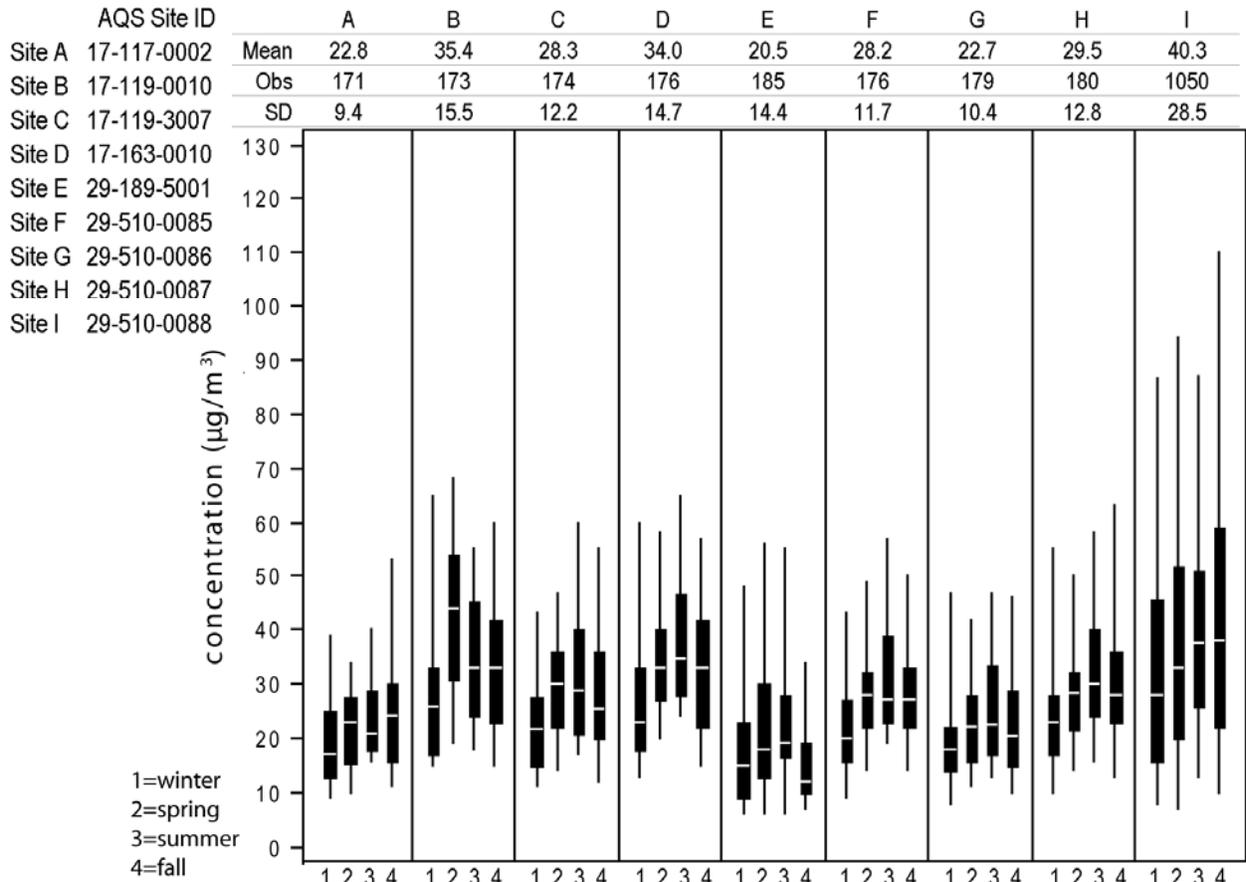
Figure A-80. Box plot illustrating the seasonal distribution of 24-h average PM_{10} concentrations for St. Louis, MO.

Table A-32.   Inter-sampler correlation statistics for each pair of PM$_{10}$ AQS data for St. Louis, MO.

	A	B	C	D	E	F	G	H	I
A	1.00	0.50	0.75	0.67	0.47	0.65	0.67	0.73	0.55
	(0.0, 0.00)	(30.0, 0.28)	(14.0, 0.17)	(23.0, 0.24)	(16.0, 0.29)	(16.0, 0.18)	(13.0, 0.17)	(18.0, 0.19)	(52.0, 0.33)
	171	161	158	156	158	163	166	168	164
B		1.00	0.65	0.63	0.46	0.68	0.68	0.64	0.52
		(0.0, 0.00)	(20.0, 0.21)	(20.0, 0.19)	(37.0, 0.42)	(23.0, 0.20)	(28.0, 0.28)	(22.0, 0.20)	(36.0, 0.28)
		173	161	158	160	167	169	170	166
C			1.00	0.75	0.57	0.80	0.76	0.82	0.65
			(0.0, 0.00)	(17.0, 0.17)	(23.0, 0.33)	(12.0, 0.13)	(13.0, 0.18)	(12.0, 0.13)	(41.0, 0.27)
			174	157	158	165	169	169	168
D				1.00	0.44	0.82	0.81	0.80	0.59
				(0.0, 0.00)	(30.0, 0.40)	(16.0, 0.15)	(21.0, 0.24)	(14.0, 0.15)	(36.0, 0.27)
				176	157	163	165	166	169
E					1.00	0.53	0.62	0.56	0.34
					(0.0, 0.00)	(22.0, 0.34)	(17.0, 0.26)	(25.0, 0.35)	(55.0, 0.42)
					185	164	166	167	179
F						1.00	0.89	0.86	0.67
						(0.0, 0.00)	(11.0, 0.16)	(12.0, 0.11)	(41.0, 0.27)
		R					176	173	174	169
G		(P90, COD)					1.00	0.83	0.65
		N					(0.0, 0.00)	(16.0, 0.19)	(47.0, 0.32)
							179	177	173
H								1.00	0.64
								(0.0, 0.00)	(41.0, 0.27)
								180	173
I									1.00
									(0.0, 0.00)
									1050
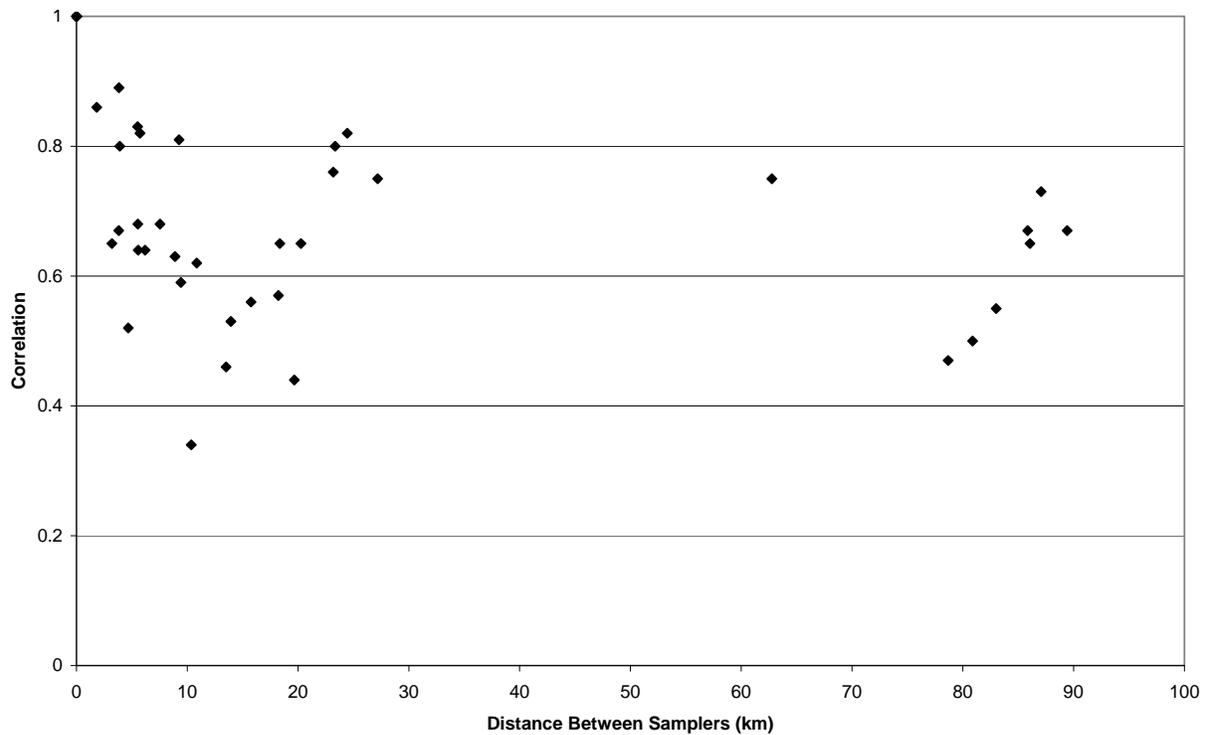
Figure A-81.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for St. Louis, MO.
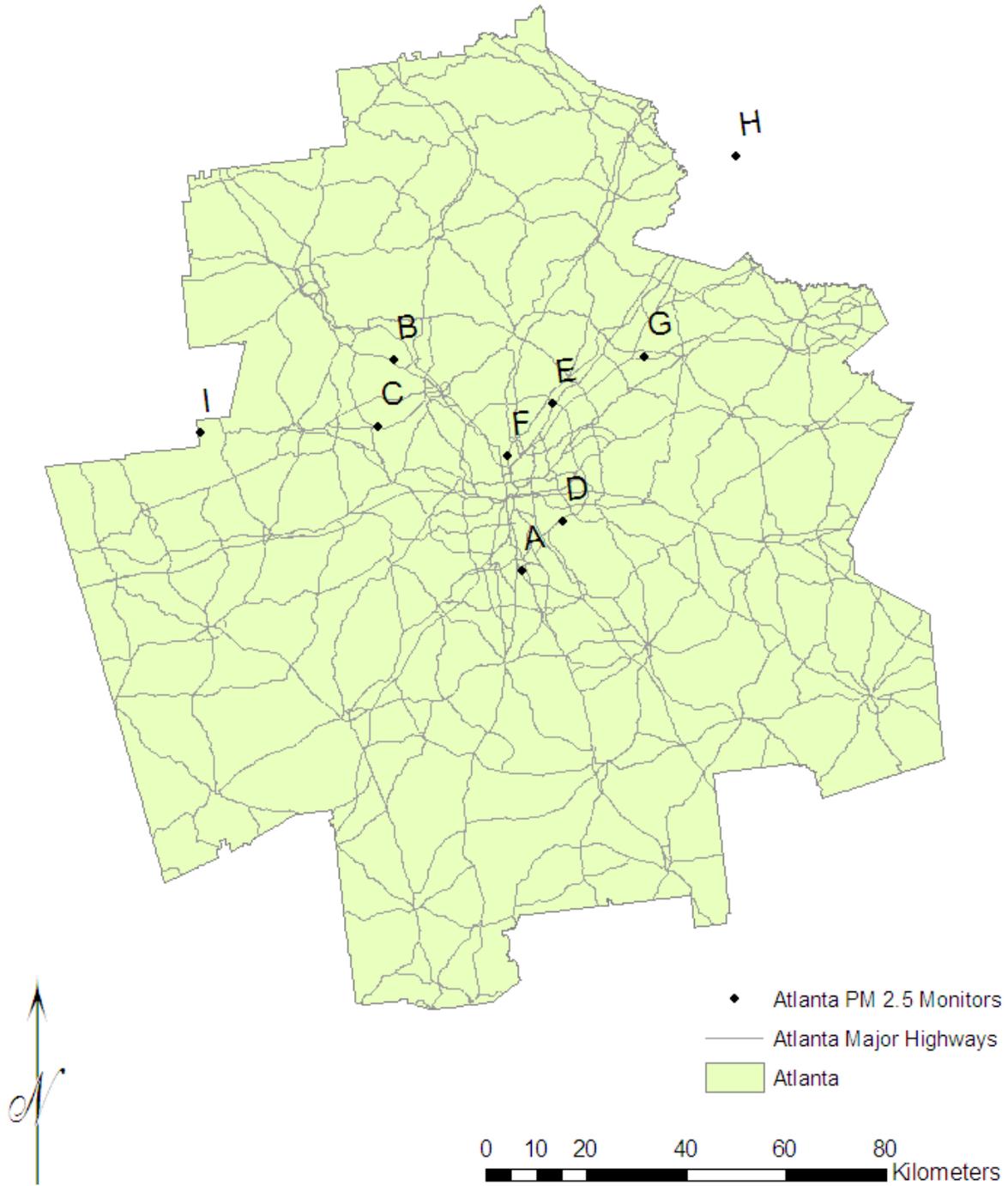
**Figure A-82.** Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Atlanta, GA.
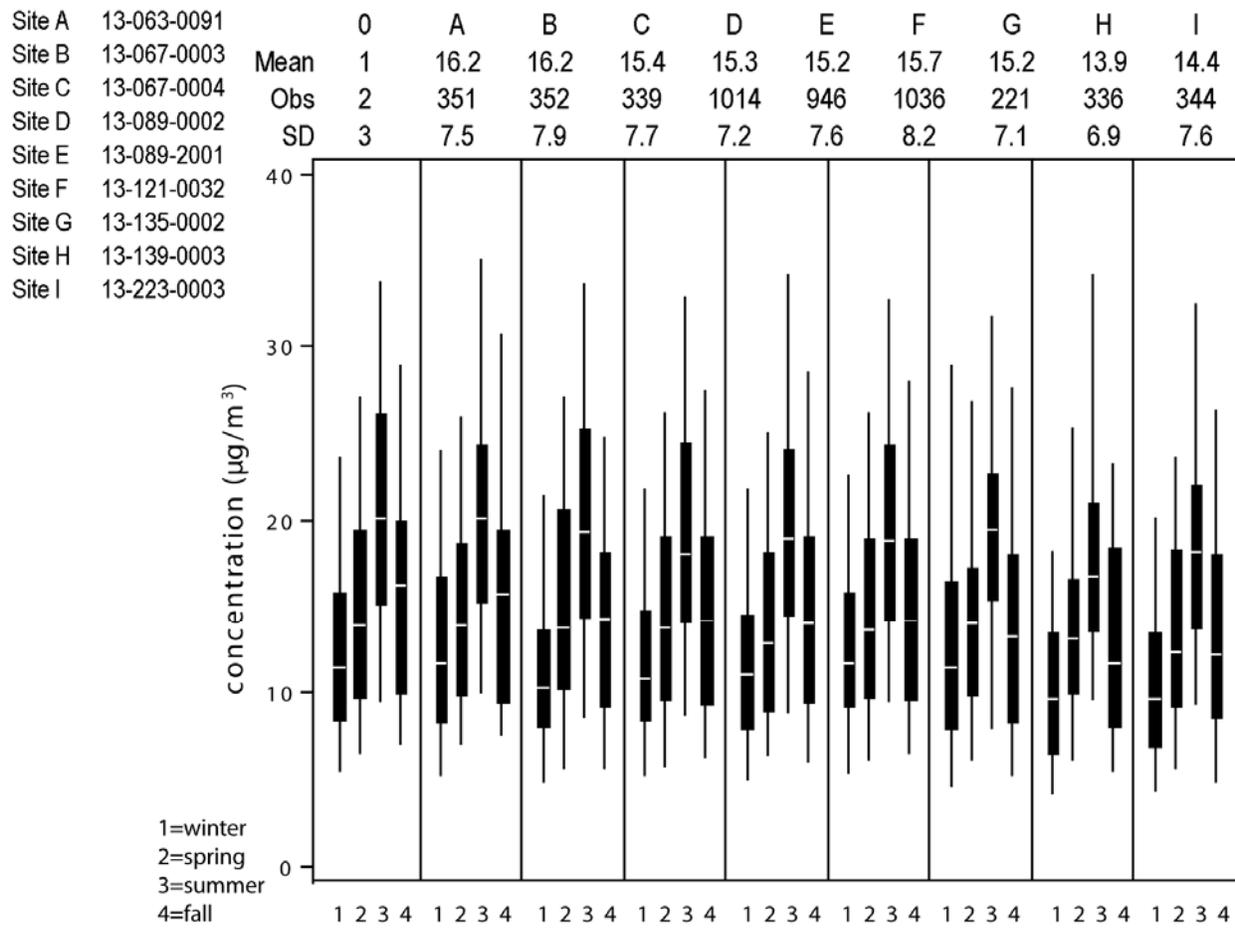
Figure A-83. Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Atlanta, GA.

Table A-33. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Atlanta, GA.

	A	B	C	D	E	F	G	H	I
A	1.00	0.88	0.87	0.93	0.89	0.91	0.85	0.72	0.85
	(0.0, 0.00)	(5.2, 0.11)	(6.2, 0.12)	(3.9, 0.11)	(5.3, 0.12)	(4.6, 0.11)	(6.9, 0.15)	(8.7, 0.19)	(7.2, 0.15)
	351	330	310	330	315	334	207	319	326
B		1.00	0.96	0.89	0.88	0.91	0.88	0.78	0.88
		(0.0, 0.00)	(4.1, 0.08)	(5.7, 0.12)	(4.6, 0.10)	(3.6, 0.08)	(5.6, 0.13)	(9.0, 0.17)	(6.5, 0.13)
		352	309	327	314	333	205	313	321
C			1.00	0.87	0.86	0.88	0.85	0.79	0.90
			(0.0, 0.00)	(5.2, 0.12)	(5.6, 0.11)	(4.4, 0.10)	(5.8, 0.13)	(7.9, 0.17)	(4.5, 0.11)
			339	315	304	324	193	298	303
D			CT	1.00	0.89	0.80	0.87	0.74	0.82
				(0.0, 0.00)	(4.8, 0.12)	(3.7, 0.11)	(5.8, 0.13)	(8.3, 0.18)	(7.3, 0.15)
				1014	883	978	208	314	322
E					1.00	0.79	0.88	0.74	0.83
					(0.0, 0.00)	(3.8, 0.11)	(5.3, 0.12)	(7.8, 0.17)	(6.4, 0.14)
					946	904	208	305	309
F		R				1.00	0.88	0.70	0.84
		(P90, COD)				(0.0, 0.00)	(5.3, 0.12)	(8.5, 0.19)	(6.3, 0.14)
		N				1036	213	321	327
G							1.00	0.73	0.79
							(0.0, 0.00)	(8.8, 0.17)	(7.4, 0.15)
							221	195	198
H								1.00	0.76
								(0.0, 0.00)	(8.7, 0.17)
								336	309
I									1.00
									(0.0, 0.00)
									344

Figure A-84. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Atlanta, GA.
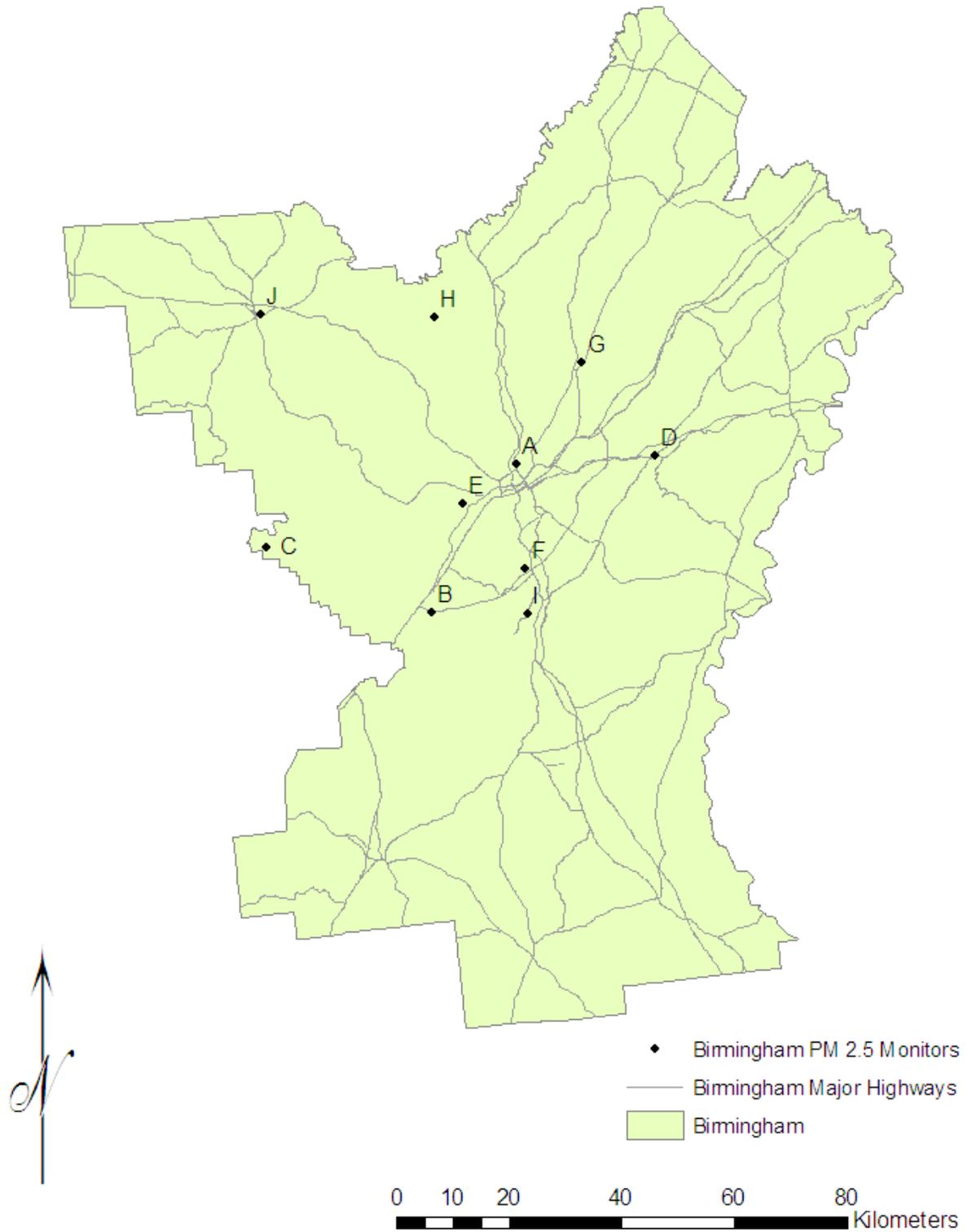
Figure A-85. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Birmingham, AL.

AQS Site ID		A	B	C	D	E	8.2	G	H	I	J
Site A	01-073-0023										
Site B	01-073-1005	Mean	18.9	15.9	14.1	16.2	17.7	15.4	14.8	14.9	14.6	14.4
Site C	01-073-1009	Obs	1087	363	359	182	1079	364	363	360	361	351
Site D	01-073-1010	SD	10.2	363	8.2	8.1	9.4	7.8	7.9	8.3	7.6	7.5
Site E	01-073-2003											
Site F	01-073-2006											
Site G	01-073-5002											
Site H	01-073-5003											
Site I	01-117-0006											
Site J	01-127-0002											

1=winter
2=spring
3=summer
4=fall
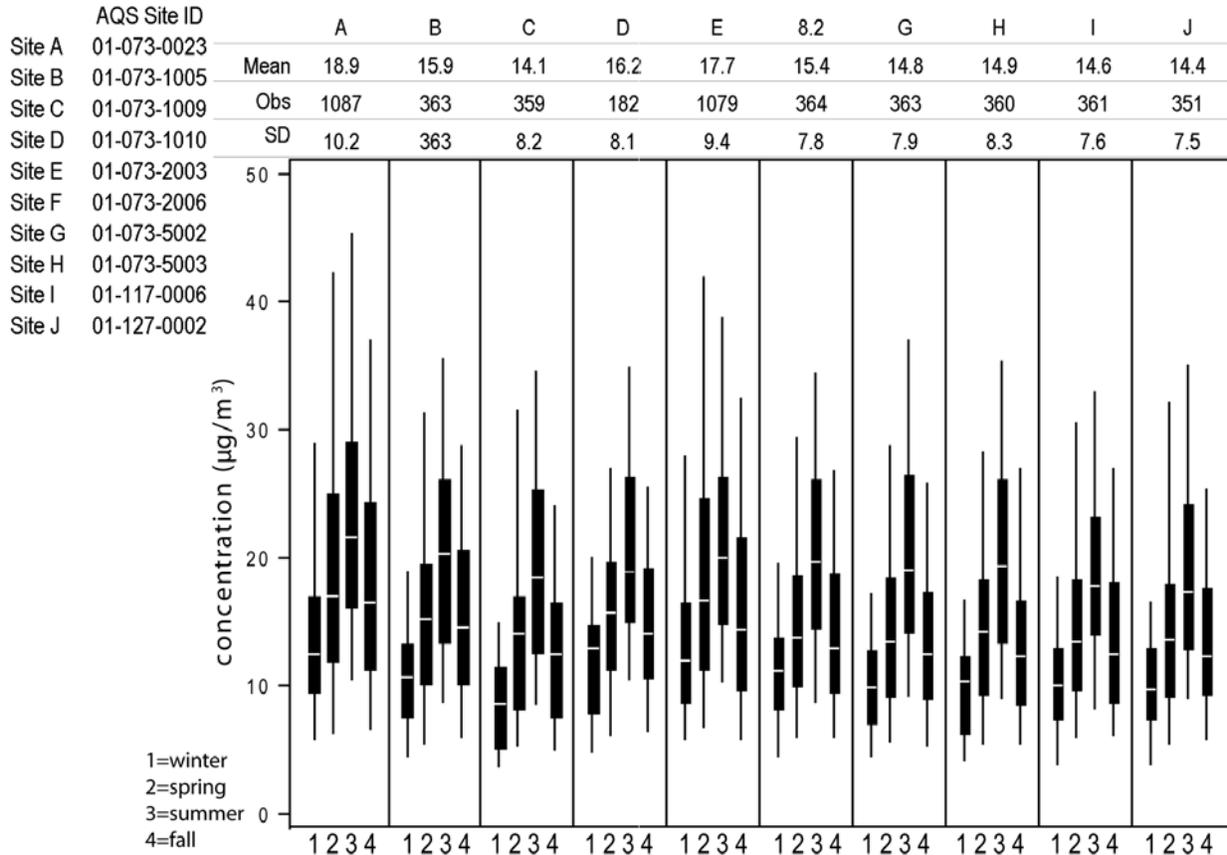
Figure A-86. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Birmingham, AL.

Table A-34. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Birmingham, AL.

	A	B	C	D	E	F	G	H	I	J
A	1.00	0.91	0.86	0.91	0.88	0.91	0.87	0.88	0.88	0.84
	(0.0, 0.00)	(10.4, 0.15)	(13.7, 0.21)	(9.7, 0.13)	(8.1, 0.13)	(10.8, 0.15)	(12.6, 0.18)	(11.7, 0.18)	(12.3, 0.18)	(12.5, 0.19)
	1087	360	356	182	1072	361	360	357	358	348
B		1.00	0.93	0.93	0.85	0.96	0.91	0.93	0.93	0.89
		(0.0, 0.00)	(5.3, 0.12)	(4.7, 0.09)	(8.3, 0.15)	(3.6, 0.08)	(5.4, 0.11)	(5.1, 0.11)	(4.9, 0.10)	(6.1, 0.12)
		363	356	181	359	358	360	355	358	348
C			1.00	0.93	0.81	0.93	0.91	0.94	0.90	0.90
			(0.0, 0.00)	(5.9, 0.13)	(10.1, 0.20)	(4.6, 0.12)	(4.3, 0.12)	(4.0, 0.10)	(4.9, 0.12)	(4.9, 0.11)
			359	180	355	354	355	350	353	343
D				1.00	0.88	0.96	0.95	0.95	0.93	0.89
				(0.0, 0.00)	(7.9, 0.12)	(3.6, 0.08)	(3.8, 0.09)	(4.7, 0.10)	(4.7, 0.10)	(6.1, 0.12)
				182	179	179	181	179	180	174
E					1.00	0.87	0.85	0.85	0.86	0.81
					(0.0, 0.00)	(8.1, 0.15)	(8.7, 0.16)	(8.8, 0.17)	(9.2, 0.16)	(10.6, 0.18)
					1079	360	359	356	357	347
F		R				1.00	0.95	0.95	0.95	0.90
		(P90, COD)				(0.0, 0.00)	(3.9, 0.09)	(4.1, 0.10)	(3.4, 0.09)	(5.6, 0.11)
		N				364	359	354	357	348
G							1.00	0.96	0.92	0.89
							(0.0, 0.00)	(3.3, 0.08)	(4.5, 0.10)	(4.9, 0.11)
							363	356	359	350
H								1.00	0.91	0.93
								(0.0, 0.00)	(5.0, 0.11)	(4.3, 0.09)
								360	354	344
I									1.00	0.87
									(0.0, 0.00)	(5.8, 0.12)
									361	349
J										1.00
										(0.0, 0.00)
										351

Figure A-87. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Birmingham, AL.

**Figure A-88.** Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Boston, MA.

Figure A-89. Box plot illustrating the seasonal distribution of 24-h average PM₂.₅ concentrations for Boston, MA.

Table A-35. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Boston, MA.

|	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A	1.00	0.80	0.77	0.71	0.84	0.79	0.78	0.79	0.79	0.77	0.77	0.61	0.71	0.68	0.73	0.87	0.81	0.85	0.86
	(0.0, 0.00)	(6.6, 0.21)	(6.2, 0.22)	(6.9, 0.23)	(4.8, 0.19)	(8.1, 0.23)	(7.7, 0.24)	(6.8, 0.22)	(7.9, 0.25)	(7.5, 0.24)	(8.1, 0.23)	(8.3, 0.29)	(8.0, 0.23)	(7.9, 0.23)	(7.0, 0.22)	(5.3, 0.18)	(7.2, 0.23)	(5.6, 0.20)	(5.2, 0.18)
	341	326	318	323	329	318	319	325	338	310	320	173	324	334	331	326	292	285	306
B		1.00	0.92	0.87	0.87	0.90	0.90	0.90	0.90	0.85	0.86	0.80	0.87	0.83	0.88	0.86	0.80	0.85	0.85
		(0.0, 0.00)	(4.1, 0.17)	(4.1, 0.18)	(4.7, 0.19)	(6.3, 0.21)	(6.2, 0.23)	(4.9, 0.19)	(7.1, 0.26)	(5.5, 0.21)	(6.6, 0.21)	(6.2, 0.23)	(5.3, 0.19)	(6.0, 0.21)	(4.7, 0.18)	(5.6, 0.17)	(7.9, 0.26)	(5.7, 0.21)	(6.0, 0.19)
		350	328	331	339	326	323	333	343	317	329	175	331	341	336	335	300	288	314
C			1.00	0.90	0.85	0.90	0.89	0.90	0.88	0.86	0.86	0.89	0.93	0.90	0.93	0.83	0.79	0.81	0.82
			(0.0, 0.00)	(3.5, 0.17)	(5.3, 0.21)	(6.3, 0.23)	(6.3, 0.24)	(5.0, 0.20)	(6.8, 0.26)	(6.2, 0.21)	(6.9, 0.21)	(4.8, 0.23)	(4.4, 0.17)	(4.6, 0.19)	(3.8, 0.18)	(5.9, 0.21)	(7.8, 0.26)	(6.2, 0.23)	(6.0, 0.21)
			342	321	331	316	318	326	336	311	321	173	323	335	328	329	290	281	309
D				1.00	0.80	0.88	0.88	0.86	0.86	0.87	0.88	0.79	0.91	0.85	0.86	0.80	0.75	0.79	0.80
				(0.0, 0.00)	(5.6, 0.20)	(5.8, 0.21)	(5.8, 0.22)	(4.6, 0.19)	(7.0, 0.26)	(5.8, 0.19)	(6.4, 0.19)	(5.7, 0.25)	(3.5, 0.18)	(4.7, 0.19)	(4.2, 0.18)	(6.2, 0.20)	(7.8, 0.25)	(6.2, 0.21)	(5.8, 0.20)
				355	336	324	329	332	345	313	325	174	329	339	334	342	300	287	321
E					1.00	0.90	0.90	0.89	0.87	0.87	0.87	0.72	0.83	0.79	0.84	0.91	0.86	0.88	0.91
					(0.0, 0.00)	(5.9, 0.19)	(5.8, 0.21)	(5.0, 0.19)	(6.9, 0.24)	(5.4, 0.20)	(6.3, 0.20)	(8.3, 0.27)	(5.8, 0.17)	(6.3, 0.20)	(4.8, 0.18)	(4.5, 0.17)	(6.3, 0.22)	(4.9, 0.18)	(3.9, 0.17)
					357	330	333	340	350	322	333	179	338	347	343	343	306	295	324
F						1.00	0.94	0.94	0.92	0.92	0.91	0.78	0.90	0.85	0.85	0.89	0.86	0.88	0.89
						(0.0, 0.00)	(3.8, 0.14)	(3.5, 0.15)	(4.5, 0.17)	(5.4, 0.18)	(4.7, 0.17)	(9.6, 0.33)	(5.3, 0.18)	(6.4, 0.20)	(7.5, 0.22)	(5.2, 0.16)	(6.0, 0.16)	(4.9, 0.16)	(5.5, 0.17)
						349	324	324	339	310	323	168	323	334	330	336	295	281	316
G							1.00	0.94	0.94	0.89	0.90	0.77	0.90	0.85	0.87	0.88	0.86	0.87	0.88
							(0.0, 0.00)	(4.0, 0.16)	(4.3, 0.15)	(5.7, 0.20)	(5.0, 0.19)	(9.0, 0.33)	(5.3, 0.18)	(6.3, 0.20)	(5.5, 0.17)	(5.3, 0.17)	(5.2, 0.17)	(5.7, 0.19)	
							398	325	338	308	320	172	326	335	329	383	296	282	356
H								1.00	0.93	0.89	0.90	0.75	0.88	0.83	0.84	0.89	0.86	0.87	0.88
								(0.0, 0.00)	(4.7, 0.19)	(5.0, 0.17)	(4.4, 0.17)	(9.4, 0.30)	(4.9, 0.18)	(5.6, 0.21)	(6.0, 0.19)	(4.5, 0.16)	(6.0, 0.19)	(4.5, 0.16)	(5.1, 0.17)
								349	342	318	327	175	332	341	336	335	299	289	314
I									1.00	0.86	0.87	0.75	0.86	0.82	0.83	0.88	0.84	0.85	0.87
									(0.0, 0.00)	(6.9, 0.23)	(6.1, 0.20)	(10.0, 0.36)	(6.7, 0.22)	(7.2, 0.21)	(8.2, 0.25)	(6.1, 0.20)	(6.0, 0.18)	(6.0, 0.18)	(6.3, 0.21)
									1015	330	341	181	352	356	357	957	314	306	936
J										1.00	0.95	0.73	0.87	0.84	0.80	0.90	0.86	0.87	0.88
										(0.0, 0.00)	(3.0, 0.14)	(9.2, 0.28)	(5.2, 0.18)	(5.9, 0.22)	(7.5, 0.22)	(5.0, 0.17)	(5.9, 0.21)	(5.3, 0.17)	(5.2, 0.18)
										335	316	167	314	326	323	321	283	272	302
K			R								1.00	0.71	0.88	0.85	0.81	0.89	0.86	0.87	0.88
			(P90, COD)								(0.0, 0.00)	(10.3, 0.31)	(6.0, 0.16)	(6.5, 0.19)	(8.2, 0.22)	(5.2, 0.16)	(5.8, 0.18)	(5.5, 0.18)	(5.5, 0.18)
			N								346	170	326	337	332	331	296	286	313
L												1.00	0.89	0.91	0.90	0.68	0.63	0.72	0.69
												(0.0, 0.00)	(6.7, 0.24)	(5.9, 0.23)	(4.8, 0.21)	(10.0, 0.29)	(12.1, 0.35)	(9.1, 0.30)	(9.8, 0.29)
												183	176	181	177	181	153	149	164
M													1.00	0.94	0.90	0.83	0.81	0.82	0.84
													(0.0, 0.00)	(3.8, 0.13)	(4.6, 0.16)	(5.5, 0.16)	(7.4, 0.20)	(5.8, 0.17)	(5.1, 0.16)
													361	341	336	345	300	288	326
N			R											1.00	0.90	0.77	0.75	0.78	0.78
			(P90, COD)											(0.0, 0.00)	(4.4, 0.17)	(6.7, 0.19)	(8.1, 0.22)	(6.4, 0.20)	(6.2, 0.19)
			N											362	346	347	309	297	327
O															1.00	0.80	0.75	0.79	0.80
															(0.0, 0.00)	(5.8, 0.19)	(8.8, 0.25)	(6.8, 0.21)	(6.0, 0.19)
															362	348	304	292	330
P																1.00	0.95	0.97	0.97
																(0.0, 0.00)	(3.6, 0.14)	(2.0, 0.09)	(2.1, 0.08)
																1027	307	299	943
Q																	1.00	0.92	0.94
																	(0.0, 0.00)	(3.1, 0.13)	(4.0, 0.16)
																	321	268	290
R																		1.00	0.94
																		(0.0, 0.00)	(2.7, 0.12)
																		313	280
S																			1.00
																			(0.0, 0.00)
																			998

Figure A-90. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Boston, MA.

Figure A-91. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Chicago, IL.

| AQS Site ID		A	B	C	D	E	F	G	H	I	J	K
Site A	17-031-0022	Mean	15.3	14.7	15.6	15.1	14.8	16.4	14.6	15.9	15.2	12.6	13.2
Site B	17-031-0050	Obs	178	343	984	333	351	345	350	335	361	356	361
Site C	17-031-0052												
Site D	17-031-0057	SD	8.8	8.4	8.9	9.0	8.2	9.1	8.2	8.5	8.3	7.8	8.2

Site A 17-031-0022
Site B 17-031-0050
Site C 17-031-0052
Site D 17-031-0057
Site E 17-031-0076
Site F 17-031-1016
Site G 17-031-2001
Site H 17-031-3103
Site I 17-031-3301
Site J 17-031-4007
Site K 17-031-4201

1=winter
2=spring
3=summer
4=fall

AQS Site ID		L	M	N	O	P	Q	R	S	T	U
Site L	17-031-6005	Mean	15.1	14.0	13.5	14.3	12.1	12.3	14.0	11.7	14.4	15.6
Site M	17-043-4002	Obs	331	179	176	174	181	347	175	164	330	351
Site N	17-089-0003											
Site O	17-089-0007	SD	8.7	8.5	8.5	8.9	8.2	7.5	8.5	7.2	7.7	8.2

Site L 17-031-6005
Site M 17-043-4002
Site N 17-089-0003
Site O 17-089-0007
Site P 17-097-1007
Site Q 17-111-0001
Site R 17-197-1002
Site S 17-197-1011
Site T 18-089-0006
Site U 18-089-0022

1=winter
2=spring
3=summer
4=fall

AQS Site ID		V	W	X	Y	Z	AA	AB	AC	AD	AE
Site V	18-089-0026	Mean	16.5	13.7	14.1	14.0	14.0	12.4	12.6	12.6	13.4	12.9
Site W	18-089-0027											
Site X	18-089-1003	Obs	339	328	334	340	347	532	346	336	346	355
Site Y	18-089-2004	SD	8.8	7.4	7.7	7.5	8.1	7.5	7.5	7.5	8.1	7.8

Site Z 18-089-2010
Site AA 18-091-0011
Site AB 18-091-0012
Site AC 18-127-0020
Site AD 18-127-0024
Site AE 55-059-0019

1=winter
2=spring
3=summer
4=fall

Figure A-92. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Chicago, IL.

Table A-36. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Chicago, IL.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	1.00	0.98	0.93	0.94	0.97	0.95	0.97	0.94	0.96	0.91	0.95	0.95	0.91	0.92	0.89
	(0.0, 0.00)	(3.1, 0.08)	(5.5, 0.12)	(4.7, 0.11)	(3.9, 0.09)	(5.7, 0.13)	(3.9, 0.09)	(4.6, 0.12)	(4.2, 0.11)	(6.8, 0.16)	(5.8, 0.14)	(4.6, 0.12)	(5.7, 0.15)	(6.6, 0.15)	(6.0, 0.16)
	178	156	176	149	154	154	151	156	164	163	166	141	165	152	156
B		1.00	0.94	0.95	0.97	0.95	0.97	0.95	0.96	0.93	0.93	0.95	0.92	0.93	0.90
		(0.0, 0.00)	(4.6, 0.11)	(3.6, 0.10)	(3.3, 0.08)	(5.2, 0.13)	(2.7, 0.07)	(4.3, 0.11)	(3.4, 0.09)	(6.3, 0.16)	(6.5, 0.15)	(4.0, 0.10)	(5.1, 0.15)	(5.8, 0.14)	(5.2, 0.15)
		343	320	276	300	296	296	289	312	315	306	288	157	152	150
C			1.00	0.96	0.92	0.91	0.90	0.94	0.92	0.90	0.91	0.92	0.88	0.92	0.86
			(0.0, 0.00)	(4.4, 0.11)	(5.7, 0.11)	(4.8, 0.11)	(6.0, 0.12)	(4.3, 0.11)	(5.5, 0.11)	(8.8, 0.18)	(7.2, 0.17)	(4.5, 0.12)	(7.5, 0.16)	(7.9, 0.16)	(7.5, 0.17)
			984	313	325	318	324	312	336	332	337	311	178	175	173
D				1.00	0.94	0.93	0.94	0.95	0.94	0.93	0.93	0.92	0.89	0.96	0.88
				(0.0, 0.00)	(3.8, 0.10)	(4.2, 0.12)	(3.8, 0.10)	(4.1, 0.13)	(3.3, 0.10)	(6.2, 0.15)	(5.2, 0.14)	(3.6, 0.10)	(5.3, 0.14)	(5.1, 0.13)	(4.5, 0.15)
				333	286	280	283	270	299	296	289	273	151	146	145
E					1.00	0.95	0.98	0.95	0.98	0.92	0.92	0.95	0.95	0.94	0.92
					(0.0, 0.00)	(5.0, 0.11)	(2.4, 0.06)	(4.5, 0.11)	(2.6, 0.07)	(5.8, 0.16)	(5.7, 0.15)	(4.4, 0.10)	(4.8, 0.11)	(5.0, 0.11)	(4.6, 0.13)
					351	306	304	292	320	321	313	286	159	154	152
F						1.00	0.95	0.95	0.96	0.89	0.91	0.94	0.94	0.94	0.94
						(0.0, 0.00)	(5.1, 0.12)	(4.5, 0.10)	(4.5, 0.10)	(8.5, 0.20)	(7.9, 0.19)	(5.7, 0.12)	(7.0, 0.15)	(7.9, 0.17)	(7.9, 0.16)
						345	301	294	322	323	311	285	161	157	154
G							1.00	0.95	0.97	0.90	0.91	0.94	0.95	0.95	0.95
							(0.0, 0.00)	(4.9, 0.12)	(3.0, 0.07)	(6.3, 0.15)	(5.8, 0.14)	(4.7, 0.10)	(4.2, 0.11)	(5.0, 0.12)	(4.4, 0.12)
							350	284	315	318	309	287	154	149	148
H								1.00	0.95	0.91	0.92	0.94	0.93	0.94	0.91
								(0.0, 0.00)	(4.3, 0.11)	(7.4, 0.19)	(6.4, 0.18)	(4.4, 0.13)	(6.4, 0.16)	(7.1, 0.16)	(5.9, 0.17)
								335	311	309	302	275	164	157	156
I									1.00	0.90	0.92	0.96	0.96	0.95	0.93
									(0.0, 0.00)	(6.7, 0.17)	(5.9, 0.16)	(3.9, 0.10)	(4.6, 0.12)	(5.3, 0.13)	(4.6, 0.14)
									361	341	328	304	173	169	166
J										1.00	0.92	0.90	0.91	0.94	0.89
										(0.0, 0.00)	(4.7, 0.13)	(7.0, 0.17)	(5.7, 0.14)	(4.4, 0.12)	(5.4, 0.16)
										356	330	304	171	165	164
K											1.00	0.93	0.94	0.96	0.92
					R						(0.0, 0.00)	(5.9, 0.15)	(5.2, 0.13)	(4.0, 0.10)	(4.9, 0.15)
					(P90, COD)						361	292	173	166	167
L					N							1.00	0.94	0.95	0.92
												(0.0, 0.00)	(6.4, 0.13)	(5.9, 0.13)	(6.0, 0.14)
												331	147	142	142
M													1.00	0.97	0.95
													(0.0, 0.00)	(3.9, 0.09)	(2.7, 0.11)
													179	160	165
N														1.00	0.95
														(0.0, 0.00)	(3.8, 0.11)
														176	152
O															1.00
															(0.0, 0.00)
															174

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
A	0.90	0.89	0.91	0.83	0.96	0.83	0.93	0.95	0.96	0.95	0.98	0.94	0.93	0.95	0.94	0.88
	(8.0, 0.19)	(7.5, 0.19)	(5.6, 0.16)	(8.0, 0.24)	(4.4, 0.11)	(7.2, 0.16)	(5.9, 0.13)	(4.7, 0.12)	(4.4, 0.10)	(4.5, 0.12)	(3.4, 0.10)	(5.8, 0.17)	(6.8, 0.17)	(6.0, 0.16)	(5.4, 0.15)	(7.1, 0.17)
	166	151	157	145	154	162	159	149	156	160	160	154	159	158	159	162
B	0.90	0.90	0.91	0.83	0.95	0.81	0.94	0.95	0.96	0.96	0.98	0.94	0.92	0.93	0.87	0.87
	(8.0, 0.20)	(6.7, 0.17)	(5.5, 0.16)	(8.0, 0.24)	(3.9, 0.10)	(6.7, 0.15)	(5.2, 0.11)	(5.0, 0.11)	(4.0, 0.10)	(4.2, 0.11)	(2.9, 0.09)	(5.9, 0.17)	(6.8, 0.17)	(6.5, 0.18)	(5.3, 0.16)	(7.2, 0.17)
	159	290	153	143	292	310	300	289	292	300	309	288	308	299	305	311
C	0.89	0.91	0.86	0.78	0.90	0.76	0.89	0.90	0.90	0.90	0.93	0.87	0.88	0.88	0.84	0.79
	(10.2, 0.22)	(8.3, 0.19)	(7.1, 0.17)	(10.4, 0.25)	(6.9, 0.13)	(8.5, 0.18)	(6.4, 0.13)	(7.7, 0.15)	(7.1, 0.14)	(7.9, 0.15)	(6.7, 0.15)	(8.6, 0.20)	(8.9, 0.20)	(9.6, 0.21)	(8.7, 0.18)	(8.5, 0.20)
	180	324	172	164	309	327	315	305	311	317	323	491	323	313	323	333
D	0.90	0.94	0.89	0.80	0.92	0.74	0.91	0.94	0.93	0.93	0.95	0.92	0.90	0.90	0.85	0.87
	(7.6, 0.19)	(6.5, 0.16)	(5.5, 0.14)	(8.6, 0.22)	(5.0, 0.12)	(7.8, 0.19)	(5.9, 0.13)	(5.4, 0.13)	(5.4, 0.13)	(5.8, 0.13)	(4.8, 0.13)	(6.4, 0.17)	(6.9, 0.18)	(7.0, 0.19)	(6.2, 0.17)	(6.9, 0.17)
	153	278	147	135	280	294	283	273	282	284	292	274	291	287	290	297
E	0.91	0.92	0.94	0.87	0.94	0.77	0.94	0.96	0.95	0.96	0.96	0.93	0.91	0.90	0.86	0.87
	(8.3, 0.18)	(5.6, 0.16)	(4.9, 0.12)	(7.1, 0.20)	(4.1, 0.10)	(7.5, 0.17)	(5.6, 0.12)	(4.3, 0.10)	(4.4, 0.11)	(3.9, 0.09)	(3.9, 0.11)	(5.8, 0.17)	(6.9, 0.17)	(6.8, 0.18)	(6.3, 0.16)	(7.3, 0.17)
	160	294	155	142	300	320	310	299	303	310	317	292	314	304	313	318
F	0.91	0.92	0.92	0.87	0.90	0.74	0.93	0.92	0.92	0.92	0.93	0.91	0.90	0.87	0.83	0.84
	(10.5, 0.23)	(8.6, 0.20)	(8.5, 0.17)	(10.0, 0.25)	(6.9, 0.14)	(9.2, 0.19)	(5.4, 0.11)	(8.2, 0.16)	(7.2, 0.15)	(7.6, 0.15)	(6.3, 0.16)	(8.5, 0.22)	(9.4, 0.21)	(9.1, 0.23)	(8.3, 0.20)	(9.3, 0.21)
	163	295	159	144	302	320	308	297	305	311	316	292	317	306	317	322
G	0.91	0.91	0.95	0.88	0.94	0.76	0.95	0.97	0.96	0.97	0.96	0.92	0.92	0.90	0.87	0.85
	(7.9, 0.19)	(5.9, 0.16)	(4.1, 0.12)	(7.1, 0.21)	(3.9, 0.10)	(7.5, 0.17)	(4.7, 0.10)	(3.7, 0.09)	(3.6, 0.09)	(3.5, 0.08)	(3.4, 0.11)	(5.7, 0.17)	(6.8, 0.16)	(6.8, 0.18)	(5.9, 0.15)	(7.5, 0.17)
	156	292	154	140	293	315	303	293	296	303	312	288	311	300	308	314
H	0.91	0.93	0.92	0.82	0.92	0.78	0.92	0.91	0.92	0.92	0.93	0.90	0.89	0.88	0.83	0.88
	(9.3, 0.23)	(7.1, 0.20)	(6.6, 0.17)	(9.6, 0.26)	(5.7, 0.13)	(7.5, 0.17)	(6.1, 0.13)	(6.8, 0.15)	(5.9, 0.15)	(6.7, 0.14)	(5.9, 0.15)	(7.7, 0.22)	(8.1, 0.22)	(8.3, 0.22)	(8.1, 0.20)	(7.6, 0.20)
	165	284	158	145	287	307	297	288	292	299	303	281	301	293	301	307
I	0.91	0.92	0.95	0.87	0.93	0.78	0.94	0.95	0.94	0.95	0.95	0.92	0.91	0.89	0.85	0.86
	(8.2, 0.21)	(6.1, 0.17)	(4.7, 0.12)	(7.7, 0.22)	(4.2, 0.10)	(7.1, 0.17)	(5.0, 0.10)	(4.6, 0.11)	(4.8, 0.11)	(4.7, 0.10)	(4.2, 0.13)	(6.5, 0.18)	(6.8, 0.18)	(7.4, 0.19)	(6.6, 0.17)	(7.0, 0.18)
	175	314	168	154	318	338	327	316	322	328	335	306	334	323	334	339
J	0.92	0.91	0.90	0.85	0.89	0.73	0.89	0.89	0.89	0.89	0.91	0.89	0.88	0.87	0.82	0.87
	(5.6, 0.14)	(5.1, 0.14)	(6.2, 0.16)	(6.7, 0.21)	(6.1, 0.17)	(8.6, 0.22)	(8.7, 0.20)	(6.0, 0.16)	(6.3, 0.16)	(6.2, 0.16)	(5.9, 0.16)	(5.6, 0.16)	(5.8, 0.16)	(6.3, 0.17)	(6.3, 0.17)	(6.4, 0.15)
	173	313	167	153	319	341	329	317	327	329	337	307	335	327	336	340
K	0.94	0.93	0.93	0.86	0.91	0.78	0.89	0.91	0.90	0.91	0.92	0.92	0.91	0.90	0.85	0.91
	(5.2, 0.12)	(4.2, 0.12)	(6.1, 0.16)	(7.2, 0.20)	(5.1, 0.16)	(8.0, 0.21)	(8.4, 0.19)	(5.2, 0.15)	(5.5, 0.15)	(5.2, 0.15)	(5.4, 0.14)	(5.2, 0.15)	(4.9, 0.15)	(5.3, 0.16)	(5.3, 0.16)	(5.1, 0.13)
	176	298	169	155	310	327	319	304	313	319	325	301	325	315	323	328
L	0.90	0.92	0.93	0.86	0.93	0.75	0.92	0.93	0.93	0.92	0.95	0.92	0.92	0.90	0.85	0.89
	(9.3, 0.20)	(6.7, 0.17)	(6.7, 0.14)	(8.9, 0.21)	(5.5, 0.12)	(8.2, 0.19)	(6.2, 0.13)	(5.7, 0.13)	(5.8, 0.13)	(6.2, 0.13)	(5.0, 0.13)	(7.2, 0.17)	(7.6, 0.17)	(7.4, 0.18)	(7.3, 0.16)	(7.1, 0.17)
	151	285	144	132	285	301	290	282	286	293	299	277	299	286	294	301
M	0.92	0.95	0.96	0.88	0.91	0.74	0.90	0.94	0.92	0.93	0.92	0.91	0.91	0.88	0.89	0.89
	(6.2, 0.16)	(4.5, 0.14)	(3.4, 0.09)	(6.3, 0.19)	(5.9, 0.14)	(9.0, 0.22)	(8.0, 0.17)	(4.7, 0.12)	(5.2, 0.14)	(5.0, 0.13)	(5.8, 0.16)	(6.4, 0.17)	(5.5, 0.15)	(6.9, 0.19)	(6.2, 0.17)	(6.9, 0.17)
	175	157	165	152	162	171	166	159	164	168	169	158	168	165	168	171
N	0.92	0.98	0.94	0.89	0.92	0.81	0.91	0.92	0.91	0.93	0.93	0.91	0.91	0.88	0.89	0.90
	(5.4, 0.13)	(2.8, 0.08)	(4.1, 0.12)	(5.8, 0.17)	(6.2, 0.13)	(7.9, 0.20)	(8.3, 0.17)	(4.9, 0.12)	(5.6, 0.14)	(4.6, 0.13)	(4.9, 0.15)	(5.4, 0.15)	(4.9, 0.14)	(6.5, 0.17)	(5.4, 0.16)	(6.0, 0.14)
	162	151	153	140	156	165	160	157	158	162	165	153	162	158	161	165
O	0.88	0.92	0.93	0.86	0.89	0.75	0.89	0.92	0.90	0.91	0.90	0.89	0.90	0.87	0.87	0.87
	(7.5, 0.18)	(4.9, 0.15)	(3.8, 0.13)	(6.5, 0.20)	(5.9, 0.15)	(8.8, 0.22)	(7.6, 0.17)	(5.1, 0.13)	(5.8, 0.15)	(5.5, 0.14)	(5.6, 0.16)	(6.1, 0.17)	(5.7, 0.16)	(7.0, 0.19)	(6.2, 0.17)	(7.0, 0.18)
	166	152	157	145	155	166	161	154	158	161	162	151	161	159	162	166
P	1.00	0.92	0.90	0.84	0.88	0.73	0.87	0.89	0.89	0.89	0.90	0.89	0.90	0.89	0.89	0.92
	(0.0, 0.00)	(5.2, 0.13)	(7.1, 0.17)	(7.2, 0.20)	(8.5, 0.20)	(12.0, 0.26)	(10.9, 0.24)	(6.7, 0.18)	(7.4, 0.18)	(6.9, 0.18)	(7.6, 0.19)	(6.1, 0.16)	(5.7, 0.15)	(6.3, 0.17)	(6.4, 0.17)	(5.7, 0.13)
	181	159	166	152	164	174	168	160	166	169	171	158	170	167	170	173
Q		1.00	0.92	0.85	0.88	0.71	0.89	0.90	0.88	0.90	0.90	0.89	0.88	0.86	0.82	0.91
		(0.0, 0.00)	(5.4, 0.16)	(7.2, 0.19)	(6.1, 0.18)	(9.3, 0.24)	(9.1, 0.21)	(5.5, 0.16)	(6.5, 0.16)	(5.5, 0.16)	(6.3, 0.16)	(5.3, 0.16)	(5.3, 0.16)	(6.3, 0.18)	(5.9, 0.17)	(5.5, 0.14)
		347	154	139	290	309	296	289	294	302	306	292	303	293	303	310
R			1.00	0.91	0.93	0.76	0.90	0.94	0.93	0.94	0.91	0.92	0.92	0.88	0.89	0.89
			(0.0, 0.00)	(5.8, 0.18)	(5.1, 0.13)	(8.6, 0.22)	(7.5, 0.17)	(4.4, 0.11)	(5.0, 0.13)	(4.0, 0.12)	(5.8, 0.17)	(6.2, 0.17)	(5.6, 0.16)	(7.1, 0.19)	(6.4, 0.17)	(7.1, 0.17)
			175	143	157	167	161	153	160	161	164	153	164	160	163	166
S				1.00	0.83	0.66	0.81	0.86	0.83	0.87	0.83	0.84	0.84	0.81	0.82	0.80
				(0.0, 0.00)	(8.5, 0.22)	(11.3, 0.28)	(11.6, 0.26)	(6.7, 0.20)	(8.0, 0.21)	(7.2, 0.19)	(7.3, 0.22)	(6.1, 0.21)	(7.4, 0.20)	(7.8, 0.23)	(7.1, 0.22)	(9.0, 0.22)
				164	144	153	148	143	146	148	151	141	151	149	148	153
T					1.00	0.81	0.93	0.95	0.97	0.96	0.97	0.92	0.91	0.92	0.87	0.85
					(0.0, 0.00)	(5.9, 0.15)	(6.2, 0.12)	(3.4, 0.10)	(3.2, 0.09)	(2.9, 0.08)	(3.2, 0.12)	(5.2, 0.17)	(5.5, 0.16)	(5.4, 0.18)	(4.9, 0.15)	(6.6, 0.18)
					330	318	307	297	302	305	315	284	312	311	313	319
U						1.00	0.77	0.79	0.81	0.81	0.81	0.78	0.76	0.79	0.74	0.69
						(0.0, 0.00)	(7.6, 0.17)	(6.6, 0.17)	(6.0, 0.15)	(6.3, 0.16)	(6.4, 0.17)	(8.1, 0.22)	(8.4, 0.22)	(7.2, 0.21)	(7.0, 0.19)	(10.0, 0.23)
						351	327	319	322	326	336	305	334	324	333	338
V							1.00	0.96	0.97	0.95	0.95	0.93	0.91	0.90	0.88	0.83
							(0.0, 0.00)	(5.9, 0.11)	(4.8, 0.10)	(5.8, 0.12)	(5.7, 0.14)	(7.7, 0.20)	(8.6, 0.20)	(8.3, 0.21)	(6.9, 0.17)	(9.3, 0.22)
							339	306	314	316	325	292	323	314	321	325
W								1.00	0.98	0.98	0.96	0.95	0.93	0.92	0.89	0.85
								(0.0, 0.00)	(2.8, 0.06)	(2.5, 0.07)	(3.6, 0.11)	(4.5, 0.15)	(4.8, 0.15)	(5.4, 0.16)	(3.9, 0.13)	(6.9, 0.17)
								328	299	306	312	281	310	306	311	316
X									1.00	0.98	0.97	0.95	0.93	0.94	0.91	0.85
									(0.0, 0.00)	(2.3, 0.07)	(3.3, 0.10)	(4.6, 0.14)	(4.9, 0.14)	(4.9, 0.15)	(3.6, 0.11)	(6.8, 0.17)
									334	311	318	286	319	305	316	321
Y										1.00	0.97	0.95	0.93	0.92	0.89	0.85
										(0.0, 0.00)	(3.6, 0.11)	(4.7, 0.16)	(5.0, 0.15)	(5.3, 0.17)	(4.4, 0.14)	(6.7, 0.18)
										340	322	296	322	311	321	326
Z											1.00	0.95	0.93	0.94	0.89	0.86
											(0.0, 0.00)	(4.6, 0.15)	(5.3, 0.15)	(4.9, 0.15)	(4.1, 0.14)	(6.8, 0.17)
											347	305	331	321	328	335
AA												1.00	0.98	0.97	0.89	0.88
												(0.0, 0.00)	(2.4, 0.07)	(2.9, 0.08)	(3.2, 0.11)	(5.9, 0.17)
												532	305	287	300	304
AB													1.00	0.96	0.89	0.86
													(0.0, 0.00)	(3.1, 0.09)	(3.7, 0.11)	(6.5, 0.17)
													346	317	328	333
AC														1.00	0.91	0.85
														(0.0, 0.00)	(2.8, 0.10)	(6.7, 0.17)
														336	320	322
AD															1.00	0.79
															(0.0, 0.00)	(7.2, 0.18)
															346	332
AE																1.00

|												(0.0, 0.00)
												355

Figure A-93. PM_{10} inter-sampler correlations as a function of distance between monitors for Chicago, IL.

**Figure A-94.** Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Denver, CO.
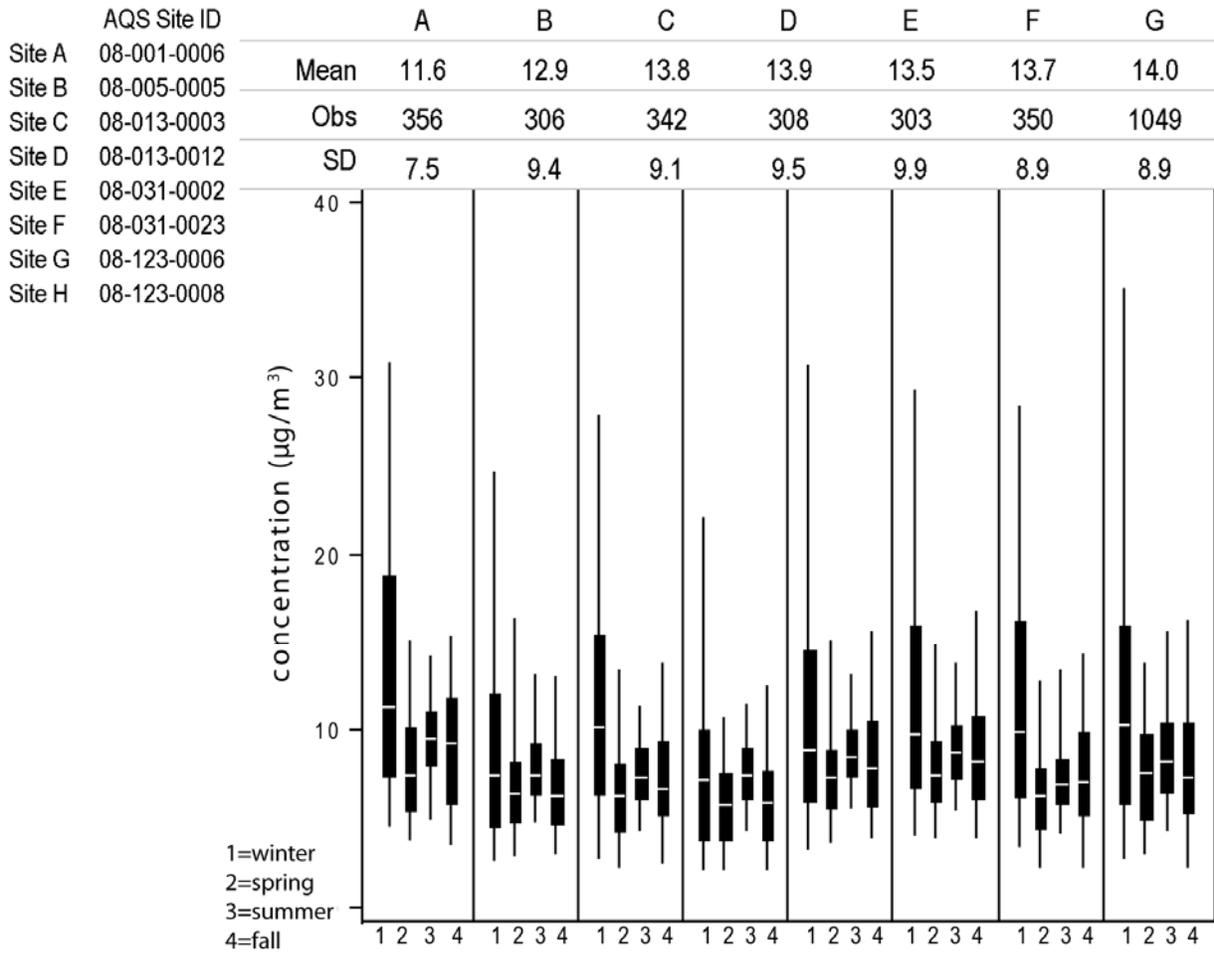
Figure A-95. Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Denver, CO.

Table A-37. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Denver, CO.

	A	B	C	D	E	F	G	H
A	1.00	0.74	0.84	0.68	0.86	0.91	0.76	0.83
	(0.0, 0.00)	(6.0, 0.21)	(5.4, 0.17)	(7.9, 0.26)	(4.1, 0.14)	(3.0, 0.11)	(5.9, 0.19)	(4.6, 0.14)
	369	353	347	332	362	339	341	325
B		1.00	0.58	0.76	0.92	0.84	0.50	0.49
		(0.0, 0.00)	(5.7, 0.19)	(3.9, 0.17)	(3.2, 0.13)	(4.4, 0.17)	(7.8, 0.23)	(6.6, 0.21)
		363	344	328	356	336	337	323
C			1.00	0.74	0.71	0.75	0.83	0.88
			(0.0, 0.00)	(4.4, 0.19)	(4.5, 0.17)	(5.4, 0.18)	(3.5, 0.14)	(3.7, 0.13)
			361	326	354	336	333	320
D				1.00	0.82	0.77	0.54	0.57
				(0.0, 0.00)	(5.6, 0.21)	(6.0, 0.24)	(7.2, 0.24)	(6.4, 0.24)
				354	347	332	318	305
E					1.00	0.94	0.64	0.60
					(0.0, 0.00)	(2.3, 0.09)	(7.1, 0.21)	(5.6, 0.18)
		R			1046	969	353	330
F		(P90, COD)				1.00	0.68	0.69
		N				(0.0, 0.00)	(6.6, 0.21)	(5.9, 0.17)
						1006	333	317
G							1.00	0.88
							(0.0, 0.00)	(3.4, 0.13)
							359	313
H								1.00
								(0.0, 0.00)
								334

Figure A-96. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Denver, CO.
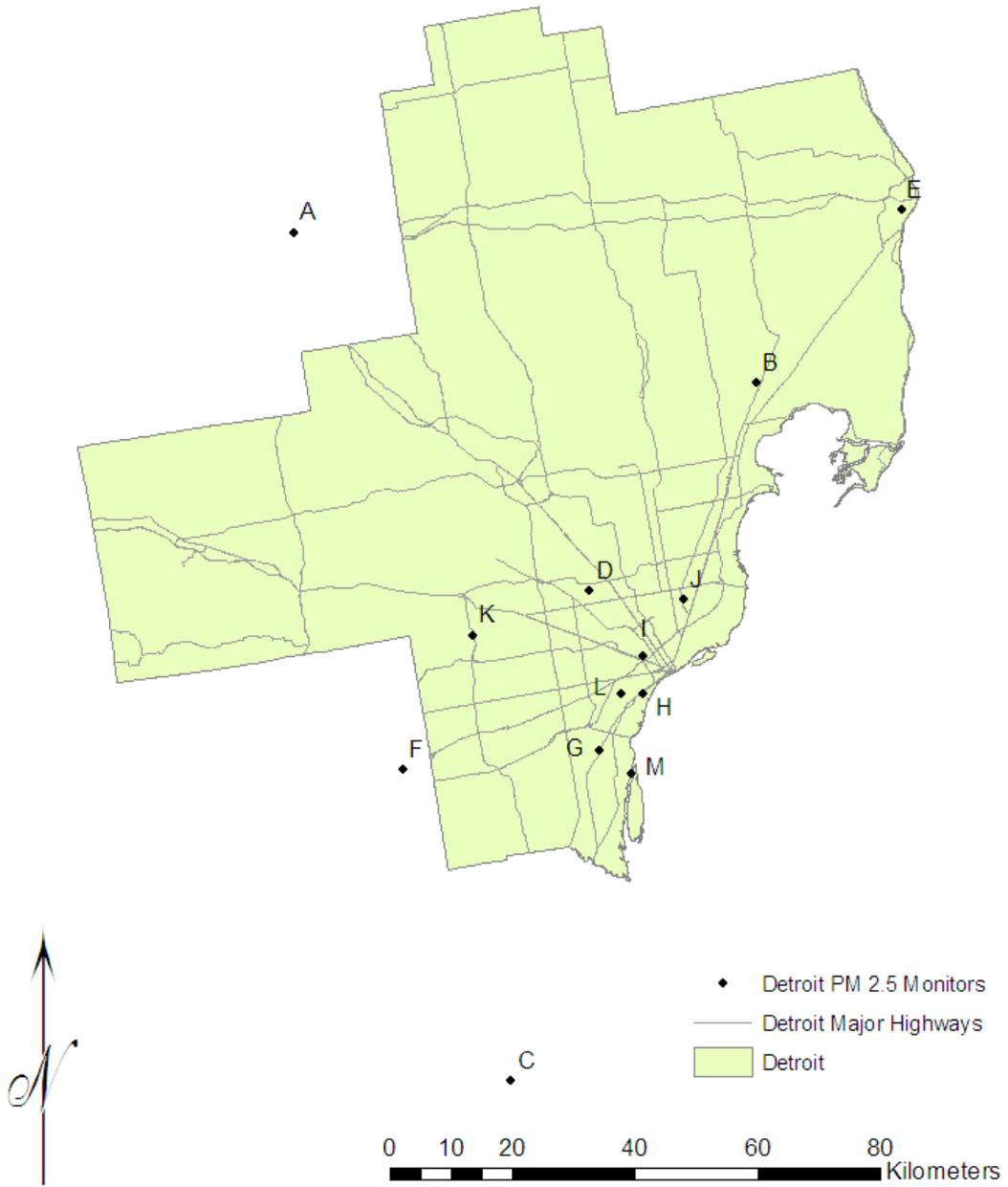
**Figure A-97.   Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Detroit, MI.**

AQS Site ID		A	B	C	D	E	F	G
Site A 26-049-0021	Mean	11.6	12.9	13.8	13.9	13.5	13.7	14.0
Site B 26-099-0009	Obs	356	306	342	308	303	350	1049
Site C 26-115-0005								
Site D 26-125-0001	SD	7.5	9.4	9.1	9.5	9.9	8.9	8.9
Site E 26-147-0005								
Site F 26-161-0008								
Site G 26-163-0001								

1=winter
2=spring
3=summer
4=fall
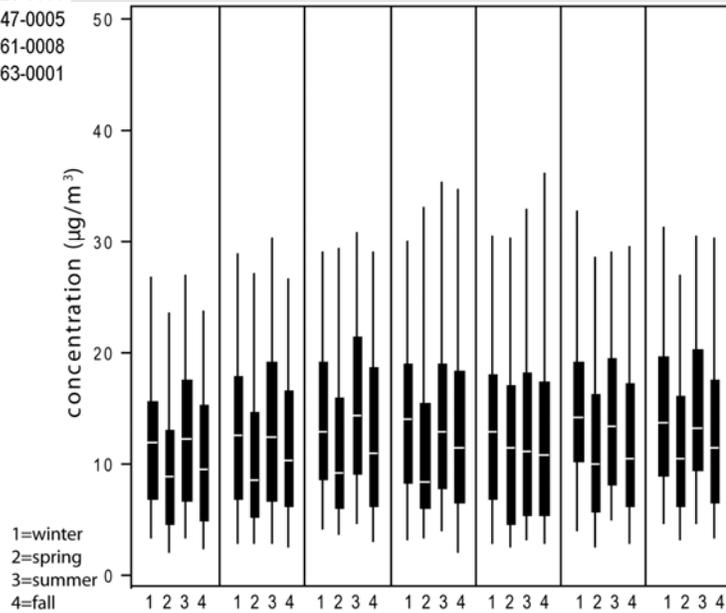
AQS Site ID		H	I	J	K	L	M
Site H 26-163-0015	Mean	15.5	15.0	14.4	13.4	17.2	14.3
Site I 26-163-0016	Obs	342	572	308	301	344	342
Site J 26-163-0019							
Site K 26-163-0025	SD	9.4	10.5	9.9	9.2	10.1	8.8
Site L 26-163-0033							
Site M 26-163-0036							

1=winter
2=spring
3=summer
4=fall
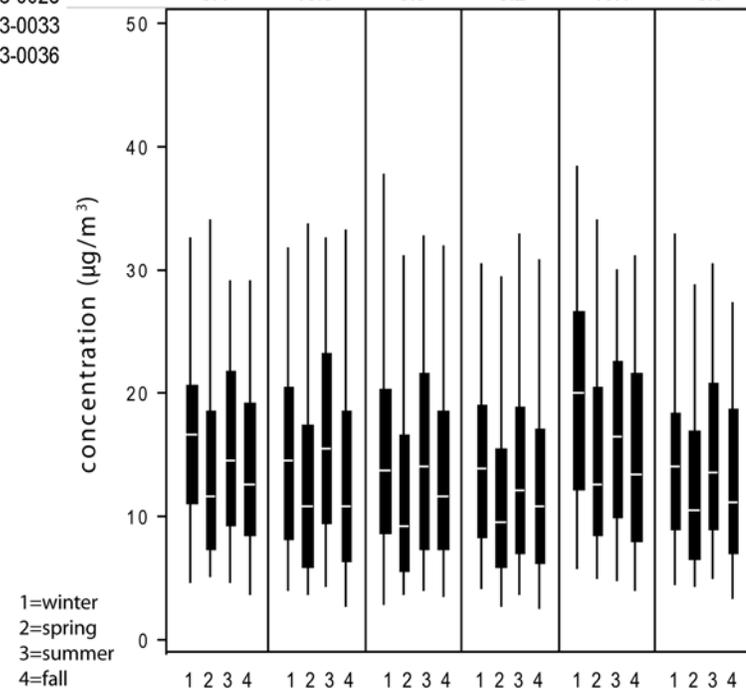
Figure A-98.   Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Detroit, MI.

Table A-38.   Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Detroit, MI.

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	1.00	0.91	0.86	0.91	0.89	0.90	0.89	0.88	0.89	0.91	0.92	0.87	0.88
	(0.0, 0.00)	(5.9, 0.17)	(7.8, 0.19)	(6.7, 0.17)	(7.6, 0.18)	(5.9, 0.18)	(8.1, 0.20)	(8.3, 0.22)	(8.0, 0.19)	(7.3, 0.17)	(5.5, 0.16)	(11.0, 0.26)	(7.8, 0.21)
	356	299	333	301	296	341	349	334	284	301	293	336	333
B		1.00	0.90	0.94	0.92	0.92	0.93	0.90	0.92	0.91	0.92	0.89	0.91
		(0.0, 0.00)	(6.8, 0.17)	(5.3, 0.14)	(5.9, 0.16)	(5.8, 0.17)	(6.2, 0.18)	(7.5, 0.21)	(5.8, 0.18)	(4.9, 0.16)	(5.4, 0.17)	(10.2, 0.24)	(6.1, 0.19)
		306	286	296	290	294	300	288	277	297	286	292	288
C			1.00	0.90	0.87	0.91	0.93	0.90	0.91	0.90	0.89	0.87	0.93
			(0.0, 0.00)	(7.0, 0.16)	(8.8, 0.20)	(5.5, 0.15)	(5.9, 0.14)	(7.2, 0.17)	(6.3, 0.16)	(6.2, 0.14)	(6.2, 0.16)	(10.4, 0.20)	(4.9, 0.13)
			342	289	284	326	335	320	273	286	279	321	319
D				1.00	0.93	0.94	0.96	0.92	0.94	0.94	0.94	0.91	0.92
				(0.0, 0.00)	(6.3, 0.15)	(4.5, 0.14)	(4.3, 0.13)	(5.8, 0.16)	(4.5, 0.12)	(3.8, 0.11)	(3.6, 0.13)	(8.2, 0.18)	(6.2, 0.15)
				308	292	296	303	291	281	297	291	290	290
E					1.00	0.90	0.90	0.89	0.90	0.90	0.90	0.87	0.87
					(0.0, 0.00)	(7.5, 0.18)	(7.3, 0.20)	(8.2, 0.22)	(7.0, 0.19)	(6.4, 0.18)	(6.9, 0.18)	(10.7, 0.25)	(7.7, 0.21)
					303	291	297	286	276	292	284	288	288
F						1.00	0.95	0.90	0.92	0.92	0.95	0.89	0.93
						(0.0, 0.00)	(4.5, 0.13)	(6.2, 0.17)	(5.7, 0.15)	(5.2, 0.14)	(3.9, 0.12)	(9.8, 0.21)	(5.7, 0.15)
						350	343	326	280	297	288	329	326
G							1.00	0.94	0.95	0.92	0.93	0.90	0.95
							(0.0, 0.00)	(5.1, 0.14)	(4.9, 0.12)	(4.5, 0.14)	(5.6, 0.16)	(8.2, 0.18)	(4.7, 0.12)
							1049	336	549	302	295	337	335
H								1.00	0.93	0.91	0.89	0.91	0.91
								(0.0, 0.00)	(4.8, 0.15)	(5.4, 0.15)	(6.9, 0.18)	(7.6, 0.16)	(6.1, 0.15)
								342	273	290	288	321	319
I									1.00	0.92	0.90	0.92	0.93
		R							(0.0, 0.00)	(4.4, 0.13)	(6.1, 0.14)	(7.9, 0.18)	(5.8, 0.14)
		(P90, COD)							572	279	271	274	274
J		N								1.00	0.91	0.90	0.91
										(0.0, 0.00)	(5.3, 0.15)	(8.1, 0.17)	(5.6, 0.13)
										308	288	291	291
K											1.00	0.88	0.91
											(0.0, 0.00)	(9.5, 0.21)	(6.3, 0.16)
											301	281	283
L												1.00	0.91
												(0.0, 0.00)	(8.5, 0.17)
												344	322
M													1.00
													(0.0, 0.00)
													342

Figure A-99.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Detroit, MI.
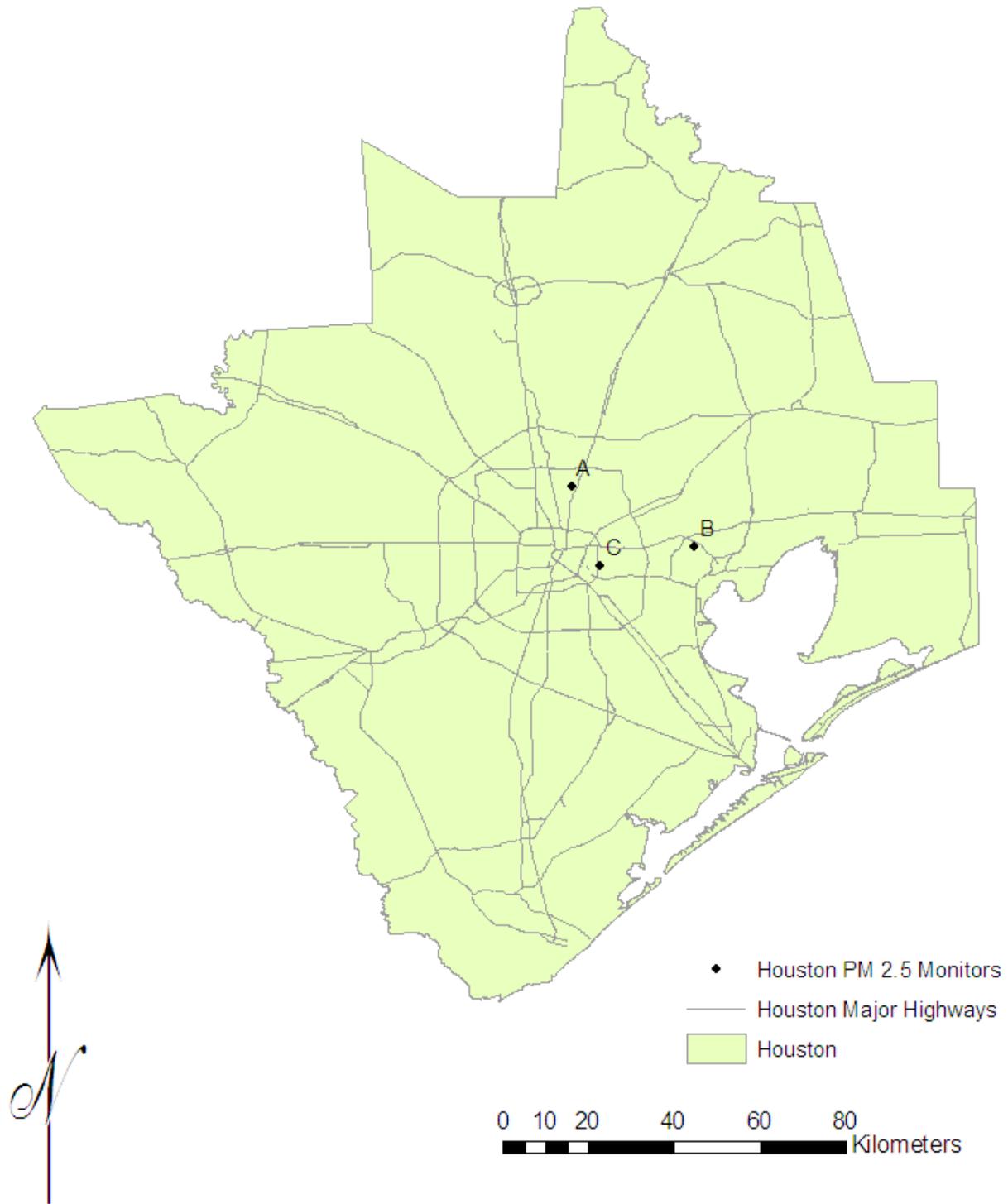
**Figure A-100.** Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Houston, TX.
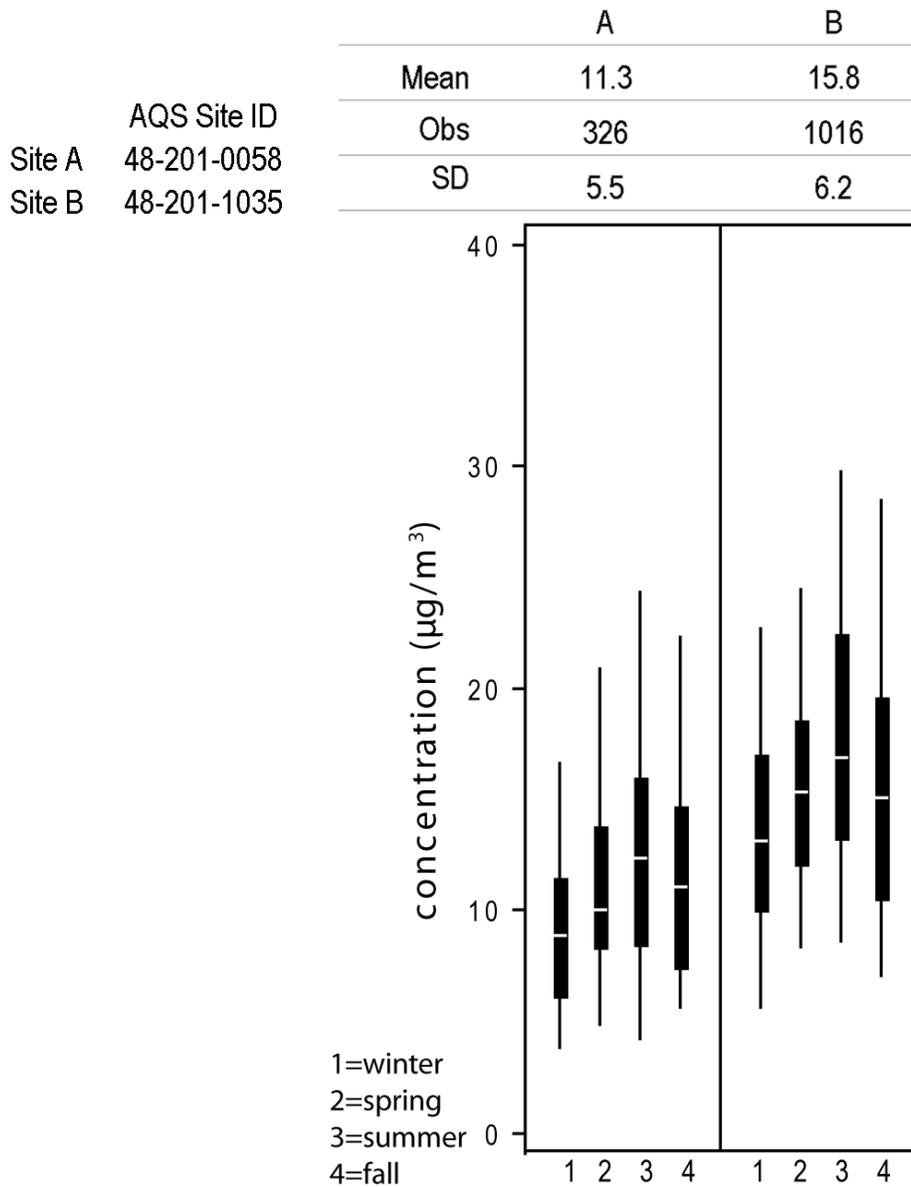
Figure A-101. Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Houston, TX.

Table A-39.   Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Houston, TX.

			A	B
A			1.00	0.66
			(0.0, 0.00)	(10.0, 0.24)
			326	310
B				1.00
				(0.0, 0.00)
				1016
	R (P90, COD) N			
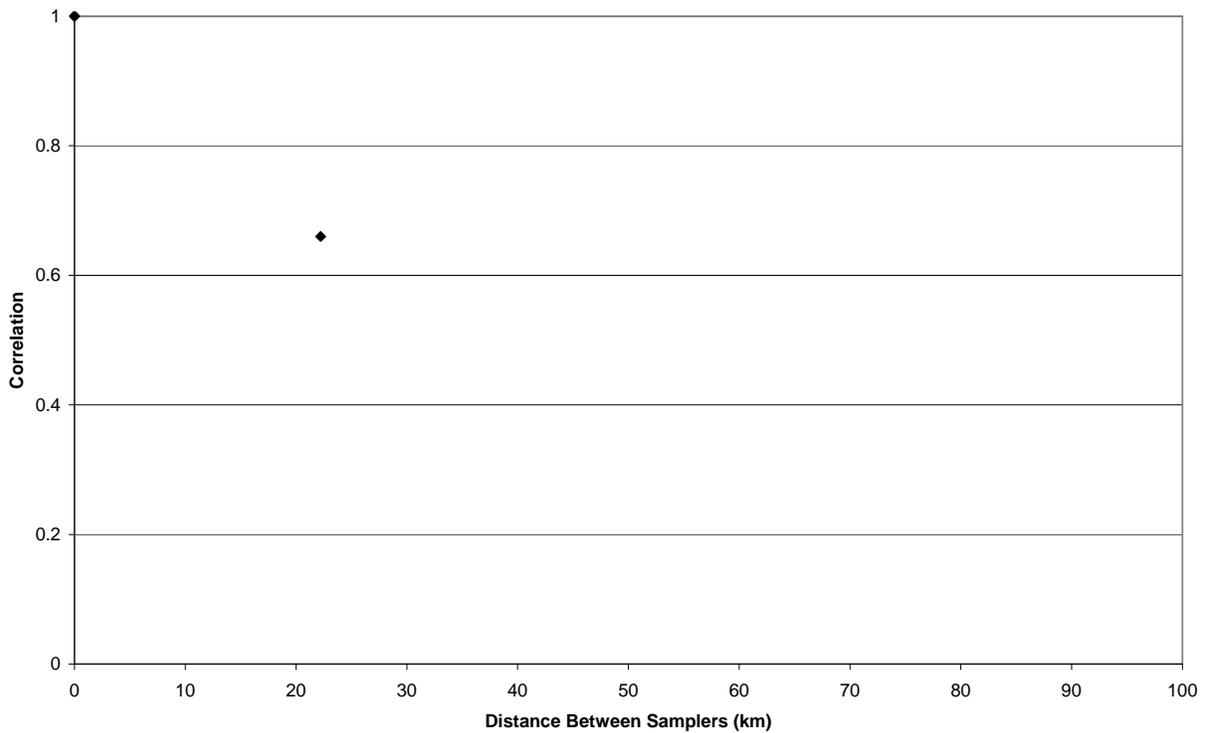
Figure A-102.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Houston, TX.
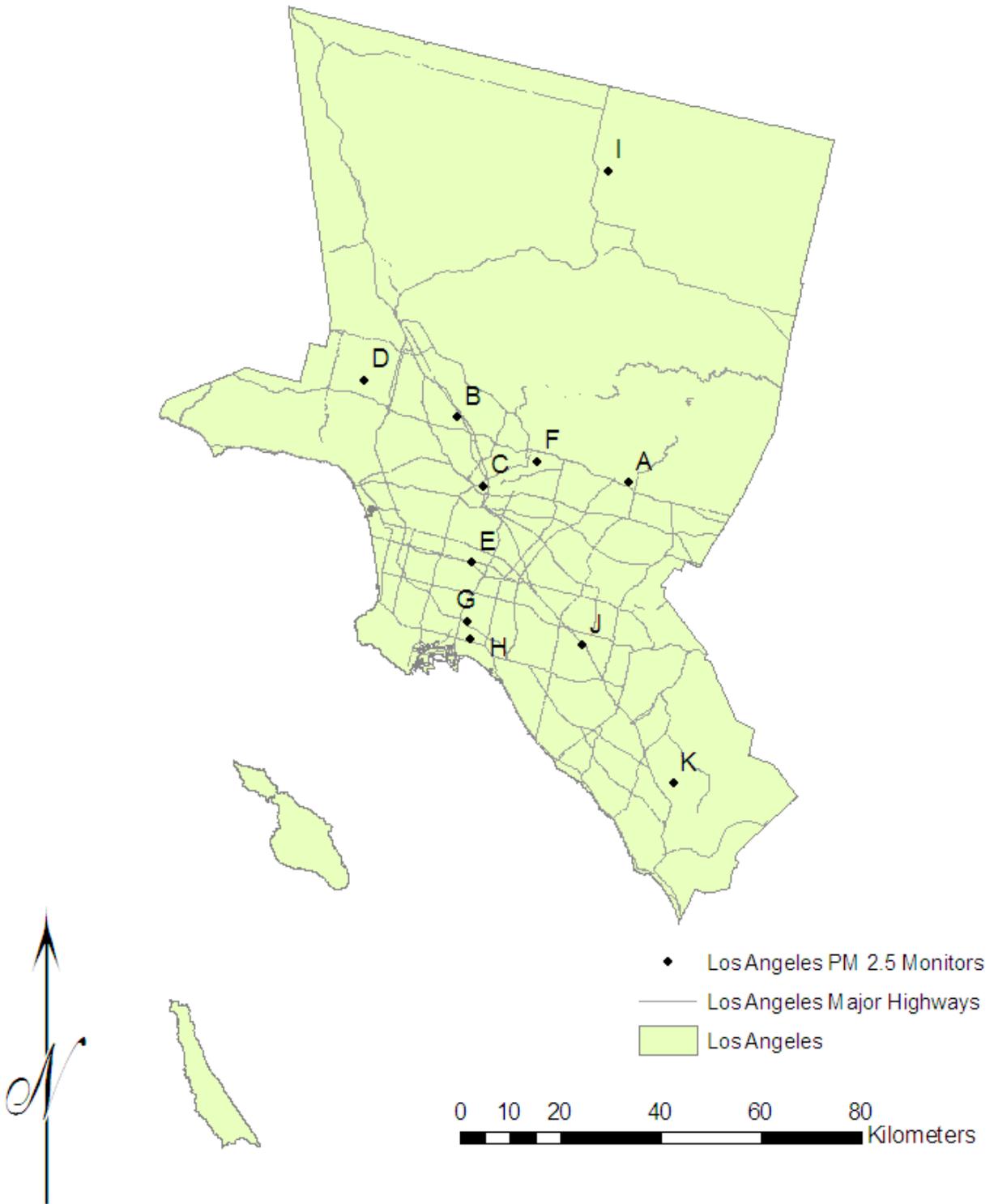
Figure A-103. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Los Angeles, CA.

AQS Site ID		A	B	C	D	E	F	G	H	I	J	K
Site A	06-037-0002											
Site B	06-037-1002	Mean	16.1	17.0	16.7	13.3	16.7	14.3	14.7	14.2	8.2	14.4	10.9
Site C	06-037-1103	Obs	862	308	1004	291	327	334	946	990	221	999	318
Site D	06-037-1201	SD	10.8	10.2	9.8	7.5	9.3	8.9	8.4	7.7	3.8	8.5	6.4
Site E	06-037-1301												
Site F	06-037-2005												
Site G	06-037-4002												
Site H	06-037-4004												
Site I	06-037-9033												
Site J	06-059-0007												
Site K	06-059-2022												
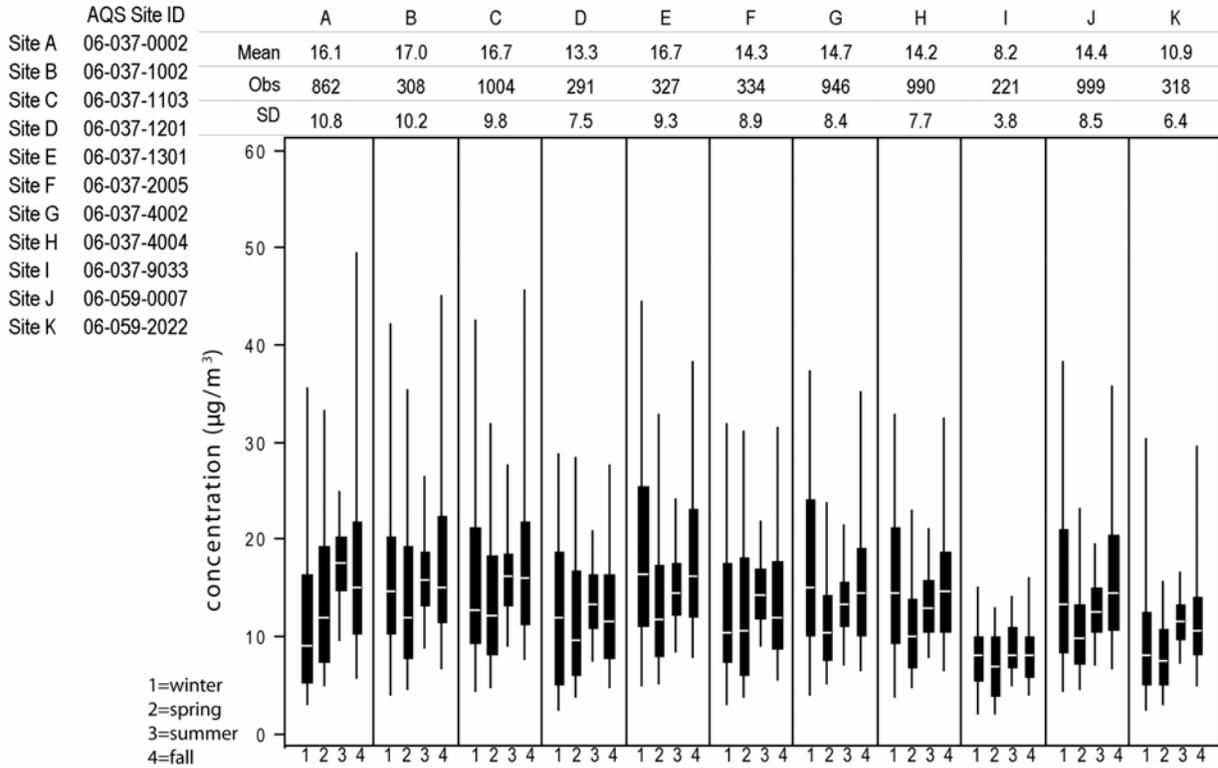
Figure A-104.   Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Los Angeles, CA.

1=winter
2=spring
3=summer
4=fall

Table A-40. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Los Angeles, CA.

	A	B	C	D	E	F	G	H	I	J	K
A	1.00	0.86	0.87	0.81	0.80	0.88	0.68	0.64	0.30	0.70	0.82
	(0.0, 0.00)	(9.0, 0.18)	(7.7, 0.16)	(9.0, 0.19)	(9.7, 0.21)	(5.8, 0.14)	(11.5, 0.22)	(12.4, 0.23)	(18.0, 0.36)	(10.5, 0.21)	(11.4, 0.23)
	862	252	803	238	262	269	761	793	179	804	259
B		1.00	0.92	0.87	0.83	0.88	0.77	0.73	0.31	0.74	0.71
		(0.0, 0.00)	(5.5, 0.11)	(9.1, 0.19)	(9.0, 0.15)	(7.6, 0.15)	(9.8, 0.17)	(11.6, 0.18)	(24.1, 0.38)	(11.9, 0.19)	(15.0, 0.27)
		308	293	250	278	279	268	282	177	292	277
C			1.00	0.80	0.89	0.92	0.84	0.79	0.29	0.82	0.78
			(0.0, 0.00)	(9.6, 0.20)	(5.8, 0.11)	(6.4, 0.13)	(9.0, 0.15)	(10.0, 0.17)	(18.6, 0.38)	(9.4, 0.16)	(13.2, 0.25)
			1004	274	315	319	880	913	213	920	305
D				1.00	0.69	0.77	0.63	0.60	0.41	0.64	0.60
				(0.0, 0.00)	(10.9, 0.23)	(7.4, 0.18)	(11.3, 0.22)	(11.1, 0.22)	(14.8, 0.31)	(9.6, 0.21)	(11.6, 0.23)
				291	263	263	256	268	164	274	261
E					1.00	0.79	0.95	0.92	0.34	0.88	0.76
					(0.0, 0.00)	(9.1, 0.19)	(5.9, 0.11)	(7.6, 0.13)	(19.7, 0.39)	(8.2, 0.15)	(13.7, 0.27)
					327	301	289	301	192	307	291
F						1.00	0.70	0.70	0.33	0.69	0.72
						(0.0, 0.00)	(10.5, 0.18)	(9.2, 0.19)	(14.8, 0.34)	(9.8, 0.19)	(9.9, 0.21)
						334	290	302	184	311	293
G							1.00	0.96	0.23	0.92	0.78
							(0.0, 0.00)	(4.0, 0.09)	(17.0, 0.35)	(5.4, 0.12)	(11.0, 0.21)
		R					946	859	194	882	277
H		(P90, COD)						1.00	0.26	0.91	0.78
		N						(0.0, 0.00)	(15.3, 0.34)	(5.9, 0.12)	(9.5, 0.21)
								990	208	914	294
I									1.00	0.21	0.31
									(0.0, 0.00)	(18.3, 0.35)	(9.7, 0.28)
									221	205	180
J										1.00	0.84
										(0.0, 0.00)	(9.8, 0.19)
										999	298
K											1.00
											(0.0, 0.00)
											318

Figure A-105. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Los Angeles, CA.
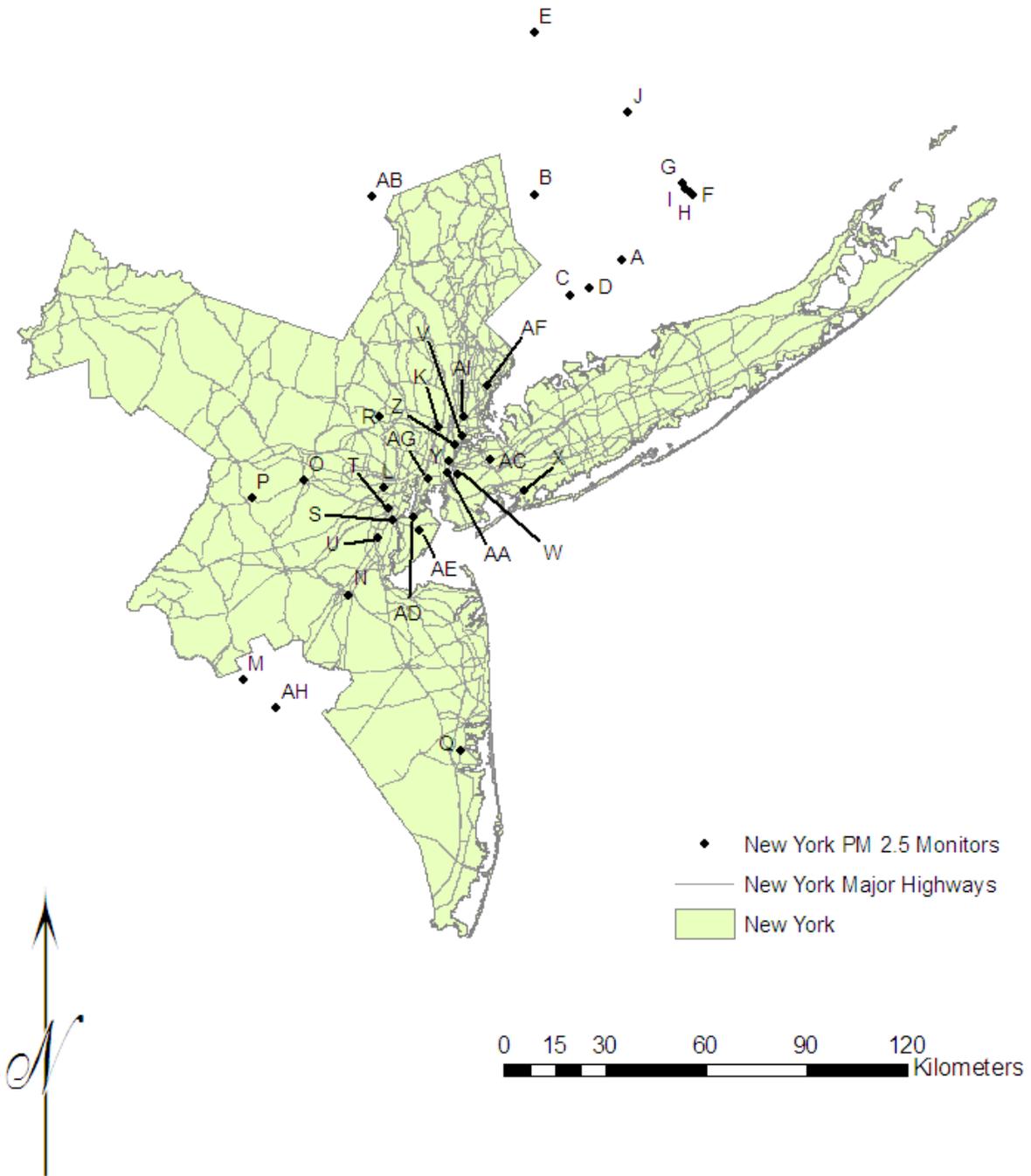
Figure A-106. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for New York City, NY.

Top panel

AQS Site ID		A	B	C	D	E	F	G	H	I	J
Site A	09-001-0010	Mean	13.2	12.5	12.3	11.2	8.0	12.1	12.4	12.8	11.1	12.6
Site B	09-001-1123	Obs	349	339	332	565	341	341	992	338	344	352
Site C	09-001-3005	SD	8.7	8.3	8.1	7.6	6.8	8.0	8.1	8.6	7.5	8.2
Site D	09-001-9003											
Site E	09-005-0005											
Site F	09-009-0026											
Site G	09-009-0027											
Site H	09-009-1123											
Site I	09-009-2008											
Site J	09-009-2123											

1=winter
2=spring
3=summer
4=fall

Bottom panel

AQS Site ID		K	L	M	N	O	P	Q	R	S	T
Site K	34-003-0003											
Site L	34-013-0015	Mean	13.2	13.3	13.7	12.3	10.8	12.1	11.3	10.0	10.6	12.9
Site M	34-017-1003	Obs	345	334	559	545	313	336	336	357	550	330
Site N	34-021-0008	SD	8.9	8.8	8.5	7.7	7.0	7.7	7.7	7.4	6.8	8.7
Site O	34-021-8001											
Site P	34-023-0006											
Site Q	34-027-0004											
Site R	34-027-3001											
Site S	34-029-2002											
Site T	34-031-0005											

1=winter
2=spring
3=summer
4=fall

	AQS Site ID		U	V	W	X	Y	Z	AA	AB	AC	AD
Site V	34-039-0006	Mean	14.5	13.2	12.9	15.5	13.0	13.0	14.0	11.4	15.9	13.5
Site W	34-039-2003	Obs	1017	352	332	349	359	1059	342	337	357	363
Site X	36-005-0080	SD	8.7	8.4	8.4	9.1	8.2	8.2	8.4	7.5	8.9	8.4
Site Y	36-005-0083											
Site Z	36-005-0110											
Site AA	36-047-0122											
Site AB	36-059-0008											
Site AC	36-061-0056											
Site AD	36-061-0079											

Site AE	36-061-0128		AE	AF	AG	AH	AI	AJ
Site AF	36-071-0002	Mean	15.3	10.8	11.8	13.3	11.4	11.7
Site AG	36-081-0124	Obs	341	342	951	337	335	355
Site AH	36-085-0055	SD	8.8	7.6	7.5	8.0	7.3	7.8
Site AI	36-085-0067							
Site AJ	36-119-1002							

Figure A-107. Box plot illustrating the seasonal distribution of 24-h average PM2.5 concentrations for New York City, NY.

Table A-41. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for New York City, NY.

Site	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
A	1.00	0.89	0.97	0.97	0.82	0.96	0.96	0.96	0.96	0.93	0.91	0.91	0.92	0.88	0.84	0.87	0.89	0.84
	(0.0, 0.00)	(5.3, 0.15)	(3.6, 0.09)	(4.8, 0.11)	(11.8, 0.33)	(3.8, 0.11)	(4.0, 0.11)	(3.4, 0.10)	(4.6, 0.12)	(5.1, 0.12)	(5.8, 0.12)	(5.7, 0.12)	(5.5, 0.13)	(6.6, 0.16)	(9.1, 0.19)	(8.3, 0.16)	(7.6, 0.16)	(9.3, 0.21)
	349	322	316	322	325	328	321	324	326	335	329	316	331	301	296	321	318	316
B		1.00	0.93	0.91	0.78	0.91	0.92	0.91	0.91	0.92	0.83	0.84	0.85	0.82	0.79	0.82	0.82	0.78
		(0.0, 0.00)	(4.5, 0.13)	(5.3, 0.14)	(10.4, 0.32)	(4.7, 0.13)	(4.6, 0.13)	(4.6, 0.14)	(5.0, 0.14)	(4.5, 0.13)	(7.3, 0.17)	(7.1, 0.17)	(7.8, 0.19)	(7.2, 0.19)	(7.7, 0.20)	(7.6, 0.18)	(6.6, 0.18)	(8.4, 0.22)
		339	312	315	319	316	313	313	315	330	319	305	321	291	292	310	307	305
C			1.00	0.98	0.82	0.96	0.95	0.96	0.97	0.94	0.91	0.91	0.91	0.89	0.84	0.88	0.89	0.84
			(0.0, 0.00)	(3.4, 0.08)	(10.8, 0.32)	(3.9, 0.10)	(4.1, 0.11)	(3.6, 0.10)	(4.0, 0.11)	(4.8, 0.11)	(5.7, 0.13)	(5.8, 0.14)	(6.5, 0.15)	(5.4, 0.15)	(6.9, 0.17)	(6.3, 0.14)	(6.2, 0.15)	(8.2, 0.20)
			332	314	309	310	308	307	310	319	314	299	316	287	289	307	307	297
D				1.00	0.85	0.96	0.96	0.94	0.96	0.92	0.90	0.89	0.91	0.88	0.87	0.89	0.90	0.86
				(0.0, 0.00)	(8.4, 0.29)	(3.4, 0.11)	(3.8, 0.11)	(5.0, 0.13)	(3.0, 0.10)	(5.5, 0.13)	(7.1, 0.15)	(6.9, 0.15)	(6.7, 0.18)	(6.3, 0.17)	(6.5, 0.16)	(6.0, 0.15)	(5.5, 0.14)	(6.6, 0.18)
				565	314	316	532	315	313	325	319	308	517	506	288	311	309	330
E					1.00	0.82	0.82	0.79	0.83	0.81	0.80	0.77	0.76	0.76	0.79	0.78	0.87	0.87
					(0.0, 0.00)	(10.0, 0.31)	(10.7, 0.33)	(11.4, 0.33)	(8.8, 0.28)	(10.3, 0.32)	(12.5, 0.34)	(13.0, 0.34)	(13.8, 0.39)	(11.6, 0.35)	(9.1, 0.30)	(10.4, 0.32)	(7.9, 0.28)	(7.3, 0.24)
					341	321	313	317	319	330	322	305	323	294	291	316	311	305
F						1.00	0.99	0.98	0.98	0.94	0.88	0.89	0.89	0.86	0.85	0.88	0.87	0.83
						(0.0, 0.00)	(2.1, 0.07)	(2.9, 0.09)	(2.8, 0.09)	(4.7, 0.11)	(6.7, 0.14)	(6.8, 0.15)	(6.8, 0.16)	(6.4, 0.17)	(6.8, 0.18)	(6.1, 0.15)	(7.3, 0.16)	(7.5, 0.21)
						341	319	321	328	321	308	323	293	295	312	310	308	
G							1.00	0.96	0.98	0.93	0.88	0.89	0.89	0.84	0.84	0.86	0.87	0.82
							(0.0, 0.00)	(2.9, 0.10)	(3.6, 0.11)	(5.2, 0.12)	(7.1, 0.15)	(6.7, 0.15)	(6.9, 0.16)	(6.9, 0.18)	(8.0, 0.19)	(7.6, 0.16)	(8.1, 0.17)	(8.4, 0.23)
							992	315	319	326	319	309	526	513	286	310	306	327
H								1.00	0.98	0.94	0.88	0.89	0.89	0.84	0.82	0.85	0.85	0.79
								(0.0, 0.00)	(3.7, 0.10)	(3.7, 0.10)	(7.1, 0.14)	(7.1, 0.14)	(6.6, 0.16)	(6.7, 0.18)	(8.1, 0.20)	(7.8, 0.17)	(7.5, 0.17)	(9.2, 0.23)
								338	320	324	318	303	321	292	285	310	307	304
I									1.00	0.95	0.89	0.90	0.89	0.87	0.85	0.87	0.88	0.83
									(0.0, 0.00)	(4.1, 0.11)	(7.0, 0.16)	(7.0, 0.16)	(7.7, 0.20)	(6.4, 0.18)	(6.6, 0.17)	(6.5, 0.16)	(6.5, 0.15)	(7.6, 0.19)
									344	327	324	307	323	296	291	313	313	310
J										1.00	0.87	0.87	0.87	0.84	0.79	0.82	0.84	0.79
										(0.0, 0.00)	(7.0, 0.16)	(7.2, 0.16)	(8.5, 0.17)	(6.9, 0.18)	(7.9, 0.20)	(8.1, 0.18)	(7.5, 0.17)	(9.0, 0.22)
										352	332	316	334	303	299	321	322	316
K		R									1.00	0.95	0.93	0.88	0.86	0.90	0.92	0.86
		(P90, COD)									(0.0, 0.00)	(3.4, 0.09)	(4.5, 0.12)	(6.4, 0.15)	(7.5, 0.17)	(5.7, 0.13)	(5.8, 0.14)	(8.7, 0.20)
		N									345	314	330	301	296	317	319	312
L												1.00	0.97	0.91	0.86	0.94	0.93	0.87
												(0.0, 0.00)	(4.1, 0.10)	(6.4, 0.14)	(8.0, 0.18)	(5.2, 0.12)	(5.9, 0.13)	(8.3, 0.20)
												334	321	289	288	309	303	301
M													1.00	0.91	0.86	0.93	0.92	0.85
													(0.0, 0.00)	(5.5, 0.14)	(8.4, 0.21)	(6.7, 0.15)	(7.5, 0.18)	(9.7, 0.25)
													559	499	300	326	318	337
N														1.00	0.93	0.95	0.91	0.88
														(0.0, 0.00)	(4.7, 0.14)	(4.1, 0.11)	(5.8, 0.15)	(7.2, 0.20)
														545	270	293	292	316
O															1.00	0.93	0.91	0.94
															(0.0, 0.00)	(4.3, 0.12)	(4.9, 0.14)	(4.3, 0.14)
															313	294	287	279
P																1.00	0.94	0.91
																(0.0, 0.00)	(4.9, 0.12)	(5.5, 0.16)
																336	308	303
Q																	1.00	0.95
																	(0.0, 0.00)	(3.8, 0.13)
																	336	307
R																		1.00
																		(0.0, 0.00)
																		357

	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
A	0.75	0.89	0.90	0.90	0.88	0.92	0.94	0.93	0.93	0.88	0.89	0.94	0.88	0.89	0.93	0.90	0.89	0.96
	(10.4, 0.21)	(6.1, 0.13)	(7.1, 0.15)	(6.0, 0.13)	(7.2, 0.15)	(7.2, 0.16)	(4.0, 0.11)	(4.7, 0.12)	(5.5, 0.13)	(7.6, 0.18)	(7.3, 0.18)	(4.4, 0.11)	(7.2, 0.19)	(6.7, 0.16)	(5.1, 0.12)	(6.2, 0.15)	(7.5, 0.16)	(4.4, 0.12)
	323	315	337	299	316	332	342	348	325	320	340	346	326	323	299	317	318	338
B	0.68	0.84	0.83	0.83	0.84	0.84	0.88	0.85	0.84	0.81	0.81	0.86	0.81	0.92	0.84	0.87	0.86	0.88
	(10.8, 0.23)	(5.9, 0.16)	(8.6, 0.20)	(6.5, 0.18)	(6.8, 0.18)	(9.0, 0.21)	(5.9, 0.16)	(6.8, 0.17)	(7.3, 0.18)	(7.9, 0.20)	(8.4, 0.22)	(7.0, 0.17)	(8.8, 0.23)	(5.8, 0.16)	(6.6, 0.17)	(6.8, 0.18)	(7.1, 0.18)	(5.5, 0.15)
	314	307	328	290	305	325	334	338	317	313	331	336	315	316	292	311	309	329
C	0.76	0.89	0.88	0.89	0.89	0.92	0.95	0.93	0.92	0.89	0.88	0.93	0.88	0.89	0.93	0.91	0.89	0.96
	(8.5, 0.20)	(6.1, 0.14)	(7.8, 0.18)	(6.4, 0.15)	(6.0, 0.15)	(7.8, 0.18)	(4.4, 0.11)	(5.4, 0.13)	(5.6, 0.15)	(6.1, 0.16)	(7.5, 0.20)	(5.3, 0.12)	(7.4, 0.20)	(6.7, 0.15)	(4.7, 0.11)	(5.7, 0.14)	(6.0, 0.15)	(3.5, 0.10)
	307	304	321	283	297	317	326	331	311	306	325	330	308	312	282	305	302	322
D	0.80	0.88	0.88	0.87	0.88	0.89	0.94	0.92	0.91	0.89	0.87	0.92	0.85	0.90	0.92	0.90	0.91	0.96
	(7.7, 0.19)	(7.3, 0.16)	(8.1, 0.20)	(7.1, 0.17)	(6.9, 0.17)	(9.7, 0.21)	(5.6, 0.14)	(6.2, 0.15)	(7.0, 0.17)	(5.9, 0.16)	(9.6, 0.23)	(6.6, 0.15)	(9.2, 0.23)	(5.4, 0.14)	(4.8, 0.12)	(6.5, 0.16)	(5.3, 0.14)	(3.7, 0.10)
	509	306	537	326	304	324	332	548	315	313	330	336	315	313	496	308	310	328
E	0.67	0.79	0.74	0.76	0.75	0.75	0.80	0.78	0.76	0.73	0.74	0.79	0.70	0.88	0.77	0.75	0.80	0.84
	(9.8, 0.32)	(11.3, 0.34)	(14.9, 0.40)	(11.7, 0.36)	(12.1, 0.36)	(15.2, 0.41)	(11.5, 0.34)	(13.1, 0.36)	(13.9, 0.38)	(10.1, 0.33)	(15.7, 0.43)	(13.1, 0.35)	(15.0, 0.42)	(7.6, 0.26)	(11.3, 0.32)	(12.5, 0.36)	(9.4, 0.31)	(9.8, 0.29)
	315	306	329	290	307	324	334	340	319	314	332	338	316	316	294	310	309	331
F	0.79	0.87	0.86	0.86	0.87	0.89	0.93	0.91	0.90	0.90	0.87	0.91	0.86	0.89	0.93	0.89	0.89	0.94
	(7.9, 0.19)	(6.7, 0.15)	(8.5, 0.19)	(6.8, 0.16)	(6.6, 0.16)	(8.2, 0.19)	(5.0, 0.12)	(6.4, 0.14)	(6.7, 0.15)	(5.6, 0.16)	(8.4, 0.20)	(6.3, 0.14)	(8.0, 0.21)	(6.4, 0.16)	(4.6, 0.12)	(5.7, 0.15)	(5.3, 0.15)	(4.1, 0.12)
	316	306	329	293	309	325	335	340	320	317	334	339	319	317	290	312	310	332
G	0.77	0.87	0.87	0.86	0.88	0.89	0.92	0.90	0.90	0.88	0.86	0.91	0.85	0.88	0.90	0.89	0.88	0.93
	(8.7, 0.21)	(6.3, 0.15)	(7.8, 0.18)	(7.0, 0.16)	(6.3, 0.15)	(8.3, 0.17)	(5.4, 0.13)	(5.7, 0.14)	(7.1, 0.15)	(7.5, 0.17)	(8.1, 0.19)	(6.4, 0.14)	(8.2, 0.20)	(6.7, 0.17)	(5.2, 0.13)	(6.1, 0.15)	(6.1, 0.16)	(5.0, 0.14)
	513	304	928	327	303	319	329	958	315	308	327	333	314	311	856	312	309	325
H	0.74	0.86	0.86	0.87	0.87	0.90	0.92	0.89	0.90	0.88	0.87	0.91	0.86	0.88	0.90	0.88	0.86	0.93
	(9.6, 0.22)	(6.6, 0.15)	(8.4, 0.18)	(7.1, 0.16)	(6.9, 0.16)	(7.5, 0.17)	(5.2, 0.13)	(5.6, 0.14)	(6.4, 0.15)	(7.3, 0.19)	(7.9, 0.19)	(5.7, 0.13)	(7.3, 0.20)	(6.9, 0.17)	(5.6, 0.14)	(6.8, 0.16)	(6.4, 0.17)	(5.0, 0.13)
	314	304	326	289	306	322	331	337	315	310	329	335	313	313	290	308	308	327
I	0.76	0.88	0.87	0.88	0.88	0.90	0.93	0.92	0.91	0.87	0.87	0.92	0.86	0.90	0.93	0.89	0.89	0.94
	(8.1, 0.20)	(7.1, 0.17)	(8.7, 0.21)	(7.4, 0.17)	(6.9, 0.17)	(9.4, 0.22)	(5.7, 0.15)	(6.5, 0.16)	(7.2, 0.18)	(6.2, 0.17)	(9.6, 0.24)	(6.3, 0.16)	(9.2, 0.24)	(5.5, 0.13)	(5.1, 0.14)	(6.7, 0.18)	(5.8, 0.16)	(4.1, 0.12)
	315	308	332	293	309	326	334	343	323	313	332	338	318	319	296	310	311	330
J	0.67	0.84	0.85	0.86	0.86	0.88	0.90	0.88	0.86	0.81	0.85	0.89	0.84	0.90	0.88	0.87	0.84	0.91
	(11.1, 0.22)	(6.6, 0.16)	(9.0, 0.19)	(6.7, 0.16)	(6.8, 0.17)	(8.8, 0.19)	(6.1, 0.14)	(7.1, 0.16)	(7.3, 0.17)	(8.2, 0.19)	(9.0, 0.21)	(6.9, 0.15)	(8.9, 0.22)	(6.4, 0.16)	(6.4, 0.15)	(7.5, 0.16)	(7.7, 0.18)	(5.6, 0.14)
	327	316	343	301	318	337	345	351	330	324	343	349	327	329	301	321	320	341
K	0.74	0.94	0.92	0.95	0.92	0.92	0.93	0.92	0.93	0.84	0.90	0.93	0.88	0.89	0.90	0.91	0.89	0.92
	(10.9, 0.21)	(3.9, 0.11)	(5.7, 0.14)	(3.4, 0.10)	(4.3, 0.12)	(6.0, 0.15)	(3.8, 0.12)	(4.2, 0.12)	(4.3, 0.12)	(8.5, 0.19)	(6.2, 0.17)	(3.8, 0.11)	(6.2, 0.18)	(7.4, 0.17)	(5.9, 0.13)	(5.0, 0.13)	(6.5, 0.15)	(4.8, 0.13)
	320	317	336	302	317	330	339	344	324	318	338	343	321	321	294	318	314	335
L	0.78	0.94	0.97	0.98	0.95	0.94	0.93	0.94	0.95	0.86	0.91	0.95	0.91	0.89	0.92	0.96	0.92	0.92
	(9.8, 0.20)	(3.9, 0.11)	(4.5, 0.12)	(2.9, 0.08)	(4.0, 0.10)	(6.3, 0.15)	(4.5, 0.12)	(4.2, 0.11)	(4.1, 0.11)	(8.1, 0.18)	(6.3, 0.17)	(4.2, 0.10)	(5.9, 0.17)	(6.8, 0.17)	(5.4, 0.12)	(4.0, 0.11)	(6.4, 0.14)	(5.4, 0.13)
	313	303	325	292	303	314	323	333	306	305	322	327	309	306	283	305	299	319
M	0.80	0.93	0.97	0.97	0.96	0.95	0.95	0.96	0.97	0.88	0.94	0.96	0.93	0.88	0.95	0.96	0.93	0.93
	(9.9, 0.22)	(5.4, 0.13)	(3.8, 0.09)	(3.5, 0.09)	(4.7, 0.11)	(4.9, 0.11)	(4.7, 0.12)	(3.5, 0.10)	(3.4, 0.09)	(8.3, 0.20)	(4.5, 0.12)	(3.5, 0.10)	(4.5, 0.13)	(8.5, 0.21)	(5.0, 0.14)	(4.3, 0.10)	(6.8, 0.16)	(5.7, 0.17)
	504	318	534	341	319	331	342	545	326	320	339	345	326	323	484	319	318	338
N	0.88	0.86	0.90	0.91	0.91	0.86	0.90	0.89	0.91	0.89	0.85	0.90	0.85	0.85	0.91	0.92	0.92	0.90
	(6.4, 0.17)	(6.5, 0.16)	(6.5, 0.15)	(5.7, 0.13)	(4.5, 0.13)	(8.2, 0.18)	(5.9, 0.14)	(5.4, 0.15)	(5.3, 0.14)	(5.6, 0.17)	(8.1, 0.18)	(5.3, 0.14)	(7.7, 0.18)	(7.5, 0.20)	(4.9, 0.14)	(4.6, 0.13)	(5.3, 0.14)	(5.4, 0.16)
	492	287	519	313	290	301	309	529	297	289	308	313	294	292	477	292	293	306
O	0.87	0.82	0.86	0.87	0.88	0.84	0.87	0.86	0.88	0.89	0.82	0.88	0.81	0.84	0.88	0.89	0.92	0.88
	(5.6, 0.16)	(7.2, 0.18)	(9.9, 0.22)	(7.3, 0.18)	(6.4, 0.16)	(11.1, 0.24)	(6.7, 0.18)	(8.6, 0.19)	(8.2, 0.20)	(5.2, 0.15)	(10.3, 0.25)	(8.4, 0.18)	(10.6, 0.25)	(7.0, 0.18)	(6.1, 0.16)	(6.1, 0.18)	(4.7, 0.14)	(5.4, 0.16)
	295	289	302	280	284	299	308	312	292	295	307	311	290	290	269	290	283	304
P	0.86	0.89	0.92	0.94	0.95	0.88	0.90	0.89	0.92	0.89	0.87	0.91	0.87	0.87	0.91	0.94	0.95	0.91
	(6.2, 0.15)	(6.2, 0.14)	(7.4, 0.17)	(5.0, 0.12)	(4.0, 0.11)	(8.9, 0.19)	(5.9, 0.14)	(6.8, 0.15)	(6.4, 0.14)	(5.3, 0.14)	(8.9, 0.21)	(6.4, 0.14)	(8.3, 0.20)	(6.7, 0.16)	(5.5, 0.13)	(4.7, 0.12)	(3.5, 0.10)	(5.0, 0.14)
	312	307	325	296	305	319	329	335	312	309	327	333	313	311	285	307	306	326
Q	0.79	0.92	0.91	0.93	0.92	0.89	0.90	0.90	0.90	0.83	0.90	0.91	0.87	0.91	0.89	0.90	0.91	0.92
	(8.1, 0.19)	(5.0, 0.14)	(8.2, 0.20)	(6.2, 0.14)	(5.4, 0.15)	(9.7, 0.22)	(6.3, 0.16)	(7.3, 0.17)	(7.3, 0.18)	(6.9, 0.19)	(9.9, 0.24)	(6.9, 0.16)	(9.5, 0.24)	(4.8, 0.14)	(6.0, 0.15)	(6.3, 0.17)	(5.3, 0.14)	(5.5, 0.13)
	313	303	327	287	304	321	328	335	314	306	329	332	311	312	287	303	302	324
R	0.82	0.86	0.84	0.85	0.87	0.82	0.87	0.84	0.86	0.83	0.81	0.86	0.78	0.88	0.86	0.87	0.90	0.88
	(6.5, 0.20)	(7.6, 0.21)	(10.9, 0.26)	(8.2, 0.21)	(7.0, 0.20)	(11.6, 0.28)	(8.6, 0.21)	(10.0, 0.23)	(9.1, 0.24)	(7.0, 0.21)	(11.2, 0.30)	(9.5, 0.22)	(11.0, 0.30)	(6.2, 0.17)	(7.6, 0.20)	(7.8, 0.22)	(5.7, 0.17)	(6.3, 0.17)
	330	296	347	291	304	314	323	355	309	301	324	327	309	308	304	298	302	320
S	1.00	0.69	0.77	0.75	0.78	0.72	0.78	0.79	0.82	0.88	0.74	0.78	0.73	0.69	0.85	0.82	0.88	0.79
	(0.0, 0.00)	(10.4, 0.22)	(10.5, 0.24)	(10.5, 0.21)	(9.2, 0.19)	(12.5, 0.25)	(8.6, 0.19)	(9.3, 0.21)	(9.4, 0.20)	(5.0, 0.16)	(11.6, 0.26)	(9.9, 0.20)	(11.5, 0.25)	(10.3, 0.22)	(7.2, 0.17)	(8.5, 0.18)	(5.5, 0.14)	(8.1, 0.19)
	550	306	525	324	306	325	336	536	319	314	333	339	322	316	478	310	312	331
T		1.00	0.92	0.93	0.93	0.92	0.91	0.91	0.90	0.80	0.87	0.93	0.85	0.89	0.88	0.90	0.86	0.91
		(0.0, 0.00)	(6.0, 0.15)	(4.5, 0.12)	(4.8, 0.13)	(6.7, 0.16)	(5.2, 0.14)	(4.9, 0.13)	(5.6, 0.14)	(8.4, 0.20)	(6.9, 0.18)	(4.9, 0.12)	(7.2, 0.20)	(6.3, 0.17)	(6.2, 0.14)	(5.8, 0.14)	(7.3, 0.17)	(5.9, 0.14)
		330	319	293	301	313	323	329	308	303	321	327	306	308	281	306	298	319
U			1.00	0.98	0.97	0.92	0.91	0.93	0.94	0.84	0.91	0.94	0.90	0.86	0.90	0.96	0.91	0.90
			(0.0, 0.00)	(3.9, 0.10)	(5.0, 0.12)	(5.4, 0.12)	(6.9, 0.15)	(5.2, 0.13)	(4.9, 0.12)	(9.9, 0.22)	(5.0, 0.12)	(5.2, 0.12)	(5.9, 0.14)	(9.6, 0.23)	(6.9, 0.17)	(5.8, 0.12)	(8.4, 0.18)	(7.5, 0.19)
			1017	341	325	337	347	987	332	326	346	351	330	330	878	325	323	343
V				1.00	0.97	0.93	0.92	0.92	0.94	0.83	0.90	0.94	0.91	0.88	0.89	0.96	0.91	0.91
				(0.0, 0.00)	(2.8, 0.09)	(6.1, 0.14)	(5.0, 0.13)	(4.4, 0.12)	(4.2, 0.12)	(8.2, 0.19)	(6.6, 0.16)	(4.3, 0.11)	(6.1, 0.16)	(7.0, 0.18)	(5.8, 0.15)	(4.0, 0.10)	(6.4, 0.15)	(5.3, 0.15)
				352	288	300	307	351	294	290	305	311	294	290	301	291	287	304
W					1.00	0.90	0.91	0.91	0.92	0.85	0.89	0.93	0.88	0.87	0.89	0.96	0.92	0.90
					(0.0, 0.00)	(7.0, 0.16)	(5.5, 0.13)	(5.3, 0.13)	(4.8, 0.13)	(7.0, 0.18)	(6.8, 0.17)	(5.0, 0.12)	(6.9, 0.18)	(6.8, 0.18)	(5.1, 0.14)	(3.7, 0.10)	(4.9, 0.13)	(5.0, 0.15)
					332	316	325	331	310	309	323	328	308	310	281	304	303	320
X						1.00	0.96	0.97	0.95	0.86	0.94	0.97	0.93	0.88	0.93	0.92	0.88	0.93
						(0.0, 0.00)	(5.8, 0.13)	(4.4, 0.11)	(5.0, 0.11)	(10.0, 0.23)	(3.3, 0.09)	(4.5, 0.11)	(4.1, 0.11)	(9.8, 0.24)	(6.9, 0.17)	(6.5, 0.14)	(9.2, 0.20)	(8.2, 0.19)
						349	344	349	328	324	342	348	326	326	301	319	319	340
Y							1.00	0.97	0.96	0.90	0.93	0.98	0.93	0.89	0.97	0.93	0.92	0.97
							(0.0, 0.00)	(3.2, 0.08)	(3.9, 0.09)	(6.5, 0.16)	(5.4, 0.15)	(2.8, 0.08)	(5.4, 0.15)	(6.5, 0.18)	(3.3, 0.09)	(4.9, 0.12)	(5.3, 0.13)	(3.5, 0.11)
							359	359	338	333	352	358	337	335	308	328	329	350
Z								1.00	0.97	0.90	0.94	0.98	0.92	0.88	0.95	0.93	0.91	0.95
								(0.0, 0.00)	(2.9, 0.09)	(7.2, 0.17)	(4.4, 0.13)	(1.8, 0.07)	(4.6, 0.14)	(7.8, 0.19)	(4.0, 0.10)	(4.7, 0.11)	(6.1, 0.14)	(4.9, 0.14)
								1059	342	337	357	363	341	342	919	337	335	355
AA									1.00	0.92	0.94	0.98	0.93	0.87	0.97	0.95	0.94	0.95
									(0.0, 0.00)	(7.1, 0.18)	(3.8, 0.11)	(2.9, 0.07)	(4.1, 0.11)	(8.1, 0.20)	(4.0, 0.11)	(4.3, 0.10)	(6.6, 0.15)	(5.1, 0.15)
									342	317	336	341	319	319	292	313	312	335
AB										1.00	0.85	0.89	0.86	0.79	0.95	0.90	0.93	0.90
										(0.0, 0.00)	(9.2, 0.24)	(7.2, 0.17)	(9.0, 0.23)	(8.1, 0.20)	(4.1, 0.13)	(6.1, 0.16)	(3.8, 0.12)	(5.5, 0.16)
										337	330	337	316	291	310	310	329	
AC											1.00	0.95	0.98	0.84	0.96	0.91	0.89	0.91
											(0.0, 0.00)	(4.4, 0.13)	(3.0, 0.08)	(10.4, 0.26)	(6.6, 0.18)	(6.6, 0.15)	(9.3, 0.21)	(7.4, 0.22)
											357	356	336	304	326	326	348	
AD												1.00	0.93	0.89	0.97	0.95	0.93	0.96
												(0.0, 0.00)	(4.6, 0.14)	(7.1, 0.18)	(4.0, 0.10)	(4.4, 0.10)	(6.0, 0.13)	(4.6, 0.13)
												363	341	339	311	333	333	354
AE													1.00	0.82	0.94	0.92	0.89	0.89

	(0.0, 0.00)	(10.0, 0.26)	(6.2, 0.18)	(5.6, 0.15)	(8.4, 0.20)	(8.0, 0.22)
	341	319	290	313	314	332
AF	1.00	0.86	0.87	0.87	0.91	
		(0.0, 0.00)	(7.0, 0.16)	(7.1, 0.18)	(6.4, 0.16)	(5.5, 0.14)
		342	289	310	313	331
AG		1.00	0.93	0.94	0.96	
			(0.0, 0.00)	(4.8, 0.12)	(4.5, 0.11)	(3.7, 0.11)
			951	289	283	304
AH			1.00	0.97	0.92	
				(0.0, 0.00)	(4.1, 0.10)	(4.9, 0.15)
				337	307	327
AI				1.00	0.92	
					(0.0, 0.00)	(4.8, 0.14)
					335	324
AJ					1.00	
						(0.0, 0.00)
						355
						1.00

Figure A-108. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for New York City, NY.

Figure A-109. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Philadelphia, PA.

AQS Site ID		A	B	C	D	E	F	G	H
Site A	10-003-1003	Mean	13.4	12.6	13.5	14.7	12.5	13.5	13.5	13.2
Site B	10-003-1007	Obs	335	346	331	999	348	539	340	317
Site C	10-003-1012	SD	7.7	7.4	7.7	8.3	7.4	8.0	8.5	8.2
Site D	10-003-2004									
Site E	24-015-0003									
Site F	34-007-0003									
Site G	34-007-1007									
Site H	42-017-0012									

1=winter
2=spring
3=summer
4=fall

AQS Site ID		I	J	K	L	M	N	O
Site I	42-029-0100	Mean	14.2	15.0	12.6	13.8	12.8	14.9	13.4
Site J	42-045-0002	Obs	277	331	307	890	805	596	780
Site K	42-091-0013	SD	8.3	8.1	7.7	8.4	8.0	8.3	7.7
Site L	42-101-0004								
Site M	42-101-0024								
Site N	42-101-0047								
Site O	42-101-0136								

1=winter
2=spring
3=summer
4=fall

Figure A-110.   Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Philadelphia, PA.

Table A-42. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Philadelphia, PA.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	1.00	0.94	0.96	0.98	0.92	0.96	0.93	0.89	0.95	0.92	0.86	0.96	0.96	0.95	0.97
	(0.0, 0.00)	(4.7, 0.12)	(3.1, 0.08)	(3.2, 0.08)	(4.8, 0.12)	(3.5, 0.10)	(4.2, 0.11)	(5.3, 0.13)	(4.2, 0.12)	(4.6, 0.14)	(4.7, 0.15)	(3.5, 0.08)	(3.7, 0.10)	(4.5, 0.12)	(3.2, 0.08)
	335	305	282	318	311	312	308	289	247	298	277	283	243	236	236
B		1.00	0.95	0.93	0.94	0.92	0.88	0.83	0.90	0.87	0.81	0.91	0.92	0.88	0.89
		(0.0, 0.00)	(4.3, 0.12)	(6.4, 0.15)	(3.4, 0.11)	(5.2, 0.14)	(6.0, 0.15)	(6.8, 0.17)	(6.7, 0.17)	(6.5, 0.18)	(5.9, 0.18)	(6.5, 0.14)	(5.0, 0.14)	(7.3, 0.17)	(5.9, 0.13)
		346	288	329	318	313	315	293	253	302	285	293	253	238	246
C			1.00	0.96	0.95	0.94	0.88	0.88	0.93	0.88	0.84	0.93	0.93	0.91	0.93
			(0.0, 0.00)	(4.3, 0.09)	(3.5, 0.11)	(4.7, 0.12)	(5.3, 0.14)	(6.0, 0.14)	(3.5, 0.12)	(6.6, 0.16)	(5.5, 0.17)	(5.0, 0.12)	(4.8, 0.13)	(6.0, 0.14)	(4.6, 0.11)
			331	312	289	292	286	270	242	278	261	281	245	225	237
D				1.00	0.91	0.94	0.92	0.88	0.94	0.90	0.85	0.95	0.93	0.93	0.95
				(0.0, 0.00)	(6.5, 0.15)	(4.9, 0.12)	(5.0, 0.14)	(6.3, 0.15)	(4.1, 0.12)	(5.3, 0.14)	(5.8, 0.18)	(4.3, 0.11)	(5.6, 0.14)	(4.2, 0.10)	(4.5, 0.11)
				999	325	490	317	297	257	312	287	801	732	540	704
E					1.00	0.91	0.87	0.83	0.90	0.86	0.86	0.88	0.90	0.87	0.89
					(0.0, 0.00)	(5.6, 0.14)	(6.1, 0.15)	(6.7, 0.16)	(6.6, 0.16)	(7.1, 0.19)	(5.7, 0.15)	(6.8, 0.15)	(5.3, 0.13)	(7.0, 0.18)	(5.7, 0.13)
					348	320	321	301	255	310	287	296	255	242	254
F						1.00	0.95	0.90	0.92	0.89	0.87	0.96	0.96	0.95	0.96
						(0.0, 0.00)	(3.4, 0.09)	(5.3, 0.13)	(5.4, 0.14)	(5.9, 0.16)	(4.4, 0.15)	(3.7, 0.10)	(3.6, 0.10)	(4.5, 0.13)	(3.4, 0.09)
						539	317	296	261	309	284	466	437	414	396
G							1.00	0.90	0.90	0.87	0.85	0.93	0.97	0.92	0.96
							(0.0, 0.00)	(4.8, 0.14)	(5.9, 0.16)	(6.2, 0.17)	(4.7, 0.16)	(3.7, 0.09)	(3.1, 0.09)	(5.7, 0.13)	(3.5, 0.08)
							340	295	258	305	289	288	251	235	240
H								1.00	0.84	0.83	0.89	0.90	0.94	0.87	0.89
								(0.0, 0.00)	(5.7, 0.16)	(8.0, 0.19)	(4.4, 0.13)	(5.0, 0.13)	(4.0, 0.12)	(5.9, 0.17)	(4.8, 0.13)
								317	240	288	275	273	234	215	227
I									1.00	0.87	0.81	0.91	0.92	0.90	0.92
									(0.0, 0.00)	(5.5, 0.17)	(5.7, 0.17)	(4.9, 0.14)	(5.4, 0.15)	(5.2, 0.16)	(5.1, 0.14)
			R						277	248	228	235	215	196	195
J			(P90, COD)							1.00	0.79	0.89	0.89	0.89	0.91
			N							(0.0, 0.00)	(7.4, 0.21)	(5.8, 0.15)	(6.4, 0.17)	(5.7, 0.13)	(5.0, 0.14)
										331	278	282	246	237	231
K											1.00	0.87	0.95	0.84	0.86
											(0.0, 0.00)	(4.7, 0.15)	(3.7, 0.13)	(6.8, 0.20)	(4.3, 0.13)
											307	268	230	211	212
L												1.00	0.98	0.95	0.97
												(0.0, 0.00)	(3.1, 0.09)	(3.7, 0.11)	(3.4, 0.07)
												890	672	512	630
M													1.00	0.95	0.96
													(0.0, 0.00)	(4.7, 0.14)	(3.2, 0.09)
													805	495	563
N														1.00	0.97
														(0.0, 0.00)	(3.5, 0.10)
														596	447
O															1.00
															(0.0, 0.00)
															780

Figure A-111. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Philadelphia, PA.
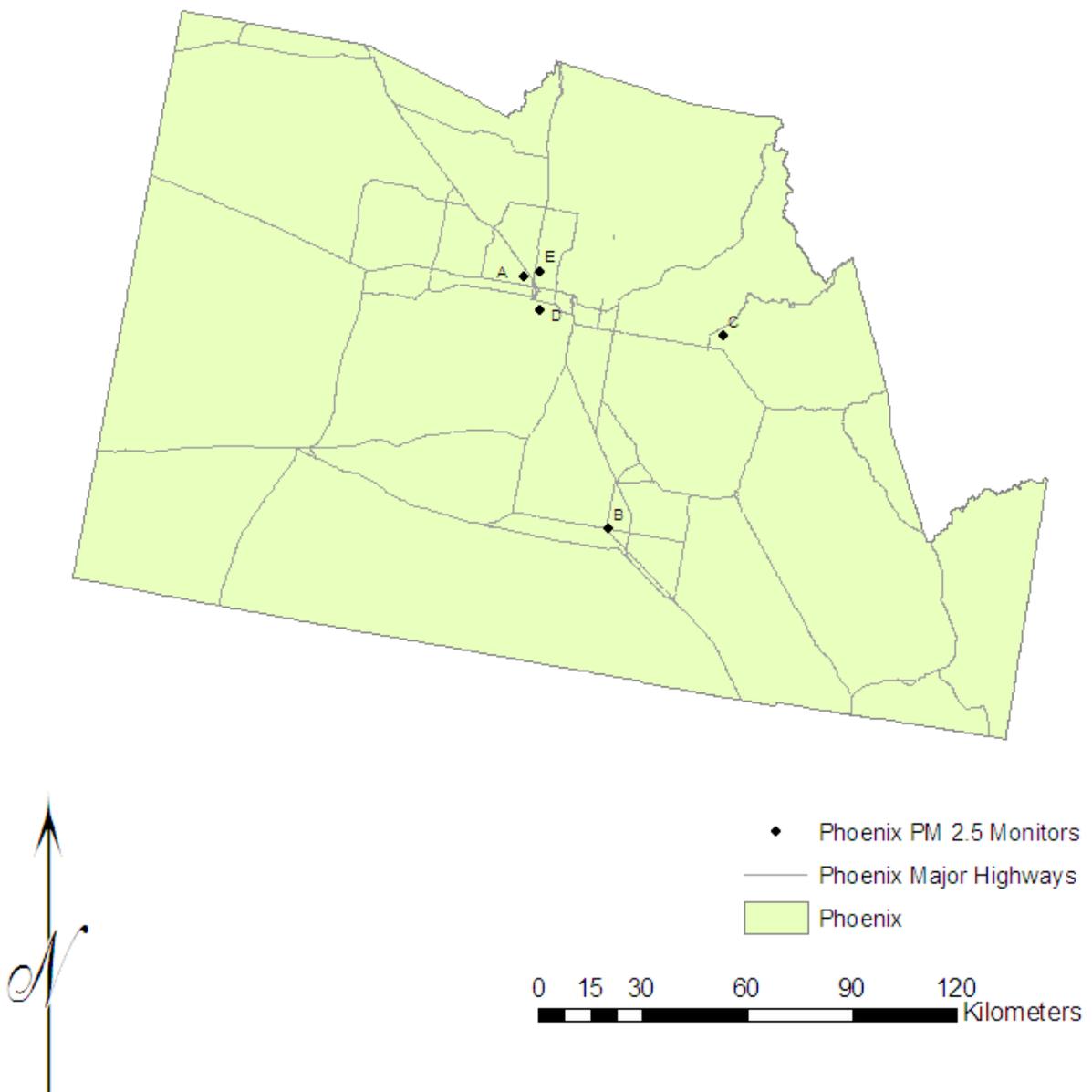
Figure A-112. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Phoenix, AZ.

AQS Site ID		A	B	C	D	E
Site A	04-013-0019					
Site B	04-013-4003	Mean	12.3	12.6	9.8	8.9	5.9
Site C	04-013-9997	Obs	370	352	360	227	325
Site D	04-021-0001	SD	7.6	7.3	5.5	4.4	2.8
Site E	04-021-3002						
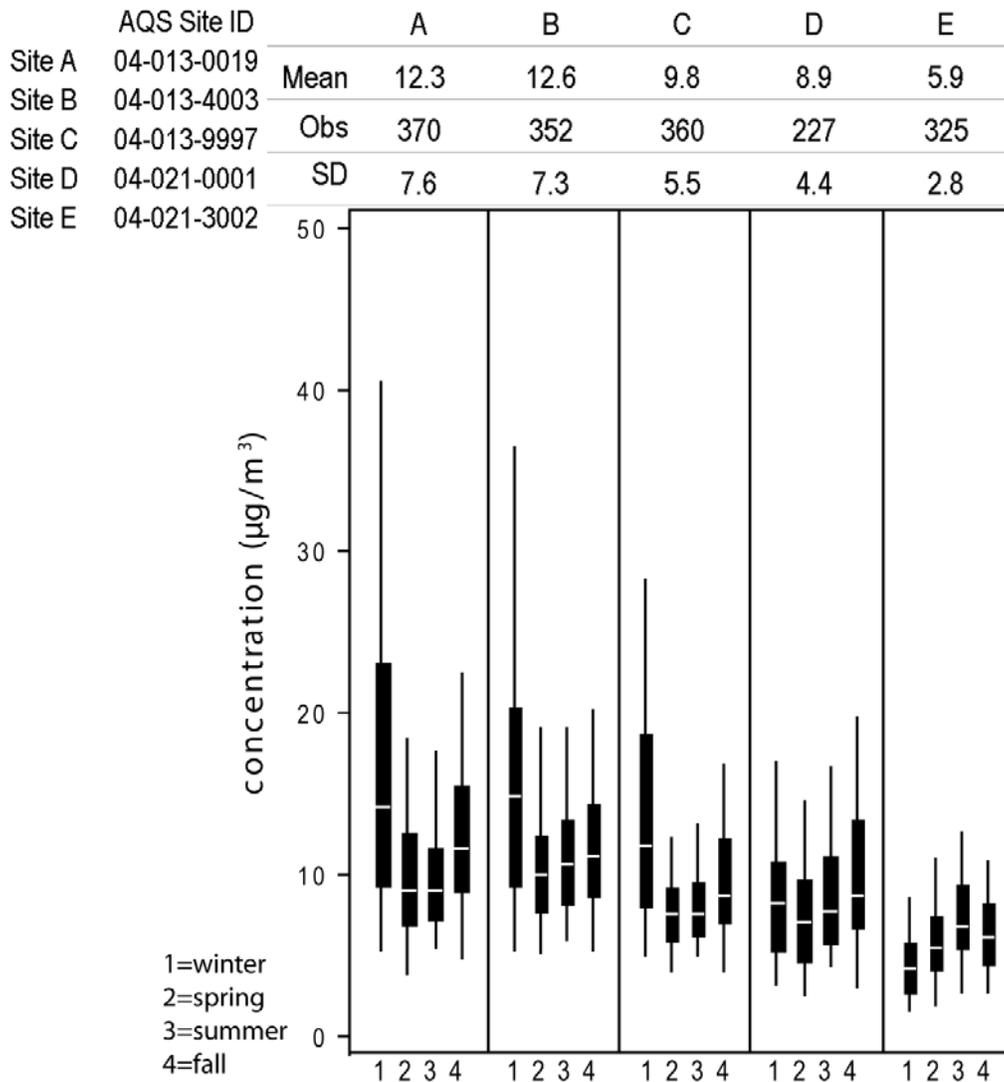
Figure A-113. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Phoenix, AZ.

Table A-43.   Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Phoenix, AZ.

	A	B	C	D	E
A	1.00	0.87	0.92	0.50	0.12
	(0.0, 0.00)	(6.4, 0.15)	(6.5, 0.16)	(10.4, 0.25)	(14.4, 0.40)
	370	345	355	222	321
B		1.00	0.89	0.54	0.23
		(0.0, 0.00)	(6.8, 0.17)	(9.6, 0.25)	(13.2, 0.40)
		352	338	212	307
C			1.00	0.54	0.18
			(0.0, 0.00)	(7.2, 0.20)	(9.3, 0.33)
			360	216	315
D				1.00	0.51
	R			(0.0, 0.00)	(7.8, 0.27)
	(P90, COD)			227	200
E	N				1.00
					(0.0, 0.00)
					325
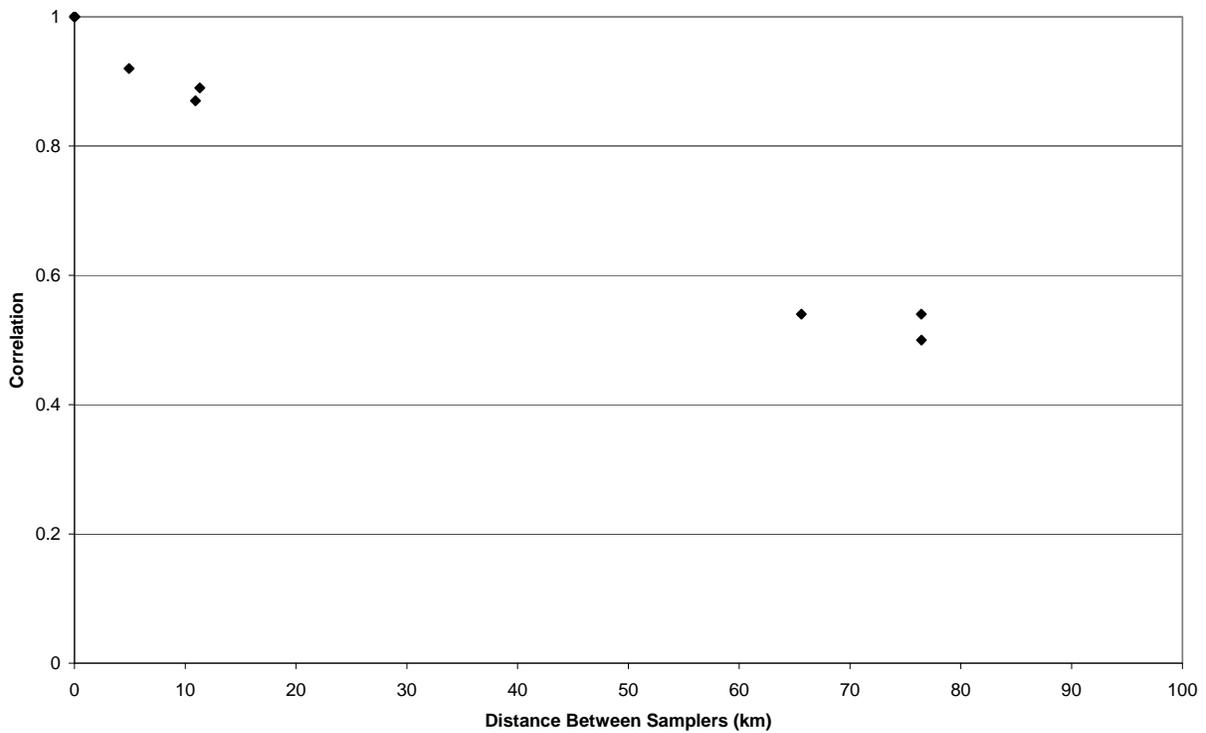
Figure A-114.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Phoenix, AZ.
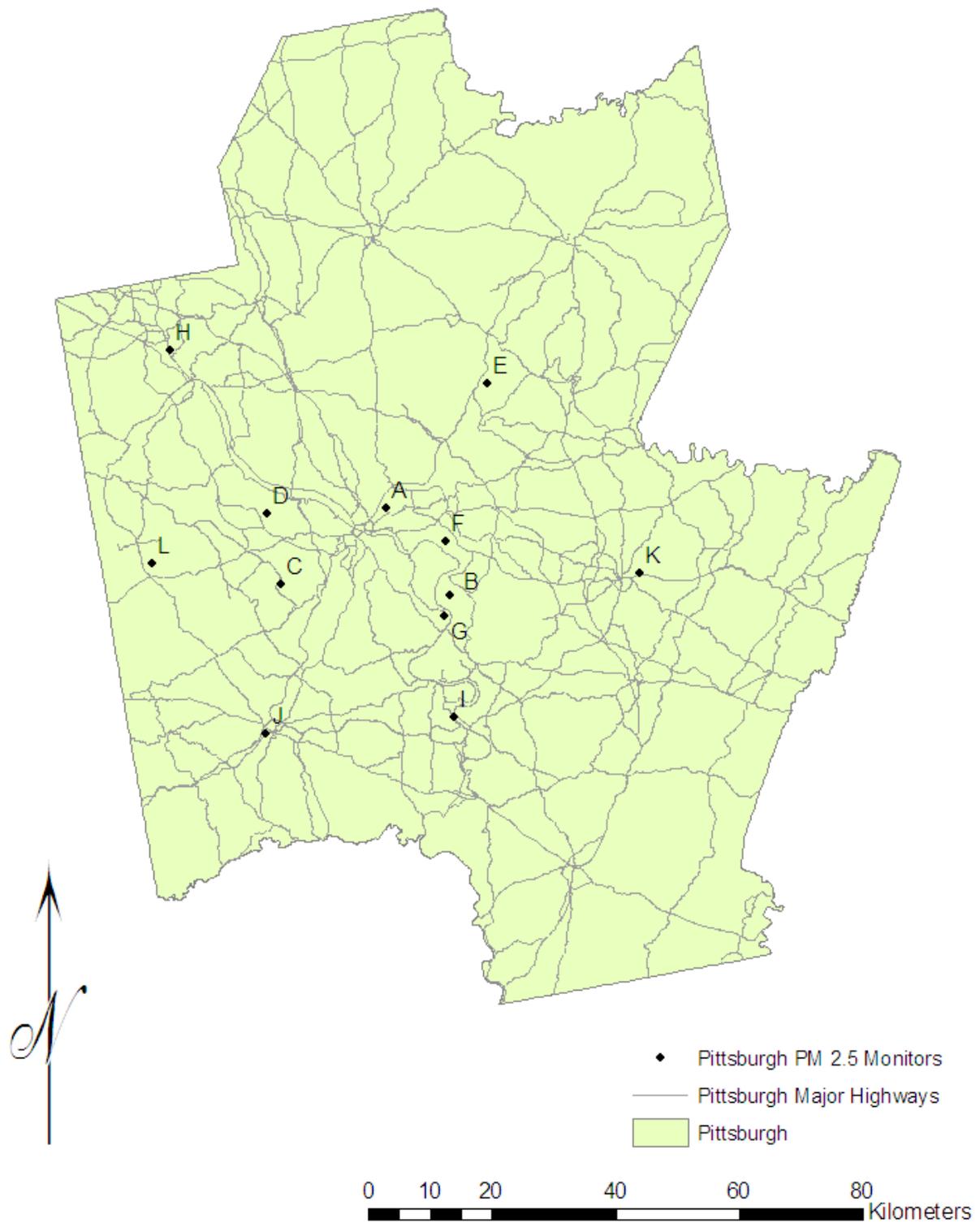
Figure A-115. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Pittsburgh, PA.

	A	B	C	D	E	F
Mean	15.1	19.8	13.2	13.6	15.1	16.4
Obs	1063	1066	306	165	332	337
SD	8.9	14.7	8.0	8.5	9.0	9.5

AQS Site ID

Site A 42-003-0008
Site B 42-003-0064
Site C 42-003-0067
Site D 42-003-0095
Site E 42-003-1008
Site F 42-003-1301

1=winter
2=spring
3=summer
4=fall

	G	H	I	J	K	L
Mean	15.3	16.4	15.5	14.8	13.4	15.4
Obs	171	328	354	345	966	350
SD	8.3	9.3	8.6	8.0	8.6	8.7

AQS Site ID

Site G 42-003-3007
Site H 42-007-0014
Site I 42-125-0005
Site J 42-125-0200
Site K 42-125-5001
Site L 42-129-0008

1=winter
2=spring
3=summer
4=fall

Figure A-116. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Pittsburgh, PA.

Table A-44.   Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Pittsburgh, PA.

	A	B	C	D	E	F	G	H	I	J	K	L
A	1.00	0.79	0.95	0.92	0.93	0.95	0.95	0.85	0.90	0.93	0.91	0.88
	(0.0, 0.00)	(15.9, 0.19)	(5.6, 0.13)	(4.7, 0.11)	(4.7, 0.11)	(4.9, 0.10)	(3.8, 0.10)	(6.4, 0.13)	(6.4, 0.13)	(5.0, 0.12)	(6.0, 0.13)	(5.6, 0.12)
	1063	1035	298	164	323	329	170	319	344	337	934	340
B		1.00	0.71	0.65	0.80	0.85	0.76	0.69	0.71	0.68	0.68	0.67
		(0.0, 0.00)	(16.9, 0.24)	(17.4, 0.25)	(14.4, 0.19)	(12.5, 0.14)	(15.7, 0.20)	(17.0, 0.19)	(15.7, 0.21)	(17.8, 0.23)	(19.3, 0.25)	(15.9, 0.21)
		1066	303	165	329	335	171	324	350	341	938	346
C			1.00	0.93	0.90	0.91	0.94	0.80	0.93	0.96	0.95	0.91
			(0.0, 0.00)	(2.8, 0.09)	(6.6, 0.16)	(8.7, 0.17)	(6.0, 0.14)	(9.4, 0.19)	(6.7, 0.15)	(4.6, 0.12)	(4.5, 0.10)	(6.5, 0.15)
			306	144	282	282	148	268	290	286	270	286
D				1.00	0.84	0.87	0.91	0.79	0.89	0.91	0.97	0.85
				(0.0, 0.00)	(6.4, 0.15)	(8.5, 0.16)	(5.8, 0.13)	(9.2, 0.17)	(5.9, 0.13)	(4.6, 0.11)	(3.1, 0.08)	(6.5, 0.15)
				165	153	161	158	156	158	155	146	157
E					1.00	0.90	0.90	0.84	0.85	0.86	0.88	0.83
					(0.0, 0.00)	(6.4, 0.13)	(6.5, 0.13)	(6.8, 0.14)	(8.3, 0.16)	(7.7, 0.16)	(7.6, 0.15)	(7.3, 0.15)
					332	313	157	295	320	315	290	318
F						1.00	0.91	0.82	0.88	0.88	0.89	0.86
						(0.0, 0.00)	(6.7, 0.13)	(7.4, 0.14)	(7.1, 0.15)	(7.9, 0.15)	(8.8, 0.17)	(7.0, 0.14)
						337	167	302	327	319	296	322
G							1.00	0.78	0.94	0.93	0.90	0.91
							(0.0, 0.00)	(7.3, 0.16)	(4.0, 0.10)	(5.0, 0.11)	(6.6, 0.15)	(5.0, 0.13)
							171	159	163	159	149	161
H								1.00	0.80	0.78	0.82	0.70
		R						(0.0, 0.00)	(8.4, 0.15)	(8.2, 0.17)	(9.0, 0.18)	(9.2, 0.18)
		(P90, COD)						328	317	309	288	314
I		N							1.00	0.93	0.89	0.88
									(0.0, 0.00)	(5.0, 0.11)	(7.2, 0.16)	(6.0, 0.13)
									354	334	310	339
J										1.00	0.93	0.88
										(0.0, 0.00)	(5.5, 0.12)	(5.9, 0.13)
										345	302	331
K											1.00	0.86
											(0.0, 0.00)	(6.9, 0.15)
											966	306
L												1.00
												(0.0, 0.00)
												350

Figure A-117.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Pittsburgh, PA.
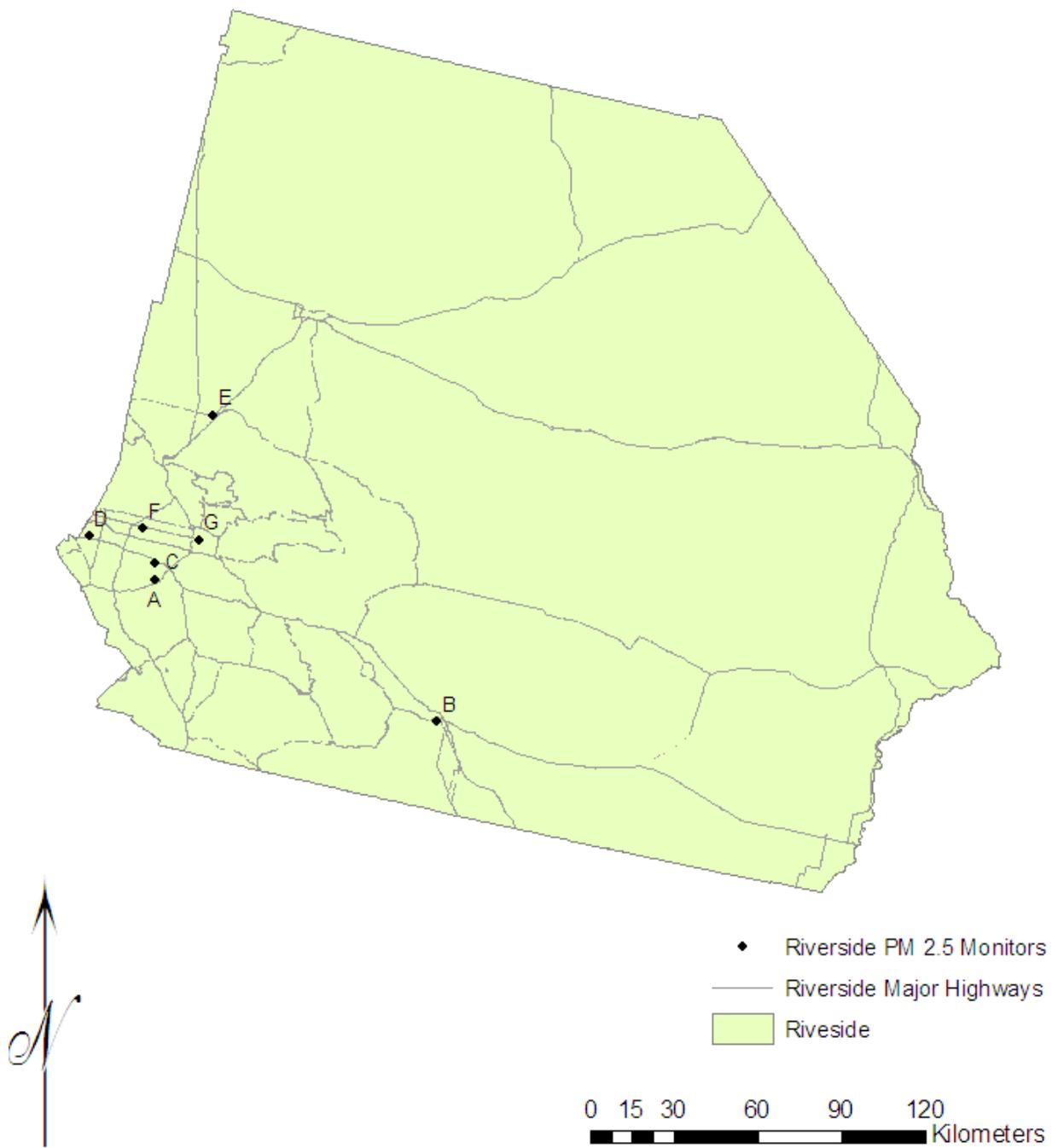
Figure A-118. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Riverside, CA.

AQS Site ID		A	B	C	D	E	F	G
Site A	06-065-1003							
		Mean	17.7	9.9	19.7	18.4	9.9	18.4	17.7
Site B	06-065-2002							
		Obs	314	310	934	319	236	328	310
Site C	06-065-8001							
		SD	11.6	4.9	12.7	10.9	4.4	11.9	12.2
Site D	06-071-0025								
Site E	06-071-0306								
Site F	06-071-2002								
Site G	06-071-9004								
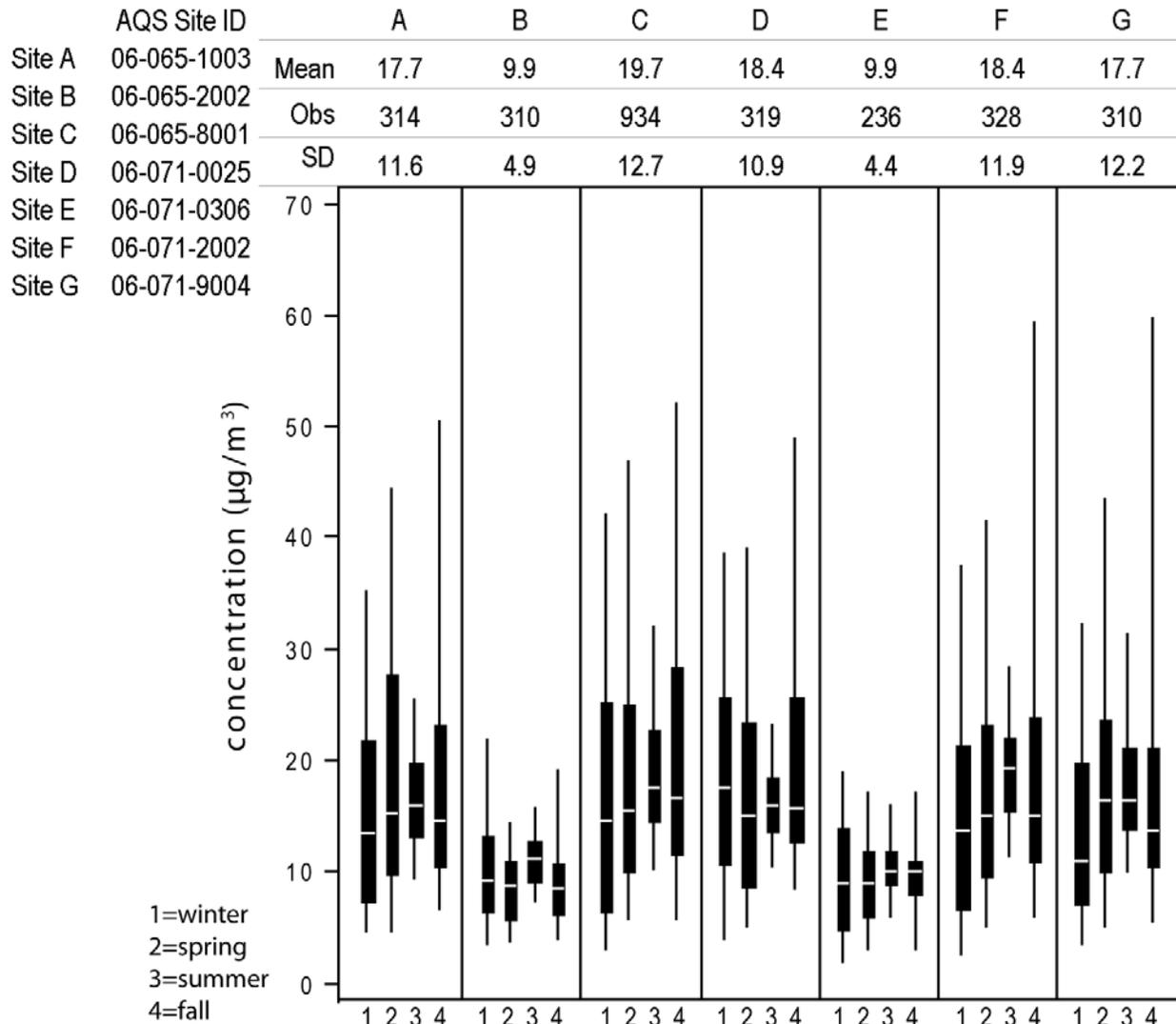
Figure A-119. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for Riverside, CA.

Table A-45.   Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Riverside, CA.

	A	B	C	D	E	F	G
A	1.00	0.45	0.96	0.92	0.36	0.94	0.90
	(0.0, 0.00)	(20.6, 0.32)	(5.0, 0.10)	(7.2, 0.13)	(22.1, 0.35)	(6.0, 0.12)	(5.7, 0.13)
	314	269	297	282	191	281	273
B		1.00	0.49	0.49	0.42	0.49	0.50
		(0.0, 0.00)	(22.7, 0.35)	(20.9, 0.34)	(8.2, 0.25)	(19.7, 0.33)	(18.8, 0.31)
		310	289	270	203	285	266
C			1.00	0.91	0.37	0.92	0.91
			(0.0, 0.00)	(8.2, 0.14)	(26.6, 0.37)	(6.9, 0.12)	(7.6, 0.12)
			934	300	227	302	287
D				1.00	0.36	0.93	0.82
				(0.0, 0.00)	(20.1, 0.35)	(6.7, 0.14)	(9.6, 0.17)
				319	195	289	274
E		R			1.00	0.40	0.41
		(P90, COD)			(0.0, 0.00)	(21.1, 0.36)	(21.6, 0.34)
		N			236	201	190
F						1.00	0.90
						(0.0, 0.00)	(6.7, 0.12)
						328	276
G							1.00
							(0.0, 0.00)
							310
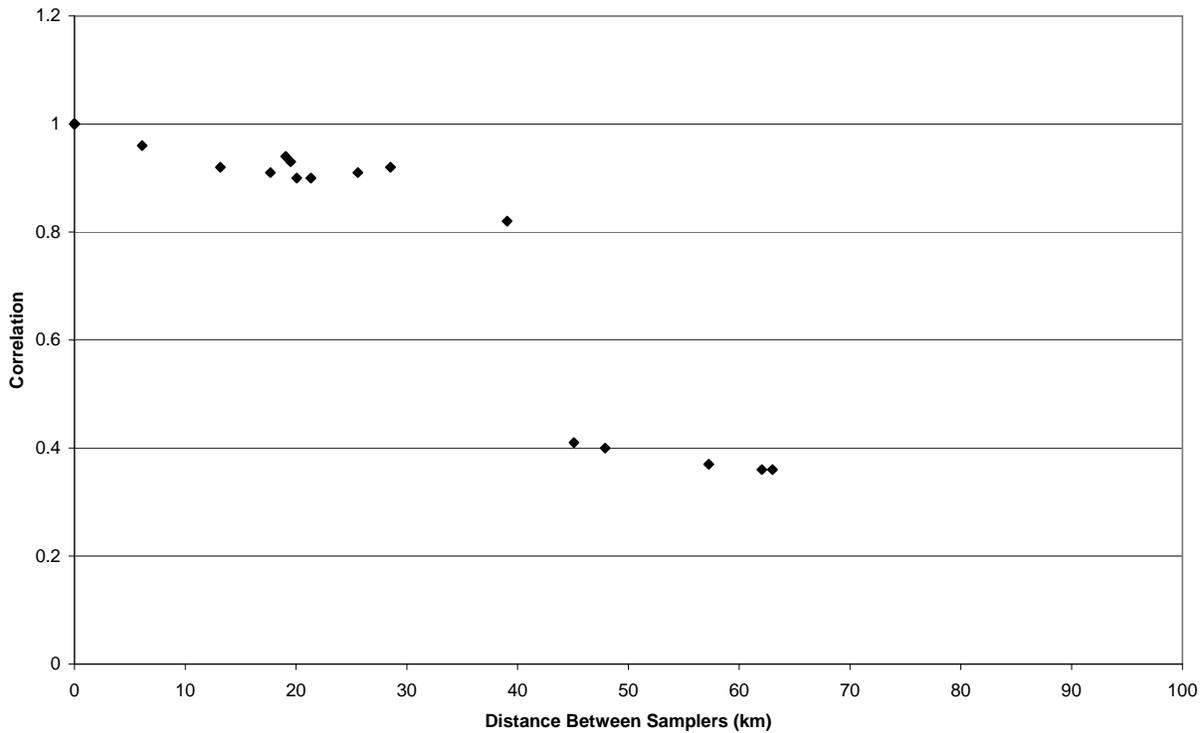
Figure A-120.   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Riverside CA.
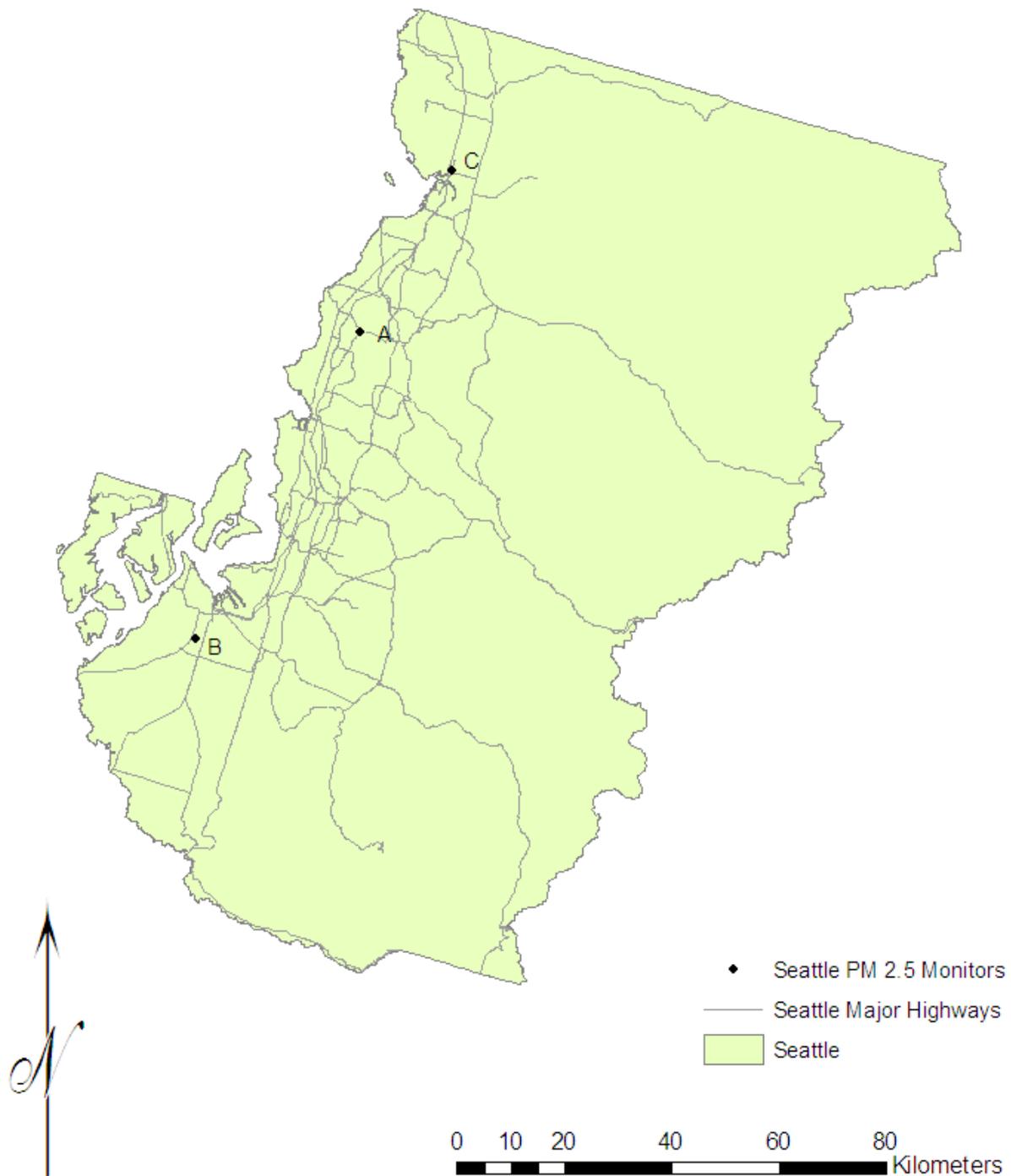
Figure A-121. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for Seattle, WA.

AQS Site ID		A	B	C
Site A 53-033-0024	Mean	8.9	10.2	9.2
Site B 53-053-0029	Obs	352	354	591
Site C 53-061-1007	SD	7.3	10.1	7.9

1=winter
2=spring
3=summer
4=fall
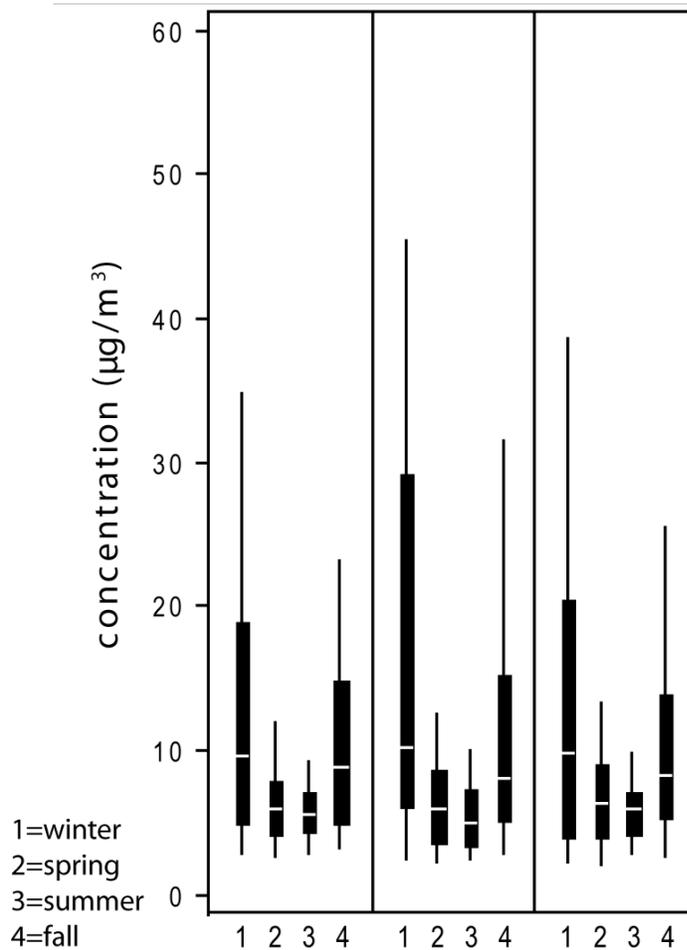
Figure A-122. Box plot illustrating the seasonal distribution of 24-h average PM$_{2.5}$ concentrations for Seattle, WA.

Table A-46. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for Seattle, WA.

			A	B	C
A			1.00	0.89	0.86
			(0.0, 0.00)	(6.3, 0.16)	(4.5, 0.14)
			352	337	331
B	R			1.00	0.80
	(P90, COD)			(0.0, 0.00)	(7.8, 0.20)
	N			354	335
C					1.00
					(0.0, 0.00)
					591
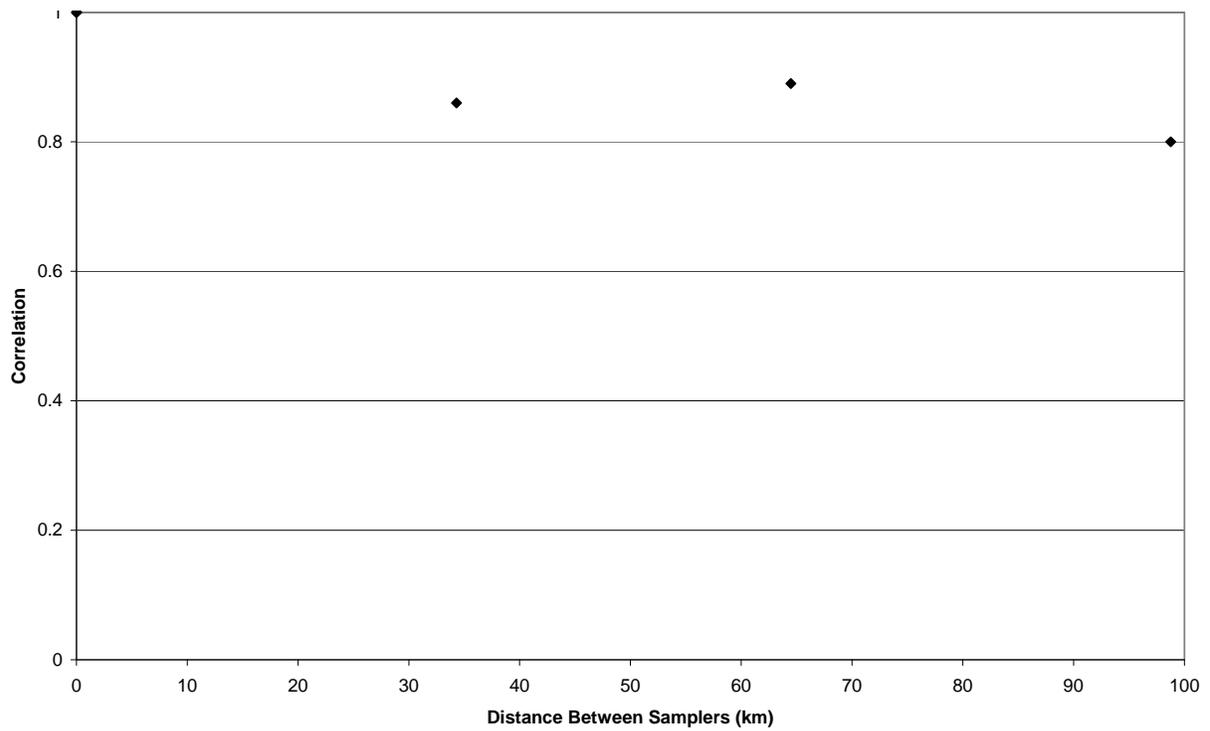
Figure A-123. PM$_{10}$ inter-sampler correlations as a function of distance between monitors for Seattle, WA.
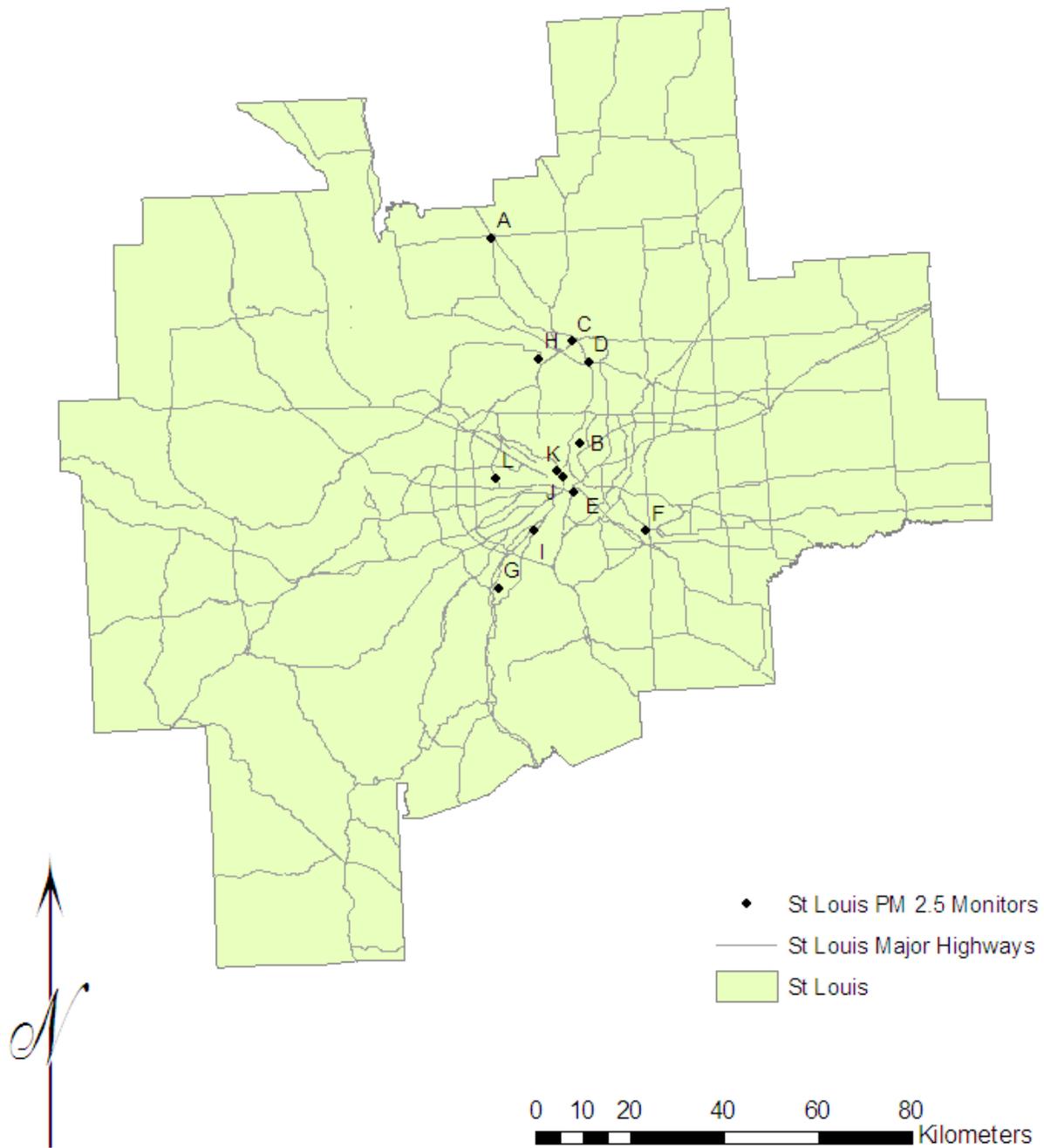
Figure A-124. Map of PM$_{2.5}$ FRM distribution with AQS Site IDs for St. Louis, MO.

AQS Site ID		A	B	C	D	E	F
Site A 17-083-1001	Mean	13.2	16.5	14.6	14.4	15.8	14.2
Site B 17-119-1007							
Site C 17-119-2009	Obs	173	329	163	349	166	349
Site D 17-119-3007							
Site E 17-163-0010	SD	7.9	8.2	7.7	7.5	7.6	7.1
Site F 17-163-4001							

1=winter
2=spring
3=summer
4=fall
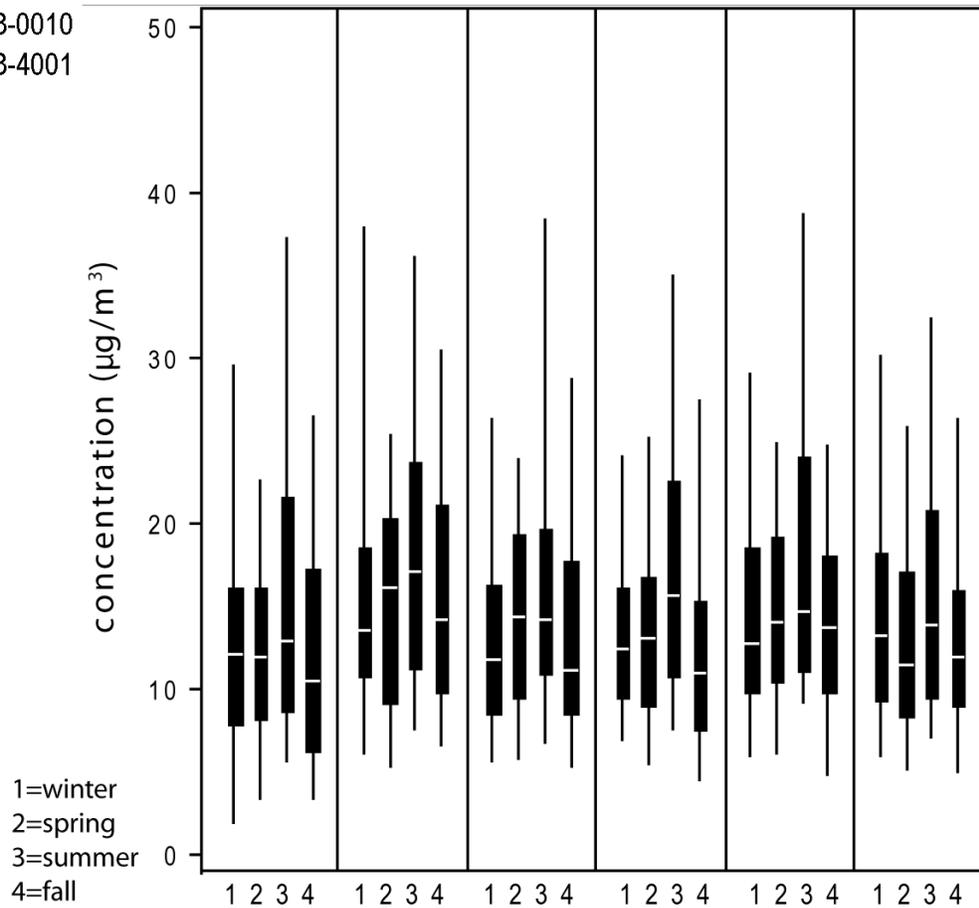
AQS Site ID		G	H	I	J	K	L
Site G	29-099-0012	Mean	13.9	13.2	13.5	14.4	14.4	14.6
Site H	29-183-1002							
Site I	29-189-2003	Obs	1040	566	619	1049	1038	1046
Site J	29-510-0007	SD	7.4	7.4	7.3	7.3	7.5	7.5
Site K	29-510-0085							
Site L	29-510-0087							

1=winter
2=spring
3=summer
4=fall
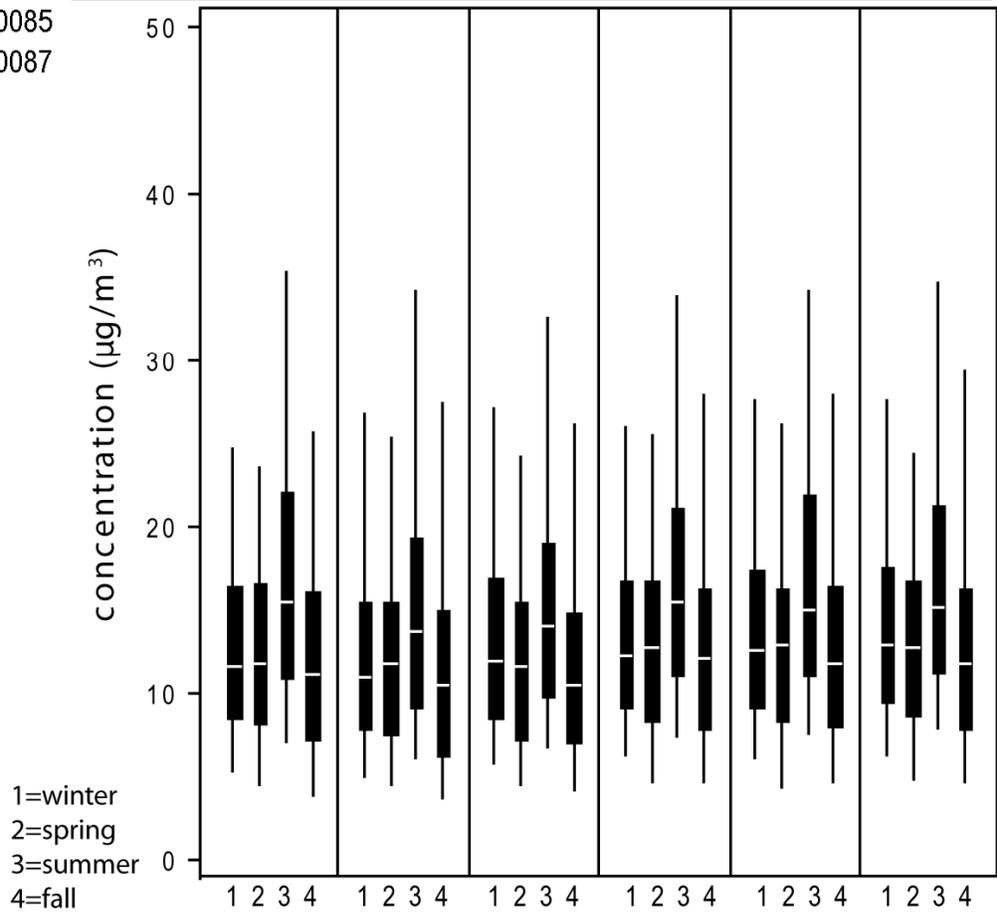
Figure A-125. Box plot illustrating the seasonal distribution of 24-h average $PM_{2.5}$ concentrations for St. Louis, MO.

Table A-47. Inter-sampler correlation statistics for each pair of PM$_{2.5}$ AQS data for St. Louis, MO.

	A	B	C	D	E	F	G	H	I	J	K	L
A	1.00	0.85	0.93	0.89	0.88	0.86	0.85	0.93	0.86	0.84	0.84	0.88
	(0.0, 0.00)	(10.5, 0.23)	(4.7, 0.17)	(5.0, 0.17)	(7.3, 0.20)	(6.2, 0.18)	(4.8, 0.17)	(4.1, 0.13)	(4.4, 0.16)	(6.0, 0.18)	(5.7, 0.19)	(5.3, 0.17)
	173	156	129	162	146	156	167	158	162	168	169	166
B		1.00	0.89	0.86	0.85	0.82	0.88	0.89	0.88	0.86	0.87	0.89
		(0.0, 0.00)	(8.6, 0.16)	(7.4, 0.16)	(7.7, 0.16)	(8.6, 0.17)	(7.8, 0.17)	(8.2, 0.18)	(7.9, 0.17)	(7.7, 0.17)	(7.5, 0.16)	(6.8, 0.14)
		329	135	301	156	306	312	305	318	316	316	315
C			1.00	0.94	0.91	0.88	0.90	0.96	0.94	0.90	0.89	0.94
			(0.0, 0.00)	(4.0, 0.11)	(6.4, 0.13)	(5.7, 0.13)	(5.5, 0.13)	(3.9, 0.11)	(5.3, 0.11)	(5.7, 0.13)	(5.6, 0.14)	(4.4, 0.11)
			163	139	124	133	158	141	144	158	160	156
D				1.00	0.89	0.84	0.89	0.94	0.92	0.89	0.88	0.92
				(0.0, 0.00)	(5.7, 0.13)	(6.0, 0.15)	(4.9, 0.12)	(4.3, 0.12)	(4.5, 0.11)	(4.7, 0.13)	(4.6, 0.12)	(3.9, 0.11)
				349	156	314	331	315	326	335	332	336
E					1.00	0.90	0.91	0.90	0.91	0.93	0.91	0.95
					(0.0, 0.00)	(5.5, 0.12)	(6.2, 0.13)	(5.8, 0.16)	(5.3, 0.14)	(5.1, 0.13)	(4.9, 0.13)	(3.7, 0.10)
					166	152	159	153	157	160	163	160
F						1.00	0.89	0.86	0.88	0.88	0.85	0.88
						(0.0, 0.00)	(5.4, 0.12)	(6.1, 0.16)	(5.4, 0.13)	(5.3, 0.14)	(5.6, 0.14)	(5.4, 0.13)
						349	333	317	332	337	332	334
G		R					1.00	0.93	0.94	0.96	0.93	0.94
		(P90, COD)					(0.0, 0.00)	(4.3, 0.10)	(3.3, 0.08)	(2.9, 0.08)	(3.9, 0.10)	(3.8, 0.10)
		N					1040	533	586	994	987	992
H								1.00	0.96	0.95	0.95	0.96
								(0.0, 0.00)	(3.0, 0.08)	(4.1, 0.12)	(3.8, 0.12)	(4.0, 0.11)
								566	550	552	546	544
I									1.00	0.96	0.95	0.96
									(0.0, 0.00)	(3.1, 0.09)	(3.1, 0.10)	(3.4, 0.09)
									619	605	599	598
J										1.00	0.96	0.97
										(0.0, 0.00)	(2.5, 0.09)	(2.5, 0.08)
										1049	1001	1007
K											1.00	0.97
											(0.0, 0.00)	(1.9, 0.07)
											1038	991
			L									1.00
												(0.0, 0.00)
												1046

Figure A-126   PM$_{10}$ inter-sampler correlations as a function of distance between monitors for St. Louis, MO.

Table A-48. Correlation coefficients of hourly and daily average particle number, surface and volume concentrations in selected particle size ranges.

Size range (nm)	Hourly averages					Daily avg
	All days (N = 5481)	Sundays (N = 701)	Weekdays (N = 3227)	Event days (N = 577)	No events (N = 4904)	All days (N = 263)
3–10	0.40	0.24	0.42	0.73	0.37	0.32
10–30	0.35	0.22	0.31	0.57	0.33	0.27
30–50	0.38	0.42	0.29	0.56	0.36	0.36
50–100	0.46	0.56	0.39	0.57	0.45	0.46
100–500	0.55	0.65	0.49	0.62	0.55	0.55
500–800	0.73	0.75	0.70	0.76	0.72	0.71
10–100	0.31	0.28	0.24	0.52	0.29	0.24
10–800	0.55	0.65	0.49	0.62	0.55	0.55
Total number	0.30	0.24	0.24	0.58	0.28	0.20
Total surface	0.57	0.63	0.51	0.65	0.56	0.57
Total volume	0.66	0.69	0.62	0.73	0.65	0.67

Source: Tuch et al. (2006)

A.1.1. Speciation
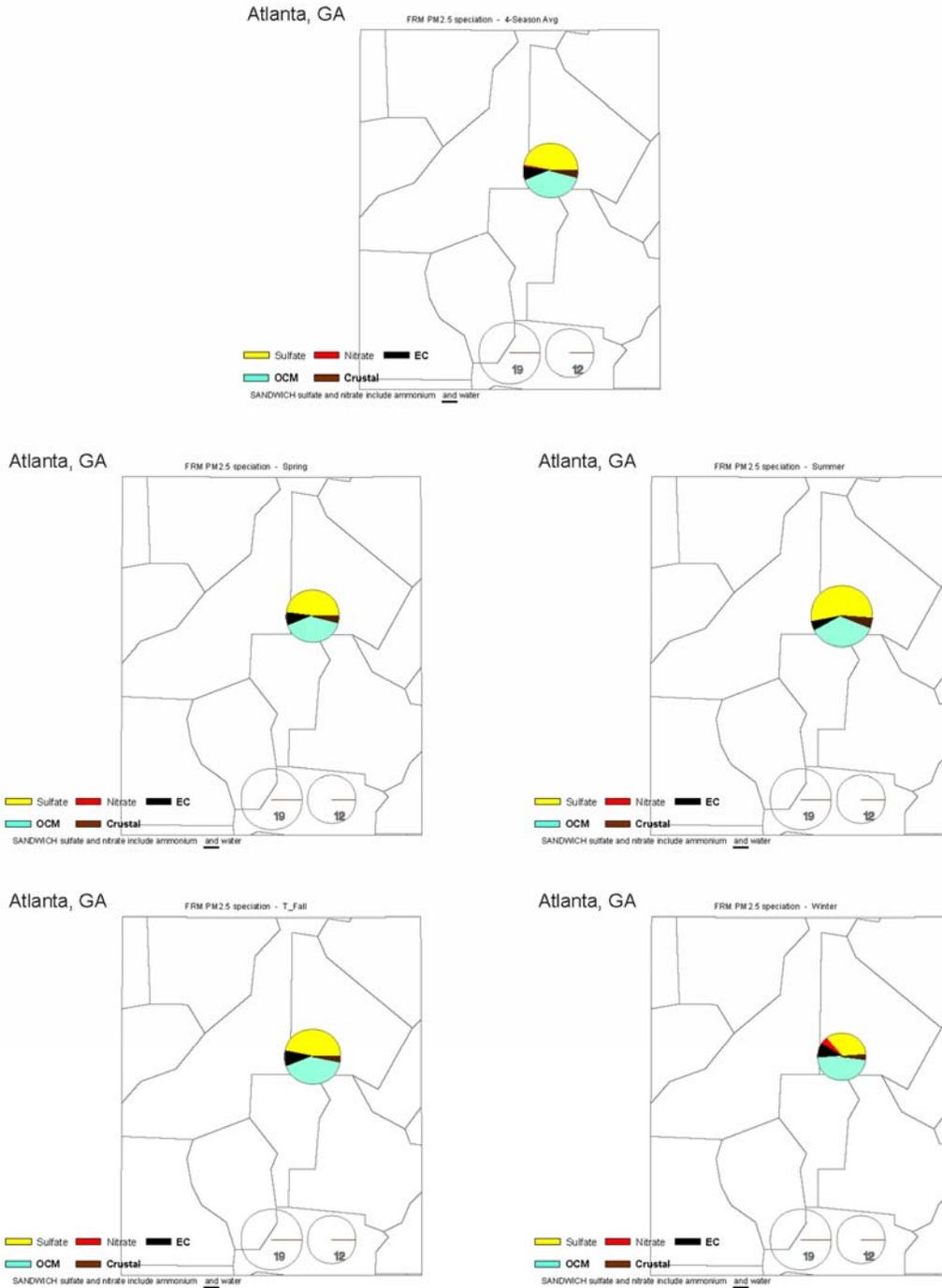
Figure A-127. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Atlanta, GA.
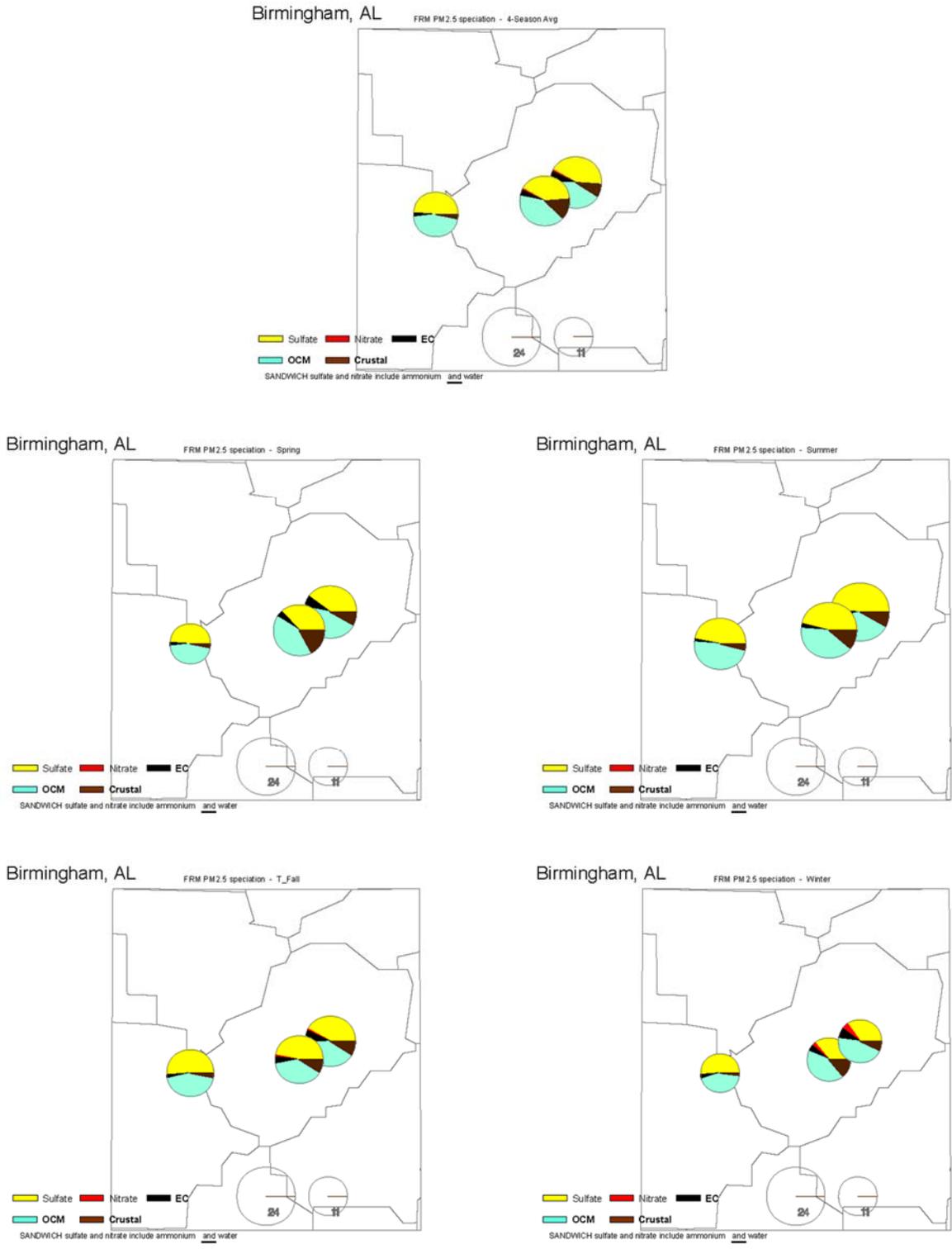
Figure A-128. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Birmingham, AL.
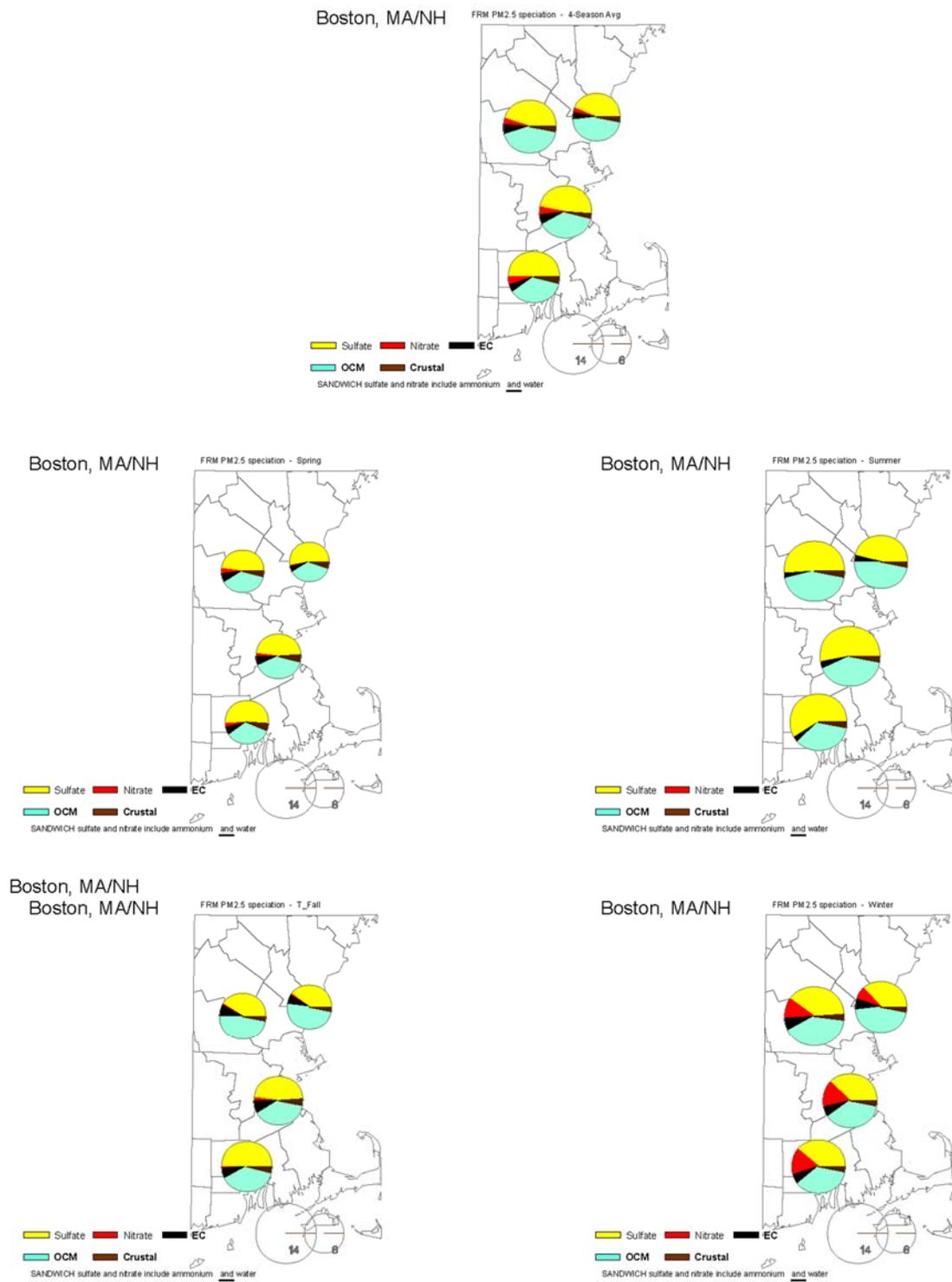
Figure A-129. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Boston, MA.
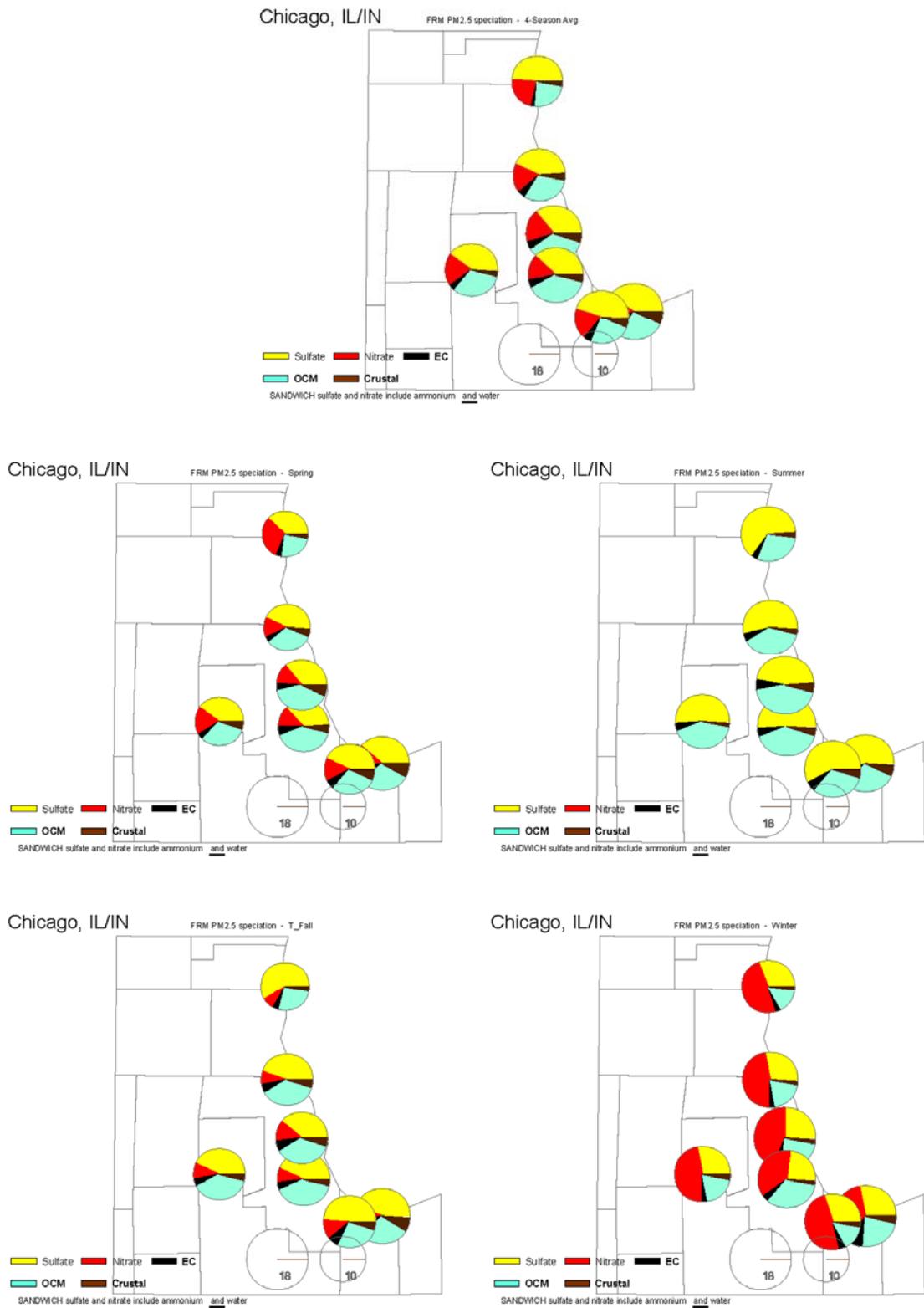
Figure A-130. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Chicago, IL.
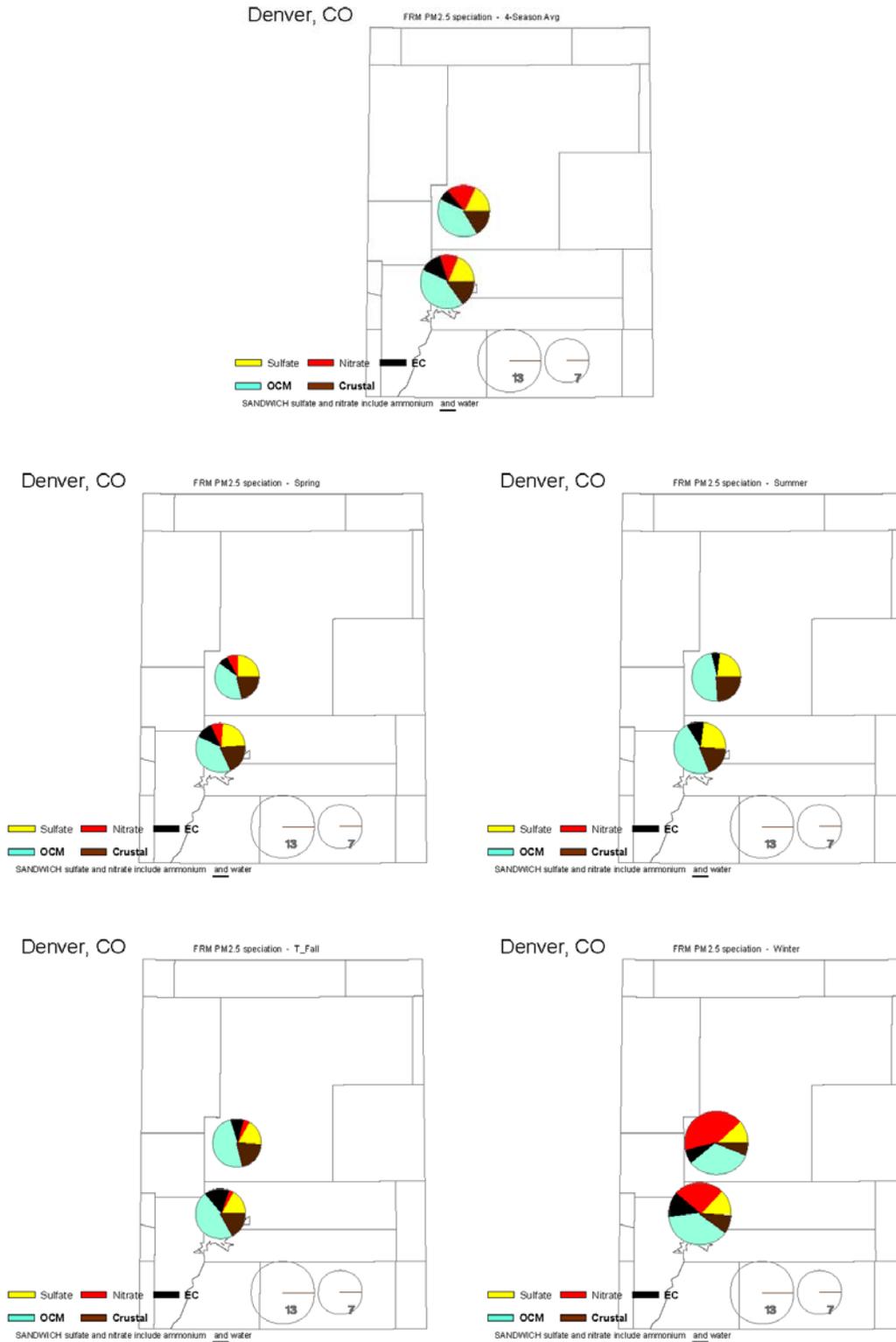
Figure A-131. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Denver, CO.
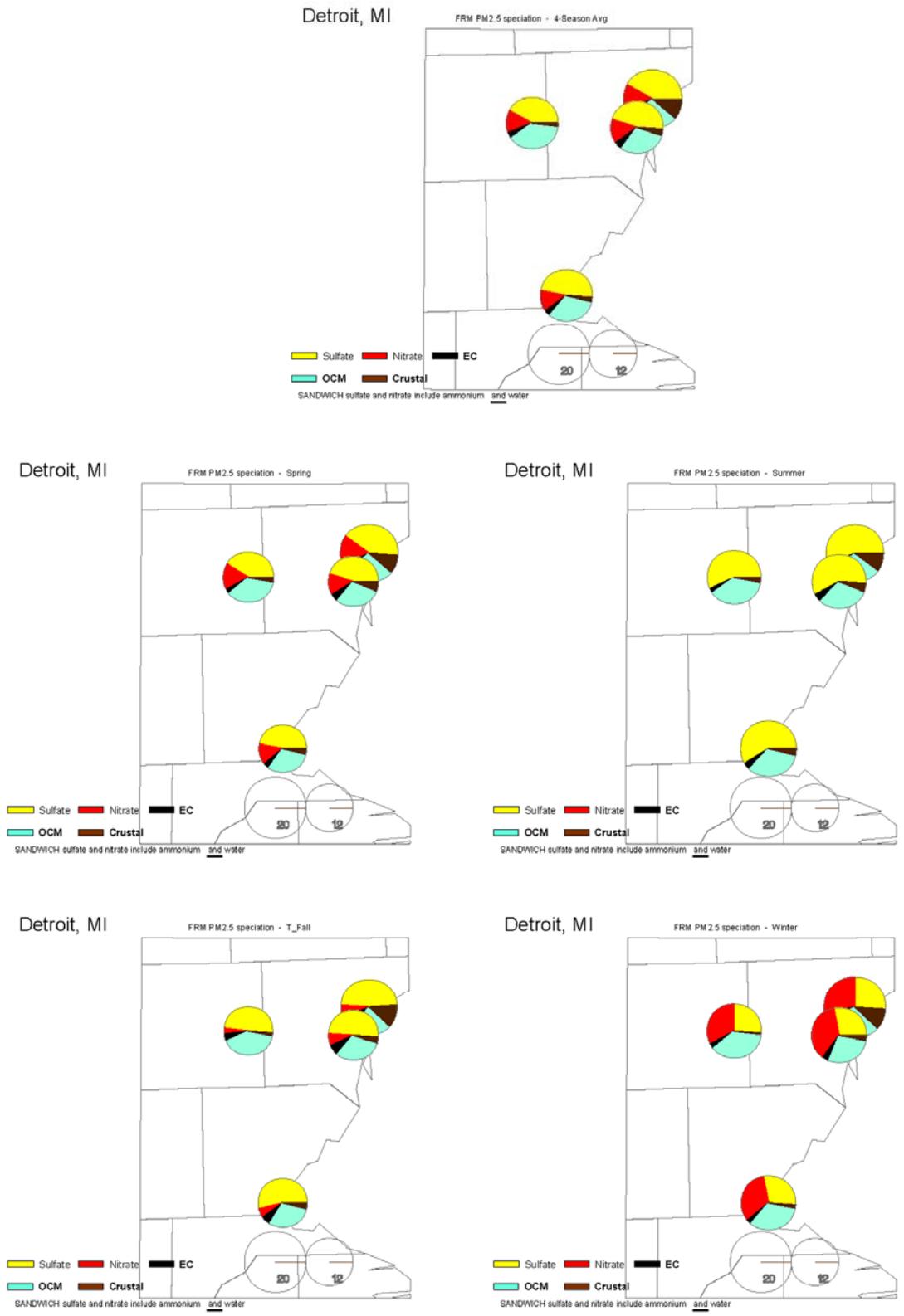
Figure A-132. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Detroit, MI.
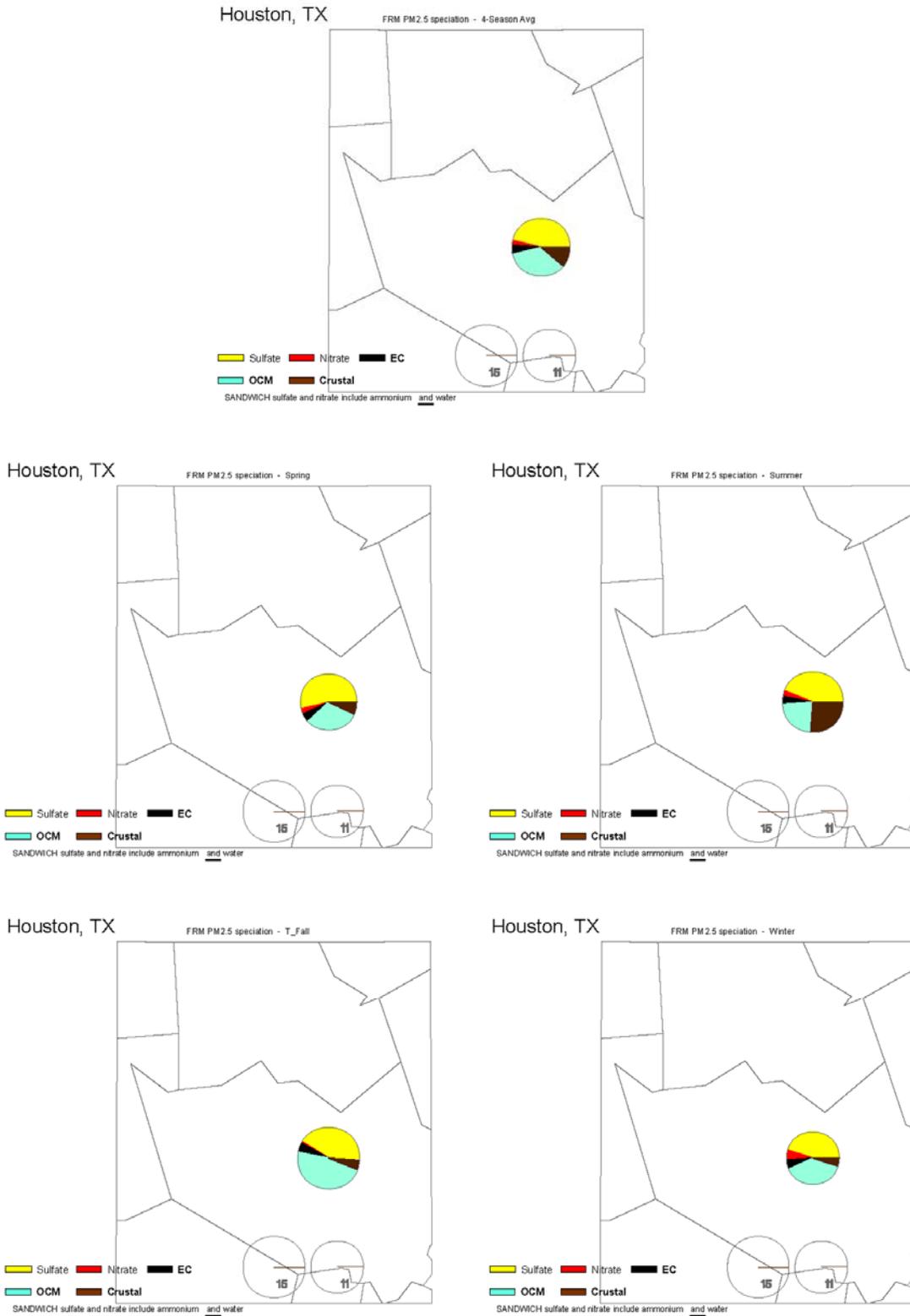
Figure A-133. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Houston, TX.
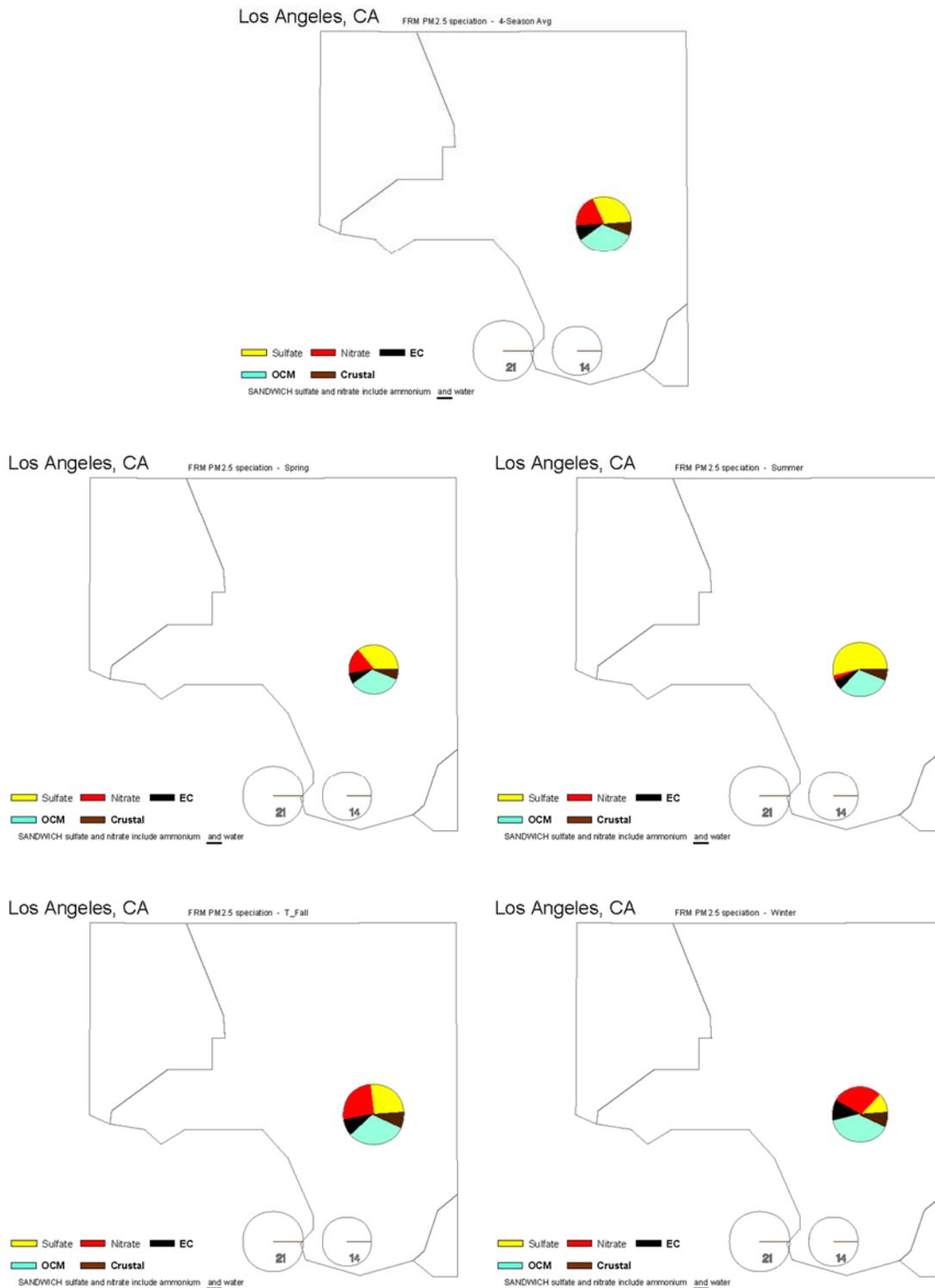
Figure A-134. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Los Angeles, CA.
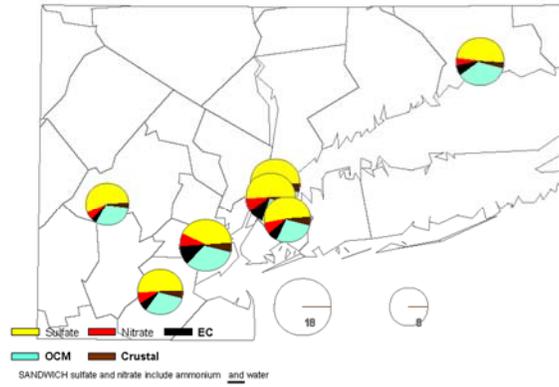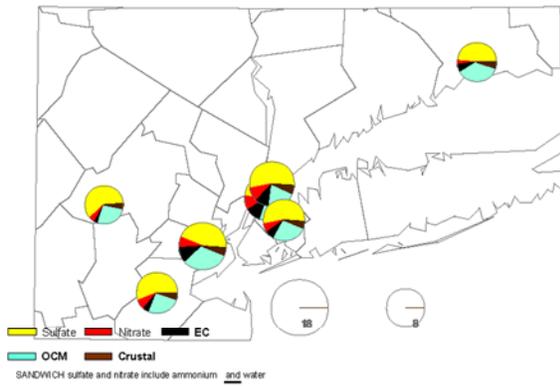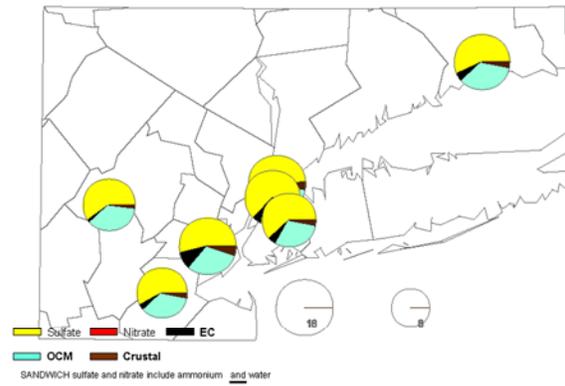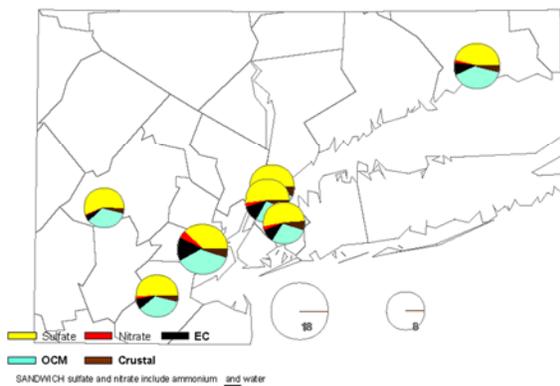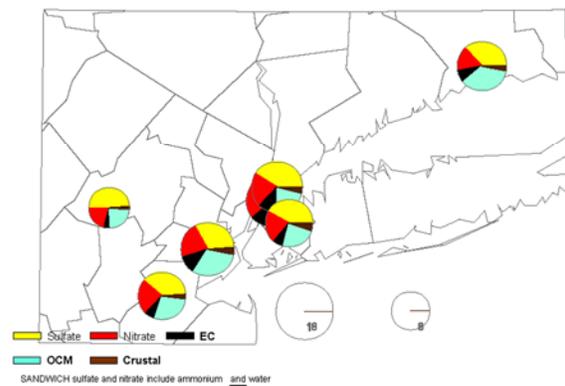
Figure A-135   Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in New York City, NY.
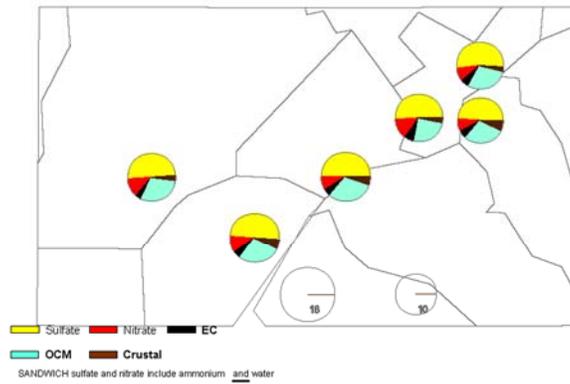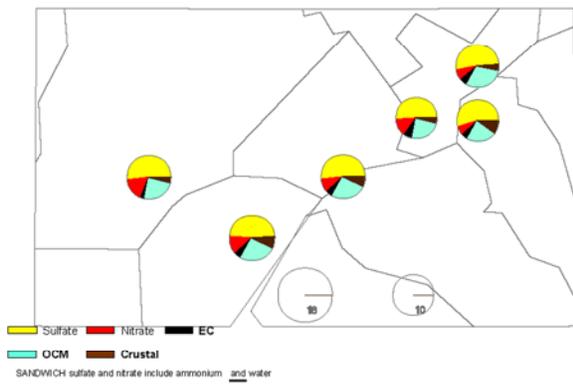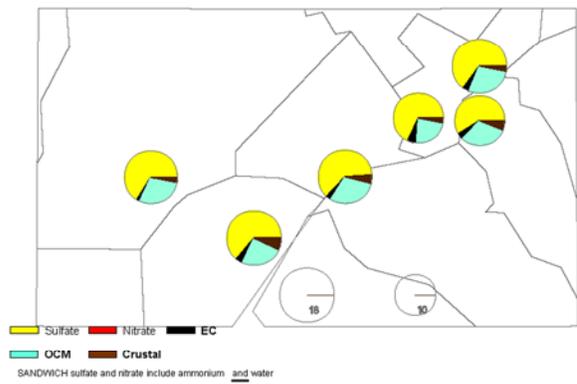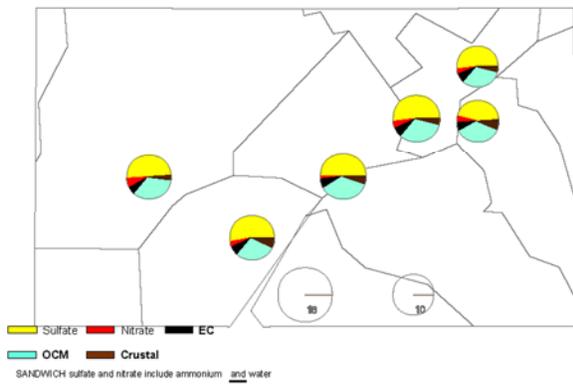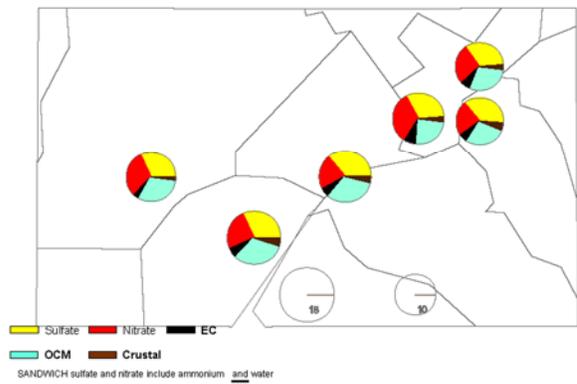
Figure A-136. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Philadelphia.
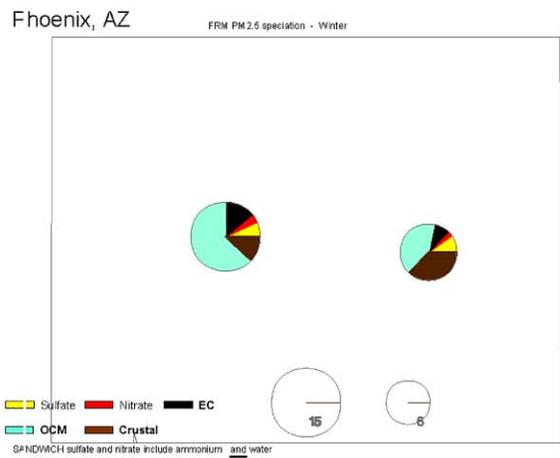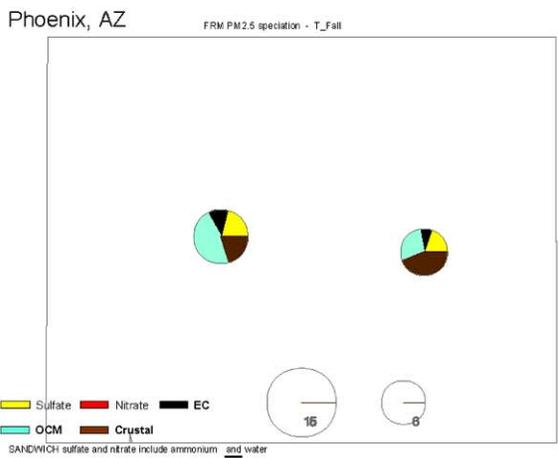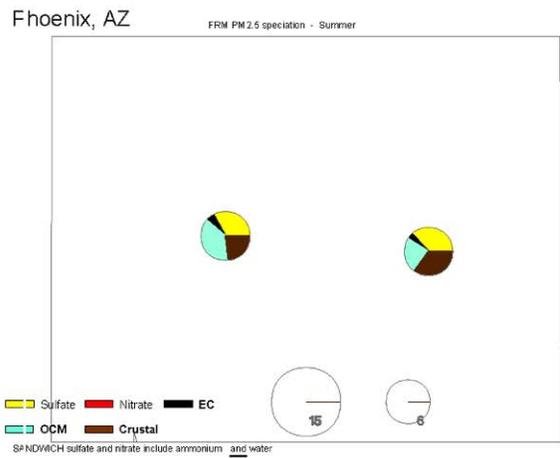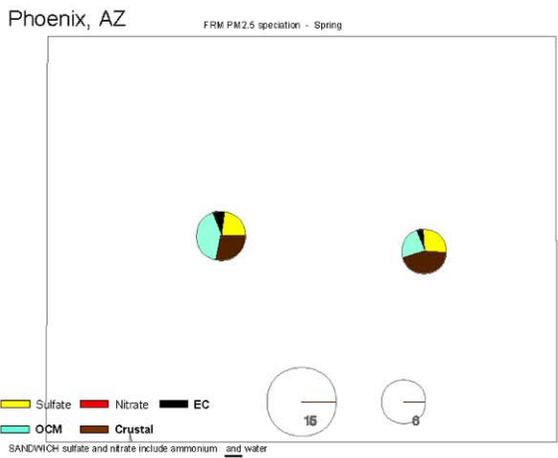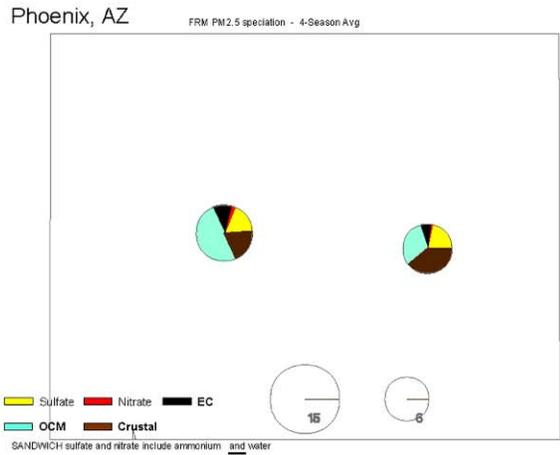
Figure A-137.   Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Phoenix, AZ.
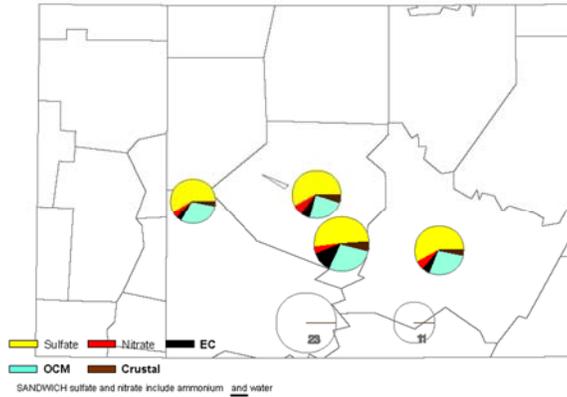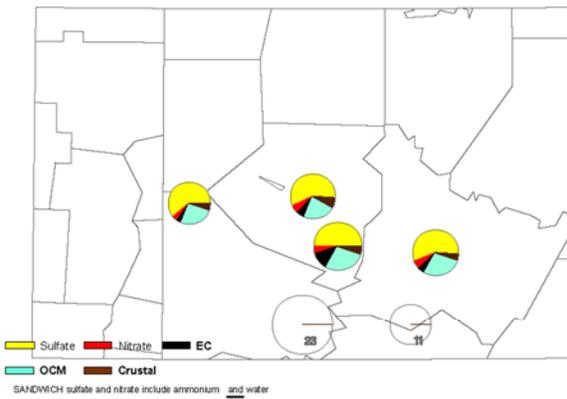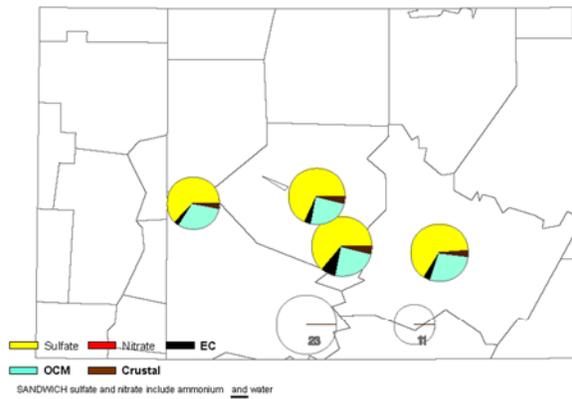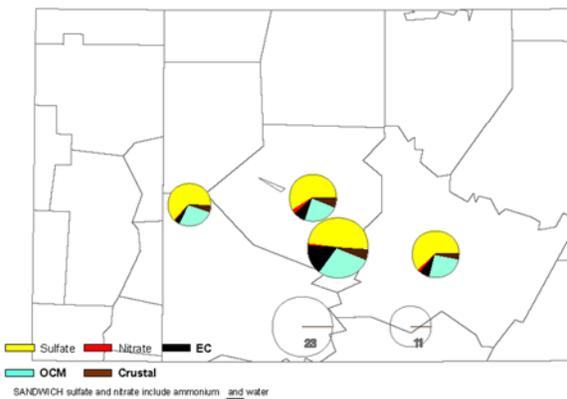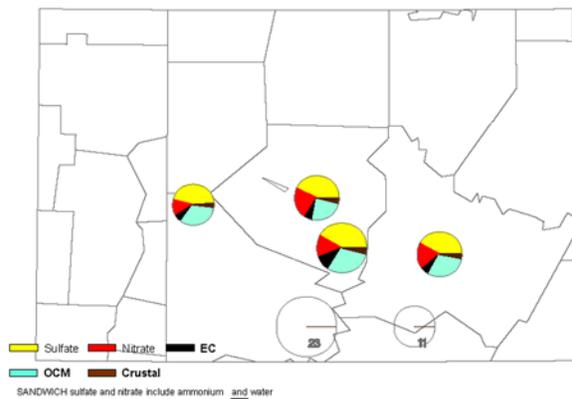
Figure A-138. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Pittsburgh, PA.
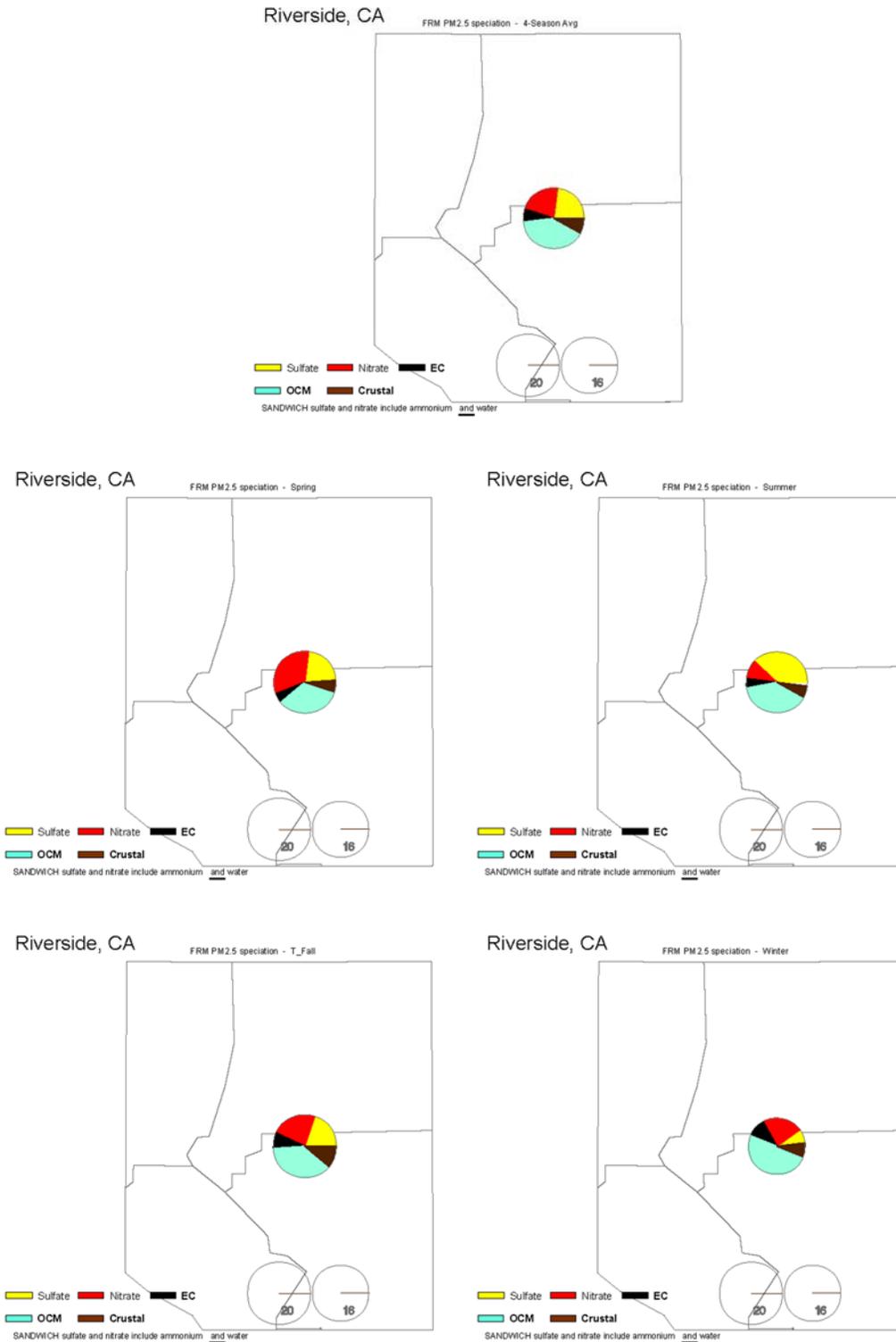
Figure A-139. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Riverside, CA.
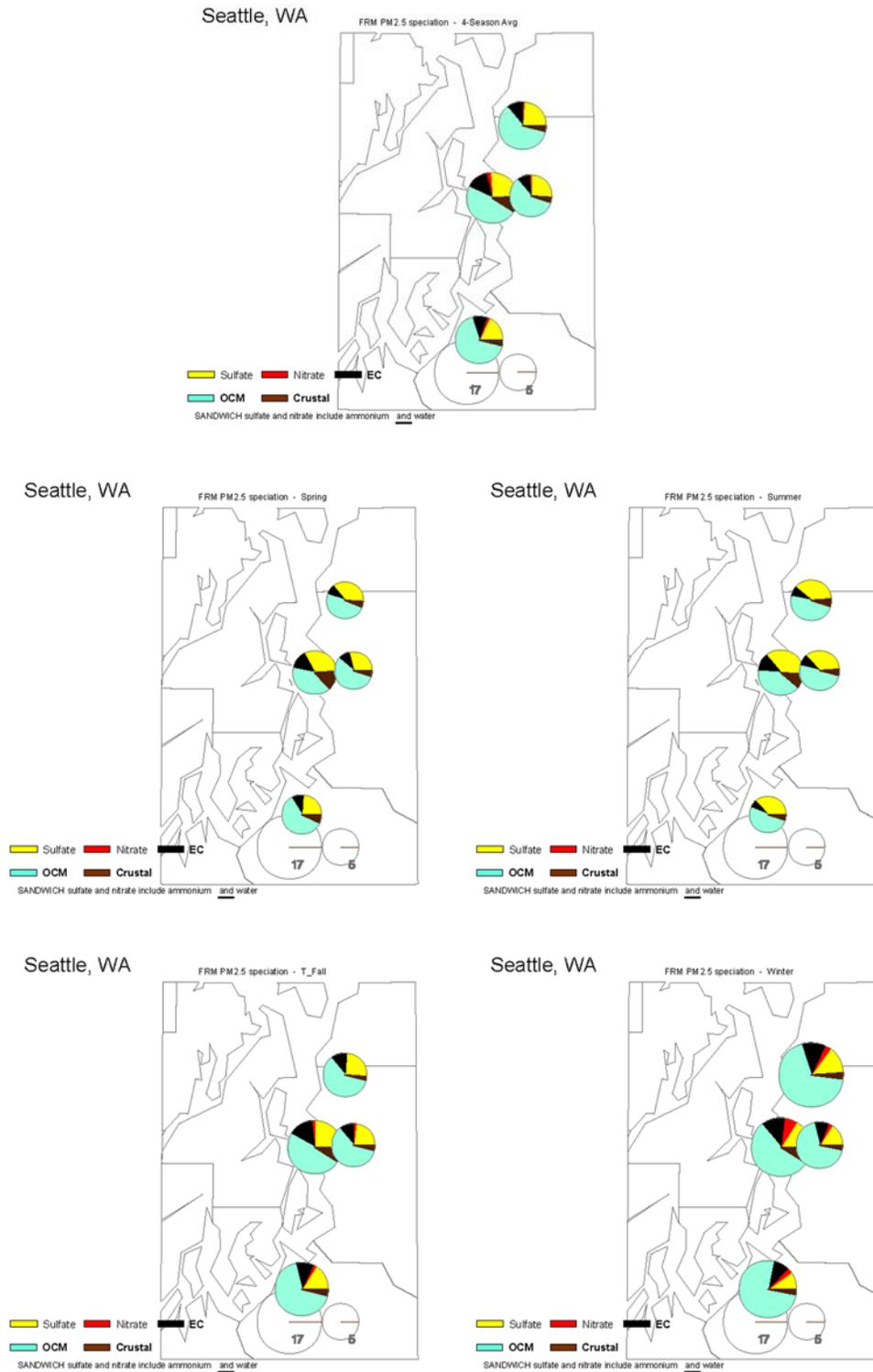
Figure A-140. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in Seattle, WA.
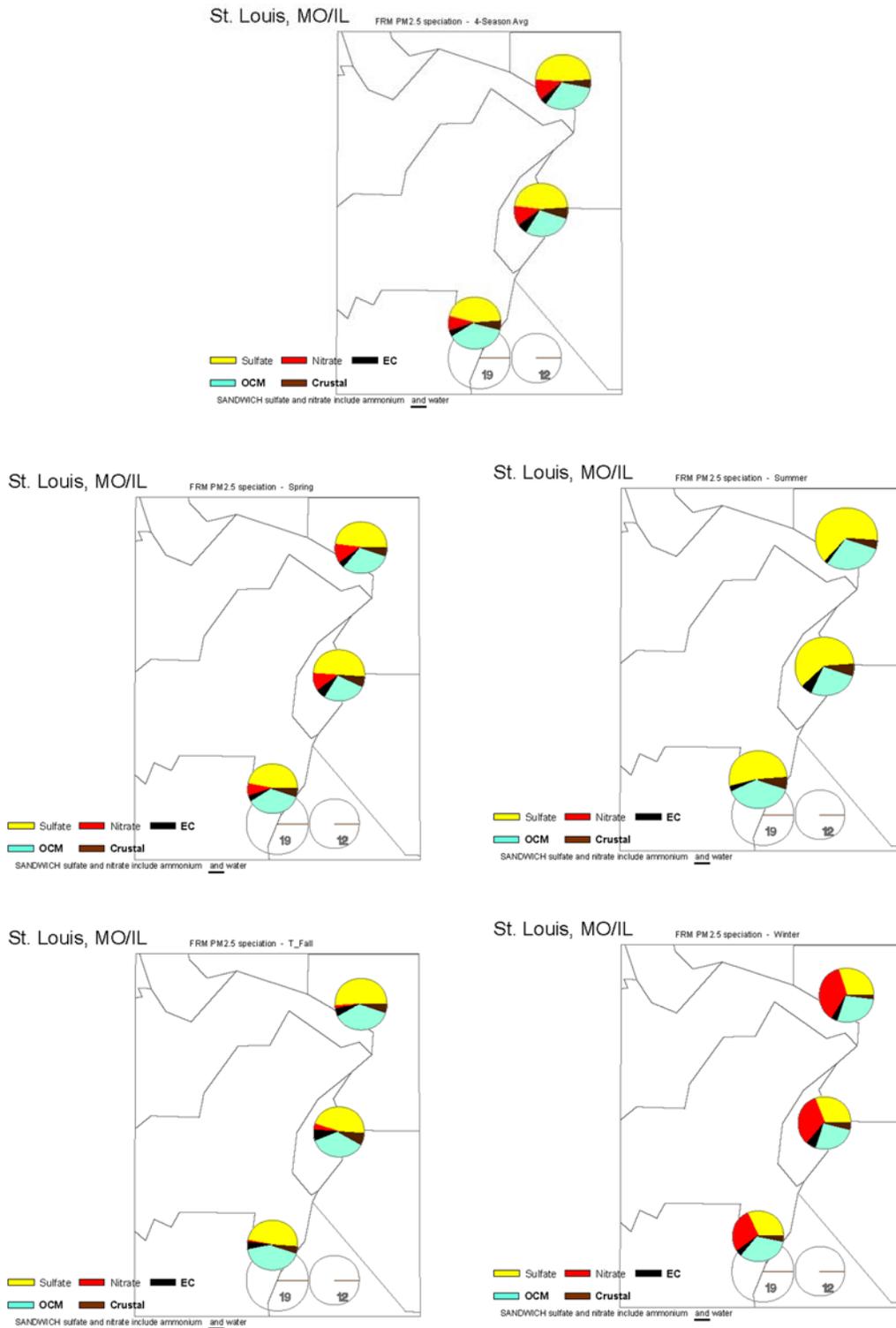
Figure A-141. Seasonally averaged PM$_{2.5}$ speciation data for 2005-2007 for a) annual, b) winter, c) spring, d) summer and e) fall derived using the SANDWICH method in St. Louis, MO.
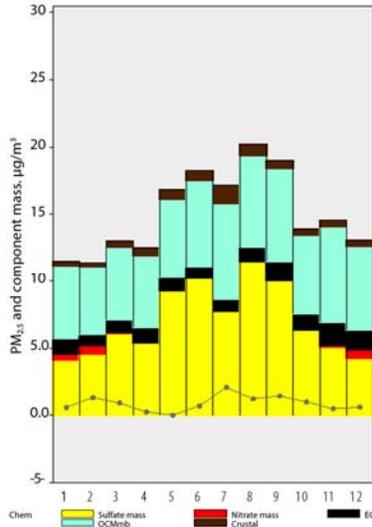
Figure A-142. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Atlanta, GA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
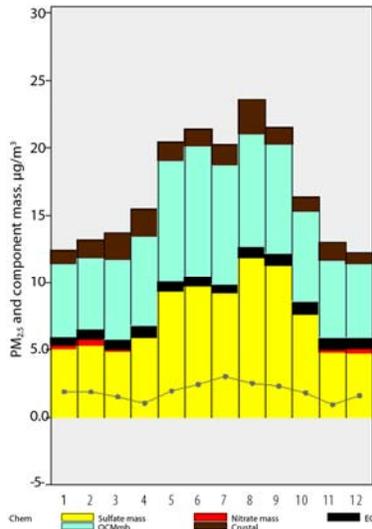
Figure A-143. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Birmingham, AL, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
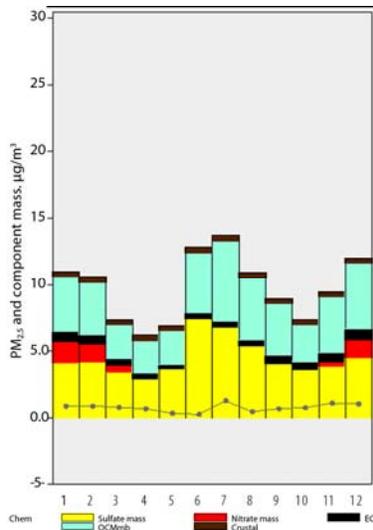
Figure A-144. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Boston, MA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
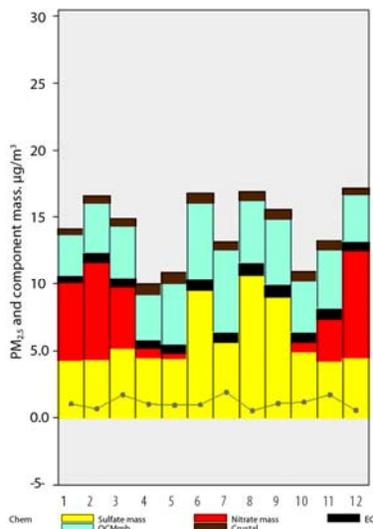
Figure A-145. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Chicago, IL, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
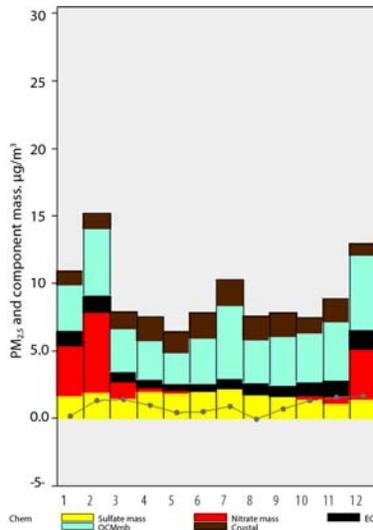
Figure A-146. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Denver, CO, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
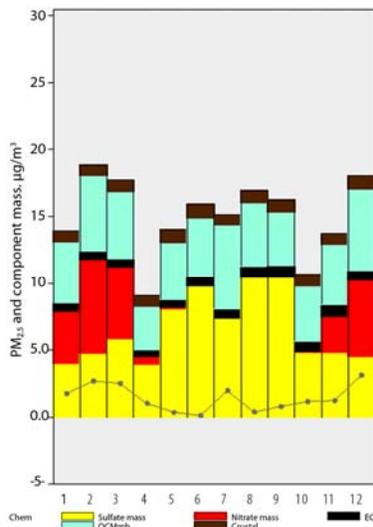
Figure A-147. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Detroit, MI, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
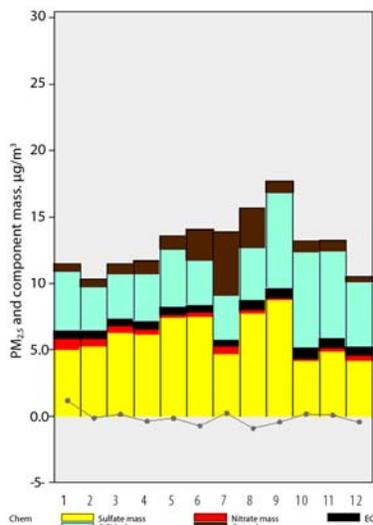
Figure A-148. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Houston, TX, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
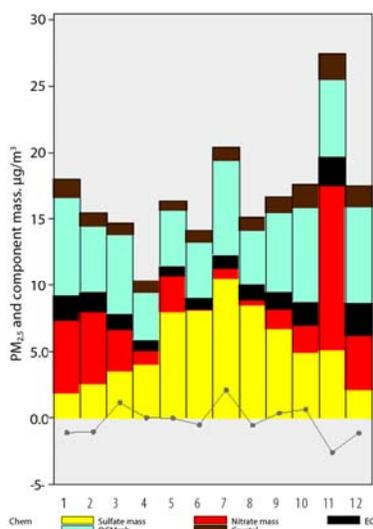
Figure A-149. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Los Angeles, CA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
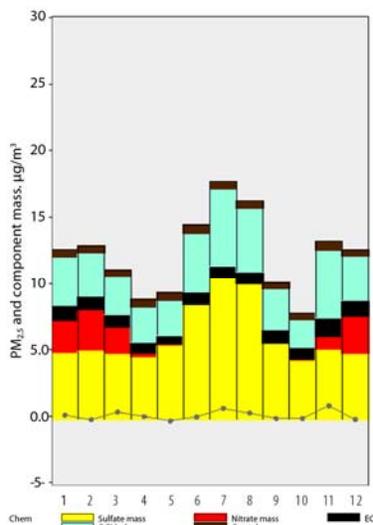
Figure A-150.   Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for New York City, NY, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
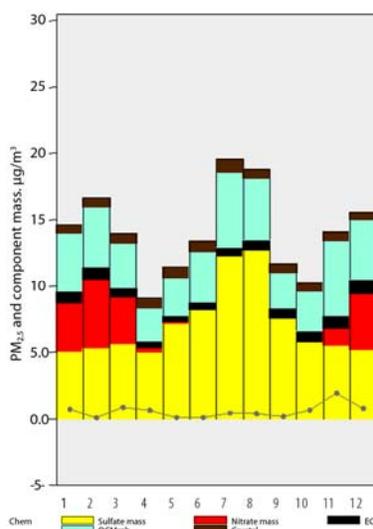
Figure A-151.   Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Philadelphia, PA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
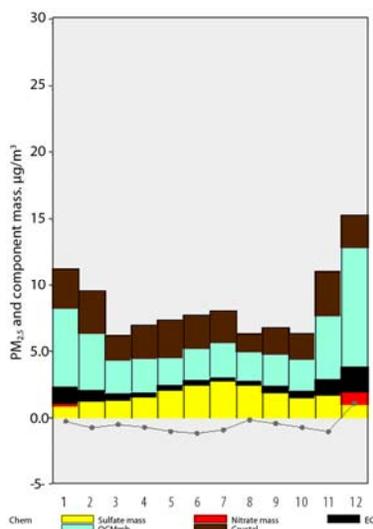
Figure A-152. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Phoenix, AZ, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
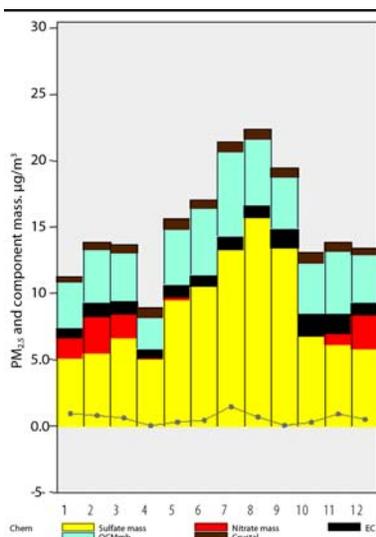
Figure A-153. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Pittsburgh, PA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
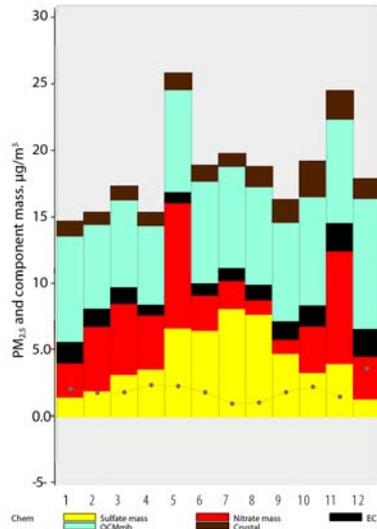
Figure A-154. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Riverside, CA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
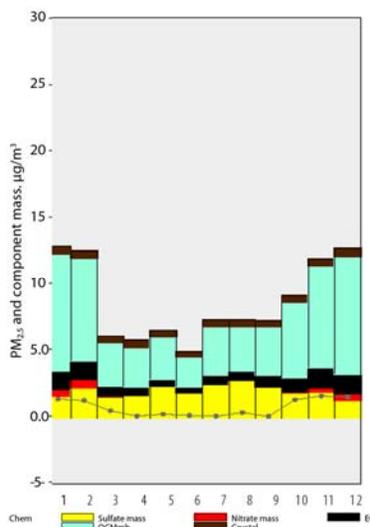
Figure A-155. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for Seattle, WA, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.
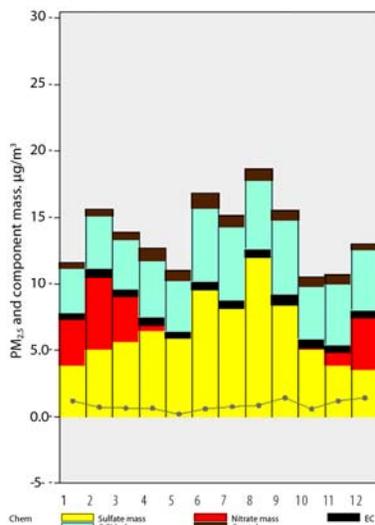
Figure A-156. Seasonal patterns in PM$_{2.5}$ chemical composition from city-wide monthly average values for St. Louis, MO, 2005-2007. The gray line represents the difference in OCM calculated using material balance and blank corrected OC x 1.4.

A.1.1. Diel Trends
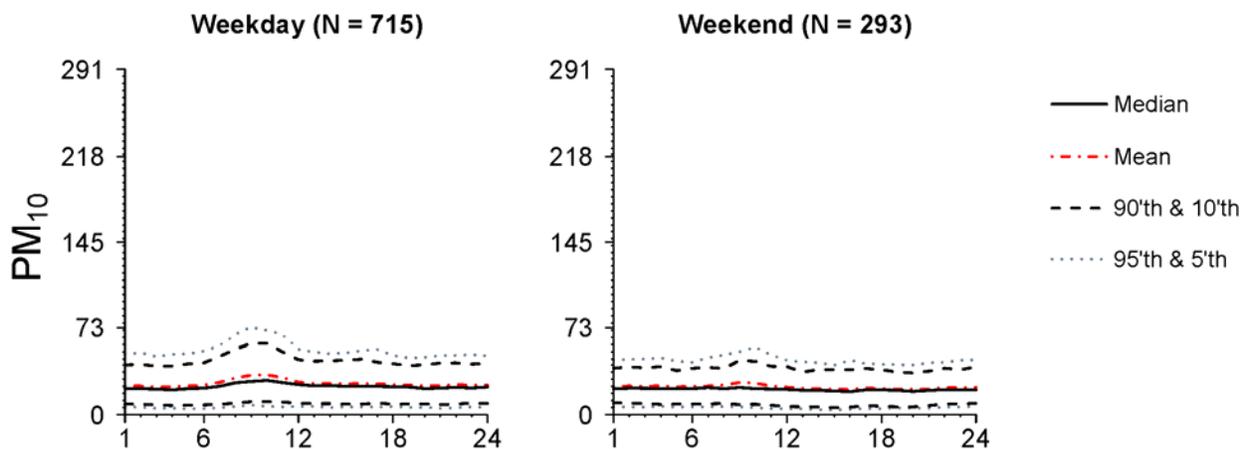
Figure A-157. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Atlanta, GA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
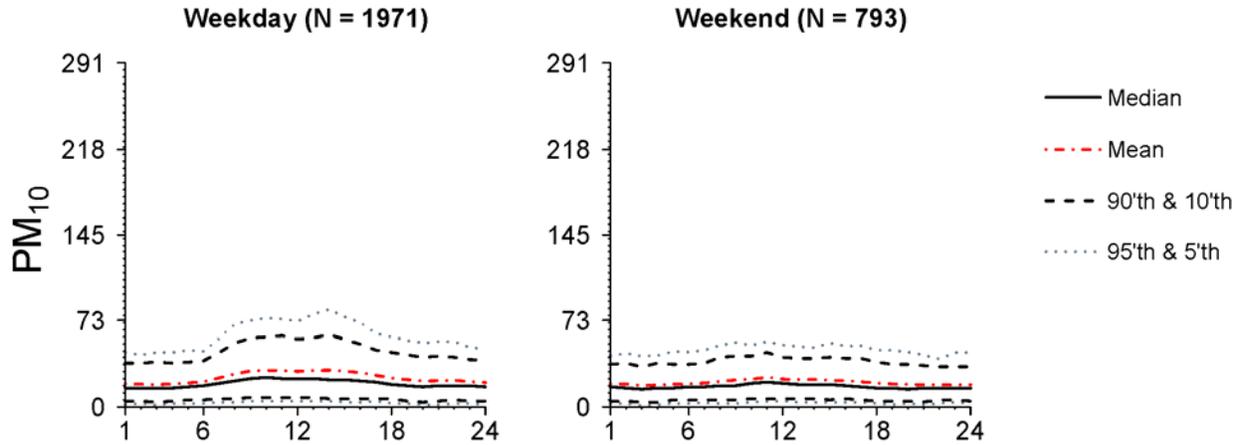
Figure A-158. Diel plot generated from all available hourly FRM/FEM PM_{10} data, stratified by weekday (left) and weekend (right), in Chicago, IL. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
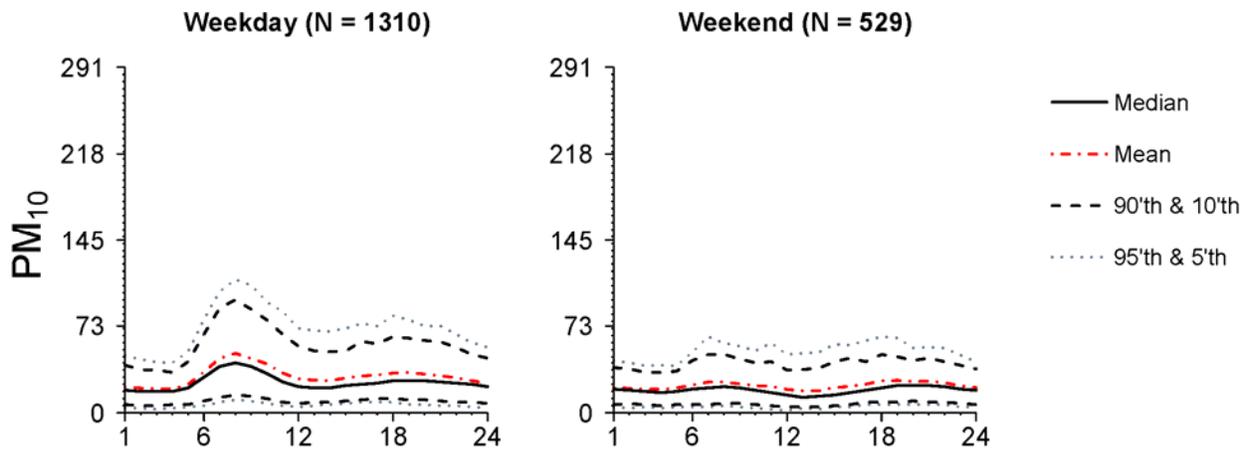
Figure A-159. Diel plot generated from all available hourly FRM/FEM PM_{10} data, stratified by weekday (left) and weekend (right), in Denver, CO. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
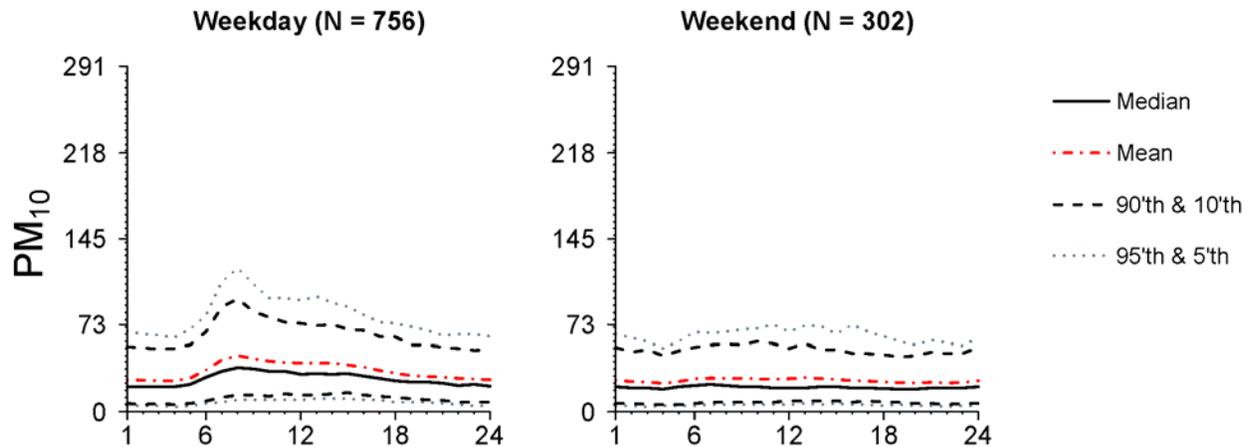
Figure A-160. Diel plot generated from all available hourly FRM/FEM PM_{10} data, stratified by weekday (left) and weekend (right), in Detroit, MI. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
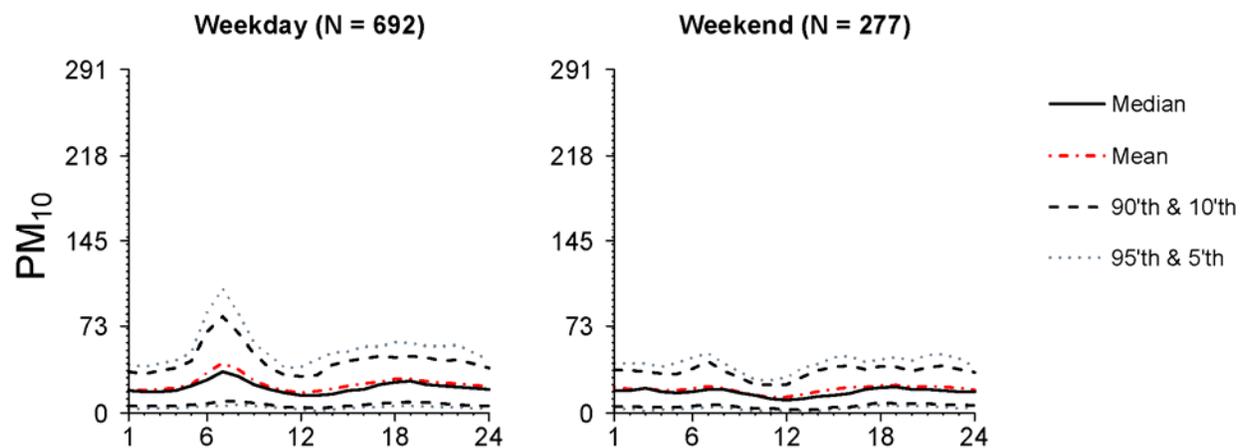
Figure A-161. Diel plot generated from all available hourly FRM/FEM PM_{10} data, stratified by weekday (left) and weekend (right), in Los Angeles, CA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
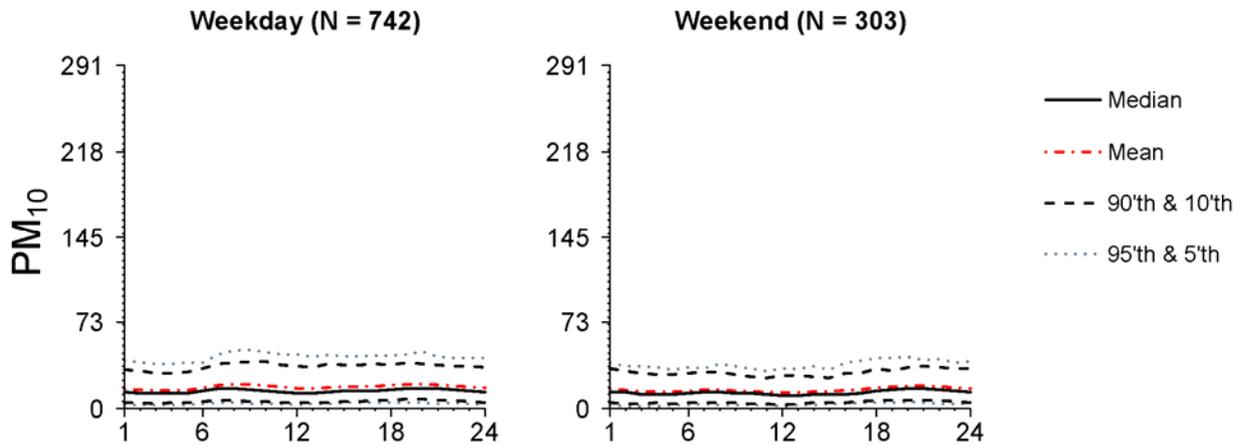
Figure A-162. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Philadelphia, PA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
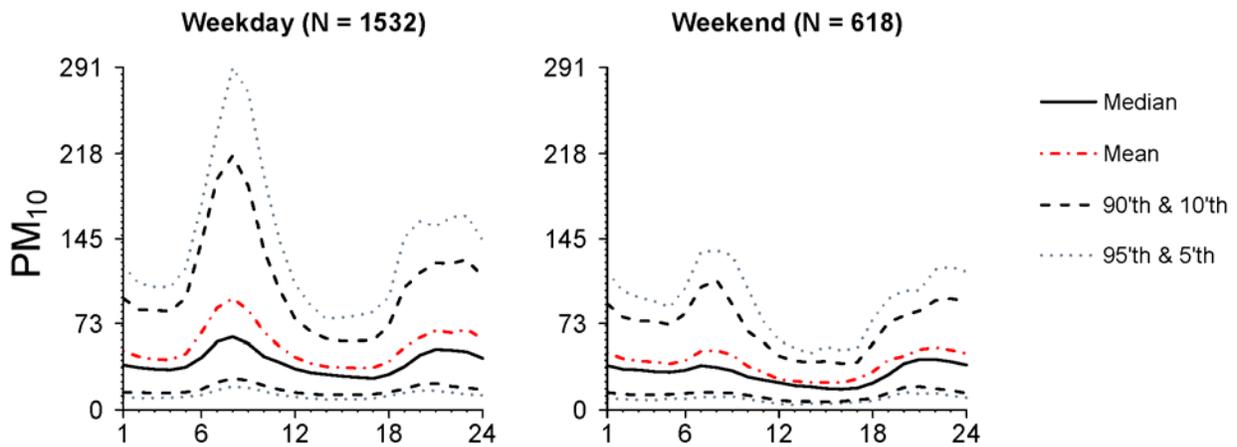
Figure A-163. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Phoenix, AZ. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
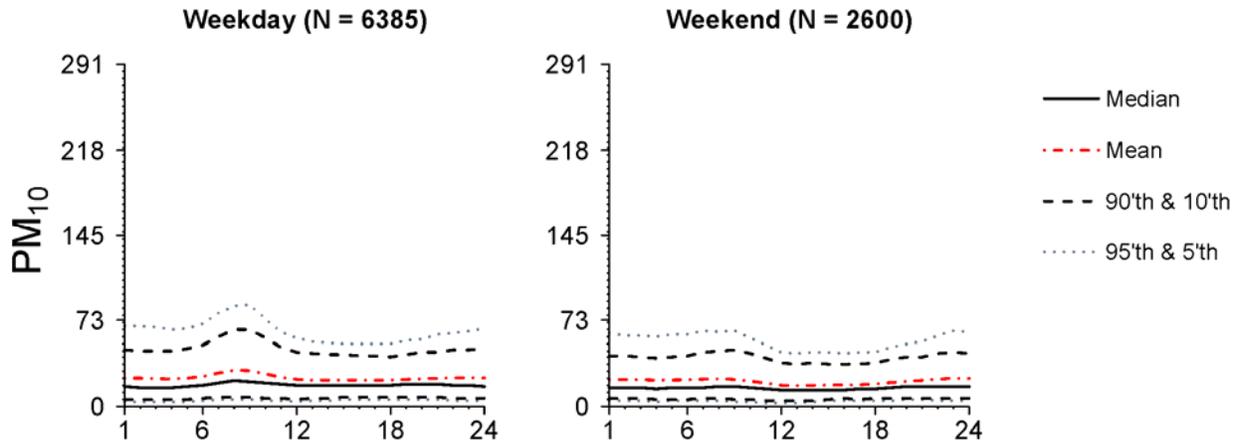
Figure A-164. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Pittsburgh, PA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
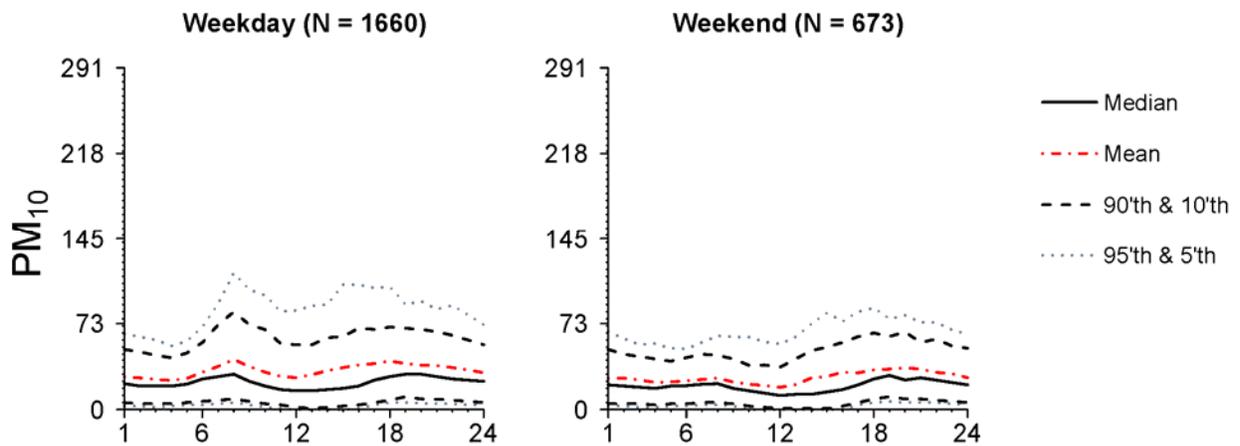
Figure A-165. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Riverside, CA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
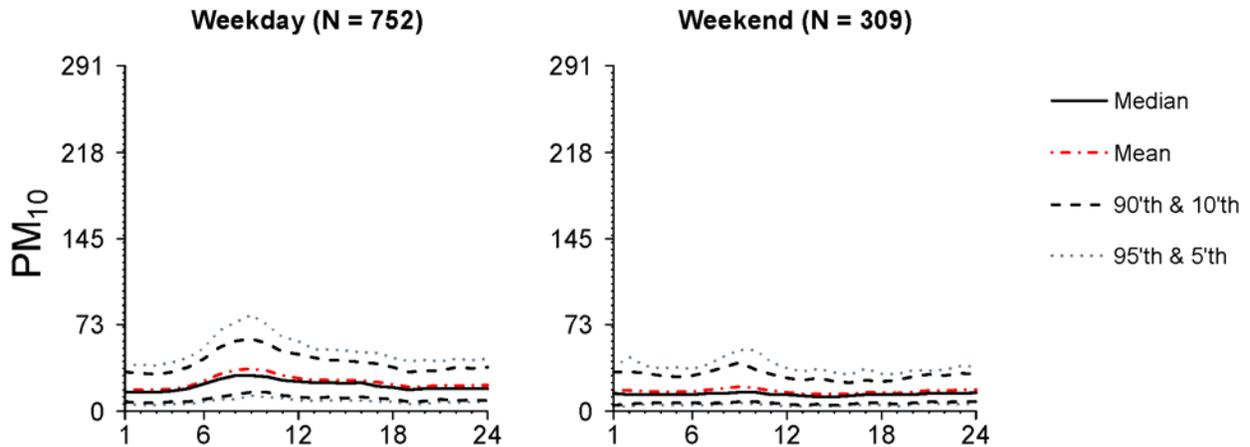
Figure A-166. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in Seattle, WA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
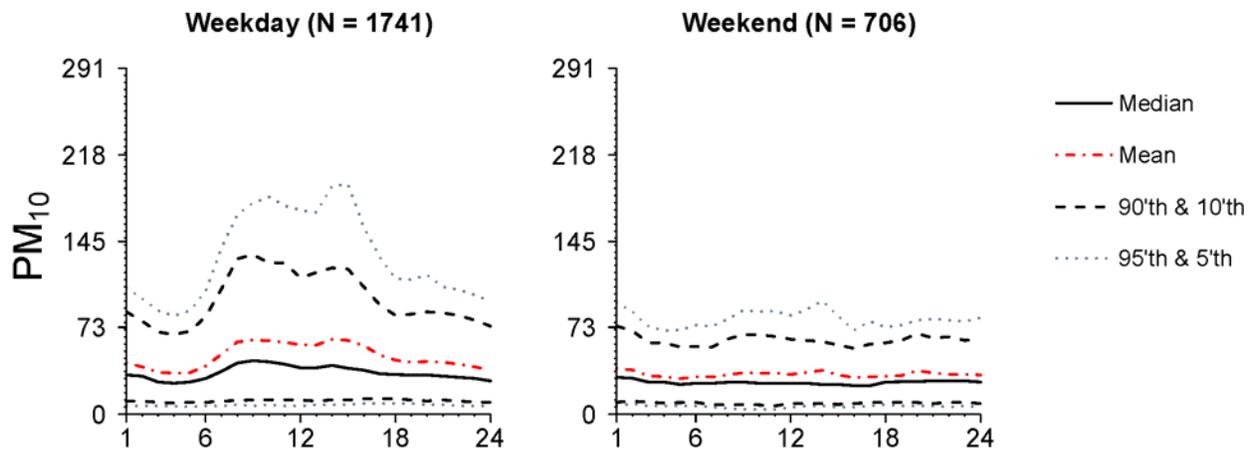
Figure A-167. Diel plot generated from all available hourly FRM/FEM PM$_{10}$ data, stratified by weekday (left) and weekend (right), in St. Louis, MO. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
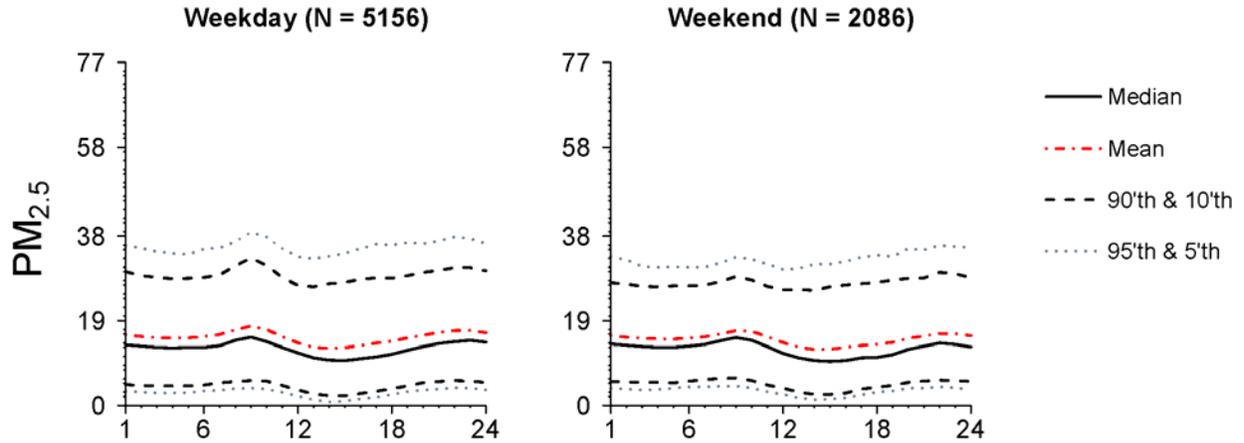
Figure A-168. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in Atlanta, GA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
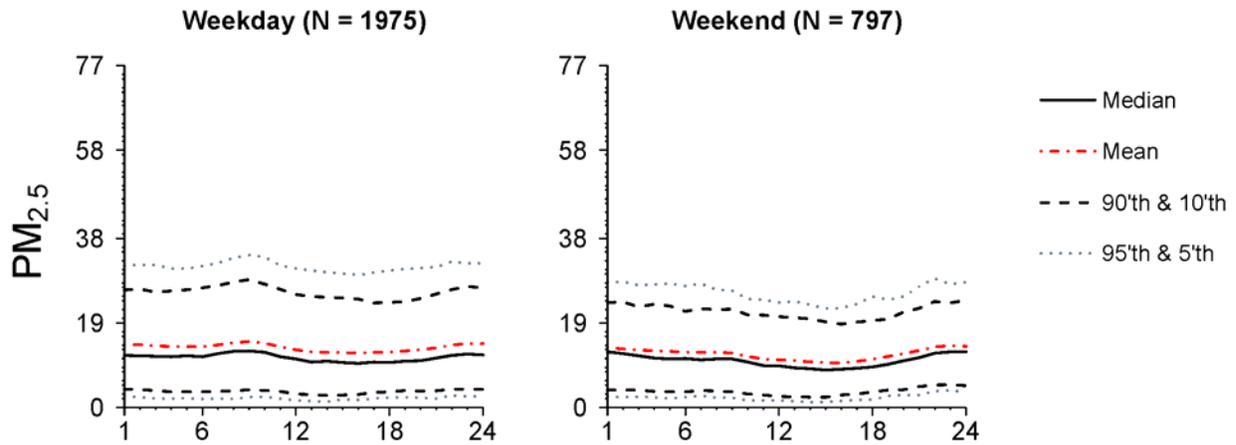
Figure A-169. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in Chicago, IL. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
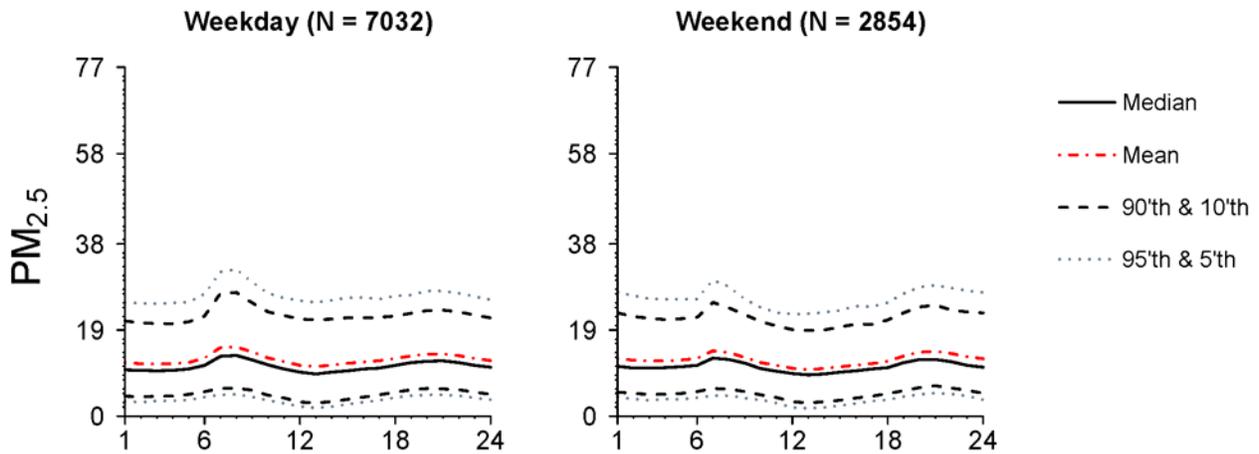
Figure A-170. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in Houston, TX. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
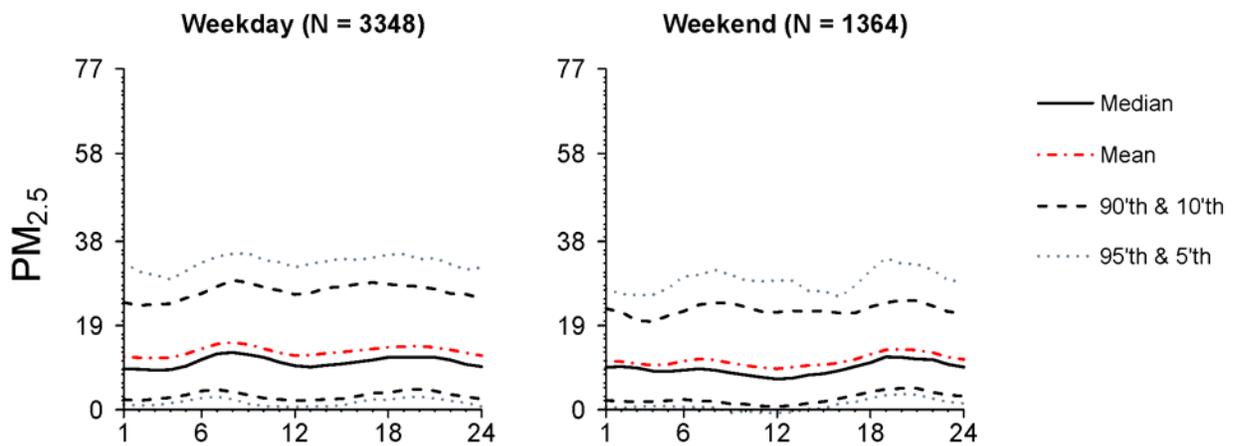
Figure A-171. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in New York City, NY. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
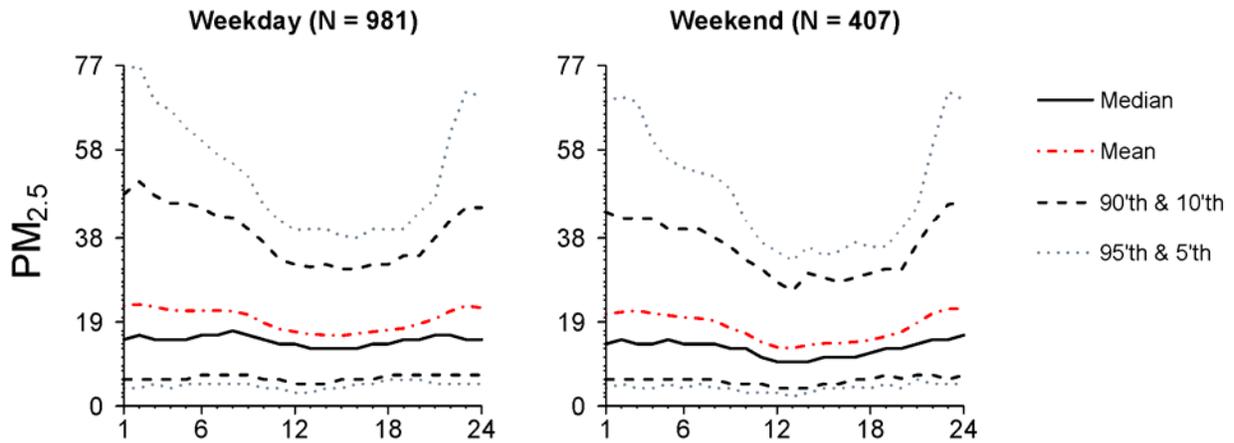
Figure A-172. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in Pittsburgh, PA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
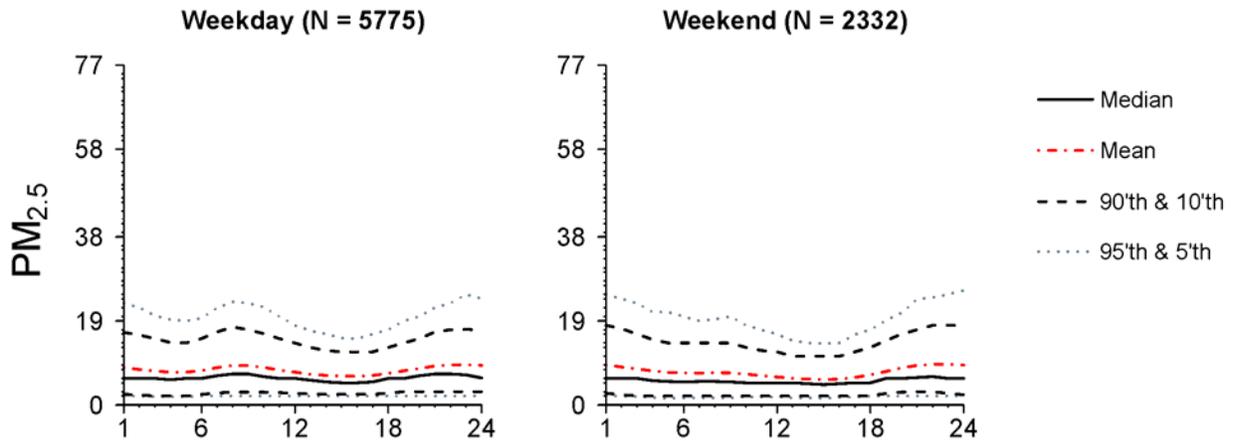
Figure A-173. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in Seattle, WA. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.
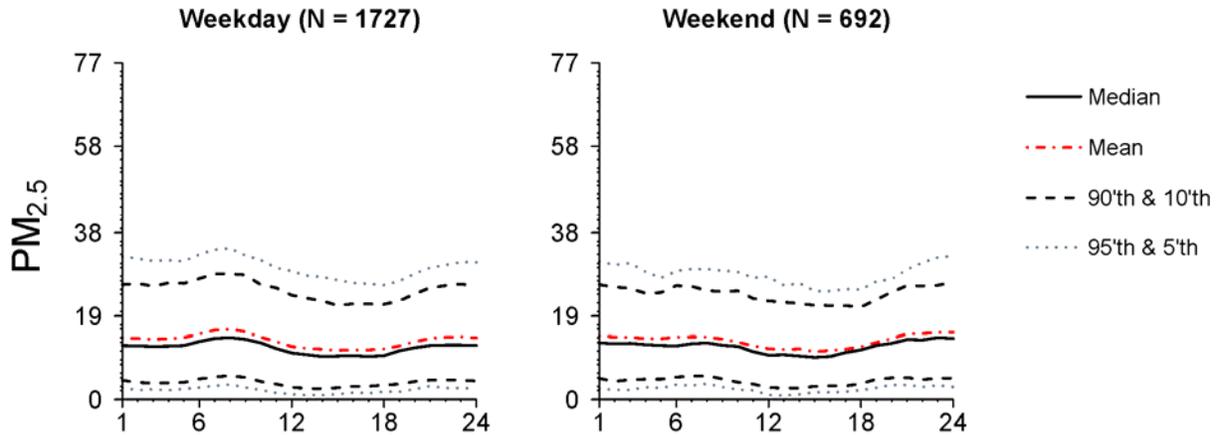
Figure A-174. Diel plots generated from all available hourly FRM-like PM$_{2.5}$ data, stratified by weekday (left) and weekend (right), in St. Louis, MO. Included are the number of monitor days (N) and the median, mean, 5th, 10th, 90th and 95th percentiles for each hour.

A.1.2. Copollutant Measurements
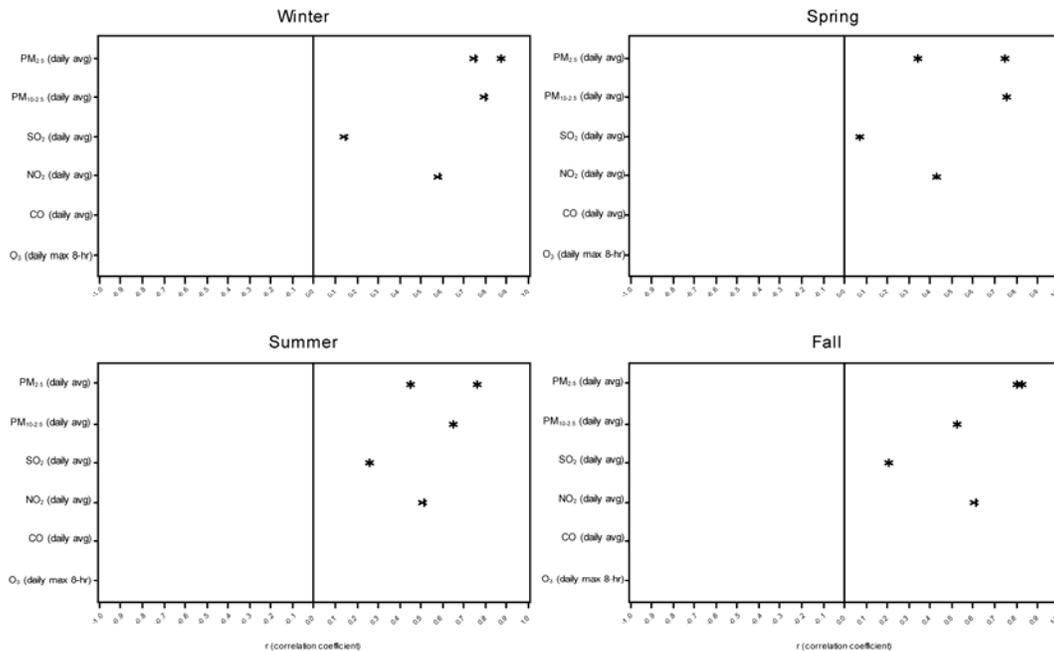
Figure A-175. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Atlanta, GA, stratified by season (2005-2007). One point is included for each available monitor pair.
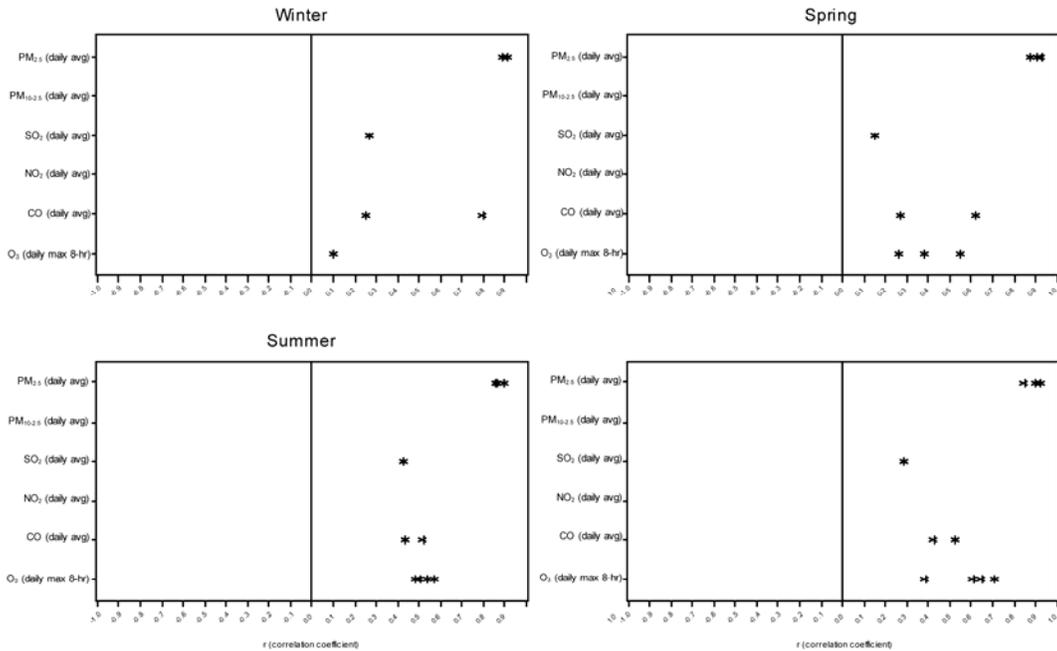
Figure A-176. Correlations between 24-h PM_{10} and co-located 24-h average $PM_{2.5}$, $PM_{10-2.5}$ SO_2, NO_2 and CO and daily maximum 8-h average O_3 for Birmingham, AL, stratified by season (2005-2007). One point is included for each available monitor pair.
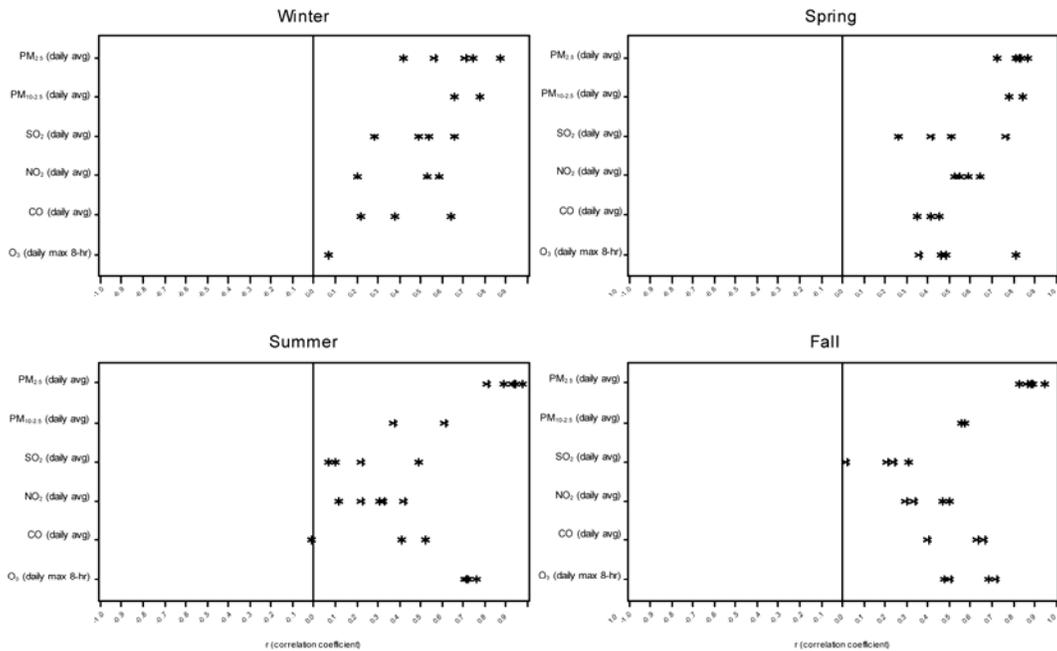
Figure A-177. Correlations between 24-h PM_{10} and co-located 24-h average $PM_{2.5}$, $PM_{10-2.5}$ SO_2, NO_2 and CO and daily maximum 8-h average O_3 for Boston, MA, stratified by season (2005-2007). One point is included for each available monitor pair.
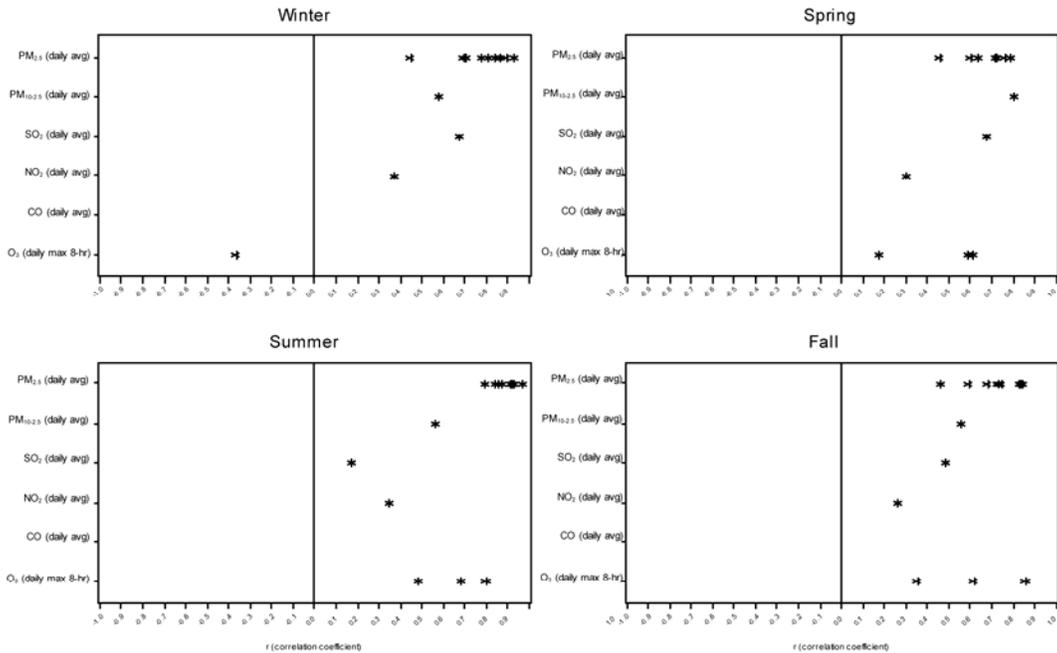
Figure A-178. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Chicago, IL, stratified by season (2005-2007). One point is included for each available monitor pair.
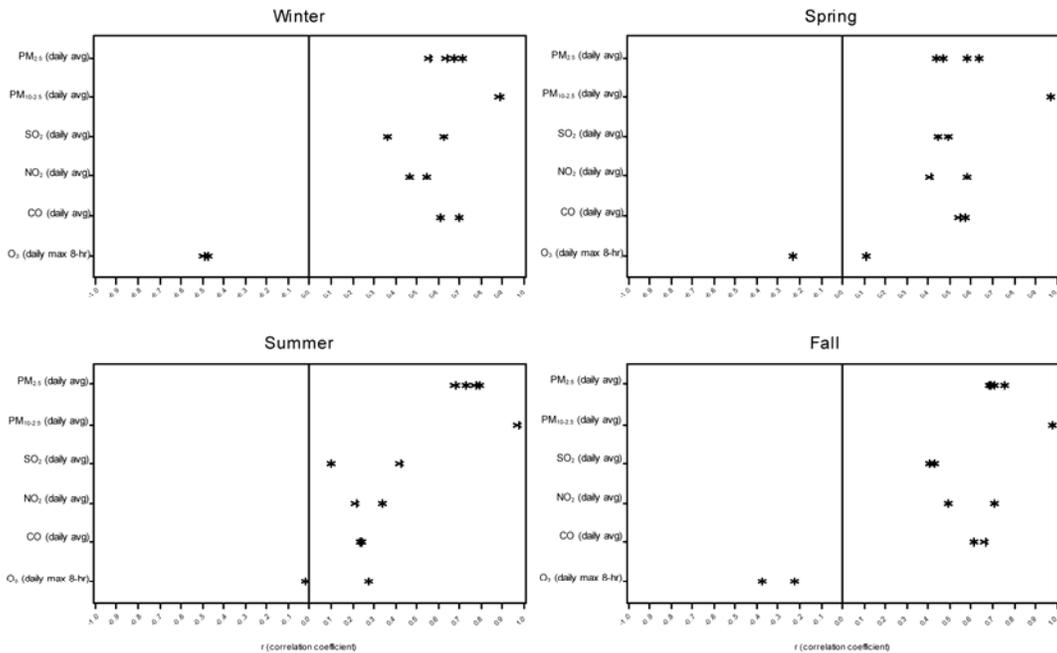
Figure A-179. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Denver, CO, stratified by season (2005-2007). One point is included for each available monitor pair.
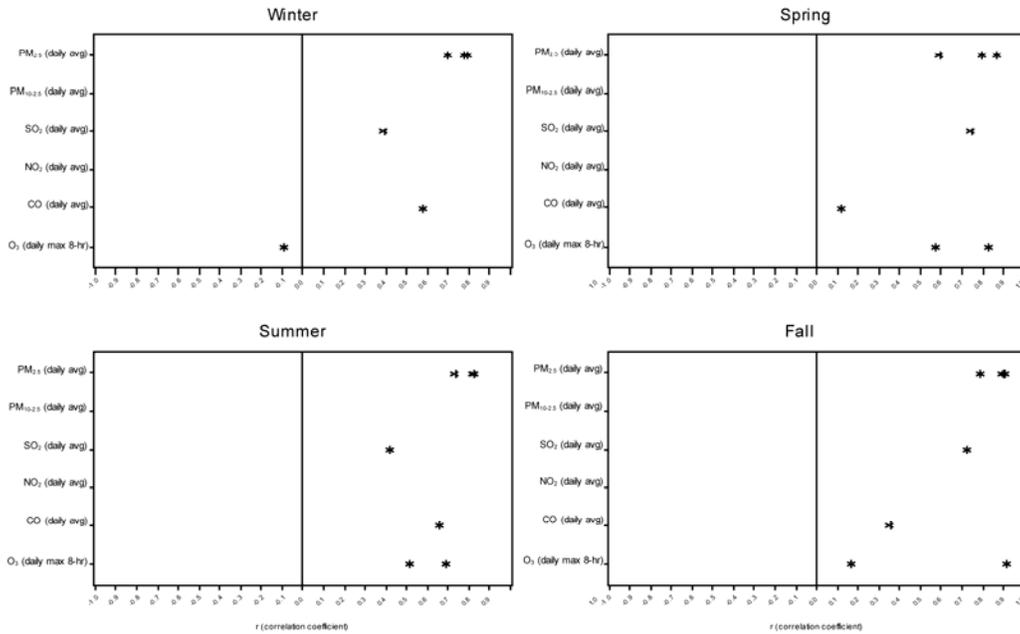
Figure A-180. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Detroit, MI, stratified by season (2005-2007). One point is included for each available monitor pair.
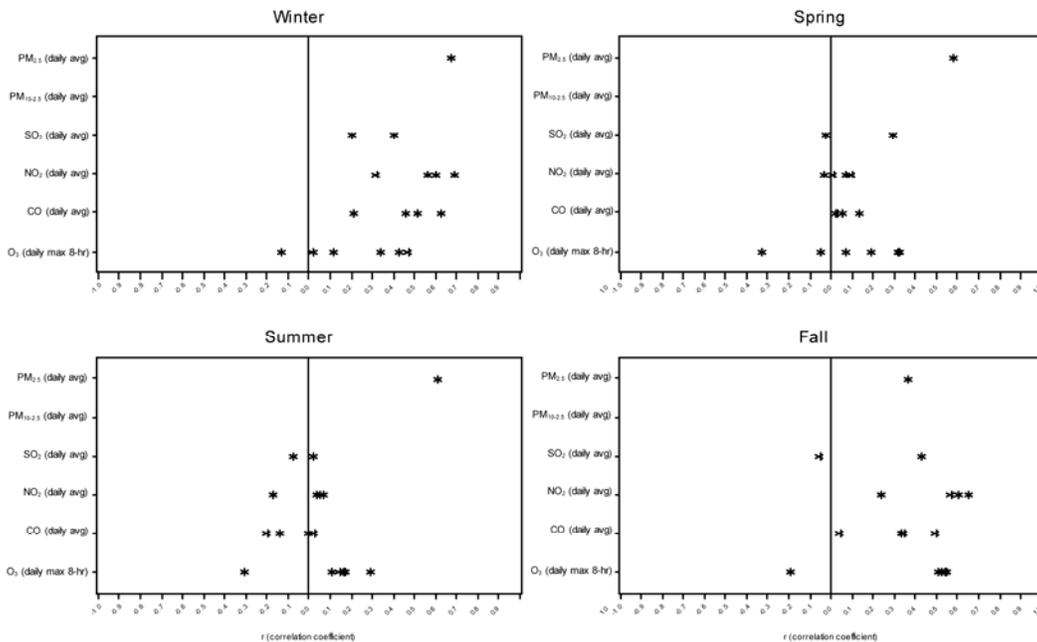
Figure A-181. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Houston, TX, stratified by season (2005-2007). One point is included for each available monitor pair.
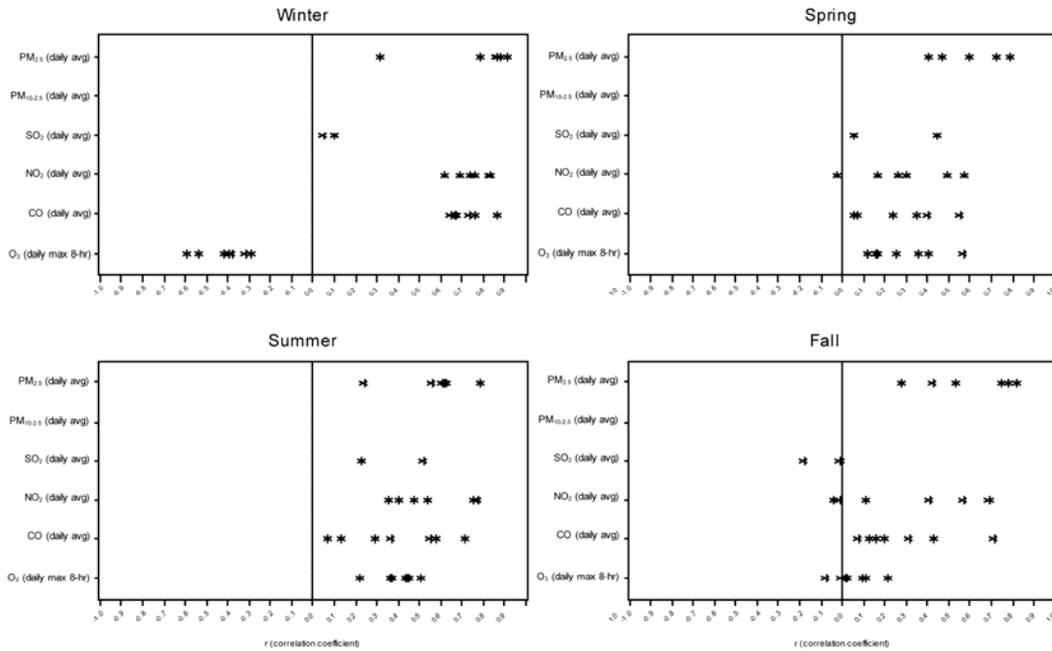
Figure A-182. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Los Angeles, CA, stratified by season (2005-2007). One point is included for each available monitor pair.
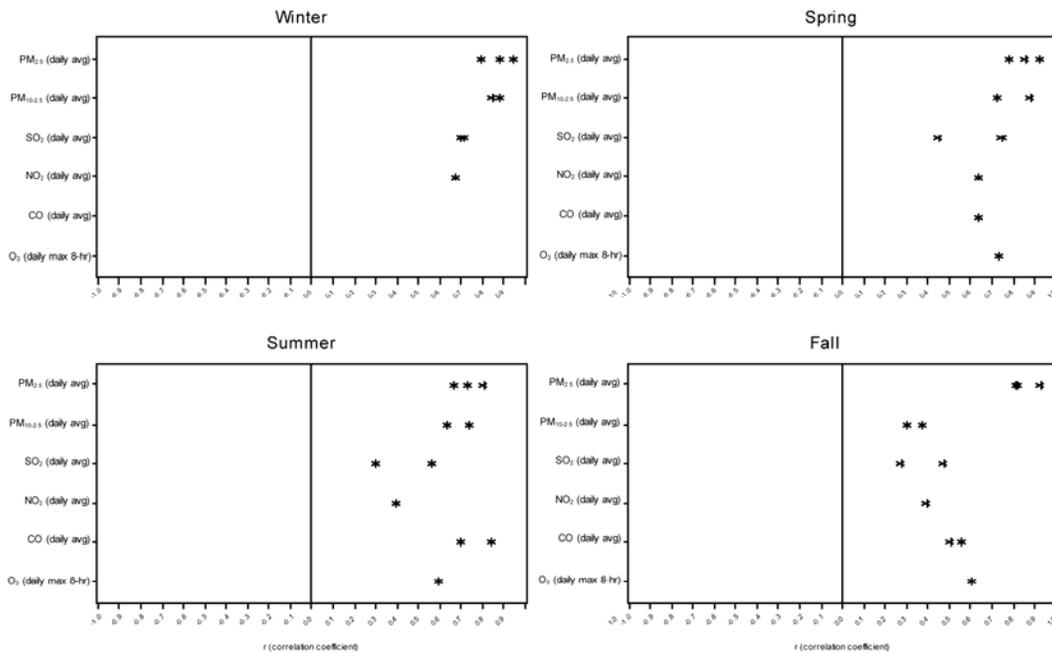
Figure A-183. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for New York City, NY, stratified by season (2005-2007). One point is included for each available monitor pair.
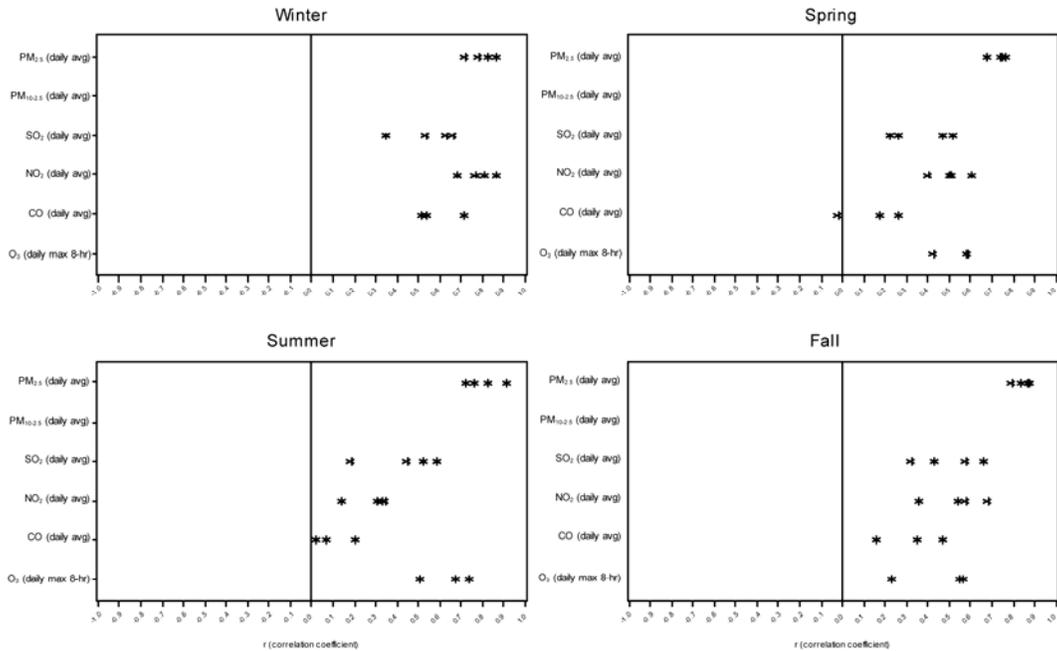
Figure A-184. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Philadelphia, PA, stratified by season (2005-2007). One point is included for each available monitor pair.
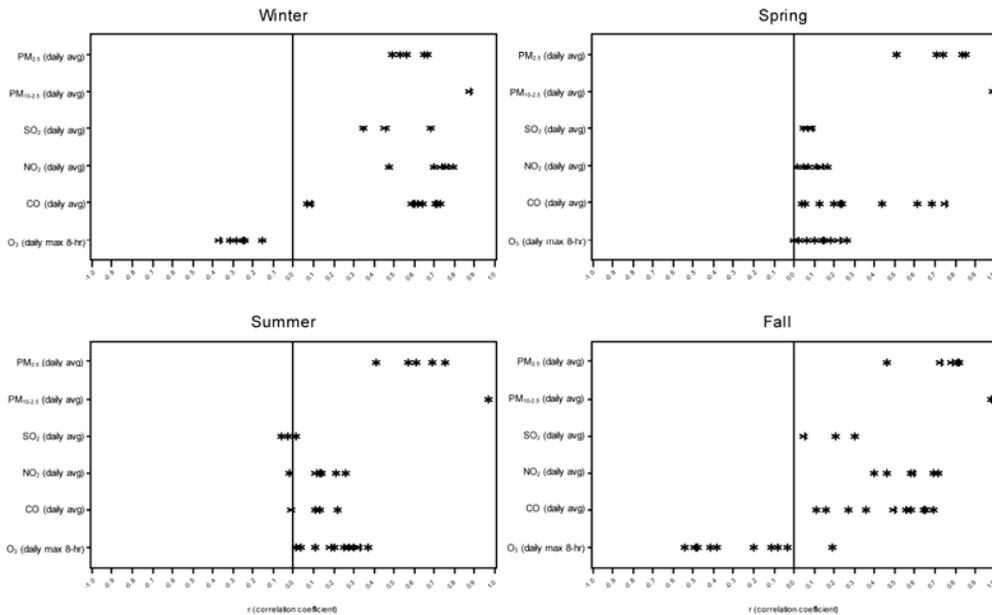
Figure A-185. Correlations between 24-h PM$_{10}$ and co-located 24-h average PM$_{2.5}$, PM$_{10-2.5}$ SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Phoenix, AZ, stratified by season (2005-2007). One point is included for each available monitor pair.
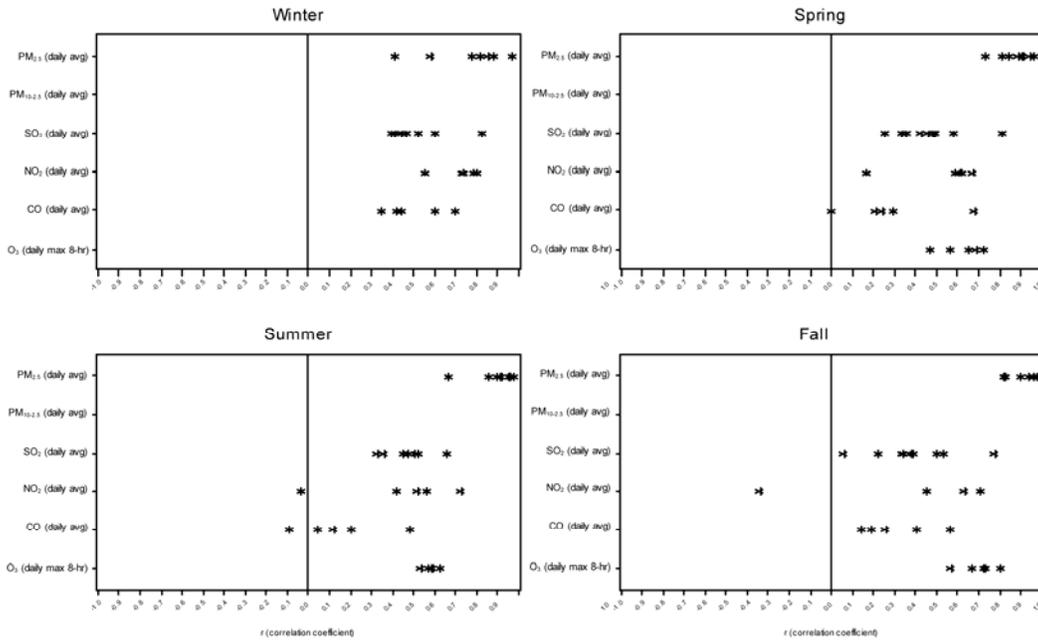
Figure A-186. Correlations between 24-h PM_{10} and co-located 24-h average $PM_{2.5}$, $PM_{10-2.5}$ SO_2, NO_2 and CO and daily maximum 8-h average O_3 for Pittsburgh, PA, stratified by season (2005-2007). One point is included for each available monitor pair.
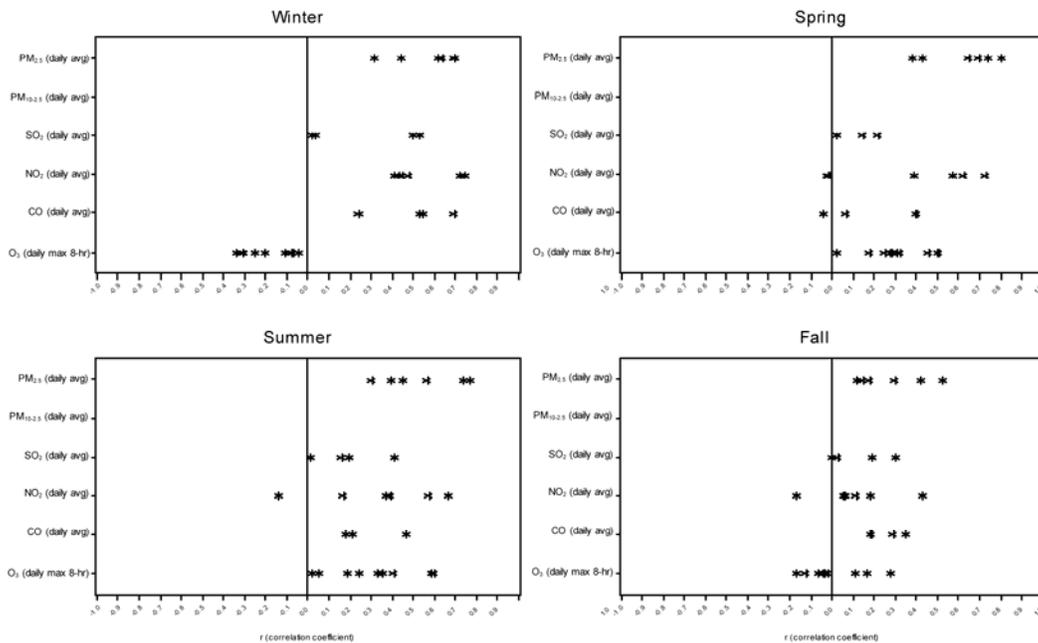
Figure A-187. Correlations between 24-h PM_{10} and co-located 24-h average $PM_{2.5}$, $PM_{10-2.5}$ SO_2, NO_2 and CO and daily maximum 8-h average O_3 for Riverside, CA, stratified by season (2005-2007). One point is included for each available monitor pair.
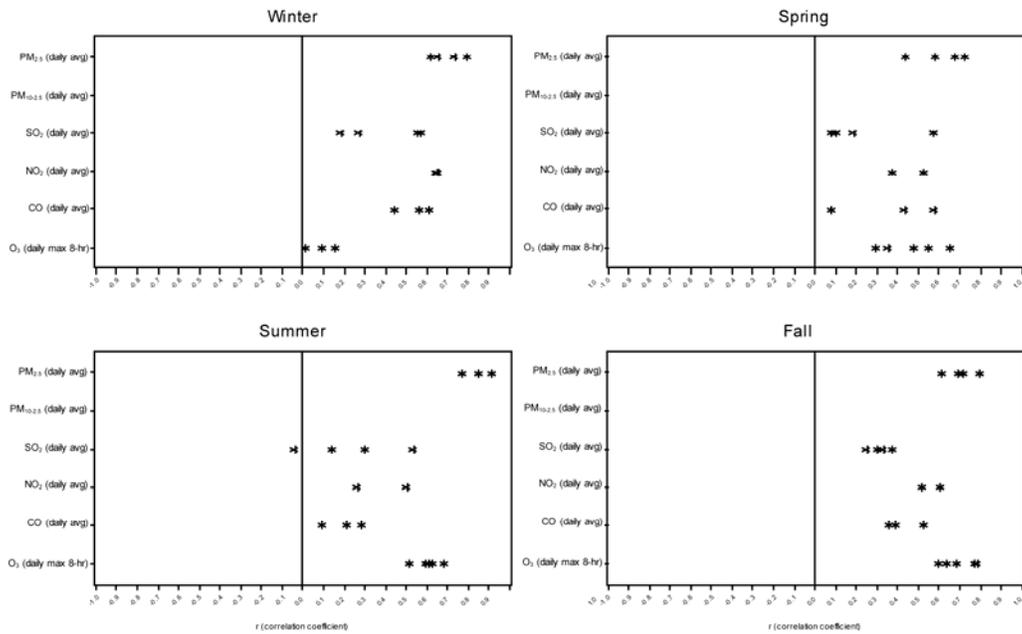
Figure A-188. Correlations between 24-h PM_{10} and co-located 24-h average $PM_{2.5}$, $PM_{10-2.5}$ SO_2, NO_2 and CO and daily maximum 8-h average O_3 for St. Louis, MO, stratified by season (2005-2007). One point is included for each available monitor pair.
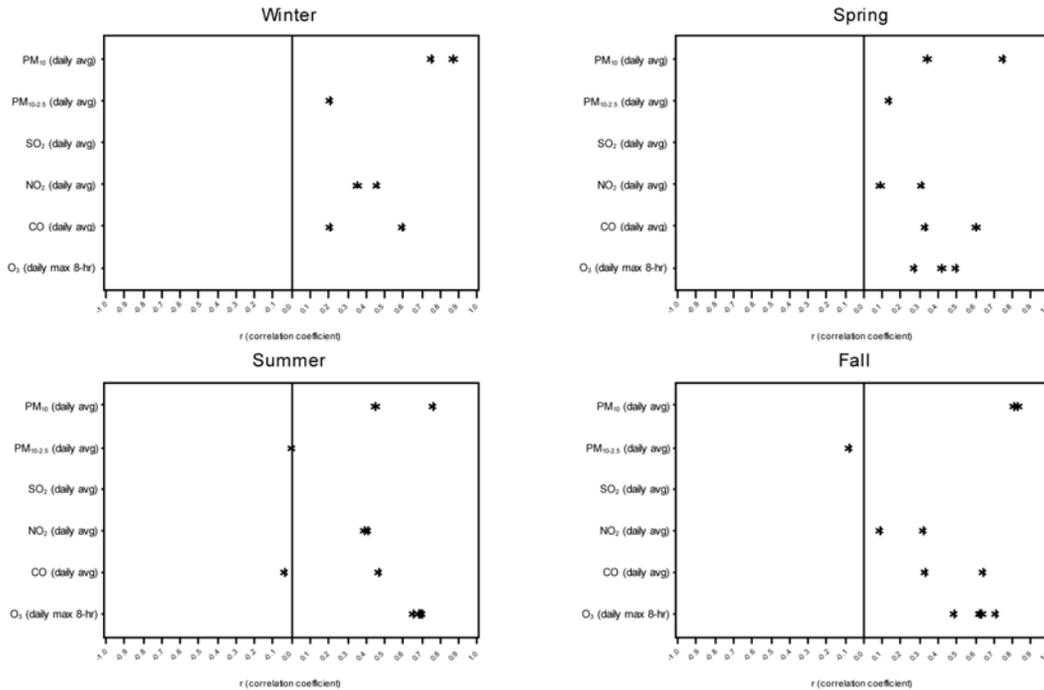
Figure A-189. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Atlanta, GA, stratified by season (2005-2007). One point is included for each available monitor pair.
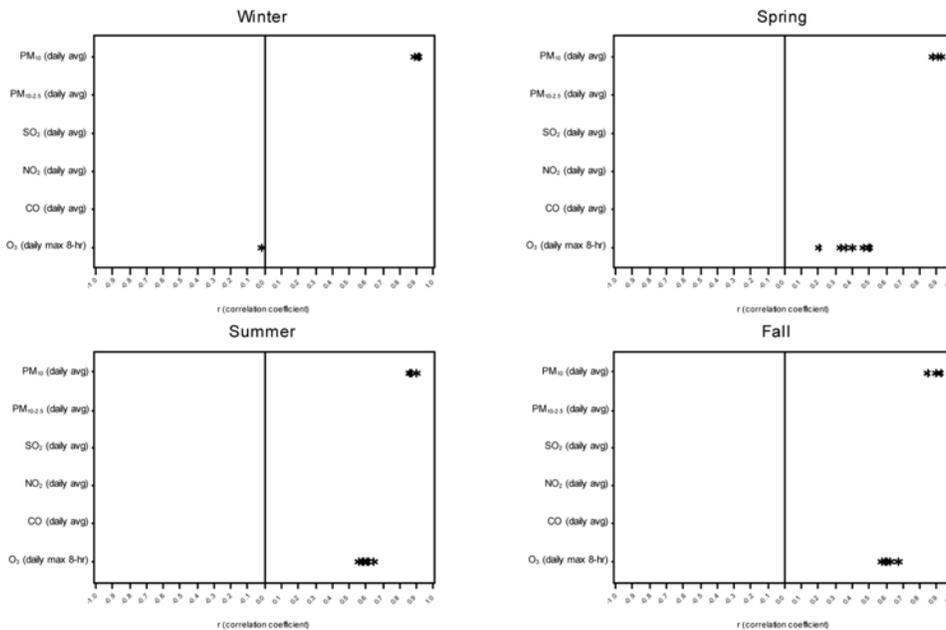
Figure A-190. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Birmingham, AL, stratified by season (2005-2007). One point is included for each available monitor pair.
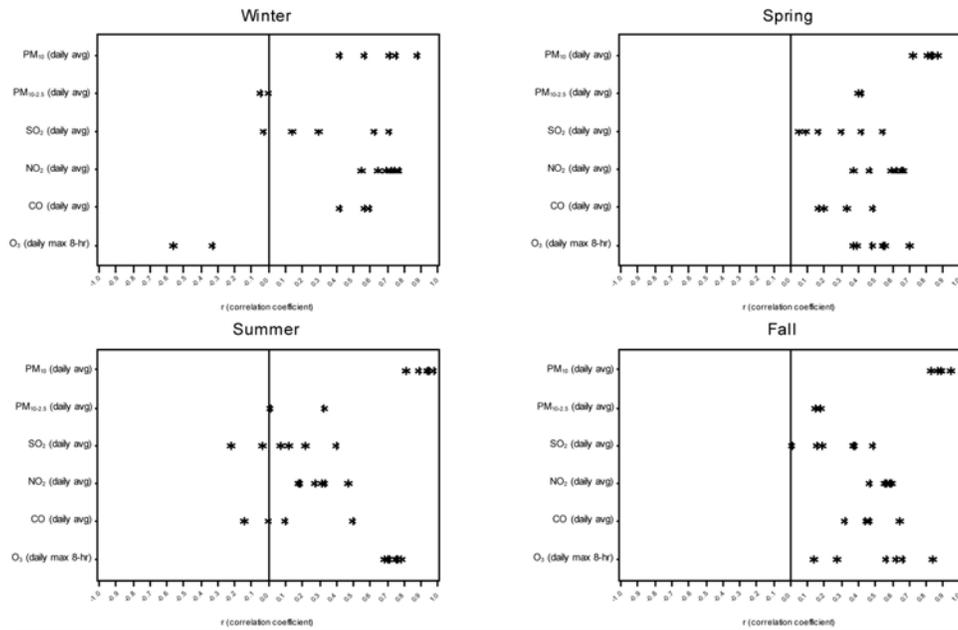
Figure A-191. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Boston, MA, stratified by season (2005-2007). One point is included for each available monitor pair.
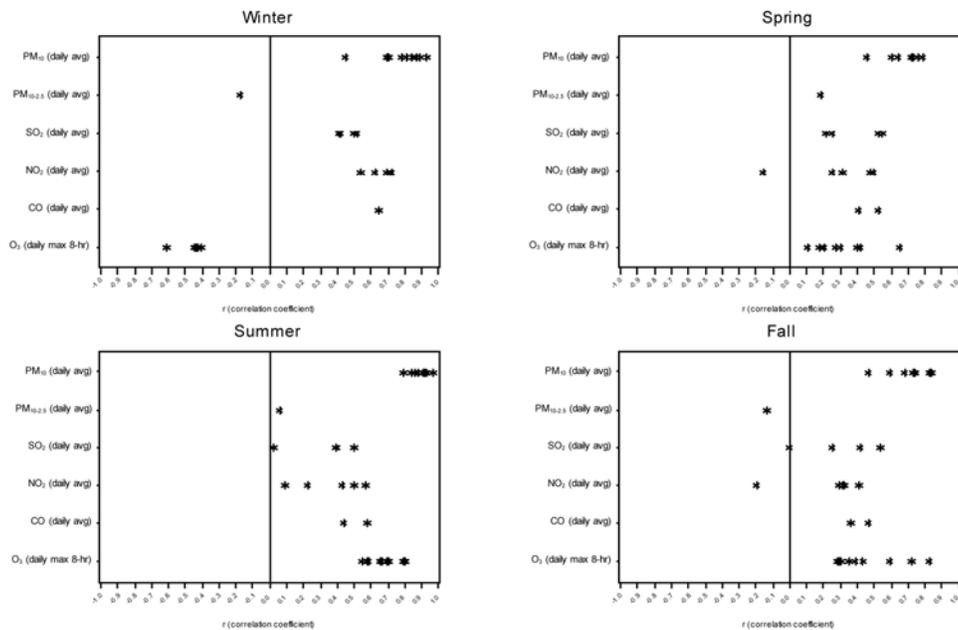
Figure A-192. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Chicago, IL, stratified by season (2005-2007). One point is included for each available monitor pair.
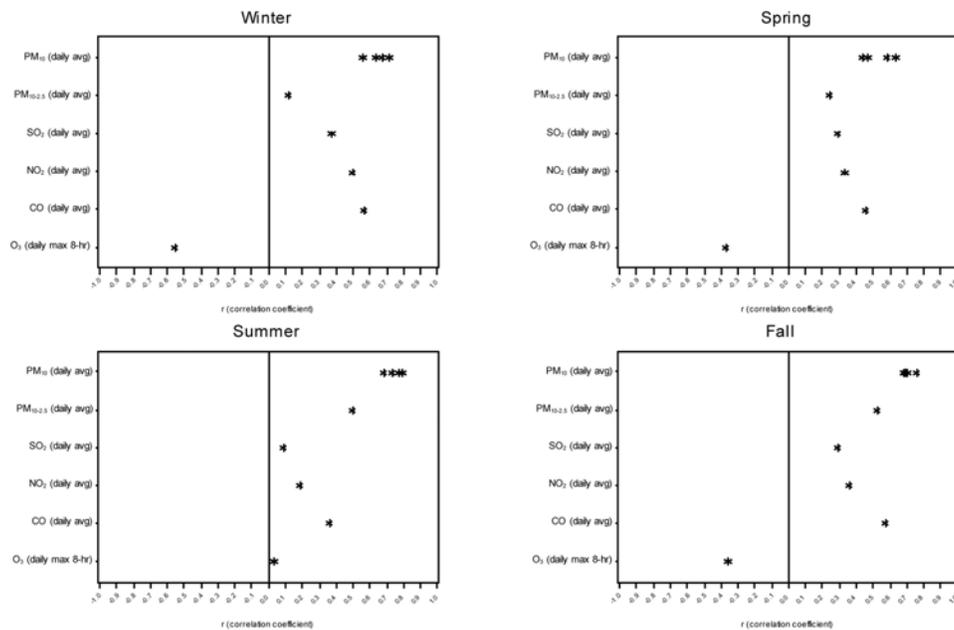
Figure A-193. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Denver, CO, stratified by season (2005-2007). One point is included for each available monitor pair.
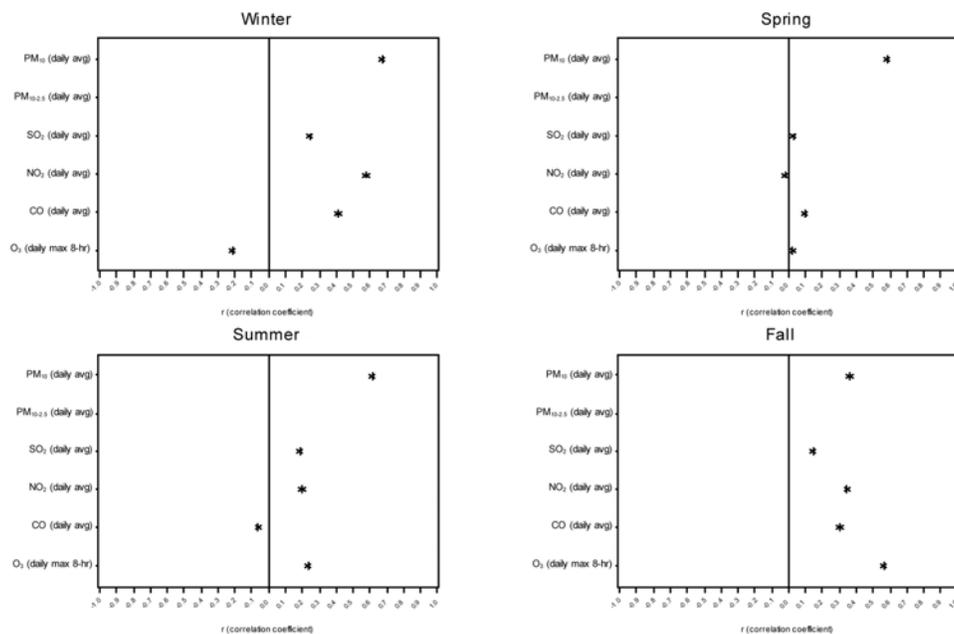
Figure A-194. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Houston, TX, stratified by season (2005-2007). One point is included for each available monitor pair.
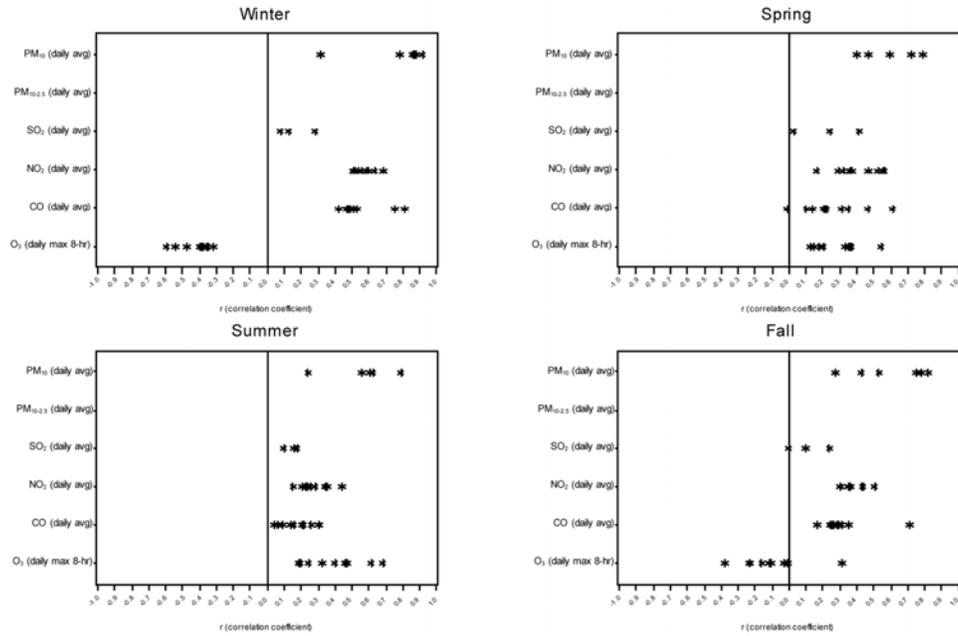
Figure A-195. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Los Angeles, CA, stratified by season (2005-2007). One point is included for each available monitor pair.
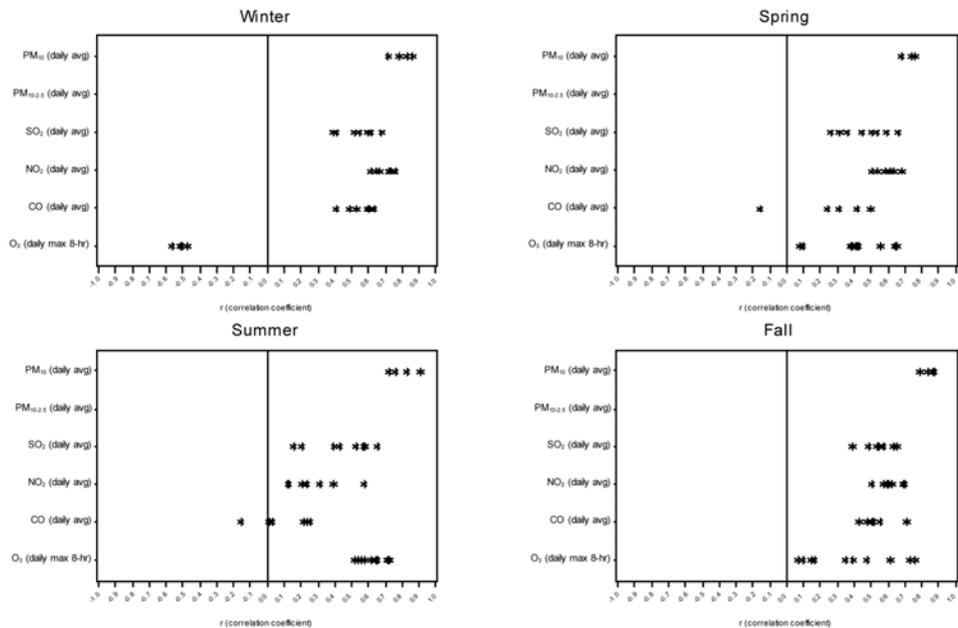
Figure A-196. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Philadelphia, PA, stratified by season (2005-2007). One point is included for each available monitor pair.
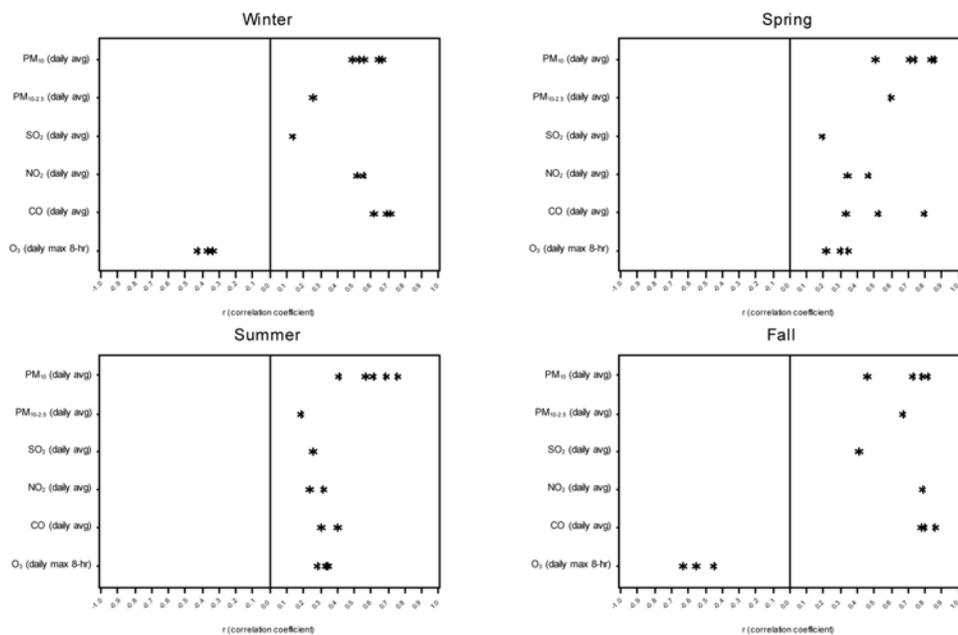
Figure A-197. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Phoenix, AZ, stratified by season (2005-2007). One point is included for each available monitor pair.
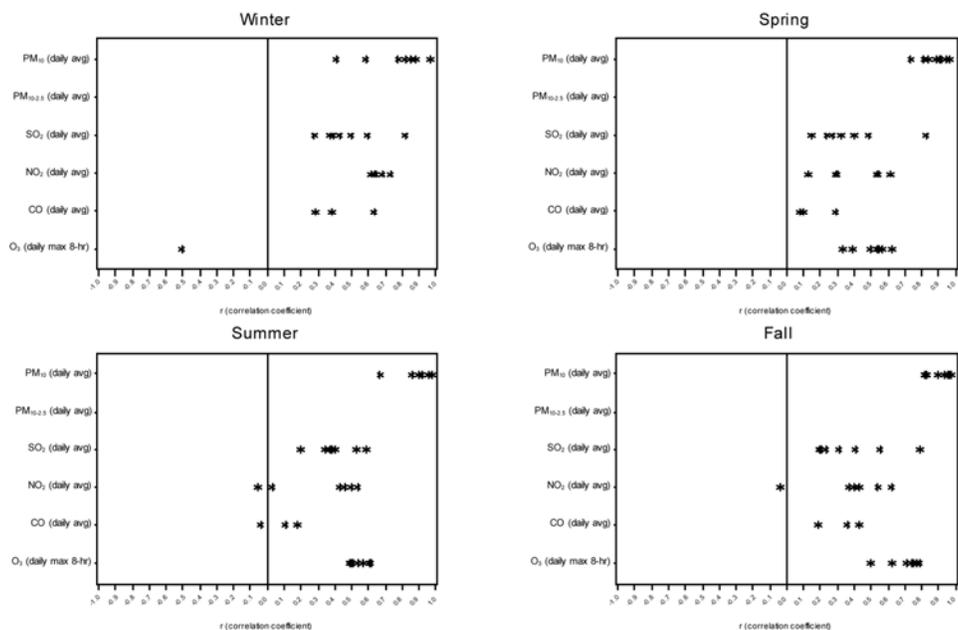
Figure A-198. Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Pittsburgh, PA, stratified by season (2005-2007). One point is included for each available monitor pair.
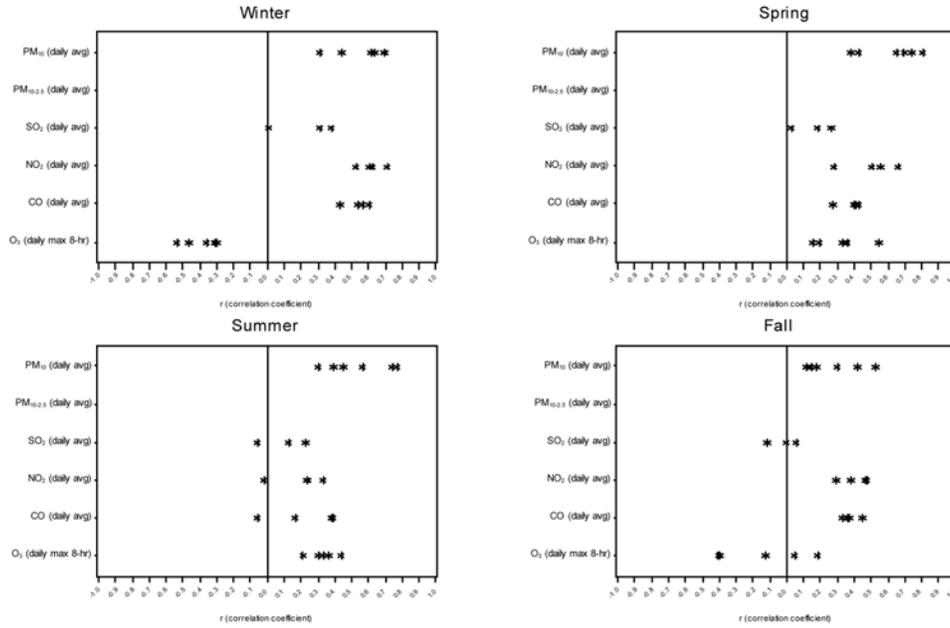
Figure A-199.   Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for Riverside, CA, stratified by season (2005-2007). One point is included for each available monitor pair.
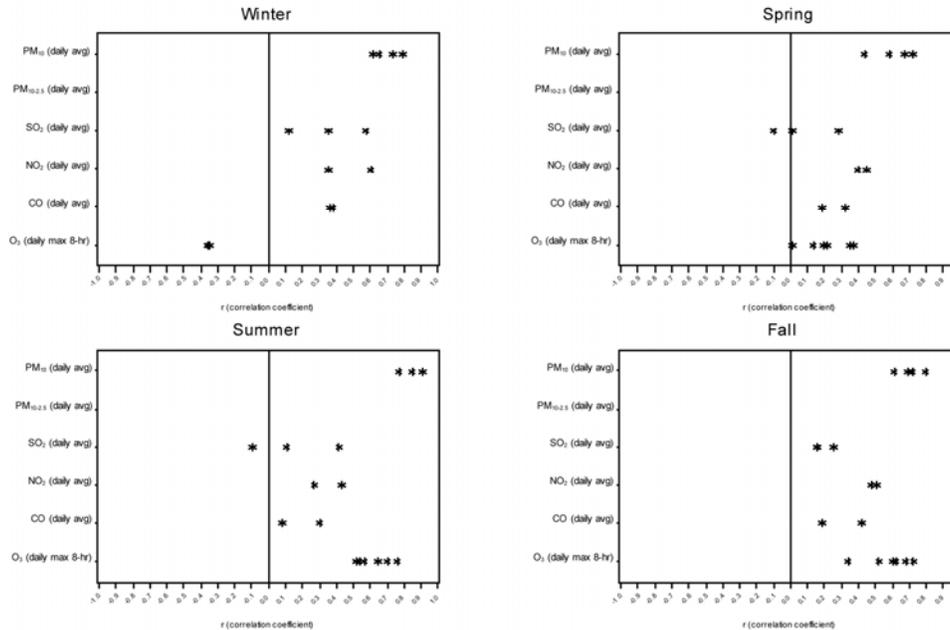
Figure A-200.   Correlations between 24-h PM$_{2.5}$ and co-located 24-h average PM$_{10}$, PM$_{10-2.5}$, SO$_2$, NO$_2$ and CO and daily maximum 8-h average O$_3$ for St. Louis, MO, stratified by season (2005-2007). One point is included for each available monitor pair.

A.2. Source Profiles

Table A-49.   Particle Speciation

Part I

Element	Symbol	Motor Vehicle Exhaust - Gasoline		Coal Combustion		Highway Road Dust		Unpaved Road Dust		Refinery	
		Weight %	Uncertainty	Weight %	Uncertainty	Weight %	Uncertainty	Weight %	Uncertainty	Weight %	Uncertainty
Aluminum	Al	0.1	-99	5.968	0.5247	5.729	0.4058	7.4822	0.9315	8.4853	2.3478
Antimony	Sb	0.01	-99	0	0.0625	0	0.0335	0	0.1601	0	0.0285
Arsenic	As			0	0.0164	0	0.0123	0	0.0226	0	0.0045
Barium	Ba	0.01	-99	1.3315	1.0801	0.1377	0.1027	0	0.5473	0	0.0979
Cadmium	Cd			0	0.0341	0	0.019	0	0.0881	0	0.0155
Calcium	Ca	0.42	-99	3.4536	1.0411	2.5657	0.1388	2.163	1.0444	0.1236	0.056
Chloride ion	Cl⁻	0.39	-99								
Chromium	Cr	0.01	-99	0.0176	0.0041	0.0271	0.0023	0.0312	0.0161	0.0443	0.0127
Cobalt	Co			0	0.0432	0	0.0668	0	0.0869	0	0.0218
Copper	Cu	0.02	-99	0.0179	0.0112	0.0219	0.0101	0.0474	0.0307	0.0299	0.0082
Total carbon	TC			4.2763	4.2579	14.3927	2.3449	4.2671	3.7193	0	1.6175
Gallium	Ga			0.014	0.014	0	0.005	0	0.0233	0	0.0059
Gold	Au										
Indium	In	0	-99	0	0.0404	0	0.022	0	0.1041	0	0.0183
Iron	Fe	1.27	-99	2.916	0.3827	4.5713	0.2661	5.5128	2.1152	1.4708	0.2216
Lanthanum	La	0	-99	0	0.2462	0	0.1341	0	0.6521	0	0.1146
Lead	Pb	0.08	-99	0.068	0.0336	0.067	0.0074	0.0288	0.0284	0.0097	0.0063
Magnesium	Mg	0.14	-99								
Manganese	Mn	0.01	-99	0.0284	0.0139	0.087	0.009	0.1372	0.0509	0.016	0.002
Mercury	Hg	0	-99	0	0.0154	0	0.0083	0	0.0383	0	0.0073
Molybdenum	Mo			0	0.0134	0	0.0071	0	0.0331	0.0079	0.0088
Nickel	Ni	0.01	-99	0.0072	0.0019	0.0081	0.0015	0.0091	0.0057	0.04	0.0065
Nitrate	NO₃⁻	0.06	-99	0	0.2116	0	0.094	0	0.6371	0	0.0772
Organic carbon	OC	59.37	-99	0	2.9263	12.7127	2.1296	4.2671	2.2637	0	1.5288
Palladium	Pd			0	0.0263	0	0.0151	0	0.0701	0	0.0127
Phosphorus	P	0.27	-99	0.9372	0.6322	0	0.0324	0.1603	0.044	0.0689	0.0144
Potassium	K	0.01	-99	0.4644	0.0602	2.7161	0.3069	2.8299	0.4949	0.0825	0.0234
Rubidium	Rb			0.0053	0.0043	0.0184	0.0023	0.0184	0.0093	0	0.002
Selenium	Se			0.0406	0.0407	0	0.0024	0	0.0108	0	0.0021
Silicon	Si	1.61	-99	9.0112	0.5675	17.596	1.4183	24.2969	4.0089	17.9733	5.1834
Silver	Ag			0	0.0312	0	0.0175	0	0.083	0	0.0151
Sodium	Na	0.01	-99								
Strontium	Sr			0.1964	0.0686	0.0395	0.0078	0.0313	0.0112	0.0094	0.0031

Element	Symbol	Motor Vehicle Exhaust - Gasoline		Coal Combustion		Highway Road Dust		Unpaved Road Dust		Refinery	
Sulfate	SO₄⁻			10.1716	8.9405	1.1604	0.2003	0.8688	1.3788	2.3243	3.4523
Sulfur	S	0.37	-99	2.948	2.729	0.598	0.0509	0.2808	0.3884	0.6304	0.9627
Thallium	Tl										
Tin	Sn			0	0.0527	0	0.0298	0	0.1464	0	0.0254
Titanium	Ti			0.4315	0.0651	0.3612	0.0313	0.5258	0.1289	0.6178	0.0711
Uranium	U										
Vanadium	V			0	0.0734	0.0288	0.0074	0	0.0646	0.0432	0.0084
Yttrium	Y			0	0.006	0.0046	0.0012	0	0.0146	0	0.0029
Zinc	Zn	0.49	-99	0.0797	0.0341	0.0932	0.0256	0.0502	0.021	0.0166	0.003
Zirconium	Zr			0.0247	0.0043	0.0128	0.0025	0.0219	0.0168	0.0166	0.0022
Ammonium	NH₄⁺	0.34	-99	0.3476	0.1352	0	0.025	0	0.1317	0.3281	0.5565
Sodium ion	Na⁺										
Carbonate	CO₃ =										
Organic carbon II	OC2										
Organic carbon III	OC3										
Organic carbon IV	OC4										
EC I	EC1										
Chlorine atom	Cl⁻			0.0629	0.0221	3.4403	0.5505	0.1519	0.0755	0.0186	0.0074
EC III	EC3										
EC	EC	16.44	-99	4.2763	3.0931	1.68	0.9817	0	2.9512	0	0.5283
Bromine Atom	Br			0.0147	0.0154	0.0037	0.0011	0	0.0078	0	0.0017
Organic carbon I	OC1										
EC II	EC2										
Sulfur dioxide	SO₂			7262.6687	7677.5681						
Potassium ion	K⁺			0.1109	0.0571	0.2295	0.1046	0.1263	0.0744	0.0115	0.0059

Part II

Element	Symbol	Residential Wood Burning		Oil Combustion		DE		Fly Ash		Incinerator	
		Weight %	Uncert-ainty	Weight %	Uncert-ainty	Weight %	Uncert-ainty	Weight %	Uncert-ainty	Weight %	Uncert-ainty
Aluminum	Al	0.0034	0.0103	0	0.05	0	0.01	1.5708	0.4755	1.15	0.83
Antimony	Sb	0.0002	0.0108	0	0.01	0	0.01	0.007	0.0218	0.01	0.15
Arsenic	As	0.0003	0.0016	0.02	0	0	0	0.001	0.0023	0	0.04
Barium	Ba	0.0093	0.0369	0	0.03	0.01	0.04	0.0303	0.0655	0.14	0.55
Cadmium	Cd	0.0013	0.0058	0	0.01	0	0.01	0	0.0154	0.01	0.08
Calcium	Ca	0.0664	0.0165	0	0.04	0.01	0.01	10.1398	1.7825	2.37	0.62

		Residential Wood Burning		Oil Combustion		DE		Fly Ash		Incinerator	
Chloride ion	Cl⁻	0.0028	0.0004					17.5498	1.5419		
Chromium	Cr	0.0003	0.0012	0.01	0.01	0	0	0.0054	0.001	0.02	0.02
Cobalt	Co	0.0005	0.0005	0.05	0.01	0	0	0.0015	0.0128	0	0.03
Copper	Cu	0.0002	0.0007	0.01	0.01	0	0	0.017	0.0013	0.08	0.1
Total carbon	TC	70.6416	7.1435	3.55	1.0855	98.94	17.859	1.4329	0.2009	55.79	27.5948
Gallium	Ga	0	0.0016	0.01	0	0	0	0.0013	0.0018	0	0.02
Gold	Au							0.0008	0.0033		
Indium	In	0.0021	0.0069	0	0.01	0	0.01	0	0.0164	0.01	0.1
Iron	Fe	0.0038	0.0017	0.68	0.1	0	0	0.8306	0.059	1.72	0.31
Lanthanum	La	0.0086	0.0431	0	0.04	0.02	0.05	0.0046	0.0868	8.43	61.15
Lead	Pb	0.0031	0.0018	0	0	0	0	0.0031	0.0031	14.56	11.69
Magnesium	Mg							0.4455	0.0465		
Manganese	Mn	0.003	0.0013	0	0	0	0	0.0426	0.0033	0.04	0.01
Mercury	Hg	0.0004	0.0027	0	0	0	0	0.0008	0.0025	27.63	47.27
Molybdenum	Mo	0	0.0024	0	0	0	0	0.0041	0.001	0.01	0.04
Nickel	Ni	0.0002	0.0005	2.36	0.23	0	0	0.0028	0.0004	0.01	0
Nitrate	NO₃⁻	0.2025	0.0156	0	0	0.06	0.01	0	0.2192	5.5	4.55
Organic carbon	OC	49.4961	5.481	1.71	0.56	90.8	14.79	1.4329	0.1592	37.21	18.03
Palladium	Pd	0.0006	0.0047	0	0	0	0	0	0.0126	0.02	0.07
Phosphorus	P	0	0.0051	0	0.65	0.01	0.02	0.5808	0.2447	0.05	0.16
Potassium	K	0.6346	0.1008	0	0	0	0	24.4341	5.0076	1.28	0.86
Rubidium	Rb	0.0007	0.0007	0	0	0	0	0.0351	0.0026	0	0.02
Selenium	Se	0.0001	0.0008	0.03	0	0	0	0.0018	0.0003	0.01	0.01
Silicon	Si	0.0443	0.0167	0	0.09	0.01	0.01	4.0201	1.2886	4.42	1.82
Silver	Ag	0.0023	0.0054	0	0	0	0.01	0	0.0143	0.02	0.08
Sodium	Na							2.8137	0.2174		
Strontium	Sr	0.0006	0.0009	0	0	0	0	0.0406	0.0029	0.02	0.01
Sulfate	SO₄²⁻	0.4553	0.0359	25.29	5.62	0.53	0.07	8.0717	0.6409	10.46	2.6
Sulfur	S	0.1533	0.0173	16.48	1.62	0.59	0.21	2.6349	0.1873	3.16	0.63
Thallium	Tl							0.0011	0.0025		
Tin	Sn	0.0006	0.0092	0	0.01	0	0.01	0.0067	0.0198	0.04	0.14
Titanium	Ti	0.001	0.012	0.01	0.01	0	0.01	0.058	0.0093	0.11	0.17
Uranium	U							0.0021	0.0052		
Vanadium	V	0.0007	0.005	0.4	0.04	0	0.01	0.0038	0.011	0.01	0.07
Yttrium	Y	0.0001	0.0011	0	0	0	0	0.0013	0.0021	0	0.02
Zinc	Zn	0.0762	0.0054	0.01	0	0.02	0.02	0.031	0.0023	0.57	0.39
Zirconium	Zr	0	0.0014	0	0	0	0	0.0039	0.0008	0	0.02
Ammonium	NH₄⁺	0.1132	0.014	0.84	0.24	0.03	0.01	0.0234	0.022	7.41	7.81
Sodium ion	Na⁺			0.11	0.02	0	0.01	4.7518	0.3438	1.81	2.63
Carbonate	CO₃ =			0	0.0214	0.2577	0.4463				
Organic carbon II	OC2	7.513	0.6675								

		Residential Wood Burning		Oil Combustion		DE		Fly Ash		Incinerator	
Organic carbon III	OC3	8.9627	1.4665								
Organic carbon IV	OC4	2.7683	1.1919								
EC I	EC1	20.342	2.9324								
Chlorine atom	Cl-	0.2874	0.0404	0.05	0.01	0.03	0.01	27.5797	8.1193	6.35	10.46
EC III	EC3	2.2878	0.4252								
EC	EC	21.1455	4.5813	1.84	0.93	8.14	10.01	0	0.1227	18.58	20.89
Bromine Atom	Br	0.0029	0.0011	0	0	0	0	0.0441	0.0032	0.19	0.3
Organic carbon I	OC1	25.1452	4.6648								
EC II	EC2	2.9362	1.2422								
Sulfur dioxide	SO$_2$										
Potassium ion	K+	0.5208	0.0795	0.01	0.01	0	0.01	14.5473	1.3393	1.01	0.42

A.3. Source Apportionment

A.3.1. Type of Receptor Models

Table A-50. Different receptor models used in the Supersite source apportionment studies: chemical mass balance.

Receptor Model	Description	Strengths and Weaknesses
EFFECTIVE VARIANCE CMB [42,121] (Note that all models based on eq 1 or 2 are CMB equations. The term CMB used here reflects the historical solution in which source profiles are explicitly used as model input and a single sample effective variance solution is reported.) CMB software is currently distributed by EPA. The most recent version is the CMB 8.2, which is run in the Microsoft Windows system.	*PRINCIPLE* Ambient chemical concentrations are expressed as the sum of products of species abundances in source emissions and source contributions (eq 1 or 2). These equations are solved for the source contribution estimates when ambient concentrations and source profiles are input. The single-sample effective variance least squares122 is the most commonly used solution method because it incorporates uncertainties of ambient concentrations and source profiles in the estimate of source contributions and their uncertainties. This reduced to the tracer solution when it is assumed that there is one unique species for each source. Choices of source profiles should avoid collinearity, which occurs when chemical compositions of various source emissions are not sufficiently different.[121] *DATA NEEDS* CMB requires source profiles, which are the mass fractions of particulate or gas species in source emissions. The species and particle size fraction measured in source emissions should match those in ambient samples to be apportioned. Several sampling and analysis methods provide time-integrated speciation of $PM_{2.5}$ and volatile organic compounds (VOCs) for CMB. Source profiles are preferably obtained in the same geographical region as the ambient samples, although using source profiles from different regions is commonly practiced in the literature. The practitioner needs to decide the source profiles and species being included in the model, on the basis of the conceptual model and model performance measures. *OUTPUT* Effective variance CMB determines, if converged, source contributions to each sample in terms of PM or VOC mass. CMB also generates various model performance measures, including correlation R^2, deviation X^2, residue/ uncertainty ratio, and MPIN matrix that are useful for refining the model inputs to obtain the best and most meaningful source apportionment resolution.	*STRENGTHS* Software available providing a good user interface. Provides quantitative uncertainties on source contribution estimates based on input concentrations, measurement uncertainties, and collinearity of source profiles. Quantifies contributions from source types with single particle and organic compound measurements. *WEAKNESSES* Completely compatible source and receptor measurements are not commonly available. Assumes all observed mass is due to the sources selected in advance, which involves some subjectivity. Chemically similar sources may result in collinearity without more specific chemical markers. Typically does not apportion secondary particle constituents to sources. Must be combined with profile aging model to estimate secondary PM.

[42] Hidy and Friedlander (1972)
[121] Watson et al. (1997)

Source: Watson et al. (2008)

Table A-51. Different receptor models used in the Supersites source apportionment studies: factor analysis.

Receptor Model	Description	Strengths and Weaknesses
PMF[123,124] PMFx (PMF2 and PMF3) software is available from Dr. Pentti Paatero at the University of Helsinki, Finland. This software is a Microsoft DOS application. EPA distributes EPA PMF76 version 1.1 as a Microsoft Windows application with better user interface.	*PRINCIPLE* PMFx contains PMF2 and PMF3. PMF2 solves the CMB equations (i.e., eqs 2 and 3) using an iterative minimization algorithm. Source profiles F_{ij} and contribution S_{jt} are solved simultaneously. The non-negativity constraint is implemented in the algorithm to decrease the number of possible solutions (local minimums) in the PMF analyses, because both source profile and contribution should not contain negative values. There is rotational ambiguity in all two-way factor analyses (i.e., F_{ij} and S_{jt} matrices may be rotated and still fit the data). PMF2 allows using the FPEAK parameter to control the rotation. A positive FPEAK value forces the program to search such solutions where there are many zeros and large values but few intermediate values in the source matrix F_{ij}. F_{key} can further bind individual elements in F_{ij} to zero. On the basis of a similar algorithm, PMF3 solves a three-way problem. PMFx and UNMIX estimate F_{ij} and S_{jt} by minimizing: $$Q \text{ or } \chi^2 = \sum_i \sum_t [E_{it}/\sigma_{it}]^2 = \sum_i \sum_t [(C_{it} - \sum_j F_{ij}S_{jt})/\sigma_{it}]^2$$ *(A-1)* Where the weighing factor, σ_{it}, represents the magnitude of E_{it}, PMFx limits solutions of eq 2 to non-negative F_{ij} and S_{jt}. *DATA NEEDS* A large number of ambient samples (usually much more than the number of factors in the model) are required to produce a meaningful solution. Species commonly used in PMF are also those in CMB. Weighting factors associated with each measurement need to be assigned before analysis. The practitioner also needs to decide the number of factors, FPEAK, and F_{key} in the model. *OUTPUT* PMFx reports all the elements in F_{ij} and S_{jt} matrices (PMF2). It also calculates model performance measures such as deviation X^2 and standard deviation of each matrix element. The practitioner needs to interpret the results linking them to source profiles and source contributions.	*STRENGTHS* Software available. Can handle missing or below-detection-limit data. Weights species concentrations by their analytical precisions. Downweight outliers in the robust mode. Derives source profiles from ambient measurements as they would appear at the receptor (does not require source measurements). *WEAKNESSES* Requires large (>100) ambient datasets. Need to determine the number of retaining factors. Requires knowledge of source profiles or existing profiles to verify the representativeness of calculated factor profiles and uncertainties of factor contributions. Relies on many parameters/initial conditions adjustable to model input; sensitive to the preset parameters.
ME2[125] ME2 code is available from Dr. Pentti Paatero at the University of Helsinki, Finland as a Microsoft DOS application.	*PRINCIPLE* The PMFx algorithm is derived from ME2. Unlike PMFx that is limited to questions in the form of eq 1 or 2, ME2 solves all models in which the data values are fitted by sums of products of unknown (and known) factor elements. The first part of the algorithm interprets instructions from the user and generates a table that specifies the model. The second part solves the model using an iterative minimization approach. Additional constraints could be programmed into the model to reduce the ambiguity in source apportionment. These constraints may include known source profiles and/or contributions (e.g., contributions are known to be zero in some cases). *DATA NEEDS* Data needs are similar to those of PMFx but are more flexible. In theory, any measured or unknown variables may be included in the model as long as they satisfy linear relationships. The users need to specify the model structure, the input, and the output. *OUTPUT* ME2 calculates and reports all unknown variables in the model.	*STRENGTHS* Software available. Can handle user-specified models. Possibility to include all measured variables into the model, such as speciated concentration over different time scales, size distributions, meteorological variables, and noise parameters. *WEAKNESSES* Require substantial training to access the full feature of the software and develop a model. Generally requires large ambient datasets. Need to assume linear relationships between all variables. Relies on many parameters/initial conditions adjustable to model input; sensitive to the preset parameters.

Receptor Model	Description	Strengths and Weaknesses
UNMIX [29,44,126] UNMIX code is available from Dr. Ron Henry at the University of Southern California as an MatLab application. A stand-alone version (UNMIX version 6) is also available from EPA.	*PRINCIPLE* UNMIX views each sample as a data point in a multidimensional space with each dimension representing a measured species. UNMIX solves eqs 2 and 3 by using a principle component analysis (PCA) approach to reduce the number of dimensions in the space to the number of factors that produce the data, followed by an unique "edge detection" technique to identify "edges" defined by the data points in the space of reduced dimension (e.g., Figures 1 and 3). The number of factors is estimated by the NUMFACT algorithm in advance127, which reports the R^2 and signal-to-noise (S/N) ratio associated with the first N principle components (PCs) in the data matrix. The number of factors should coincide with the number of PCs with S/N ratio >2. Once the data are plotted on the reduced space, an edge is actually a hyperplan that signifies missing or small contribution from one or more factors. Therefore, UNMIX searches all the edges and uses them to calculate the vertices of the simplex, which are then converted back to source composition and contributions. Geometrical concepts of self-modeling curve resolution are used to ensure that the results obey (to within error) non-negativity constraints on source compositions and contributions. *DATA NEEDS* A large number of ambient samples (usually much more than the number of factors in the model) are required to achieve a meaningful solution. Species commonly used in UNMIX are also those in CMB. The measurement precision is not required. The practitioner needs to specify the number of factors on the basis of the NUMFACT results. *OUTPUT* UNMIX determines all the elements in the factor (Fij) and contribution (Sjt) matrices. It also calculates the uncertainty associated with the factor elements and model performance measures including: (1) R^2, (2) S/N ratio, and (3) strength.	*STRENGTHS* Software available with graphical user interface. Does not require source measurements. Provide graphical problem diagnostic tools (e.g., species scatter plot). Provide evaluation tools (e.g., R^2, S/N ratio). *WEAKNESSES* Requires large (>100) ambient datasets. Need to assume or predetermine number of retained factors. Does not make explicit use of errors or uncertainties in ambient measurements. Cannot use samples containing missing data in any species. Limited to a maximum of 7 or 14 (UNMIX version 6) factors. Can report multiple or no solutions. Requires knowledge of existing source profiles to evaluate the solutions.

Receptor Model	Description	Strengths and Weaknesses
PDRM[97] PDRM was developed under the Supersites Program and requires MatLab or equivalent software to perform the calculation.	*PRINCIPLE* PDRM estimates contributions from selected stationary sources for a receptor site using high time-resolution measurements and meteorological data. In PDRM, eq 2 is modified to: $$C_k = \sum_j ER_{i,j}\left(\frac{X}{Q}\right)_{j,t} + E_k \qquad (A\text{-}2)$$ where $ER_{i,j}$ is interpreted as the emission rate of species i from stationary source j and $(X/Q)_{j,t}$ is the meteorological dispersion factor averaged over the time interval t. Equation 4 is solved for $ER_{i}j$ and $(X/Q)_{j,t}$ simultaneously by a nonlinear fit minimizing the objective function, FUN: $$FUN = \sum_{i=1}^{l}\sum_{t=1}^{m}\sum_{j=1}^{n}\left[ER_{i,j}\left(\frac{X}{Q}\right)_{j,t}^{PDRM} - C_k\right]^2 \qquad (A\text{-}3)$$ Because the number of solutions for a product of unknowns is infinite, additional constraints are set up for $(X/Q)_{j,t}$ on the basis of the Gaussian plume model, thus: $$LB\left(\frac{X}{Q}\right)_{j,t}^{Met} \le \left(\frac{X}{Q}\right)_{j,t}^{PDRM} \le UB\left(\frac{X}{Q}\right)_{j,t}^{Met}$$ $$\left(\frac{X}{Q}\right)_{j,t}^{Met} = \frac{1}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right]\right.$$ $$\left. + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right]\right\} \qquad (A\text{-}4)$$ Eqs 6 and 7 limit the solution of eq 5 within the lower (LB) and upper (UB) bound of those predicted by the Gaussian plume model using different parameterizations. *DATA NEEDS* PDRM requires speciated measurements at a higher time-resolution than typical CMB or PMF applications because of the fast-changing meteorological parameters. PDRM also requires data for eq 7: transport speed (u), lateral and vertical dispersion parameters (σ_y and σ_z), and stack height (h). *OUTPUT* PDRM determines emission rates and contributions from each point source considered in the model at the same time resolution as the measurement.	*STRENGTHS* Explicitly include meteorological information and stack configuration of stationary sources into the model. Do not require source measurements. Do not need to interpret the relations between factors and sources. Commercial software (e.g., MatLab) available for performing nonlinear fit. Suitable for high time-resolution measurement. *WEAKNESSES* Can only handle stationary sources but not area or mobile sources. Need to assume that only stationary sources are considered in the model contribute significantly for a measurement at the receptor site. Do not account for uncertainty in the measurement. Meteorological data may not be always available or accurate. Gaussian plume model may not be representative of the actual atmospheric dispersion. Sensitive to the imposed constraints (UB and LB).

Receptor Model	Description	Strengths and Weaknesses
PLS128	*PRINCIPLE*	*STRENGTHS*

PLS128

PRINCIPLE

PLS examines the relationships between a set of predictor (independent) and response (dependent) variables. It assumes that the predictor and response variables are controlled by independent "latent variables" less in number than either the predictor or the response variables. In recent applications, [96] PM chemical composition and size distribution are used as predictor (X) and response (Y) variables, respectively. Eq 2 is modified to:

$$X_k = \sum_i T_{if} P_{jt} + E_k \qquad \text{(A-5)}$$

$$Y_{it} = \sum_i U_{if} C_{jt} + D_k \qquad \text{(A-6)}$$

where T and U are matrices of so-called "latent variables," and P and C are loading matrices. If X and Y are correlated to some degree, T and U would show some similarity. Equations 8 and 9 are solved by an iterative algorithm "NIPALS," which attempts to minimize E,D, and the difference between T and U simultaneously. If T and U end up being close enough, the X and Y variables can be explained by the same latent variables. These latent variables may then be interpreted as source or source categories.

DATA NEEDS

Typical applications of PLS require both chemical speciated and size-segregated measurements. The practitioner needs to decide the number of latent variables on the basis of the correlation of resulting T and U matrices.

OUTPUT

PLS calculates latent variables, which are common factors best explaining the predictor and response variables, and the residues from fitting. R_x and R_y,

$$R_x = 1 - \text{var}(E)/\text{var}(X) \qquad \text{(A-7)}$$

$$R_y = 1 - \text{var}(D)/\text{var}(Y) \qquad \text{(A-8)}$$

indicate the degree to which variables X and Y are explained by the latent variables.

STRENGTHS

Fit two types of measurements (e.g., chemistry and size) with common factors. Provide more information to identify sources.

Analyze strongly collinear and noisy dataset.

Do not require source measurements.

WEAKNESSES

Requires large (>100) ambient datasets.

Difficult to relate latent variables to any physical quantities.

Do not provide quantitative source contribution estimates.

Need to decide the number of latent variables.

Do not explicitly make use of measurement uncertainties.

Can result in no solution.

[29] Henry (1997)
[44] Lewis (2003)
[96] Ogulei et al. (2006b)
[97] Park et al. (2005b)
[123] Paatero (1997)
[124] Paatero et al. (2002)
[125] Paatero (1999)
[126] Henry (2003)

Source: Watson et al. (2008)

Table A-52. Different receptor models used in the Supersites source apportionment studies: tracer-based methods.

Receptor Model	Description	Strengths and Weaknesses
EF [129,130] The EF method may use a MLR algorithm, which is available in most statistical and spreadsheet software	*PRINCIPLE* A tracer (or marker) for a particular source or source category is a species enriched heavily in the source emission against other species and other sources. Using EFs-, concentration of the ith pollutant at a receptor site at time t (i.e., $C_{i,t}$) can be expressed as: $$C_{i,t} = \sum_l \frac{1}{EF_{i,pj}} C_{pj,t} + Z_{i,t} = \sum_l \left(\frac{F_i}{F_{pj}}\right) C_{pj,t} + Z_{i,t}$$ *(A-7)* where the enrichment factor $EF_{i,pj}$ is the ratio of emission rate of the pollutant of interest (F_{ij}) and tracer species (F_{pj}) from source j. $C_{pj,t}$ is the concentration of tracer species for source j at time t, and $Z_{i,t}$ represents contributions from all other sources (including the background level). The solution for eq 12 is situation-dependent. $EF_{i,pj}$ is usually unknown but may be estimated from source profiles, edges of a two-way scatter plot (e.g., Figures 1 and 3), or the ratio of $C_{i,t}$ to $C_{pj,t}$ for a particular period when it is believed that a single source is dominant. In cases where $Z_{i,t}$ is a constant, $EF_{i,pj}$ may be derived from MLR. *DATA NEEDS* The minimum data needs include concentrations of all primary tracers at the receptor site. Known EFs or background levels are helpful. *OUTPUT* The EF method determines contributions to species i from each source considered in the model.	*STRENGTHS* No special software needed. Indicate presence or absence of particular emitters. Provides evidence of secondary PM formation and changes in source impacts by changes in ambient composition. Could use a large (>100) dataset or a small (e.g., < 10) dataset. *WEAKNESSES* Semiquantitative method, not specific especially when the EFs are unknown in advance. Limited to sources with unique markers. Tracer species must be exclusively from the sources or source categories examined. Provide very limited error estimates. More useful for source/process identification than for quantification.
NNLS [131,132] The MatLab Optimization Toolbox provides a function "lsqnonneg" for performing the NNLS calculation.	*PRINCIPLE* NNLS also solves the EF equation (eq 12 or equivalent) with known target species and tracer concentrations. Conventional MLR solutions to eq 12 may lead to negative EFs due to the uncertainty in measurements or colinearity in source contributions. This is avoided in the NNLS approach since additional non-negative constraints are built into the algorithm, i.e.: $$EF_{i,pj} \geq 0$$ *(A-8)* Utilizing orthogonal decomposition, a NNLS problem can be reduced to the more familiar least-distance programming and solved by a set of iterative subroutines developed and tested by Lawson and Hanson.[131] In a more general sense, NNLS linearly relates a response variable to a set of independent variables with only non-negative coefficients. *DATA NEEDS* When applied to EF or MLR problems, NNLS requires the concentration of target (response) and tracer (independent) species. *OUTPUT* NNLS generates non-negative regression coefficients for an EF/MLR problem and these coefficients can be related to the source contributions.	*STRENGTHS* Implemented by many statistical software packages. Generate only non-negative EFsor regression coefficients. Do not require source measurements. Possible to include meteorological or other (besides chemistry) data into the model. *WEAKNESSES* Require a large (>100) set of ambient measurements. Semiquantitative method, not specific. Do not explicitly consider measurement uncertainties. Tracer species must be exclusively from the sources or source categories examined. Non-negative constraints may not be appropriate in some cases.

Receptor Model	Description	Strengths and Weaknesses
FAC[111]	**PRINCIPLE** FAC provides a simple mean of estimating the SOA production rate using the emission inventories of primary precursor VOCs. FAC is actually a source-oriented modeling technique but it does not take into account all the atmospheric processes. FAC is defined as the fraction of SOA that would result from the reactions of a particular VOC: $$[SOA] = \sum_i FAC_i \times ([VOC_i]_0 \times \text{Fraction of VOC } i \text{ reacted})$$ *(A-9)* where $[VOC_i]_0$ is the emission rate of VOC_i and $[SOA]$ is the formation rate of SOA. Equation 14 can be viewed as an extension of eq 12 but concentrations are replaced with emission rates and EFs are replaced with FACs. FAC and the fraction of VOC reacted under typical ambient conditions have been developed for a large number of hydrocarbons $>C_6$.[111] The most significant SOA precursors are aromatic compounds (especially toluene, xylene, and trimethylbenzenes) and terpenes. In most applications, these FACs are used directly to estimate SOA. **DATA NEEDS** FAC requires the VOC emission inventory in the region of interest. The knowledge of O_3 and radiation intensity is also helpful for slight modifications of the FACs. **OUTPUT** FAC method estimates the total production rate of SOA.	**STRENGTHS** Link SOA to primary VOC emissions so that SOA can also be treated as primary particles in the PM modeling. Simple and inexpensive. **WEAKNESSES** Ignore the influence of aerosol concentration and temperature-dependent gas-particle partitioning on SOA yield. Limited by the accuracy of VOC emission inventory. Do not directly infer the contribution of each source to ambient SOA concentration. Difficult to verify.

[111] Grosjean and Seinfeld (1989)
[129] Dams et al. (1970)
[130] Reimann and De Caritat (2000)
[131] Lawson and Hanson (1974)
[132] Wang and Hopke (1989)

Source: Watson et al. (2008)

Table A-53. Different receptor models used in the Supersites source apportionment studies: meteorology-based methods.

Receptor Model	Description	Strengths and Weaknesses
CPF [134,135]	*PRINCIPLE* CPF estimates the probability that a given source contribution from a given wind direction will exceed a predetermined threshold criterion (e.g., upper 25th percentile of the fractional contribution from the source of interest). The calculation of CPF uses source contributions (i.e., S_{jt} in eq 2) determined for the receptor site and local wind direction data matching each of the source contributions in time. These data are then segregated to several sectors according to wind direction and the desired resolution (usually 36 sectors at a 10° resolution). Data with very low wind speed (e.g., < 0.1 m/sec) are usually excluded from analysis because of the uncertain wind direction. CPF is then determined by: $$CPF(\theta) = \frac{m_{\Delta\theta}}{n_{\Delta\theta}}$$ (A-10) where $m_{\Delta\theta}$ is the number of occurrences in the direction sector $\theta \rightarrow \theta + \Delta\theta$ that exceeds the specified threshold, and $n_{\Delta\theta}$ is the total number of wind occurrences in that sector. Because wind direction is changing rapidly, high-time resolution measurements (e.g., minutes to hours) are preferred for a CPF analysis. If the calculated source contributions represent long-term averages, wind direction needs to be averaged over the same duration. In addition to source contribution, CPF can be applied directly to pollutant concentration measurements at a receptor site. *DATA NEEDS* CPF requires the time series of source contributions at a receptor site, which is usually determined by CMB or factor analysis methods using speciated measurements at the site. CPF also requires wind direction and wind speed data averaged over the same time resolution as the sampling duration. *OUTPUT* CPF reports the probability of "high" contribution from a particular source or factor occurring within each wind direction sector. The results are often presented in a wind rose plot (e.g., Figure 6a).	*STRENGTHS* Infer the direction of sources or factors relative to the receptor site. Provide verification for the source identification made by factor analysis method. Easy to implement. *WEAKNESSES* Criterion for the threshold is subjective. Absolute source contribution (or fractional contribution) may be influenced by other factors besides wind direction (e.g., wind speed, mixing height). Local and near-surface wind direction only has a limited implication for long-range transport. Easy to be biased by a small number of wind occurrences in a particular sector. Work better for stationary sources than area or mobile sources.

Receptor Model	Description	Strengths and Weaknesses
NPR [136,137]	**PRINCIPLE** NPR calculates the expected (averaged) source contribution as a function of wind direction following: $$S(\theta) = \frac{\sum_i K\left(\frac{\theta - W_i}{\Delta\theta}\right) \times S_i}{\sum_i K\left(\frac{\theta - W_i}{\Delta\theta}\right)}$$ (A-11) where W_i is the wind direction for the ith sample and S_i is the contribution from a specific source to that sample, determined from measurements at the receptor site. K is a weighting function called the kernel estimator. There are many possible choices for K. Henry et al.[136] recommend either Gaussian or Epanechnikov functions. The most important decision in NPR is the choice of the smoothing parameter $\Delta\theta$. If $\Delta\theta$ is too large, $S(\theta)$ will be too smooth and meaningful peaks could be lost. If it is too small, $S(\theta)$ will have too many small, meaningless peaks. $\Delta\theta$ needs to be chosen according to the project-specific spatial distribution of sources. NPR also estimates the confidence intervals of $S(\theta)$ based on the asymptotic normal distribution of the kernel estimates, thus: $$\Delta S(\theta) = \frac{\sum_i K\left(\frac{\theta - W_i}{\Delta\theta}\right) \times (S_i - S(\theta))^2}{\left(\sum_i K\left(\frac{\theta - W_i}{\Delta\theta}\right)\right)^2}$$ (A-12) **DATA NEEDS** NPR requires the same data as the CPF method, including the time series of source/factor contributions (or fractional contributions) at the receptor site and local wind direction data matching the sampling duration in time. **OUTPUT** NPR reports the distribution of source contribution as a function of wind direction and the confidence level associated with it.	**STRENGTHS** Infer the direction of sources or factors relative to the receptor site. Provide verification for the source identification made by factor analysis method. Require no assumption about the function form of the relationship between wind direction and source contribution. Provide uncertainty estimates. Easy to implement. **WEAKNESSES** Choices for the kernel estimator and smoothing factor are subjective. Absolute source contribution (or fractional contribution) may be influenced by other factors besides wind direction (e.g., wind speed, mixing height). Local and near-surface wind direction only has a limited implication for long-range transport. Easy to be biased by a small number of wind occurrences in a particular sector. Work better for stationary sources than area or mobile sources.

Receptor Model	Description	Strengths and Weaknesses
TSA [138] TSA requires the calculation of air parcel back trajectory, which is often accomplished using the HY-SPLIT model.[115,139] HY-SPLIT version 4.5 is available at http://www.arl.noaa.gov/-ready/hysplit4.html.	*PRINCIPLE* Similar to CPF, TSA clusters the measured pollutant concentration or calculated source contribution according to the wind pattern. However, air parcel back trajectory, rather than local wind direction, is used. A back trajectory traces the air parcel backward in time from a receptor. The initial height is often between 200 and 1000 m above ground level where the wind direction could differ from the surface wind direction substantively. For each sample i, TSA obtains one or more trajectories and calculates their total residence time in the jth directional sector ($\tau_{i,j}$, i.e., the total number of 1-h trajectory end points that fall into the sector). The pollutant concentration or source contribution in the sample, S_i, is then linearly apportioned into each directional sector according to $\tau_{i,j}$ and averaged over all samples to produce the directional dependent pollutant concentration/source contribution for the period of interest: $$\bar{s}_j = \sum_i s_i \left(\frac{\tau_{i,j}}{\sum_i \tau_{i,j}} \right) / N$$ (A-13) where N is the number of samples. Compared with CPF and NPR, TSA considers the entire air mass history rather than just the wind direction at the receptor. *DATA NEEDS* TSA requires the time series of pollutant concentration or source contribution at the receptor site, and back trajectories initiated over the site during the sampling duration. Trajectory is usually calculated once every hour so TSA is more suitable for analyzing measurements of >1-h resolution. *OUTPUT* TSA reports the avg pollutant concentration or source contribution as a function of wind direction based on back trajectory calculations.	*STRENGTHS* Infer the direction of sources or factors relative to the sampling site. Provide verification for the source identification made by factor analysis method. Account for air mass transport over hundreds to thousands of kilometers and on the order of several days. Can represent plume spread from vertical wind shear at different hours of day by adjusting the initial height of back trajectories. *WEAKNESSES* Need to generate and analyze the back trajectory data. Uncertainty in back trajectory calculation increases with its length in time. Source contribution depends on not only trajectory residence time but also entrainment efficiency, dispersion, and deposition. Difficult to resolve the direction of more localized sources.

Receptor Model	Description	Strengths and Weaknesses
PSCF [140] PSCF requires the calculation of air parcel back trajectory, which is often accomplished using the HY-SPLIT model.[115,139] HY-SPLIT version 4.5 is available at http://www.arl.noaa.gov/-ready/hysplit4.html.	*PRINCIPLE* Ensemble air parcel trajectory analysis refers to the statistical analysis on a group of trajectories to retrieve useful patterns regarding the spatial distribution of sources. Uncertainties associated with individual trajectory calculations largely cancel out for a sufficient number of trajectories or trajectory segments. As a popular ensemble back trajectory analysis, PSCF estimates the probability that an upwind area contributes to high pollutant concentration or source contribution. Back trajectories are first calculated for each sample at the receptor site. To determine the PSCF, a study domain containing the receptor site is divided into an array of grid cells. Trajectory residence time (the time it spends) in each grid cell is calculated for all back trajectories and for a subset of trajectories corresponding to "high" pollutant concentration or source contribution at the site. PSCF in cell (i,j) is then defined as: $$PSCF_{ij} = \frac{\text{Sum of "high" residence time in cell } (i, j)}{\text{Sum of all residence time in cell } (i, j)}$$ *(A-14)* The criterion for high pollutant concentration or source contribution is critical for the PSCF calculation. The 75th or 90th percentile of the concentration or factor is often used.[113,141,142] Residence time can be represented by the number of trajectory end points in a cell. *DATA NEEDS* Similar to TSA, PSCF calculation requires the time series of pollutant concentration or source contribution at the receptor site, and back trajectories initiated over the site during the sampling period. Trajectories should be calculated with 1-to 3-h segment to reduce the uncertainty from interpolation (if needed). *OUTPUT* PSCF reports the probability that an upwind area contributes to high pollutant concentrations or source contribution at the downwind receptor site. The results are often presented as a contour plot on the map. A high probability usually suggests potential source region (e.g., Figure 4b).	*STRENGTHS* Infer the location of sources or factors relative to the sampling site. Provide verification for the source identification made by factor analysis method Account for air mass transport over hundreds to thousands of kilometers and on the order of several days. Resolve the spatial distribution of source strength (qualitatively). *WEAKNESSES* Need to generate and analyze the back trajectory data. Need to correct for the central tendency (residence time always increases toward the receptor site regardless of source contribution). Uncertainty in back trajectory calculation increases with its length in time. Source contribution depends on not only trajectory residence time but also entrainment efficiency, dispersion, and deposition. Difficult to resolve the location of more localized sources.

Receptor Model	Description	Strengths and Weaknesses

SQTBA [117, 143]

SQTBA requires the calculation of air parcel back trajectory, which is often accomplished using the HY-SPLIT model.[115,139] HY-SPLIT version 4.5 is available at http://www.arl.noaa.gov/ready/hysplit4.html.

PRINCIPLE

SQTBA is another type of ensemble air parcel trajectory analysis. The concept of SQTBA is to estimate the "transport field" for each trajectory ignoring the effects of chemical reactions and deposition. Back trajectories are first calculated for each sample at the receptor site, and a study domain containing the receptor site is divided into an array of grid cells. SQTBA assumes that the transition probability that an air parcel at (x',y',t'), where x' and y' are spatial coordinates and t' means time, will reach a receptor site at (x,y,t) is approximately normally distributed along the trajectory with a standard deviation that increases linearly with time upwind[144,145], thus:

$$Q(x, y, t|x', y', z') = \frac{1}{2\pi(at')^2} \exp\left[-\frac{1}{2}\left(\left(\frac{X - x'(t')}{at'}\right)^2 + \left(\frac{Y - y'(t')}{at'}\right)^2\right)\right]$$

(A-15)

where (X,Y) is the coordinate of the grid center, a is the dispersion speed, and $x'(t')$ and $x'(t')$ represent the trajectory. The probability field, Q, for a given trajectory is then integrated over the upwind period, τ, to produce a two-dimensional "natural" (nonweighted) transport field:

$$T_k(x, y|x', y') = \frac{\int_{-\tau}^{0} Q(x, y, t|x', y', z')}{\int_{-\tau}^{0} dt'}$$

(A-16)

After the transport field for each trajectory is established, they are weighted by the corresponding pollutant concentration or source contribution at the receptor site and summed to yield the overall SQTBA field.[117]

DATA NEEDS

SQTBA requires the time series of pollutant concentration or source contribution at the receptor site, and back trajectories initiated over the site during the sampling period. Trajectories should be calculated with 1 to 3-h segment to reduce the uncertainty from interpolation (if needed).

OUTPUT

SQTBA put more weight on trajectories associated higher pollutant concentration or source contribution and therefore the resulting field may imply the major transport path.

STRENGTHS

Imply the location of sources or factors relative to the sampling site.

Account for air mass transport over hundreds to thousands of kilometers and on the order of several days.

Resolve the spatial distribution of source strength (qualitatively).

WEAKNESSES

Need to generate and analyze the back trajectory data.

Need to correct for the central tendency (residence time always increases toward the receptor site regardless of source contribution).

Need to estimate dispersion velocity.

Involve complicated calculations.

Physical meaning of the SQTBA field is unclear.

Difficult to resolve the location of more localized sources.

Receptor Model	Description	Strengths and Weaknesses
RTWC [146] RTWC requires the calculation of air parcel back trajectory, which is often accomplished using the HY-SPLIT model.[115,139] HY-SPLIT version 4.5 is available at http://www.arl.noaa.gov/ready/hysplit4.html	*PRINCIPLE* As an ensemble air parcel trajectory analysis, RTWC requires back trajectories calculated for each sample at the receptor site, and a study domain containing the receptor site divided into an array of grid cells. RTWC assumes that no major pollutant sources are located along "clean" (associated with low pollutant concentrations) trajectories and that "polluted" trajectories picked up emissions along their paths. In practice, RTWC distributes pollutant concentrations at the receptor to upwind grid cells along the back trajectories according to the trajectory residence times in those cells.[117,146] $$S_{i,k} = S_k \frac{\text{resident time in cell } i}{\text{average residence time in each cell}}$$ *(A-17)* where S_k is the pollutant concentration or source contribution determined upon the arrival of trajectory k and $S_{i,k}$ is the redistributed pollutant concentration or source contribution for cell i upwind. RTWC is known for the problem of "tailing effect," i.e., spurious source areas can be identified when cells are crossed by a very small number of trajectories. Although some corrections were proposed[147] these approaches are purely empirical.	*STRENGTHS* Imply the location of sources or factors relative to the sampling site. Account for air mass transport over hundreds to thousands of kilometers and on the order of several days. Resolve the spatial distribution of source strength (qualitatively). *WEAKNESSES* Need to generate and analyze the back trajectory data. Need to correct for the central tendency and tailing effect. The amount of emission entrainment should not be proportional to the residence time of trajectories (so there is no linear relationship between RTWC field and source strength). Physical meaning of the RTWC field is unclear. Difficult to resolve the location of more localized sources.

[113] Pekney et al. (2006)
[117] Zhou et al. (2004)
[134] Ashbaugh (1983)
[135] Ashbaugh et al. (1984)
[136] Henry et al. (2002)
[137] Yu et al. (2004)
[138] Parekh and Husain (1981)
[140] Hopke et al. (1995)
[143] Keeler and Samson (1989)
[144] Samson (1978)
[145] Samson (1980)
[146] Stohl (1996)
[147] Cheng et al. (1993)

Source: Watson et al. (2008)

A.3.2. Receptor Model Results

Table A-54. PM$_{10}$ receptor model results

Sampling Site	Wood Smoke	Diesel	Gasoline Vehicles	Natural Gas Combustion	Vegetative Detritus	Tire Wear Debris	Total % Allocated
Apline, CA, 1994-1995[2]	15.00	33.19	46.46		5.31	6.91	99.955752
Apline, CA, 1995[2]	9.92	58.78	11.47		19.63	9.43	99.795918
Apline, CA, 1995[2]	10.97	65.64	10.81		12.66	5.31	100.07722
Atascadero, CA, 1994-1995[2]	44.22	22.16	26.44				99.733333
Atascadero, CA, 1995[2]	21.36	38.99	12.41		17.89		100.08772
Atascadero, CA, 1995[2]	73.45	18.11			3.14		100.01241
Lake Arrowhead, CA, 1994-1995[2]	6.86	46.55	33.92	2.73	9.85	20.42	99.896907
Lake Arrowhead, CA, 1995[2]	4.85	65.20	7.40	4.95	17.65		100.04902
Lake Arrowhead, CA, 1995[2]	9.91	38.90	46.70	0.79	3.66	28.01	99.955947
Lake Elsinore, CA, 1994-1995[2]	12.72	44.01	18.61		4.21	9.78	99.967638
Lake Elsinore, CA, 1995[2]	17.13	74.72		0.26	7.81	29.17	99.924528
Lake Elsinore, CA, 1995[2]	6.84	38.48	10.85	0.21	15.55	11.93	99.946809
Lancaster, CA, 1994-1995[2]	22.49	43.14	20.56	0.45	3.73	26.38	100.14006
Lancaster, CA, 1995[2]	3.69	46.18	12.66	0.20	8.21		100.09967
Lancaster, CA, 1995[2]	34.89	37.30	7.33	0.61	7.78		99.839228
Lompoc, CA, 1994-1995[2]		18.16	49.65		5.89	26.00	100.07092
Lompoc, CA, 1995[2]	13.09	51.27	14.73		20.73	14.11	99.818182
Lompoc, CA, 1995[2]		79.42	10.19		10.87	16.61	100.48077
Long Beach, CA, 1994-1995[2]	10.12	43.24	16.49	0.13	3.97	19.52	99.955423
Long Beach, CA, 1995[2]	2.38	70.25	5.47	0.86	6.79	15.71	99.865643
Long Beach, CA, 1995[2]	14.32	56.80	6.15	0.72	5.34	9.85	99.939832
Mira Loma, CA, 1994-1995[2]	4.68	48.87	18.10		8.82	20.31	100
Mira Loma, CA, 1995[2]	5.20	53.72	6.65		18.79	19.06	100.07092
Mira Loma, CA, 1995[2]	27.97	41.88	8.87		11.50	20.17	100.07519
Riverside, CA, 1994-1995[2]	14.14	46.67	12.03		6.83		99.972222
Riverside, CA, 1995[2]	6.20	52.15	7.93	0.16	14.54	7.85	100.0409
Riverside, CA, 1995[2]	25.28	47.65			6.91	8.15	100
San Dimas, CA, 1995[2]	7.62	71.35	4.87	0.15	8.35	12.78	100.17308
San Dimas, CA, 1995[2]	22.01	61.34	4.48	0.23	3.70	15.05	99.919463
Santa Maria, CA, 1994-1995[2]	18.66	23.99	22.03		5.58	14.70	100.14493
Santa Maria, CA, 1995[2]	12.94	52.57	11.87	0.27	9.63	11.25	100.05348
Santa Maria, CA, 1995[2]	12.24	48.13	10.79	0.47	18.04	9.81	104.71963
Upland, CA, 1994-1995[2]	20.33	46.39	14.08		4.49		100
Upland, CA, 1995[2]	7.33	68.69	3.50	0.17	9.19		100.12891
Upland, CA, 1995[2]	28.10	46.52	4.90	0.33	10.30		99.952774

[1]Abu-Allaban et al. (2007)
[2]Manchester-Neesvig et al. (2003)

Table A-85. PM$_{2.5}$ receptor model results

Sampling Site	Measured PM$_{2.5}$ Concentration	Vegetative Burning	Road Dust, Soil	(NH$_4$)$_2$SO$_4$	NH$_4$NO$_3$	NaCL	Tailpipe	Brake Wear	Total % Allocated
Albany, NY 2000-2004[1]	34.9	7.60	11.70	2.70	4.90	11.70	2.90		118.91
Birmingham, AL, 2000-2004[1]	24.1	3.90	8.40	3.70	2.70	0.10	5.70		101.66
Houston, TX, 2000-2004[1]	17.6	3.10	6.90	1.60	2.50	0.10	3.80		106.25
Long Beach, CA, 2000-2004[1]	46.8	4.60	9.60	2.10	18.90	0.80	6.50	3.50	98.29

[1]Abu-Allaban et al. (2007)

A.4. Exposure Assessment

A.4.1. Exposure Assessment Study Findings

Abou Chakra et al. (2007)
Study Design: Experimental, in vitro. HeLa cells incubated with organic extracts of personal PM$_{10}$ and PM$_{2.5}$ samples
Period: NR
Location: 3 French metropolitan areas (Paris, Rouen, Strasbourg) with varying air quality and emission sources
Population: Individuals from urban areas with varying air pollution levels and emissions sources
Age Groups: Children ages 6-13. Ages of adults not given
Indoor Source: NR
Personal Method: Harvard multi-pollutant Chempass personal exposure sampler placed in backpacks with BGI pump operating at 1.8 l/min.
Personal Size: PM$_{10}$, PM$_{2.5}$
Microenvironment Size: NR
Ambient Size: NR
Component(s): organic extracts of PM$_{10}$, organic extracts of PM$_{2.5}$
Primary Findings: Genotoxic effects were stronger for organic extracts of PM$_{2.5}$ than for PM$_{10}$ and greater in winter than summer. Greater effects for winter samples may be attributed to elevated winter PAH concentrations. Genotoxic effects of organic PM$_{2.5}$ extracts were St

Abu-Allaban et al. (2004)
Study Design: Exposure assessment of real world motor vehicle emissions
Period: May 18-22, 1999
Location: Tuscarosa Mountain Tunnel, Pennsylvania Turnpike
Population: Highway tunnel
Age Groups: NR
Indoor Source: NR
Personal Method: No personal exposure assessment was conducted.
Personal Size: NR
Microenvironment Size: 0.01-0.5 µm
Ambient Size: NR
Component(s): NR
Primary Findings: Monitoring sessions with the highest fraction heavy-duty vehicles had the highest particle concentrations; Observed particle size distribution was a combination of 2 bimodal log-normal distributions: a dominant nucleation mode (86% of area under the curve)

Adar et al. (2007)
Study Design: Cohort
Period: March 2002 - June 2002
Location: St. Louis, Missouri
Population: Senior citizens exposed to traffic-related PM

Age Groups: = 60

Indoor Source: NR

Personal Method: Samples of FENO were collected between 0800 and 0900 h on the mornings before and after each trip. In the hours surrounding these samples, group-level measurements of particle concentrations also were collected using several continuous instruments installed on two portable carts. These carts were first positioned in a central location inside the participants' living facilities 24-h before each trip. The carts remained at the facilities until it was time for the trips, at which point they followed the participants from the health testing room, onto the bus, to the group activity, and to lunch. After the trip home aboard the bus, the carts were returned to the central location in the living facility where they remained until the conclusion of the health testing on the following morning. Continuous measurements of ambient particles and gases also were collected from a central monitoring station in East St. Louis, Illinois.; Specifics-; Two portable carts containing continuous air pollution monitors were used to measure group-level micro-environmental exposures to traffic related pollutants, including fine particulate mass (< 2.5 µm aerodynamic diameter; PM2.5), black carbon, and size-specific particle counts. PM2.5 concentrations were measured continuously using a DustTrak aerosol monitor model 8520 with a Nafion diffusion dryer. Integrated samples of PM2.5 mass also were collected using a Harvard Impactor for daily calibration of the trip and facility periods. Continuous black carbon concentrations were measured using a portable aethalometer with a 2.5-µm impaction inlet. Particle counts were measured using a model CI500 optical particle counter with a modified flow rate of 0.1 cubic feet per minute.

Personal Size: NR

Microenvironment Size: PM$_{2.5}$ \

Ambient Size: PM$_{2.5}$; PM$_{10}$

Component(s): BC; Pollen and Mold also assessed

Primary Findings: Fine particle exposures resulted in increased levels of FENO in elderly adults, suggestive of increased airway inflammation. These associations were best assessed by microenvironmental exposure measurements during periods of high personal particle exposures.In pre-trip samples, both microenvironmental and ambient exposures to fine particles were positively associated with FENO. For example, an interquartile increase of 4 µg/m^3 in the daily microenvironmental PM$_{2.5}$ concentration was associated with a 13% [95% confidence interval (CI), 2–24%) increase in FENO. After the trips, however, FENO concentrations were associated predominantly with microenvironmental exposures, with significant associations for concentrations measured throughout the whole day. Associations with exposures during the trip also were strong and statistically significant with a 24% (95% CI, 15–34%) increase in FENO predicted per interquartile increase of 9 µg/m^3 in PM$_{2.5}$. Although pre-trip findings were generally robust, our post-trip findings were generally robust, our post-trip finding were generally robust, our post-trip findings were sensitive to several influential days.

Adgate et al. (2002)

Study Design: Comparison of outdoor, indoor and personal PM$_{2.5}$ in three communities.

Period: April-June, June-August, September-November, 1999

Location: Battle Creek, East St. Paul, and Phillips, Minnesota, constituting the Minneapolis-St. Paul metropolitan area.

Population: adults in urban areas

Age Groups: mean age 42 + 10, range 24-64 yrs.

Indoor Source: No

Personal Method: Inertial impactors (PEM) in a foam-insulated bag with shoulder strap with the inlet mounted on the front.

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: The relative level of concentrations report in other studies was duplicated. Outdoor < indoor < personal. On days with paired samples (n = 29), outdoor concentrations were significantly lower (mean difference 2.9 µg/m^3, p = 0.026) than outdoor at home.

Adgate et al. (2007)

Study Design: NR

Period: 1999-; April 26-June 20, June 21-August 11, September 23-November 21

Location: Minneapolis-St. Paul metropolitan area

Population: NR

Indoor Source: Cigarette smoke, resuspension of house dust from carpets, furniture and clothes, and emissions from stoves and kerosene heaters (Leaderer et al., 1993; Ferro et al., 2004).

Personal Method: Personal monitoring was conducted using a and consisted of two consecutive days, and was conducted so that the two 24-h averages matched indoor (I) and personal (P) measurements were collected in concert with O samples in each community. Gravimetric concentrations for P and I were collected using inertial impactor environmental monitoring inlets and air sampling pumps. To obtain I measurements, monitors were placed inside each residence in a room where the participants reported spending the most waking hours. P measurements were obtained by carrying personal pumps in small bags.; Outdoor central site samples (O) were collected near the approximate geographic center of each neighborhood and monitors ran from midnight to midnight for two consecutive 24-h periods, followed by a day to change filters. Gravimetric O PM$_{2.5}$ concentrations were obtained using a federal reference method sampler.

Personal Size: PM$_{2.5}$ - broken down into TE

Microenvironment Size: PM$_{2.5}$ - broken down into TE

Ambient Size: PM$_{2.5}$ - broken down into TE

Component(s): Ag, Al, Ca, Cd, Co, Cr, Cs, Cu, Fe, K, La, Mg, Mn, Na, Ni, Pb, S, Sb, Sc, Ti, Tl, V, Zn

Primary Findings: The relationships among P, I, and O concentrations varied across TEs. Unadjusted mixed-model results demonstrated that O monitors are more likely to underestimate than overestimate exposure to many of the TEs that are suspected to play a role in the causation of air pollution related health effects. These data also support the conclusion that TE exposures are more likely to be underestimated in the lower income and centrally located PHI community than in the comparatively higher income BC K community. Within the limits of statistical power for this sample size, the adjusted models indicated clear seasonal and community related effects that should be incorporated in long-term exposure estimates for this population.

Adgate et al. (2003)

Study Design: Time-series epidemiologic study

Period: April - November 1999; spring: 26 April - 20 June; summer: 21 June - 11 August; Fall: 23 September - 21 November

Location: Minneapolis-St. Paul, Minnesota

Population: Healthy non-smoking results

Age Groups: 24-64 yrs (mean age 42 ± 10)

Indoor Source: NR

Personal Method: Personal and indoor gravimetric PM concentrations were collected using $PM_{2.5}$ inertial impactor environmental monitoring inlets and air sampling pumps. Monitors were placed inside each participant's residence in the room where he/she reported spending the majority of their waking hours to obtain indoor (I) measurements. Participants also carried personal pumps in small bags to obtain personal (P) measurements. Start times for indoor and personal monitors were always within a few minutes of each other.; Gravimetric outdoor (O) and central site $PM_{2.5}$ concentrations were obtained using a federal reference method sampler and EPA site requirements for ambient sampling. Gravometric samples were collected near the approximate geographic center of each neighborhood, and monitors ran from midnight to midnight for two consecutive 24-h periods, followed by a day to change filters.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Personal (P) $PM_{2.5}$ concentrations were higher than indoor (I) concentrations, which were higher than outdoor (O) concentrations. In healthy non-smoking adults, moderate median PI; modest median IO; and minimal median PO longitudinal correlation coefficients were observed for $PM_{2.5}$ measurements. A sensitivity analysis indicated that correlations did not increase if the days with exposures to environmental tobacco smoke or occupational exposures were excluded. In the sample population neither P nor I monitors provided a highly correlated estimate of exposure to O $PM_{2.5}$ over time. These results suggest that the studies showing relatively strong longitudinal correlation coefficients between P and O $PM_{2.5}$ for individuals sensitive to air pollution health effects do not necessarily predict exposure to $PM_{2.5}$ in the general population.

Alander et al. (2004)

Study Design: Exposure assessment, characterization of effects of fuel reformulation, engine design, and exhaust after-treatment on PM emissions

Period: NR

Location: laboratory

Population: Diesel-powered passenger cars of different engine types and different formulations of diesel fuel

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): total carbon, organic carbon, elemental carbon, sulfate, nitrate, chloride

Primary Findings: Reformulated low sulfur diesel fuel produced 40% less total carbon mass compared to standard fuel. Organic carbon constituted 27-61% carbon mass from an indirect ignition engine. Low sulfur fuel reduced organic carbon mass by 10-55%, depending on engine.

Allen et al. (2003)

Study Design: Use of continuous light scattering data to separate indoor PM into indoor- and outdoor-generated components to enhance knowledge of the outdoor contribution to total indoor and personal PM exposures.

Period: November 1999 - May 2001

Location: Seattle, WA

Population: Elderly people and children spending most of their time (up tp 70%) indoors.; The study included healthy elderly subjects, elderly with COPD and coronary heart disease (CHD), and child subjects with asthma.

Age Groups: Age n; 0-29 25; 30-59 36; >60 22; unknown 2

Indoor Source: Suggested (not identified)

Personal Method: NR. Indoor and outdoor sampling conducted

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): Sulfur

Primary Findings: A recursive mass balance model can be successfully used to attribute indoor PM to its outdoor and indoor components and to estimate an avg P, a, k, and NH_4^+ for each residence.

Allen et al. (2007b)

Period: Heating season: October-February; Non-heating season: March-September; (Year not specified)

Location: Seattle, WA

Population: NR

Age Groups: NR

Indoor Source: NR

Personal Method: Indoor and outdoor $PM_{2.5}$ was measured using a 10-l/min single-stage Harvard Impactor (HI) with 37-mm Teflon filters. The relationship between particle mass concentration and light scattering coefficient (bsp) was also measured on a continuous basis indoors and outdoors using nephelometers (model 902 and 903).

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): Sulfur (measured by XRF)

Primary Findings: We show that RM can reliably estimate F_{inf}. Our simulation results suggest that the RM F_{inf} estimates are minimally impacted by measurement error. In addition, the average light scattering response per unit mass concentration was greater indoors than outdoors. Results show that the RM method is unable to provide satisfactory estimates of the individual components of F_{inf}. We show that individual homes vary in their infiltration efficiencies, thereby contributing to exposure misclassification in epidemiologic studies that assign exposures using ambient monitoring data. This variation across homes indicates the need for home-specific estimation methods, such as RM or sulfur tracer, instead of techniques that give average estimates of infiltration across homes.

Allen et al. (2007a)

Study Design: Primarily a study of exposure to indoor PBDE congeners.

Period: Jan-Mar 2006

Location: Greater Boston area, Massachusetts

Population: urban dwellers

Age Groups: NR

Indoor Source: NR

Personal Method: No particulate sampled

Personal Size: No particulate sampled

Microenvironment Size: No particulate sampled

Component(s): polybrominated diphenyls (PBDEs), divided into 13 congeners and total BDE (SBDE), which includes both vapor and particulate phase.

Primary Findings: Total personal air concentrations (particulate ± vapor) were 469 pg/m^3 for non-209 BDEs and 174 pg/m^3 for BDE 209, significantly higher than bedroom and main living room concentrations (p = 0.01). The ratio of personal air to room air increased from 1 for vapor-phase congeners to 4 for fully particulate-bound congeners, indicating a personal cloud effect.

Andresen et al. (2005)

Study Design: Residential exposure assessment: personal and indoor

Period: June-July 2002-December 2002

Location: Mysore, India

Population: Women working at home, non-smoking, and primary household cook

Age Groups: 18-50-years-old

Indoor Source: Cooking fuel source

Personal Method: $PM_{2.5}$: gravimetric filter measurement

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Using kerosene for cooking was associated with higher personal $PM_{2.5}$ exposure in both winter and summer compared to LPG.; Kerosene use during winter was associated with higher personal $PM_{2.5}$ compared to summer.; LPG use was associated with comparable personal $PM_{2.5}$ across both seasons.; Indoor $PM_{2.5}$ measurements followed similar patterns by fuel-type and season.; Socioeconomic status, age, season, and income were significant predictors of cooking fuel choice.

Annesi-Maesano et al. (2007)

Study Design: Population based

Period: March 1999 to October 2000

Location: Bordeaux, France; Clermont-Ferrand, France; Créteil, France; Marseille, France; Strasbourg, France; Reims, France

Population: School children

Age Groups: 10.4 ± 0.7 years

Indoor Source: NR

Personal Method: $PM_{2.5}$ was monitored simultaneously in both schoolyards (proximity level) and fixed-site monitoring stations (city level) using 4L/min battery operated pumps attached to polyethylene filter sampling cartridges.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Results show an increased risk for EIB and flexural dermatitis at the period of the survey, past year atopic asthma and SPT positivity to indoor allergens in children exposed to high levels of traffic-related air pollution ($PM_{2.5}$ concentrations exceeding 10 µg/m^3). Our population based findings are

also consistent with experimental data that have demonstrated that inhalation of traffic-related air pollutants either individually or in combination, can enhance the immune responses and airway response to inhaled allergens, such as pollens or house dust mites, in atopic subjects.

Balakrishnan et al. (2002)

Study Design: Exposure assessment

Period: July - December 1999 (20 weeks)

Location: 50 villages, Tamil Nadu, India

Population: men and women in rural households. Children exempt

Age Groups: All, children exempt

Indoor Source: Yes

Personal Method: personal sampler for cooks during cooking time

Personal Size: Respirable Particulates (based on NIOSH protocol)

Microenvironment Size: Respirable Particulates (based on NIOSH protocol)

Ambient Size: Respirable Particulates (based on NIOSH protocol)

Component(s): NR

Primary Findings: Fuel type, type and location of the kitchen, and the time spent near the kitchen while cooking are the most important determinants of exposure across rural households.

Balasubramanian and Lee (2007)

Study Design: Case study of 3 rooms of 1 flat on the 8th floor, and "outside the home."

Period: May 12-23, 2004

Location: Singapore

Population: Residents of an urban area in a densely populated country.

Age Groups: NR

Indoor Source: Time-activity logs identified tobacco smoking, cooking, household cleaning and general resident movements.

Personal Method: `NR

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Primary Findings: Indoor/outdoor ratios (I/O) suggest that chemicals such as chloride, sodium aluminum, cobalt, copper, iron, manganese, titanium vanadium, zinc, elemental carbon were derived from the migration of outdoor particles (I/O < 1 or ~1).

Barn et al. (2008)

Study Design: measure indoor infiltration factor (FiaC) of $PM_{2.5}$ from forest fires/wood smoke, effectiveness of high-efficiency particulate air (HEPA) filter air cleaners in reducing indoor $PM_{2.5}$, and to analyze the home determinants of Fia and air cleaner effectiveness (ACE).

Period: 2004-2005 (summer 2004 and 2005, winter 2004)

Location: British Columbia, Canada

Population: homes affected by either forest fire smoke or residential wood smoke

Age Groups: NR

Indoor Source: NR

Personal Method: Pdr (Personal Data Ram) for ambient air sampling

Personal Size: Indoor home $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: outdoor home $PM_{2.5}$

Component(s): NR

Primary Findings: Use of HEPA filter air cleaners can dramatically reduce indoor $PM_{2.5}$ concentrations. Number of windows and season predict indoor infiltration Fia (P< 0.001).

Baxter et al. (2007a)

Study Design: Part of a prospective birth cohort study performed by the Asthma Coalition for Community, Environment, and Social Stress (ACCESS)

Period: 2003-2005. Non-heating season- May to October; Heating season- December to March

Location: Boston (urban)

Population: Lower socio-economic status (SES) households

Age Groups: NR

Indoor Source: NR

Personal Method: $PM_{2.5}$ samples were collected with Harvard personal environmental monitors (PEM).; NO concentrations were measured using Yanagisawa passive filter badges.

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): EC

Primary Findings: Our regression models indicate that $PM_{2.5}$ was influenced less by local traffic but had significant indoor sources, while EC was associated with local traffic and NO_2 was associated with both traffic and indoor sources. However, local traffic was found to be a larger contributor to indoor NO_2 where traffic density is high and windows are opened, whereas indoor sources are a larger contributor when traffic density is low or windows are closed. Similarly, traffic contributed up to 0.2 mg/m^3 to indoor EC for homes with open windows, with an insignificant contribution for homes where windows were closed.; Comparing models based on p-values and using a Bayesian approach yielded similar results, with traffic density volume within a 50m buffer of a home and distance from a designated truck route as important contributors to indoor levels of NO_2 and EC, respectively. However, results from the Bayesian approach also suggested a high degree of uncertainty in selecting the best model. We conclude that by utilizing public databases and focused questionnaire data we can identify important predictors of indoor concentrations for multiple air pollutants in a high-risk population.

Baxter et al. (2007b)

Study Design: Simultaneous indoor and outdoor samples taken in 43 low SES homes in heating and non-heating seasons. Homes were selected from a prospective birth cohort study of asthma etiology (n = 25). Non-cohort homes were in similar neighborhoods (n = 18).

Period: 2003-2005

Location: Boston, Massachusetts

Population: Lower SES populations in urban areas

Indoor Source: home type, year built, tobacco smoke, opening windows, time spent cooking, use of candles or air freshener, cleaning activities, air conditioner use.

Personal Method: NR

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: NR

Component(s): EC (m -1 x 10 -5); Ca (ng/m^3); Fe (ngim3); K (ng1m3); Si (ng/m^3); Na (ng/m^3); CI (ng/m^3); Zn (ng/m'); S (rig/m^3); V (ng/m^3)

Copollutant(s): NO_2

Primary Findings: The effect of indoor sources may be more pronounced in high-density multi-unit dwellings. Cooking times, gas stoves, occupant density and humidifiers contributed to indoor pollutants.

BéruBé et al. (2004)

Study Design: 6 homes in Wales and Cornwall were monitored four times per year, inside samples in the living areas and outside the home.

Period: NR but < 2003

Location: Wales and Cornwall, UK

Population: urban, suburban, and rural homes

Indoor Source: Tobacco smoke, pets, cleaning, traffic load

Personal Method: NR

Personal Size: NR

Microenvironment Size: PM_{10} mass

Ambient Size: NR

Component(s): NR

Primary Findings: There are greater masses of PM_{10} indoors, and that the composition of the indoor PM_{10} is controlled by outdoor sources and to a lesser extent by indoor anthropogenic activities, except in the presence of tobacco smokers. The indoor and outdoor PM_{10} collected was characterized as being a heterogeneous mixture of particles (soot, fibers, sea salt, smelter, gypsum, pollen and fungal spores).

Branis et al. (2005)

Study Design: Human exposure assessment in a university lecture hall

Period: Oct. 8, 2001 - Nov. 11, 2001

Location: Prague, Czech Republic

Population: University students

Age Groups: NR

Indoor Source: Presence of people identified as a source of course ($PM_{2.5-10}$) particles,; Outdoor air identified as a source of indoor fine particles ($PM_{1.0}$ and $PM_{2.5}$)

Personal Method: Harvard impactors with membrane Teflon filters

Personal Size: PM_1, $PM_{2.5}$, PM_{10}

Microenvironment Size: PM_1, $PM_{2.5}$, PM_{10}

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: Presence of people is an important source of coarse particles indoors; Outdoor air may be an important source of fine indoor particles

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Brauer et al. (2006)

Study Design: Cohort study of otitis media and traffic related air pollution

Period: Dec. 1997-Jan 1999

Location: Netherlands and Munich, Germany
Population: Children living near high traffic roads
Age Groups: 0-2 yrs
Indoor Source: environmental tobacco smoke at home, gas cooking, indoor moulds and dampness, number of siblings, breast-feeding, and pets indoor.
Personal Method: NR
Personal Size: NR
Microenvironment Size: NR
Ambient Size: $PM_{2.5}$; Light absorbing carbon
Component(s): Light absorbing carbon
Copollutant(s): NO_2
Primary Findings: These findings indicate an association between exposure to traffic-related air pollutants and the incidence of otitis media.

Brauer et al. (2007)
Study Design: Cohort study from birth to 5 yrs. Exposure obtained from stationery monitors identified as closest to birth home.
Location: The Netherlands
Population: children
Age Groups: 0-5 yrs
Indoor Source: NR
Personal Method: NR
Personal Size: NR
Microenvironment Size: $PM_{2.5}$ and Soot/filter absorbance
Copollutant(s): NO_2
Primary Findings: Adjusted odds ratios for wheeze, doctor-diagnosed asthma, ENT infections and flu indicated positive associations with air pollution. No associations for eczema and bronchitis. Findings at age 4 confirm findings at age 2 in the cohort.

Brunekreef et al. (2005)
Study Design: exposure assessment
Period: winter and spring 1998-1999
Location: Amsterdam and Helsinki
Population: elderly
Age Groups: 50-84 years
Indoor Source: NR
Personal Method: Amsterdam: Gillian with made to fit bags with belt with GK2.05 cyclone samplers 4L/min; Helsinki: BGI with shoulder strap or backpack with GK2.05 cyclone samplers 4L/min
Personal Size: $PM_{2.5}$
Microenvironment Size: $PM_{2.5}$
Ambient Size: $PM_{2.5}$
Component(s): Sulfate
Primary Findings: In both cities personal and indoor $PM_{2.5}$ were lower than highly correlated with outdoor concentrations. For most elements, personal and indoor concentrations were also highly correlated with outdoor concentrations.

Cao et al. (2005)
Study Design: case study: 2 roadside homes (RS), 2 urban (UR), 2 rural (RU).
Period: March-April 2004
Location: Hong Kong, China
Population: all
Age Groups: NR
Indoor Source: NR
Personal Method:
Personal Size: $PM_{2.5}$
Microenvironment Size: $PM_{2.5}$
Ambient Size:
Component(s): OC, EC
Primary Findings: $PM_{2.5}$ concentrations were: roadside >urban >rural. Indoor $PM_{2.5}$ has an avg of 24.4-36.8% OC and 3.6-6.9% EC.

Chakrabarti et al. (2004)
Study Design: This is an evaluation of the active-flow pDR for $PM_{2.5}$ against the β Attenuation Monitor (BAM) and the gravimetric pDR
Period: NR

Location: Los Angeles, California

Population: NR

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: The personal pDR can be deployed as a personal monitor. The $PM_{2.5}$ cyclone prevents larger particles from biasing the results. Along with a wearable humidity and temperature monitor for correcting the readings, the results correlate highly with other methods. The samples can be taken every 15 minutes to provide a more accurate picture of personal exposure in various settings.

Chang et al. (2007)

Study Design: Panel study

Period: 2003 to 2005

Location: Taipei County, Taipei

Population: Elderly people

Age Groups: 53-75yrs (median = 66.2 ± 6.5)

Indoor Source: NR

Personal Method: Personal exposures to PM were measured simultaneously with ECG in real-time for twenty-four hours by using a personal dust monitor (DUSTcheck portable dust monitor, model 1.108) which recorded 1-min mass concentrations of PM_1, $PM_{2.5}$, and PM_{10}, as well as ambient temperature and relative humidity. To measure subjects' personal PM exposures, all subjects were instructed to keep the DUSTcheck monitor with them at all times.; Details were reported previously (Chuang et al. 2005)

Personal Size: PM_{10}; $PM_{2.5-10}$; $PM_{2.5}$; $PM_{1-2.5}$; PM_1

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Results of our study indicated that short-term and medium-term PM exposures were associated with the reduction of heart rate variability in the elderly, with stronger effects found for coarse particles in comparison with particles of other size ranges.; In general, increase was observed with PM for H and the LF/HF ratio, where the strongest significant effects on H were found at short-term intervals (1–4 h) for $PM_{2.5-10}$ and at medium-term duration (5–8 h) for particles smaller than 2.5 lm in diameter. On the other hand, among the different-sized particles, $PM_{2.5-10}$ exposures showed the strongest significant association with decreases in time-domain (SDNN, r- MSSD) and frequency-domain parameters (LF, HF) in most averaging periods. Especially for the longer duration of 5–8 h, the strongest association was found for the 6-h moving average of $PM_{2.5-10}$ exposures.

Charron et al. (2007)

Study Design: Environmental PM exposure assessment. In this article, a total of 185 days with daily PM_{10} concentrations exceeding the limit value of $50\mu g/m^3$ measured between January 2002 and December 2004 are discussed.

Period: January 2002 and December 2004

Location: Marylebone Road, Westminster, London

Population: NR

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: $PM_{2.5}$ PM_{10}

Ambient Size: NO_3^-; SO_4^{2-}; OC; EC

Copollutant(s): NO_X; CO

Primary Finding(s): The regional background was the largest contributor to PM_{10} concentrations measured at Marylebone Road between January 2002 and December 2004

Chillrud et al. (2004)

Study Design: repeated measures on a cohort of high school students in New York City

Period: summer and winter of 1999 (eight weeks each)

Location: Manhattan, Bronx, Queens, Brooklyn, NY

Population: persons traveling the subway

Age Groups: 14-18 yrs

Indoor Source: No

Personal Method: sampling packs carried by subjects

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$; Home indoor and home outdoor

Ambient Size: $PM_{2.5}$. Urban fixed-site and upwind fixed site operated for three consecutive 48-h periods each week.

Component(s): Elemental iron, manganese, and chromium are reported in this study out of 28 elements sampled.

Primary Findings: Personal samples had significantly higher concentration of iron, manganese, and chromium than home indoor and ambient samples. The ratios of Fe (ng/ μg of $PM_{2.5}$) vs Mn (pg/ μg $PM_{2.5}$) showed personal samples to be twice the ratio for crustal material. Similarly for the Cr/Mn ratio.; The ratios and strong correlations between pairs of elements suggested steel dust as the source. Time-activity data suggested subways as a source of the elevated personal metal levels.

Chuang et al. (2005)

Study Design: Panel Study

Period: Taipei, Taiwan

Location: Individuals with CHD, prehypertension, and hypertension

Population: no

Personal Method: Yes, a technician carrying a DUSTcheck; monitor accompanied each patient

Personal Size: $PM_{0.3-1.0}$,; $PM_{1.0-2.5}$,; $PM_{2.5-10}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: HRV reduction in susceptible population was associated with $PM_{0.3-1.0}$ but was not; associated with either $PM_{1.0-2.5}$ or $PM_{2.5-10}$.; $PM_{0.3-1.0}$ exposures at 1- to 4-h moving averages were associated with SDNN and r-MSSD in both cardiac and hypertensive; patients. For an interquartile increase in $PM_{0.3-1.0}$, there were 1.49–4.88% decreases in SDNN and 2.73–8.25% decreases in r-MSSD. $PM_{0.3-1.0}$ exposures were also associated with decreases in LF; and HF for hypertensive patients at 1- to 3-h moving averages except for cardiac patients at moving averages of 2 or 3 h.

Cohen et al (2004)

Study Design: Field evaluation study to test performance of new technology to measure number concentration of acidic ultrafine particles (UFP)

Period: July 1999-September 2000

Location: New York City and nearby suburban location

Population: 4 outdoor rural sites and 1 indoor rural site (cafeteria) in Tuxedo, NY. 1 suburban residential site in Newburgh, NY. 1 outdoor urban site in New York City

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted.

Personal Size: NR

Microenvironment Size: Ultrafine (UFP)

Ambient Size: Ultrafine (UFP)

Component(s): acidic UFP, Hydrogen ions, sulfate ions, ammonium ions

Primary Findings: Iron nanofilm detectors can be used with confidence under a range of ambient conditions. Concentrations of UFP determined by atomic force microscopy analysis of detectors in MOI-EAS and UDM appeared to underestimate number concentrations of total UFP and

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Connell et al. (2005)

Study Design: Times-series

Period: May 2000 - May 2002

Location: Steubenville, Ohio = ST; Saint Vincent College, Latrobe, PA (eastern site) = E; Tomlinson Run State Park, New Manchester, WV (northern site) = N; Hopedale, OH (western site) = W; Jesuit Univ., Wheeling, WV (southern site) = S

Population: NR

Age Groups: No

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Ambient Size: PM_{10} & $PM_{2.5}$

Component(s): ammonium, sulfate, nitrate, chloride, and 21 elements, elemental carbon and organic carbon.

Copollutant(s): SO_X, NO_X, Co, and O_3.

Primary Findings: The average $PM_{2.5}$ in Steubenville was 18.4 μg/m³, 3.4 μg/m³ above the annual $PM_{2.5}$ NAAQS.

Conner and Williams (2004)

Study Design: This is part of the EPA Baltimore PM Study of the Elderly.

Period: July-August, 1998

Location: Towson, Maryland

Population: 65+ adults

Age Groups: 65+ yrs

Indoor Source: personal sampling devices (PEM)

Personal Method: PM$_{2.5}$
Personal Size: PM$_{2.5}$
Microenvironment Size: NR
Ambient Size: NR
Primary Finding(s): A greater variety of particles was observed in the personal samples compared to the fixed-location apartment samples.

Cortez-Lugo et al. (2008)
Study Design: Cohort
Period: Feb-Nov 2000
Location: Mexico City, Mexico
Population: Ambulatory adults with moderate to severe COPD, active smokers excluded
Age Groups: adults
Indoor Source: carpeting, aerosol sprays used, boiler use and location, animals, mold, tobacco smoking, windows closed
Personal Method: Personal pumps with 37-mm Teflon filters, flow rate 4 l/min in a bag with shoulder strap. The impactor was near the breathing zone
Personal Size: PM$_{2.5}$
Microenvironment Size: PM$_{2.5}$ & PM$_{10}$
Ambient Size: PM$_{2.5}$ & PM$_{10}$
Component(s): NR
Primary Findings: Indoor PM$_{2.5}$ concentrations explained 40% of the variability of personal exposure.; The best predictors of personal exposure were indoor contact with animals (12%), 1-25), mold (27%, 11-48), being present during cooking (27, 12-43), and aerosol use (17%, 4-31).

Crist et al. (2008)
Study Design: Indoor, outdoor, and personal monitoring
Period: January 1999 - August 2000
Location: Ohio
Population: Fourth & fifth-grade children
Age Groups: 9-11-years-old
Indoor Source: Filter, portable pump
Personal Method: Filter, PM$_{2.5}$
Personal Size: Indoor school; Filter, PM$_{2.5}$
Microenvironment Size: Outdoor school; Filter, PM$_{2.5}$
Ambient Size: NR

Cyrys et al. (2003)
Study Design: Exposure assessment, source apportionment of urban aerosol
Period: September 1, 1995 - December 21, 1998
Location: Erfurt, Germany
Population: Urban populations
Age Groups: NR
Indoor Source: NR
Personal Method: No personal exposure assessment was conducted
Personal Size: NR
Microenvironment Size: NR
Ambient Size: Ultrafine (UFP, 0.01-2.5 µm), PM$_{2.5}$, PM$_{10}$
Component(s): Si, Al, Ti, Ca, Fe, Cr, Mg, Na, K, Mn, Ni, V, Co, Sc, Cu, Zn, Pb, Br, S
Primary Findings: Low correlation between UFP number concentration and fine particle mass and differences in their diurnal patterns suggest that different sources contribute to particles in the 2 size ranges. Elements Si, Al, Ti and Ca were highly correlated and had low e

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Cyrys et al. (2006)
Study Design: Exposure assessment, evaluation of sampling methodologies
Period: Sept 1 2000-August 31, 2001
Indoor Source: Indoor
Personal Method: No personal monitoring was conducted
Personal Size: NR
Microenvironment Size: NR
Ambient Size: NR
Component(s): Restricted sampling scheme (covering 23% of study period) was able to estimate reliable annual and winter averages in Erfurt, Germany. Daily PM$_{2.5}$ means measured by EPA-WINS were higher than those measured by HI, but differences between samplers were small.

Delfina et al. (2004)

Study Design: Panel study with repeated measures

Period: Sep-Oct 1999 or Apr-Jun 2000

Location: Alpine, California

Population: Children

Age Groups: 9-19 yrs

Indoor Source: No

Personal Method: Personal dataRAM (pDR) carried at waist level using a fanny pack, shoulder harness, or vest.

Personal Size: $PM_{2.5}$ (approximate); 0.1-10 range

Microenvironment Size: PM_{10} & $PM_{2.5}$; measured immediately outside the house and in the living room of the home.

Ambient Size: PM_{10}

Copollutant(s): O_3 and NO_2 measured at central site

Primary Findings: Percent predicted FEV_1 was inversely associated with personal exposure to fine particles. Also with indoor, outdoor and central site gravimetric $PM_{2.4}$, PM_{10}, and with hourly TEOM PM_{10}.

Delfino et al. (2006)

Study Design: Cohort. Measured daily expired NO (FENO)

Period: Aug-Dec 2003

Location: Riverside and Whittier, California

Population: Children with asthma exacerbations in previous 12 months, non-smokers, non-smoking households

Age Groups: 9-18 yrs

Indoor Source: No

Personal Method: Wore a backpack during waking hours for $PM_{2.5}$, EC and OC, NO_2, temperature, and relative humidity. Exhaled air collected in Mylar bags to analyze for NO.

Personal Size: 24-h $PM_{2.5}$; 1-h max $PM_{2.5}$; 8-h max $PM_{2.5}$; 24-h NO_2

Microenvironment Size: NR

Ambient Size: 24-h $PM_{2.5}$; 24-h PM_{10}; 8-h max O_3; 8-h max NO_2; 24-h NO_2; 8-h max CO

Component(s): 24-h $PM_{2.5}$ EC; 24-h $PM_{2.5}$ OC

Primary Findings: PM associations with airway inflammation in asthmatics may be missed using ambient particle mass.; The strongest positive associations were between eNO and 2-day average pollutant concentrations. Per IQR increases: 1.1 ppb FENO/24 $\mu g/m^3$ personal $PM_{2.5}$.; 0.7 ppb FENO/0.6 $\mu g/m^3$ personal EC; 1.6 ppb FENO / 17 ppb personal NO_2; Ambient $PM_{2.5}$ and personal and ambient EC were significant only when subjects were taking inhaled corticosteroids.; Subjects taking both inhaled steroids and antileukotrienes had no significant associations.; Distributed lag models showed personal $PM_{2.5}$ in the preceding 5 h was associated with FENO.

Demokritou et al. (2002)

Study Design: Exposure assessment, evaluation of newly developed personal cascase impactor

Period: NR

Location: laboratory chamber

Population: newly developed personal PM sampler

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: 9.6-20um, 2.6-9.6um, 1.0-2.6, 0.5-1.0

Ambient Size: NR

Component(s): NR

Primary Findings: The first stage showed excellent separation of particles larger than 9.6 μm from the airstream. In the second stage, for particles above 4.0um, the collection efficiency was greater than 95%. In the third stage, the collection efficiency for particles a

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Dermentzoglou et al. (2003)

Study Design: Sampled rooms in 1 apartment for 2 h and compared to ambient air.

Period: NR, but winter < 2003

Location: Thessaloniki, Greece

Population: Urban apartment dwellers

Age Groups: NR

Indoor Source: woodburing fireplace, cigarette smoking, cooking fish, chicken, sausage & potato.

Personal Method: NR

Personal Size: NR

Microenvironment Size: $PM_{3.0}$

Ambient Size: NR

Component(s): PAHs, Pb, Cd, Cu, Mn, Ni, V As

Primary Findings: Smoking could be associated with the highest indoor concentration of total and carcinogenic PAHs.The highest level of pyrens, and phnanthrenes were during fish frying. Smoking and fish frying had significant effect on Cd in indoor air, while woodburning had no effect of PAH or heavy metal levels.

Diapouli et al. (2007)

Study Design: Exposure assessment. Sampling of schools, residence, private vehicle

Period: Schools- 11/2003-02/2004 and 10/2004-12/2004.; Residence- 10/2004; Vehicle- 10/204-12/2004

Location: Athens, Greece

Population: Primary school children

Age Groups: NR

Indoor Source: NR

Personal Method: Handheld portable Condensation Particle Counters (TSI, Model 3007) were used for all sampling locations. Primary schools indoor measurements were primarily conducted inside classrooms, at table height. However, at three of the schools, rooms of different uses were selected. These included a teachers' office (where smoking was permitted)., a computer day lab (used by students only part of the day), and a library and gymnasium (where intense activity took place almost all day long). Outdoor measurements took place in the yard of each school. Residence samples were taken in a bedroom at breathing height and on the terrace, for indoor and outdoor samples, respectively. In-vehicle samples were taken by placing the CPC 3700 on the passenger seat while the vehicle drove along predetermined routes.

Personal Size: NR

Microenvironment Size: 0.01-1 µm

Ambient Size: 0.01-1 µm

Component(s): NR

Primary Findings: The results showed that children attending primary schools in the Athens area are exposed to significant PM concentration levels, both indoors and outdoors, Vehicular emissions seem to be a major contributor to the measured outdoor concentration levels at the studied sites. Indoor PM concentrations appeared to be influenced by both vehicular emissions and indoor sources including cleaning activities, smoking, a high number of people in relation to room volume and furniture material (i.e., carpet.).; UFPs concentrations diurnal variation, both outside the schools and the residence, supports the close relation of UFPs levels with traffic density. Indoor concentrations within schools exhibited variability during the school day only when there were significant changes in room occupancy. 24-h variation of indoor concentrations at the residence followed quite well (R2 = 0.89) the outdoor one, with a delay of 1-h or less.

Diapouli et al. (2008)

Study Design: Indoor, outdoor air monitoring of PM. To determine children exposure in school environment. To evaluate relationship between indoor and outdoor levels.

Period: Athens, Greece

Location: Primary schools

Population: NR

Indoor Source: Indoor PM$_{2.5}$ and PM$_{10}$: Presence of children and activities of children in classrooms PM$_1$: Vehicles

Personal Method: Harvard PEM, Teflon filters Dust Trak Condensation particle counter

Personal Size: NR

Microenvironment Size: Weight concentration: PM$_{2.5}$, PM$_{10}$ Number concentration: PM$_1$

Ambient Size: Weight concentration: PM$_{2.5}$, PM$_{10}$ Number concentration: PM$_1$

Component(s): NO$_3$-, SO$_4^{2-}$

Primary Findings: High levels of PM$_{10}$ and PM$_{2.5}$ measured indoors and outdoors. PM$_{10}$ more variable spatially than PM$_{2.5}$. Indoor/Outdoor ratio for PM$_{10}$ and PM$_{2.5}$ close to 1 at almost all sites. Ratio of PM$_1$ smaller than 1 in all cases. Vehicular traffic presumed to be the main source of PM$_1$. Indoor PM$_{2.5}$ and PM$_{10}$ levels dependent on the amount of activity in classroom and outdoor levels. Indoor SO$_4^{2-}$ concentrations strongly associated with outdoor levels. Result suggests that SO$_4^{2-}$ can be used as a proper surrogate for indoor PM of outdoor origin.

Dills et al. (2006)

Study Design: dose-response, variability, and applicability of methoxyphenols as biomarkers in a realistic exposure situation mimicking indoor open fire cooking

Period: August. Year not specified

Location: Seattle, WA

Population: non-smokers exposed to woodsmoke

Age Groups: 20 - 65

Indoor Source: not required. Subjects exposed to wood smoke. One subject fitted with an integrating nephelometer for a continuous estimate of particle exposure, and a continuous monitor for CO, CO$_2$, and temperature. For 24-h prior to the exposure, subjects collected all urine voids at 'will in separate containers for a baseline ofmethoxyphenol excretion. Subjects then collected all urine voids at will for 48 h ostexposure for measuring wood smoke biomarker elimination.

Personal Method: Air collected at breathing level using Harvard Personal Environmental Monitor for PMZ.5 (HPEM2.5)

Personal Size: PM$_{2.5}$

Microenvironment Size: NA. No microenvironmental studied

Ambient Size: NR

Component(s): 22 methoxyphenols, levoglucosan, and 17 polynuclear hydrocarbons for personal filter samples and urine samples.

Primary Findings: According to the authors "A 12-h average creatinine-adjusted methoxyphenol concentration is a practical metric for the biomarker exposure to woodsmoke." Propylguaiacol, syringol, methylsyringol, ethylsyringol, and ropylsyringol had peak urinary concentrations after the woodsmoke exposure.

Dimitroulopoulou et al. (2006)

Study Design: Exposure assessment. Development of a model to predict indoor $PM_{2.5}$ concentrations under various emissions scenarios

Period: 1997-1999

Location: 5 sites in the UK: Harwell, Birmingham East, Bradford, Bloomsbury, Marylebone Rd.

Population: Indoor environments within homes

Age Groups: NR

Indoor Source: smoking, cooking

Personal Method: No personal exposure assessment was conducted.

Personal Size: NR

Microenvironment Size: PM_{10}, $PM_{2.5}$

Ambient Size: PM_{10}, $PM_{2.5}$

Component(s): NR

Primary Findings: Modeled mean concentrations were most sensitive to variation in outdoor concentrations, air exchange rates, and deposition velocity. Modeled peak concentrations were most sensitive to variations in emissions rates and room size. Cooking activities incre

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Ebelt et al. (2005)

Study Design: Personal exposure assessment related to health outcomes for a sensitive sub-population

Period: Summer 1998

Location: Vancouver, British Columbia, Canada

Population: 16 persons who had COPD

Age Groups: Mean subject age 74 yrs, Range 54 to 86

Indoor Source: Separated total personal exposure into "ambient" and "non-ambient" based on sulfate results and modeling.

Personal Method: "Subjects wore a $PM_{2.5}$ sampler that provided 24-h integrated personal $PM_{2.5}$ exposure data." No other details reported.

Personal Size: $PM_{2.5}$

Microenvironment Size: "ambient exposure": $PM_{2.5}$, PM_{10}, $PM_{2.5}$ -10; "non-ambient exposure": $PM_{2.5}$

Ambient Size: $PM_{2.5}$, PM_{10}, $PM_{2.5}$ -10

Component(s): Ambient sulfate,; ambient non-sulfate,; personal sulfate,; personal ambient non-sulfate

Primary Findings: Ambient exposures and (to a lesser extent) ambient concentrations were associated with health outcomes; total and nonambient particle exposures were not.

Farmer et al. (2003)

Study Design: case control

Period: 12 months

Location: Prague, Czech Republic (2 sites); Košice, Slovak republic; Sofia, Bulgaria

Population: Policeman and Busdrivers usually working through busy streets in 8-10h shifts and a Control population.

Age Groups: Variable, range not stated

Indoor Source: NR

Personal Method: Personal Monitoring Devices; Blood and Urine Samples; Stationary Versatile Air Pollution Samplers (VAPS)

Personal Size: PM_{10}

Microenvironment Size: NR

Ambient Size: PM_{10}; $PM_{2.5}$ (not reported)

Component(s): EOM; EOM2; B[a]P; c-PAHs

Primary Findings: Extractable organic matter (EOM) per PM_{10} was at least 2-fold higher in winter than in summer, and c-PAHs over 10-fold higher in winter than in summer. Personal exposure to B[a]P and to total c-PAHs in Prague ca. was 2-fold higher in the exposed group compared to the control group, in Košice ca. 3-fold higher, and in Sofia ca. 2.5-fold higher.

Farmer et al. (2003)

Study Design: Molecular epidemiology studies of carcinogenic environmental pollutants, particularly PAHs

Period: NR

Location: Prague, Czech Rep.; Kosice, Slovak Rep.; Sofia, Bulgaria

Population: Policemen and bus drivers

Age Groups: NR

Indoor Source: No

Personal Method: "Personal monitors for PM_{10}"; Extraction by dichloromethane and analyzed for PAH by HPLC with fluorimetric detection.

Personal Size: PM_{10}

Microenvironment Size: NR

Ambient Size: PM_{10}; Extractable organic material (EOM); B[a]P; cPAHs

Component(s): Benzo[a]pyrene (B[a]P); Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)

Primary Findings: Personal exposure to B[a]P and to total carcinogenic PAHs in Prague was two fold higher in the exposed group compared to controls, in Kosice three fold higher, and in Sofia 2.5 fold higher.

Ferro et al. (2004)

Study Design: Case study, 1 home

Period: Redwood City, California

Location: NR

Population: NR

Age Groups: NR

Personal Method: Co-located real-time particle counters and integrated filter samplers (Met-One Model 237B) were used to measure personal (PEM), indoor (SIM) and outdoor (SAM) PM concentrations. The PEM was attached to a backpack frame and worn by the investigator while performing prescribed activities. The SIM was attached to a six foot step-ladder with the intake at breathing height. The SAM was located under a two-sided roofed shed in the backyard of the home with the filter samplers supported by a metal stand and the real-time particle counters sitting on a table.

Personal Size: PM_5

Microenvironment Size: $PM_{2.5}$; PM_5

Ambient Size: $PM_{2.5}$; PM_5

Component(s): NR

Primary Findings: The results of this study indicate that house dust resuspended from a range of human activities increases personal PM concentrations and this resuspension effect significantly contributes to the personal cloud. The results of this study also suggest that normal human activities that resuspend house dust may contribute significantly to the strong correlations found between personal exposure and indoor PM concentrations in previous studies. The PEM/SIM ratios for human activity presented in this paper are also in the range of those reported by previous studies.

Ferro et al. (2004)

Study Design: Modeling of PM source strengths from human activities

Period: April 2000

Location: Redwood City, CA

Population: Residential home occupants

Age Groups: NR

Indoor Source: Yes. Vacuuming resulted in the maximum $PM_{2.5}$ source strength while two persons walking around and sitting on furniture resulted in the maximum PM_5 source strength.

Personal Method: Met-One Model 237B laser particle counters (2.8 Lpm); AIHL design cyclone samplers with filters (21 and 11 Lpm for $PM_{2.5}$ and PM_5 respectively)

Personal Size: $PM_{2.5}$, PM_5

Microenvironment Size: $PM_{2.5}$, PM_5

Ambient Size: $PM_{2.5}$, PM_5

Component(s): NR

Primary Findings: The source strengths were found to be a function of the number of persons performing the activity, the vigor of the activity, and the type of flooring.; Proximity to the source played a large role in the observed differences between indoor concentration and personal exposure.

Fromme et al. (2007)

Study Design: explorative analysis

Period: Winter session: December 2004-March 2005; summer session: May to July 2005

Location: Munich (and surrounding districts), Germany

Population: Primary and secondary school children

Age Groups: NR

Indoor Source: NR

Personal Method: Filter-based measurements of $PM_{2.5}$ in the classrooms were conducted with a medium volume sampler using a flow controlled pump (Derenda, Teltow, Germany). The sample inlet was a $PM_{2.5}$ sampler, having a 50% collection efficiency for particles with a 2.5 mm aerodynamic diameter. A Munktell 47mm binder free glass fibre filter with a pore size of 2 mm was used. Continuous measurements of PM (e.g. PM_{10}, PM4, $PM_{2.5}$) were also done using an optical laser aerosol spectrometer (LAS) (Dust monitor 1.108). A TSI model 3034 scanning mobility particle sizer (SMPS) (TSI Inc., Shoreview, MN, USA) was used to measure particle number concentrations (PNC) for a discrete size distribution of aerosols. Indoor carbon dioxide was measured using a continuously monitoring infrared sensor (Testo 445).; The sampling and measuring position in the classroom was opposite to the black board, about one meter above floor level, the level at which the pupils would normally inhale.

Personal Size: NR

Microenvironment Size: $PM_{2.5}$; PM4; PM_{10}

Ambient Size: PM_{10},PN (particle number)

Copollutant(s): CO_2

Primary Findings: Results clearly show that exposure to PM in school is high. This study identified parameters correlated with increased concentrations of PM such as high CO_2 concentrations and low class level. Strong seasonal variability was observed, with air quality being particularly poor in winter. The influence of season on PM concentrations we observed has been reported before from the US (Keeler et al., 2002). This difference is most likely due to the different ventilation practice in summer and winter. Further parameters correlated with increased concentrations of PM were small room size, high number of occupants, high CO_2 concentrations and low class level. No significant differences between PM and values in classrooms with carpets and those with hard surface floorings were reported. The number of fine and ultra fine particles measured in class rooms was in the same range or lower as the results from residences or outdoor monitoring sites (reported in similar studies) and show little variation during t

Gadkari et al. (2007)

Study Design: Evaluation of relative source contribution estimates of various routes of personal RPM in different urban residential environments.

Period: summer 2004 (March 15 - June 15)

Location: Chattisgarh, India

Population: All likely. Not specified

Age Groups: 21 - 61 years, average age 40 ± 15 years

Indoor Source: No

Personal Method: Personal respirable dust samplers (RDS) with GFF

Personal Size: RPM

Microenvironment Size: NR

Ambient Size: RPM

Component(s): Fe, Ca, Mg, Na K, Cd, Hg, Ni, Cr, Zn, As, Pb, Mn and Li

Primary Findings: Authors conclude that "(1) indoor activities and poor ventilation qualities are responsible for major portion of high level of indoor RPM, (2) majority of personal RPM is greatly correlated with residential indoor RPM, (3) time–activity diary of individuals has much impact on relationship investigations of their personal RPM with their respective indoor and ambient-outdoor RPM levels; as reported in earlier reports and (4) residential indoors, local road-traffic and soil-borne RPMs are the dominating routes of personal exposure compared to ambient outdoor RPM levels.

Gauvin et al. (2002)

Study Design: Fine particle exposure assessment for children in French urban environments, part of VESTA study

Period: March 1998 - December 2000

Location: Paris, Grenoble, Toulouse, France

Population: Children aged 8 - 14 years

Indoor Source: Yes - ETS from mother, rodents at home.

Personal Method: SKC pump 4 Lpm with $PM_{2.5}$ inlet and 37 mm, 2 micron Teflon filter

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: The final model explains 36% of the between subjects variance in $PM_{2.5}$ exposure, with ETS contributing more than a third to this.

Geyh et al. (2004)

Study Design: An evaluation of a modified personal monitoring pump (PMASS)

Period: NR

Location: Fresno, CA and Baltimore, Maryland

Population: persons for personal sampling

Age Groups: NR

Indoor Source: PMASS and PEM "adjusted mass measurements downward by 22% to eliminate measurement bias with the Harvard impactor."

Personal Method: particle mass

Personal Size: particle mass

Microenvironment Size: NR

Ambient Size: EC, OC, nitrate

Primary Finding(s): PMASS measurements of mass showed a significant bias of -24% compared to the reference sampler.; For microenvironmental sampling the PMASS for mass concentrations again had a bias of -34%, but for EC, OC and nitrate were much closer but still with a bias of 6.6% to 17.5%.

Geyh et al. (2004)

Study Design: Exposure assessment- representative population (WTC truck drivers) study

Period: October 2001 and April 2002

Indoor Source: Indoor

Personal Method: Each driver was given two monitors consisting of small portable pumps and battery packs worn at the waist, and sampling cartridges worn on the shoulder within the breathing zone. Monitoring was conducted across a work shift on all days of the week during both day and night shifts (6: 00am to 6: 00pm, and 6: 00pm to 6: 00am, respectively). Drivers were asked to wear their monitors at all times. If they were planning to sleep in their trucks, they were told they could remove the pumps from their belts and place them on the seat beside them.; Area monitoring was also conducted at the site at four locations around the perimeter of the disaster site on streets approximately representing the north, east, and south/southwest boundaries of the debris field. In addition, monitoring was also conducted directly in the debris pile for several days. The set of monitors were hung at head height either from scaffolding, from a chain link fence, or placed on supports, such as tank cages in the debris pile.; Sampling pumps used for particle sampling were either SKC Universal pumps(model 223-PCXR4), BGI personal sampling pumps (model 400S0, or ELF personal sampling pumps (MSA Inc). VOC sampling was conducted with SKC pocket pumps (Personal Packet Pump 210 series).

Personal Size: TD; PM_{10}; $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: TD; PM_{10}; $PM_{2.5}$

Component(s): EC; OC

Copollutant(s): VOC(s)

Primary Findings: During October, the median personal exposure to TD was 346 μg/m^3. The maximum area concentration 1742 μg/m^3, was found in the middle of the debris. The maximum TD concentration found at the perimeter was 392 μg/m^3 implying a strong concentration gradient from the middle of debris outward. PM$_{2.5}$/PM$_{10}$ ratios ranged from 23% to 100% suggesting significant fire activity during some of the sampled shifts. During April, the median personal exposure to TD was 144 μg/m^3, and the highest area concentration, 195 μg/m^3, was found at the perimeter. Although the overall concentrations on PM at the site were significantly lower in April, the relative contributions of fine particles to the PM$_{10}$, and EC and OC to the TD were similar. During both months, volatile organic compounds concentrations were low. Comparison of recorded EC and OC values from October 2001 and April 2002 with previous studies suggests that the primary source of exposure to EC for the WTC truck drivers was emissions from their own vehicles.

Goyal and Sidhartha (2004)

Study Design: Actual air monitoring measurements are compared with a model.

Period: 1998-1999

Location: Delhi, India

Population: Residents near coal-fired power plants (BTPS)

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: Suspended PM (SPM)

Component(s): NR

Primary Findings: Measured SPM values are higher during the day than at night. This is because "point sources dominate during the daytime convective conditions. At night the small depth of the nocturnal boundary layer prevents the dispersion of the pollutants from the elevated point source to reach the surface. Convective turbulence breaks up the surface-based inversion and the fumigation process leads to an increased contribution from the point sources."

Graney et al. (2004)

Study Design: The study was designed to assess the trace metal quantification abilities of several analytical methods to measure the total as well as soluble amounts of metals with PM$_{2.5}$ collected from indoor and PM samples. (X-ray fluorescence and instrumental neutron activation analysis)

Location: Retirement facility in Towson, Maryland

Population: Retirement facility with subjects who spent 94% of their time indoors

Age Groups: Mean age = 84 yrs

Indoor Source: No, this was not the objective of the study

Personal Method: Measured using personal exposure monitors (MSP Inc) with nozzle to remove particles >4 μg/m^3

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: NR

Component(s): 42 elements were analyzed for in the PM$_{2.5}$ samples collected from personal and well as indoor samples

Primary Findings: 1) Most of the extractable components of the metals were in a water-soluble form suggesting a high potential for bioavailability of elements from respiratory exposure to PM$_{2.5}$. 2)based on comparison of trace metals in central indoor site vs. PE samples, resident activities result in exposure to higher conc of soluble trace metals

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Guo et al. (2004)

Study Design: Human exposure assessment

Period: Sept. 2001 - Jan. 2002

Location: Hong Kong

Population: Shoppers at food markets

Age Groups: NR

Indoor Source: Yes. Elevated concentrations of PM at three markets probably due to outdoor particulates from vehicular exhaust. Poultry stalls in the markets had higher PM$_{10}$ due to live chickens.

Personal Method: TSI Dust Trak Model 8520. In some locations an Anderson Hi-Vol sampler with filters weighed by electronic microbalance were used to calibrate the Dust Trak.

Personal Size: PM$_{10}$

Microenvironment Size: PM$_{10}$

Ambient Size: PM$_{10}$

Component(s): NR

Primary Findings: Indoor PM$_{10}$ concentrations at the markets were generally below Hong Kong Indoor Air Quality Objectives. Outdoor sources were dominant at the five markets, with elevated levels at three markets due to vehicular exhaust.

Hanninen et al. (2003)

Study Design: EXPOLIS - human exposure assessment

Period: 1996 - 2000

Location: Athens, Greece; Basle, Switzerland; Helsinki, Finland; Prague, Czech Republic

Population: Residential homes

Age Groups: NR

Indoor Source: Yes. Sources identified in statistical analysis: wooden building material, use of stove other than electric, PVC floors, attached garage

Personal Method: Pump & filter with gravimetric analysis; Elemental composition using energy dispersive X-ray fluorescence

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): $PM_{2.5}$ -bound sulfur

Primary Findings: Associated with indoor concentration: wooden building material, city, building age, floor of residence (i.e. ground, 1st, etc.), and use of stove other than electric.

Haverinen-Shaughnessy et al. (2007)

Study Design: Cross-sectional

Period: Winter, year not reported

Location: Eastern Sweden

Population: Elementary school teachers

Age Groups: NR

Personal Method: Button inhalable aerosol samplers

Personal Size: particle mass

Microenvironment Size: particle mass

Ambient Size: NR

Component(s): Absorbance coefficient/m x 10^{-5}; Total fungi (spores/m^3); Total bacteria (cells/m^3); Viable fungi MEA (CFU/m^3); Viable fungi DG18 (CFU/m^3); Viable bacteria (CFU/m^3)

Primary Findings: The recall period of 7 days provided the most reliable data for health effect assessment. Both personal exposure and concentrations of pollutants at home were more frequently associated with health symptoms than work exposures.

Hazenkamp-von Arx et al. (2003)

Study Design: Exposure assessment

Period: November 2000-February 2001

Location: 21 European cities: Antwerp City, Antwerp South, Albacete, Barcelona, Basel, Erfurt, Galdakao, Grenoble, Goteborg, Huelva, Ipswich, Norwich, Ovledo, Pavia, Paris, Reykjavik, Tartu, Turin, Umea, Uppsala, Verona

Population: European urban environments

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Winter mean $PM_{2.5}$ concentrations were lowest in Iceland and Sweden and highest in Northern Italy (Turin, Verona). Cities also varied in daily concentrations. Geographical differences may be explained by differences in emissions (proximity of monitor to traffic.

Henderson et al. (2007)

Study Design: Land use regression was employed to model oxides of nitrogen and fine particulates using two measures of traffic (road length and vehicle density)

Period: Sampling was conducted from Feb 24 through Mar 14 and Sep 8 through Sep 26, 2003

Location: Vancouver, British Columbia, Canada

Population: NR

Age Groups: NA

Indoor Source: NR

Personal Method: Personal monitoring was not conducted. Ambient fine particles were collected on PTFE filters using Harvard Impactors. Flow rate was 4 L/min Absorption coefficients were also calculated

Personal Size: NR

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Copollutant(s): NO, NO_2

Primary Findings: Adjusted R2 for the linear regression models predicting NO, NO_2, $PM_{2.5}$, and ABS from fifty-five variables describing each sampling site ranged from 0.39 to 0.62. The resulting maps show the distribution of NO to be more heterogeneous than that of NO_2, supporting the usefulness of land use regression for assessing spatial patterns of traffic-related pollution

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Hertel et al. (2008)

Study Design: Exposure assessment

Location: Denmark

Population: bicycle commuters

Age Groups: NR

Indoor Source: no

Personal Method: NR

Personal Size: $PM_{2.5}$, PM_{10}

Microenvironment Size: NR

Ambient Size: NR

Component(s): NO_2

Primary Findings: It is possible to significantly reduce the accumulated air pollution exposure during the daily bicycle route between home and work by following the low exposure route. Travelling outside the rush hour time periods significantly reduced the accumulated air pollution exposure along the routes through the city.

Ho et al. (2004)

Study Design: Human exposure assessment

Period: 25 Sept. 2002 to 8 March 2003

Location: Hong Kong

Population: Occupied buildings located near major roadways

Age Groups: NR

Indoor Source: Yes. Regression of indoor versus outdoor concentrations of OC and EC revealed an indoor source of OC not present for EC, presumably due to such activities of cooking, smoking, and cleaning.

Personal Method: Co-located mini-volume samplers (flow rate 5 L/min) and Partisol model 2000 sampler with 2.5 micron inlet. All samples on 47 mm Whatman quartz microfiber filters, weighed on an electronic microbalance. Analyzed for OC and EC using DRI Model 2001 Thermal/Optical Carbon Analyzer

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): OC; EC; OM; TCA

Primary Findings: The major source of indoor EC, OC, and $PM_{2.5}$ appears to be penetration of outdoor air, with a much greater attenuation in mechanically ventilated buildings.

Hoek et al. (2008)

Study Design: Exposure assessment, characterizing indoor/outdoor particle relationships

Period: October 2002-March 2004

Location: 4 European cities: Amsterdam, Athens, Birmingham, Helsinki

Population: urban populations

Age Groups: NR

Indoor Source: Smoking, candle burning, cooking/frying

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, Ultrafine (UFP)

Ambient Size: PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, Ultrafine (UFP)

Component(s): soot, sulfate

Primary Findings: Correlation between 24-avg central site and indoor concentrations was lower for UFP than for $PM_{2.5}$, soot, or sulfate, probably related to greater losses during infiltration due to smaller particle size. Infiltration factors for UFP and $PM_{2.5}$ were low

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Holguin et al.(2003)

Study Design: Longitudinal analysis (repeated measures) of local $PM_{2.5}$ and biological markers of cardiovascular dysregulation

Period: 3 months (Feb 8 - Apr 30 2000)

Location: Mexico City, Mexico

Population: Elderly residents of a nursing home (non-smokers)

Age Groups: 60-96

Indoor Source: Sources of indoor PM concentrations may be idling buses parked for a few hours close to living areas at least 3 times per week

Personal Method: Mini-vol portable air samplers operating at 4 l/min used to monitor outdoor and indoor $PM_{2.5}$ concentrations at a nursing home. Gravimetric analysis of filters. Personal exposure calculated using time-weighted averages of outdoor and indoor concentration

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Increases in personal $PM_{2.5}$ concentrations were associated with significant decreases in the high-frequency component of heart rate variability (HRV-HF) among elderly. Associations remained significant after adjusting for ozone.; Indoor and outdoor $PM_{2.5}$

Hopke et al. (2003)

Study Design: Epidemiology-Exposure study

Period: 26 July to 22 August 1998

Location: Retirement facility in Towson, MD

Population: "a potentially susceptible elderly subpopulation"

Age Groups: mean age of 84

Indoor Source: ammonium sulfate and ammonium nitrate, secondary sulfate, OC, and motor vehicle exhaust

Personal Method: Personal exposure samples were collected on 37mm Teflon filters using inertial impactor PEM in the breathing zone of the subjects. A "scalper" (MSP, PEM-019) nozzle was used on the PEM to exclude particles >4mm in order to reduce the potential of overloading the impactor. Centralized indoor sampling was conducted in an unoccupied apartment on the fifth floor of the retirement facility (central indoor). The windows of the apartment were kept closed and the front door was kept open to the common hallway with a small fan providing active air exchange. Residential outdoor sampling at the retirement facility was conducted from the rooftop of an attached three-story nursing care facility (outdoor). $PM_{2.5}$ measurements at an ambient site in Towson, MD were made on the roof of a sampling shelter approximately four meters off the ground (community). Daily community, outdoor, and central indoor $PM_{2.5}$ samples were collected with VAPS samplers.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: VAPS and PEM data from the BPMEES were separately analyzed by different receptor models. These two approaches were complementary and allowed for evaluation of all of the available data. A three-way analysis of the VAPS data provided four sources of $PM_{2.5}$: nitrate–sulfate, sulfate, OC, and MV exhaust. The largest contribution to the community, outdoor, and central indoor sampling locations was the sulfate source. Infiltration of the sources varied depending on the source and ranged from 38% to 4% for the Sulfate, and Nitrate–Sulfate sources, respectively. In addition, MV exhaust had a penetration rate similar to Sulfate (32%). The OC source had little variability compared to the other sources and contributed approximately 8% of the community and outdoor PM and 18% of the central indoor PM.; The PEM data were analyzed using a complex model with a target for soil that included factors that are common to all of the types of samples (external factors) and factors that only apply to the data from the individual and apartment samples (internal factors). From these results, the impact of outdoor sources and indoor sources on indoor concentrations were assessed. The identified external factors were sulfate, soil, and an unknown factor. Internal factors were identified as gypsum or wall board, personal care products, and a factor representing variability not explained by the other indoor sources. The latter factor had a composition similar to outdoor particulate matter and explained 36% of the personal exposure. External factors contributed 63% to personal exposure with the largest contribution from sulfate (48%).

Jacquemin et al. (2007)

Study Design: Assessment of relationship between outdoor and personal concentrations of PM25] absorbance and sulfur among post-myocardial infarction patients

Period: January 2004 - June 2004

Location: Barcelona, Spain

Population: survivors of a myocardial infarction exposed to environmental tobacco smoke (ETS)

Age Groups: n = 38 (males: 32 (84%), age over or equal to 65: 15 (39%)

Indoor Source: Not identified in this study. Results from other studies discussed.

Personal Method: Personal samplers (BGI GK2.05 cyclones and battery operated BGI AFC400S pumps)

Personal Size: $PM_{2.5}$

Microenvironment Size: NA

Ambient Size: $PM_{2.5}$

Component(s): Sulfur (S)

Primary Findings: Authors say "Our results suggest that outdoor measurements of absorbance and sulfur can be used to estimate both the daily variation and levels of personal exposures also in Southern European countries, especially when exposure to ETS has been taken into account. For PM2.s, indoor sources need to be carefully considered."

Jansen et al. (2005)

Study Design: Panel Study

Period: Amsterdam: 11/2/1998-6/18/1999; Helsinki: 11/1/1998-4/30/1999

Location: Amsterdam, The Netherlands; Helsinki, Finland

Population: Elderly Cardiovascular Patients

Age Groups: 50-84 y/o

Indoor Source: No

Personal Method: Personal: $PM_{2.5}$ GK2.05; cyclones; Indoor & Outdoor: Harvard Impactors; Reflectance: EEL 43 reflectometers; Elemental Composition: Tracor Spectrace 5000 ED-XRF system

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): Estimated Elemental Carbon (Abs); Elemental composition of a subset of personal, indoor and outdoor samples

Primary Findings: For most elements, personal and indoor; concentrations were lower than and highly correlated with outdoor concentrations. The highest correlations (median r.0.9) were found for sulfur and particle absorbance (EC), which both represent fine; mode particles from outdoor origin. Low correlations were observed for elements that represent the coarser part of the $PM_{2.5}$ particles (Ca, Cu, Si, Cl⁻).

Jansen et al. (2005)

Study Design: Panel Study

Period: Winter 2002-2003

Location: Seattle, Washington, USA

Population: Elderly Respiratory Disease Patients (asthma/COPD)

Age Groups: 71-86 years

Indoor Source: No

Personal Method: Personal PM_{10}: MPEM10; Indoor home and Outdoor home $PM_{2.5}$, PM_{10}: Single-stage inertial Harvard Impactors and 37-mm Teflon filters

Personal Size: PM_{10}

Microenvironment Size: PM_{10}, $PM_{2.5}$, fine particles (~PM_1)

Ambient Size: PM_{10}, $PM_{2.5}$

Component(s): BC, as an estimate of elemental carbon (EC)

Primary Findings: For 7 subjects with asthma, a 10 $\mu g/m^3$ increase in 24-h average outdoor PM_{10}; and $PM_{2.5}$ was associated with a 5.9 [95% CI, 2.9–8.9] and 4.2 ppb (95% CI, 1.3–7.1) increase in FENO, respectively. A 1 $\mu g/m^3$ increase in outdoor, indoor, and personal BC was associated with increases in FENO of 2.3 ppb (95% CI, 1.1–3.6), 4.0 ppb (95% CI,2.0–5.9), and 1.2 ppb (95% CI, 0.2–2.2), respectively. No significant association was found between; PM or BC measures and changes in spirometry, blood pressure, pulse rate, or SaO2 in these subjects.

Jaques et al. (2004)

Study Design: Exposure assessment, field evaluation of continuous $PM_{2.5}$ monitor in comparison to integrated samplers

Period: February-August 2002

Location: Claremont, California

Population: continuous $PM_{2.5}$ sampler, time-integrated $PM_{2.5}$ samplers

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: $PM_{2.5}$ mass measurements using the Differential TEOM monitor are consistent with those of the MOUDI and Partisol. Differences can be explained by loss of ammonium nitrate from reference time-integrated samplers. Partisol underestimates MOUDI measured mass.

Jedrychowski et al. (2006)

Study Design: Prospective cohort

Period: 11/2000-3/2003

Location: Krakow, Poland

Population: Non-smoking pregnant women

Age Groups: Yes

Personal Method: Personal; Exposure Monitor Sampler (PEMS, Harvard; School of Public Health) with

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: The contribution of the background ambient PM_{10} level was very strong determinant of the total personal exposure to $PM_{2.5}$ and it explained about 31% of variance between the subjects.

Jo and Lee (2006)

Study Design: case study

Period: Winter of 2004 and summer of 2005

Location: Daegu, Korea

Population: Residents of high-rise apartment buildings

Age Groups: NR

Indoor Source: All of the surveyed apartments were constructed with concrete and iron frames. The apartments used liquid petroleum gas for cooking and as their primary heating system. The exhaust gas generated from heating or cooking was mechanically vented out of the apartments.

Personal Method: The PM_{10} concentrations were measured using real-time light scattering PM_{10} monitors (HAZDUST Model EPAM-500). The CO concentrations were measured using a CO dosimeter (CMCD-10P) equipped with an activated charcoal-Purafil prefilter.; From each building, one lower-floor apartment (first or second floor) and one higher-floor apartment (between 10th and 15th floor) were simultaneously surveyed. The concentrations of CO and PM_{10} were measured at the breathing height in the main living area where the participants spent most of their time and from the apartment balconies outdoors.

Personal Size: NR

Microenvironment Size: PM_{10}

Ambient Size: PM_{10}

Component(s): CO

Primary Findings: This study found that the outdoor air concentrations of CO and PM_{10} were higher for lower-floor apartments than for higher-floor apartments situated in residential areas. In addition, the concentrations were significantly higher in winter and in summer, regardless of the floor height of the apartments. The indoor concentrations in the lower- and higher-floor apartments, however, were not consistent with the outdoor concentrations. Proximity to a major roadway was found to increase the indoor and outdoor concentrations of PM_{10} in high-rise apartments and therefore cause elevated exposures of the residents during presence at home. This was not observed for CO. Atmospheric stability was found to elevate indoor and outdoor air pollutant concentrations and was therefore determined to be another important factor regarding the level of exposure to CO and PM_{10}.

Johannesson et al. (2007)

Study Design: Cohort

Period: Spring and Fall seasons of 2002 and 2003

Location: Gothenburg, Sweden

Population: General adult population

Age Groups: 23-51 yrs

Indoor Source: NR

Personal Method: Fine particles were measured for 24-h using both personal and stationary monitoring equipment. Personal monitoring of $PM_{2.5}$ and PM_1 was carried out simultaneously with parallel measurements of $PM_{2.5}$ and PM_1 indoors in living rooms and outside the house on a balcony, porch, etc. In addition, urban background $PM_{2.5}$ levels were measured. Personal monitoring was performed in two ways. The 20 randomly selected subjects carried personal monitoring equipment for $PM_{2.5}$ only, while the 10 staff members carried two pieces of personal monitoring equipment at the same time. On the first measuring occasion, the staff members carried one $PM_{2.5}$ cyclone and one PM_1 cyclone. On the second occasion, duplicate monitors for $PM_{2.5}$ were used. For personal and residential monitoring, the BGI Personal Sampling Pump was used together with the GK2.05 cyclone for $PM_{2.5}$ sampling and the Triplex cyclone SCC1.062 for PM_1 sampling. The personal sampling pump was placed in a small shoulder bag and the cyclone attached to the shoulder strap near the subject's breathing zone. The personal monitoring equipment was carried by the subject during awake time. During the night, it was placed in the living room. For indoor monitoring in living rooms, cyclones ($PM_{2.5}$ and PM_1) were placed at about 1.5 m above the floor. The same setup was used for residential outdoor monitoring. The urban background monitor was placed on top of a roof somewhat south of the city center but not near any major highway.

Personal Size: $PM_{2.5}$; PM_1

Microenvironment Size: $PM_{2.5}$; PM_1

Ambient Size: $PM_{2.5}$; PM_1

Component(s): BS

Primary Findings: Personal exposure of $PM_{2.5}$ correlated well with indoor levels, and the associations with residential outdoor and urban background concentrations were also acceptable. Statistically significantly higher personal exposure compared with residential outdoor levels of $PM_{2.5}$ was found for nonsmokers. PM_1 made up a considerable proportion (about 70–80%) of $PM_{2.5}$. For BS, significantly higher levels were found outdoors compared with indoors, and levels were higher outdoors during the fall than during spring. There were relatively low correlations between particle mass and BS. The urban background station provided a good estimate of the residential outdoor concentrations of both $PM_{2.5}$ and $BS_{2.5}$ within the city. The air mass origin affected the outdoor levels of both $PM_{2.5}$ and $BS_{2.5}$; however, no effect was seen on personal exposure or indoor levels.

Jones et al. (2006)

Study Design: NR

Period: January 2002-December 2004

Location: England: London Marylebone Road (Located beside arterial road in street canyon carrying approximately 80,000 vehicles per day); London North Kensington (In grounds of school in west London suburb); Harwell (On western side of business park surrounded by agricultural land)

Population: NR

Age Groups: NR

Indoor Source: NR

Personal Method: No personal monitoring.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM_{10}

Component(s): NaCl; Strongly bound H_2O; Secondary organic material

Primary Findings: Using existing co-located and coincident data it has been possible to show that the removal of three natural components—sea salt (NaCl), strongly bound water and secondary organic matter—would reduce the number of days on which the PM_{10} concentration exceeds 50 $\mu g/m^3$ by about 50%. At each site, amongst the three natural components considered, the strongly bound water makes the greatest contribution to the mean or median concentrations of PM_{10}, followed by NaCl, and SOC respectively. Strongly bound water was shown to have the biggest effect on the number of days on which the PM_{10} concentrations exceeded a value of 50 $\mu g/m^3$ however, removal of estimated NaCl and SOC components also had a noteworthy effect on reducing PM_{10} concentrations. Therefore, application of this proposed measure would make a very major difference to the likelihood of compliance or otherwise with the 24-h limit value for PM_{10}.

Jones et al. (2007)

Study Design: monitoring living room, child's bedroom, cot, and at 2 heights 1.4 & 0.2 m above the floor

Period: NR but probably 2006

Location: Perth, Australia

Population: Children 0-2 yrs

Age Groups: 0-2 yrs

Indoor Source: House age, house type, building material, # of stories, attached garage, main heating fuel, air conditioning

Personal Method: NR

Personal Size: NR

Microenvironment Size: PM_{10}, $PM_{2.5}$, PMT

Ambient Size: NR

Component(s): NR

Primary Findings: No difference between samples at 0.2 and 1.4 m from floor in 3 PM fractions, no difference between living room, child's bedroom, and crib. Large variability between homes.

Kaur et al. (2005b)

Study Design: Exposure assessment, evaluation of exposures between modes of transport, routes, timing

Period: April 28 - May 23, 2003

Location: Street canyon intersection in Central London, UK

Population: users of an urban street canyon intersection

Age Groups: NR

Indoor Source: NR

Personal Method: $PM_{2.5}$ measured usnig high-flow gravimetric personal samplers ($PM_{2.5}$) operating at a flow rate of 16 l/min carried in a backpack with sampling head positioned in personal breathing zone; Ultrafine particles measured using TSI P-TRAK Ultrafine Particle Counters in which ambient aerosol mixes with isopropyl alcohol. Alcohol condenses to form droplets that can be easily counted by a photodetector as they pass through a laser beam.

Personal Size: $PM_{2.5}$, Ultrafine particles (UFP, 0.02-1.0um)

Microenvironment Size: $PM_{2.5}$, Ultrafine particles (UFP, 0.02-1.0um)

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Personal exposures to $PM_{2.5}$ while walking were significantly lower then while riding in a car or taxi, likely a function of greater distance to roadside. No significant differences in $PM_{2.5}$ were observed between exposures on the high traffic road compared with the backroad. Personal exposure levels were lowest during midday measurements for $PM_{2.5}$ and highest in the early evening. Personal exposures to ultrafine particles were lowest while walking and highest while riding the bus. Exposures to ultrafine particles were also significantly higher on the high traffic road and during morning measurements. Exposure to ultrafine particles were highest in the morning, likely the result of peak traffic density in the morning. Exposure assessment also revealed that the background and curbside monitoring stations were not representative of the personal exposure of individuals to $PM_{2.5}$ and CO at and around a street canyon intersection.

Kaur, et al. (2005b)

Study Design: Personal exposure assessment of pedestrians walking along high-traffic urban road

Period: April 19, 2004-June 11, 2004

Location: Central London, UK

Population: Pedestrians

Age Groups: NR (adults, presumably)

Indoor Source: NR

Personal Method: $PM_{2.5}$: gravimetric filter measurement; Ultrafine PM (0.02 - 1 μm) P-TRAK device; Reflectance: reflectometer measurement of $PM_{2.5}$ filter

Personal Size: $PM_{2.5}$; Ultrafine PM (0.02 - 1 μm); Reflectance ("blackness") of $PM_{2.5}$ filter

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$; Ultrafine PM (0.02 - 1 μm); Reflectance ("blackness") of $PM_{2.5}$ filter

Component(s): NR

Primary Findings: $PM_{2.5}$ pedestrian exposure was well correlated with and above background fixed-site monitoring levels. PM pedestrian exposure was influenced by proximity to curbside and the side of the road walked on.

Kim et al. (2005)

Study Design: Panel study

Period: 8/1999-11/2001

Location: Toronto, Canada

Population: Cardiac-compromised patients

Age Groups: Mean age: 64 years

Indoor Source: Yes. Tracer molecules/elements were used to investigate sources of indoor PM, including regional long range transport, combustion, local crustal materials. All were statistically significantly associated with indoor $PM_{2.5}$

Personal Method: Rupprecht and Patashnick ChemPass Personal Sampling System

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): Sulfate, Elemental carbon (EC), Calcium, Magnesium, Potassium, Sodium

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Kim et al. (2005)

Study Design: Panel study

Period: 8/1999-11/2001

Location: Toronto, Canada

Population: Cardiac-compromised patients

Age Groups: Mean age: 64 years

Indoor Source: Indoor sources; Gas range (68%); indoor grill (11%); outdoor barbeque (30%); Gas heating fuel: (68%); Oil heating fuel (7%)

Personal Method: Rupprecht and Patashnick ChemPass Personal Sampling System

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: Personal PM$_{2.5}$ exposures were higher than outdoor ambient levels. Personal PM$_{2.5}$ exposures levels were correlated with ambient levels, mean r = 0.58

Koenig et al. (2003)

Study Design: Comprehensive exposure assessment ("The research was part of an intensive exposure assessment and health effects panel study of susceptible subpopulations in Seattle from; 1999 through 2002 (Liu et al. 2003).")

Period: 10 day monitoring session winter 2000-2001; 10 day monitoring session spring 2001

Location: Seattle, WA

Population: Asmatic children

Age Groups: 6-13 yrs

Personal Method: Harvard personal environmental monitors; Continuous PM monitors (nephelometers); Harvard Impactors; TEOM monitors; and exhaled breath measurements into an NO-inert Mylar balloon

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: "In this study we found a consistent relationship between daily eNO values in children with asthma and daily PM$_{2.5}$ measured at fixed sites and on subjects. As hypothesized, we found that the use of ICS therapy modified the association between eNO and PM$_{2.5}$. Including ambient NO values for the hour of the home visit from a central site in our model and discarding high NO days (>100 ppb) attenuated the magnitude but did not alter the association between PM$_{2.5}$ and eNO in all analyses. Same-day outdoor, indoor, personal, and central PM$_{2.5}$ levels were associated with eNO in either analysis. We conclude that these data suggest ambient PM$_{2.5}$ exposure in Seattle is associated with an increase in eNO in children with asthma. Because eNO is a marker of airway inflammation, and PM has been shown to cause inflammation in animal studies, our result is biologically plausible. This finding also agrees with previous asthma research in Seattle that showed associations between PM$_{2.5}$ and lung function decrements in children

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Koistinen et al. (2004)

Study Design: Representative population-based study

Period: Oct 1996-Dec 1997

Location: Helsinki, Finland

Population: non-smoking adults not exposed to environmental tobacco smoke.

Age Groups: adults 25-55 yrs

Indoor Source: Soil from outdoors, cooking, smoking, aerosol cleaners, sea salt, combustion sources

Personal Method: Aluminum briefcase with personal sampling monitor

Personal Size: PM$_{2.5}$; BS

Microenvironment Size: PM$_{2.5}$; BS

Ambient Size: PM$_{2.5}$; BS

Component(s): % contribution to PM$_{2.5}$; Outdoor - Indoor - Work - Personal; CoPM * 35 28 32 33; Secondary** 46 36 37 31; Soil 16 27 27 27; Detergents 0 6 2 6; Sea Salt 3 2 1 2

Primary Findings: Population exposure assessment of PM$_{2.5}$, based on outdoor fixed-site monitoring, overestimates exposures to outdoor sources like traffic and long-range transport and does not account for the contribution of significant indoor sources.

Kousa, A., et al. (2002)

Study Design: Population based exposure assessment

Period: October 1996 to June 1998

Location: Helsinki, Finland; Basel, Switzerland; Prague, Czech Republic; Athens, Greece

Population: Adult urban populations

Age Groups: 25-55 yrs

Indoor Source: NR, Workplace and residential outdoor samples could not be collected for every participant. The number of non- ETS-exposed participants were particularly small in Prague (12) and Athens (29), and therefore these results from these cities should be interpreted with caution. The population sampling and sample representativity issues are described in detail in Rotko et al. (2000b), and, for the Basel sample, in Oglesby et al. (2000b).

Personal Method: The 48 h $PM_{2.5}$ exposure was measured by a personal exposure monitor (PEM). Two filter holders were provided for each participant. One 'workday filter' for work and commuting, about 2 8–10 h, and one 'leisure time filter' for the remaining time. Microenvironmental $PM_{2.5}$ monitors (MEMs) were placed at the participant's home outdoors and indoors and in their workplaces. The pumps were programmed to run at home outdoors and indoors during the expected leisure time hours and at workplace during expected working hours of each participant. The personal and microenvironmental $PM_{2.5}$ sampling methods and QA/QC results are presented in detail in Koistinen et al. (1999).

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$; PM_{10}

Component(s): NR

Primary Findings: In Helsinki the concentration associations are high between the outdoor air concentrations of $PM_{2.5}$ and PM_{10} measured simultaneously at different locations. The highest exposure correlations are observed between the personal exposures and the respective indoor air concentrations. Correlations between the personal exposures and outdoor/ambient air concentrations are considerably lower (all centers). Personal exposures during leisure time correlate better with outdoor/ambient concentrations than during the workday (Helsinki and Prague). Leisure time and workday exposures correlate poorly with each other (all centers). Removing ETS improved the correlations between personal (indoor) air and ambient (outdoor) air, but decreased the correlations between personal exposures and indoor air concentrations and also between the personal exposures during workday and leisure time. In spite of these generalizations, there are considerable differences between the cities.

Koutrakis et al. (2005)

Study Design: panel study

Period: Baltimore: 6/28/98-8/22/98 (summer), 2/1/99-3/16/99 (winter); Boston: 6/13/99-7/23/99 (summer), 2/1/00-3/12/00 (winter)

Location: Baltimore, MD Boston, MA

Population: Healthy older adults, children, adults with COPD

Age Groups: Children: 9-13 y/o; Seniors: 65+ y/o; COPD Subjects: NR

Indoor Source: No

Personal Method: Personal exposure samples of $PM_{2.5}$; were collected using a specially designed multipollutant sampler (Demokritou et al. 2001). $PM_{2.5}$ was collected using personal environmental monitors (PEMs) and 37-mm; Teflon filters (Teflo, Gelman Sciences, Ann Arbor MI).

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): Elemental Carbon (EC); SO_4^{2-}

Primary Findings: Ambient $PM_{2.5}$ and SO_4 are strong predictors of respective personal exposures. Ambient SO_4 is a strong predictor of personal exposure to $PM_{2.5}$. Because $PM_{2.5}$ has substantial indoor sources and SO_4 does not, the investigators; concluded that personal exposure to SO_4 accurately reflects exposure to ambient $PM_{2.5}$ and therefore the ambient component of personal exposure to $PM_{2.5}$ as well.

Kulkarni and Patil (2003)

Study Design: Personal exposure assessment of toxic metals

Period: NR

Location: Mumbai, India; (Two localities or sites, namely, Marol and Sakinaka, denoted as Sites 1 and 2 respectively)

Population: Outdoor workers- low-income group population working and residing in industrial areas

Age Groups: NR

Indoor Source: low grade cooking fuel and inadequate ventilation

Personal Method: A personal sampler (Cassela/ SKC make), which consists of a diaphragm pump and operates on rechargeable batteries, was used along with a cyclone to measure personal exposure to Respirable PM (RPM). The device was fitted to the waist belt of the respondent and connected by a flexible tube to the cyclone, which can be clipped to the shirt collar. The inlet of the cyclone was kept near the breathing level of the respondent. After working hours, the personal sampler was worn by the respondent in his/ her residence. Before sleeping, the sampler was removed from the waist and kept in the "on" condition as close to the breathing level as possible.; The RPM in ambient air was measured simultaneously by using high volume sampler (HVS) with a cyclone attachment for removal of particles with size greater than 10 μm.

Personal Size: PM_5

Microenvironment Size: NR

Ambient Size: PM_5

Component(s): Lead; Nickel; Cadmium; Copper; Chromium; Potassium; Iron; Manganese

Primary Findings: All listed metals were detected in the ambient air where as only Lead, Cadmium, Manganese, and Potassium were detected in personal exposures. Mean daily exposure to lead exceeds the Indian NAAQS by a factor of 4.2. However, ambient concentration of lead conforms to this standard. There is a rising trend in the personal exposures and ambient levels of cadmium. However, they are low and do not pose any major health risk as yet. Personal exposures to toxic metals exceed the corresponding ambient levels by a large factor ranging from 6.1 to 13.2. Thus, ambient concentrations may underestimate health risk due to personal exposure of toxic metals. Outdoor exposure to toxic metals is greater than the indoor (ratios ranging from 2.3 to 1.1) except for potassium (ratio 0.77). However, there is no significant correlation between these two.

Kumar et al. (2004)

Study Design: Use of one year's 24-h monitoring data to model exposure to vehicular emissions.

Period: Apr 1991-Feb 1992

Location: Mumba, India

Population: exposure to lead at busy intersections

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: Suspended PM (SPM)

Component(s): Al: As: Ca: Cu: Cr: Fe: Hg: K: Mg: Mn: Na: Ni: NO_2: Pb: O2: SO_4: SPM: *Concentration in ng/m^3, number of samples = 45.

Primary Findings: Application of a hybrid, receptor cum dispersion model is one possible way to evaluate effective emission factors for vehicles in different operating conditions like those at traffic-junctions. The composite approach of receptor and dispersion model gives realistic effective emission factors and will be useful for air quality management.

Lai et al. (2006)

Study Design: Population-based assessment of urban adult exposures. Identifying determinants of indoor PM concentrations

Period: 1996-2000

Location: Athens, Basel, Helsinki, Milan, Oxford, Prague

Population: Homes of urban adults

Age Groups: NR

Indoor Source: number of people smoking at home, duration of gas stove use. A previous paper is cited for full details on sampling methodology (Jantunen et al, 1998)

Personal Method: No personal exposure assessment was conducted.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): BS

Primary Findings: Number of people smoking at home, outdoor $PM_{2.5}$ conc., wind speed, duration of gas stove use, and outdoor temperature were significant determinants of indoor $PM_{2.5}$. City-specific effects included outdoor $PM_{2.5}$ conc., smoking, and wind speed.; Outdoor BS,

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Lai et al. (2004b)

Study Design: Personal exposure study

Period: December 1998 - February 2000

Location: Oxford, UK

Population: Adults

Age Groups: 25-55 yrs (avg = 41)

Indoor Source: cooking, active smoking, passive smoking heating by gas heater

Personal Method: Personal exposure monitors (PEM) were carried by the participant for 48-h personal sampling, and microenvironmental monitors (MEM) were placed inside the participant's home (residential indoor), outside the home (residential outdoor) and in the participant's workplace (workplace indoor).; The $PM_{2.5}$ samplers used were GK2.05 cyclones (KTL) with 2um pore Gelman Teflo filters, and WINS $PM_{2.5}$ impactors for personal exposure and residential outdoor samples, respectively. VOC sampling was accomplished with Perkin Elmer Tenax-TA tubes, CO Enhanced Measurer T15s were used for CO samples, and NO_2 passive sampling badges were used to sample NO_2. No residential outdoor CO or NO_2 samples were taken.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): Ag Cr Mn Si; Al Cu Na Sm; As Fe Ni Sn; Ba Ga P Sr; Br Ge Pb Ti; Ca Hg Rb Tl; Cd I S Tm; Cl K Sb V; Co Mg Se Zn; Zr

Primary Findings: Both the indoor and outdoor environments have sources that elevated the indoor concentrations in a different extent, in turn led to higher personal exposures to various pollutants.; Geometric mean (GM) of personal and home indoor levels of $PM_{2.5}$, 14 elements, total VOC (TVOC) and 8 individual compounds were over 20% higher than their GM outdoor levels. Those of NO 2, 5 aromatic VOCs, and 5 other elements were close to their GM outdoor levels. For $PM_{2.5}$ and TVOC, personal exposures and residential indoor levels (in GM) were about 2 times higher among the tobacco-smoke exposed group compared to the non-smoke exposed group, suggesting that smoking is an important determinant of these exposures. Determinants for CO were visualized by real-time monitoring, and we showed that the peak levels of personal exposure to CO were associated with smoking, cooking and transportation activities. Moderate to good correlations were only found between the personal exposures and residential indoor levels for both $PM_{2.5}$ (r = 0: 60; p< 0: 001) and NO_2 (r = 0: 47; p = 0: 003).

Lai et al. (2004a)

Study Design: Longitudinal exposure assessment

Period: January 4-14, 2001

Location: Taipei, Taiwan; (highway toll station)

Population: Highway toll station workers

Age Groups: 19.3-43.6 yrs; mean = 25.7 ± 5.71

Indoor Source: Indirect exposure assessment was based on information on (a) lane-specific traffic density (available for all lanes throughout the study period), (b) estimated relationships between lane- and shift-specific traffic density and the average $PM_{2.5}$ concentrations, and (c) information on time periods spent by individuals in different working environments.

Personal Method: Direct exposure assessments were conducted by installing battery-operated personal $PM_{2.5}$ monitors (University Research Glassware Corp.) in the booth near the breathing zone of the workers.

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Toll workers on Taipei highways are exposed high concentrations of $PM_{2.5}$. Mean $PM_{2.5}$ concentration per vehicle in the truck and bus lanes was 6.4 and 3.7 times higher, respectively, than that of ticket- or car-payment car lanes. There was a statistically significant correlation between traffic density and $PM_{2.5}$ concentrations in car lanes with ticket payments and truck and bus lanes. Wind speed and humidity had a significant inverse association with $PM_{2.5}$ concentration in car lanes with ticket and cash payments. Bus and truck lane was the strongest determinant of $\log(PM_{2.5})$. The results of this study show that personal exposure to $PM_{2.5}$ can be reliably estimated using indirect traffic approaches.

Larson et al. (2004)

Study Design: Time-series epidemiologic study

Period: Sep 26, 2000-May 25, 2001

Location: Seattle, Washington

Population: "Susceptible populations"

Age Groups: time-activity diary

Personal Method: Harvard Personal Environmental Monitor

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$ outside subject's residence, and inside residence

Ambient Size: $PM_{2.5}$ at Central outdoor site (downtown Seattle)

Component(s): Light absorbing carbon (LAC) and trace elements

Primary Findings: Five sources of $PM_{2.5}$ identified: vegetative burning, mobile emissions, secondary sulfate, a source rich in chlorine, and crustal-derived material. The burning of vegetation (in homes) contributed more $PM_{2.5}$ mass on average than any other sources in all microenvironments.

Lee et al. (2006b)

Study Design: Exposure assessment for instrument development

Period: 11/2003, 5/2004

Location: Boston, MA

Population: NR

Age Groups: No

Personal Method: A new personal respirable particulate sampler(PRPS), operating at 5L/min. Sampler is designed to collect $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{4.5}$; and PM_{10} as well as O_3, SO_2, and NO_2. Sampler consists of 5 impaction stages, a backup filter, and two diffusion passive samplers. Particles are collected onto a polyurethane foam (PUF) substrate.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM>10, $PM_{10-2.5}$, $PM_{2.5}$

Component(s): NR

Primary Findings: In the field, the PM_{10}, $PM_{2.5}$, and sulfate concentrations measured by PRPS were in a very good agreement with those obtained from the; reference samplers.; In the lab, the size distributions measured by the PRPS were found to be much closer to those; measured by the real-time particle sizing instruments than to those measured by the MOI.

Lee et al. (2006a)

Study Design: Cross-sectional

Period: NR, but prior to 2006

Location: Charleston, Ottawa, Clarksville, Ohio

Population: Farmers

Age Groups: NR, but prior to 2006

Indoor Source: Hogs, poultry, cattle, feed, bedding

Personal Method: The dust & microorganisms passed thru an optical particle counter and a filter sampler to collect airborne microorganisms.

Personal Size: 0.7-1 μm; 1-2 μm; 2-3 μm; 3-5 μm; 5-10 μm; Total dust

Microenvironment Size: NR

Ambient Size: NR

Component(s): fungal spores and bacteria

Primary Findings: The highest contribution of large particles (3-10) µm in total particles was found during grain harvesting. In animal confinements the particles were dominated by smaller particles < 3 µm. A high proportion of the particles between 2-10 µm were fungal spores.

Lewne et al. (2006)

Study Design: Personal exposure study to investigate the occurrence of systematic differences in the PE exposure to motor exhaust and to study if these are influenced by the choice of exposure indicator: gaseous or particulate

Period: Sep 1997 to Oct 1999

Location: Stockholm, Sweden

Population: Taxi, bus, and lorry drivers

Age Groups: NR

Indoor Source: NR

Personal Method: PM was measured with a logging instrument Data-RAM, using nephelometric monitoring (Data-RAM measures PM 0.1 to 10 µm)

Personal Size: PM_{10}

Microenvironment Size: NR

Ambient Size: PM_{10}

Component(s): NR

Component(s): NO_2

Primary Findings: a. Lorry drivers experienced the highest exposure and taxi drivers the lowest with bus drivers in an intermediate position, regardless of whether NO_2 or particles were used as exposure indicator. b. The levels of both NO_2 and particles were higher for bus drivers in the city than for them driving in the suburbs. c. Using diesel or petrol as a fuel for taxis had no influence on the exposure for the drivers, indicating that the taxi drivers' exposure mainly depends on exhaust from surrounding traffic

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Lewne et al. (2007)

Study Design: 7 groups of occupations defined by common or high exposure to DE

Period: Oct 2002-June 2004

Location: Stockholm, Sweden

Population: persons exposed to DE

Indoor Source: vehicle exhaust

Personal Method: pump units and gravitmetric for PM_1 & $PM_{2.5}$ and real-time monitoring of elemental carbon and total carbon. Diffusive samplers for NO_2 as an indicator of the gas phase of exhaust.

Personal Size: PM_1, $PM_{2.5}$, and DataRAM (PM0.1-10)

Microenvironment Size: NR

Ambient Size: NR

Component(s): elemental carbon (EC), total carbon (TC)

Primary Findings: Tunnel construction workers has the highest levels of exposure for all indicators, followed by diesel-exposed garage workers. The other 5 groups were significantly lower with no difference between the groups.

Li et al. (2003a)

Study Design: Concurrent 10-min average indoor and outdoor concentrations of PM_{10} and $PM_{2.5}$ were recorded for 2 days each in 10 homes with swamp coolers

Period: summer 2001

Location: El Paso, Texas

Population: cooking, cleaning, walking

Age Groups: NR

Indoor Source: NR

Personal Method: $PM_{2.5}$ and PM_{10}; indoor and outdoor; tapered element oscillating microbalance (TEOM) instruments. 2 days were monitored for $PM_{2.5}$, and 2 for PM_{10}.

Personal Size: NR

Microenvironment Size: NR

Primary Findings: Evaporative coolers were found to act as PM filters, creating indoor concentrations approximately 40% of outdoor PM_{10} and 35% of outdoor $PM_{2.5}$, regardless of cooler type.

Liao et al. (2006)

Study Design: Case study

Period: January 18-27, 2003

Location: Changhwa, Central Taiwan

Population: Traditional Taiwanese residences

Indoor Source: Chinese style cooking, incense burning, cleaning, and people's moving

Personal Method: A portable laser dust monitor (DM1100) was used to analyze the indoor and outdoor PM characteristics. The DM1100 was placed in a single indoor location, 1.5 m above the floor, adjacent to areas of the kitchen, altar, and living room where the housing activities occurred.

Personal Size: NR

Microenvironment Size: $PM_{0.5-5}$

Ambient Size: $PM_{0.5-5}$

Component(s): NR

Primary Findings: Results indicate that only 2.6-8% of indoor particles are from outdoor sources. Both indoor and outdoor PM concentrations increase with PM size intervals, as do the deposition rates from cooking events.; "Our results revealed that cooking and incense burning events were major contributors to indoor concentrations for the particle sizes 1-5 µm… Our results demonstrated the importance of knowing the time-activity data and the real-time indoor and outdoor particle size distribution information for understanding exposure to particles of indoor sources. More importantly, this research illustrates that an exposure assessment based on $PM_{0.5-5}$ measured indoors can provide valuable information on the fate of indoor particles and hazard to human health."

Liu et al. (2003)

Study Design: Part of a larger exposure assessment and health effect panel study

Period: Winter 2000-2001 and spring 2001

Location: Seattle, WA

Population: Children with asthma

Age Groups: 6-13 yrs

Indoor Source: NR

Personal Method: Personal $PM_{2.5}$ measurements were collected from each subject using the Harvard personal environmental monitors.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: We conclude that the ambient-generated component of $PM_{2.5}$ exposure is consistently associated with increases in eNO and the indoor-generated component is less strongly associated with eNO. As a result, our eNO results support our hypothesis that $PM_{2.5}$ of outdoor origin could be more potent per unit mass than particles of indoor origin. However, our lung function data indicate that $PM_{2.5}$ of indoor origin might be more potent per unit mass in resulting in decrements of lung functions, although the results across functional tests were not consistent.; We tentatively conclude that partitioning personal exposure into indoor- versus outdoor-generated particles is useful in understanding the health effects of sources of personal $PM_{2.5}$ and that the effects of indoor- versus outdoor-generated particles differ for different health points.

Liu et al. (2005)

Study Design: Exposure assessment, validation set within a prospective occupational cohort (boiler workers)

Period: NR (healthy working adults)

Population:

Personal Method: Yes, A personal environmental monitor (PEM, Model 200, MSP Co, Shoreview, MN) with a pump at 4L/min

Personal Size: PM_{10}

Microenvironment Size: PM_{10}

Ambient Size: NR

Component(s): Metals: Vanadium (V), Nickel (Ni), Iron (Fe), Chromium (Cr), Cadmium (Cd), lead (Pb), Manganese (Mn)

Primary Findings: The validation demonstrated good approximations of actual exposures with differences less than 5% for PM.

Liu et al. (2003)

Study Design: Comprehensive exposure assessment

Period: 1999-2001

Location: Seattle, WA

Population: High-risk subpopulations

Age Groups: Children: 6-13 yrs; Elderly: 65-90 yrs (one person was below 65 but not specified)

Personal Method: Personal $PM_{2.5}$ exposures were determined using the Harvard Personal Environmental Monitor for $PM_{2.5}$ (HPEM2.5). Each subject carried an HPEM2.5 in the breathing zone for 24 h, except while sleeping, showering, or using the restroom. The monitor was attached to the shoulder strap of either a backpack or a fanny pack that contained the air pump. When the monitor was not worn, it was placed at an elevation of 3–5 feet (e.g., on a table) close to the subjects.; The indoor and outdoor PM concentrations were measured with single-stage inertial Harvard Impactors (HI) and 37-mm Teflon filters for PM_{10} and $PM_{2.5}$. One HI2.5–HI10 pair was located inside each home in the main activity room and connected to a Medo pump (model vp0935a). Concurrently, one HI2.5–HI10 pair was located outside each home and connected to a Gast pump (model DOA-V191-AA). All HI sampling periods were for 24-h at a flow rate of 10 L/min. HI2.5, HI10, and HPEM2.5 were also co-located with the federal reference method monitor for $PM_{2.5}$ (FRM2.5) at the central Beacon Hill site, which is located in a semiresidential area (elevation, 300 feet) and is maintained by the Washington State Department of Ecology.

Personal Size: $PM_{2.5}$; PM_{10}

Microenvironment Size: $PM_{2.5}$; PM_{10}

Ambient Size: $PM_{2.5}$; PM_{10}

Primary Findings: The average personal exposures to $PM_{2.5}$ were similar to the average outdoor $PM_{2.5}$ concentrations but significantly higher than the average indoor concentrations. Indoor and outdoor $PM_{2.5}$, PM_{10}, and the ratio of $PM_{2.5}$ to PM_{10} were significantly higher during the heating season. The increase in outdoor PM_{10} in winter was primarily due to an increase in the $PM_{2.5}$ fraction. A similar seasonal variation was found for personal $PM_{2.5}$. The children in the study experienced the highest indoor $PM_{2.5}$ and PM_{10} concentrations. Personal $PM_{2.5}$ exposures varied by study group, with elderly healthy and CHD subjects having the lowest exposures and asthmatic children having the highest exposures. Within study groups, the $PM_{2.5}$ exposure varied depending on residence because of different particle infiltration efficiencies.; $PM_{2.5}$ exposures among the COPD and CHD subjects can be predicted with relatively good power with a microenvironmental model composed of three microenvironments. The prediction power is the lowest for the asthmatic children

Lonati et al. (2005)

Study Design: Comparison sampling of an urban background site, UB during cold season and warm season with no traffic and a vehicle tunnel (TU) cold season.

Period: Aug 2002-Nov 2003

Location: Milan, Italy

Population: urban population

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): EC, OC, Particulate organic matter (OM); Total mass; Chloride, Nitrate, Sulfate, Ammonium, Crustal elements, Metals, undefined+F12

Primary Findings: Higher PM$_{2.5}$ during the cold season, about twice the warm season. Tunnel data are 7 times the urban background. The vehicle contribution to PM$_{2.5}$ is 11% in the warm season and 6% in the cold season.

Lung et al. (2007)

Period: weekdays between Nov 1998 and Feb 1999

Location: 6 communities in Taiwan, China: 2 in Taipei, 2 in Taichung, and 2 in Kaohsiung. Sites are industrial, commercial, residential and mixed.

Age Groups: 18 to >70

Indoor Source: Being in kitchen, park, major boulevard, stadium, incense burning, household work, factory, environmental tobacco smoke, traffic, ventilation conditions

Personal Method: Personal Environmental Monitor with a SKC personal pump at 2 L/min, 37 mm Teflon filters

Personal Size: PM$_{10}$

Microenvironment Size: PM$_{10}$

Ambient Size: PM$_{10}$

Component(s): None

Primary Findings: Outdoor rather than indoor levels contributed significantly to personal exposure.; Important factors include time spend outdoors and on transportation, riding a motorcycle, passing by factories, cooking or being in the kitchen, incense burning at home.

Magari et al. (2002)

Study Design: Cross-sectional study of boilermakers

Period: NR

Location: NR

Population: NR, probably metal tradesmen

Age Groups: No

Personal Method: Gil-Air 5 personal pump

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): V, Nr, Cr, Mn, Cu, Pb

Primary Findings: There were statistically significant mean increase in the standard deviation of the normal-to-normal heart rate index (SDNN) of 11.30 msec and 3.98 msec for every 1 µg/m^3 increase in the lead and vanadium concentrations after adjusting for mean heart rate, age, and smoking status.

Maitre et al. (2002)

Study Design: Personal (occupational) and ambient (in traffic area) PM and particle-bound PAH exposure assessment: This study evaluates individual airborne exposure to gaseous and particulate carcinogenic pollutants in a group of policemen working close to traffic in the center of Grenoble, France.

Period: summer (June); winter (January) (year not indicated)

Location: City of Grenoble, located in the southeast of France

Population: Non-smoking policemen working outdoors on foot

Age Groups: NR

Indoor Source: NR

Personal Method: Cyclone and filter with personal sampling pump (SKC, United Kingdom)

Personal Size: Respirable particles (defined in this paper as the mass of particles that pass through a size selective orifice with a 50% collection efficiency at a cut-off aerodynamic diameter of 4 µm)

Microenvironment Size: NR

Ambient Size: Respirable particles (defined in this paper as the mass of particles that pass through a size selective orifice with a 50% collection efficiency at a cut-off aerodynamic diameter of 4 µm)

Component(s): PAH, benxene-toluene-xylenes (BTX), aldehydes; Personal BaP; Personal PAHc; Personal PAH; Personal Benzene; Personal Toluene; Personal Xylene; Personal BTX; Personal Formaldehyde; Personal Acetaldehyde; Personal Aldehydes; Stationary BaP; Stationary PAHc; Stationary PAH; Stationary Benzene; Stationary Toluene; Stationary Xylene; Stationary BTX; Stationary Formaldehyde; Stationary Acetaldehyde; Stationary Aldehydes

Primary Findings: The occupational exposure of policemen does not exceed any currently applicable occupational or medical exposure limits. Individual particulate levels should preferably be monitored in Grenoble in winter to avoid underestimations.

Malm et al. (2005)

Study Design: Exposure assessment, characterization of physical and optical properties of carbonaceous aerosol species, and comparison of several semi-continuous monitoring systems

Period: July 15-September 4, 2002

Location: Yosemite National Park at the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring site

Population: Different monitoring instruments to quantify ambient aerosol concentrations

Age Groups: NR

Indoor Source: No personal exposure assessment was conducted

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: Inorganic ions (sulfate, nitrate), organic carbon in PM_{10} and $PM_{2.5}$ size ranges, elemental carbon

Primary Finding(s): 70% of the organic mass was made up of elemental carbon. 24-h bulk measurements of various aerosol species compared more favorably with each other than with the semi-continuous data.; Semi-continuous sulfate (PILS) correlated well with 24-h measurem

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Mar et al. (2005)

Period: 1999-2001

Location: Seattle, WA USA

Population: "Older subjects" (< 57 y/o), nonsmokers

Age Groups: Age 57+ y/o

Indoor Source: No

Personal Method: Harvard Impactor

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$, PM_{10}

Ambient Size: $PM_{2.5}$, PM_{10}

Component(s): NR

Primary Findings: Healthy subjects; taking no medications had decreases in heart rate associated with; indoor and outdoor $PM_{2.5}$ and PM_{10}. Healthy subjects on medication; had small increases in systolic blood pressure associated with indoor; $PM_{2.5}$ and outdoor PM_{10}.

McCormack, et al. (2007)

Study Design: Stratified analysis of subjects in the BIESAK study

Period: NR but < 2003

Location: East Baltimore, Maryland

Population: low-income children with asthma

Age Groups: 2-6 yrs

Indoor Source: sweeping, vacuuming, smoking, stove use, burned food, oven, candles/incense, open windows, space heater

Personal Method: NR

Personal Size: NR

Microenvironment Size: PM_{10} AND $PM_{2.5}$; in child's bedroom

Ambient Size: PM_{10} AND $PM_{2.5}$; Central monitoring site

Primary Findings: Indoor concentrations of $PM_{2.5}$ & PM_{10} were twice as high as the ambient.; Sweeping, smoking, and ambient PM contributed significantly to higher indoor concentrations. Sweeping (not vacuuming) increased the PM_{10} by 3-4 $\mu g/m^3$.

Meng et al. (2005b)

Study Design: 3 Cohorts, one in New Jersey, 1 in Los Angeles, and 1 in Houston.; Personal, home indoor, and home outdoor samples taken for $PM_{2.5}$.

Period: Summer, 1999 - spring, 2001

Location: Houston, Texas; Los Angeles, California; and Elizabeth, New Jersey

Population:

Personal Method: MSP monitors on the front strap of the sampling bag near the breathing zone. Pump, battery, and motion sensor were on the hip or back.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: NR

Component(s): NR

Primary Findings: The median contribution of ambient sources to indoor PM$_{2.5}$ using the mass balance approach was 56% for all study homes, 63% for California, 52% for New Jersey, and 33% for Texas.

Meng et al. (2005b)

Study Design: Evaluation of the use of central-site PM, rather than actual exposure, in PM epidemiology

Period: summer 1999 - spring 2001

Location: 3 cities: Houston (TX), Los Angeles County (CA), and Elizabeth (NJ)

Population: People suffering from cardiovascular and respiratory morbidity likely. Not specified

Age Groups: All age groups possible. Not specified

Indoor Source: likely sources mentioned. Not identified

Personal Method: NR. Indoor and outdoor sampling conducted

Personal Size: PM$_{2.5}$

Microenvironment Size: NA

Ambient Size: NR

Component(s): EC, OC, S, Si

Primary Findings: Use of central-site PM$_{2.5}$ as an exposure surrogate underestimates the bandwidth of the distribution of exposures to PM of ambient origin.

Meng et al. (2005a)

Study Design: RIOPA Study: matched indoor home & outdoor exposure assessment

Period: May-October (hot); November-April (cool); (1999-2001)

Location: Los Angeles County, CA; Elizabeth, NJ; Houston, TX

Population: Non-smoking homes

Indoor Source: Combustion (primary); atmospheric (secondary); sulfate, organics, nitrates; mechanically (abrasion) generated.

Personal Method: Filter (not specified)

Personal Size: NR

Microenvironment Size: Indoor home.; PM$_{2.5}$

Ambient Size: PM$_{2.5}$, outdoor home

Component(s): organic and elemental carbon; 24 elements (metals)

Mihaltan et al. (2006)

Study Design: Indoor air monitoring. To assess the effect of smoking on air quality in hospitality venues (restaurant, pubs and bars).

Period: NR

Location: Romania

Population: Restaurant/pubs/bars

Age Groups: NA

Indoor Source: Smoking

Personal Method: Personal aerosol monitor

Personal Size: NR

Microenvironment Size: Respirable suspended particles, PM$_{2.5}$

Ambient Size: NR

Component(s): NR

Primary Findings: Hospitality venues allowing indoor smoking are significantly more polluted than indoor smoke-free venues and outdoor air in Romania.

Miller et al. (2007a)

Study Design: Exposure Assessment, evaluation study of effectiveness and accuracy of a nephelometer (portable, direct reading photometer) to measure tailpipe emissions of elemental carbon from diesel engines

Period: NR

Location: in laboratory

Population: 2 Exposure assessment methods to measure elemental carbon

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): EC, Total Carbon

Primary Findings: EC measurements made with a Thermo Electron Personal DataRAM 1200 direct reading nephelometer showed good correlation with EC mass concentrations quantified by thermal optical analysis of PM$_{2.5}$ and PM$_{1.0}$ samples collected on quartz filters (reference NIOS

Miller et al. (2007b)

Study Design: Comprehensive study of key contaminants

Period: Ottawa, Ontario, Canada

Location: NR

Population: NR

Age Groups: NR

Personal Method: PM$_{2.5}$ and PM$_{10}$ filter samples were collected in the living room of each home for 7 days, using SKC sampler model 200 PEM on tared teflon filters. Concurrent PM$_{2.5}$ samples were collected on 47-mm Teflo 2- μm filters with MiniVol air samplers mounted on a tripod ~2 meters in front of the house.; Particulate samples for analysis of airborne endotoxin, ergosterol, and ß1, 3-D-glucan were collected on a three-piece cartridge equipped with an endotoxin-free polycarbonate filter in the living room sand bedrooms of each home. In the living room, samplers were located at a height between 1.22m and 1.83 m from the floor and no closer than 0.5 m to surfaces. In bedrooms, the samples were collected form as close to the beds as feasible. BC concentrations were continuously recorded for 7 days with a Magee Scientific Aethalometer in the living room of each house.

Personal Size: NR

Microenvironment Size: PM$_{2.5}$; PM$_{10}$

Ambient Size: NR

Component(s): BC; Also assessed: Endotoxin; Ergosterol; Glucan; Dust samples: Dust >300; Der p1; Der f1; Fel d1;

Primary Findings: Airborne concentrations of the contaminants measured generally were unremarkable, although the mass of settled dust per square meter was well above that associated with increased asthma and comfort symptoms clinical response, particularly in urban homes. When co-occurrence of inflammatory agents and dust mite allergen burdens in the houses was considered, three homes had higher relative amounts of the agents considered. Based on what is known about clinical interactions between, for example, endotoxin and dust mite allergens, a combined exposure possibly results in an increased relative risk of allergic disease.

Molnár et al. (2005)

Study Design: Indoor/outdoor exposure assessment related to domestic wood burning

Period: 10 February to 12 March 2003

Location: Hagfors, Sweden

Population: Adult residents of Hagfors

Age Groups: NR

Indoor Source: NR

Personal Method: Identical sets of equipment were used for both personal exposure and indoor sampling: a GK2.05 (KTL) cyclone connected to a BGI 400S Personal Sampling Pump with a flow rate of 4 l min 1. Each person was equipped with an easily carried shoulder bag with the cyclone and pump attached to it. The cyclone was attached to the shoulder strap and placed near the breathing zone. The personal sampler was worn all day, and at night it was placed next to the stationary indoor sampler in the living room, owing to the noise of the pump.; Two different types of impactors were used for the outdoor sampling: one Sierra Andersen series 240, dichotomous virtual impactor that separates particles into two size ranges, coarse and fine particles (PM$_{10-2.5}$ and PM$_{2.5}$, respectively); and one EPA-WINS impactor (PQ100 EPA-WINS Basel PM$_{2.5}$ Sampler) for collecting PM$_{2.5}$ particles. The outdoor measurements were made at a single location on the roof of a single car garage, belonging to one of the subjects, in the middle of the study area.

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{10-2.5}$; PM$_{2.5}$

Ambient Size: PM$_{10-2.5}$; PM$_{2.5}$

Component(s): BS; S; Cl; K; Ca; Mn; Fe; Cu; Zn; Br; Rb; Pb

Primary Findings: Statistically significant contributions of wood burning to personal exposure and indoor concentrations have been shown for K, Ca, and Zn. Increases of 66–80% were found for these elements, which seem to be good wood-smoke markers. In addition, Cl, Mn, Cu, Rb, Pb, and BS were found to be possible wood-smoke markers, though not always to a statistically significant degree for personal exposure and indoor concentrations. For some of these elements subgroups of wood burners had clearly higher levels which could not be explained by the information available. Sulfur, one of the more typical elements mentioned as a wood-smoke marker, showed no relation to wood smoke in this study due to the large variations in outdoor concentrations from LDT air pollution. This was also the case for PM$_{2.5}$ mass. Personal exposures and indoor levels correlated well among the subjects for all investigated species, and personal exposures were generally higher than indoor levels. The correlations between the outdoor and personal or ind

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Molnár et al. (2006)

Study Design: Cross-sectional

Period: Autumn and spring in 2002 and 2003

Location: Goteborg, Sweden,

Population: Persons living in urban settings

Age Groups: 20 subjects 20-50 yrs randomly selected from the population and 10 from departmental colleagues.

Indoor Source: nr

Personal Method: The volunteer subjects had a small shoulder bag with one PM$_{2.5}$ cyclone and a pump attached. Intake was in the breathing zone. Pump was carried during the day and placed next to the indoor cyclone during the night.; Ten subjects from their staff wore 2 sets of sampling equipment near the breathing zone. A GK2.05 cyclone for PM$_{2.5}$ and a Triplex cyclone for PM$_1$ in a small shoulder bag.

Personal Size: PM$_{2.5}$ and PM$_1$

Microenvironment Size: NR

Ambient Size: NR

Component(s): S; Cl; K; Ca; Ti; V; Mn; Fe; Ni Cu; Zn Br Pb.

Primary Findings: PM$_{2.5}$ personal exposures were significantly higher than both outdoor and urban background for the elements Cl, K, Ca, Ti, Fe, and Cu.; Personal exposure was also higher tan indoor levels of Cl, Ca, Ti, Fe, and Br, but lower than outdoor Pb./ Residential outdoor levels were significantly higher than the corresponding indoor levels for Br and Pb, but lower for Ti and Cu. The residential levels were also significantly higher than the urban background for most elements.

Molnár et al. (2007)

Study Design: microenvironmental monitoring of PM and elements in 10 schools, 10 preschools, and 20 non-smoking homes.

Period: 1 Dec 2003- 1 July 2004

Location: Stockholm, Sweden

Population: children

Age Groups: 6-11 yrs (no pre-school children) but sampling was conducted at 10 preschools.

Indoor Source: Smoking, gas stoves,

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): S; K; Ca; Ti; V; Cr; Mn; Fe; Ni; Cu; Zn; Br; Pb

Primary Findings: Significantly lower indoor concentrations of S, Ni, Br and Pb, elements from long-range transported air masses, were found in all locations. Only Ti was significantly higher indoors in all locations, probably because of TiO$_2$ in paint pigment. Similar differences were found during both seasons for homes and schools. At preschools the infiltration of the long-range transported elements S, Br and Pb was lower in winter than in spring, and also the crustal elements Ti, Mn and Fe had higher indoor concentrations during spring. There were spatial differences outdoors, with significantly lower concentrations of elements of crustal and traffic origin in the background area community.

Monkkonen et al. (2005)

Study Design: Human exposure assessment in homes in India

Period: Nagpur Mar to Oct 2002; Mysore Aug to Dec 2002

Location: Nagpur and Mysore, India

Population: Residential homes in India

Age Groups: NR

Indoor Source: Yes; cooking w/ kero. & LPG; Toaster; Burning incense; Infiltration of outdoor air; Burning coconut husks

Personal Method: TSI Condensation Particle Counter Model 3007 (CPC counts all particles >10 nm); TSI Model 8520 Dust Trak; PM$_{2.5}$ Environmental Monitor with Whatman PTFE membrane filters and gravimetric analysis

Personal Size: PM$_{2.5}$ for mass (μg/m^3); Total PM for counts (particles/cm^3)

Microenvironment Size: PM$_{2.5}$ for mass (μg/m^3); Total PM for counts (particles/cm^3)

Ambient Size: Total PM for counts (particles/cm^3)

Component(s): NR

Primary Findings: The maximum concentrations observed in most cases were due to indoor combustion sources. Besides cooking stoves that use LPG or kerosene as the main fuel, high indoor concentrations can be explained by poor ventilation systems.

Mwaiselage et al. (2006)

Study Design: Cross-sectional; personal monitoring. To determine the effects of cement exposure on acute respiratory health.

Period: June - August 2001

Location: Dar es Salaam, Tanzania

Population: Cement factory workers

Age Groups: NR

Indoor Source: Cement production

Personal Method: Cellulose Acetate Filter, Sidekick pump

Personal Size: Respirable dust, total dust

Microenvironment Size: NR

Ambient Size: NR

Component(s): Ca, Al, Fe, K

Primary Findings: Results of Cox Regression analysis showed that prevalence ratios for cough, short breathness and stuffy nose for high exposed workers in the production department compared to low exposed workers in the low exposed workers working in the maintenance department and the administration building are 6.7, 4.5 and 1.9 respectively. Cross shift decrease in PEF was more in the higher among high exposed workers (7.6%) than low exposed workers (2.7%). The observed acute acute respiratory health effects are most likely related to exposure of workers to high concentrations of irritant cement dust.

Na et al. (2005)

Study Design: Human exposure assessment

Period: Sept. 2001 - January 2002

Location: Mira Loma, CA

Population: Residential homes and a high school

Age Groups: NR

Indoor Source: Indoor EC (elemental carbon) concentrations primarily of outside origin; Indoor $PM_{2.5}$ significantly influenced by indoor OC (organic carbon) sources, including indoor smoking.

Personal Method: $PM_{2.5}$: Particle trap impactor with 47 mm Teflo substrates; EC/OC: Particle trap impactor with 47 mm QAT Tissuquartz quartz fiber filter, analysis by thermal.optical carbon aerosol analyzer (NIOSH Method 5040)

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): EC (Elemental carbon); OC (Organic carbon)

Primary Findings: Indoor $PM_{2.5}$ was significant influenced by indoor OC sources.; Indoor EC sources were predominantly of outdoor origin.

Naumova et al. (2002)

Study Design: Exposure assessment

Period: 6/1999-5/2000

Location: Los Angeles County, CA; Houston, TX; Elizabeth, Nj

Population: US. General Population

Age Groups: NR

Indoor Source: No

Personal Method: None - area sampling only (in home and outdoors)

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): PAH (total and specific)

Primary Findings: See Component Column. Many of the study findings pertain to combined particle-bound and gas-phase PAHs, and are not presented here.

Naumova et al. (2003)

Study Design: RIOPA Study - PAH partitioning indoor and outdoor. To evaluate the hypothesis that outdoor air pollution contributed strongly to indoor air pollution.

Period: July 1999-June 2000

Location: Los Angeles, CA, Houston, TX, Elizabeth, NJ

Population: Houses

Age Groups: NR

Indoor Source: NR

Personal Method: Modified MSP Samplers, 37 mm quartz filter

Personal Size: NR

Microenvironment Size: Filter, $PM_{2.5}$

Ambient Size: Filter, $PM_{2.5}$

Component(s): Organic Carbon (OC), Elemental Carbon (EC)

Primary Findings: Multiple linear regression (MLR): log PAH particulate partition coefficient (kp) vs log vapor pressure: coefficient (std) 0.888 (0.009) fraction of elemental carbon in PM: coefficient (std) 3.686 (0.238) fraction of elemental carbon in PM: coefficient (std) 0.469 (0.055) temperature: coefficient (std) -0.0456 (0.002) intercept (std) 8.398 (0.604) R2 = 0.845. Both EC and OC carbon are important predictors of gas/particle partitioning of PAHs, with EC being a better predictor. Because EC is highly correlated with(and is a good tracer of) primary combustion-generated OC, this result suggests that PAHs more readily sorb on combustion-generated aerosol containing EC. Enrichment of the indoor aerosol in nin-combustion OC suggests that sorption of PAHs is more important in the indoor air compared to the outdoor air. The MLR developed in this work will improve prediction of gas/particle partitioning of PAHs in indoor and outdoor air.

Nerriere et al. (2005b)

Study Design: Exposure assessment

Period: 2001-2003; Lung cancer mortality: 1999

Location: 4 French Cities (Grenoble, Paris, Rouen, Strasbourg)

Population: 6-13 y/o children not exposed to passive smoke; 30-71 y/o adults (average age ~40y/o) not occupationally exposed

Personal Method: yes, using Harvard Chempass worn in a backpack

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Number of cases attributable to $PM_{2.5}$ exposure (95% CI); Attributable Fraction (%) (95% CI): Paris: 303 (42-553); 8 (1-16); Grenoble: 12 (3-22); 10 (3-19); Rouen: 19 (3-35); 10 (2-19); Strasbourg: 43 (7-71); 24 (4-10)

Nerriere et al. (2005a)

Study Design: Exposure assessment. stratified sampling of children and adults in 3 environments: high traffic emissions, local industrial sources, and urban background.

Period: "Hot" season May-June and "cold" season Feb-Mar. Grenoble in 2001, Paris in 2002, Rouen in 2002-2003, Strasbourg 2003.

Location: Grenoble, Paris, Rouen, and Strasbourg, France

Population: Persons living, working, or going to school in 3 urban areas: one highly exposed to traffic emissions, one influenced by local industrial sources, and a background urban environment. Industrial sources of pollution were present in each city.

Age Groups: 6-13 yrs and 20-71 yrs. All non-smokers and not exposed to environmental tobacco smoke or industrial air pollution.

Indoor Source: Daily activity diaries used to do

Personal Method: Rucksack with Harvard ChemPass

Personal Size: $PM_{2.5}$, PM_{10}

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$, PM_{10}

Copollutant(s): NO_2

Primary Findings: The difference between ambient air concentrations and average total exposure is pollutant specific. $PM_{2.5}$ and PM_{10} concentrations underestimate population exposures across almost all cities, season, and age groups, the opposite is true for NO_2.

Ng et al. (2005)

Study Design: Study is to model the dispersion of the 911 WTC destruction cloud to areas of the city and boroughs using "representative persons." Input data are from extant monitoring stations throughout the area.

Period: 14 Sep., 2001 to 30 Sep., 2001

Location: Lower Manhattan, New York City, New York

Population: NYC residents

Age Groups: NR, but both adults and children

Indoor Source: Smoking, cooking

Personal Method: Simulated

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Although the outdoor $PM_{2.5}$ was lower than the NAAQS value, personal exposure levels were higher than outdoor and might be of concern.

Nikasinovic et al. (2006)

Study Design: cross-sectional

Period: Oct 1999-Jun 2002

Location: Paris, France

Population: asthmatic children

Age Groups: 7-14 yrs

Indoor Source: Presence of pets, smoking in the home, house dust mites, home ventilation frequency, allergies to grass, cats, pollen, gas cooking, barometric pressure.

Personal Method: active sampler in a rucksack carried by the children whenever they moved.

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: PM_{10}

Copollutant(s): Ozone

Primary Findings: Pollutant concentrations did not differ between the 2 groups. In asthmatic children only personal $PM_{2.5}$ levels were correlated to nasal markers after adjustment for age, sex, house mites, pollens, cat, tobacco smoke, barometric pressure, and respiratory infection.

Noullett et al (2006)

Study Design: cohort

Period: 5 February to 16 March 2001

Location: Prince George, British Columbia

Population: Children

Age Groups: 10 - 12 yrs

Indoor Source: NR, Each child completed a time activity diary every 30 min on the days that they carried the monitor. A motion sensor (HOBO, Onset Computer Corporation) was also placed in each pack and data from the sensor was downloaded each morning and then compared to each child's time activity diary as a quality assurance measure.

Personal Method: $PM_{2.5}$ Harvard Personal Environment Monitors (HPEM2.5) with a PTFE Teflon filter (Pall Gelman R2PJ037) were used for both the ambient and personal sampling. At ambient sampling sites, the HPEM2.5 was suspended approximately 4 ft above the school rooftop (20 ft from the ground at all schools), connected to a large flow controlled pump and situated in an open area on the roof free of air vents, exhausts or intakes. BGI air sampling pumps and

battery packs (BGI-400S and BGI-401) were used for the personal monitoring and were contained in a child-size backpack. The sampler was attached to the strap of the backpack in the breathing zone of the child with the inlet facing downwards and protected by a 4-in piece of plastic tubing. Subjects were required to wear the pack whenever possible and otherwise to keep the pack close to them and as close to their breathing zone as possible

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): SO_4; ABS (light absorbing carbon)

Primary Findings: In Prince George, a combination of topography, meteorological conditions and location of ambient sources resulted in episodic levels of fine PM during the short study period in the winter of 2001. Thermal inversions were moderately associated with both high ambient levels and personal exposures and were likely responsible for the spatial variation and, in combination with wind, the temporal variation in ambient concentrations throughout the city. The clear link between thermal inversions and both high ambient levels and measured personal exposures during $PM_{2.5}$ episodes support management strategies to reduce ambient sources during periods of limited dispersion in an effort to reduce exposure levels. Despite the significant spatial variation found in ambient levels throughout the city for all three measures, there was a high correlation between the outdoor sites suggesting that a single monitor would represent temporal trends. Similar to the findings in other studies, both sulfate and light

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O'Neill et al. (2004)

Study Design: Time-series epidemiologic study of PM_{10}-associated mortality, comparison of different samplers

Period: January 1, 1994-December 30, 1998

Location: 5 sites in Mexico City, Mexico

Population: urban environments

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM_{10}, $PM_{2.5}$

Component(s): NR

Primary Findings: PM_{10} levels were higher in the winter. PM_{10} levels measured using different methods were not well correlated with each other. Re-analysis of associations between $PM_{2.5}$ and mortality with sensitivity analyses (non-parametric modeling) produced lower eff

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Offenberg et al. (2004)

Study Design: Exposure assessment

Period: 6/1999-5/2000

Location: Los Angeles County, CA; Houston, TX; Elizabeth, Nj

Population: US. General Population

Age Groups: NR

Indoor Source: No

Personal Method: None - area sampling only (in home and outdoors)

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): chlordane

Primary Findings: Geometric mean particle-bound chlordane concentrations were higher indoors relative to outdoors, suggesting indoor sources.

Ogulei et al. (2006a)

Study Design: Exposure Assessment

Period: 11/1999-3/2000

Location: Reston, VA

Population: US homes

Age Groups: NR

Indoor Source: Yes. Nine primary sources of PM were identified: gas burner; use (boiling water), deep-frying tortillas and miscellaneous; cooking of dinner, burning of citronella candle, combined gas burner and gas oven use (broiling salmon), sweeping/vacuuming, use of electric toaster; oven, traffic, wood smoke, and pouring of kitty litter.

Personal Method: None

Personal Size: NR

Microenvironment Size: A range: 0.01-20.0 mm

Ambient Size: NR

Component(s): NR

Primary Findings: Each particle source identified in the study produces distinct particle size distributions

Pang et al. (2002a)

Study Design: Field test of prototype Personal Particulate Organic and Mass Sampler

Period: November 2000 - May 2001

Location: Seattle, WA

Population: NR

Age Groups: NR

Indoor Source: NR

Personal Method: Outdoor sampling for $PM_{2.5}$ mass: The PPOMS was co-located with two Federal Reference Method (FRM) samplers and a HPEM sampler at the Beacon Hill EPA Air Quality and Particulate Speciation Monitoring Site. Samples were collected on each sample day for 24 hr, starting at 0:00 PST.; Indoor sampling for particulate carbon: The PPOMS was co-located with an integrated particle sampler and a Harvard impactor (HI2.5) inside of two residences. Five samples were collected at each house over the course of several days.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): EC; OC

Primary Findings: "This study shows that the PPOMS design provides a 2.5 μm size-selective inlet that also prevents the adsorption of gas-phase SVOC onto quartz filters, thus eliminating the filter positive artifacts. The PPOMS meets a significant current challenge for indoor and personal sampling of particulate organic carbon. The PPOMS design can also simplify accurate ambient sampling for $PM_{2.5}$."

Paschold et al. (2003)

Study Design: Concurrent 48-h indoor and outdoor concentrations of PM_{10} and $PM_{2.5}$ in 10 homes with swamp coolers

Period: summer of 2001

Location: El Paso, Texas

Population: Homes with evaporative coolers

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: PM_{10} and $PM_{2.5}$

Ambient Size: NR

Component(s): Geologic material; Sodium; Magnesium; Aluminum; Potassium; Calcium; Titanium; Manganese; Iron; Trace metals; Copper; Zinc; Barium; Lead

Primary Findings: Indoor elemental concentrations in PM_{10} were approximately 50–70% lower than outdoor concentrations in 9 of 10 homes, consistent with the PM_{10} indoor/outdoor (I/O) mass concentrations previously reported. $PM_{2.5}$ I/ O ratio correlations were not as strong as for PM_{10}; however, reduced correlations could be attributed to a pattern of recurring outlier data pairs, consisting of the same 3 or 4 elements in all 10 homes.

Polidori et al. (2007)

Study Design: time-series epidemiologic study

Period: Site A (Group 1 [G1]); -Phase 1: July 6 to August 20, 2005; -Phase 2: October 19 to December 10, 2005; Site B Group 2 [G2]); -Phase 1: August 24 to October 15, 2005; -Phase 2: January 4 to February 18, 2006

Location: Los Angeles, California (Two Retirement homes)

Population: Elderly residents of Los Angeles, California retirement homes

Age Groups: NR

Indoor Source: No

Personal Method: Two identical sampling stations were installed at each location, one indoors and one outdoors. The indoor sampling station at site A was located in the recreational area of the first community's main building, adjacent to a construction site where work was ongoing. The indoor sampling area at site B was situated in the dining room of the second community's main building. At both sites, the outdoor station, set up inside a movable trailer, was positioned within 300m from the indoor station. Two β-attenuation mass monitors (BAMS) (Model 1020) were used at each indoor and outdoor sampling station to measure hourly $PM_{2.5}$ mass concentrations. Continuous NO, NO_2, and CO measurements were taken indoors and outdoors using Thermo Environmental NO_X analyzers (Model 42), and Dasibi CO Analyzers (Model 3008) respectively. O_3 concentrations were also monitored at each sampling station by using API Ozone Analyzers (Model 400A). At both indoor and outdoor sampling areas, a water-based condensation particle counter (CPC model 3785), and a semicontinuous OC-EC analyzer (Model 3F) were operated side by side. A modified National Institute for Occupational Safety and Health (NIOSH) analysis protocol was used here to evolve particulate OC and EC.

Personal Size: NR

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$, PN

Component(s): OC; EC; OC1; OC2-4

Primary Findings: Measured indoor and outdoor concentrations of $PM_{2.5}$, OC, EC, PN, O_3, CO, and NO_X were generally comparable, although at G2, a substantial peak in indoor OC, PN, and $PM_{2.5}$ (probably from cooking) was typically observed between 6: 00 and 9: 00 am. The study average percentage contribution of outdoor SOA to outdoor particulate OC was 40% and varied between 40% and 45% in the summer (during G1P1) and 32% and 40% in the winter (during G2P2). The low AERs (0.25-0.33 h-1) calculated for G1 and G2 are consistent with the structural characteristics of the sampling sites, the low number of open windows and doors, and the presence of central air conditioners. F_{inf} estimates were highest for EC and also for OC. Lower F_{inf} values were obtained for $PM_{2.5}$ and PN, because these compounds are composed of both volatile and nonvolatile inorganic and organic compounds. Based on a single compartment mass balance model, it was found that 13-17% (G2P2) to 16-26% (G1P1) of measured indoor OC was emitted or formed indoors. Although the G2 indoor site was characterized by higher indoor morning OC peaks because of cooking, the overall contribution of indoor sources to measured indoor OC was higher at the

G1 site. The modeling results also showed taht the measured indoor $PM_{2.5}$ emitted or formed indoors was highly variable (from 6-21% at G1P1 to 45-51% at G1P2). The average percentage contribution of indoor SOA of outdoor origin to measured indoor OC varied from ~35% (at site 1) to ~45% (at site 2). Also, outdoor-generated primary OC composed, on average, 36-44% of measured indoor OC during G2P1 and G1P1 respectively.

Poupard et al. (2005)

Study Design: Explore relationships between indoor and outdoor air quality

Period: NR

Location: La Rochelle, France

Population: School buildings

Age Groups: NR

Indoor Source: No

Personal Method: GRIMM 1.108 analyzer

Personal Size: 15 size intervals from 0.3 to 15 microns

Microenvironment Size: NR

Ambient Size: 15 size intervals from 0.3 to 15 microns

Component(s): NR

Primary Findings: Influence of room occupancy on particle concentrations indoors changes with particle size; Indoor ozone and particle concentrations are negatively correlated

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Price et al. (2003)

Study Design: Exposure assessment, comparison of PM_{10} samplers

Period: November 2000 to August 2001

Location: Sunderland, England (northeast England), monitoring at curbside

Population: urban populations near high traffic areas

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: Correlation between TEOM and partisol appeared to be seasonal, with strongest correlation in the summer when ambient PM_{10} concentrations were relatively low. In the winter and spring, when PM_{10} levels are higher, the Partisol sampler records grea

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Ramachandran et al. (2003)

Study Design: Matched $PM_{2.5}$ 24-h and 15 min averages at 9-10 residences in each of 3 communities and at 3 central sites, in 3 seasons.

Period: The measurements were made over 3 seasons—spring (April 26–June 2), summer (June 20–August 10), and fall (September 23–November 20) of 1999.

Location: Phillips, East St. Paul, and Battle Creek, Metropolitan Minneapolis-St. Paul, Minnesota

Population: Urban residential communities

Age Groups: 23 females, 9 males; mean age 42 ± 10, range 24–64 years

Indoor Source: No

Personal Method: NR

Personal Size: NR

Microenvironment Size: $PM_{2.5}$ in residences

Ambient Size: At 3 central sites, $PM_{2.5}$

Component(s): NR

Primary Findings: Outdoor $PM_{2.5}$ concentrations across the Minneapolis– St. Paul area appear to be spatially homogeneous on a 24-h time scale as well as on a 15 min time scale. Short-term average outdoor $PM_{2.5}$ concentrations can vary by as much as an order of magnitude within a day.

Riojas-Rodríguez et al. (2006)

Study Design: Panel Study

Period: 12/2001-4/2002

Location: Mexico City, Mexico

Population: Patients with heart disease

Age Groups: Avg Age: 55 y/o (range: 25-76)

Indoor Source: Nub

Personal Method: Yes, using nephelometers (personal data ram (PDR) model 1200, Monitoring Instruments for the Environment, Inc) connected to a 4L/min pump

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Authors found a decrease in HRV measured as high frequency (Ln) (coefficient = -0.008, 95% confidence interval (CI) to -0.015, 0.0004) for each 10 microg/m^3 increase of personal PM$_{2.5}$ exposure.

Robinson et al. (2007)

Study Design: A pollution mapping exercise was undertaken to measure average pollution levels on a number of transects across the New South Wales Valley and the variation with height and land use was determined. Spatial variation was then used to predict population exposure to PM$_{2.5}$ pollution and the effect on health

Period: Pollution measurements were made between 17 July 1996 and 10 September 1996

Location: Armidale, New South Wales, Australia

Population: Armidale, New South Wales, Australia

Age Groups: NA

Indoor Source: NR

Personal Method: A portable Radiance Research M903 integrating nephelometer was used to measure ambient air pollution at four transects; Ambient air pollution was also measured using a fixed site Belfort nephelometer

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: 1. Considerable variability was observed in winter woodsmoke pollution levels 2. A small number of badly operated heaters can have a large influence on local air quality 3. Pollution was generally higher in residential areas 4. Annual exposure to PM$_{2.5}$ pollution in Armidale from woodsmoke was double that from all sources in Sydney.

Rojas-Bracho et al. (2004)

Study Design: Cohort, repeated measures. 18 COPD patients in non-smoking homes were sampled either in winter 1996 or 1997. 16 of these also were sampled in the summer. All subjects were sampled for 6 consecutive days in winter, and one or two sets of 6 consecutive days in the summer.

Period: 1996-1997

Location: Boston, Massachusetts

Population: COPD patients

Age Groups: housecleaning, cooking, transport in motor vehicles, low-effort home activities, moderate-effort home activities, activities in public places, and resting or sleeping.

Personal Method: PEM attached to shoulder strap of a bag (near breathing zone) containing the pump and batteries.

Personal Size: PM$_{2.5}$, PM$_{10}$, & PM$_{2.5-10}$

Microenvironment Size: PM$_{2.5}$, PM$_{10}$, & PM$_{2.5-10}$

Ambient Size: NR

Component(s): NR

Primary Findings: During both seasons personal exposures were higher than indoor or outdoor means, except the winter indoor concentrations were higher than the personal or outdoor.

Rotko et al. (2002)

Study Design: European multi-city air pollution study

Period: Athens, Greece (A): 26 January 1997–4 June 1998; Basel, Switzerland (B): 3 February 1997–23 January 1998; Milan, Italy (M): 10 March 1997–23 May 1998; Oxford, UK (O): November 1998–7 October 1999; Prague, Czech Republic (P): 3 June 1997–4 June 1998; Helsinki, Finland (H): 26 September 1996–10 December 1997

Location: Athens, Greece (A); Basel, Switzerland (B); Milan, Italy (M); Oxford, UK (O); Prague, Czech Republic (P); Helsinki, Finland (H)

Population: Adults

Age Groups: 25-55yrs

Indoor Source: NR

Personal Method: Personal PM$_{2.5}$ exposures were collected on two different filters: one for the working hours including commuting (personal work) and the other for the remaining hours of 48-h measurement period (personal leisure time). In addition to personal exposure monitoring, PM$_{2.5}$ concentrations were measured in each home (indoors and outdoors) and workplace (indoors). The PM$_{2.5}$ concentration measured at work was the avg of two consecutive workdays and at home of the remaining hours of the 48-h monitoring period. PM$_{2.5}$ personal cyclones were used as pre-separators at flow rate of 4 l min 1 and the EPA-WINS impactors were employed at 16.7 l min 1 for the microenvironment measurements with Gelman Teflo filters (37- and 47-mm, respectively).

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: PM$_{2.5}$

Copollutant(s): NO$_2$

Primary Findings: * There was a large variation in the levels of air pollution annoyance between the six studied cities. The highest annoyance levels were experienced while in traffic.; * The significant determinants of air pollution annoyance were the city, self-reported sensitivity to air pollution and respiratory

symptoms, downtown residence and gender of the subject.; * No consistent or significant correlations were seen between the individual levels of annoyance and exposure concentrations to either PM$_{2.5}$ or NO$_2$.; * High air pollution annoyance in traffic, however, was significantly associated with home outdoor concentrations of both PM$_{2.5}$ and NO$_2$ and downtown living (NO$_2^-$ model).; * When average annoyance levels and concentrations were averaged for each city, the perceived annoyance levels at home correlated highly with the measured personal 48-h PM$_{2.5}$ and NO$_2$ exposures and home indoor NO$_2$ concentration, annoyance at work correlated with personal workday exposure and workplace PM$_{2.5}$ concentrations, and annoyance in traffic wi

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Salma et al. (2005)

Study Design: 2 types of samplers collected aerosols in an urban area. 23 samples were collected with each device separately for day and night.

Period: Spring 2002

Location: Budapest, Hungary

Population: urban dwellers

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: See direct quote in the note below

Component(s): Al; Si; Ca; Ti; Fe; Cl; Zn; Na; Mn; Ni; Cu; Pb; K; S; Br

Primary Findings: The variation in the overall size distributions and RMCs for the various elements indicated the existence of multiple sources, including vehicular (both combustion and frictional) and industrial emissions, resuspension of road and soil dust, and long-range transport of air masses. The significant coarse mode for some typical anthropogenic elements (Cu and Zn) and the observed coarse mode concentration differences between daytime periods and nights (e.g., for Ca) point to the importance of frictional sources and road dust resuspension in cities, which are both primarily related to road traffic.

Salma et al. (2007)

Study Design: examination of aerosol air quality and its temporal variation in the Budapest metro

Period: April 20 and 21, 2006

Location: Budapest, Hungary

Population: underground metro commuters

Age Groups: NR

Indoor Source: No. Air monitoring equipment consisted of a tapered element oscillating microbalance (TEOM), a wind monitor (Campbell), and a laboratory-made Gent-type stacked filter unit (SFU) aerosol sampler. OM was equipped with a PM$_{10}$ inlet facing upwards and was operated with the filter heated to 40 1C to prevent moistening. The sampling station was ventilated without filtration by drawing air from the opposite platform to the roof level of a 12-story building next to the station.

Personal Method: no personal monitoring. In situ aerosol measurement and sample collection at the metro station.

Personal Size: PM$_{10}$-2.0 and PM2.0

Microenvironment Size: NA

Ambient Size: NR

Component(s): 30 elements (Na, Mg, Al, Si, P, S, Cl-, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ba, and Pb)

Primary Findings: The concentrations observed in the Astoria underground station were clearly lower (by several orders of magnitude) than the corresponding workplace limits.

Sanserson and Farant (2004)

Study Design: Indoor and outdoor air monitoring of PAH. Investigate the relationship between indoor and outdoor PAH.

Period: NR

Location: Canada

Population: Residential homes in neighborhoods around aluminum smelting plant

Age Groups: NR

Indoor Source: NR

Personal Method: Indoor: quartz filter, XAD-2 Resin Outdoor: glass fiber filter

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): 4-6 ring PAHs on indoor particle

Primary Findings: Indoor concentration of 4-6-ring PAH linked to outdoor sources in residences without any major indoor source, but with industrial facility as the main outdoor source. Study suggests that simultaneous measurements of indoor and outdoor concentrations of PAH >4 rings predominantly associated with fine PM could provide useful estimates of particle infiltration efficiency.

Sarnat et al. (2006)

Study Design: Outdoor-indoor pollutant infiltration, occupied residences

Period: July 28, 2001 - February 25, 2002

Location: Los Angeles, CA

Population: NR

Indoor Source: Yes; cleaning, cooking, home ventilation (open windows/doors), kitchen fans, air conditioner/heating usage, number of occupants, nearby roadways

Personal Method: NR

Personal Size: NR

Microenvironment Size: $PM_{2.5}$, Particle number

Ambient Size: $PM_{2.5}$

Component(s): BC (nonvolatile component); NO_3 (volatile component)

Primary Findings: a) Infiltration rate for $PM_{2.5}$ was intermediate, while BC was highest, NO_3 lowest.; b) Infiltration rate varied with particle size, air exchange rate, outdoor NO_3; c) $PM_{2.5}$ infiltration was lowest for volatile component; d) Outdoor volatile $PM_{2.5}$ components may be less representative of indoor exposure to volatile $PM_{2.5}$ of ambient origin.; e) Outdoor nonvolatile $PM_{2.5}$ components may be more representative of indoor exposure to nonvolatile $PM_{2.5}$ of ambient origin.

Sarnat et al. (2006)

Study Design: Personal and ambient exposure assessment

Period: June 14-August 18 (summer); Sep 24-Dec 15 (fall), 2000

Location: Steubenville, OH

Population: Nonsmoking, older adults

Age Groups: No

Personal Method: Integrated filter gravimetric measurement

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): SO_4; EC

Primary Findings: a) 24-h ambient measurements more representative of personal particle exposure than gases; b) ventilation is an important exposure modifier.

Sarnat et al. (2005)

Study Design: time-series epidemiologic study

Period: Summer 1999 and winter 2000

Location: Boston, Massachusetts. Comparisons to a previous study in Baltimore are made.

Population: School children and seniors

Age Groups: NR

Indoor Source: $PM_{2.5}$

Personal Method: NR

Personal Size: $PM_{2.5}$

Microenvironment Size:

Ambient Size:

Component(s): SO_4,

Copollutant(s): O_3, NO_2, SO_2

Primary Findings: Substantial correlations between ambient $PM_{2.5}$ concentrations and corresponding personal exposures.; Summertime gaseous pollutant concentrations may be better surrogates of personal $PM_{2.5}$ exposures (especially personal exposures to $PM_{2.5}$ of ambient origin) than they are surrogates of personal exposures to the gases themselves.

Sax et al. (2006)

Study Design: 2 Cohorts, one in NYC and 1 in LA.; Personal, home indoor, and home outdoor samples taken for $PM_{2.5}$, VOCs, and aldehydes.

Period: 1999-2000, winter and summer in NYC, winter and fall in LA.

Location: New York City, New York, and Los Angeles, California

Population: 13-19 yrs

Age Groups: No

Indoor Source: Customized backpack

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Primary Finding(s): Most VOCs has median upper-bound lifetime cancer risks that exceeded the USEPA benchmark of 1 x 10 -6 and were generally greater that the EPA modeled estimates, more so for compounds with predominant indoor sources. Chromium, nickel, and arsenic had median personal cancer risks above the benchmark with exposures largely from outdoors and other microenvironments. The EPA model overestimate risks for beryllium and chromium and underestimate risks for nickel and arsenic.

Scheepers et al. (2003)

Study Design: Field Study

Period: Pilot Study; March 15-18, 1999, and March 22-25, 1999 (coal mine); April 12-14, 1999 (oil shale mine); Main Study; June 5-22, 2000

Location: Pilot Study; Ostrava, Czech Republic (black coal mine); Kohtla-Järve, Estonia (oil shale mine); Main Study; Kohtla-Järve, Estonia (oil shale mine)

Population: Coal miners with high exposures to Diesel-powered machinery

Age Groups: NR

Indoor Source: NR

Personal Method: Personal sampling was accomplished by each individual worker carrying personal air sampling equipment (GSA 200 or Gillian) during two shifts in the same work week (1 shift for the main study). The air sampling pumps operated in the breathing zones of the individual workers and operated at an electronically controlled flow rate of 2.0l/min.; Inhalable dust samples were collected using a sampler head developed by the Institute für Gefahrstoff Forschung der Bergbau Berufsgenossenschaft (IGF). Respirable dust was collected using an elutriator pre-separator type MPGII (IGF). Particles were collected on polystyrene membrane filters with a Teflon coating. All samples were taken at a height of ~1.5 m above the floor.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): 1-nitropyrene (1-NP)

Primary Findings: This study confirms that 1-NP in black coal and oil shale mines is mostly associated with respirable particles and that mining operations involving diesel-powered engines exposures to DEP may be 3- to 10-fold higher for underground miners than workers on the surface. Furthermore, measurements of particle-associated 1-NP is a more sensitive and discriminating indicator o exposure to DEP than inhalable or respirable particles because of the relatively high concentrations of mine dust in mining operations.; Respirable dust concentration were 2- to 3-fold higher in the breathing zone than at fixed sampling locations while 1-NP concentrations were found to be 2.5-fold and 10-fold higher in the coal mine and oil shale mine respectively. This is thought to be due to location of fixed sampling points as well as wind and humidity levels within the mines themselves. For these reasons and others, personal air sampling is preferred over air sampling at fixed sites.

Shalat et al. (2007)

Study Design: Indoor home exposure assessment; sampling technology demonstration

Period: Winter heating season

Location: Residential home

Population: Children

Age Groups: Pre-toddler (6- to 12-month-old) children

Indoor Source: Mobile robotic and stationary. Filter and real-time nephelometer.

Personal Method: Floor; Filter: inhalable particles (approximately < 100 μm)

Personal Size: Indoor home; Nephelometer: total suspended particles.

Microenvironment Size: NR

Ambient Size: NR

Shao et.al. (2007)

Study Design: exposure assessment

Period: July and Winter 2003

Location: Beijing, China

Population: general population

Age Groups: NR

Indoor Source: soot aggregates, coal fly ash, minerals, unknown fine particles

Personal Method: PM_{10} selective inlet heads 30L/min flow rate with polycarbonate filters

Personal Size: PM_{10}

Microenvironment Size: PM_{10}

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: 1. Plasmid scission assay, coupled with the image analysis, can be used to evaluate the relationship between particle physico-chemistry and toxicity.

Shilton et al. (2002)

Study Design: Respirable particulates inside and outside of a building were collected and compared

Period: 24-h sampling from 12: 45 pm Mondays to Fridays between 9/19/00 to 5/01/01

Location: Wolverhampton city center, University of Wolverhamptom, UK

Population: Building near traffic dominated by heavy-duty diesel vehicles

Indoor Source: Outdoor (primary); Mn,Al, NO_3, Cl^- (wind-blown dust); Cu and Zn-(traffic emissions)

Personal Method: Active sampling using Casella sampler (filter)-

Personal Size: Respirable PM (inside and outside)

Microenvironment Size: Respirable PM (inside)

Ambient Size: Respirable PM (outside)

Component(s): Respirable PM, metals (Zn, Cu, Mn, Al), sulfate, nitrate, and chloride

Primary Findings: The indoor particulate concentration was driven by ambient concentration; meteorological-induced changes in ambient PM were detected indoors;

Simons et al. (2007)

Study Design: NR

Period: Baltimore, Maryland; and surrounding counties

Location: Children with asthma

Population: Inner city - 6-12 yrs; Surrounding counties - 6-17 yrs

Age Groups: Gas stoves, cats, dogs, smokers, mold/mildew carpet, outside PM, dryer vents

Indoor Source: Indoor air was collected from the child's bedroom with 4 L/min MSP impactors over a 72-h period.

Personal Method: NR

Personal Size: $PM_{2.5}$; PM_{10}

Microenvironment Size: $PM_{2.5}$; PM_{10}

Ambient Size: Allergens were also assessed: Dust mite; Bla/g; Mus/m; Fel/d; Can/ f; Airborne Mus/m

Primary Finding(s): Compared with the homes of suburban children with asthma, the homes of inner city Baltimore children with asthma had higher levels of airborne pollutants (including PM, NO_2 and O_3 amongst others) and home characteristics that predispose to greater asthma morbidity. In the inner city homes, median and GM PM_{10} levels were almost three times as high and the GM $PM_{2.5}$ levels were more than three times higher than in the suburban homes. Median GM NO_2 and GM O_3 levels were found in similar ratios. It is important to note that PM_{10} levels were found to be markedly higher in homes on arterial streets compared to those not on arterial streets. Although standards specific for home indoor air quality have not been established, we found that the inner city children were exposed to home pollutant levels in excess of the Environmental Protection Agency's National Ambient Air Quality standards.

Smith et al. (2006)

Study Design: Location: U.S.

Population: Trucking industry

Age Groups: working age

Indoor Source: Diesel tractors, cigarette smoking, site pollution

Personal Method: Terminal workers had samplers in a special harness; Drivers had a sampling box placed in the cab.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$; Area samplers in the offices, freight dock, or shop.

Ambient Size: $PM_{2.5}$; Samplers were located in the yard upwind of the terminal.

Component(s): Elemental carbon (EC); Organic carbon (OC)

Sørensen et al. (2005)

Study Design: panel study

Period: 11/1999, 8/2000

Location: Copenhagen, Denmark

Population: Healthy young adults, nonsmokers

Age Groups: 20-33 y/o, median age = 24y/o

Indoor Source: No

Personal Method: International Gravity Bureau (BGI, Toulouse; France) (Kenny and Gussman 1997), a KTL; $PM_{2.5}$ cyclone (Jantunen et al. 1998), a; BGI400 pump (BGI Inc., Waltham, MA; USA) (flow 4 L/min)

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): Transition metals (vanadium; chromium, iron, nickel, copper, and platinum)

Primary Findings: The 8-oxodG concentration in; lymphocytes was significantly associated with vanadium and chromium concentrations with a 1.9% increase in; 8-oxodG per 1 Mg/L increase in vanadium and a 2.2% increase in 8-oxodG per 1 Mg/L increase chromium.

Sørensen et al. (2003)

Study Design: Epidemiologic personal exposure study

Period: Autumn- November 1999; Winter- January to February 2000; spring- April to May 2000; summer- August 2000

Location: Central Copenhagen

Population: University students

Age Groups: 20-33 yrs (median = 24 yrs)

Indoor Source: NR

Personal Method: Particles were sampled using a KTL $PM_{2.5}$ cyclone developed for the European EXPOLIS study (17), a International Gravity Bureau 400 pump (4l/min), and a battery pack. The equipment was placed in a backpack, which the subjects carried or placed nearby when they were indoor. Sampling was

done on 37-mm Teflon filters.; Urban background concentrations of $PM_{2.5}$ were measured on the rooftop of a building (20 meters above the ground) on the Copenhagen University campus.

Personal Size: $PM_{2.5}$

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): BS

Primary Findings: Personal $PM_{2.5}$ exposure was found to be a predictor of 8-oxodG in lymphocyte DNA. No other associations between exposure markers and biomarkers could be distinguished. ETS was not a predictor of any biomarker in the present study. The current study suggests that exposure to $PM_{2.5}$ at modest levels can induce oxidative DNA damage and that the association to oxidative DNA damage was confined to the personal exposure, whereas the ambient background concentrations showed no significant association.; For most of the biomarkers and external exposure markers, significant differences between the seasons were found. Similarly, season was a significant predictor of SBs and PAH adducts, with average outdoor temperature as an additional significant predictor.

Sørensen et al. (2005)

Study Design: Repeated measures cohort study.

Period: Nov 1999-Aug 2000

Location: Copenhagen, Denmark

Population: residents of downtown Copenhagen

Age Groups: 20-33 yrs old, all non-smokers

Indoor Source: Used a questionnaire to get time exposed to environmental tobacco smoke, burning candles, frying food, open windows

Personal Method: wore a backpack, or placed nearby when indoors.

Personal Size: $PM_{2.5}$ and BS

Microenvironment Size: Bedroom and front door; $PM_{2.5}$ and BS

Ambient Size: Street monitoring station and roof of a campus building; $PM_{2.5}$ and BS

Copollutant(s): NO_2

Primary Findings: For NO_2 there was a significant association between personal exposure and the bedroom, the front door and the background, whereas for $PM_{2.5}$ and BS only the bedroom and the front door concentrations, and not the background, were significantly associated with personal exposure. The bedroom concentration was the strongest predictor of all three pollution measurements. The association between the bedroom and front door concentrations was significant for all three measurements, and the association between the front door and the background concentrations was significant for $PM_{2.5}$ and NO_2, but not for BS, indicating greater spatial variation tbr BS than for $PM_{2.5}$ and NO_2. For NO_2, the relationship between the personal exposure and the front door concentration was dependent upon the "season," with a stronger association in the warm season compared with the cold season, and for $PM_{2.5}$ and BS the same tendency was seen. Time exposed to burning candles was a significant predictor of personal $PM_{2.5}$, BS and NO_2 exposure, and time exposed to ETS only associated with personal $PM_{2.5}$ exposure. These findings imply that the personal exposure to $PM_{2.5}$, BS and NO_2 depends on many factors besides the outdoor levels, and that information on season or outdoor temperature and residence exposure, could improve the accuracy of the personal exposure estimation. Regression coefficients for personal exposure and: front door $PM_{2.5}$ in warm season was 0.67 *, and in the cold season, 0.28. Front door BS in warm season was 0.86 *, and in the cold season, 0.45.* Front door NO_2 in warn season was 0.68 *, and cold season 0.32.*

Sram et al. (2007)

Study Design: Exposure-Control study: 53 policemen (exposed) and 52 age- and sex-matched healthy volunteers (control) were enrolled. Ambient and PE PM_{10}, $PM_{2.5}$, and c-PAHs were monitored and chromosomal aberrations were analyzed.

Period: Feb 6 - 20, 2001

Location: Prague, Czech Republic

Population: Policemen working outdoors in Prague

Age Groups: NA

Indoor Source: Personal monitoring using personal samplers (name of instrument not stated)

Personal Method: PM_{10} $PM_{2.5}$

Personal Size: NR

Microenvironment Size: PM_{10} $PM_{2.5}$

Ambient Size: c-PAHs, B[a]P

Component(s): Ambient air exposure to c-PAHs increased fluorescent in situ hybridization (FISH) cytogenetic parameters in non-smoking policemen exposed to ambient PM

Srivasta et al (2007)

Study Design: Exposure assessment of indoor environment

Period: April 5-June 26, 2000

Location: laboratory in Delhi, India

Population: Building occupants

Age Groups: NR

Indoor Source: Re-entrainment of existing dust on floor and other surfaces

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: Suspended PM (SPM)

Ambient Size: NR

Component(s): metals: Ca, Mg. Cu, Zn, Cd, Pb, Cr, Mn, Fe, Co, Ni

Primary Findings: Gravimetric analysis and atomic absorption spectrometry results indicated that the suspended PM (SPM) and metal (lead) concentrations were higher than the National Ambient Air Quality Standards for Delhi, India and SPM standards for residential and sensitive areas. The maximum concentrations of SPM were observed to be due to penetration of outdoor particles originating from wind-blown crustal dust and vehicular pollution. Scanning electron microscopy analysis of particles showed dominance of crystalline silicon and spherical soot particles in samples

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Stein et al. (2002)

Study Design: Exposure assessment, evaluation of an aerodynamic particle sizer to accurately measure size-distributed particle mass from number concentrations

Period: NR

Location: laboratory

Population: PM monitoring devices

Age Groups: NR

Indoor Source: No personal exposure assessment was conducted

Personal Method: NR

Personal Size: 1.0-13um

Microenvironment Size: NR

Ambient Size: NR

Primary Finding(s): Significant errors were observed in APS size-distribution measurements with measured mass median diameters (MMAD) as much as 17 times higher than from cascade impactors. Analysis of APS-correlated time of flight and light scattering data indicated that th

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Strand et al. (2007)

Study Design: Cohort

Period: Winter of 1999-2000; winter of 2000-2001

Location: Denver, Colorado, USA

Population: Asthmatic Children

Indoor Source: No

Personal Method: Modeling/Extrapolation from fixed-site ambient monitoring (multiple methods)

Personal Size: No

Microenvironment Size: NR

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Using modeled or extrapolated personal ambient PM exposure results in a deattenuation of decrements in FEV_1 associated with PM exposure, relative to use of fixed-site ambient monitoring PM levels. Associations between FEV_1 decrements and the various estimation procedures (modeling and extrapolation) were similar to each other.

Tang et al. (2007)

Study Design: Cohort Study

Period: 12/2003-2/2005

Location: Sin-Chung City, Taiwan

Population: Asthmatic children

Age Groups: 6-12 years

Indoor Source: No

Personal Method: Portable particle monitor; DUSTcheck Portable Dust Monitor, model 1.108, GRIMM Labortechnik Ltd., Germany

Personal Size: PM_{10}, $PM_{2.5}$, PM_1, $PM_{2.5-10}$, $PM_{1-2.5}$

Microenvironment Size: NR

Ambient Size: PM_{10}, $PM_{2.5}$, $PM_{2.5-10}$

Component(s): NR

Primary Findings: Results of linear mixed-effect model analysis suggested that personal PM data was more suitable for the assessment of change in children's PEFR than ambient monitoring data.

Tatum et al. (2002)

Study Design: Methodological: in this study, the performance of the gravimetric version of the RespiCon was examined in various forest products industry facilities. The precision of the RespiCon was assessed and its performance was compared with that of both a respirable cyclone and an inhalable dust sampler. In addition, some RespiCon samples were examined using scanning electron microscopy to determine physical particle size distribution.

Period: NA

Location: Various forest products industry facilities

Population: occupational

Age Groups: NA

Indoor Source: No

Personal Method: NR

Personal Size: NR

Microenvironment Size: Respirable (< PM4um), Thoracic (< PM$_{10}$um), and Inhalable fractions (all PM) of airborne PM.

Ambient Size: NR

Component(s): NR

Primary Findings: The RespiCon is a useful sampling device for those situations in which it is important to simultaneously collect either personal or area samples of the respirable, thoracic, and inhalable fractions of airborne PM.

Thomaidis et al. (2003)

Study Design: Exposure assessment (chemical characterization of PM$_{2.5}$ aerosols, source apportionment)

Period: March 1995-March 1995

Location: Two sites in Athens, Greece: 1. Patission in Athens city center and mainly affected by local traffic; 2. Rentis located in a semi-urban industrial area 5 km outside city center and mainly influenced by small industries

Population: urban populations

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure sampling.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): Pb, Cd, Ni, As

Primary Findings: Pb exhibited higher values during the winter, possibly due to increased diesel oil combustion from central heating and motor vehicles. No seasonal variation was observed for other metals. Annual mean levels of Pb at both sites were below the European Union guidelines.

Thornburg et al. (2004)

Study Design: PM exposure studies: RTP PM Panel Study; Tampa Asthmatic Children's Study

Period: RTP: summer 2000 - spring 2001; Tampa: October - November 2002

Location: Research Triangle Park (RTP), NC and; Tampa, FL

Population: Residential home occupants

Age Groups: NR

Indoor Source: Yes. Resuspension of PM$_{10}$ from a carpet was identified as a major source in one home (a trailer), while cooking was identified as a source in many homes.

Personal Method: 20 Lpm Harvard impactors and 2 Lpm Personal Exposure Monitors both with 37 mm Teflo filters and gravimetric analysis.; Also, MIE pdr1000 nepholometer.

Personal Size: PM$_{2.5}$, PM$_{10}$

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$, PM$_{10}$

Component(s): NR

Primary Findings: The association of duty cycle with indoor-outdoor (I/O) ratio was confounded by the short time span of ventilation system operation and the presence of strong indoor sources.

Toivola, M et al.

Study Design: Random sample of teachers

Period: Nov 1998-Mar 1999 and Nov-Dec 1999

Location: 2 cities in eastern Finland

Population: elementary school teachers

Personal Method: Button inhalable aerosol sampler

Personal Size: Particle Mass; BS

Microenvironment Size: Particle Mass; BS

Ambient Size: NR

Component(s): Total Fungi, total bacteria, viable fungi, viable bacteria

Primary Findings: Personal BS exposure correlated with both home and work BS exposures. BS concentrations explained best the variation of particle mass in personal and home concentrations.

Tovalin et al. (2006)

Study Design: Biomarker (DNA damage in blood) exposure assessment

Period: Mexico City and Puebla, Mexico

Location: Occupationally exposed outdoor workers

Population: 18-60 years old

Age Groups: NA

Personal Method: Personal: integrated filter gravimetric measurement. Questionnaire

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: a) In Mexico City, outdoor workers had greater DNA damage than indoor (median tail length 46.8 vs. 30.1 µm).; b) In Mexico City, outdoor workers had a greater proportion of cells with high DNA damage (tail length = 41 µm).; c) In Puebla, outdoor and indoor workers had similar damage.; d) DNA damage was correlated with PM$_{2.5}$ and ozone exposure.; e) High DNA damage in workers was associated with ozone, PM$_{2.5}$, and 1-ethyl-2-methyl benzene (VOC) exposure.

Tovalin-Ahumada et al. (2007)

Study Design: Point study

Period: April and May, 2002

Location: Mexico City (Ne and SE) and Puebla, Mexico

Population: Indoor and outdoor workers in large urban areas

Age Groups: 18 years of age and older

Indoor Source: NR, The exposures described in this report were monitored as part of a larger study directed at evaluating the association between personal exposures to PM$_{2.5}$ and VOCs and genetic damage in outdoor and indoor workers reported elsewhere (Tovalin et al., 2006).

Personal Method: Personal exposures to PM$_{2.5}$ were monitored using 37mm Teflon filters (Model 225-9006, SKC Inc.), fitted to a single stage personal impactor (Model PEM-761-203A, SKC) and personal sampling pumps (Model PCXR4, SKC). Two PM$_{2.5}$ personal air samples (occupational and nonoccupational) were obtained during a 24-h period for each worker in Mexico City and for the indoor workers in Puebla. Only one PM$_{2.5}$ personal sample could be obtained during a 24-h period (an overall exposure) for the bus drivers in Puebla because of their work shift (from 4AM to 8 PM) with rotating start and end times. At the beginning of the work shift, each participant was asked to carry a backpack holding the pump; the impactor was attached to the backpack strap, in the breathing zone. At the end of the work shift, the impactor and pump were removed, and replaced with a new sampling setup that was worn by the worker until the beginning of the next day work shift.

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): Si; S; K; Ca; Cl(e); Ti; V; Cr; Mn; Fe; Co; Ni; Cu; Zn; Mo(e); Cd(e); Se; Br; Rb; Sr(e); As; Pb

Primary Findings: The results of this study suggest that outdoor workers in both Mexican cities experienced higher exposures to PM$_{2.5}$ than indoor workers, and that these exposures are well above either the 35 µg/m^3 US-EPA or the 65 µg/m^3 24-h Mexican standards for PM$_{2.5}$. Both subgroups experienced higher occupational than nonoccupational exposures. Mexico City outdoor workers had higher exposures to Soil, Fuels and Industrial emission-related elements than Puebla outdoor workers did. However, Mexico City outdoor workers had half the exposure to soil dust-related elements and fuel related elements than Puebla outdoor workers. However the S exposure was similar in all groups but high, product of the high vehicles density in the areas, responsible for 60% of the emission in Mexico City (Secretaria del Medio Ambiente, 2005). This study of Mexico City results correlates well with a previous PM$_{2.5}$ emissions inventory results, which determined that 81.14% of particles are released from mobile sources

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Trenga CA et al, 2006

Study Design: panel study with repeated measures

Period: 3 sampling periods: Oct 1999-Aug 2000, Oct 2000-May 2001, Oct 2001-Feb 2002

Location: Seattle, Washington

Population: Adults with and without COPD and children with asthma

Age Groups: adults ages 56-89 and children ages 6-13

Indoor Source: NR

Personal Method: carrying personal monitor (Harvard Personal Environmental Monitor for PM$_{2.5}$)

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: Coarse (PM$_{10}$-PM$_{2.5}$) and PM$_{2.5}$ for residential outdoor, PM$_{2.5}$ for central site

Component(s): NR

Primary Findings: FEV$_1$ decrements associated with 1-day lagged central site PM$_{2.5}$ in adult subjects with COPD. Associations between PM and lung function decrements were significant only in asthmatic children not receiving anti-inflammatory medication. Same day central s

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Turpin et al. (2007)

Study Design: RIOPA Study: 24-h integrated indoor, outdoor, and personal samples collected in 3 cites.

Period: summer 1991-spring 2001

Location: Elizabeth, NJ, Houston, TX, and Los Angeles County, CA

Population: 309 adults and 118 children (89-18)

Indoor Source: NR

Personal Method: PEM on the front strap of a harness near the breathing zone. The bag on the hip contained the pump, battery pack, and motion sensor

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$, in the main living area (not kitchen)

Ambient Size: PM$_{2.5}$, in the front or back yard

Component(s): 18 volatile organics, 17 carbonyl, PM$_{2.5}$ mass and >23 PM$_{2.5}$ species, organic carbon, elemental carbon, and PAHs

Primary Findings: The best estimate of the mean contribution of outdoor to indoor PM$_{2.5}$ was 73% and the outdoor contribution to personal was 26%.

Urch et al. (2004)

Study Design: The study was a crossover design in which each participant received a 2-h exposure to filtered air (FA) and CAP+O$_3$, assigned randomly and on separate occasions. Study objective is to examine the relationship between total and constituent PM$_{2.5}$ mass concentrations and acute vascular response.

Period: 2000-2001 I believe, although this is not explicitly stated.

Location: Downtown Toronto, Canada

Population: 24 young (35 ± 10yr) healthy, nonasthmatic, nonsmoking people

Age Groups: 35 ± 10years

Indoor Source: NR

Personal Method: During exposures a sample was collected immediately upstream to the participant on a 47-mm Gelman Teflon filter with a 2-μm pore size at an airflow of 15 L/min.

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: PM$_{2.5}$

Component(s): Total carbon (elemental carbon, organic carbon), NO$_3$-, SO$_4^{2-}$. NH$_4^+$, K$^+$, Cl-, Ca, Fe, Al, Mg, Zn, Mn, Pb, Cu, Ba, Se, Cr, Ni, V, Ar, Cd all have median, min, and max reported for ambient levels. NO$_3$-, SO$_4^{2-}$. NH$_4^+$ all have median, min, and max reported for directly measured personal exposure levels. Total carbon (elemental carbon, organic carbon), Ca, K$^+$, Fe, Cl-, Al, Mg, Zn, Pb, Mn, Cu, Ba, Se, Cr, Ni, V, Ar, Cd all have median, min, and max reported for estimated personal exposure

Primary Findings: A significant negative association between both the organic and elemental carbon concentrations and the difference in the post-exposure change in the BAD between CAP+O$_3$ and FA exposure days.

Vallejo et al (2006)

Study Design: 4/2002-8/2002

Period: Mexico City, Mexico

Location: Health young, non-smoking adults

Population: Mean age: 27 years

Age Groups: No

Personal Method: pDR nephelometric method (personal DataRam, pDR1200)

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: Mean personal PM$_{2.5}$ level was 74 mg/m^3

Vallejo et al. (2006)

Study Design: Pilot Study

Period: April-August 2002

Location: Mexico City, Mexico

Population: Healthy residents of Mexico City

Age Groups: 21-40 yrs

Indoor Source: NR

Personal Method: The participant carried a personal PM$_{2.5}$ monitor (DataRAM 1200) during a single 13 our period starting at 09:00. Indoor situations included activities at home, at work, at school, or in public places such as theaters, stores, restaurants coffee shops, and subway transportation. Outdoor activities included walking, standing, or sitting in an open space, driving a car or using public transportation (bus or taxi).

Personal Size: NR

Microenvironment Size: PM$_{2.5}$

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: The descriptive analysis showed that overall outdoor median concentration of PM$_{2.5}$ was higher than the indoor one. In the indoor microenvironment, the highest concentrations occurred in the subway followed by the school, and the lowest was at home. The outdoor microenvironment with the highest concentrations was the public transportation (bus), while the automobile had the lowest. It was found that PM$_{2.5}$ concentration levels had a circadian-like behavior probably related to an increase in the population daily activities during the morning hours, which decrease in the evening, especially at indoor microenvironments. The Center city area was found to have the highest concentrations of PM$_{2.5}$.; Multivariate analysis corroborated that PM$_{2.5}$ concentrations are mainly determined by geographical locations and hour of the day, but not by the type of microenvironment.

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van Roosbroeck aet al. (2006)

Study Design: Personal exposure assessment, effect of traffic-related pollutants

Period: March-June 2003
Location: Amsterdam, The Netherlands
Population: Schoolchildren
Age Groups: 9-12-year-olds
Indoor Source: Environmental tobacco smoke, cooking
Personal Method: Integrated filter gravimetric measurement. Light absorbance.
Personal Size: $PM_{2.5}$ absorbance = "soot" ˜ EC (see Notes)
Microenvironment Size: NR
Ambient Size: $PM_{2.5}$ absorbance = "soot" ˜ EC (see Notes)
Component(s): NR
Primary Findings: Children living near busy roads had 35% higher personal exposure to 'soot' than children living in urban background locations.

Van Roosbroeck et.al. (2006)
Study Design: exposure assessment
Period: 9 months (no year provided)
Location: Utrecht, The Netherlands
Population: school children
Age Groups: 10-12 years
Indoor Source: NR
Personal Method: $PM_{2.5}$ GK2.05 cyclones 4 L/min in a custom made backpack; NO_2 and NO_X Ogawa passive samplers
Personal Size: $PM_{2.5}$
Microenvironment Size: NR
Ambient Size: $PM_{2.5}$
Copollutant(s): NO_2
Primary Findings: Increased personal exposure to the traffic-related air pollutants soot and NO_X was seen in children at the Freeway school. No increased personal exposure in any of the studied air pollutants was found for children at Ring School.

Van Roosbroeck et.al. (2006)
Study Design: exposure assessment
Period: 9 months (no year provided)
Location: Utrecht, The Netherlands
Population: school children
Age Groups: 10-12 years
Indoor Source: NR
Personal Method: $PM_{2.5}$ GK2.05 cyclones 4 L/min in a custom made backpack; NO_2 and NO_X Ogawa passive samplers
Personal Size: $PM_{2.5}$
Microenvironment Size: NR
Ambient Size: $PM_{2.5}$
Copollutant(s): NO_X
Primary Findings: Increased personal exposure to the traffic-related air pollutants soot and NO_X was seen in children at the Freeway school. No increased personal exposure in any of the studied air pollutants was found for children at Ring School.

Verma et al. (2003)
Study Design: task-based exposure assessment of current occupational exposures to chemical agents of Ontario construction workers
Period: June 2000
Location: Ontario, Canada
Population: Ontario construction workers
Age Groups: NR
Indoor Source: known source: construction activities
Personal Method: Air samples: personal sampling pumps and collection media. Direct-reading particulate monitor: DustTrak
Personal Size: respirable, inhalable, total, and silica dust; man-made mineral fibers (MMMF)
Microenvironment Size: NR
Ambient Size: NR
Component(s): NR
Primary Findings: Authors state "Ontario construction workers are exposed to potentially hazardous levels of chemical agents."

Vinzents et al. (2005)
Study Design: Panel Study

Period: 3/2003 - 6/2003
Location: Copenhagen, Denmark
Population: Healthy young adults
Age Groups: Mean age = 25 years
Indoor Source: No
Personal Method:
Personal Size: Ultra-fine particles (UFP): Condensation particle counters; (TSI 3007; TSI, St. Paul, MN, USA)
Microenvironment Size: UFP (10–100 nm)
Ambient Size: PM_{10}
Primary Findings: NR

Wallace (2005)

Study Design: Exposure Assessment (Indoor, outdoor air monitoring for concentration of ultrafine particles. To determine indoor source of ultrafine particles - determine the contribution of vented gas clothes dryer)

Period: Not specifically stated. An 18 month period including 2000.

Location: NR

Population: NR

Age Groups: NR

Indoor Source: Vented gas clothes dryer

Personal Method: Scanning mobility particle sizer, differential mobility analyzer, condensation particle counter

Personal Size: NR

Microenvironment Size: Ultrafine (PM 0.01-0.45)

Ambient Size: Ultrafine (PM 0.01-0.45)

Component(s): NR

Primary Findings: Vented gas clothes dryer was determined to be a major source of indoor ultrafine particles. It consistently produced an order of magnitude increase in ultrafine particle concentration compared to times when there was no indoor source.

Wallace and Williams (2005)

Study Design: Cohort

Period: 2000-2001

Location: Raleigh, North Carolina

Population: African-American persons with elevated risk from exposure to particles.

Age Groups: NR

Indoor Source: NR

Personal Method: PEM $PM_{2.5}$ monitor

Personal Size: $PM_{2.5}$

Microenvironment Size: Indoors $PM_{2.5}$

Ambient Size: Outdoors near residence $PM_{2.5}$ $PM_{2.5}$

Component(s): sulfur

Primary Findings: Using outdoor particles to determine the effect on health is not accurate. The infiltration factor is a good estimator for personal exposure. Indoor and outdoor measurements of sulfur could be used in the absence of personal exposure measurement to estimate the contribution of outdoor fine particles to personal exposures.

Wallace et al. (2006)

Study Design: Time series: Continuous monitoring of subjects with controlled hypertension or implanted defibrillators were monitored for 7 consecutive days in 4 seasons.

Period: 2000-2001

Location: North Carolina, probably near Research Triangle Park

Population: Health-compromised adults, non-smokers

Age Groups: adults [range not specified]

Indoor Source: cooking, cleaning, personal care, smoking

Personal Method: PEM

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$; Indoor and outdoor

Ambient Size: NR

Component(s): NR

Primary Findings: Use of continuous particle measuring instruments allowed more precise identification of sources, frequency and magnitude of short-term peaks, and more accurate calculation of individual personal clouds.

Wallace et al. (2003)

Study Design: Inner City Air Pollution (ICAP) study- Randomized controlled trial

Period: NR

Location: Bronx, NY; Manhattan, NY; Boston, MA; Chicago, IL; Dallas, TX; Seattle, WA; Tucson, AZ

Population: Asthmatic children and their residences

Age Groups: 5-11 yrs

Indoor Source: Combustion-related particles: smoking, cooking, use of a wood stove or fireplace, use of candles or incense, gas or kerosene space heaters or stoves.

Personal Method: NR

Personal Size: NR

Microenvironment Size: 0.10 µg - 5 µg; (see note below)

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Geometric mean values of indoor concentrations in the seven locations differed by less than a factor of 2, and the shape of the distributions was very similar across cities, both for the nominal 2-week averages and for hourly averages. The hourly averages exceeded 100 µg/m^3 for at least 2% of all measurements in all cities, and exceeded 1,000 µg/m^3 on at least a few occasions in each city. The most important particle source in these homes was smoking. A second, less powerful source was cooking, particularly frying/ sautéing or reporting a smoky cooking event. Use of incense also led to significant increases in particle concentrations. Dusting frequently also led to higher concentrations, possibly considerably higher than indicated by the pDR because of its lack of sensitivity for coarse particles. Infiltration of outdoor air added about half of the outdoor air concentration to the concentrations produced by the indoor sources, a result similar to that found by previous studies. Most of the observed variance in indoor concentrations was day to day, with roughly similar contributions to the variance from visit to visit and home to home within a city and only a small contribution made by variance among cities. The small variation among cities and the similarity across cities of the observed indoor air particle distributions suggest that sources of indoor concentrations do not vary considerably from one city to the next, and thus that simple models can predict indoor air concentrations in cities having only outdoor measurements. A new finding from this study was the observation that concentrations of fine particles peak in the late evening in homes with smoking, perhaps reflecting the influence of after dinner smoking.

Wang et al. (2006)

Study Design: Exposure assessment, identification of sources of outdoor and indoor PM and trace elements

Period: Aug 4 -Sep 10, 2004

Location: Guangzhou, China

Population: 4 hospitals

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted.

Personal Size: NR

Microenvironment Size: PM_{10}, $PM_{2.5}$

Ambient Size: PM_{10}, $PM_{2.5}$

Component(s): Trace elements: Na, Al, Ca, Fe, Mg, Mn, Ti, K, V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As, Se

Primary Findings: High correlation between $PM_{2.5}$ and PM_{10} suggest that they came from similar emission sources. Outdoor infiltration could lead to direct transportation of PM indoors. Human activities and ventilation types could also influence indoor PM levels.

Ward et al. (2007)

Study Design: Indoor air sampling to determine size fractionated concentrations of PM, OC, EC, and total carbon

Period: Jan-Mar 2005

Location: Libby, Montana

Population: Children exposed to wood-burning stoves in elementary and middle schools

Indoor Source: Burning wood in stoves for heating

Personal Method: NR

Personal Size: NR

Microenvironment Size: PM >2.5, 1.0-2.5, 0.5-1.0, 0.25-0.5, and < 0.25 µm

Ambient Size: PM >2.5, 1.0-2.5, 0.5-1.0, 0.25-0.5, and < 0.25 µm

Component(s): Organic carbon (OC) and elemental carbon (EC) in 5 size fractions: >2.5, 1.0-2.5, 0.5-1.0, 0.25-0.5, and < 0.25 µm

Primary Findings: Total measured PM mass concentrations were much higher inside the elementary schools, with particle size fraction (>2.5, 0.5-1.0, 0.25-0.5, and < 0.25 mm) concentrations between 2 and 5 times higher when compared to the middle school. The 1.0-2.5 mm fraction had the largest difference between the two sites, with elementary school concentrations nearly 10 times higher than the; middle school values.

Weichenthal et al. (2006)

Study Design: Cross-sectional survey comparing heating systems

Period: Dec 2005 - Mar 2006

Location: Montreal, Quebec, Pembroke, Ontario, Canada

Population: NR

Personal Method: Yes, by questionnaire on age/size of home, cleaning frequency, type of stove and other cooking appliances, use of kitchen exhaust fan, number of smokers, burning candles, use of candles, portable heaters, natural gas clothes dryer.

Personal Size: NR

Microenvironment Size: NR

Ambient Size: Ultrafine Particles < 100 nm in diameter, PM_4

Component(s): NR

Primary Findings: Ultrafine Particles < 100 nm in diameter

Weisel et al. (2005)

Study Design: Matched indoor, outdoor, and personal concentrations in proximity to pollution sources.

Period: May 1999-Feb 2001

Location: Elizabeth, NJ, Houston, TX, and Los Angeles County, CA

Population: urban children and adults

Age Groups: Child: 6-19 yrs; Adult: 17-89

Indoor Source: Age of house, recent renovations (< 1 yr), type of home (single, multiple family), attached garage, carpet indoors, local pollution sources.

Personal Method: PEM on a harness with inlet near breathing zone.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: $PM_{2.5}$

Component(s): NR

Primary Findings: Personal $PM_{2.5}$ were significantly higher than indoor and outdoor by one-way ANOVA and Sheffe test ($P< 0.001$).

Wichman et al. (2005)

Study Design: Exposure assessment; Ambient (indoor); Personal

Period: November 29, 1993-March 30, 1994; October 17, 1994-December 22, 1994

Location: Amsterdam, The Netherlands

Population: Adults and schoolchildren living near high-traffic or low-traffic roads.

Age Groups: Adults (50-70 years); Schoolchildren (10-12 years)

Indoor Source: No

Personal Method: Personal impactor

Personal Size: Absorbance coefficient measurements of PM_{10} filter samples

Microenvironment Size: Absorbance coefficient measurements of PM_{10} filter samples

Ambient Size: Absorbance coefficient measurements

Component(s): NR

Primary Findings: Found tentative support for using type of road as a proxy for indoor and personal exposure to traffic-related absorbance (PM).

Williams et al. (2003)

Study Design: Cohort study, longitudinal

Period: summer 2000, fall 2000, winter 2001, and spring 2001

Location: SE Raleigh, North Carolina; Chapel Hill, North Carolina

Population: Elderly persons

Age Groups: = 50 years

Indoor Source: NR, While no smokers were enrolled into the study, 18 participants occasionally recorded passive exposures to environmental tobacco smoke. Since this study attempted to determine the effects of ambient PM upon personal and residential settings, and ETS exposures typically overwhelm ambient contributions, gravimetric values believed to have been heavily influenced by ETS were excluded from the analysis.

Personal Method: A number of filter-based PM monitors widely used in other PM studies were employed here as described below in Table 1.; A nylon vest, matched to the body size of the participant, was used to support and retain all of the personal monitoring equipment. All of the personal monitoring equipment was located in the participants breathing zone (chest area) with the exception of the nephelometer which was secured to the front pocket of the vest with the inlet fully exposed. Each participant was asked to wear the vest at all times with the exception of sleeping, bathing or the changing of clothes. In those instances, they were asked to secure the vest on nearby furniture or fixture. A local State of North Carolina AIRS monitoring platform in Raleigh, NC was selected to serve as the ambient monitoring site.

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$; PM_{10}; $PM_{10-2.5}$

Ambient Size: $PM_{2.5}$; PM_{10}; $PM_{10-2.5}$

Component(s): NR

Primary Findings: No statistical difference in personal $PM_{2.5}$ concentration exposures existed between the two cohorts. Neither seasonality nor community settings were determined to be critical factors in aggregate personal $PM_{2.5}$ exposures in the two subpopulations. $PM_{2.5}$, and to a lesser extent PM_{10}, mass concentrations were determined to be generally homogeneous across a large spatial area. The lack of a seasonal effect observed in the RTP was unexpected due to the historically higher $PM_{2.5}$ levels observed in central North Carolina during the spring and summertime when automotive traffic is highest and regional power plant demands for electricity are greatest (and subsequent release of emissions). $PM_{2.5}$ personal cloud estimates in the current study were in agreement

with those observed in other PM studies involving susceptible subpopulations having more sedentary lifestyles. Mean personal PM$_{2.5}$ exposures in the current study had a moderate Pearson correlation relative to ambient or residential outdoor mass concentrations i

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Wilson and Zewar-Resa (2006)

Study Design: Exposure assessment using Advanced Dispersion Modeling to estimate long-term personal PM exposures in small areas within a city

Period: July 2003 and June 2004 - 2 winter months

Location: Christchurch, New Zealand

Population: urban environments

Age Groups: NR

Indoor Source: NR

Personal Method: No personal exposure assessment was conducted

Personal Size: NR

Microenvironment Size: NR

Ambient Size: PM$_{10}$

Component(s): NR

Primary Findings: Despite the area's high intraurban PM concentration variability and meteorological and topographical complexity, the model performed satisfactorily overall, except for the Mount Pleasant site. The mean of observed measurements across all sites was close t

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Wilson et al. (2006)

Study Design: Exposure assessment; Ambient (outdoor); Ambient (indoor infiltrating from outdoors); Non-ambient (indoor from indoor sources & 'personal cloud')

Period: April-September 1998

Location: Vancouver, Canada

Population: Subjects with physician-diagnosed COPD

Age Groups: 54-86-years-old

Indoor Source: No

Personal Method: Personal: integrated filter gravimetric measurement; TEOM: outdoor ambient

Personal Size: PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: NR

Component(s): NR

Primary Findings: a) Measured ambient PM$_{2.5}$ exposure comprised 71% ambient PM$_{2.5}$ exposure was 71% of measured ambient concentration and 44% of measured total personal exposure; b) Nonambient exposure was independent of ambient exposure; C) Pearson correlations of longitudinal estimated ambient exposure with ambient concentration averaged 0.88 (0.77-0.92).

Wu et al. (2006)

Study Design: Panel study/exposure assessment

Period: 9/3/2002-11/1/2002 (The fall agricultural burning season

Location: Pullman, WA

Population: Asthmatic adults

Age Groups: (mean age = 27y/o, min = 18, max = 52 y/o)

Indoor Source: No

Personal Method: Yes, using two co-located Harvard; Personal Environmental Monitors (HPEM2.5; Harvard School of Public Health, Boston, MA), each connected to its own pump (BGI; AFC 400S, Waltham, MA) operated at 4 L/min

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$

Ambient Size: PM$_{2.5}$

Component(s): levoglucosan (LG); Elemental Carbon (EC); Organic Carbon (OC)

Wu et al. (2005)

Study Design: Panel study with repeated measures

Period: 1999-2000

Location: Alpine, CA

Population: asthmatic children

Age Groups: 9-17 yrs

Indoor Source: No

Personal Method: pDR, continuously and 1-min concentrations (passive), in a fanny pack.

Personal Size: PM$_{2.5}$

Microenvironment Size: PM$_{2.5}$, Home inside & home outside

Ambient Size: PM$_{2.5}$

Component(s): NR

Primary Findings: Personal exposure was higher than those at fixed sites. Subjects received only 45.0% of their exposure indoors at, even though they spent more than 60% of their time there. In contrast, 29.2% of their exposure was received at school where they spent only 16.4% of their time. Thus, exposures in microenvironments with high PM levels where less time is spent can make significant contributions to the total exposure.

Wu et al. (2005)

Study Design: Modeling of individual exposure using ambient data from a 10-year longitudinal study.

Location: Southern California: Lancaster, San Dimas, Upland, Mira Loma, Riverside, Long Beach and Lake Elsinore.

Population: Children

Age Groups: NR

Personal Size: No measurements presented in this study

Microenvironment Size: NR

Yeh and Small (2002)

Study Design: comparative assessment of AME and IES models

Period: 1997 (364 days) spring: March-May, summer: June-August, Fall: September-November, winter: December-February

Location: Los Angeles County, CA

Population: general population; ETS and Non ETS Homes

Age Groups: NR

Indoor Source: Indoor Cooking, ETS, Other sources and unexplained particulates that maybe generated with engaging in various activities

Personal Method: NR

Personal Size: PM$_{10}$ PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: PM$_{10}$ PM$_{2.5}$

Component(s): NR

Primary Findings: Adjusting from outdoor concentrations to personal exposures and correcting dose-response bias are nearly equal. Roughly the same premature mortalities associated with short-term exposure to both ambient PM$_{2.5}$ and PM$_{10}$ are predicted by both models

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Population: general population; ETS and Non ETS Homes

Age Groups: NR

Indoor Source: Indoor Cooking, ETS, Other sources and unexplained particulates that maybe generated with engaging in various activities

Personal Method: NR

Personal Size: PM$_{10}$ PM$_{2.5}$

Microenvironment Size: NR

Ambient Size: PM$_{10}$ PM$_{2.5}$

Component(s): NR

Primary Findings: Adjusting from outdoor concentrations to personal exposures and correcting dose-response bias are nearly equal. Roughly the same premature mortalities associated with short-term exposure to both ambient PM$_{2.5}$ and PM$_{10}$ are predicted by both models

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Location: Los Angeles County, CA

Population: general population; ETS and Non ETS Homes

Age Groups: NR

Indoor Source: Indoor Cooking, ETS, Other sources and unexplained particulates that maybe generated with engaging in various activities

Personal Method: NR

Personal Size: PM$_{10}$

Microenvironment Size: NR

Ambient Size: PM$_{10}$

Component(s): NR

Primary Findings: Adjusting from outdoor concentrations to personal exposures and correcting dose-response bias are nearly equal. Roughly the same premature mortalities associated with short-term exposure to both ambient PM$_{2.5}$ and PM$_{10}$ are predicted by both models

Yip et al. (2004)

Study Design: A panel study with repeated measures with personal & home monitoring for 8 2-week periods. Children were stratified into smoking and non-smoking households.

Period: 2000-2001

Location: Detroit, Michigan

Population: School-age children with asthma

Age Groups: 7-11 yrs

Personal Method: PEM in a backpack

Personal Size: PM_{10}

Microenvironment Size: PM_{10}; indoor at home & indoor at school

Ambient Size: PM_{10}

Component(s): NR

Primary Findings: Personal PM concentrations were significantly correlated with home environment (r = 0.38 to 0.70), with the strongest relationships in home with non-smokers.

Zhang et al. (2005)

Study Design: Several co-located instruments were used to simultaneously sample air at the Pittsburgh EPA Supersite for 15 days

Period: 7-22 Sep 2002

Location: Pittsburgh, Pennsylvania

Population: urban population

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: NR

Microenvironment Size: NR

Ambient Size: Nonrefractory-PM_1

Component(s): Sulfate, Ammonium, Nitrate, Organics, Chloride

Primary Findings: Reasonably good agreement was observed on particle concentrations, composition, and size distributions between the AMS data and measurements from co-located instruments (given the difference between the PM_1 and $PM_{2.5}$ size cuts), including TEOM, semicontinuous sulfate, 2-h- and 24-h-averaged organic carbon, SMPS, 4-h-averaged ammonium, and micro-orifice uniform deposit impactor.

Zhao et al. (2006)

Study Design: aerosol source apportionment under four environments (personal, residential indoor, residential outdoor and ambient) to evaluate the relationship between different environments through exposure analysis, and to demonstrate the utility of the combined receptor model on air quality studies of various environments.

Period: June 2000 to May 2001

Location: Raleigh and Chapel Hill, NC

Population: NR. People with respiratory ailments most likely.

Age Groups: NR

Indoor Source: Yes (4 main sources to residential indoor PM: Cu-factor mixed with indoor soil, secondary sulfate, Personal care and activity, ETS and its mixture)

Personal Method: Personal Exposure Monitors (PEM) and Harvard Impactor monitors (HI)

Personal Size: NR

Microenvironment Size: NR

Ambient Size: NR

Component(s): OC, EC, and elements

Primary Findings: As per the authors "Secondary sulfate was the largest source for both residential outdoor and ambient PM. Cooking and personal care activity were two major internal sources for personal and residential indoor PM samples. In this study, secondary sulfate and motor-vehicle emission contributed significantly to the personal and residential indoor PM.

Zhao et al. (2007)

Study Design: Comprehensive analysis of the sources of PM_{15} exposure on children with moderate to severe asthma in urban-poor settings.

Period: two winter periods (October 2002-March 2003 and October 2003-March 2004)

Location: Elementary school for children with significant asthma, Denver, CO

Population: Schoolchildren in urban-poor settings suffering from moderate to severe asthma

Age Groups: 6 - 13 years (60% in the range 10-13 years, rest in the range 6-9 years)

Indoor Source: Yes, House cleaning compounds, and smoking were identified as primary internal sources.

Personal Method: Personal Exposure Monitor (PEM)

Personal Size: $PM_{2.5}$

Microenvironment Size: $PM_{2.5}$

Ambient Size: PM$_{2.5}$

Component(s): EC, Cl, Si, NO$_3$

Primary Findings: Four external sources and three internal sources were resolved in this study. Secondary nitrate and motor vehicle were two major outdoor PM$_{2.5}$ sources. Cooking was the largest contributor to the personal and indoor samples. Indoor environmental tobacco smoking also has an important impact on the composition of the personal exposure samples.

Zhu et al. (2005)

Study Design: 4 apartments near the freeway were monitored at 2 times for 6 consecutive days, 24 h per day. Subjects did not enter the bedrooms where the samplers were, no cooking, cleaning, children, or pets.

Period: Oct. 2003-Dec. 2003 and Dec. 2003-Jan. 2004

Location: Los Angles, CA

Population: Urban populations near major freeways.

Age Groups: NR

Indoor Source: NR

Personal Method: NR

Personal Size: Indoor and Outdoor ultrafine particles (6-220 nm)

Microenvironment Size: NR

Component(s): CO

Primary Findings: The size distributions of indoor aerosols showed less variability than the adjacent outdoor aerosols. Indoor to outdoor ratios for ultrafine particle concentrations depended strongly on particle size. I/O ratios were dependent on the indoor ventilation mechanisms applied. Size-dependent particle penetration factors and deposition rates were predicted from data by fitting a dynamic mass balance model.

Zöllner et al. (2007)

Study Design: PM exposure was investigated in and outside of schools

Period: Winter period of 2005 and 2006

Location: Baden-Wuerttemberg, Germany

Population: School children

Age Groups: NR

Personal Method: No personal monitoring done. PM$_{2.5}$ was collected with filter device LVS 6.01 and analyzed gravimetrically; fifteen particle fractions (0.30 μm to >20 μm) were recorded with laser particle counters; >0.02 μm particles were recorded using condensation particle counters

Personal Size: NR

Microenvironment Size: They only reported concentrations for PM$_{2.5}$. PM 0.02 to >20 were collected and analyzed but only PM$_{2.5}$ concentration were reported.

Ambient Size: They only reported concentrations for PM$_{2.5}$. PM 0.02 to >20 were collected and analyzed but only PM$_{2.5}$ concentration were reported.

Primary Findings: 1. The impaction of PM was strongly influenced by specific weather conditions 2) Time resolution of measurements in classrooms showed variation in particle concentration depending on the type of building and indoor activities 3)Concentrations of very small particles indoors and in ambient air measured by condensation particle counter were influenced by traffic emissions.

Table A-56.   Examples of studies showing developments with UFP sampling methods since the 2004 PM AQCD.

Reference	PM Size Ranges	PM Constituents	Instruments	Primary Findings
Biswas et al. (2005)			CPC (water)	Water-based CPC performance eval
Feldpausch et al. (2006)	20 – 100 nm	Carbonaceous aerosols	DS with CPC, compared with DMA	The DS with CPC compared fairly well with the DMA for particle sizes up to 40 nm with 20 – 40% underestimation depending on discharge frequency settings. The DS sampling period is 3 – 5 s in comparison with the 1 min scanning time of the DMA.
Hering et al. (2005)			CPC (water)	Water-based CPC performance eval
Herrmann et al. (2007)	3 – 40 nm	Ag, NaCl	CPC (water and butanol)	Roughly 95% collection efficiency for d >5 for TSI models 3776 and 3786, 95% efficiency for d >20 nm for model 3775, near 90% efficiency for d>20 nm for model 3785, near 90% efficiency for d >25 nm for model 3772.
Kinsey et al. (2006)	10 nm – 5 μm	DE	TEOM, SMPS, CPC, DustTrak, E-BAM, ELPI, integrated filter samples	TEOM best comparison with gravimetric filter among mass concentration analyzers, ELPI and SMPS comparable for differential number distribution but ELPI not useful for gravimetric analysis because mass is not significant at small end of distribution.

Reference	PM Size Ranges	PM Constituents	Instruments	Primary Findings
Kulmala et al. (2005)			CPC	Changing temperature difference between saturator and condenser within CPC allowed for differences in cut-off diameters.
Kulmala et al. (2007)	2 – 20 nm	Atmospheric aerosol, Ag	Battery of CPCs (water, butanol, n-butanol)	Used the battery to discriminate between water-soluble, water-insoluble, butanol-soluble, and butanol-insoluble nucleation-mode particles
Ntziachristos and Samaras (2006)	7 nm – 1 µm	Automobile exhaust	5 instruments used simultaneously to reduce uncertainty: Teflon-coated filter downstream of constant volume sampling, ELPI with thermodenuder, CPC, SMPS, diffusion charger	Use of four reduced variables combining output from all instruments (ratio of particle number concentration from CPC and ELPI, estimated mean geometric mobility diameter from signal of diffusion charger and number concentration from CPC, ratio of signal of diffusion charger to constant volume sampler mass, ratio of constant volume sampler mass to volume collected by ELPI) resulted in identification of clear outliers and factors related to driving and fuel properties rather than measurement errors.
Olfert et al. (Olfert et al.)	30 – 100 nm	NaCl, ambient	FIMS (compared with SMPS)	Particle number concentrations reported by the FIMS were 8 – 23% higher than the SMPS using an inversion technique designed to correct for particle residence time in the FIMS, which operates at 0.1 s resolution.
Petäjä et al. (2006)			CPC (water)	Water-based CPC performance eval
Winkler et al. (2008)	1.5 – 4 nm	Tungsten oxide	CPC (n-Propanol)	Authors remove excess charge on particles with ion trap to detect particles down to ~ 1 nm (by eliminating electrostatic attraction to agglomerate).

Table A-57. Summary of in-vehicle studies of exposure assessment.

Reference	Study Design	Mode of Transport	Exposures			Primary Findings
Rossner et al. (2008)	Measured PM$_{2.5}$ exposure of 50 city bus drivers and 50 controls in Prague, Czech Republic using personal samplers (type not specified) and VOCs using passive samplers. PM$_{2.5}$ filters analyzed for c-PAHs. Focus of study is oxidative stress biomarkers in drivers. Study period: winter 2005, summer 2006, winter 2006.	Bus	Units: ng/m^3 winter 2005: 　　Bus　　Control c-PAH　7.1 (3.7)　9.4 (5.5) B[a]P　1.3 (0.7)　1.8 (1.0) summer 2006: 　　Bus　　Control c-PAH　1.8 (0.5)　2.0 (0.8) B[a]P　0.2 (0.1)　0.3 (0.2) winter 2006: 　　Bus　　Control c-PAH　5.4 (3.5)　4.1 (1.7) B[a]P　1.0 (0.5)　0.8 (0.4)			c-PAH and B[a]P exposure to bus drivers was significantly higher in Winter 2006, but control exposure was significantly higher in Winter 2005 for c-PAH and B[a]P and in summer 2006 for c-PAH. No significant difference in VOC exposure between bus drivers and controls was observed. Oxidative stress markers were significantly higher in bus drivers than controls for all seasons.
Fruin et al. (2008); Westerdahl et al. (2005) [Note: same data presented.]	On-road zero emissions vehicle driven on 33-mi arterial road and 75-mi freeway was equipped measured UFP (CPCs, SMPS, EAD), BC (aethalometer), NO$_X$ (chemiluminescence), PM-bound PAHs (UV-photoionization), CO (Q-Trak). DVD analysis of traffic density and car speed. Study Period: Feb-Apr 2003 for 2- to 4-h periods.	Car	Arterial range of medians: UFP (1000p/cm^3)　13-43 PM$_{2.5}$ (µg/m^3)　7.9-45 BC (µg/m^3)　0.74-3.3 Freeway range of medians: UFP (1000p/cm^3)　47-190 PM$_{2.5}$ (µg/m^3)　25-110 BC (µg/m^3)　2.4-13			Measurements of freeway UFP, BC, PM-bound PAH, and NO concentrations were roughly one order of magnitude higher than ambient measurements. Multiple regression analysis suggests these concentrations were a function of truck density and total truck count. (Only PM measurements reported here).

Reference	Study Design	Mode of Transport	Exposures	Primary Findings
Briggs et al. (2008)	UFP (P-Trak) and PM_{10}, $PM_{2.5}$, and PM_1 (OSIRIS light scatter) were operated in a car while driving or walking on one of 48 routes in London. Trips ranged 1.5-15 min by car and were repeated up to 5 times to improve statistics. Study Period: Weekdays in May and June 2005.	Car Walking	Units: PM_1 – PM_{10} ($\mu g/m^3$), UFP (p cm-3) Avg Car Exposure: PM_{10} 5.87 (3.09) $PM_{2.5}$ 3.01 (1.10) PM_1 1.82 (1.10) UFP 21639 (14379) Avg Walking Exposure: PM_{10} 27.56 (13.16) $PM_{2.5}$ 6.59 (3.12) PM_1 3.37 (3.40) UFP 30334 (17245)	In-car concentrations of $PM_{2.5}$, PM_1, and UFP correlated well with walking concentrations (R = 0.806, 0.800, 0.799 respectively). Avg walking concentrations were 1.4 – 4.7 times higher than avg in-car concentrations. Cumulative walking exposures (not shown here) were 4.4 – 15.2 times higher than those in cars, likely resulting from longer transit times for walking.
Gomez-Perales et al. (2007)	$PM_{2.5}$ (personal filter pump), CO (T15 electrochemical cell), and benzene (canister) were measured on transit routes, and $PM_{2.5}$ filters were analyzed for mass, OC/EC, SO_4^{2-}, NO_3^-, and trace metals. Study period: 3-h morning and evening rush hour Jan – March 2003	Bus Minibus Metro	Units: $PM_{2.5}$ mass ($\mu g/m^3$), components (% of mass) Bus: $PM_{2.5}$ 20-58 $(NH_4)NO_3$ 5-8 $(NH_4)_2SO_4$ 10-18 OC 17-39 EC 8-20 Crustal 15-18 Non-crustal 2-3 Unknown 6-24 Minibus: $PM_{2.5}$ 25-55 $(NH_4)NO_3$ 4-13 $(NH_4)_2SO_4$ 7-22 OC 22-37 EC 9-19 Crustal 12-13 Non-crustal 3-3 Unknown 4-26 Metro: $PM_{2.5}$ 24-41 $(NH_4)NO_3$ 5-8 $(NH_4)_2SO_4$ 10-21 OC 35-42 EC 9-13 Crustal 10-16 Non-crustal 2-4 Unknown 5-20	Buses and minibuses had similar concentration levels for $PM_{2.5}$ mass, and metro exposures were lower. CO and benzene concentrations were higher on minibuses than buses. OC was the largest PM constituent for all modes of transport. Measured concentrations were higher in the morning than in the evening rush hour periods. Maximum historical wind speeds (1995-2003) appeared to be inversely associated with measured concentration.

Reference	Study Design	Mode of Transport	Exposures				Primary Findings

Reference	Study Design	Mode of Transport	Exposures	Primary Findings
Diapouli et al. (2007)	UFP (CPC) concentrations were measured at school, residential, and in-vehicle environments in Athens, Greece. Study Period: school hours, Nov 2003 – Feb 2004 and Oct – Dec 2004	"In-vehicle" (not specified)	15-min median (1000p/cm^3): School indoor — 13.6 School outdoor — 16.6 Residence indoor — 11.2 Residence outdoor — 24.0 In-vehicle — 78.0	In-vehicle UFP concentrations were roughly 3.5 – 7 times higher than school or residence concentrations. Indoor concentration diel patterns were also shown to follow outdoor levels, which suggests that indoor levels are of outdoor origin.
Gulliver and Briggs (2007)	TSP, PM$_{10}$, PM$_{2.5}$, and PM$_1$ sampled (OSIRIS light-scatter devices) in a car while driving or walking on one of 48 routes in London. Trips ranged 1.5-15 min by car and were repeated up to 4 times to improve statistics. Study Period: Jan – Mar 2005.	Car Walk	Mean conc (µg/m^3): Walk Car BG TSP-PM$_{10}$ 19.1 (19.8) 18.2 (18.0) 4.9 (5.1) PM$_{10-2.5}$ 22.1 (22.8) 15.1 (14.2) 10.0 (9.0) PM$_{2.5-1}$ 10.9 (10.4) 8.3 (8.4) 7.6 (7.1) PM$_1$ 4.8 (3.4) 2.9 (2.6) 4.2 (2.4)	Walking exposures larger than car and background, and car exposures were generally larger than background except for PM$_1$. Peak exposures during walking were significantly higher than peak in-car exposures.

Sabin et al. (2005)	BC (aethalometer), particle-bound PAH (UV-photoionization), and NO (luminol reaction) were measured on 3 diesel school buses, 1 diesel school bus with a particle trap, and one compressed gas bus during before- and after-school commutes. Study Period: May – June 2002.	School bus (diesel, diesel with particle trap (TO), compressed gas (CNG))	In-bus mean concentration, Units: BC (µg/m^3), PAH (ng/m^3)
			Windows closed:
			
			    BC PAH
			BG 2.5 27
			CNG 2.3 57
			TO 7.1 190
			diesel 11 290
			
			Windows open:
			
			    BC PAH
			BG 1.9 26
			CNG 1.5 43
			TO 2.3 42
			diesel 3.9 58
				Mean concentrations on diesel buses without newer emissions control technologies were 2 – 4.4 times higher than background. On buses with particle traps, concentrations were 1.2 – 2.5 times higher than background, while concentrations on compressed gas-fueled school buses were actually lower than background.

Gulliver and Briggs (2004)	PM$_{10}$, PM$_{2.5}$, and PM$_1$ sampled (OSIRIS light-scatter devices) in a car while driving or walking on northern corridor of Northhampton UK. Study Period: 1-h interval of morning and evening rush hour during Winter 1999 – 2000.	Car Walk	Walk Car BG PM$_{10}$ 38.2 43.2 26.6 PM$_{2.5}$ 15.1 15.5 PM$_1$ 7.1 7.0	In-car PM$_{10}$ concentrations were elevated compared with walking and background. PM$_{2.5}$ and PM$_1$ concentrations were comparable for walking and background. Periods of elevated PM$_{2.5}$ compared with PM$_{10}$ generally corresponded to times when SO$_4^{2-}$ levels were also high.

Gomez-Perales et al. (2004)	PM$_{2.5}$ (personal filter pump), CO (T15 electrochemical cell), and benzene (canister) were measured on transit routes, and PM$_{2.5}$ filters were analyzed for mass, OC/EC, SO$_4^{2-}$, NO$_3^-$, and trace metals.
	Study period: 3-h morning and evening rush hour May – June 2002
		Bus
		Minibus
		Metro
			PM$_{2.5}$ (µg/m^3):
			
			  Bus 68
			  Minibus 71
			  Metro 61
				Generally, PM$_{2.5}$ concentration was higher in the morning than evening rush hour, but variability was higher for minibuses than other modes of transport. Wind speed was found to be associated with PM$_{2.5}$ concentration on minibuses.

Table A-58. Summary of personal PM exposure studies with no indoor source during 2002-2008.

Reference	Location	Personal		Micro		Ambient	
SOUTH WEST							
Delfino, RJ et al. Riverside and Whittier, California		Method: PEM Riverside:				Method: FRM Riverside:	
		n	13			24-h $PM_{2.5}$	36.63 (23.46)
		24-h $PM_{2.5}$	32.78 (21.84)			24-h PM_{10}	70.82 (29.36)
		1-h max $PM_{2.5}$	97.94 (70.29)				
		8-h max $PM_{2.5}$	47.21 (30.0)			Whittier:	
						24-h $PM_{2.5}$	18.0 (12.14)
		Whittier:				24-h PM_{10}	35.73 (16.6)
		n	32				
		24-h $PM_{2.5}$	36.2 (21.84)				
		1-h max $PM_{2.5}$	93.63 (75.19)				
		8-h max $PM_{2.5}$	51.75 (36.88)				
Delfino, RJ et al.	Alpine, California	Method: pDR		Method: HI		Method: TEOM	
		Last 2-h $PM_{2.5}$	34.4 (33.7)	Indoor 24-h PM_{10}	30.3 (11.9)	Diurnal PM_{10}	35.1 (11.3)
		Diurnal $PM_{2.5}$	55.7 (31.6)	Indoor 24-h $PM_{2.5}$	12.1 (5.4)	Nocturnal PM_{10}	23.3 (8.4)
		Nocturnal $PM_{2.5}$	22.3 (13.6)	Outdoor 24-h PM_{10}	25.9 (10.4)	1-h max PM_{10}	54.4 (13.8)
		1-h max $PM_{2.5}$	151.0 (120.3)	Outdoor 24-h $PM_{2.5}$	11.0 (5.4)	4-h max PM_{10}	44.5 (12.4)
		4-h max $PM_{2.5}$	87.5 (55.3)			8-h max PM_{10}	39.8 (11.2)
		8-h max $PM_{2.5}$	67.6 (39.0)			24-h PM_{10}	23.6 (9.1)
		24-h $PM_{2.5}$	37.9 (19.9)			24-h $PM_{2.5}$	10.3 (5.6)
Wu, CF et al. 2005	Alpine, CA	Method: pDR		Method: pDR		Method: pDR	
		n	11	n	14	n	8
		Avg of 24-h $PM_{2.5}$	11.4 (7.8)	Avg of 24-h $PM_{2.5}$	5.6 (2.9)	Avg of 24-h $PM_{2.5}$	14.0 (11.4)
				Method: HI		Method: HI	
				n	14	n	8
				Avg of 24-h $PM_{2.5}$	9.8 (2.5)	Avg of 24-h $PM_{2.5}$	14.3 (7.8)
Turpin, BJ et al.	Los Angeles County, CA (and Elizabeth, NJ, Houston, TX)	Method: PEM Avg of 48-h $PM_{2.5}$		Method: HI Avg of 48-h $PM_{2.5}$: 16.2		Method: HI Avg of 48-h $PM_{2.5}$: 19.2	
		Child	40.2				
		Adult	29.2				
NORTH WEST							
Jansen et al. (2005)	Seattle, Washington, USA	Method: PM Results		Method: HI Indoor home:		Method: HI	
				PM_{10}	11.93	PM_{10}	18.0
				$PM_{2.5}$	7.29	$PM_{2.5}$	14.0
				Outdoor home:			
				PM_{10}	13.47		
				$PM_{2.5}$	10.47		

Reference	Location	Personal		Micro		Ambient	
Mar et al. (2005)	Seattle, WA USA	Method: HI PM$_{2.5}$:		Method: HI PM$_{2.5}$:		Method: HI PM$_{2.5}$:	
		Healthy:	9.3 (8.4)	Healthy:	7.4 (4.8)	Healthy:	9.0 (4.6)
		CVD:	10.8 (8.4)	CVD:	9.5 (6.8)	CVD:	12.7 (7.9)
		COPD:	10.5 (7.2)	COPD:	8.5 (5.1)	COPD:	9.2 (5.1)
				PM$_{10}$:		PM$_{10}$:	
				Healthy:	12.7 (7.8)	Healthy:	14.5 (7.0)
				CVD:	16.2 (11.3)	CVD:	18.0 (9.0)
				COPD:	14.1 (6.6)	COPD:	14.3 (6.8)
Wu CF et al. 2006	Pullman, WA	During non-burning times: 13.8 (11.1) During burning episodes: 19.0 (11.8)					
Trenga CA et al, 2006	Seattle, Washington	Method: PEM Median PM$_{2.5}$		Method: HI Median PM$_{2.5}$		Method: HI Residential Outdoor Median PM$_{2.5}$	
		Child	11.3	Child	7.5	Child	9.6
		Adult	8.5	Adult	7.6	Adult	8.6
						Residential Outdoor Median PMcoarse	
						Child	4.7
						Adult	5.0
						Residential Outdoor Median PM$_{2.5}$ central site	
						Child	11.2
						Adult	10.3
Koenig, J.Q. et al	Seattle, WA	13.4 ± 3.2 µg/m³		Inside homes = 11.1 ± 4.9		Outside homes = 13.3 ± 1.4 3 Central-sites = 10.1 ± 5.7	
Liu, S., et al	Seattle, WA	Summary of PM concentrations (µg/m³) between October 1999 and May 2001 by study group. Group Mean ± SD Personal PM$_{2.5}$ COPD 10.5 ± 7.2 Healthy 9.3 ± 8.4 Asthmatic 13.3 ± 8.2 CHD 10.8 ± 8.4		Summary of PM concentrations (µg/m³) between October 1999 and May 2001 by study group. Group Mean ± SD Indoor PM$_{2.5}$ COPD 8.5 ± 5.1 Healthy 7.4 ± 4.8 Asthmatic 9.2 ± 6.0 CHD 9.5 ± 6.8 PM$_{10}$ COPD 14.1 ± 6.6 Healthy 12.7 ± 7.8 Asthmatic 19.4 ± 11.1 CHD 16.2 ± 11.3		Summary of PM concentrations (µg/m³) between October 1999 and May 2001 by study group. Location Pollutant Group Mean ± SD Outdoor PM$_{2.5}$ COPD 9.2 ± 5.1 Healthy 9.0 ± 4.6 Asthmatic 11.3 ± 6.4 CHD 12.7 ± 7.9 PM$_{10}$ COPD 14.3 ± 6.8 Healthy 14.5 ± 7.0 Asthmatic 16.4 ± 7.4 CHD 18.0 ± 9.0	

SOUTH CENTRAL

Reference	Location	Personal		Micro		Ambient	
Turpin, BJ et al.	Houston (and Elizabeth, NJ, and Los Angeles County, CA)	Houston Child: 36.6 Adult: 37.2		Houston: 17.1		Houston: 14.7	

MID-WEST

Reference	Location	Personal		Micro		Ambient	
Sarnat SE et al	Steubenville, OH	Mean (SD): PM$_{2.5}$ Summer n = 169 mean (SD) = 19.9 (9.4) Fall mean (SD) = 20.1 (11.6)				Mean (SD): PM$_{2.5}$ Summer n = 65 mean (SD) = 20.1 (9.3) Fall mean (SD) = 19.3 (12.2)	

Reference	Location	Personal	Micro	Ambient
Adgate, JL et al. 2002	Battle Creek, East St. Paul, and Phillips, Minnesota, constituting the Minneapolis-St. Paul metropolitan area.	Battle Creek All Seasons: 118, 22.7, (25.7), 16.2 (2.2) Spring: 41, 26.3 (25.7), 19.4 (2.1) summer: 31, 28.5 (36.1), 20.3 (2.1) Fall 46, 15.5 (13.4), 11.9 (2.1) E. St. Paul All Seasons: 107, 30.5 (38.7), 20.6 (2.3) Spring: 44, 33.9 (34.4), 23.9 (2.3) summer: 25, 20.5 (15.0), 17.2 (1.8) Fall: 38, 33.1(51.9), 19.5 (2.5) Phillips All Seasons: 107, 26.5 (24.3), 20.9 (2.0) Spring: 28, 37.5 (37.6), 30.0 (1.8) summer: 40, 22.7 (15.3), 19.2 (1.7) Fall: 39, 22.7 (16.7), 17.6 (2.1)	Battle Creek All Seasons: 108, 10.6 (6.6), 9.0 (1.8) Spring: 25, 12.7 (7.7), 11.0 (1.7) summer: 36, 8.9 (3.8), 8.1 (1.5) Fall: 47, 10.9 (7.4), 8.8 (2.0) E. St. Paul All Seasons: 97, 17.4 (20.3), 12.2 (2.2) Spring: 30, 20.7 (26.4), 13.6 (2.4) summer: 26, 15.8 (11.4), 13.7 (1.6) Fall 41 16.0 19.6 10.4 2.4 Phillips All Seasons: 89, 14.2 (13.0), 11.3 (1.9) Spring: 15, 16.9 (14.2), 13.0 (2.1) summer: 36, 13.2 (6.4), 11.4 (1.7) Fall: 38,14.4 (16.7), 10.6 (2.0)	Battle Creek All Seasons: 88 9.4 (6.2), 7.8 (1.8) Spring: 36, 10.5 (7.1), 8.5 (2.0) summer: 22, 8.7 (4.4), 7.8 (1.6) Fall: 30, 8.4 (6.2), 7.1 (1.7) E. St. Paul All Seasons: 95, 10.8 (6.6), 9.3 (1.8) Spring: 36, 12.0 (7.3), 10.1 (1.9) summer: 25, 8.5 (3.2), 7.8 (1.6) Fall: 34, 11.3 (7.5), 9.6 (1.8) Phillips All Seasons: 88, 10.0 (5.8), 8.7, (1.7) Spring: 30 (12.1), 7.2 (10.5) summer: 30, 8.6 (3.8), 7.8 (1.6) Fall: 28, 9.3 (5.5), 8.1 (1.7)
Crist et al	Ohio River Valley near Columbus	Athens (rural): 17.61 (17.81) Koebel (urban): 14.59 (13.05) New Albany (suburb): 13.93 (12.25)	Indoor Athens (rural): 17.20 (13.56) Koebel (urban): 14.98 (12.30) New Albany (suburb): 16.52 (13.53)	Outdoor Athens (rural): 13.66 (8.91) Koebel (urban): 13.89 (9.29) New Albany (suburb): 12.72 (8.86)

SOUTH EAST

Reference	Location	Personal	Micro	Ambient
Wallace and Williams (2005)	Raleigh, North Carolina	$PM_{2.5}$ pers = 23.0 (16.4) $PM_{2.5}$ pers/$PM_{2.5}$ out = 1.31 (0.99)	$PM_{2.5}$ in = 19.4 (16.5) $PM_{2.5}$ in/$PM_{2.5}$ out = 1.08 (1.05)	$PM_{2.5}$ out = 19.5 (8.6) 18.1 (8.1)
Williams, R. et al., 2003	SE Raleigh, North Carolina Chapel Hill, North Carolina	Pooled PM mass concentrations ($\mu g/m^3$) across all subjects, residences, seasons, and cohorts Variable N Geo mean Mean RSD(a) Personal $PM_{2.5}$ (b) 712 19.2 23.0 70.1 (a) Relative standard deviation of the presented arithmetic mean. (b)Measured using PEMs.	Pooled PM mass concentrations ($\mu g/m^3$) across all subjects, residences, seasons, and cohorts Variable N Geo mean Mean RSD(a) Indoor $PM_{2.5}$ (c) 761 15.3 19.1 80.1 Outdoor $PM_{2.5}$ (c) 761 17.5 19.3 43.7 Indoor PM_{10}(b) 761 23.2 27.7 70.6 Outdoor PM_{10}(b) 761 27.5 30.4 46.4 Indoor PM_{10} 2.5(d) 761 6.3 8.6 111.8 Outdoor PM_{10} 2.5(d) 761 8.5 11.1 86.9 (a) Relative standard deviation of the presented arithmetic mean. (b)Measured using PEMs. (c)Measured using HI samplers. (d)Measured by difference in PEM PM_{10} monitor and co-located HI $PM_{2.5}$ mass concentrations.	Pooled PM mass concentrations ($\mu g/m^3$) across all subjects, residences, seasons, and cohorts Variable N Geo mean Mean RSD(a) Ambient $PM_{2.5}$ (c) 746 17.3 19.2 44.9 Ambient PM_{10}(b) 752 27.9 31.4 51.5 Ambient $PM_{10-2.5}$(d) 210 8.6 10.0 62.3 (a) Relative standard deviation of the presented arithmetic mean. (b)Measured using PEMs. (c)Measured using HI samplers. (d)Measured by difference in PEM PM_{10} monitor and co-located HI $PM_{2.5}$ mass concentrations.

Reference	Location	Personal	Micro	Ambient

NORTH EAST

Reference	Location	Personal	Micro	Ambient
Koutrakis et al. (2005)	Baltimore, MD Boston, MA	$PM_{2.5}$: (Baltimore, Boston) Winter: Seniors: 15.1 (14.6), 14.1 (6.0) Children: 24.0 (21.8), 18.5 (12.8) COPD: 16.4 (12.7), NR Summer: Seniors: 22.1 (10.1), 18.8 (9.7) Children: 18.6 (8.1), 30.3 (14.2) COPD: NR, NREC: (Baltimore, Boston) Winter: Seniors: NR, 1.4 (0.9) Children: 2.8 (1.8), 1.6 (1.6) COPD: 2.0 (1.2), NR Summer: Seniors: NR, NR Children: NR, NR COPD: NR, $NRSO_4$: (Baltimore, Boston) Winter: Seniors: 1.9 (1.1), 1.9 (1.2) Children: NR, 2.3 (1.7) COPD: 1.5 (0.8), NR Summer: Seniors: 5.7 (3.5), 2.9 (1.9) Children: NR, NR COPD: NR, NR		$PM_{2.5}$: (Baltimore, Boston) Winter: All: 20.1 (9.4), 11.6 (6.8) summer: Seniors: 25.2 (11.5), 12.7 (5.4) Children: 23.2 (14.0), 17.0 (11.5) COPD: NR, NREC: (Baltimore, Boston) Winter: All: 1.2 (0.6) summer: NR, $NRSO_4$: (Baltimore, Boston) Winter: All: 4.0 (1.7), 3.1 (1.8) summer: Seniors: 10.5 (7.1), 3.1 (1.8) Children: NR, 6.5 (6.0)
Turpin, BJ et al.	Elizabeth, NJ, (and Houston, TX, and Los Angeles County, CA+	Elizabeth Child: 54.0 Adult: 44.8	Elizabeth: 20.1	Elizabeth 20.4
Sarnat, JA et al.	Boston, Massachusetts. Comparisons to a previous study in Baltimore are made.	Winter-Children: $PM_{2.5}$: 17.4-25.8 SO_4: 1.6-3.3 Winter-Seniors: $PM_{2.5}$: 10.8-16.2 SO_4: 1.6-2.6 Summer-Children $PM_{2.5}$: 25.4-32.8 SO_4: 2.7-3.3 Summer-Seniors $PM_{2.5}$: 17.8-20.5 SO_4: 2.7-3.3	NR	Winter: $PM_{2.5}$: 6.5-15.5 SO_4: 1.7-4.2 Summer: $PM_{2.5}$: 11.9-21.4 SO_4: 3.6-9.0

Table A-59.   Summary of PM species exposure studies.

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Gadkari et al. (2007)	Personal: RPM Micro: NR Ambient: RPM	Fe, Ca, Mg, Na K, Cd, Hg, Ni, Cr, Zn, As, Pb, Mn and Li	Source contributions varied widely among 12 sites. Indoor: 0-95% Ambient: 0-26% Road: 0-94% Soil: 0-75%	Authors conclude that "(1) indoor activities and poor ventilation qualities are responsible for major portion of high level of indoor RPM, (2) majority of personal RPM is greatly correlated with residential indoor RPM, (3) time–activity diary of individuals has much impact on relationship investigations of their personal RPM with their respective indoor and ambient-outdoor RPM levels as reported in earlier reports and (4) residential indoors, local road-traffic and soil-borne RPMs are the dominating routes of personal exposure compared to ambient outdoor RPM levels.
Koistinen et al. (2004)	Personal, Micro, and Ambient: $PM_{2.5}$	Black smoke, SO_4^{2-}, NO_3^-, NH_4^+, Al, Ca, Cl, Cu, K, Mg, P, S, Si, Zn	% contribution to $PM_{2.5}$ Outdoor - Indoor - Work - Pers CoPM * 35 28 32 33 Secondary** 46 36 37 31 Soil 16 27 27 27 Detergents 0 6 2 6 Sea Salt 3 2 1 2 * CoPM is the difference between total mass and other identified components; i.e., primary combustion particles, nonvolatile primary and secondary organic particles, and particles from tire wear, water, etc. ** Secondary particles are the sum of sulfate, nitrate, and ammonium.4 factors were identified for each exposure type (residential indoor, residential outdoor, workplace indoor, and personal). The factors contained the elements Al, Ca, Cl, Cu, K, Mg, P, S, Si, Zn, and black smoke. (insert in cell to left after consolidating PM size)	Population exposure assessment of $PM_{2.5}$, based on outdoor fixed-site monitoring, overestimates exposures to outdoor sources like traffic and long-range transport and does not account for the contribution of significant indoor sources.
Turpin et al. (2007)	Personal: $PM_{2.5}$ Micro: $PM_{2.5}$, in the main living area (not kitchen) Ambient: $PM_{2.5}$, in the front or back yard	18 volatile organics, 17 carbonyl, $PM_{2.5}$ mass and >23 $PM_{2.5}$ species, organic carbon, elemental carbon, and PAHs	For Los Angeles Carbon (µgC/m3) EC 1.4 OC 4.1 Elements (ng/m3) Ag 0.5; Al 24.7; As 0.5; Ba 22.9; Br 5.3; Ca 80.9; Cd 0.4; Cl 62.0; Co ND; Cr 0.6; Cu 5.5; Fe 162.9; Ga 0.1; Ge 0.1; Hg 0.1; In 0.3; K 74.1; La 2.3; Mn 2.9; Mo 0.4; Ni 2.0; Pb 4.7; Pd 0.3; P 0.1; Rb 0.1; S 1022.9; Sb 2.1; Se 1.4; Si 128.9; Sn 7.9; Sr 1.8; Ti 10.4; V 5.3; Y 0.1; ; Zn 16.4; Zr 0.5	The best estimate of the mean contribution of outdoor to indoor $PM_{2.5}$ was 73% and the outdoor contribution to personal was 26%.
Delfino et al. (2006)	Personal: 24-h $PM_{2.5}$ 1-h max $PM_{2.5}$ 8-h max $PM_{2.5}$ Ambient: 24-h $PM_{2.5}$ 24-hPM_{10} (also 24-h NO_2, 8-h max O_3, 8-h max NO_2, 24-h NO_2, 8-h max CO)	24-h $PM_{2.5}$ EC 24-h $PM_{2.5}$ OC	Mean (SD), units: µg/m³: Riverside 24-h $PM_{2.5}$ EC = 1.61 (0.78) 24-h $PM_{2.5}$ OC = 6.88 (1.86) Whittier 24-h $PM_{2.5}$ EC = 0.71 (0.43) 24-h $PM_{2.5}$ OC = 3.93 (1.49)	PM associations with airway inflammation in asthmatics may be missed using ambient particle mass. The strongest positive associations were between eNO and 2-day avg pollutant concentrations. Per IQR increases: 1.1 ppb FENO/24 µg/m³ personal $PM_{2.5}$. 0.7 ppb FENO/0.6 µg/m³ personal EC 1.6 ppb FENO / 17 ppb personal NO_2 Ambient $PM_{2.5}$ and personal and ambient EC were significant only when subjects were taking inhaled corticosteroids. Subjects taking both inhaled steroids and antileukotrienes had no significant associations. Distributed lag models showed personal $PM_{2.5}$ in the preceding 5 h was associated with FENO.

Reference	Particle Sizes Measured	Component	Results					Primary Findings

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Salma et al. (2007)	Personal: PM$_{10-2.0}$ and PM2.0 Micro: NA Ambient: NR	30 elements (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ba, and Pb)	Units: ng/m^3: PM$_{10-2.0}$; PM$_{2.0}$; Mg 296 130; Al 531 93; Si 2.09 442; S 978 828; Cl 305 104; K 318 127; Ca 2.57 413; Ti 47 25; Cr 35 15; Mn 310 148; Fe 33.5 15.5; Ni 29 8; Cu 496 190; Zn 118 50; Br 13 DL; Ba 145 DL; Pb 47 21; PM 83.6 33.0	The concentrations observed in the Astoria underground station were clearly lower (by several orders of magnitude) than the corresponding workplace limits.

Lai et al. (2004) — Personal, Micro, and Ambient: PM$_{2.5}$

Component: Ag Cr Mn Si Al Cu Na Sm As Fe Ni Sn Ba Ga P Sr Br Ge Pb Ti Ca Hg Rb Tl Cd I S Tm Cl K Sb V Co Mg Se Zn Zr

GM (GSD), units: ng/m^3

	P	RI		RO	WI I/O
Al	280 (7.0)	67 (7.2)	22 (2.9)	110 (7.5)	1.4
As	4.7 (1.6)	3.7 (1.8)	2.6 (2.7)	6 (—)	1.4
Br	4.7 (2.2)	3.9 (2.0)	2.4 (2.5)	6.2 (2.5)	1.6
Ca	260 (2.0)	120 (2.1)	30 (1.6)	280 (2.9)	3.3
Cd	23 (1.4)	19 (1.8)	7 (—)	43 (2.2)	—
Cl	400 (3.0)	270 (3.9)	220 (5.2)	380 (3.9)	1.0
Cu	120 (1.3)	88 (1.7)	2.3 (2.8)	230 (2.1)	37.1
Fe	59 (2.3)	30 (3.8)	19 (3.5)	85 (2.9)	1.6
Ga	0.9 (2.1)	0.6 (2.2)	0.2 (2.2)	2.0 (3.4)	2.4
K	250 (2.4)	180 (2.7)	93 (2.0)	130 (4.0)	1.7
Mg	260 (2.1)	130 (3.1)	140 (2.9)	120 (2.8)	0.7
Mn	2.1 (2.6)	1.8 (2.4)	2.2 (1.5)	3.5 (3.0)	0.8
Na	2100 (1.6)	1800 (1.7)	1100 (3.2)	2700 (1.9)	1.6
Ni	11 (2.2)	8.6 (2.5)	18 (—)	23 (2.9)	—
P	110 (2.1)	70 (2.2)	27 (1.8)	86 (2.4)	2.5
Pb	26 (1.7)	19 (1.8)	9.4 (2.8)	32 (2.0)	1.9
S	1200 (1.9)	1200 (2.0)	890 (4.8)	1.2	
Se	8.4 (1.5)	6.8 (1.7)	2.3 (1.8)	16 (2.2)	2.8
Si	740 (3.4)	360 (2.9)	95 (2.2)	570 (3.8)	2.6
Sn	35 (1.5)	27 (1.8)	0 (—)	68 (2.6)	—
Ti	6.2 (1.7)	2.8 (2.2)	1.1 (2.0)	6.1 (3.2)	2.3
V	1.8 (1.5)	1.4 (1.9)	4 (—)		—
Zn	18 (2.4)	15 (2.2)	13 (2.5)	23 (2.4)	0.9

Primary Findings (Lai et al. 2004): Both the indoor and outdoor environments have sources that elevated the indoor concentrations in a different extent, in turn led to higher personal exposures to various pollutants.

Geometric mean (GM) of personal and home indoor levels of PM$_{2.5}$, 14 elements, total VOC (TVOC) and 8 individual compounds were over 20% higher than their GM outdoor levels. Those of NO 2, 5 aromatic VOCs, and 5 other elements were close to their GM outdoor levels. For PM$_{2.5}$ and TVOC, personal exposures and residential indoor levels (in GM) were about 2 times higher among the tobacco-smoke exposed group compared to the non-smoke exposed group, suggesting that smoking is an important determinant of these exposures. Determinants for CO were visualised by real-time monitoring, and we showed that the peak levels of personal exposure to CO were associated with smoking, cooking and transportation activities. Moderate to good correlations were only found between the personal exposures and residential indoor levels for both PM$_{2.5}$ (r = 0: 60; p< 0: 001) and NO$_2$ (r = 0: 47; p = 0: 003).

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Adgate et al. (2007)	Personal, Micro, and Ambient: PM$_{2.5}$ - broken down into TE	Ag, Al, Ca, Cd, Co, Cr, Cs, Cu, Fe, K, La, Mg, Mn, Na, Ni, Pb, S, Sb, Sc, Ti, Tl, V, Zn	Median, units: ng/m^3: 　　O　　I　　P S　334.4　272.1　351.6; Ca　232.2　85.0　174.1; Al　96.3 23.3 58.6; Na　33.1　20.6　31.9; Fe　12.6 43.1 78.6; Mg　10.9　16.3　27.5; K　3.2　38.4 47.5; Ti　3.0　0.8　1.4; Zn　2.7　6.5　9.6; Cu　2.4　1.5　4.9; Ni　NA　-0.1 1.8; Pb　1.5　2.4　3.2; Mn　0.6　1.5　2.3; Sb　0.08　0.21　0.30; Cd　0.05 0.12 0.14; V　0.05　0.12　0.16; La　0.02 0.05 0.11; Cs　0.00　0.00　0.00; Th　0.00 0.00 0.00; Sc　0.00　0.00　0.01; Ag　0.00 0.07 0.08; Co　NA　0.02　0.07; Cr　-0.09　　1.2　2.6	The relationships among P, I, and O concentrations varied across TEs. Unadjusted mixed-model results demonstrated that O monitors are more likely to underestimate than overestimate exposure to many of the TEs that are suspected to play a role in the causation of air pollution related health effects. These data also support the conclusion that TE exposures are more likely to be underestimated in the lower income and centrally located PHI community than in the comparitively higher income BC K community. Within the limits of statistical power for this sample size, the adjusted models indicated clear seasonal and community related effects that should be incorporated in long-term exposure estimates for this population.
Ebelt et al. (2005)	Personal: PM$_{2.5}$ Micro: "ambient exposure": PM$_{2.5}$, PM$_{10}$, PM$_{2.5}$ -10; "non-ambient exposure": PM$_{2.5}$ Ambient: PM$_{2.5}$, PM$_{10}$, PM$_{2.5}$ -10	Ambient sulfate, ambient non-sulfate, personal sulfate, personal ambient non-sulfate	Mean (SD), units µg/m^3 Ambient sulfate: 2.0 (1.1), ambient non-sulfate: 9.3 (3.7), personal sulfate: 1.5 (0.9), personal ambient non-sulfate: 6.5 (3.0)	Ambient exposures and (to a lesser extent) ambient concentrations were associated with health outcomes; total and nonambient particle exposures were not.
Farmer et al. (2003)	Personal: PM$_{10}$ Micro: NR Ambient: PM$_{10}$ Extractable organic material (EOM) B[a]P cPAHs	Benzo[a]pyrene (B[a]P) Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)	Units: ng/m^3: Exposed, controls: Prague: cPAHs = 12.04(11.10), 6.17 (3.48) B[a]P = 1.79 (1.67), 0.84 (0.60) Kosice: cPAHs = 21.72 (3.12), 6.39 (1.56) B[a]P = 2.94 (1.44), 1.07 (0.66) Sofia: cPAHs = 93.84 (55.0) police, 94.74 (120.34) bus drivers, 41.65 (33.36) B[a]P = 4.31 (2.6) police, 5.4 (3.18) bus drivers, 1.96 (1.53)	Personal exposure to B[a]P and to total carcinogenic PAHs in Prague was two fold higher in the exposed group compared to controls, in Kosice three fold higher, and in Sofia 2.5 fold higher.
Jansen et al. (2005)	Personal: PM$_{10}$ Micro: PM$_{10}$, PM$_{2.5}$, fine particles (~PM$_1$) Ambient: PM$_{10}$, PM$_{2.5}$	BC, as an estimate of elemental carbon (EC)	Mean (IQ Range), units: µg/m^3: BC Indoor: 1.34 (1.12) Outdoor 2.01 (1.68) Personal 1.64 (2.05)	For 7 subjects with asthma, a 10 µg/m^3 increase in 24-h avg outdoor PM$_{10}$ and PM$_{2.5}$ was associated with a 5.9 [95% CI, 2.9–8.9] and 4.2 ppb (95% CI, 1.3–7.1) increase in FENO, respectively. A 1 µg/m^3 increase in outdoor, indoor, and personal BC was associated with increases in FENO of 2.3 ppb (95% CI, 1.1–3.6), 4.0 ppb (95% CI,2.0–5.9), and 1.2 ppb (95% CI, 0.2–2.2), respectively. No significant association was found between PM or BC measures and changes in spirometry, blood pressure, pulse rate, or SaO2 in these subjects.

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Sørensen et al. (2003)	Personal: $PM_{2.5}$ Micro: NR Ambient: $PM_{2.5}$	BS (black smoke)	Units: 10^{-6}/m n Median Q25-Q75 All 177 6.8 (5.0-13.2) Autumn 42 7.1 (6.5-17.2) Winter 46 8.2 (5.1-13.3) Spring 46 12.6 (5.4-10.4) Summer 47 8.1 (3.4-9.0)	Personal $PM_{2.5}$ exposure was found to be a predictor of 8-oxodG in lymphocyte DNA. No other associations between exposure markers and biomarkers could be distinguished. ETS was not a predictor of any biomarker in the present study. The current study suggests that exposure to $PM_{2.5}$ at modest levels can induce oxidative DNA damage and that the association to oxidative DNA damage was confined to the personal exposure, whereas the ambient background concentrations showed no significant association. For most of the biomarkers and external exposure markers, significant differences between the seasons were found. Similarly, season was a significant predictor of SBs and PAH adducts, with avg outdoor temperature as an additional significant predictor.
Molnár et al. (2005)	Personal: 2.5 Micro and Ambient: $PM_{10-2.5}$ and $PM_{2.5}$	BS (black smoke) S Cl K Ca Mn Fe Cu Zn Br Rb Pb	Median, unit = ng/m^3 Wood burners Ref 1-sided p-value BS 0.97 0.74 0.053 S 880 650 0.500 Cl 200 160 0.036 K 240 140 0.024 Ca 76 43 0.033 Mn 4.8 3.5 0.250 Fe 64 49 0.139 Cu 8.9 2.4 0.016 Zn 38 22 0.033	Statistically significant contributions of wood burning to personal exposure and indoor concentrations have been shown for K, Ca, and Zn. Increases of 66–80% were found for these elements, which seem to be good wood-smoke markers. In addition, Cl, Mn, Cu, Rb, Pb, and BS were found to be possible wood-smoke markers, though not always to a statistically significant degree for personal exposure and indoor concentrations. For some of these elements subgroups of wood burners had clearly higher levels which could not be explained by the information available. Sulphur, one of the more typical elements mentioned as a wood-smoke marker, showed no relation to wood smoke in this study due to the large variations in outdoor concentrations from LDT air pollution. This was also the case for $PM_{2.5}$ mass. Personal exposures and indoor levels correlated well among the subjects for all investigated species, and personal exposures were generally higher than indoor levels. The correlations between the outdoor and personal or ind

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Johannesson et al. (2007)	Personal, Micro, and Ambient: PM$_{2.5}$, PM$_1$	BS- Black Smoke	BS2.5 Mean SD Personal 0.65 0.47 Exclusively smokers 0.62 0.47 Residential indoor 0.56 0.47 Exclusively smokers 0.52 0.46 Residential outdoor 0.68 0.51 Exclusively smokers 0.71 0.54 Urban background 0.63 0.37 All measurements 0.68 0.40 PM$_1$/BS1 Personal 0.55 0.20 Residential indoor 0.54 0.45 Exclusively smokers 0.49 0.43 Residential outdoor 0.66 0.51 Exclusively smokers 0.68	Personal exposure of PM$_{2.5}$ correlated well with indoor levels, and the associations with residential outdoor and urban background concentrations were also acceptable. Statistically significantly higher personal exposure compared with residential outdoor levels of PM$_{2.5}$ was found for nonsmokers. PM$_1$ made up a considerable proportion (about 70–80%) of PM$_{2.5}$. For BS, significantly higher levels were found outdoors compared with indoors, and levels were higher outdoors during the fall than during spring. There were relatively low correlations between particle mass and BS. The urban background station provided a good estimate of the residential outdoor concentrations of both PM$_{2.5}$ and BS2.5 within the city. The air mass origin affected the outdoor levels of both PM$_{2.5}$ and BS2.5; however, no effect was seen on personal exposure or indoor levels.
Sram et al. (2007)	Personal: PM$_{10}$, PM$_{2.5}$ Micro: NR Ambient: PM$_{10}$, PM$_{2.5}$	c-PAHs, B[a]P	B[a]P: exposed 1.6 ng/m^3, control 0.8 ng/m^3; c-PAHs: exposed 9.7 ng/m^3, control 5.8 ng/m^3	Ambient air exposure to c-PAHs increased fluorescent in situ hybridization (FISH) cytogenetic parameters in non-smoking policemen exposed to ambient PM
Na et al. (2005)	Personal: PM$_{2.5}$ Micro: NR Ambient: PM$_{2.5}$	EC (Elemental carbon) OC (Organic carbon)	Mean (SD), units = μg/m^3 Residential homes: EC 2.0 (NR) OC 14.8 (NR) High school (EC): Weekday samples 1.1 (0.9) Weekend samples 1.0 (0.5) High school (OC): Weekday samples 8.8 (4.7) Weekend samples 7.4 (2.4)	Indoor PM$_{2.5}$ was significant influenced by indoor OC sources. Indoor EC sources were predominantly of outdoor origin.
Geyh et al. (2005)	Personal: TD, PM$_{10}$, PM$_{2.5}$ Micro: NR Ambient: TD, PM$_{10}$, PM$_{2.5}$	EC OC VOC also assessed	Mean (SD), units = μg/m^3: Summary Statistics by Area Location October 2001: Albany and West EC 5.9 (NA) OC 36 (NA) Liberty and Greenwich EC 5.3 (59) OC 30 (56) Park Place and Greenwich EC 14.5 (5.4) OC 72 (26) Church and Dey EC 7.9 (3.3) OC 48 (15) April 2002: Liberty and West EC 4.2 (2.1) OC 26 (13) Barclay and Greenwich EC 4.0 (2.6) OC 18 (14) Church and Dey EC 4.5 (1.9) OC 27 (15) Middle of the Pile EC 6.7 (1.0) OC 40 (25)	During October, the median personal exposure to TD was 346 μg/m^3. The maximum area concentration 1742 μg/m^3, was found in the middle of the debris. The maximum TD concentration found at the perimeter was 392 μg/m^3 implying a strong concentration gradient from the middle of debris outward. PM$_{2.5}$/PM$_{10}$ ratios ranged from 23% to 100% suggesting significant fire activity during some of the sampled shifts. During April, the median personal exposure to TD was 144 μg/m^3, and the highest area concentration, 195 μg/m^3, was found at the perimeter. Although the overall concentrations on PM at the site were significantly lower in April, the relative contributions of fine particles to the PM$_{10}$, and EC and OC to the TD were similar. During both months, volatile organic compounds concentrations were low. Comparison of recorded EC and OC values from October 2001 and April 2002 with previous studies suggests that the primary source of exposure to EC for the WTC truck drivers was emissions from their own vehicles.

Reference	Particle Sizes Measured	Component	Results				Primary Findings
Zhao et al. (2007)	Personal, Micro, and Ambient: PM$_{2.5}$	EC, Cl, Si, NO$_3$	Units = µg/m^3: Personal: EC: 1.64 NO$_3$: 0.135, Si: 0.176, Cl: 0.116; Indoor: EC: 1.819 NO$_3$: 0.013, Si: 0.051, Cl: 0.024; Outdoor: EC: 1.876 NO$_3$: 0.292, Si: 0.115, Cl: 0.013				Four external sources and three internal sources were resolved in this study. Secondary nitrate and motor vehicle were two major outdoor PM$_{2.5}$ sources. Cooking was the largest contributor to the personal and indoor samples. Indoor environmental tobacco smoking also has an important impact on the composition of the personal exposure samples.
Meng et al. (2005)	Personal: PM$_{2.5}$ Micro: NA Ambient: NR	EC, OC, S, Si	Mean (SD), units = ng/m^3: Indoor: EC: 1165.9 (2081.0) OC: 7725.5 (9359.3) S: 902.3 (602.2) Si: 124.0 (79.0) Outdoor: EC: 1144.1 (968.1) OC: 3777.7 (2520.1) S: 1232.3 (633.2) Si: 141.1 (171.3)				Use of central-site PM$_{2.5}$ as an exposure surrogate underestimates the bandwidth of the distribution of exposures to PM of ambient origin.
Smith et al. (2006)	Personal: PM$_{2.5}$ Micro: PM$_{2.5}$ Area samplers in the offices, freight dock, or shop. Ambient: PM$_{2.5}$ Samplers were located in the yard upwind of the terminal.	Elemental carbon (EC) Organic carbon (OC)	Work Area	EC	OC	EC/TC	
			Office	0.31 (3.72)	11.29 (1.63)		
			Dock	0.53 (3.24)	5.01 (1.76)	3% (3.10)	
			Yard	0.73 (2.89)	7.77 (1.65)	9% (2.49)	
			Shop	1.54 (3.52)	10.37 (2.00)	8% (2.21)	
			Non-smokers on-site:			12% (2.13)	
			Clerk	0.09 (9.98)	15.97 (1.31)		
			Dock worker	0.76 (2.13)	13.89 (1.45)	1% (10.19)	
			Mechanic	2.00 (3.82)	16.89 (1.64)	5% (1.96)	
			Hostler	0.88 (3.04)	14.89 (1.86)	10% (2.71)	
			Non-smokers off-site			5% (2.09)	
			Pickup/deliver driver	1.09 (2.46)	12.40 (1.54)		
			Long haul driver	1.12 (1.91)	19.26 (2.30)	8% (2.13)	
			Smokers On-Site			7% (1.82)	
			Clerk	1.19 (1.70)	32.25 (1.70)	NR	
			Dock worker	0.98 (1.93)	24.02 (1.87)		
			Mechanic	2.41 (2.27)	24.35 (1.78)		
			Hostler	1.74 (2.21)	43.92 (2.03)		
			Smokers off-site				
			Pickup & Delivery drivers	1.33 (3.84)	24.24 (2.14)		
			Long haul drivers	1.37 (2.40)	32.81 (3.23)		
Koutrakis et al. (2005)	Personal: PM$_{2.5}$ Micro: NR Ambient: PM$_{2.5}$	Elemental Carbon (EC), SO$_4^{2-}$	Mean (SD) data are provided for Baltimore and Boston, units = µg/m^3: EC: (Baltimore, Boston) Winter: Seniors: NR, 1.4 (0.9) Children: 2.8 (1.8), 1.6 (1.6) COPD: 2.0 (1.2), NR SO$_4$: (Baltimore, Boston) Winter: Seniors: 1.9 (1.1), 1.9 (1.2) Children: NR, 2.3 (1.7) COPD: 1.5 (0.8), NR Summer: Seniors: 5.7 (3.5), 2.9 (1.9)				Ambient PM$_{2.5}$ and SO$_4$ are strong predictors of respective personal exposures. Ambient SO$_4$ is a strong predictor of personal exposure to PM$_{2.5}$. Because PM$_{2.5}$ has substantial indoor sources and SO$_4$ does not, the investigators concluded that personal exposure to SO$_4$ accurately reflects exposure to ambient PM$_{2.5}$ and therefore the ambient component of personal exposure to PM$_{2.5}$ as well.

Reference	Particle Sizes Measured	Component	Results					Primary Findings
Chillrud et al. (2004)	Personal: PM$_{2.5}$ Micro: PM$_{2.5}$ Home indoor and home outdoor Ambient: Urban fixed-site and upwind fixed site operated for three consecutive 48-h periods each week.	Elemental iron, manganese, and chromium are reported in this study out of 28 elements sampled.	Mean of duplicate samples: PM$_{2.5}$: 62 µg/m^3 Fe: 26 µg/m^3 Mn: 240 ng/m^3 Cr: 84 ng/m^3 Variability: 1-15%					Personal samples had significantly higher concentration of iron, manganese, and chromium than home indoor and ambient samples. The ratios of Fe (ng/ µg of PM$_{2.5}$) vs Mn (pg/ µg PM$_{2.5}$) showed personal samples to be twice the ratio for crustal material. Similarly for the Cr/Mn ratio. The ratios and strong correlations between pairs of elements suggested steel dust as the source. Time-activity data suggested subways as a source of the elevated personal metal levels.
Jansen et al. (2005)	Personal, Micro, and Ambient: PM$_{2.5}$	Estimated Elemental Carbon (Abs) Elemental composition of a subset of personal, indoor and outdoor samples	Mean (SD), units = µg/m^3:					For most elements, personal and indoor concentrations were lower than and highly correlated with outdoor concentrations. The highest correlations (median r.0.9) were found for sulfur and particle absorbance (EC), which both represent fine mode particles from outdoor origin. Low correlations were observed for elements that represent the coarser part of the PM$_{2.5}$ particles (Ca, Cu, Si, Cl).
				Amsterdam		Helsinki		
				P	O	P	O	
			PM$_{2.5}$	14.5	15.7	9.4	11.4	
			Abs	1.4	1.6	1.3	1.9	
			S	912.3	1299.9	605.3	1435.7	
			Zn	13.2	18.3	11.7	18.6	
			Fe	57.0	71.3	41.6	79.2	
			K	87.4	70.3	103.1	93.9	
			Ca	72.9	40.2	68.5	36.4	
			Cu	5.4	2.5	4.3	1.8	
			Si	29.7	13.7	79.5	93.9	
			Cl	40.8	72.7	9.8	44.2	

Reference	Particle Sizes Measured	Component	Results		Primary Findings
Molnar et al. (2006)	Personal: PM$_{2.5}$ and PM$_1$ Micro and Ambient: NR	S Cl K Ca Ti V Mn Fe Ni Cu Zn Br Pb	Urban background PM$_{2.5}$ mean, median, range S 620 320 95-1900 Cl 97 54 25-460 K 55 50 32-130 Ca 21 17 6.6-6.2 Ti 2.1 1.9 1.3-3.8 V 3.4 2.4 1.0-13 Mn 1.6 1.4 0.67- 3.8 Fe 36 33 7.1-100 Ni 1.6 1.2 0.33- 5.7 Cu 2.1 1.4 0.33-11 Zn 14 11 2.8-38 Br 1.7 1.4 0.47-44.3 Pb 3.3 2.1 0.94-11 Personal PM$_{2.5}$ mean, median, range S - < 470 270-1400 Cl 270 170 60-920 K 140 96 39-690 Ca 110 80 27-670 Ti 11 9.5 3.7-27 V 4.7 4.0 2.7-9.4 Mn - - - Fe 68 69 23-150 Ni 4.2 2.6 0.89-46 Cu 10 6.6 1.1-81 Zn 21 16 6.6-70 Br 2.0 1.3 0.91-14 Pb 2.9 2.6 0.92-8.3 Personal PM$_1$ S - < 470 240-1200 Cl - < 110 54-160 K 80 82 50-130 Ca 32 23 8.4-87 Ti 6.5 6.3 3.7-11 V - < 4.2 2.8-8.9 Mn - - - Fe 28 25 7.6-68 Ni 8.2 1.2 0.83-58 Cu 5.0 4.4 1.6-14 Zn 15 14 7.6-37 Br 1.6 1.5 0.83-4.4 Pb 3.6 2.8 1.1-11	Residential Outdoor PM$_{2.5}$ mean, median, range S 640 460 190-1800 Cl 6.3 140 57-840 K 200 78 32-200 Ca 82 28 4.6-85 Ti 34 5.2 3.3-21 V 6.3 3.9 2.1-14 Mn Fe 5.5 31 8.8-200 Ni 45 < 1.6 0.65-5.5 Cu 2.6 1.3 0.65-17 Zn 22 15 5.5-85 Br 2.0 >450 0.91-51 Pb 4.6 2.6 0.90-20 Residential Outdoor PM$_1$ S - 1.3 24-2000 Cl - < 110 44-170 K 76 68 34-170 Ca - < 12 5.1-78 Ti - < 5.0 2.2-9.5 V 5.6 4.47 2.2-14 Mn Fe 23 14 3.7-140 Ni 3.3 1.4 0.73-28 Cu - < 1.1 0.73-12 Zn 15 14 5.2-30 Br 1.5 1.4 0.78-4.3 Pb 4.1 1.5 1.0-17	PM$_{2.5}$ personal exposures were significantly higher than both outdoor and urban background for the elements Cl, K, Ca, Ti, Fe, and Cu. Personal exposure was also higher tan indoor levels of Cl, Ca, Ti, Fe, and Br, but lower than outdoor Pb./ Residential outdoor levels were significantly higher than the corresponding indoor levels for Br and Pb, but lower for Ti and Cu. The residential levels were also significantly higher than the urban background for most elements.
Kulkarni and Patil (2003)	Personal: PM$_5$ Micro: NR Ambient: PM$_5$	Lead Nickel Cadmium Copper Chromium Potassium Iron Manganese	Personal samples: Mean ± SD Type Lead Occupational 4.384 ± 7.766 µg/m^3 Residential 4.093 ± 5.925 µg/m^3 24-h integrated 4.205 ± 1.523 µg/m^3 Cadmium Occupational 0.201 ± 0.158 µg/m^3 Residential 0.111 ± 0.165 µg/m^3 24-h integrated 0.134 ± 0.140 µg/m^3 Manganese Occupational 1.979 ± 7.842 µg/m^3 Residential 0.180 ± 0.261 µg/m^3 24-h integrated 1.983 ± 6.824 µg/m^3 Potassium Occupational 3.473 ± 4.691 µg/m^3 Residential 4.589 ± 4.619 µg/m^3 24-h integrated Check		All listed metals were detected in the ambient air where as only Lead, Cadmium, Manganese, and Potassium were detected in personal exposures. Mean daily exposure to lead exceeds the Indian NAAQS by a factor of 4.2. However, ambient concentration of lead conforms to this standard. There is a rising trend in the personal exposures and ambient levels of cadmium. However, they are low and do not pose any major health risk as yet. Personal exposures to toxic metals exceed the corresponding ambient levels by a large factor ranging from 6.1 to 13.2. Thus, ambient concentrations may underestimate health risk due to personal exposure of toxic metals. Outdoor exposure to toxic metals is greater than the indoor (ratios ranging from 2.3 to 1.1) except for potassium (ratio 0.77). However, there is no significant correlation between these two.

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Wu et al. (2006)	Personal: $PM_{2.5}$ Micro: $PM_{2.5}$ Ambient: $PM_{2.5}$	levoglucosan (LG) Elemental Carbon (EC) Organic Carbon (OC)	Mean personal exposure: LG: 0.018 (0.024) EC: 0.4 (0.5) OC: 8.5 (2.7). Ambient: check component During non-burning times: 0.026 (0.030) During burning episodes: 0.010 (0.012)	Authors "found a significant between-subject variation between episodes and non-episodes in both the Exposure during agricultural burning estimates and subjects' activity patterns. This suggests that the LG measurements at the central site may not always represent individual exposures to agricultural burning smoke "Evidence of "Hawthorne Effect": During declared episodes (i.e. real and sham), subjects spent less time indoors at home and more time in transit or indoors away from home than during non-declared episode periods. The differences remained even when limited to weekdays only.
Larson et al. (2004)	Personal: $PM_{2.5}$ Micro: $PM_{2.5}$ outside subject's residence, and inside residence Ambient: $PM_{2.5}$ at Central outdoor site (downtown Seattle)	Light absorbing carbon (LAC) and trace elements	Personal RI RO Central Mass 10,500 10,250 12,693 11,970 Al 32 19 21 31 As 1 1 2 2 LAC * 1439 01105 1830 1741 Br 3 2 3 3 Ca 72 46 36 50 Cl 248 173 75 78 Cr 2 2 1 2 Cu 3 4 2 3 Fe 63 35 61 95 K 57 54 78 67 Mn 2 2 3 6 Ni	Five sources of $PM_{2.5}$ identified: vegetative burning, mobile emissions, secondary sulfate, a source rich in chlorine, and crustal-derived material. The burning of vegetation (in homes) contributed more $PM_{2.5}$ mass on avg than any other sources in all microenvironments.
Brunekreef et al. (2005)	Personal, Micro & Ambient: $PM_{2.5}$	Nitrate	Mean (SD), units = ng/m^3: Amsterdam: Personal 1389(1965) Indoor 1348(1843) outdoor 4063(4435) Helsinki: Personal 161(202) Indoor 267(215) Outdoor 1276(1181)	In both cities personal and indoor $PM_{2.5}$ were lower than highly correlated with outdoor concentrations. For most elements, personal and indoor concentrations were also highly correlated with outdoor concentrations.
Sorenson et al. (2005)	Personal: $PM_{2.5}$ & Black smoke (BS) Micro: $PM_{2.5}$ & Black smoke (BS) Ambient: Street monitoring station and roof of a campus building $PM_{2.5}$ & Black smoke (BS)	Black Smoke (BS) (also NO_2)	Mean, IQR, Units = $\mu g/m^3$: Personal: Cold Season: 10.2 (5.6-14.8) Warm Season: 7.1 (5.5-11.4) Micro: Cold Season Home Indoor: 6.2 (5.5-11.4) Home front door: 10.8 (7.4-16.3) Warm Season Home Indoor: 6.1 (3.7-7.6) Home front door: 8.8 (5.6-11.54) Ambient: Cold Season: Street Station: 31.6 (27.5-34.0) Urban Background: 7.7 (5.9-11.0) Warm Season: Street Station: 30.6 (24.7-36.0) Urban Background: 6.8 (4.6-8.6)	Indoor sources of PM and BS (as well as NO_2) were shown to be greatly influenced by indoor sources.
Ho et al. (2004)	Personal: $PM_{2.5}$ Micro: NR Ambient: $PM_{2.5}$	OC EC OM TCA	Mean, unit = $\mu g/m^3$ Indoors: OM = 18.1; TCA = 22.9 Outdoors: OM = 20.1; TCA = 26.5	The major source of indoor EC, OC, and $PM_{2.5}$ appears to be penetration of outdoor air, with a much greater attenuation in mechanically ventilated buildings.

Reference	Particle Sizes Measured	Component	Results			Primary Findings
Maitre et al. (2002)	Personal: PM4 Micro: NR Ambient: PM4	PAH, benxene-toluene-xylenes (BTX), aldehydes, BaP PAHc, formaldehyde, acetaldehyde	**Median**			The occupational exposure of policemen does not exceed any currently applicable occupational or medical exposure limits. Individual particulate levels should preferably be monitored in Grenoble in winter to avoid underestimations.
				Personal	Ambient	
			Resp $\mu g/m^3$	124	124 (mean)	
			BaP ng/m^3	0.28	0.14	
			PAHc ng/m^3	1.19	1.56	
			PAH ng/m^3	13.14	12.26	
			Benzene $\mu g/m^3$	23.5	17	
			Toluene $\mu g/m^3$	94.5	52	
			Xylene $\mu g/m^3$	74	39	
			BTX $\mu g/m^3$	192	108	
			Formaldehyde $\mu g/m^3$	21	17.5	
			Acetaldehyde $\mu g/m^3$	17	10.5	
			Aldehyde $\mu g/m^3$	38	28	
Farmer et al. (2003)	Personal: PM_{10} Micro: NR Ambient: PM_{10} $PM_{2.5}$ (not reported)	PM_{10} EOM EOM2 B[a]P c-PAHsb	Prague-SM	Winter	Summer	Extractable organic matter (EOM) per PM_{10} was at least 2-fold higher in winter than in summer, and c-PAHs over 10-fold higher in winter than in summer. Personal exposure to B[a]P and to total c-PAHs in Prague ca. was 2-fold higher in the exposed group compared to the control group, in Košice ca. 3-fold higher, and in Sofia ca. 2.5-fold higher.
			EOM ($\mu g/m^3$)	14.93	4.96	
			EOM2 (%)	23.9	13.4	
			B[a]P ($\mu g/m^3$)	3.5	0.28	
			c-PAHsb ($\mu g/m^3$)	24.69	2.29	
			Prague-LB	Winter	Summer	
			EOM ($\mu g/m^3$)	10.86	3.72	
			EOM2 (%)	27.9	14.1	
			B[a]P ($\mu g/m^3$)	2.9	0.17	
			c-PAHsb ($\mu g/m^3$)	20.36	1.32	
			Košice	Winter	Summer	
			EOM ($\mu g/m^3$)	15.3	1.67	
			EOM2 (%)	26.4	6.9	
			B[a]P ($\mu g/m^3$)	1.37	0.15	
			c-PAHsb ($\mu g/m^3$)	11.87	1.2	
			Sofia	Winter	Summer	
			EOM ($\mu g/m^3$)	24.6	3.95	
			EOM2 (%)	27.37	13.3	
			B[a]P ($\mu g/m^3$)	4.84	0.36	
			c-PAHsb ($\mu g/m^3$)	36.44	2.43	
Hanninen et al. (2004)	Personal: $PM_{2.5}$ Micro: NR Ambient: $PM_{2.5}$	$PM_{2.5}$ -bound sulphur		Indoor	Outdoor	Associated with indoor concentration: wooden building material, city, building age, floor of residence (i.e. ground, 1st, etc.), and use of stove other than electric.
			Athens	5.3 (2.0)	7.6 (5.1)	
			Basel	2.6 (1.6)	3.3 (1.6)	
			Helsinki	1.6 (1.3)	2.2 (1.5)	
			Prague	3.1 (1.3)	4.0 (1.5)	
Shilton et al. (2002)	Personal, Micro, and Ambient: Respirable PM	Respirable PM, metals (Zn, Cu, Mn, Al), sulphate, nitrate, and chloride	Indoor Outdoor Zn (ng/m^3) 241.1 179.5 Cu (ng/m^3) 43.3 24.99 Mn (ng/m^3) 15.6 4.18 Al (ng/m^3) 305.2 52.90 SO_4 (ng/m^3) 4.72 3.47 Cl (ng/m^3) 1.08 0.15 NO_3 (ng/m^3).35 1.08			The indoor particulate conc was driven by ambient conc; meteorological-induced changes in ambient PM were detected indoors;

Reference	Particle Sizes Measured	Component	Results			Primary Findings
Noulett et al. (2005)	Personal: PM$_{2.5}$ Micro: NR Ambient: PM$_{2.5}$	SO$_4$ ABS (light absorbing carbon)	Measurement Mean s.d. Ambient SO$_4$ 2.72* 3.11 Ambient ABS 1.4** 1.0 Personal SO$_4$ 1.33* 1.47 Personal ABS 1.0** 1.7 * Mean SO$_4$ values reported in µg/m^3 ** Mean ABS values reported in 10^{-5}/m-1			SO$_4$ and light absorbing carbon concentrations had higher personal-ambient correlations and less variability. This indicates that SO$_4$ and ABS were of outdoor origin, while PM$_{2.5}$ mass was of varied indoor and outdoor origin.

Mean (SD), units = µg/m^3:

Sarnat et al. (2006b RMID 9114)	Personal: PM$_{2.5}$ Micro: NR Ambient: PM$_{2.5}$	SO$_4$ EC		Personal	Ambient	High association between personal and ambient SO$_4^{2-}$ and EC, especially for SO$_4^{2-}$ for which there is no significant indoor source.
			SO$_4$			
			Summer	5.9 (4.2)	7.7 (4.8)	
			Fall	4.4 (3.3)	6.2 (4.7)	
			EC			
			Summer	1.1 (0.6)	1.1 (0.5)	
			Fall	1.2 (0.7)	1.1 (0.7)	

| Sarnat et al. (2005 RMID 9171) | Personal: PM$_{2.5}$ Micro: n/a Ambient: PM$_{2.5}$ | SO$_4$, O$_3$, NO$_2$, SO$_2$ | Correlations between personal PM$_{2.5}$ and ambient gas O$_3$ correlated in summer. Spearman's R $\approx$ 0.4, anti-correlated in winter, R $\approx$ 0.3-0.1. NO$_X$ somewhat correlated in summer. R~0.3 Winter, R~0.2-0.4 SO$_2$ not well correlated in summer or winter. R~0-0.1. CO somewhat correlated in summer. R $\approx$ 0.1-0.3. Correlated in winter R~0.2-0.3. No results were significant. | | | Substantial correlations between ambient PM$_{2.5}$ concentrations and corresponding personal exposures. Summertime gaseous pollutant concentrations may be better surrogates of personal PM$_{2.5}$ exposures (especially personal exposures to PM$_{2.5}$ of ambient origin) than they are surrogates of personal exposures to the gases themselves. |

Brunekreef et al. (2005)	Personal, Micro, and Ambient: PM$_{2.5}$	SO$_4^{2-}$, NO$_3$-	Mean, units = µg/m^3: SO$_4^{2-}$:			In both cities personal and indoor PM$_{2.5}$ were lower than highly correlated with outdoor concentrations. For most elements, personal and indoor concentrations were also highly correlated with outdoor concentrations.
				P	I	O
			Amsterdam	4.6	4.7	5.9
			Helsinki	2.7	3.0	5.0
			NO$_3$-:			
				P	I	O
			Amsterdam	1.4	1.4	4.0
			Helsinki	0.2	0.3	1.3

| Kim et al. (2005) | Personal: PM$_{2.5}$ Micro: NR Ambient: PM$_{2.5}$ | Sulfate, Elemental carbon (EC), Calcium, Magnesium, Potassium, Sodium | Mean (SD), units = µg/m^3: SO$_4^{2-}$: 2.7 (3.2) Ca^{2+}: 0.12 (0.12) Mg^{2+}: 0.02 (0.01) K: 0.07 (0.08) Na$^+$: 0.09 (0.20) EC: 0.60 (0.54) | | | Traffic-related combustion, regional, and local crustal materials were found to contribute 19% ± 17%, 52% ± 22%, and 10% ± 7%, respectively. Among participants that spent considerable time indoors, exposure to outdoor PM$_{2.5}$ includes a greater relative contribution from combustion sources, compared with outdoor (ambient) PM$_{2.5}$ measurements. |

| Wallace and Williams (2005) | Personal: PM$_{2.5}$ Indoor Micro: PM$_{2.5}$ Outdoor Micro: PM$_{2.5}$ | Sulfur | Mean (SD), units = ng/m^3: Personal: 1046 (633) Indoor: 1098 (652) Outdoor: 1951 (1137) | | | Generally, infiltration factor provides a reliable estimate of personal exposure. Sulfur can be used in lieu of personal exposure to PM because it is derived from outdoors. |

Reference	Particle Sizes Measured	Component	Results	Primary Findings
Be´ne´dicte et al. (2007)	Personal: PM$_{2.5}$ Micro: NA Ambient: PM$_{2.5}$	Sulfur	Mean, units = µg/m³: Personal: 1.3 outdoor: 1.2	Authors say "Our results suggest that outdoor measurements of absorbance and sulphur can be used to estimate both the daily variation and levels of personal exposures also in Southern European countries, especially when exposure to ETS has been taken into account. For PM$_{2.5}$, indoor sources need to be carefully considered."

Table A-60. Summary of personal PM exposure source apportionment studies.

Reference	Study Design	Results					Primary Findings
Hopke et al. (2003)	Source apportionment of personal (PEM) and indoor central and apartment (VAPS) and outdoor (VAPS) PM$_{2.5}$, Baltimore retirement home with 10 elderly subjects, July-Aug 1998.	% contr	P	I	I C	O	63% of personal exposure could be attributed to outdoor sources (with 46% from sulfate), and resuspension of indoor PM during vacuuming, cleaning, or other activities contributed 36% of personal exposure.
		External					
		Secondary SO$_4^{2-}$	46.3	64.0	79.0	64.0	
		Unknown	13.6	14.5	17.4	14.5	
		Soil	2.8	3.1	3.6	3.1	
		Internal					
		Gypsum	0.7	0.4	0.0	0.0	
		Activity	36.2	17.8	0.0	0.0	
		Personal care	0.4	0.3	0.0	0.0	
Larson et al. (2004)	Source apportionment of personal (PEM) and residences (HI) and central outdoor (HI) PM$_{2.5}$ around Seattle with 10 elderly subjects and 10 asthmatic children, Sep 2000 and May 2001. The purpose of the article was to compare PMF2 and PMF3 methods.	PMF2:					Results showed that vegetative burning was the largest contributor to personal exposure and that was related to outdoor combustion. Crustal exposures were related to indoor activities.
		% contr	P	I	O		
		Veg burn	28.8	47.6	56.7		
		Mobile	0.0	3.6	7.5		
		Fuel oil	0.0	0.0	6.7		
		S, Mn, Fe	8.1	0.0	0.0		
		Secondary	0.0	34.5	20.9		
		Cl-rich	9.9	3.6	3.7		
		Crustal	25.2	10.7	4.5		
		Crustal2	27.9	0.0	0.0		
		PMF3:					
		% contr	P	I	O		
		Veg burn	41.0	57.4	71.3		
		Mobile	7.2	4.3	8.2		
		Secondary	19.3	13.8	18.0		
		Crustal	32.5	24.5	2.5		

Reference	Study Design	Results					Primary Findings

Zhao et al. (2006) — Source apportionment of personal (PEM) and residential indoor (HI) and residential outdoor (HI) and central outdoor (HI) PM$_{2.5}$, Raleigh and Chapel Hill NC with 38 subjects, summer 2000 and Spring 2001.

% contr	P	I R	O R	O
Motor vehicle	10.0	9.4	17.2	19.4
Soil	3.5	3.7	9.3	8.5
Secondary SO$_4^{2-}$	15.9	22.5	59.3	61.9
Secondary NO3-	4.4	4.7	7.6	7.8
ETS	7.0	10.0	0.0	0.0
Personal care and activity	8.0	19.1	0.0	0.0
CU-factor mix w indoor soil	0.4	1.2	0.0	0.0
Cooking	52.5	53.6	0.0	0.0

Secondary sulfate was the largest ambient source and the largest ambient contribution to personal exposure. Cooking produced the largest contribution to personal and indoor concentrations. Note that sums over 100% because multiple sources obscured PMF resolution

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Meng et al. (2007) — Source apportioned infiltration for personal (PEM) and residential indoor (HI) and residential outdoor (HI) and central outdoor (HI) PM$_{2.5}$, Los Angeles, Houston, and Elizabeth, NJ with 100 non-smoking residences and residents in each city, in each season between summer 1999 and spring 2001 (RIOPA).

% contr	Outdoor	Indoor (Outdoor Origin)
Mechanically generated	2	17
Primary Combustion	43	43
Secondary Formation*	55	40

*excludes nitrates

Primary Findings: Differential infiltration of the PM$_{2.5}$ resulted in a reduction of secondary formation products relative to outdoors.

Reff et al. (2007) — Functional group distinction for personal (PEM) and residential indoor (HI) and residential outdoor (HI) and central outdoor (HI) PM$_{2.5}$, Los Angeles, Houston, and Elizabeth, NJ with 100 non-smoking residences and residents in each city, in each season between summer 1999 and spring 2001 (RIOPA). PM$_{2.5}$ samples from 219 homes were used for this analysis.

SO$_4^{2-}$:

R	O	I	P
O	1.0		
I	0.54-0.76	1.0	
P	0.54-0.73	0.84-0.90	1.0

C = O:

R	O	I	P
O	1.0		
I	0.12-0.61	1.0	
P	-0.13-0.69	0.07-0.77	1.0

CH:

R	O	I	P
O	1.0		
I	-0.08-0.35	1.0	
P	-0.07-0.19	0.41-0.85	1.0

Primary Findings: The main finding was that indoor and personal levels of CH in organic carbons were found to be substantially higher than outdoors. This reduced the polarity of indoor and personal organic carbons

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Zhao et al. (2007) — Source apportionment of personal (PEM) and indoor school (FRM) and outdoor school (FRM) PM$_{2.5}$, Denver with 56 asthmatic children, Oct 2002-March 2003 and Oct 2003-March 2004.

% contr	P	I	O
Secondary SO$_4^{2-}$	4.3	8.9	9.6
Soil	6.6	4.2	12.4
Secondary NO$_3^-$	9.4	2.8	40.8
Motor vehicle	13.3	26.5	26.5
Cl-based cleaning	2.8	0.4	0.0
Cooking	54.8	30.2	0.0
ETS	9.2	2.1	0.0

Primary Findings: The largest personal exposure was from cooking (54.8%), but motor vehicle emissions were the largest outdoor contributor (13.3%) to personal exposure. Secondary nitrate comprised the largest outdoor source but accounted for only 9.4% of personal exposure.

Reference	Study Design	Results	Primary Findings
Strand et al. (2006)	Using positive matrix factorization and an extrapolation method to estimate $PM_{2.5}$ based on SO_4^{2-} and Fe components.	Estimation method, Mean (SD, range): PMF: 7.42 (1.93, 3.43 - 12.89) Extrapolation Method: Using sulphate: 6.38 (1.60, 3.20 - 10.97) Using sulphate & iron: 6.50 (1.36, 3.54 - 10.12) Using sulphate & iron, temperature adjusted: 7.02 (1.48, 3.79 - 11.02) Using sulphate (no gamma): 8.23 (2.06, 4.12 - 14.14)	Similar results were found with each technique.

Table A-61. Summary of PM infiltration studies.

Reference	Study Design	F_{inf}	I/O	F_{inf} by component	I/O by component
Allen et al. (2003)	Enhance knowledge of the outdoor contribution to total indoor and personal PM exposures; continuous light scattering monitoring; Elderly and children spending most of their time indoors; Seattle, Wa.; healthy individuals, elderly with COPD or CHD and children with asthma; 44 residences measured for 55 10-day sessions.	$PM_{2.5}$: 0.65 ± 0.21 (avg ± SD; across all monitoring events); 0.79 ± 0.18 (Non-heating season); 0.53 ± 0.16 (heating season)	n/a	n/a	% of Indoor $PM_{2.5}$ generated outdoors: Mean 78.7 SD 16.9 Min,max 40.2,100.0
Barn et al. (2008)	Measure infiltration factor from $PM_{2.5}$ from forest fires and determine effectiveness of high-efficiency particulate air (HEPA) filter; pDR for ambient air sampling; homes affected by forest fire or residential wood smoke; British Columbia, Canada; n/a; 38 homes sampled (19 winter, 13 summer)	n/a	$PM_{2.5}$ Mean by Season: -summer w/ HEPA 0.19 (0.20) -Summer w/o HEPA: 0.61 (0.27) -Winter w/ HEPA: 0.10 (0.08) -Winter w/o HEPA: 0.28 (0.18) -Both w/ HEPA: 0.13 (0.14) -Both w/o HEPA: 0.42 (0.27)	n/a	n/a
*Baxter, LK, et al. 2007	Part of ACCESS cohort study of asthma etiology; measurement methodology; lower SES populations; Boston, MA; cohort study; 43 homes, 25 in cohort and 18 not. 23 homes monitored in both seasons, 15 in the non-heating season only.	$PM_{2.5}$ 0.91 0.23	$PM_{2.5}$: 1.14 (0.71)	Pollutant b1 R2 NO_2 0.48 0.07 EC 0.72 0.49 Ca 0.56 0.30 Fe 0.38 0.26 K 0.83 0.52 Si 0.02 0.00 Na 0.46 0.43 Cl 0.40 0.12 Zn 0.85 0.28 S 0.95 0.78 V 0.60 0.77	NO_2: 0.99 (0.63) EC: 0.89 (0.64) Ca: 1.16 (1.90) Fe: 0.69 (1.40) K: 1.10 (0.95) Si: 1.04 (1.31) Na: 1.05 (1.84) Cl: 3.18 (3.79) Zn: 0.83 (1.13) S: 0.76 (0.32) V: 0.76 (0.46)

Reference	Study Design	F_{inf}	I/O	F_{inf} by component	I/O by component

Baxter, LK et al.	Part of ACCESS cohort study of asthma etiology; Bayesian variable selection; lower socio-economic status households; urban Boston; no pre-exsisting health; 43 sites among 39 households	n/a	PM$_{2.5}$: Indoor/outdoor: 0.23 Indoor/ambient: 0.20	NO$_2$: R2 0.25 NO$_2$: b1 Ambient concentrations 0.79 Ambient concentrations open windows 0.98 Ambient concentrations closed windows 0.64	R2
					
					      Indoor/ Indoor/
					      Outdoor ambient
					NO$_2$ 0.07 0.02
					EC 0.49 0.16

Crist et al. (2008)	Ambient, indoor, and personal PM$_{2.5}$ concentration assessment; indoor and personal samples by Whatman Teflon filters, ambient samples taken by TEOMs; fourth and fifth-grade children; Ohio River Valley near Columbus, OH; no pre-existing health conditions; 90 children (30 at each site), 3 of which had personal monitors.
	
	194-332 days of indoor, outdoor, & personal samples. N samples taken at schools range 31-235.
		n/a	PM$_{2.5}$:
			
			       SD Non-SD
			Athens 2.61 0.8
			      (5.76) (0.7)
			Koebel 1.71 1.27
			      (3.17) (1.16)
			New 2.98 0.82
			Albany (5.47) (0.6)
				n/a	n/a

Hanninen et al. 2004	EXPOLIS human exposure assessment; pump and filter with gravimetric analysis, elemental composition using energy dispersive X-ray fluorescence; residential homes, no targeted age group; Athens, Greece, Basle, Switzerland, Helsinki, Finland, Prague, Czech Republic; n/a; Homes by city Athens 50, Basle 50, Helsinki 189, Prague 49.	PM$_{2.5}$ Mean (SD) Athens 0.70 (0.12) Basle 0.63 (0.15) Helsinki 0.59 (0.17) Prague 0.61 (0.14)	n/a	Sulphur Mean (SD) Athens 0.82 (0.14) Basle 0.80 (0.19) Helsinki 0.70 (0.20) Prague 0.72 (0.16)	n/a

Ho et al. (2004)	Exposure assessment of occupied buildings located near major roadways; Co-located mini-volume samplers and Partisol model 2000 sampler with 2.5 micron inlet; occupants of mechanically ventilated and non-ventilated buildings located within 10m of major roadways; Hong Kong, China; no exsisting health conditions;
	
	1 classroom(MV), 1 office(MV), and 3 residences(NV)
		PM$_{2.5}$:
		          R2
		All 0.42
		MV 0.81
		NV 0.83
			PM$_{2.5}$:
			      I/O Range
			All 0.8 0.2-1.6
			MV < 0.7
			NV 0.9 0.6-1.6
				OC:
				          R2
				MV 0.66
				NV 0.71
				
				EC:
				          R2
				MV 0.42
				NV 0.76
					OC:
					     I/O Range
					OC 1.0 0.6-1.2
					
					EC:
					     I/O Range
					EC 0.8 0.5-1.1

Reference	Study Design	F_{inf}					I/O	F_{inf} by component	I/O by component

Hoek et al, (2008) — Exposure assessment, indoor/outdoor particle relationships; indoor sampling for 4 days of every week; urban populations 35 or older; 4 European cities; diagnosed with asthma or COPD, and had to work less than 16 hours per week outside the home; 153 homes sampled.

UFP:

	24-h Central	24-h Res.	1-h Central	1-h Res.
Helsinki	0.06	0.42	0.06	0.67
Athens	0.25	0.42	0.14	0.48
Amsterdam	0.43	0.19	0.41	0.21
Birmingham	0.15	0.22	0.22	0.23

I/O: n/a F_{inf} by component: n/a   I/O by component: n/a

Hopke, P.K., et al. 1998 — Analysis of data from 1998 BPMEES; measurements taken every other day in fifth floor unoccupied apartment; 10 elderly subjects of mean age 84; Towson, MD; 10 potentially susceptible elderly

F_{inf}: n/a   I/O: n/a

F_{inf} by component:
Nitrate-sulfate = 0.03
Sulfate = 0.38
OC = 0.77
MV Exhaust = 0.32

I/O by component:

Sulfate:

	Median	Range
Indoor	0.96	0.56-0.98
Out	0.95	0.56-0.98

Unknown:

	Median	Range
Indoor	0.12	0.39-0.80
Outdoor	0.28	0.19-0.89

Crustal:

	Median	Range
Indoor	0.11	0.46-0.66
Outdoor	0.13	0.46-0.66

Li et al. (2003b) — Effect of swamp coolers on indoor PM concentrations; concurrent 10-min avg indoor and outdoor concentrations recorded for 2 days; El Paso, TX; 10 homes with swamp coolers

PM_{10}:

Cooler on	0.57
Cooler off	0.66
All	0.60

$PM_{2.5}$:

Cooler on	0.63
Cooler off	0.73
All	0.65

I/O: n/a F_{inf} by component: n/a   I/O by component: n/a

Meng et al. 2005 — This study is not based upon empirical evidence but rather numbers predicted by various models

Ng et al. (2005) — This study is not based upon empirical evidence but rather I/O ratios predicted by various models

Reference	Study Design	F_{inf}			I/O		F_{inf} by component	I/O by component	
Turpin, BJ et al.	RIOPA Study; samples taken hourly for 1 or 2 days, questionnaires given to characterize activity; 309 adults and 118 children; Elizabeth NJ, Houston TX, and Los Angeles County CA; no preexisting health conditions; $PM_{2.5}$ in 219 homes, twice in 169. Indoor outdoor samples for organic analysis in 152 homes, twice in 132.	$PM_{2.5}$:			R2:		n/a	n/a	
		Mean	0.69		All	0.18			
		Median	0.70		LA	0.44			
		SD	0.23		Elizabeth	0.12			
		Least-trimmed squared regression used to estimate this infiltration factor for 144 indoor-outdoor pairs of measurements.			Houston	0.06			
*Kim et al. year	Panel study; Rupprecht and Patashnick ChemPass Personal Sampling System; 28 patients mean age 64 years; Toronto, Canada; cardiac-compromised patients; 28 adult patients	n/a			n/a		PM Regression EQ: $PM_{2.5} = 12.68 + 12.66*EC$ $PM_{2.5} = 14.14 + 2.16*SO_4^{2-}$ $PM_{2.5} = 16.29 + 28.19*Ca^{2+}$		r
								SO_4^{2-} and - Ca^2	0.26
								Mg^{2+}	0.17
								K^+	0.47
								Na^+	0.07
								EC	0.23
								EC and – Ca^{2+}	0.52
								Mg^{2+}	0.51
								K^+	0.37
								Na^+	0.32
								Ca^{2+} and – Mg^{2+}	0.76
								K^+	0.34
								Na^+	0.30
								Mg^{2+} and -K^+	0.44
								Na^+	0.25
								K^+ and-Na^+	0.26

Table A-62.   Summary of PM – copollutant exposure studies.

Reference	PM metric	Copollutant metric	Association between PM and copollutant							Primary findings
Fruin et al. (2008)	In-vehicle UFP, BC, PM-bound PAH	In-vehicle NO_X, CO	R	UFP	$PM_{2.5}$	NO	BC	CO	CO_2	Measurements of freeway UFP, BC, PM-bound PAH, and NO concentrations were roughly one order of magnitude higher than ambient measurements. Multiple regression analysis suggests these concentrations were a function of truck density and total truck count.
			UFP	1	0.71	0.97	0.95	0.63	0.72	
			$PM_{2.5}$		1	0.69	0.89	0.66	0.68	
			NO			1	0.91	0.78	0.85	
			BC				1	0.65	0.74	
			CO					1	0.94	
			CO_2						1	
			Note that these correlations are computed from data presented by Fruin et al. (2008)for mean concentrations at different locations.							

Reference	PM metric	Copollutant metric	Association between PM and copollutant							Primary findings
Schwartz et al. (2007)	Ambient and personal $PM_{2.5}$ data from the Baltimore panel study	Ambient and personal O_3 and NO_2 data from the Baltimore panel study.	Median β for regressions:							Results suggest that ambient O_3 exposure may be related to personal SO_4^{2-} exposure but not to personal $PM_{2.5}$ exposure on the whole. Ambient NO_2 exposure was associated with personal $PM_{2.5}$ exposure, possibly because both have traffic sources.

			Ambient $PM_{2.5}$	Ambient O_3	Ambient NO_2
Personal $PM_{2.5}$			0.0143	-0.0016	0.0115
Personal $PM_{2.5}$ of ambient origin			0.0183	-0.0037	0.0124
Personal SO_4^{2-}			0.0051	0.0035	0.0006
Personal O_3			0.0014	0.0010	0.0009
Personal NO_2			0.0015	0.0009	0.0010

Reference	PM metric	Copollutant metric								Primary findings
Tolbert et al. (2007)	Ambient PM_{10}, $PM_{10-2.5}$, $PM_{2.5}$, EC, OC, TC, SO_4^{2-}, water-soluble metals, oxygenated hydrocarbons	Ambient O_3, NO_2, CO, SO_2								Low correlations were seen between SO_2 and PM constituents. Components were used in a multi-pollutant model to predict emergency department visits in Atlanta. CO was found to be the most significant predictor of cardiovascular disease visits in one-, two-, and three-pollutant models, and O_3 was the most significant predictor of respiratory disease visits in one-, two-, and three-pollutant models.

	PM_{10}	O_3	NO_2	CO	SO_2	PMc	PM2.5
PM_{10}	1.0						
O_3	0.6	1.0					
NO_2	0.5	0.4	1.0				
CO	0.5	0.3	0.7	1.0			
SO_2	0.2	0.2	0.4	0.3	1.0		
PMc	0.7	0.4	0.5	0.4	0.2	1.0	
PM2.5	0.8	0.6	0.6	0.4	0.2	0.5	1.0
SO_4^{2-}	0.7	0.6	0.1	0.1	0.1	0.3	0.8
EC	0.6	0.4	0.6	0.7	0.2	0.5	0.7
OC	0.7	0.5	0.6	0.6	0.2	0.5	0.7
TC	0.7	0.5	0.7	0.6	0.2	0.5	0.7
Metals	0.7	0.4	0.3	0.4	0.1	0.5	0.7
OHC	0.5	0.4	0.2	0.3	0.1	0.4	0.5

	SO_4^{2-}	EC	OC	TC	Metals	OHC
SO_4^{2-}	1.0					
EC	0.3	1.0				
OC	0.3	0.8	1.0			
TC	0.3	0.9	1.0	1.0		
Metals	0.7	0.5	0.5	0.5	1.0	
OHC	0.5	0.4	0.4	0.4	0.5	1.0

Reference	PM metric	Copollutant metric	Association between PM and copollutant		Primary findings
Brook et al. (2007)	Anbient PM_{10}, $PM_{10-2.5}$, $PM_{2.5}$, SO_4^{2-}, and trace metals in 10 Canadian cities.	Ambient NO_2, NO	R with	NO_2 (min, Max)	NO_2 showed the strongest association with mortality, but it is unclear if this association is due to health effects of NO_2 or health effects of copollutant PM.
			NO_2	1.00 (1.00, 1.00)	
			NO	0.67 (0.51, 0.77)	
			$PM_{2.5}$	0.54 (0.45, 0.71)	
			$PM_{10-2.5}$	0.31 (0.04, 0.50)	
			PM_{10}	0.50 (0.23, 0.70)	
			SO_4^{2-}	0.33 (0.10, 0.48)	
			Fe	0.44 (0.29, 0.56)	
			Zn	0.39 (0.28, 0.52)	
			Ni	0.20 (0.06, 0.40)	
			Mn	0.51 (0.37, 0.62)	
			As	0.21 (0.07, 0.39)	
			Al	0.07 (-0.17, 0.18)	
			Cu	0.03 (-0.07, 0.15)	
			Pb	0.28 (0.16, 0.39)	
			Si	0.19 (0.00, 0.32)	
			Se	0.14 (-0.04, 0.35)	
Ito et al. (2007)	Ambient $PM_{2.5}$	Ambient O_3, NO_2, SO_2, CO	Shown in figure format only.		Authors tested relationship between meteorological variables and copollutants to determine if multi-pollutant models are impacted by spatial or temporal variation or by meteorological conditions. Multicollinearity varied by pollutant and season.

Reference	PM metric	Copollutant metric	Association between PM and copollutant				Primary findings
Kaur et al. (2005b)	Fixed-site and personal $PM_{2.5}$, personal UFP	Fixed site and personal CO	Personal R:				Fairly low correlation was observed between $PM_{2.5}$ and CO and between $PM_{2.5}$ and UFP, stronger correlations between UFP and CO.
				$PM_{2.5}$	UFP	CO	
			$PM_{2.5}$	1	0.5	0.2	
			UFP	0.5	1	0.7	
			CO	0.2	0.7	1	

Reference	PM metric	Copollutant metric	Association between PM and copollutant					Primary findings
Kaur et al. (2005a)	Fixed-site and personal $PM_{2.5}$ analyzed post-sample for light absorbance (as indicator for carbonaceous aerosol), personal UFP	Fixed site and personal CO	Personal R:					Strongest correlation observed between UFP and absorption, which is reasonable given that much absorptive carbonaceous aerosol is in the ultrafine range.
			R	$PM_{2.5}$	Abs	CO	UFP	
			$PM_{2.5}$	1	0.3	-0.1	0.0	
			Abs	0.3	1	0.2	0.7	
			CO	-0.1	0.2	1	0.1	
			UFP	0.0	0.7	0.1	1	

Reference	PM metric	Copollutant metric	Association between PM and copollutant				Primary findings
Sørenson et al. (2005)	Personal, indoor residential, and outdoor residential $PM_{2.5}$ and BC	Personal, indoor residential, and outdoor residential NO_2	Personal exposure regression coefficients to:				Personal NO_2 concentration is more strongly influenced by background than $PM_{2.5}$ or BC.
				$PM_{2.5}$	BC	NO_2	
			Bedroom	0.72	0.47	0.70	
			Front door	0.46	0.61	0.60	
			Background	0.29	0.03	0.56	

Reference	PM metric	Copollutant metric	Association between PM and copollutant				Primary findings
Sabin et al. {, 2005 #396}	BC, particle-bound PAH on a school bus.	NO_2 on a school bus.		BC	PB-PAH	NO_2	Less correlation was observed between NO_2 and PM species. This study was aimed more at fuel choices and control technologies for children's exposures on school buses.
			BC	1	0.94	0.49	
			PB-PAH		1	0.37	
			NO_2			1	
			Note that these correlations are computed from data presented by Sabin et al. for mean concentrations when the test bus travelled behind different vehicles.				
Lai et al. (2004)	Microenvironmental and personal $PM_{2.5}$ and trace elements	Microenvironmental and personal VOCs, NO_2, and CO.	R	$PM_{2.5}$	TVOC	NO_2	The EXPOLIS Oxford study was more focused on the indoor-outdoor exposure relationship, but the correlation results showed no important relationships between the pollutants shown.
			TVOC	0.21			
				0.21			
				0.41			
				-0.32			
			NO_2	-0.1	-0.11		
				-0.02	-0.01		
				-0.16	-0.23		
				0.09	0.03		
			CO	-0.07	0.07	0.3	
				NR	NR	NR	
				NR	NR	NR	
				NR	NR	NR	
			Correlation coefficients listed (in order) for personal exposure, residential indoor, residential outdoor, and workplace indoor.				
Gomez-Perales et al. {, 2007 #449;, 2004 #448}	Microenvironmental $PM_{2.5}$ with SO_4^{2-}, NO_3^-, EC, OC.	Microenvironmental CO.	Ratio of Conc	$PM_{2.5}$	CO	Benzene	Morning and evening measurements of $PM_{2.5}$ were on avg higher and more variable than for benzene and CO (in order). Benzene and CO had higher and more variable concentrations for minibuses than for buses and metros, respectively, while $PM_{2.5}$ concentrations were not substantially different for buses and minibuses.
			Minibus/Bus	1.04	1.54	2.01	
				1.20	1.40	1.33	
			Minibus/Metro	1.70	2.02	3.20	
				1.43	3.03	3.10	
Sarnat et al. (2001)	Fixed site and personal $PM_{2.5}$ monitors.	Ambient O_3, NO_2, SO_2, and CO	R	$PM_{2.5}$	O_3	NO_2	SO_2	CO	Strong association between ambient NO_2 and personal $PM_{2.5}$ suggests that ambient gas may be a suitable surrogate for personal exposure.

Reference	PM metric	Copollutant metric							Primary findings
			R	$PM_{2.5}$	O_3	NO_2	SO_2	CO	
			$PM_{2.5}$	1	0.67	0.37	---	0.15	
			O_3	-0.72	1	0.02	---	-0.06	
			NO_2	0.75	-0.71	1	---	0.75	
			SO_2	-0.17	0.41	-0.17	1	-0.32	
			CO	0.69	-0.67	0.76	-0.12	1	

Table A-63.   Summary of studies relating PM, SES, and mortality and/or morbidity.

Reference	Population Studied	Data interval	Metrics Used (health; pollutant; SES variable)	Study Outcome
Bateson and Schwartz {, 2004 #1580}	Residents (>65) of Cook Co. IL with prior cardiac or respiratory hospitalization, 1988-1991	Days	All-cause mortality; PM_{10}; median household income, % with bachelor's degree, % not speaking English at home	No significant change in mortality with a 10 $\mu g/m^3$ increase in PM_{10} with SES variables.

Reference	Population Studied	Data interval	Metrics Used (health; pollutant; SES variable)	Study Outcome
Cifuentes et al. (1999)	Residents (aged 25-64) of Santiago, Chile, 1988-1996	Days	Non-trauma mortality; $PM_{2.5}$; educational level	Relative risks of non-trauma mortality were at or near significance in the group having only elementary education.
Filleul et al. (2003)	Residents (aged >65) of Bordeaux, France, 1988-1997	Days	Non-trauma mortality; BC (10th or 90th percentile levels); education level, previous occupation (domestic, skilled, intellectual)	No significant effect between BC and non-trauma mortality was observed for either SES variable.
Filleul et al. (2004)	Residents (aged >65) of Bordeaux, France, 1988-1997	Days	Non-trauma mortality, cardio-respiratory mortality; BC; educational level, previous occupation (never worked, white-collar, blue collar)	Blue collar SES group had a significant odds ratio of non-trauma mortality; high education level had a significant odds ratio for cardio-respiratory mortality.
Filluel et al. (2005)	Adults (aged 25-59 at enrollment) in 7 French cities, 1974-2000	Years	Non-trauma mortality; BC, TSP; educational level	No trend as a function of education level.
Finkelstein et al. (2003)	Adults (aged >40) in Hamilton-Burlington, Canada, 1992-2001	Years	Non-trauma mortality; TSP; mean household income	Significantly higher relative risk as a function of TSP exposure for low and high income strata
Finkelstein et al. (2003)	Adults (aged >40) in Hamilton-Burlington, Canada, 1992-2001	Years	Cardio-vascular mortality; Pollution index (TSP and SO_2) (regional, urban, near-road), traffic proximity; deprivation index	No significant relative risk as a function of pollution index or traffic proximity.
Gouveia & Fletcher (2000)	Residents (aged >65) of Sao Paulo, Brazil, 1991-1993	Days	Non-trauma mortality; PM_{10}; composite SES index	Non-significant results show relative risk of non-trauma mortality as a function of PM_{10} slightly higher in advantaged neighborhoods.
Gwynn & Thurston (2001)	Residents of NY City, 1988-1990	Days	Respiratory hospital admissions; PM_{10}, sulfate; race, insurance	Higher but non-significant relative risk for non-whites than whites but neither with relative risk significantly different from 1 for PM_{10}; relative risk significantly higher than 1 for sulfate among non-whites.
Hoel et al. (2002)	Adults (aged 55-69 at enrollment) in The Netherlands, 1992-2000	Years	Non-trauma mortality; BC (regional, urban, near-road); educational level	No significant difference in relative risk as a function of BC exposure for education level
Ito and Thurston (1996)	Residents of Cook County, IL, 1985-1990	Days	Mortality; PM_{10}; race, sex	Mortality increased with PM_{10}, effects of sex and race were noted with black females >white females >black males >white males
Krewski et al. (2000)	Adults (aged 25-74 at enrollment) in Six Cities cohort, 1974-1991	Years	Non-trauma mortality, cardio-pulmonary mortality; $PM_{2.5}$, sulfates; educational level	Relative risk significantly greater than 1 for non-trauma mortality among those with less than high school education caused by increased $PM_{2.5}$ and sulfate exposures
Krewski et al. (2000)	Adults (aged >30 at enrollment) in American Cancer Society cohort, follow-up 1982-1989	Years	Non-trauma mortality, cardio-pulmonary mortality; $PM_{2.5}$, sulfates; educational level	Relative risk significantly greater than 1 for non-trauma and cardio-pulmonary mortality as a function of $PM_{2.5}$ exposure for less than high school and high school education; relative risk significantly greater than 1 for non-trauma and cardio-pulmonary mortality as a function of sulfate exposure for less than high school education.
Lee et al. (2006)	Children (aged < 15) in Seoul, Korea, 2002	Days	Hospitalized for asthma; PM_{10}; SES (listed as "high," "medium," or "low" of monitor site without explanation of criteria)	PM_{10} level does not vary linearly with increasing SES. Relative risk significantly greater than 1 for high and low SES.
Linn et al. (1999)	Residents of South Coast Air Basin, CA, 1992-1995	Days	Respiratory and cardiovascular hospital admissions; PM_{10}; sex, ethnicity (white, black, Hispanic, other)	Impact of PM_{10} on cardiovascular effects increased in blacks and whites relative to Hispanics and others.
Martins et al. (2004)	Residents (aged >60) of six zones of Sao Paulo, Brazil, 1997-1999	Days	Respiratory mortality; PM_{10}; % with college education, % families with monthly income >$3500, % living in slums	% with college education and % families with monthly income >$3500 have negative impact of effect of PM_{10} on respiratory mortality, % people living in slums had positive effect.
Norris et al. (2000)	Children (aged <18) in Seattle, WA, 1995-1996	Days	Emergency room visits for asthma; PM_{10}; high vs. low emergency room use	Relationship between PM_{10} and emergency room visits not significantly impacted by overall emergency room use.

Reference	Population Studied	Data interval	Metrics Used (health; pollutant; SES variable)	Study Outcome
O'Neill et al. (2004)	Residents (aged >65) of Mexico City, Mexico, 1996-1998	Days	Non-trauma mortality; PM_{10} and O_3; % homes with electricity, % homes with piped water, % literacy, % indigenous language speakers	PM_{10} not associated with non-trauma mortality (but significant associations for O_3).
Ou et al. (2008)	Residents (aged >30) of Hong Kong, 1998	Days	Non-trauma mortality; PM_{10}; housing type, occupational level, education level	Housing type and blue-collar caused significantly greater impact of PM_{10} on mortality compared with single family housing or white-collar and never employed, respectively.
Pope et al. (2002)	Adults (aged >30 at enrollment) in American Cancer Society cohort, follow-up 1982-1989	Years	Mortality; $PM_{2.5}$; education level	Non-trauma mortality increased with $PM_{2.5}$ increase; greatest impact among those with less than high school education.
Romieu (2004)	Children (1 mo. – 1 yr.) in Ciudad Juarez, Mexico, 1997-2001	Days	Total mortality, respiratory mortality; PM_{10}; composite SES index	No significant association between pollutants and total mortality; significant odds ratio for respiratory mortality and PM_{10} for lowest SES; nearly significant association between SES and PM_{10}
Samet et al. (2000)	Residents (all ages) of 20 US cities, 1987-1994	Days	Non-trauma mortality; PM_{10} (adj for O_3, SO_2, NO_2, CO); % high school graduates, % annual income <\$12,675, % annual income >\$100,000	No significant association between PM_{10}-related non-trauma mortality and SES variables.
Schwartz (2000)	Residents (all ages) of 10 US cities, 1986-1993	Days	Non-trauma mortality; PM_{10}; unemployment rate, % below poverty level; % with college degree	No significant difference in the effect of poverty, college degree, or unemployment rate on the influence of PM on mortality, but unemployment rate effect slightly higher.
Tolbert et al. (2000)	Children (aged <16) in Atlanta, GA, 1993-1995	Days	Emergency room visits for asthma; PM_{10}; race, Medicaid status, sex	Impact of PM_{10} on asthma emergency room visits was not impacted by any SES variable.
Villeneuve et al. (2003)	Residents (aged >65) of Vancouver, Canada, 1986-1999	Days	Non-trauma mortality; TSP, PM_{10}, and $PM_{2.5}$; mean family income	Significantly higher non-trauma mortality as a function of TSP for high and low income.
Wheeler & Ben-Schlomo (2005)	Respondents to Health Survey of England, 1995-1997	n/a	Decreased lung function, asthma prevalence; air quality index based on PM_{10}, NO_2, SO_2, benzene; social class, sex	In urban areas, lower SES significantly associated with poor air quality; in rural areas, higher SES significantly associated with poor air quality. Lower SES was shown to impact the relationship between PM_{10} and lung function among men but not women.
Wilson et al. (2007)	Residents (all ages) of Phoenix, AZ, 1995-1997	Days; lag 0-5, 6-day moving avg	Non-trauma mortality, cardiovascular mortality; $PM_{2.5}$, $PM_{10-2.5}$; % <HS diploma, % below poverty level, location within city	The lower SES region of Central Phoenix had higher risk of mortality as a function of $PM_{2.5}$ exposure. Modification of the effect of $PM_{10-2.5}$ on mortality was observed for the higher SES region.
Wojtyniak et al. (2001)	Residents (aged 0-70 or >70) of Cracow, Lodz, Poznan, and Wrockrw (Poland), 1990-1996	Days	Non-trauma and cardiovascular mortality; BC; educational level	Non-trauma and cardiovascular mortality was significantly associated with BC for those with less than secondary education.
Wong et al. (2008)	Residents of 209 tertiary planning units (smallest classification for a town), 1996-2002	Days	Non-trauma and cardiovascular mortality; PM_{10}; social deprivation index	Significant associations between PM_{10} and non-trauma and cardiovascular mortality for medium and high social deprivation index.
Zanobetti et al. (2000a)	Residents of 10 US cities, 1985-1994	Days	Respiratory and cardiovascular hospital admissions; PM_{10}; % poverty, % non-white	No significant effect of SES factors on relationship between hospital admissions and PM_{10}.
Zanobetti et al. (2000b)	Medicare recipients in Cook County, IL, 1985-1994	Days	Respiratory and cardiovascular hospital admissions; PM_{10}; race, sex	No significant effect of SES factors on relationship between hospital admissions and PM_{10}.
Zanobetti & Schwartz (2000)	Residents (all ages) of Chicago, Detroit, Minneapolis-St. Paul, and Pittsburgh, 1986-1993	Days	Non-trauma mortality; PM_{10} (excluding days when concentrations exceeded 150 $\mu g/m^3$); education below or above high school	Higher but non-significant % increase in non-trauma mortality with 10 $\mu g/m^3$ increase in PM_{10} for people with less than high school education.

Reference	Population Studied	Data interval	Metrics Used (health; pollutant; SES variable)	Study Outcome
Zeka et al. (2006)	Residents (all ages) of 20 US cities, 1989-2000	Days	Non-trauma mortality, respiratory mortality, cardiac mortality, mortality from infarction, mortality from stroke; PM_{10}; educational level	No significant relationship between increased mortality (any type) with 10 $\mu g/m^3$ increase in PM_{10} for any SES factors.

Some studies measured constituents other than PM; those metrics and results are not reported here.

Adapted from Laurent et al. (2008) and O'Neill et al. (2003).

A.1.1. Monitor Distribution with Respect to Socioeconomic Status
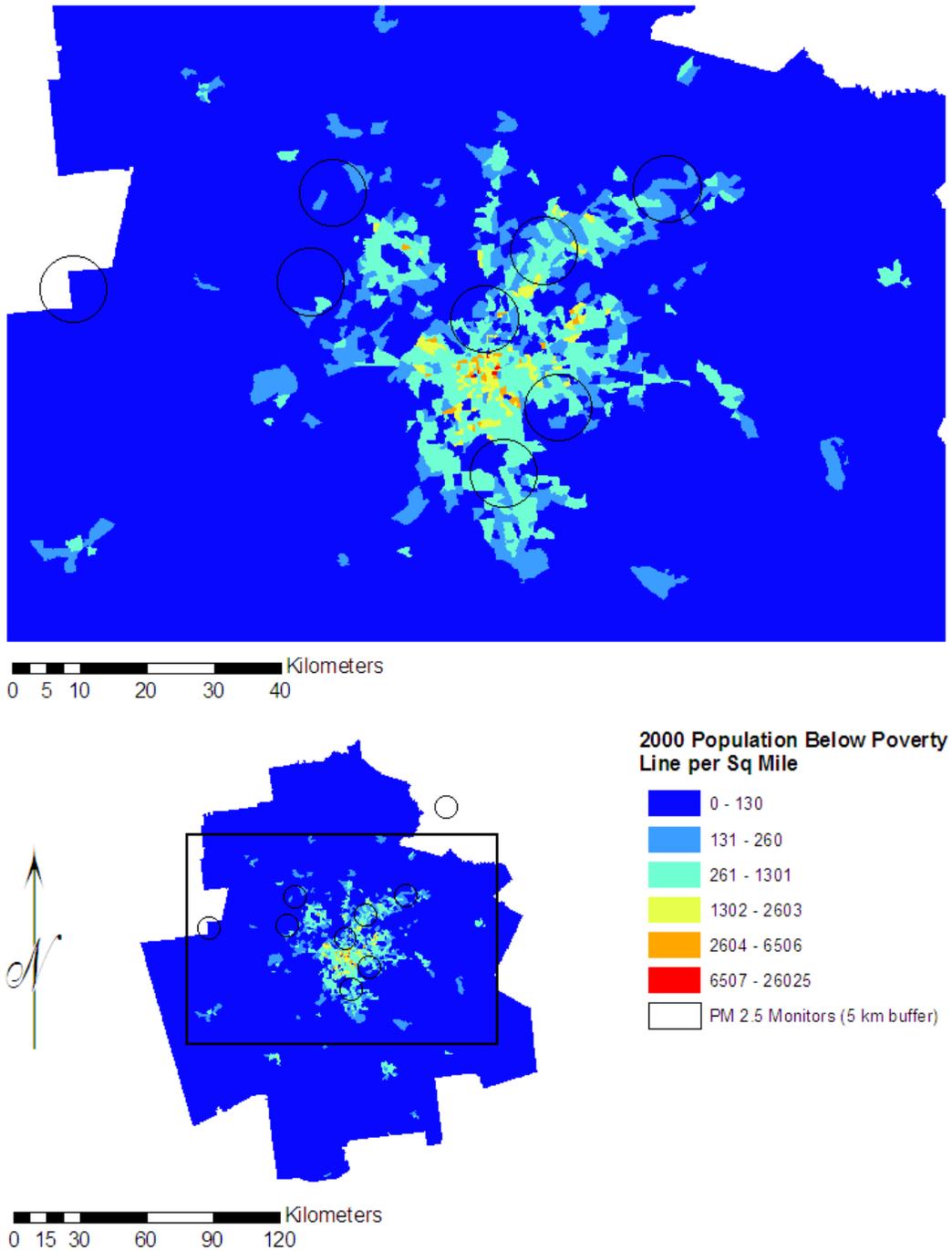
Figure A-201. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Atlanta, GA.
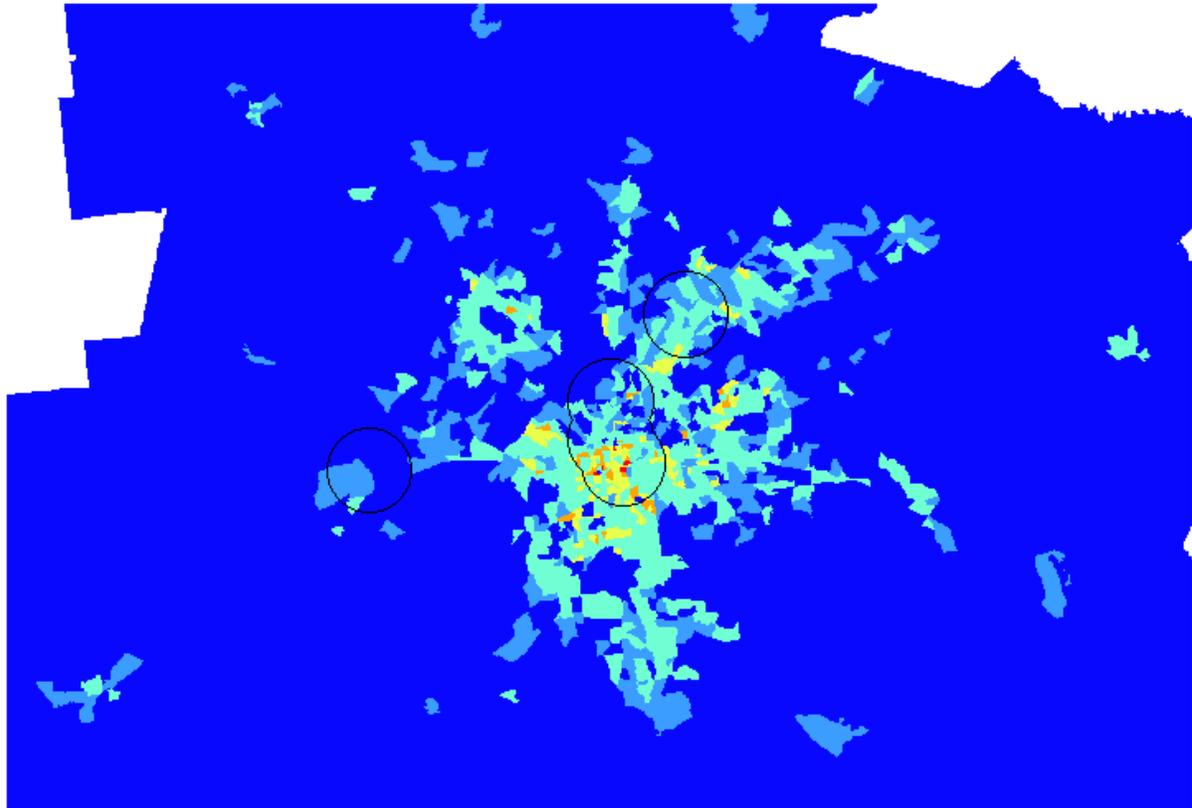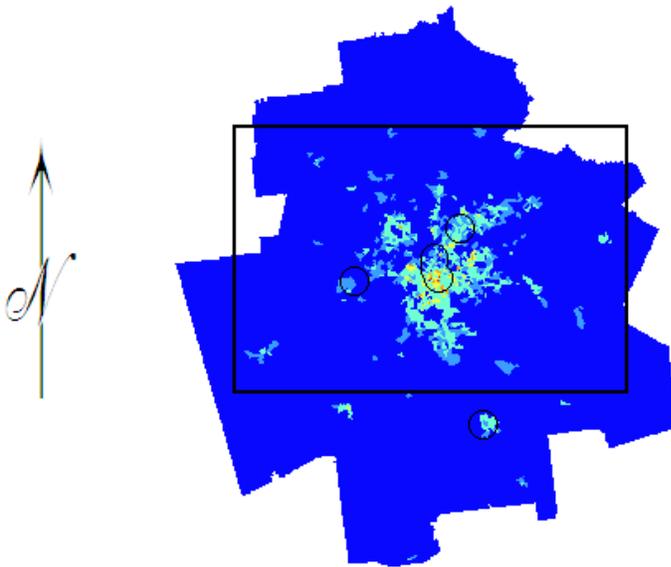
2000 Population Below Poverty Line per Sq Mile

- ■ 0 - 130
- ■ 131 - 260
- ■ 261 - 1301
- ■ 1302 - 2603
- ■ 2604 - 6506
- ■ 6507 - 26025
- ☐ PM 10 Monitors (5 km buffer)

**Figure A-202.** PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Atlanta, GA.

Figure A-203. PM₂.₅ sampler distribution in comparison with number of individuals having less than high school education, Atlanta, GA.
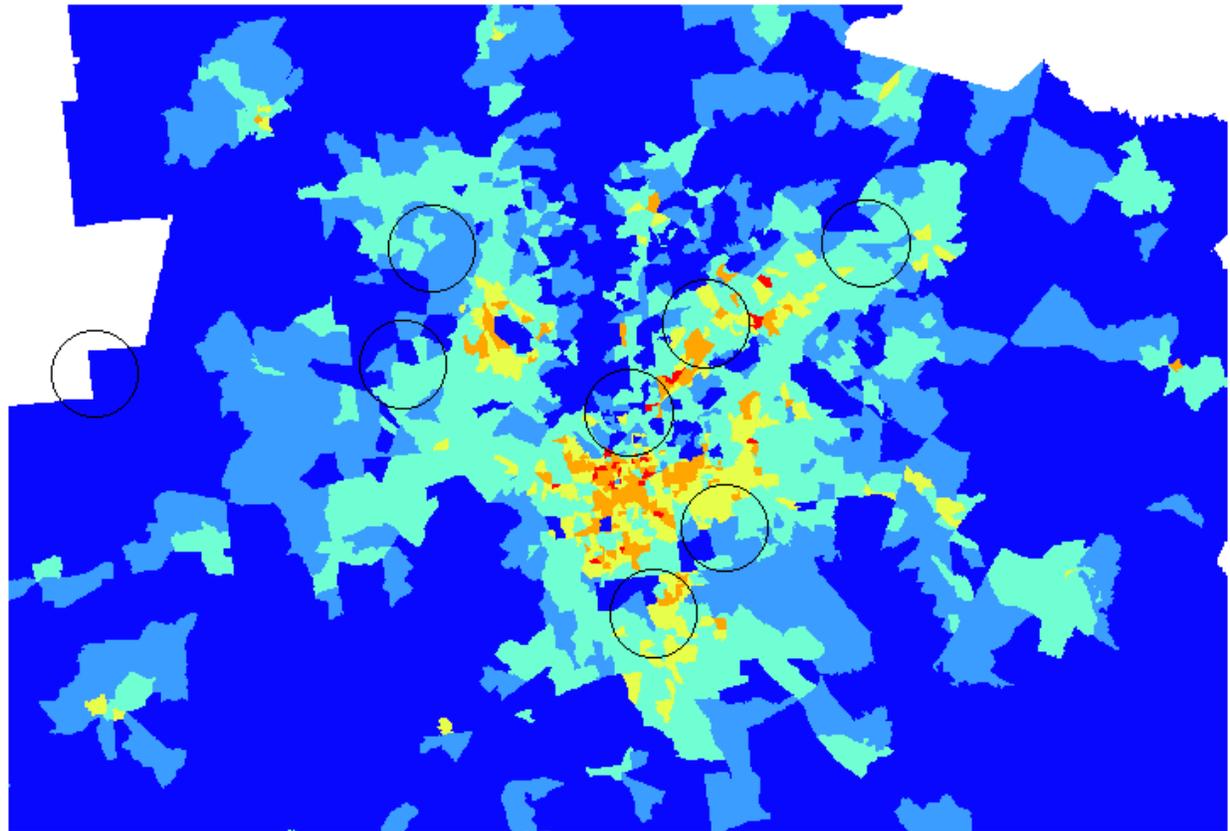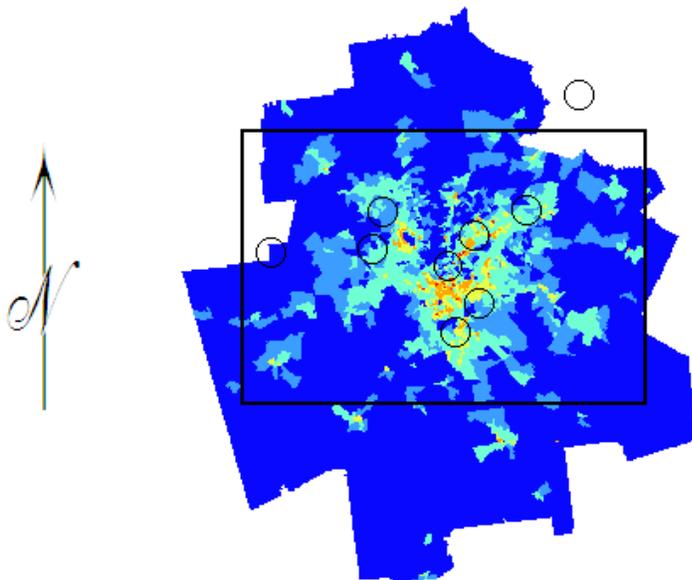
2000 Population with Less than High School Degree per Sq Mile

- 0 - 40
- 41 - 80
- 81 - 401
- 402 - 803
- 804 - 2006
- 2007 - 8025
- PM 10 Monitors (5 km buffer)
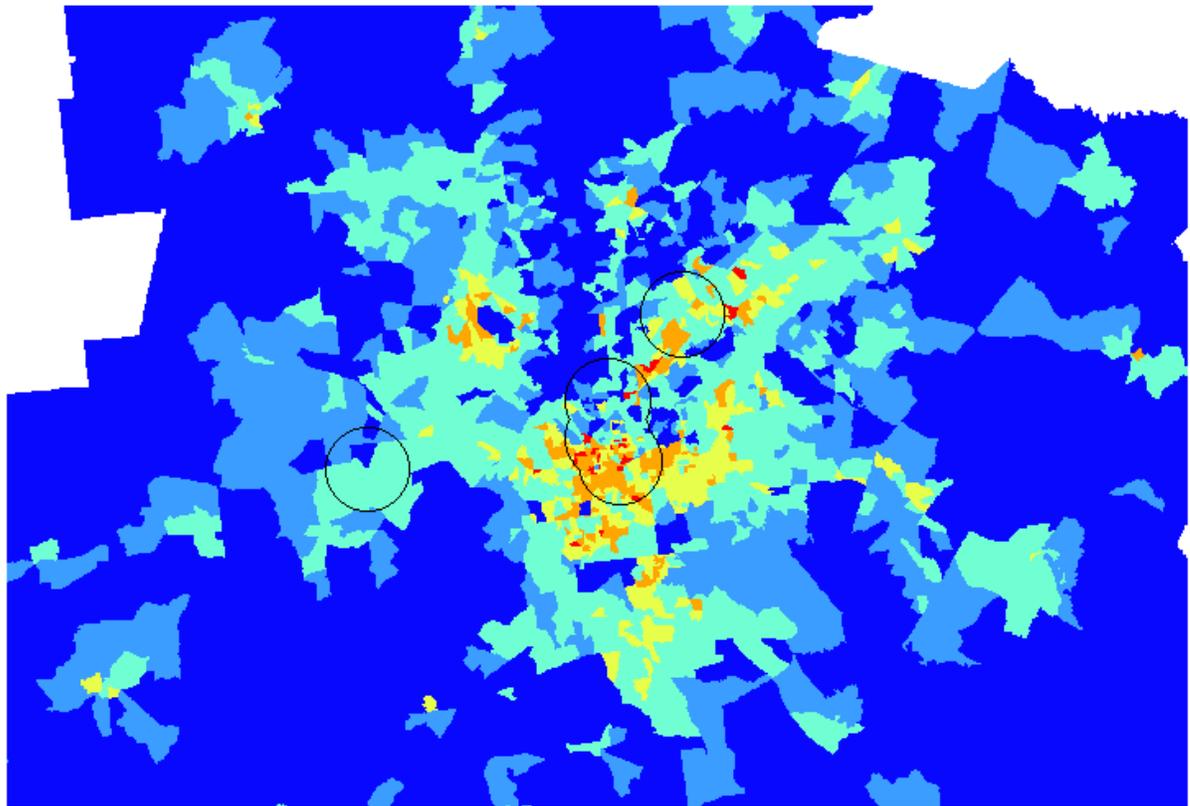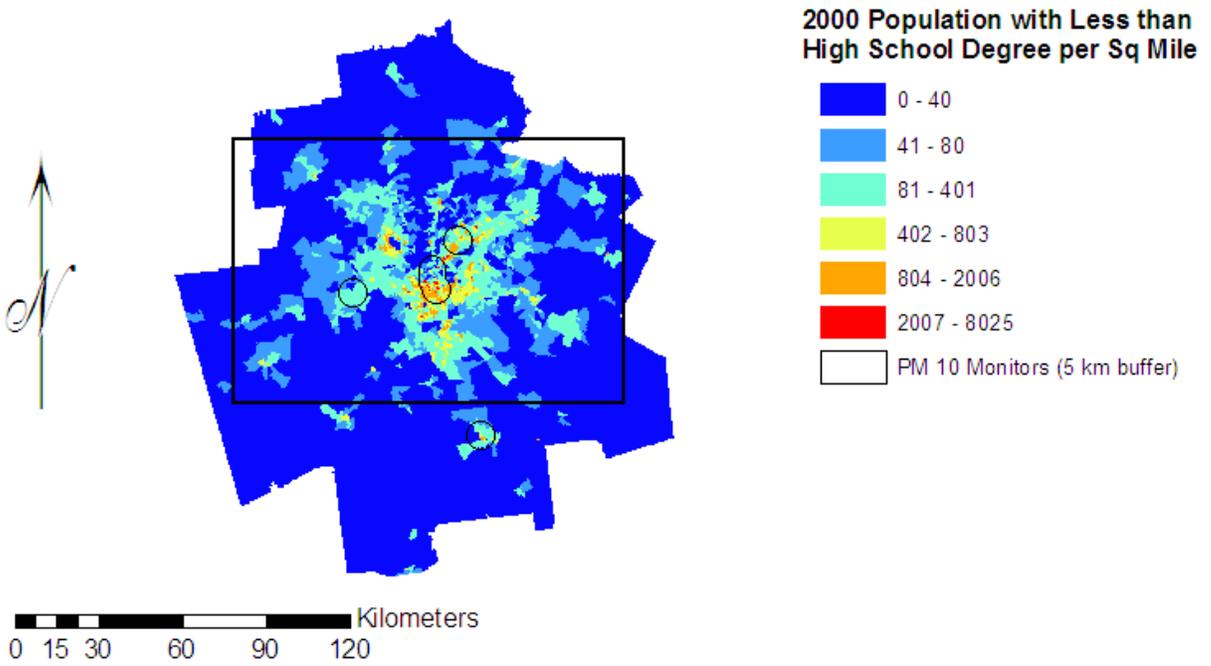
**Figure A-204.** PM₁₀ sampler distribution in comparison with number of individuals having less than high school education, Atlanta, GA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 35
- 36 - 70
- 71 - 350
- 351 - 699
- 700 - 1748
- 1749 - 6992
- PM 2.5 Monitors (5 km buffer)
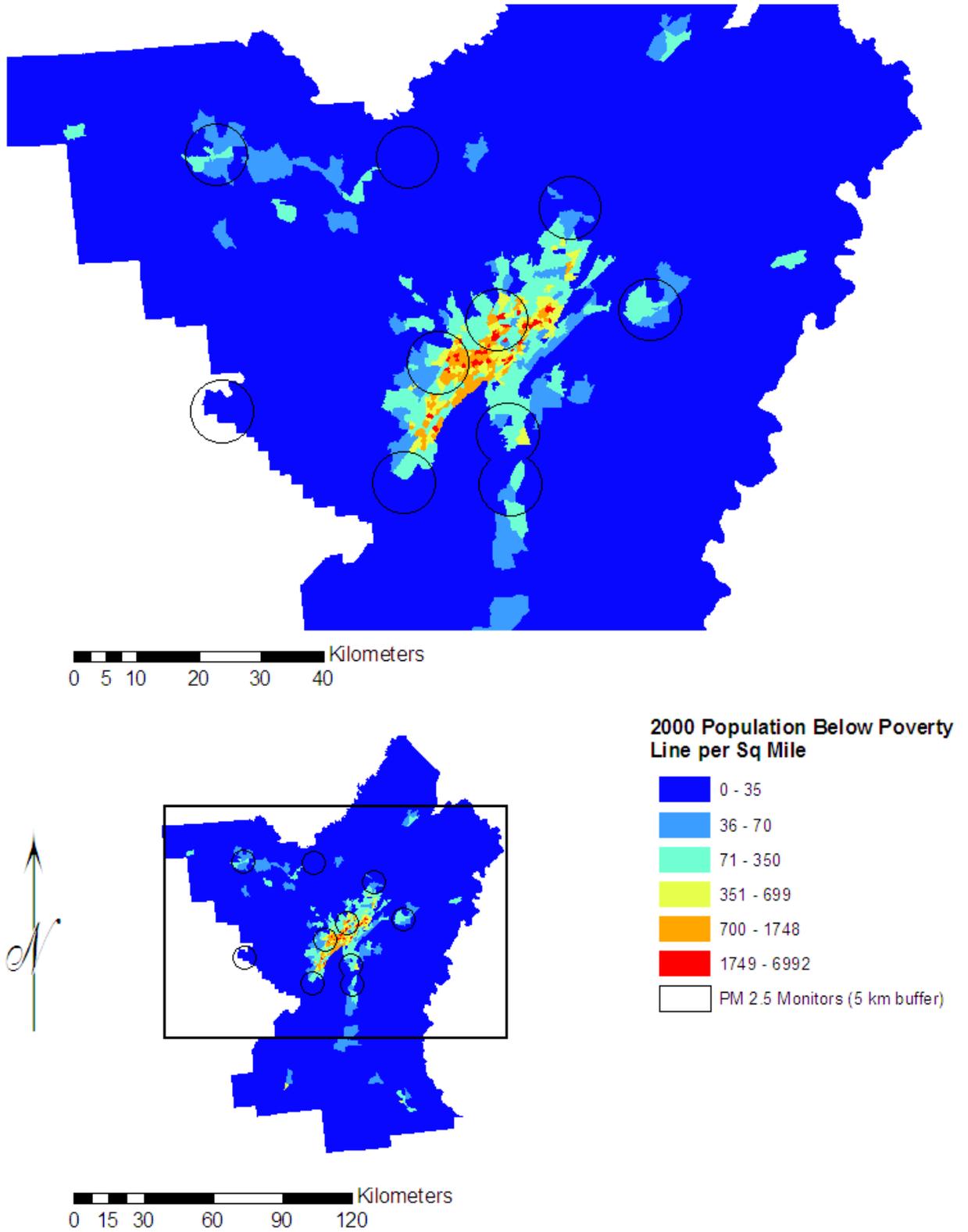
Figure A-205. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Birmingham, AL.

2000 Population Below Poverty Line per Sq Mile

- 0 - 35
- 36 - 70
- 71 - 350
- 351 - 699
- 700 - 1748
- 1749 - 6992
- PM 10 Monitors (5 km buffer)
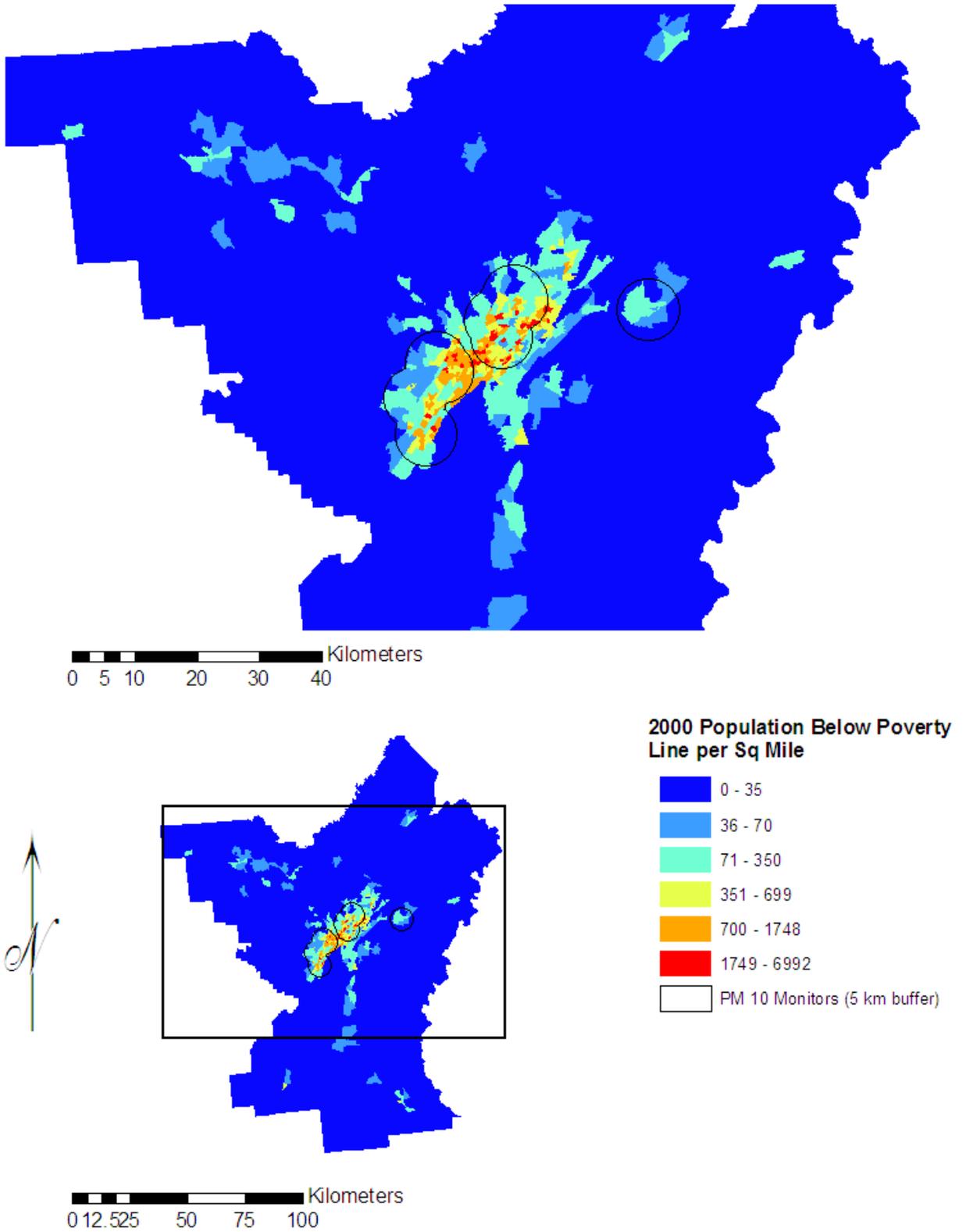
Figure A-206. PM_{10} sampler distribution in comparison with number of individuals below the poverty line, Birmingham, AL.
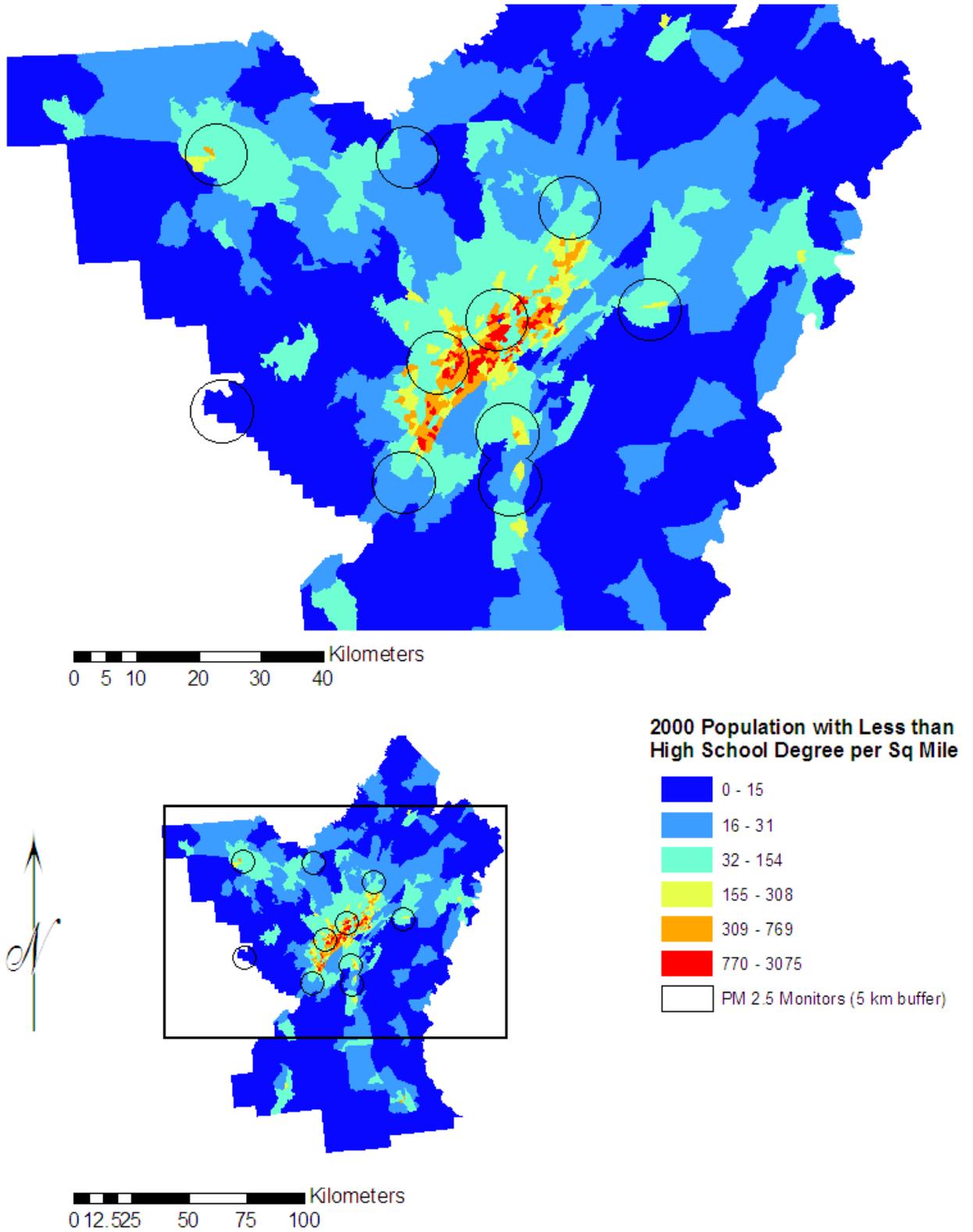
Figure A-207.   PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Birmingham, AL.
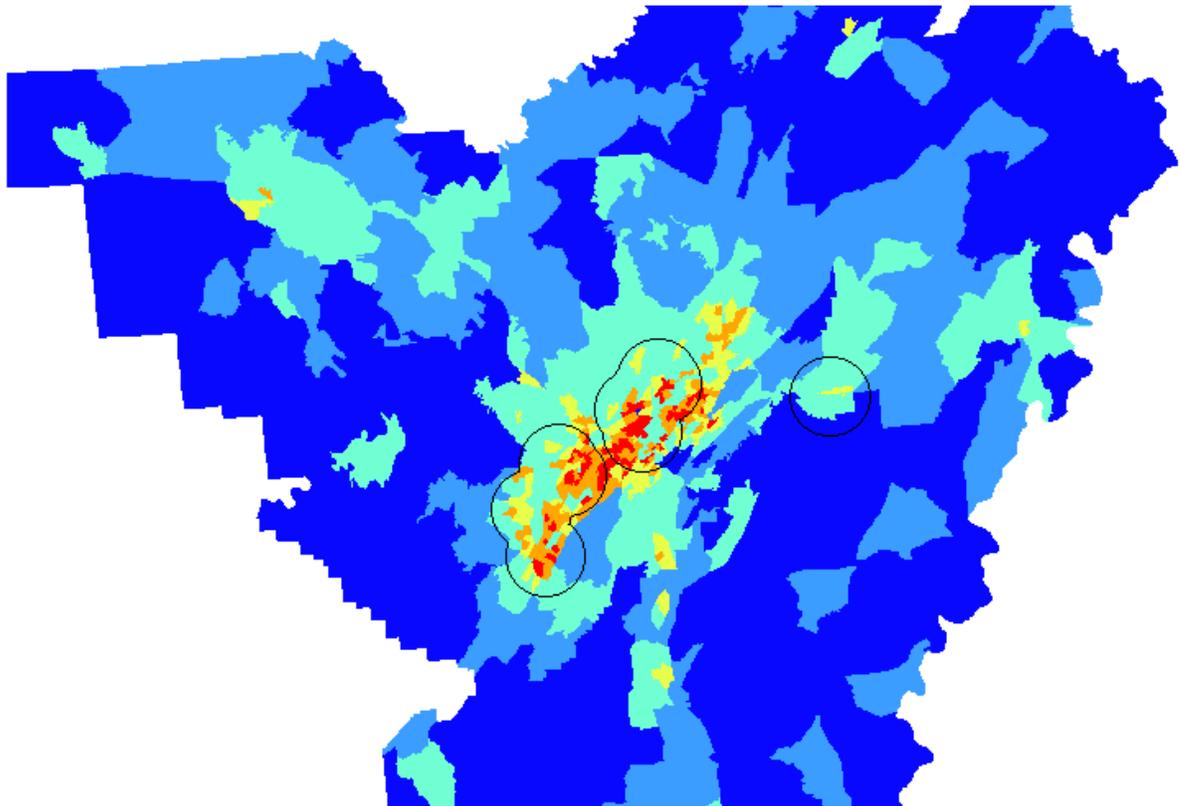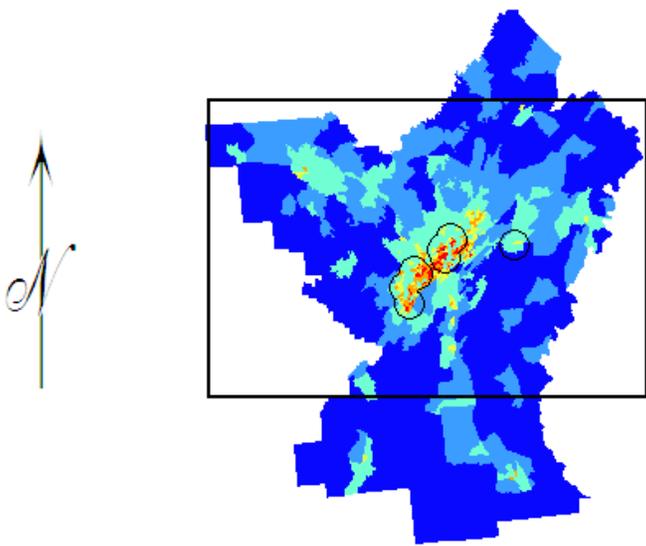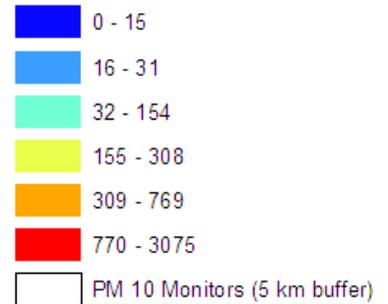
Figure A-208. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Birmingham, AL.

Legend: 2000 Population with Less than High School Degree per Sq Mile

- 0 - 15
- 16 - 31
- 32 - 154
- 155 - 308
- 309 - 769
- 770 - 3075
- PM 10 Monitors (5 km buffer)
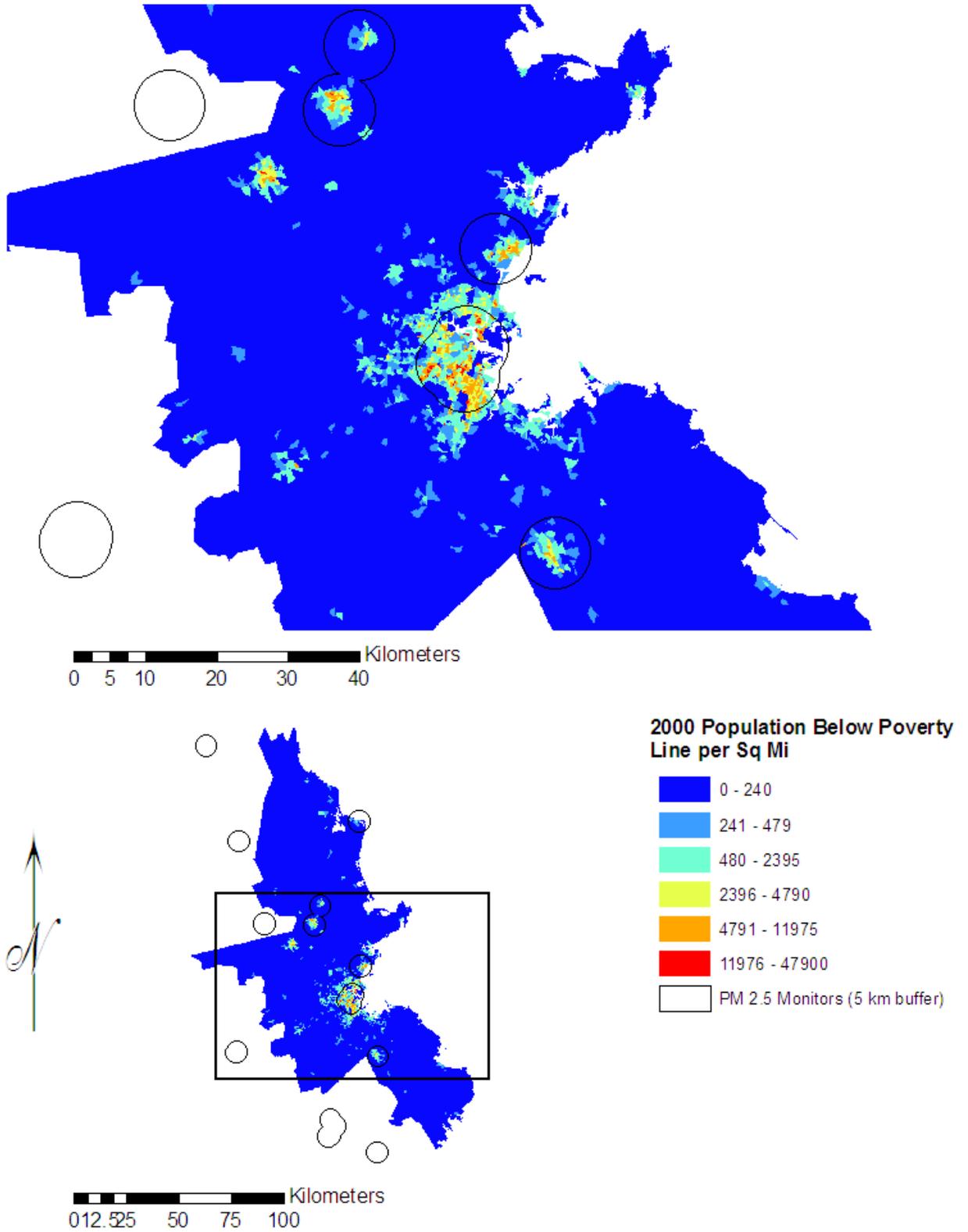
Figure A-209. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Boston, MA.

2000 Population Below Poverty Line per Sq Mi

- 0 - 240
- 241 - 479
- 480 - 2395
- 2396 - 4790
- 4791 - 11975
- 11976 - 47900
- PM 10 Monitors (5 km buffer)
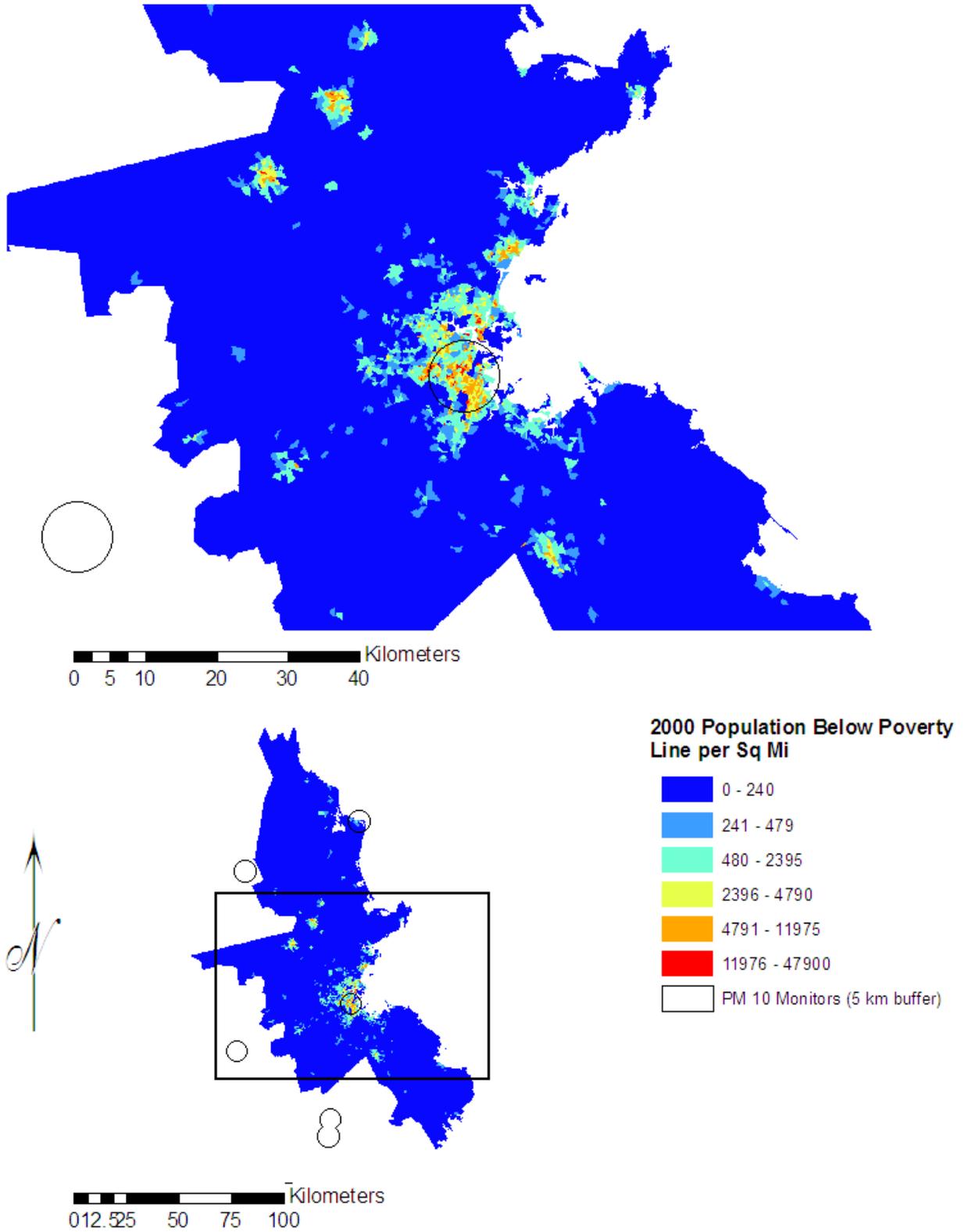
Figure A-210. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Boston, MA.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 238
- 239 - 476
- 477 - 2380
- 2381 - 4760
- 4761 - 11900
- 11901 - 47600
- PM 2.5 Monitors (5 km buffer)
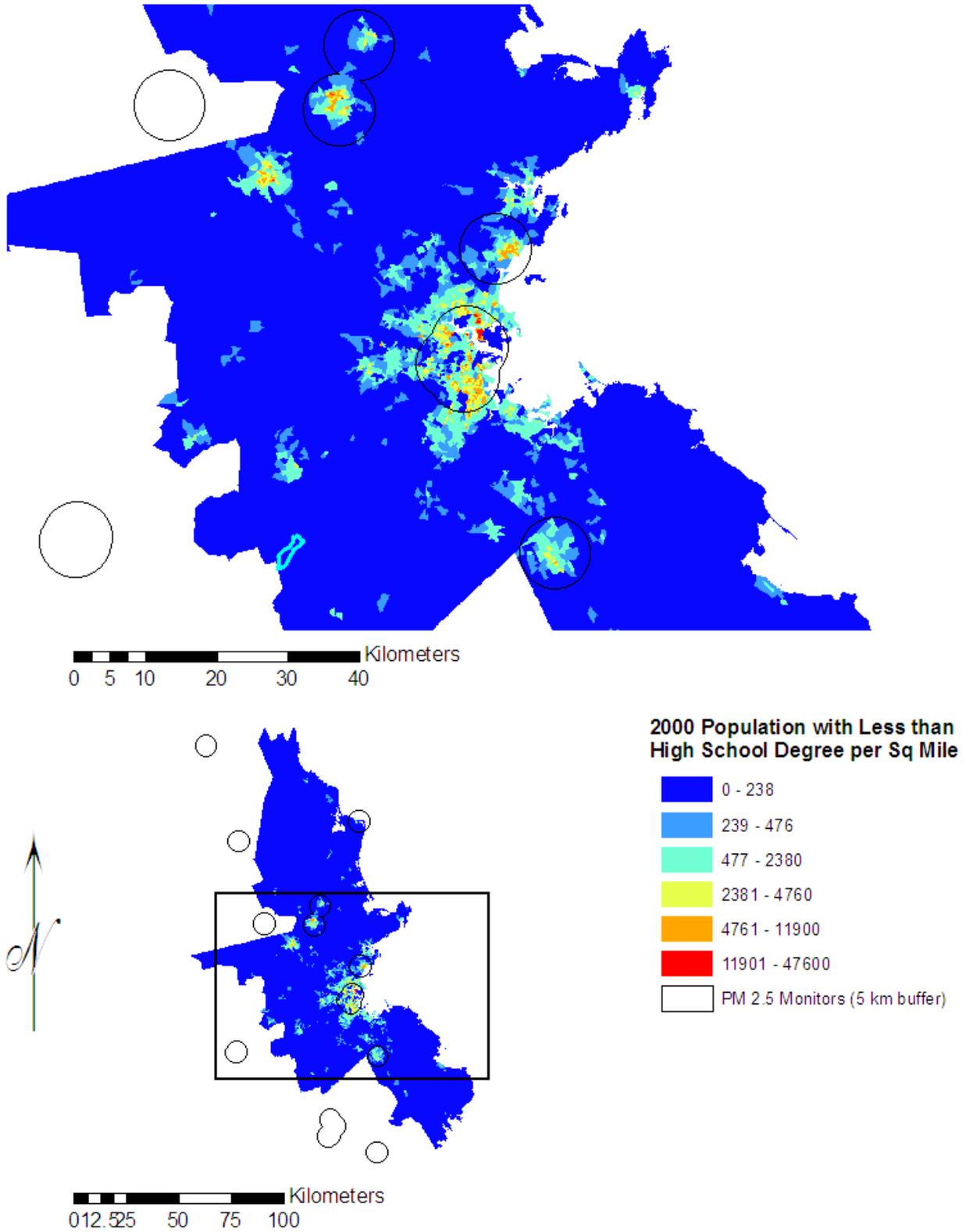
Figure A-211. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Boston, MA.
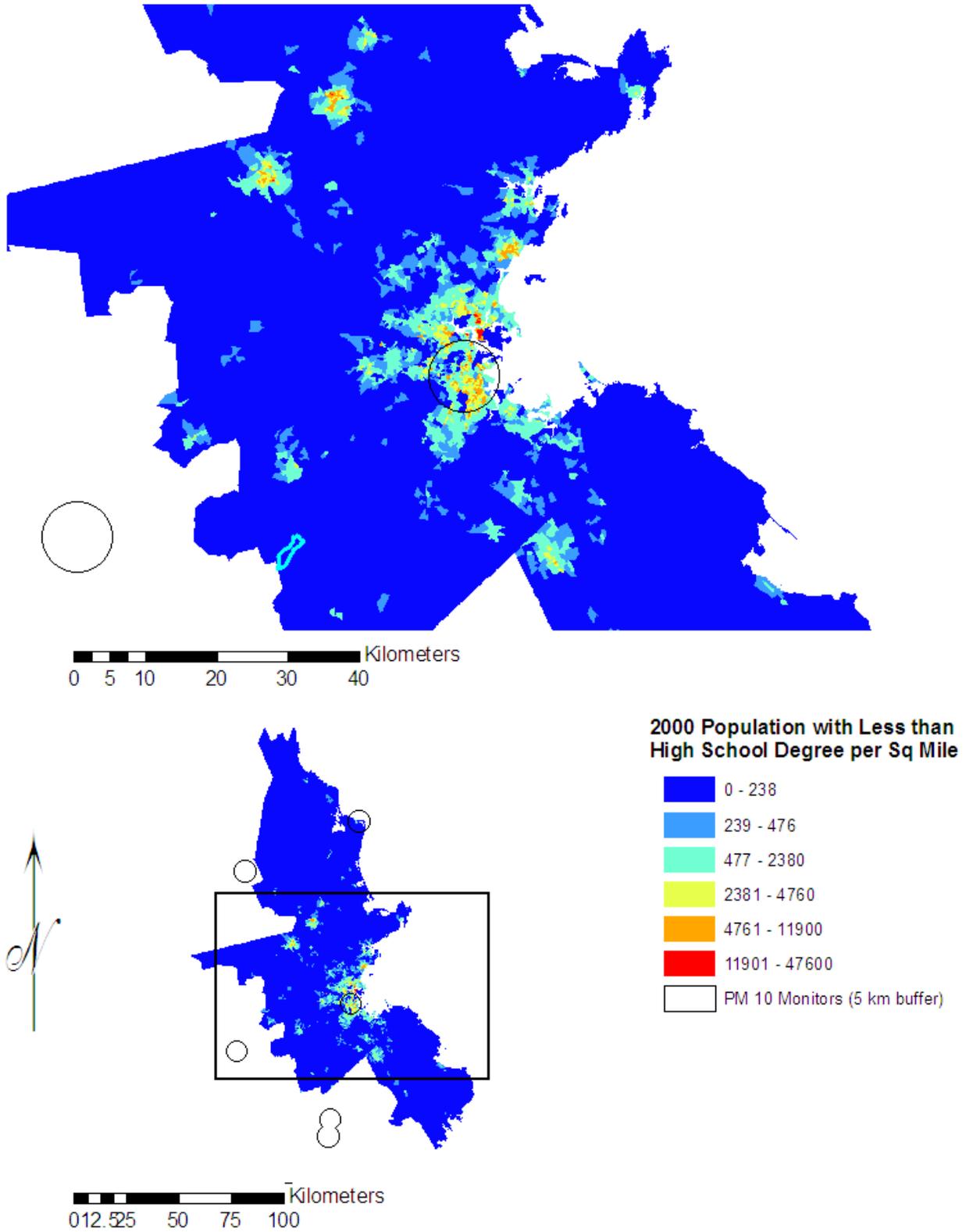
Figure A-212.   PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Boston, MA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 288
- 289 - 576
- 577 - 2878
- 2879 - 5757
- 5758 - 14392
- 14393 - 57567
- PM 2.5 Monitors (5 km buffer)
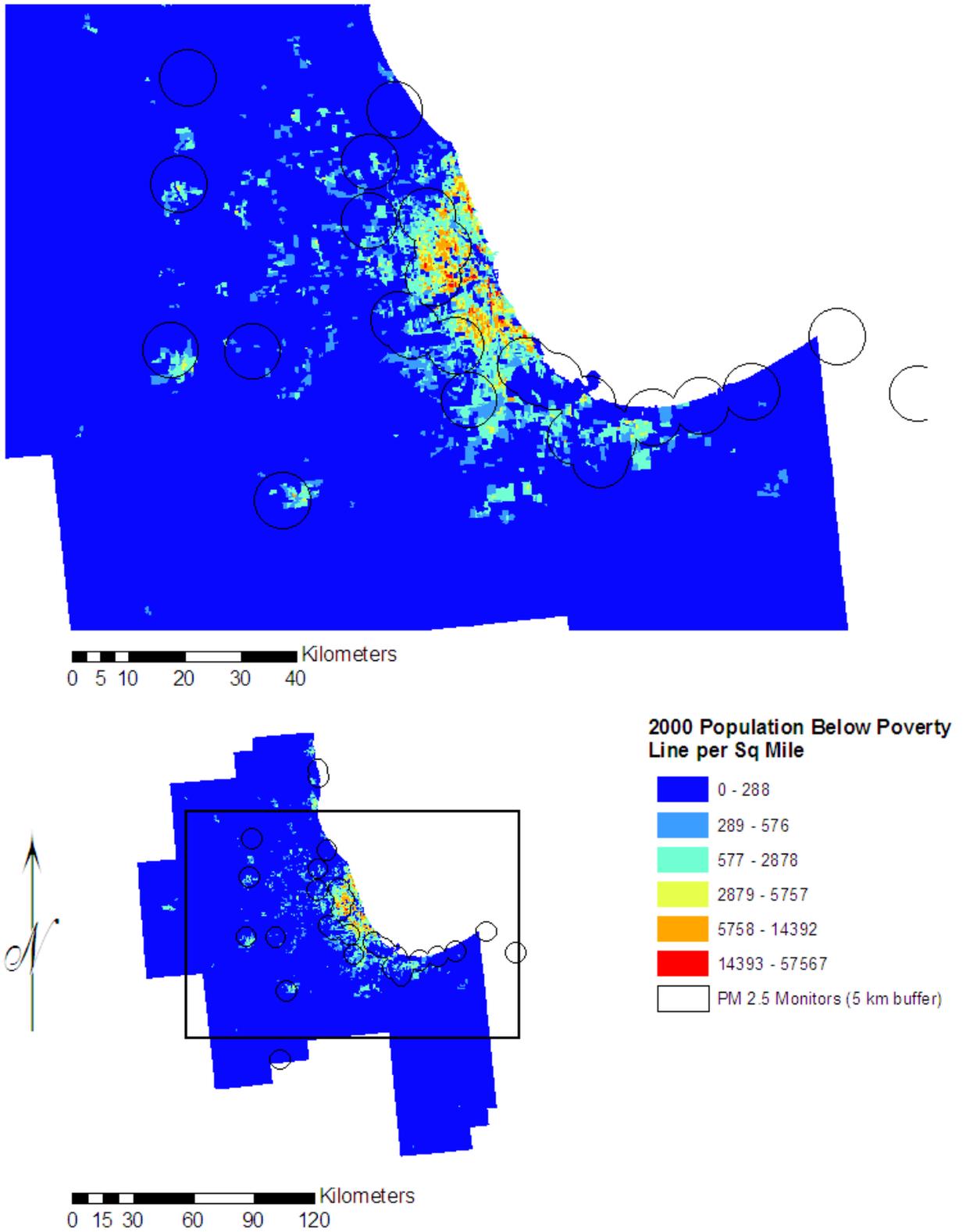
Figure A-213. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Chicago, IL.
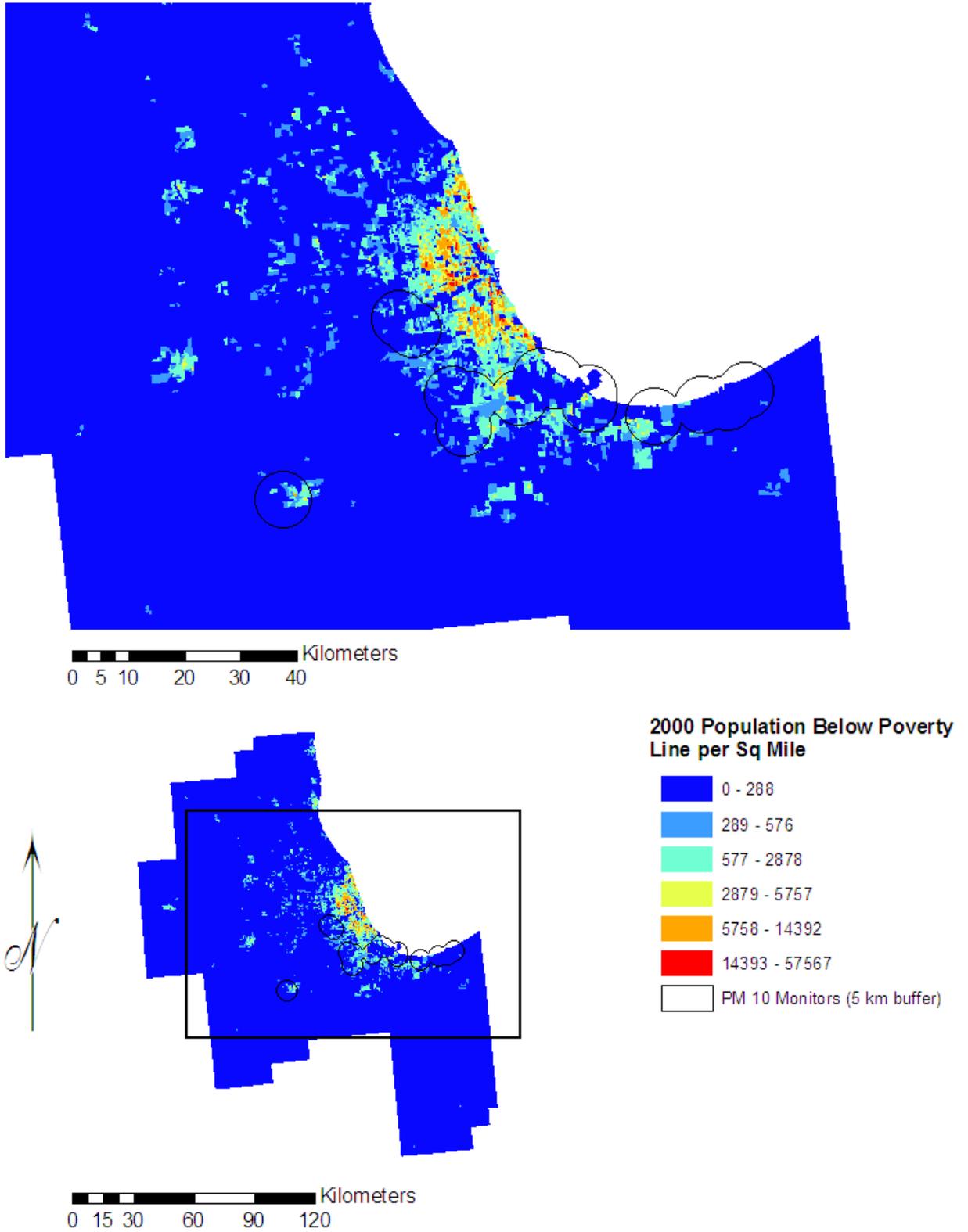
Figure A-214. PM₁₀ sampler distribution in comparison with number of individuals below the poverty line, Chicago, IL.

Kilometers

0 5 10 20 30 40

2000 Population with Less than High School Degree per Sq Mile

- 0 - 116
- 117 - 232
- 233 - 1162
- 1163 - 2323
- 2324 - 5808
- 5809 - 23233
- PM 2.5 Monitors (5 km buffer)

Kilometers

0 15 30 60 90 120
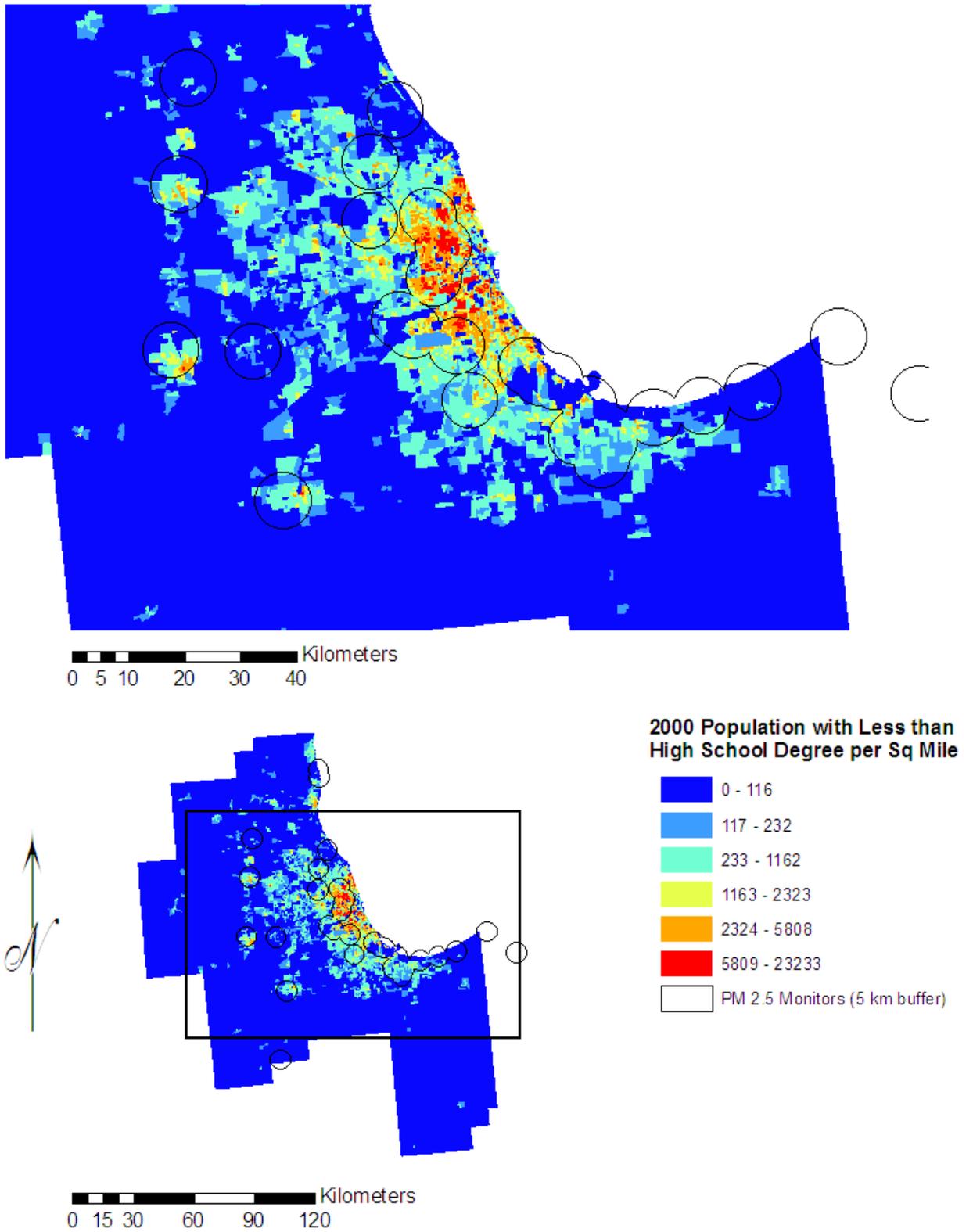
Figure A-215.   PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Chicago, IL.

2000 Population with Less than High School Degree per Sq Mile

- ■ 0 - 116
- ■ 117 - 232
- ■ 233 - 1162
- ■ 1163 - 2323
- ■ 2324 - 5808
- ■ 5809 - 23233
- □ PM 10 Monitors (5 km buffer)
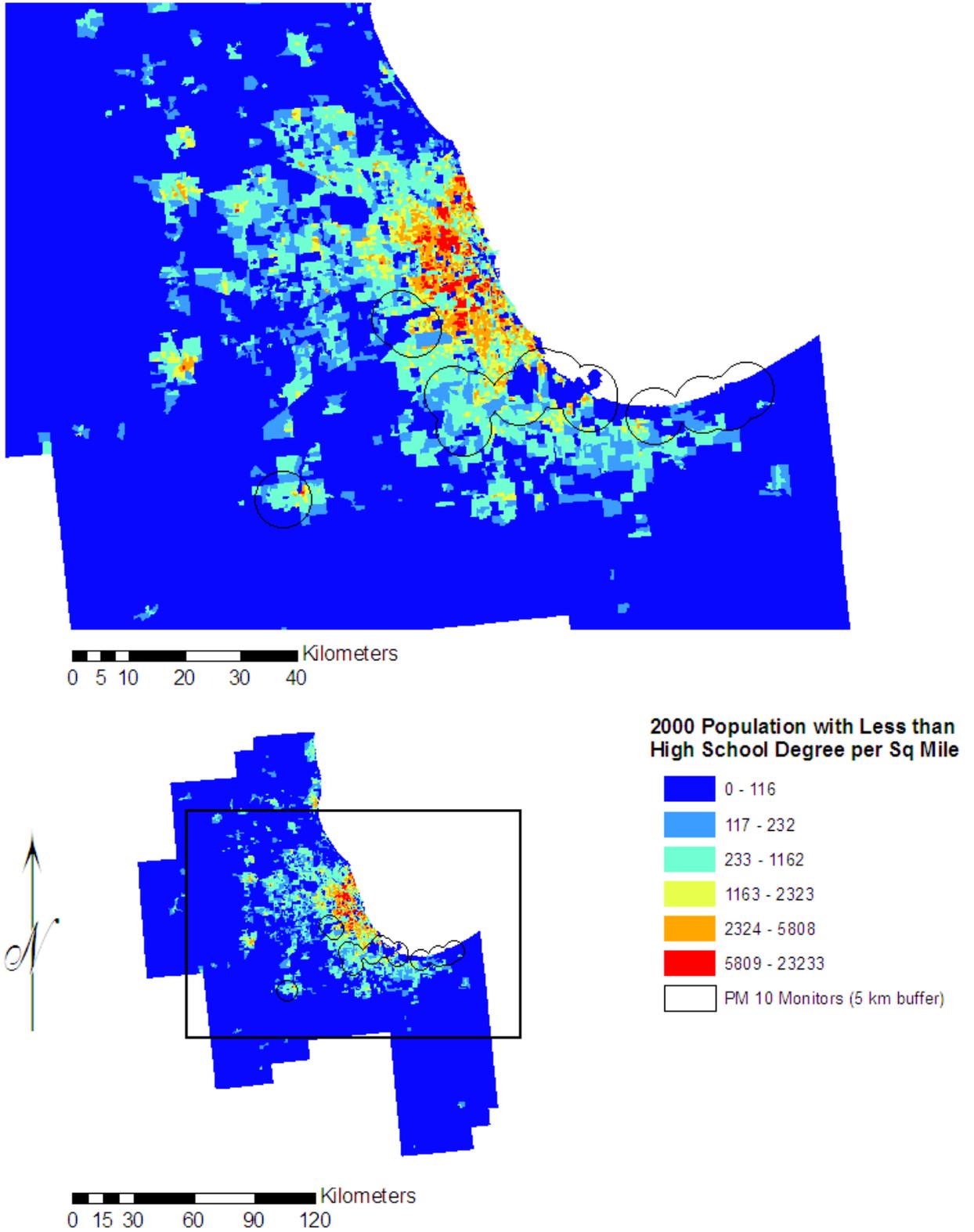
Figure A-216. PM₁₀ sampler distribution in comparison with number of individuals having less than high school education, Chicago, IL.

2000 Population Below Poverty Line per Sq Mile

- 0 - 42
- 43 - 84
- 85 - 422
- 423 - 844
- 845 - 2111
- 2112 - 8442
- PM 2.5 Monitors (5 km buffer)
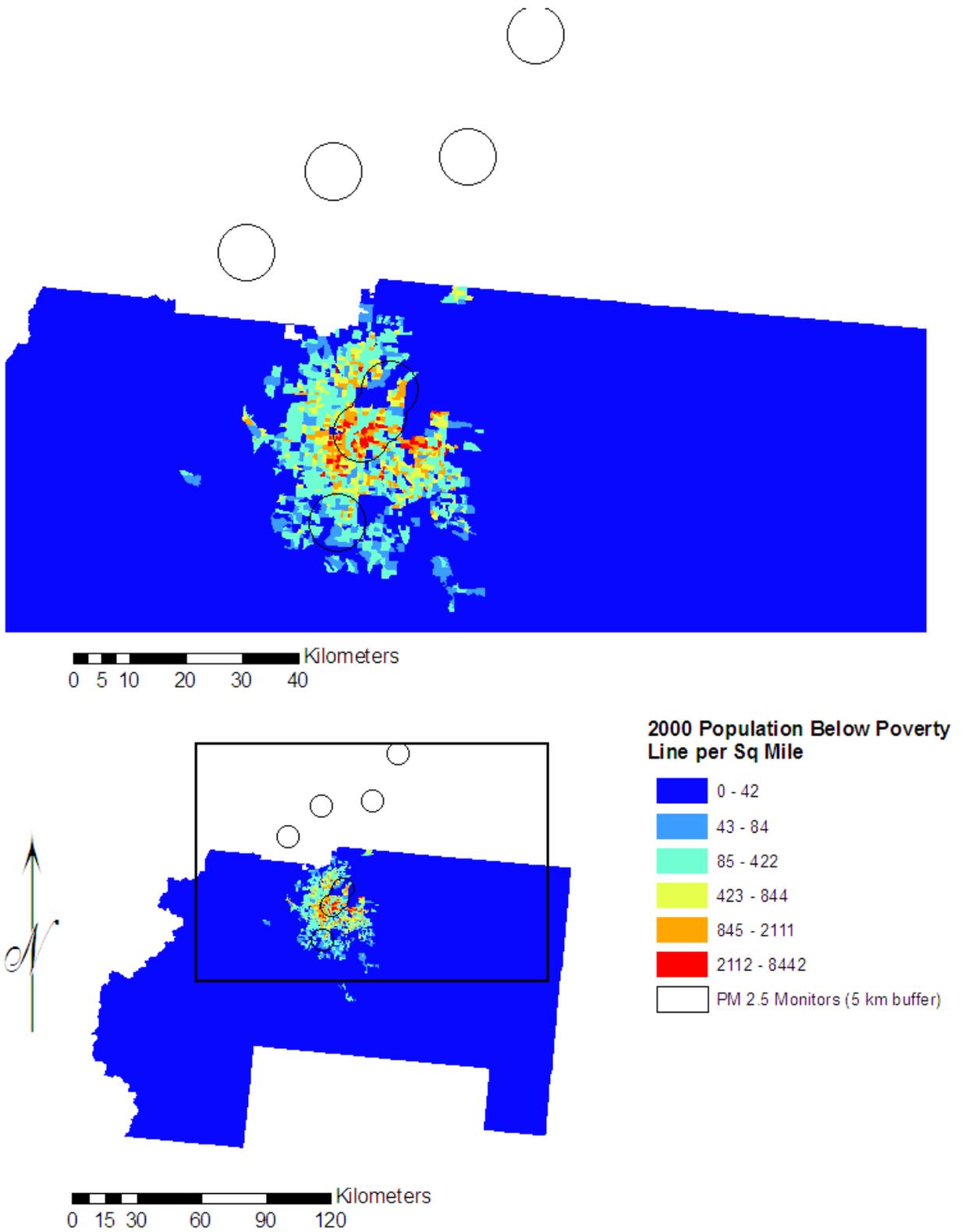
Figure A-217. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Denver, CO.
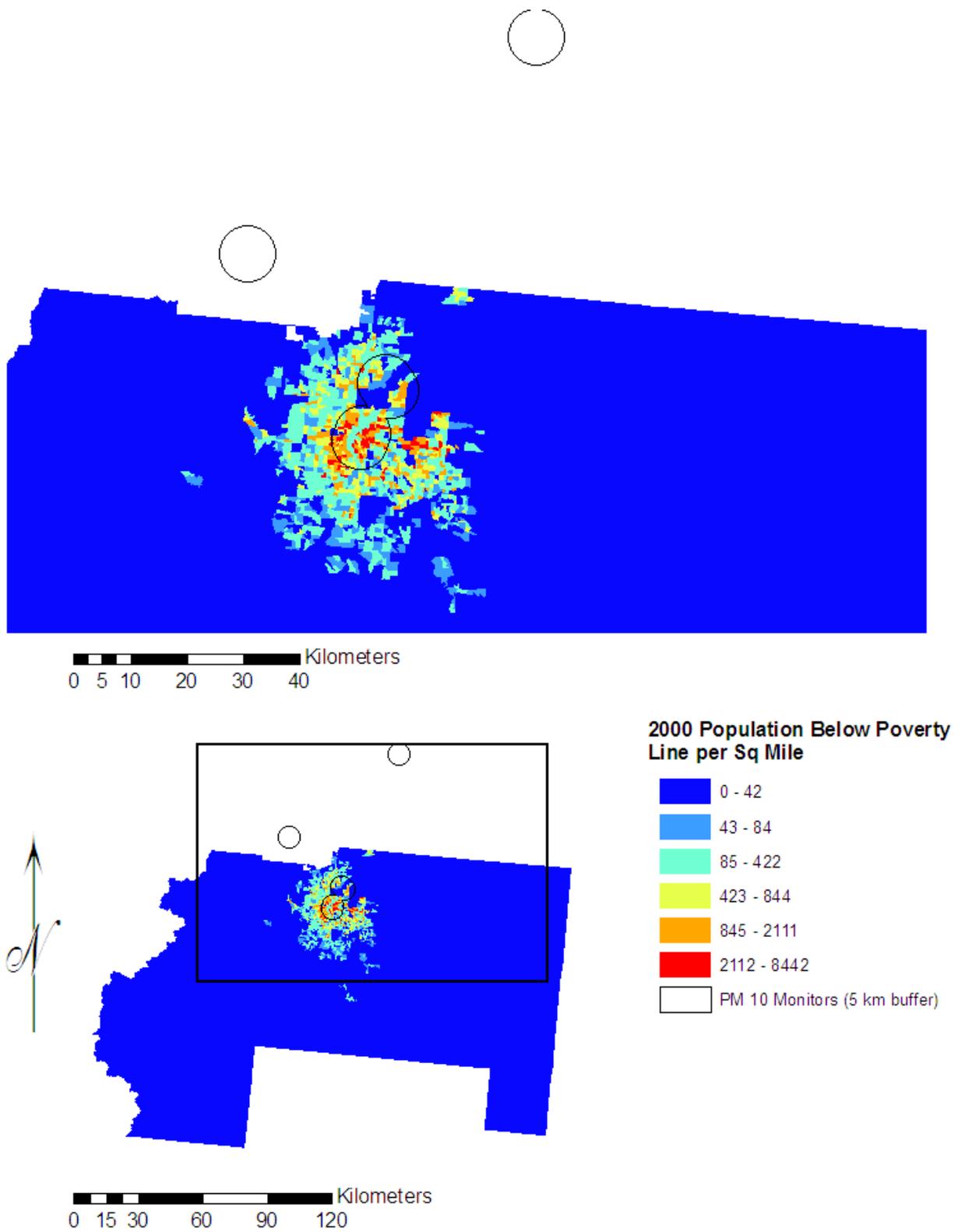
Figure A-218. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Denver, CO.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 44
- 45 - 87
- 88 - 436
- 437 - 872
- 873 - 2179
- 2180 - 8717
- PM 2.5 Monitors (5 km buffer)
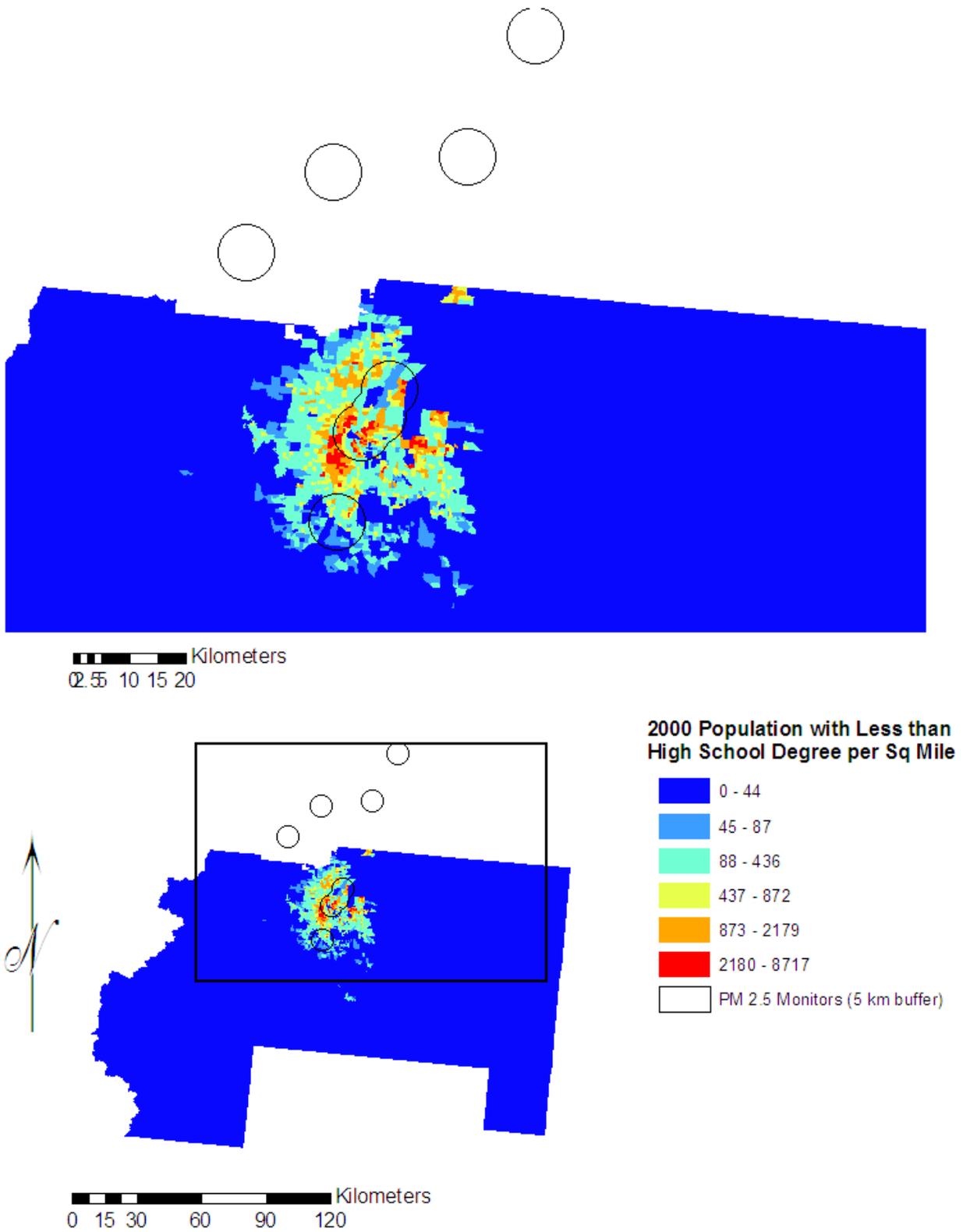
Figure A-219. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Denver, CO.

**2000 Population with Less than High School Degree per Sq Mile**

- 0 - 44
- 45 - 87
- 88 - 436
- 437 - 872
- 873 - 2179
- 2180 - 8717
- PM 10 Monitors (5 km buffer)
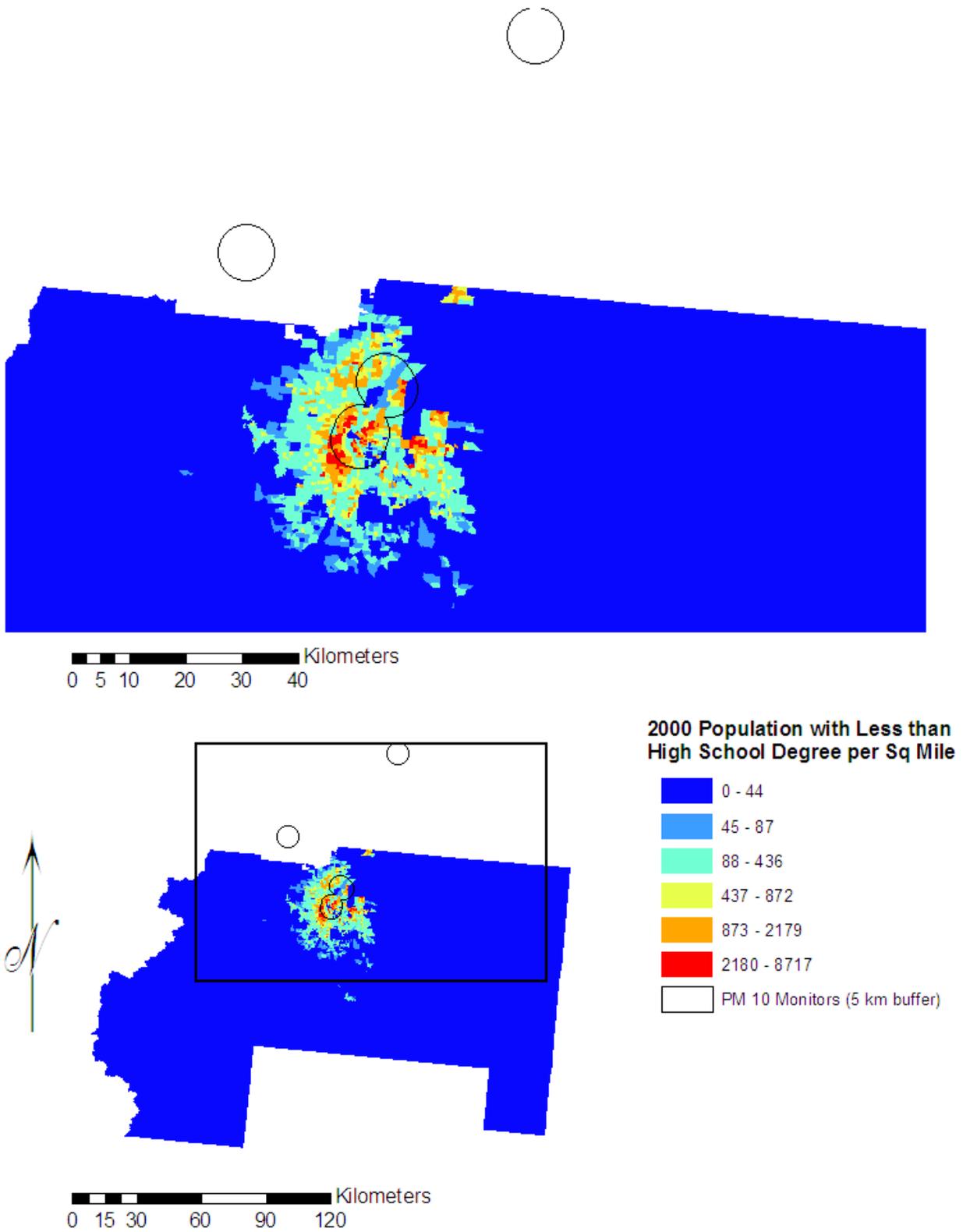
Figure A-220. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Denver, CO.

2000 Population Below Poverty Line per Sq Mile

- 0 - 71
- 72 - 142
- 143 - 712
- 713 - 1423
- 1424 - 3558
- 3559 - 14233
- PM 2.5 Monitors (5 km buffer)
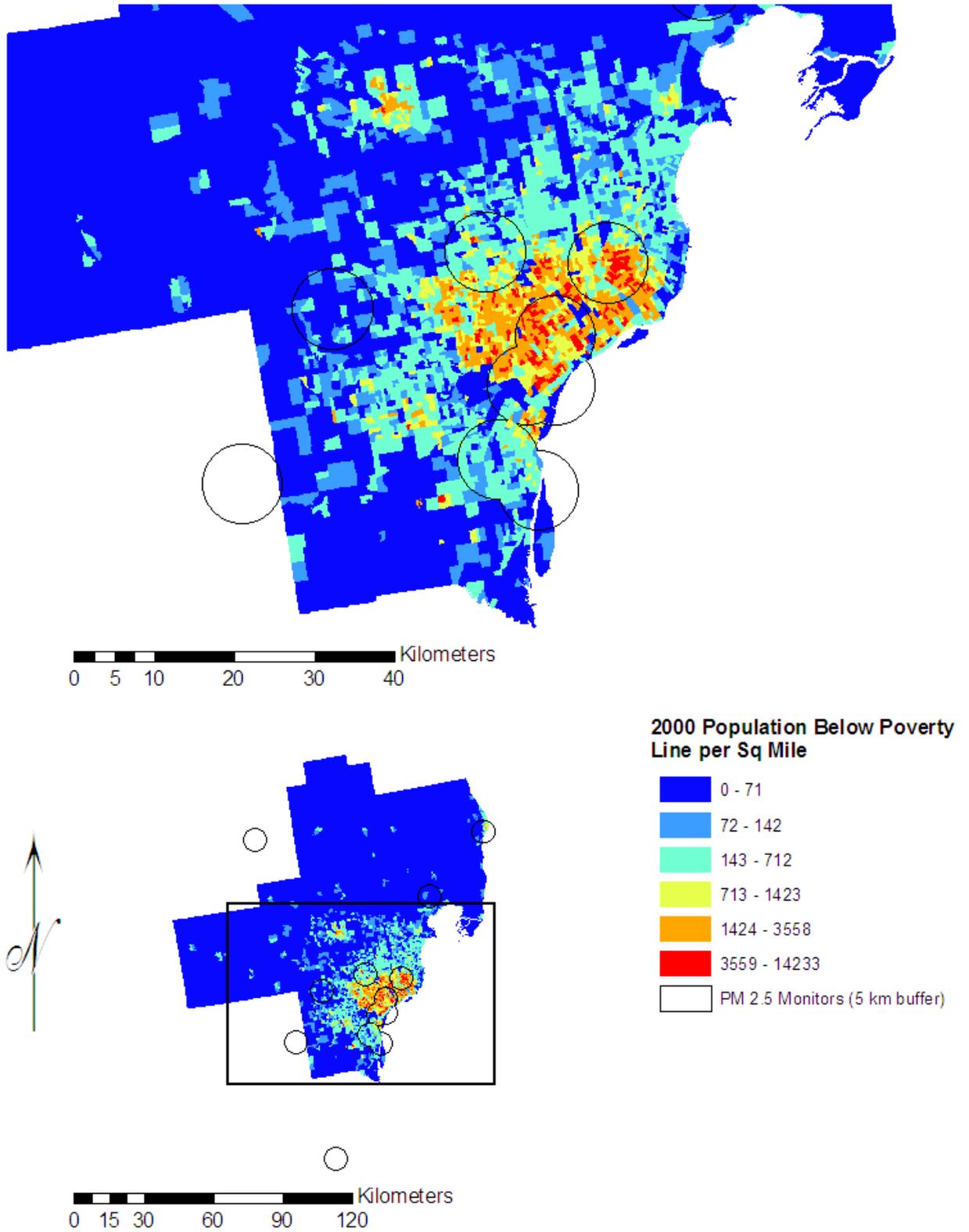
Figure A-221.   PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Detroit, MI.

2000 Population Below Poverty Line per Sq Mile

- 0 - 71
- 72 - 142
- 143 - 712
- 713 - 1423
- 1424 - 3558
- 3559 - 14233
- PM 10 Monitors (5 km buffer)
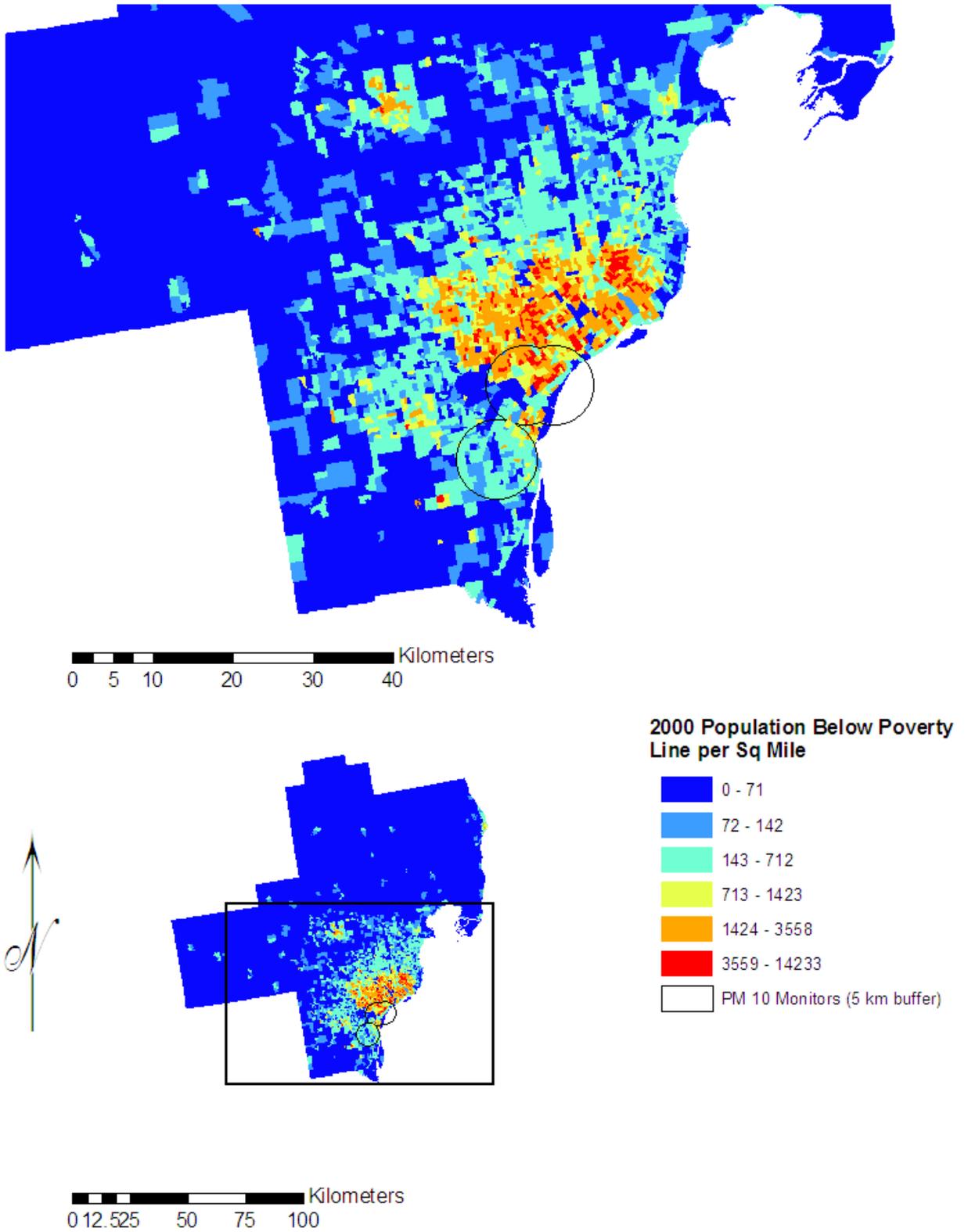
Figure A-222. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Detroit, MI.
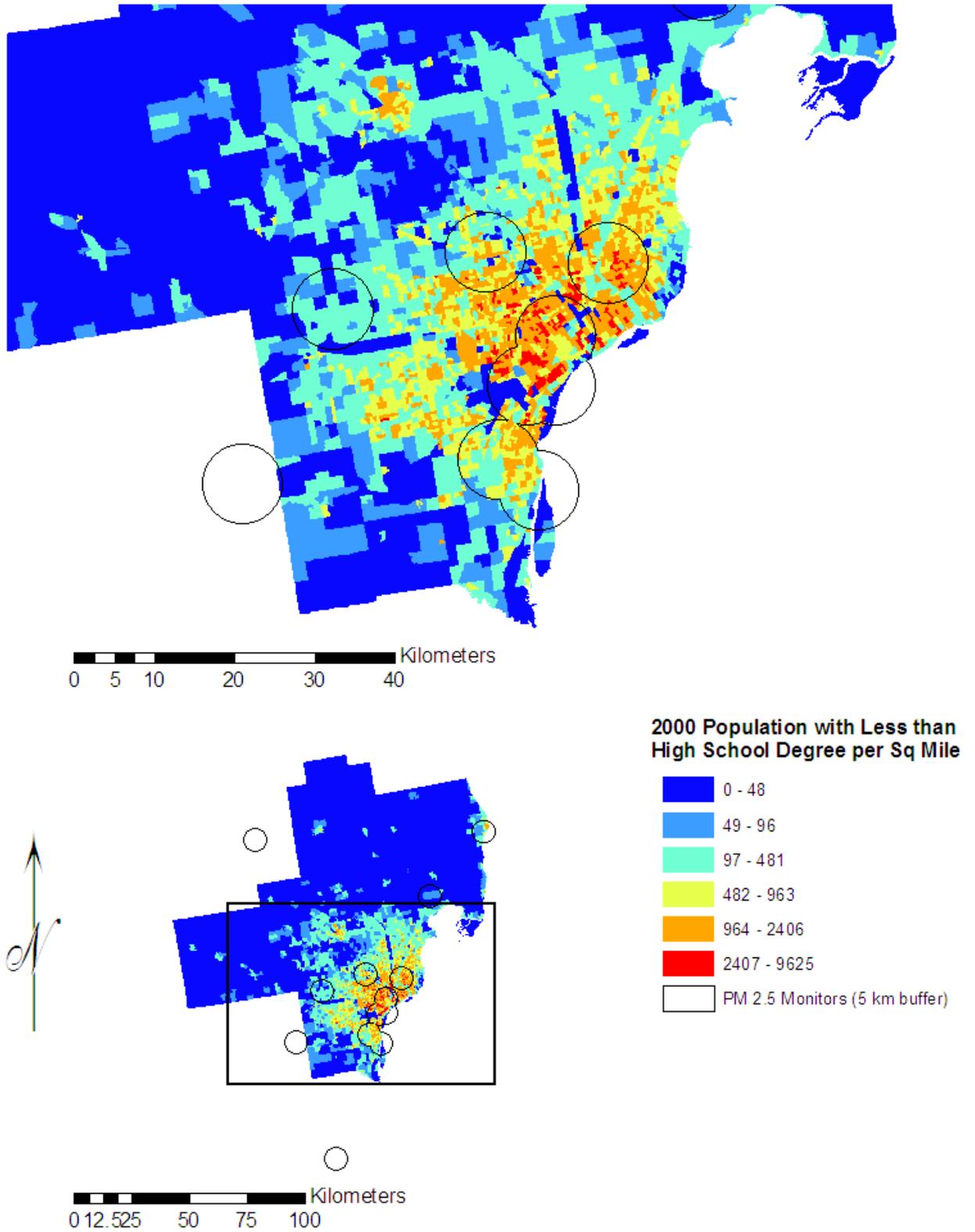
Figure A-223. PM_{2.5} sampler distribution in comparison with number of individuals having less than high school education, Detroit, MI.

Legend: 2000 Population with Less than High School Degree per Sq Mile

- 0 - 48
- 49 - 96
- 97 - 481
- 482 - 963
- 964 - 2406
- 2407 - 9625
- PM 2.5 Monitors (5 km buffer)

2000 Population with Less than High School Degree per Sq Mile

- 0 - 48
- 49 - 96
- 97 - 481
- 482 - 963
- 964 - 2406
- 2407 - 9625
- PM 10 Monitors (5 km buffer)
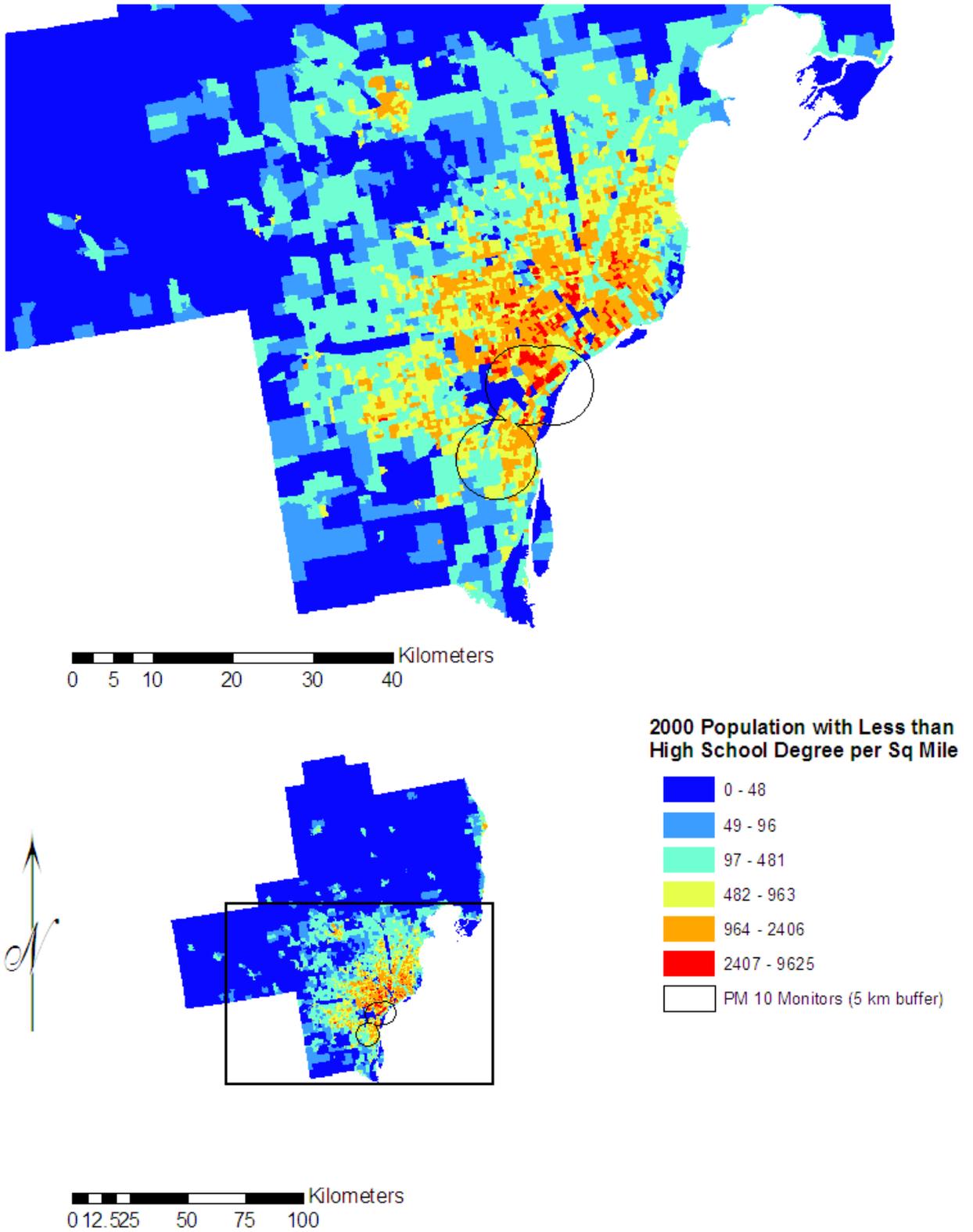
Figure A-224. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Detroit, MI.

**2000 Population Below Poverty
Line per Sq Mile**

- 0 - 135
- 136 - 270
- 271 - 1351
- 1352 - 2702
- 2703 - 6754
- 6755 - 27017
- PM 2.5 Monitors (5 km buffer)
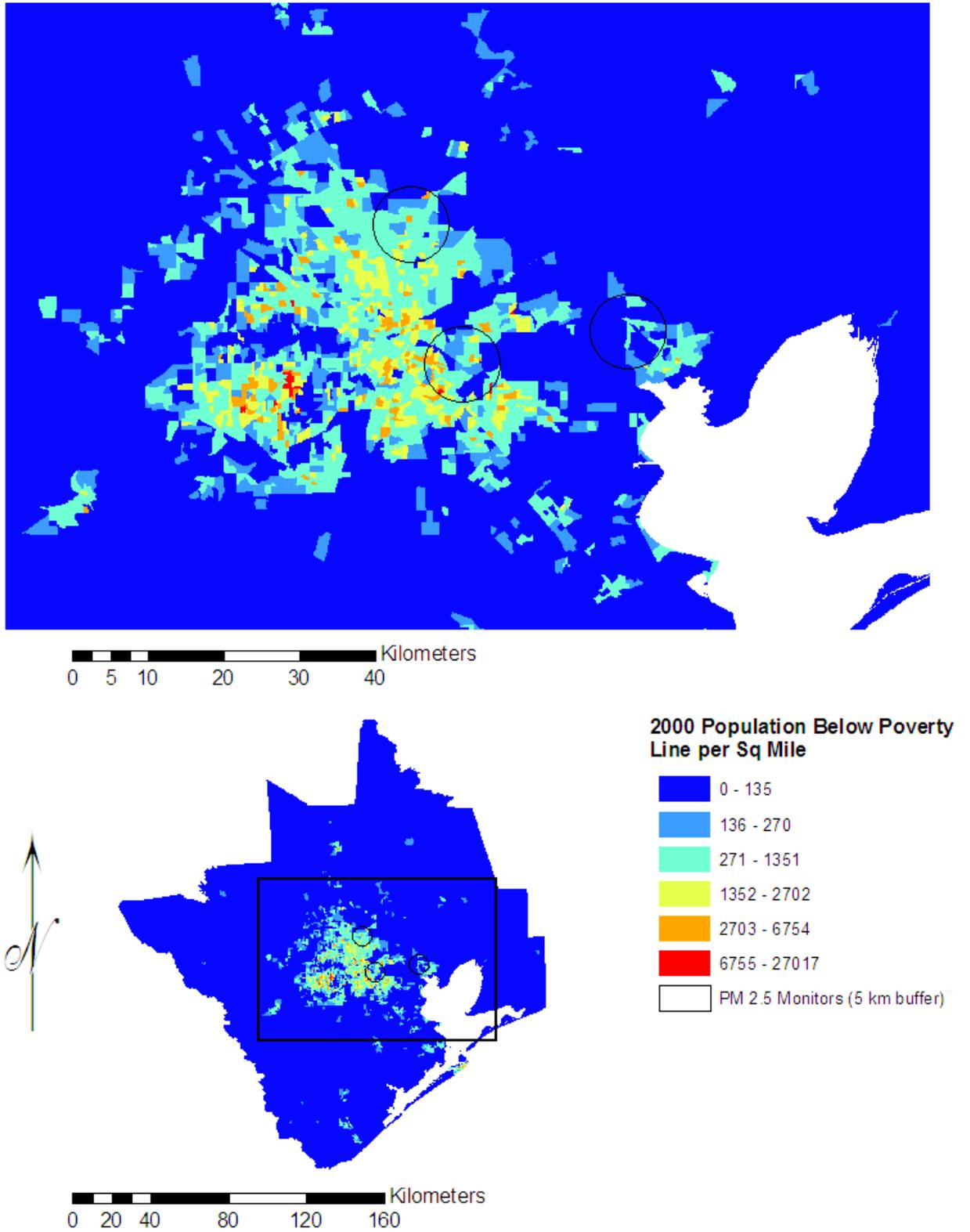
Figure A-225.   PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Houston, TX.

2000 Population Below Poverty
Line per Sq Mile

- 0 - 135
- 136 - 270
- 271 - 1351
- 1352 - 2702
- 2703 - 6754
- 6755 - 27017
- PM 10 Monitors (5 km buffer)
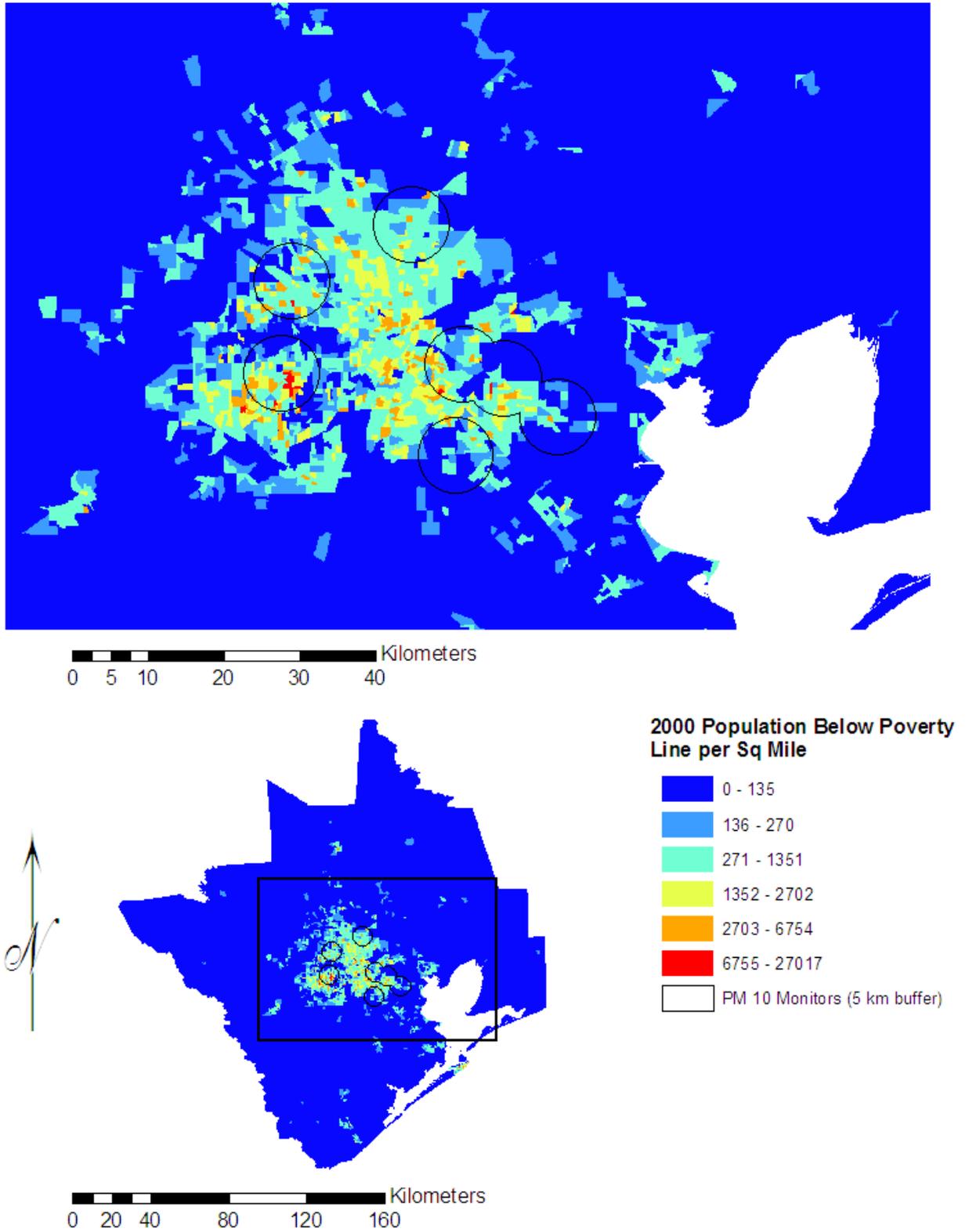
Figure A-226. PM₁₀ sampler distribution in comparison with number of individuals below the poverty line, Houston, TX.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 152
- 153 - 303
- 304 - 1516
- 1517 - 3032
- 3033 - 7579
- 7580 - 30317
- PM 2.5 Monitors (5 km buffer)
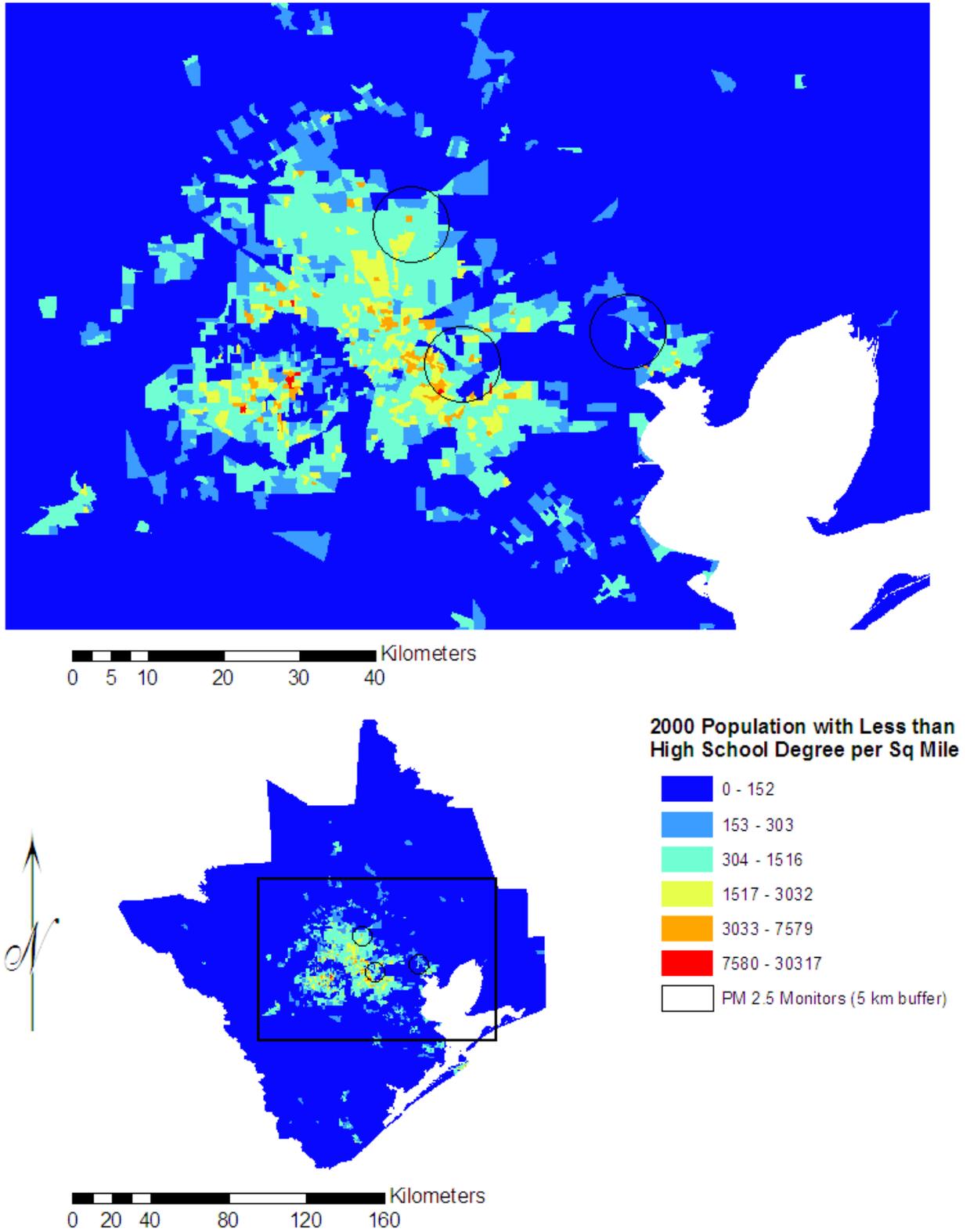
Figure A-227. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Houston, TX.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 152
- 153 - 303
- 304 - 1516
- 1517 - 3032
- 3033 - 7579
- 7580 - 30317
- PM 10 Monitors (5 km buffer)
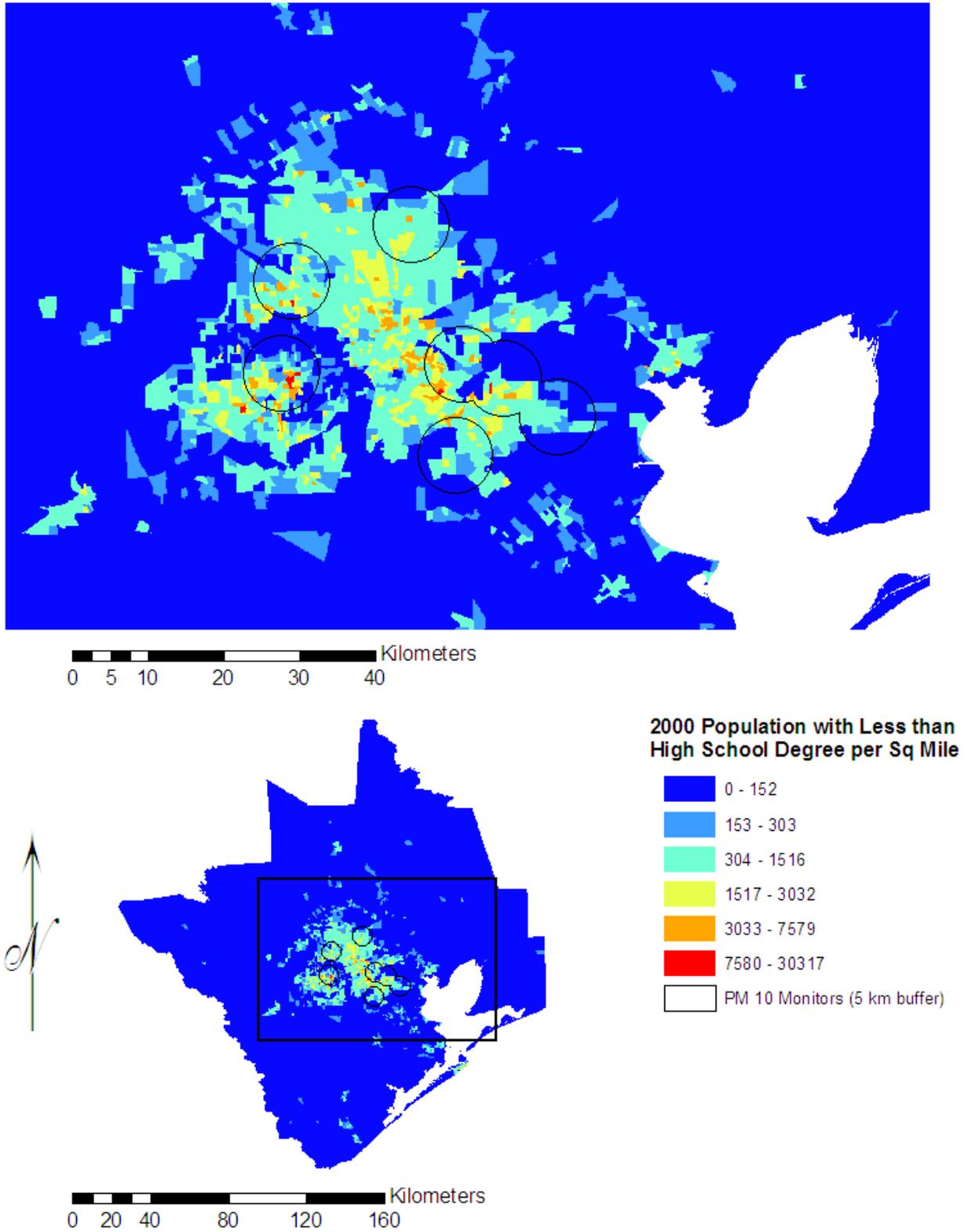
Figure A-228.   PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Houston, TX.

2000 Population Below Poverty Line per Sq Mile

- 0 - 277
- 278 - 554
- 555 - 2770
- 2771 - 5540
- 5541 - 13850
- 13851 - 55400
- PM 2.5 Monitors (5 km buffer)
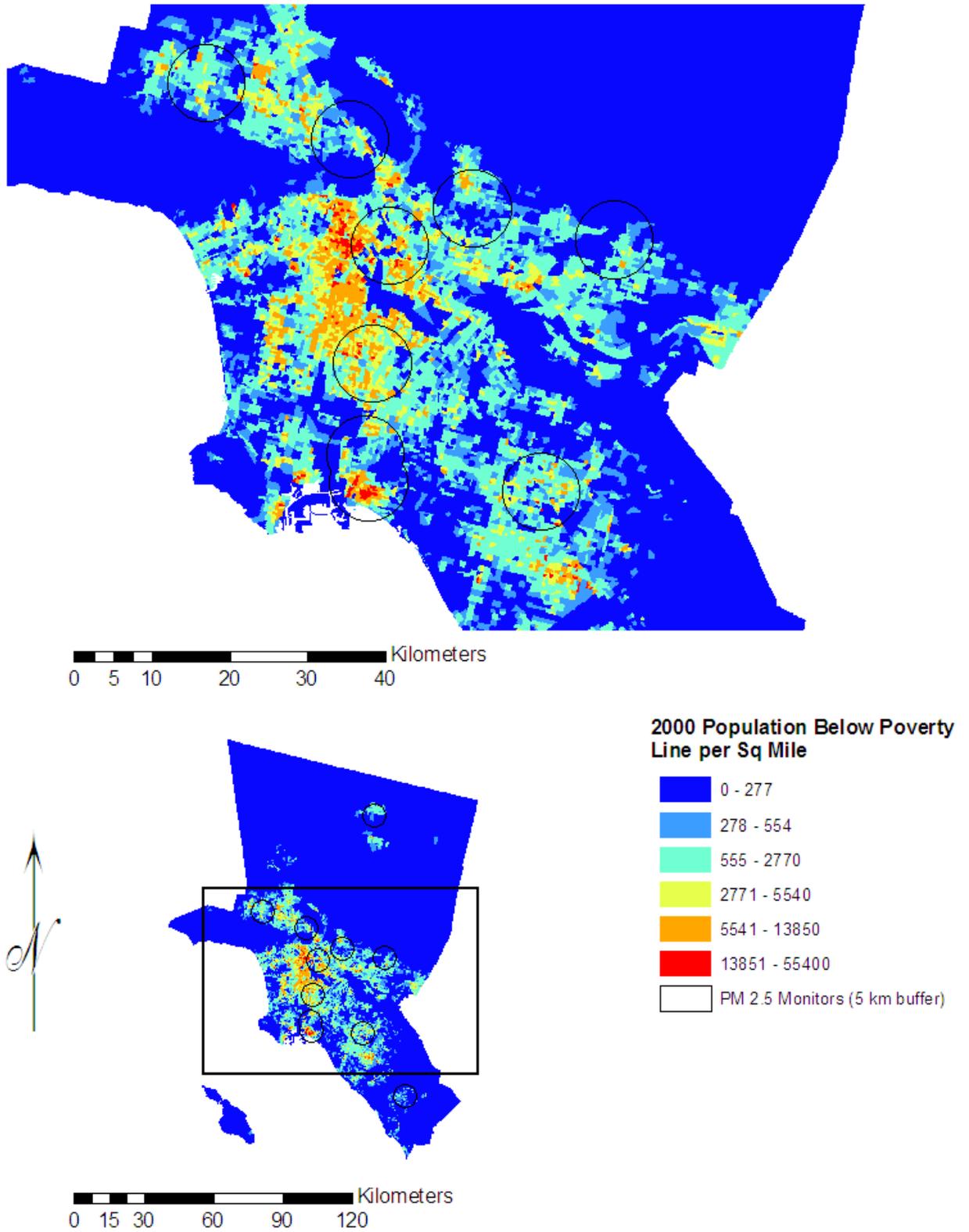
Figure A-229 PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Los Angeles, CA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 277
- 278 - 554
- 555 - 2770
- 2771 - 5540
- 5541 - 13850
- 13851 - 55400
- PM 10 Monitors (5 km buffer)
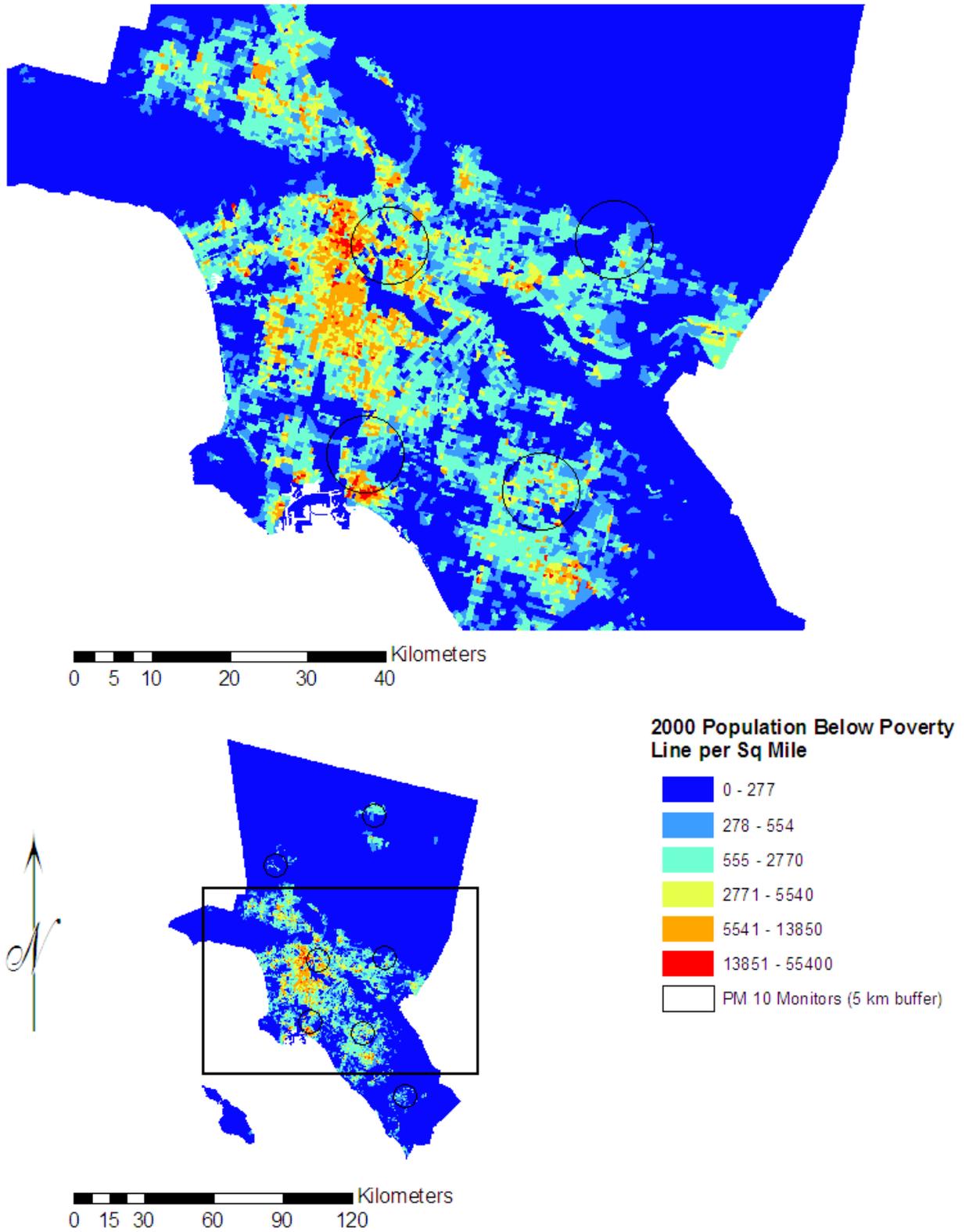
Figure A-230.   PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Los Angeles, CA.
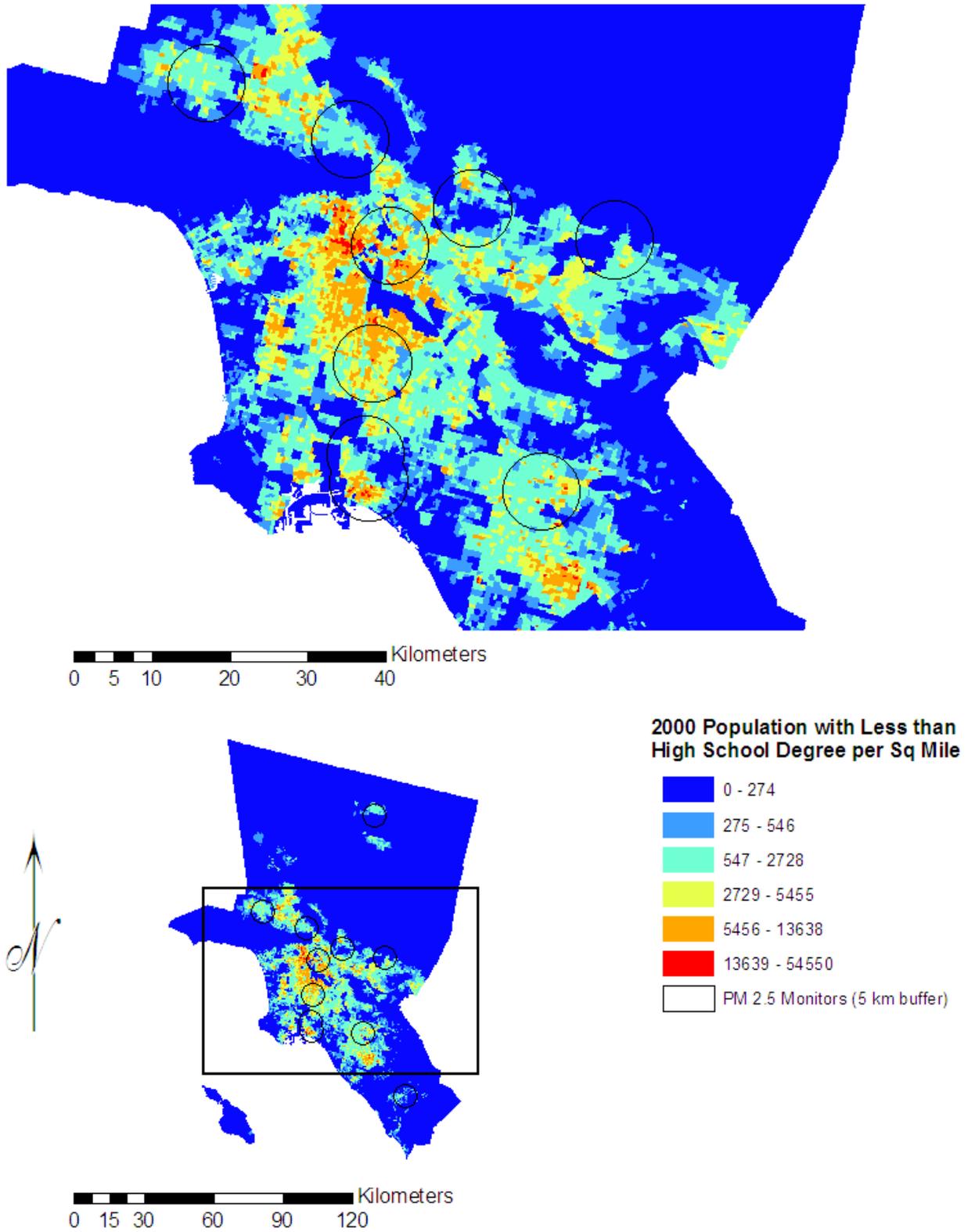
Figure A-231. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Los Angeles, CA.
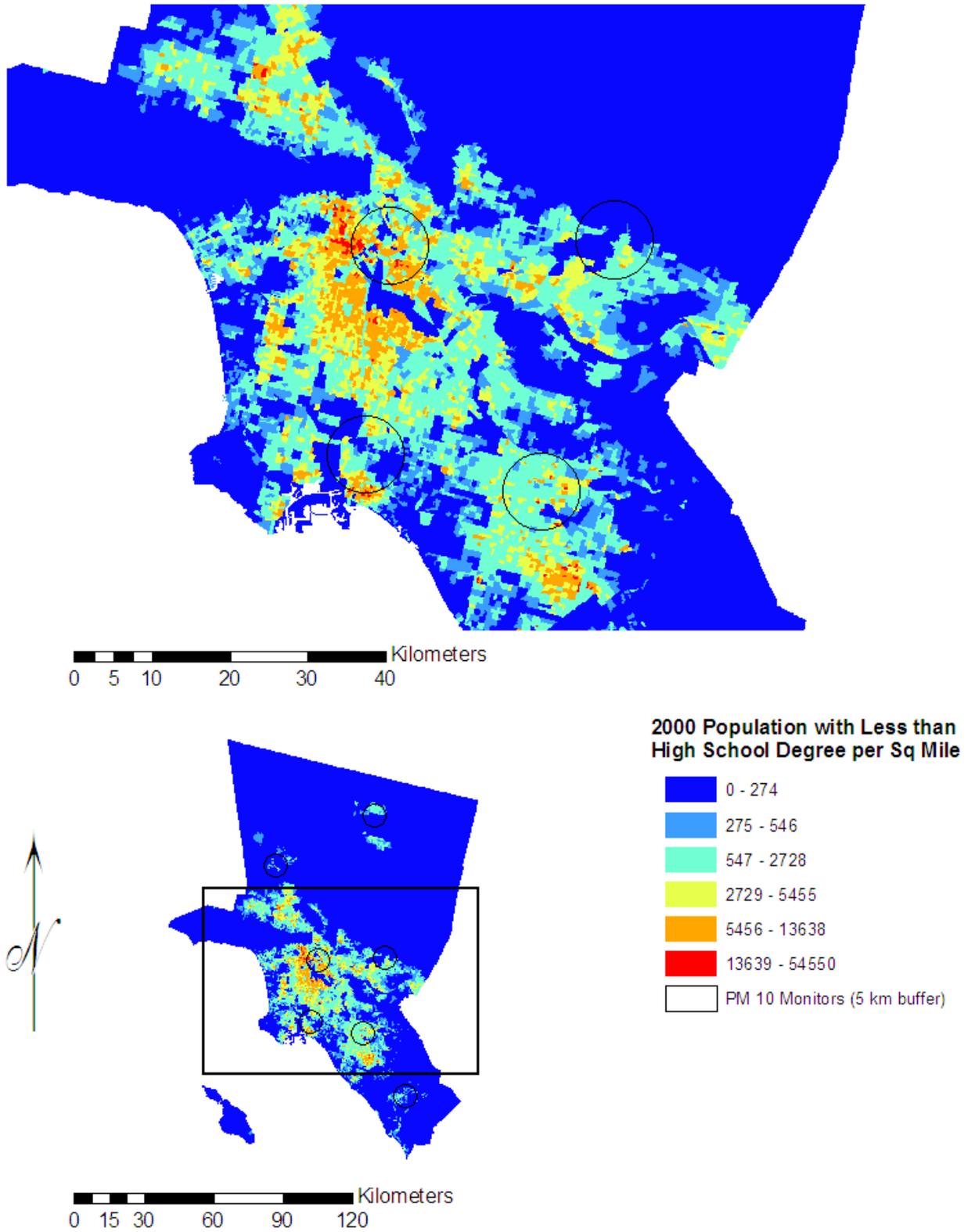
Figure A-232. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Los Angeles, CA.
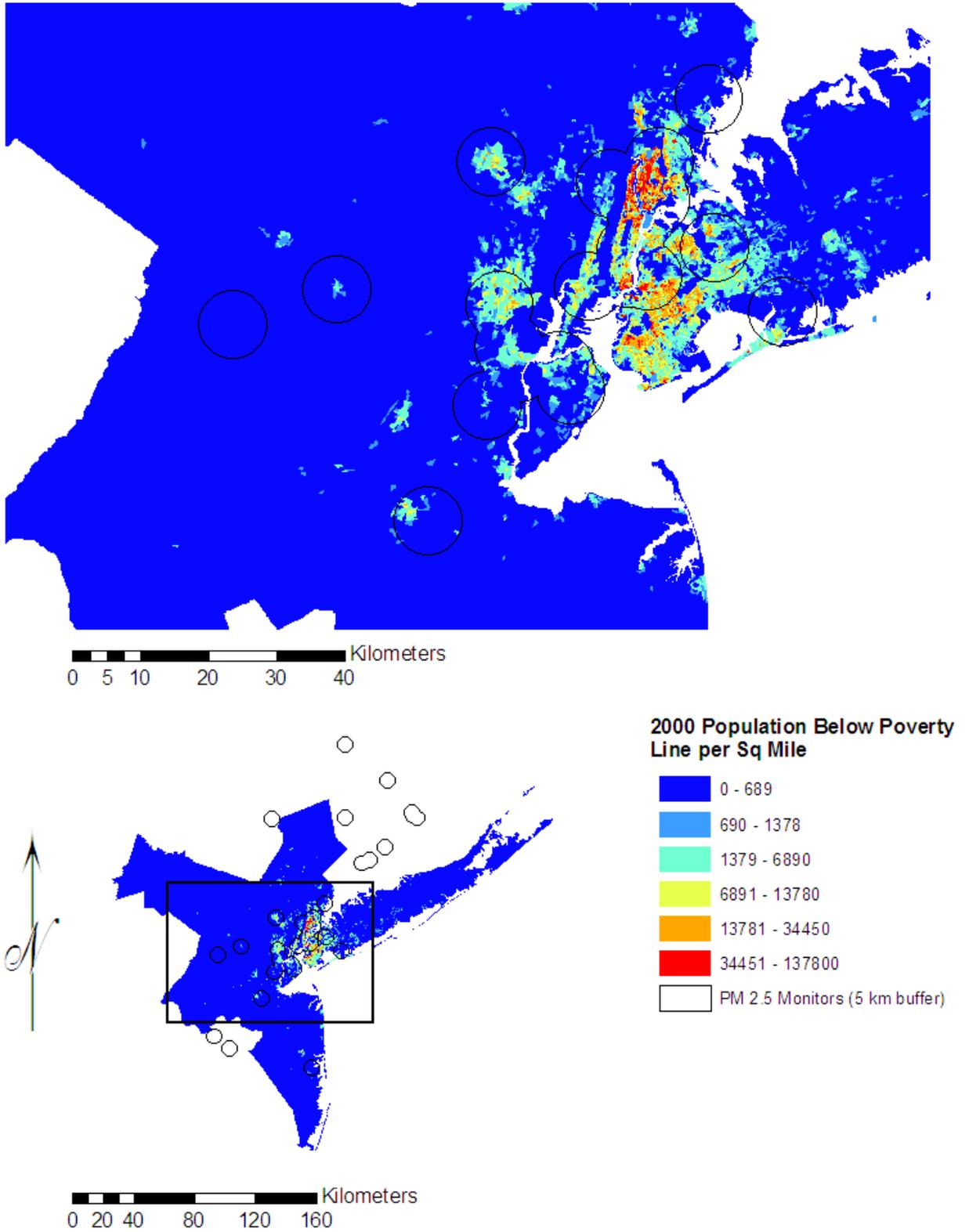
Figure A-233. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, New York City, NY.

2000 Population Below Poverty Line per Sq Mile

- 0 - 689
- 690 - 1378
- 1379 - 6890
- 6891 - 13780
- 13781 - 34450
- 34451 - 137800
- PM 10 Monitors (5 km buffer)
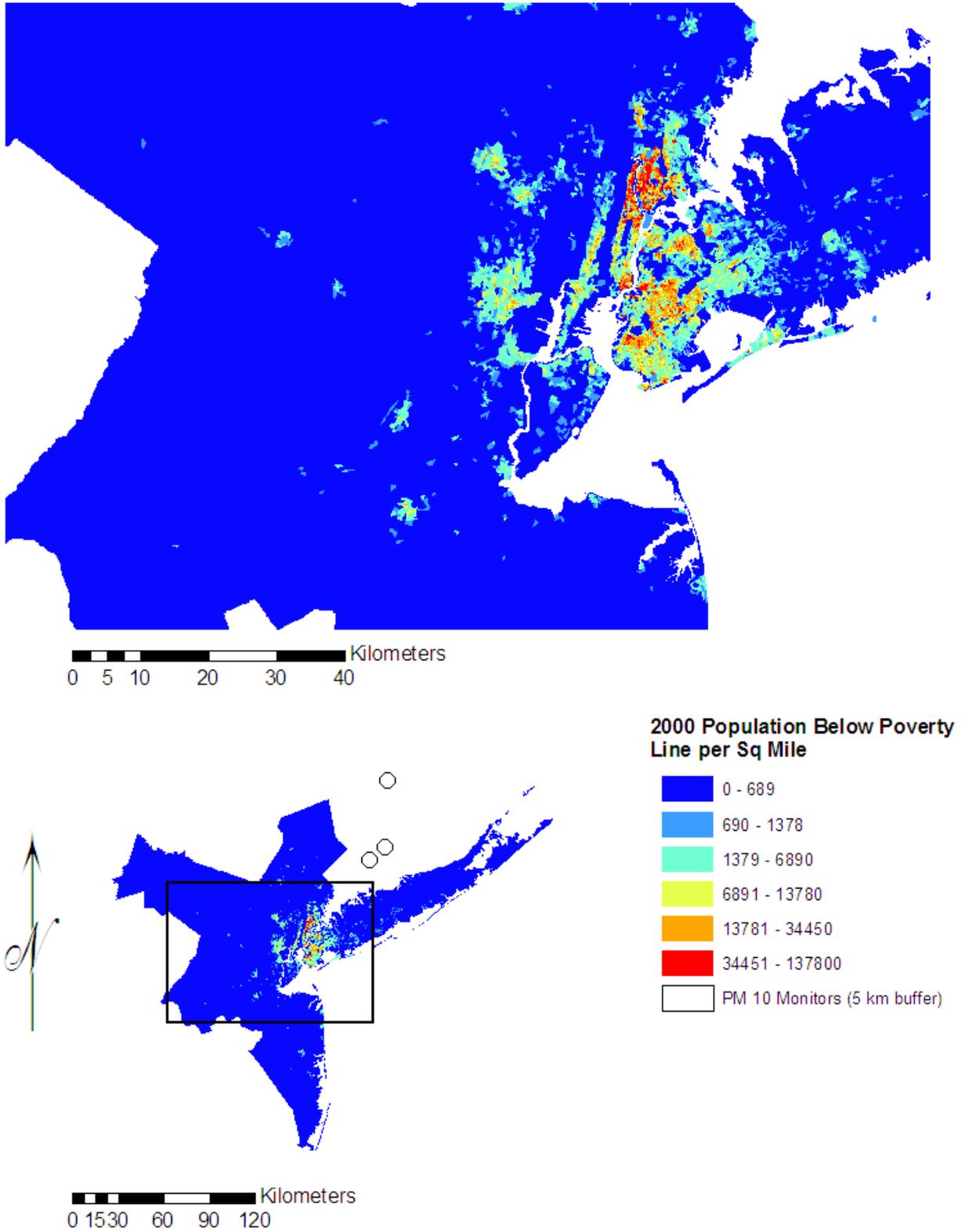
Figure A-234.   PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, New York City, NY.
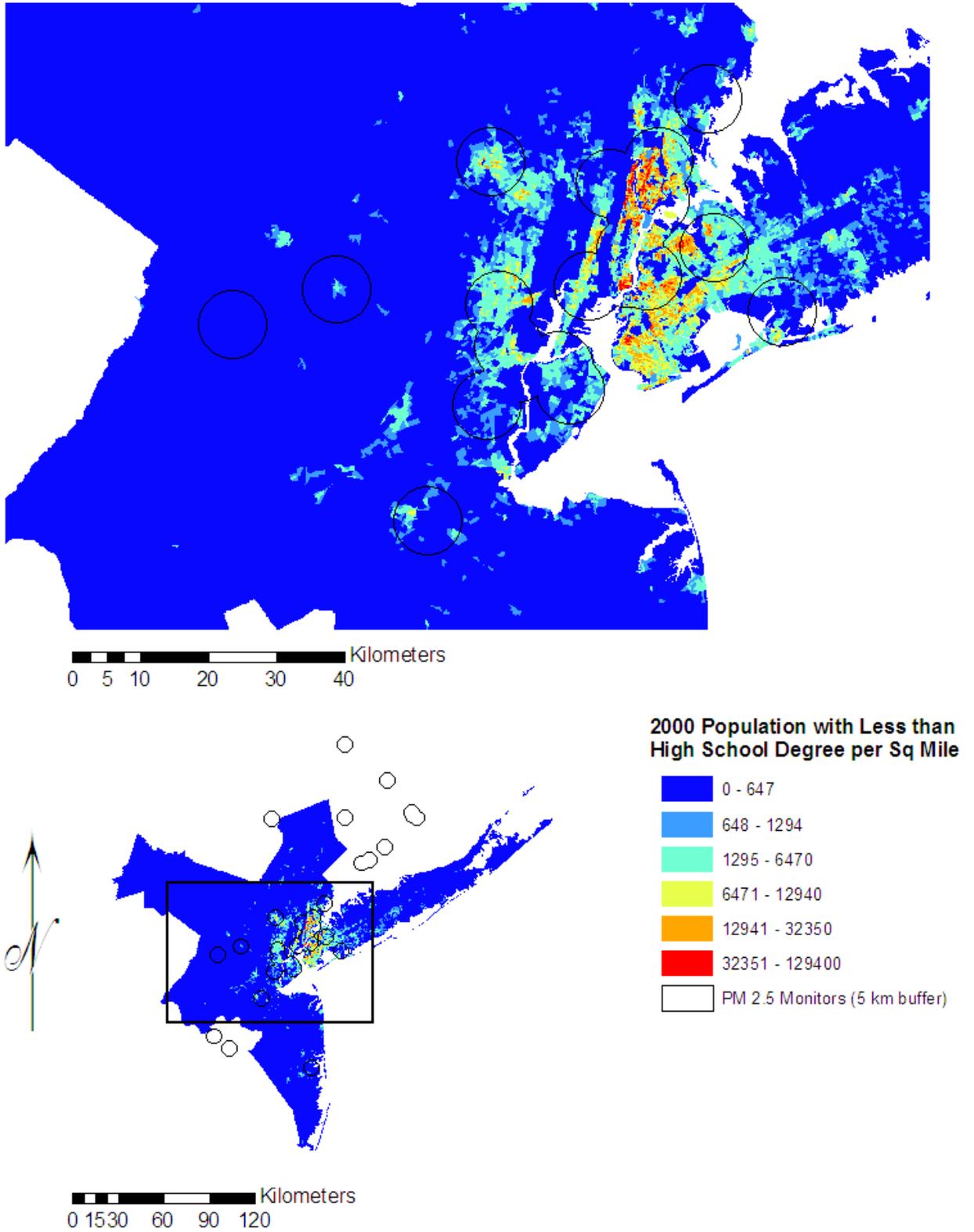
Figure A-235. PM₂.₅ sampler distribution in comparison with number of individuals having less than high school education, New York City, NY.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 647
- 648 - 1294
- 1295 - 6470
- 6471 - 12940
- 12941 - 32350
- 32351 - 129400
- PM 10 Monitors (5 km buffer)
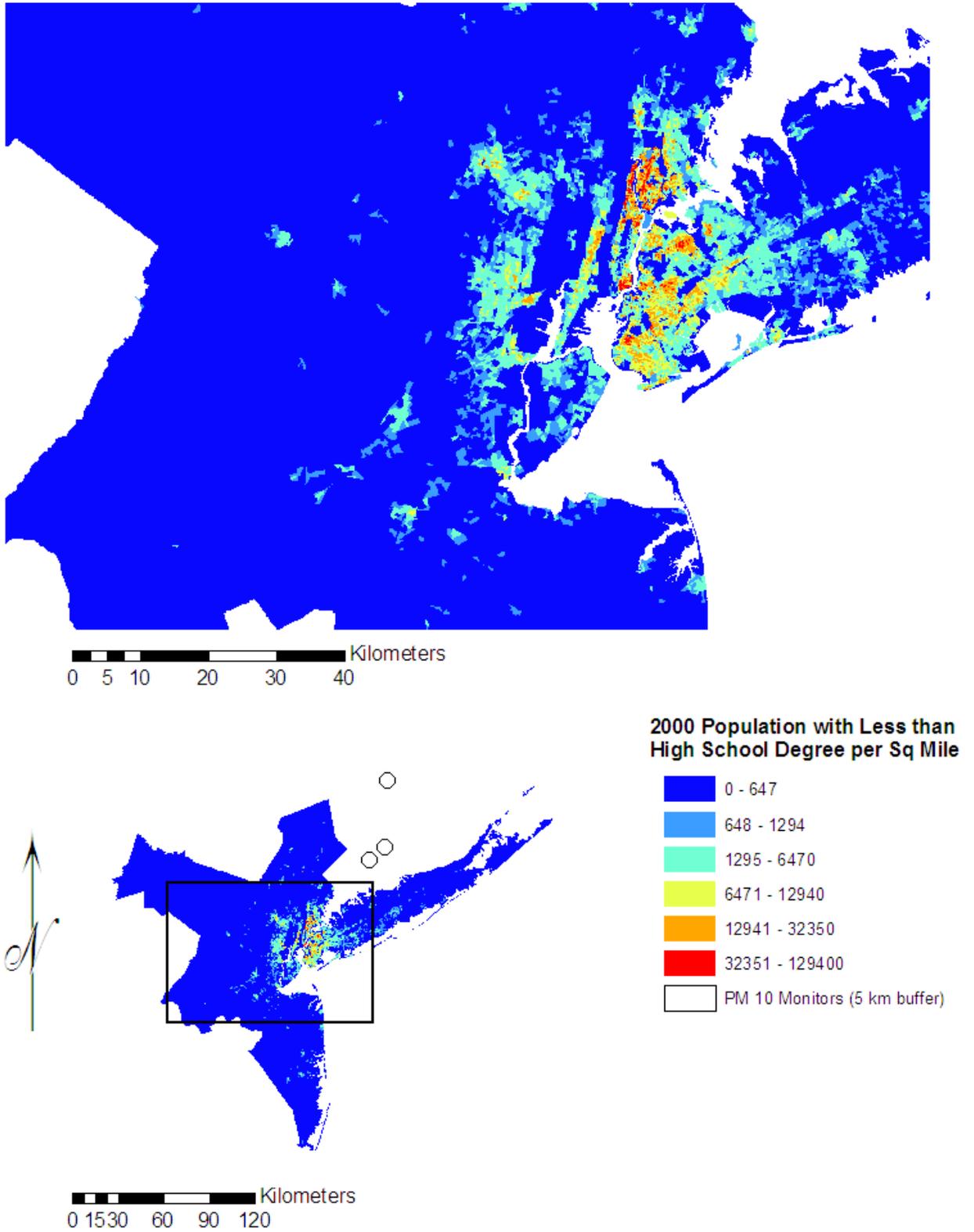
Figure A-236. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, New York City, NY.
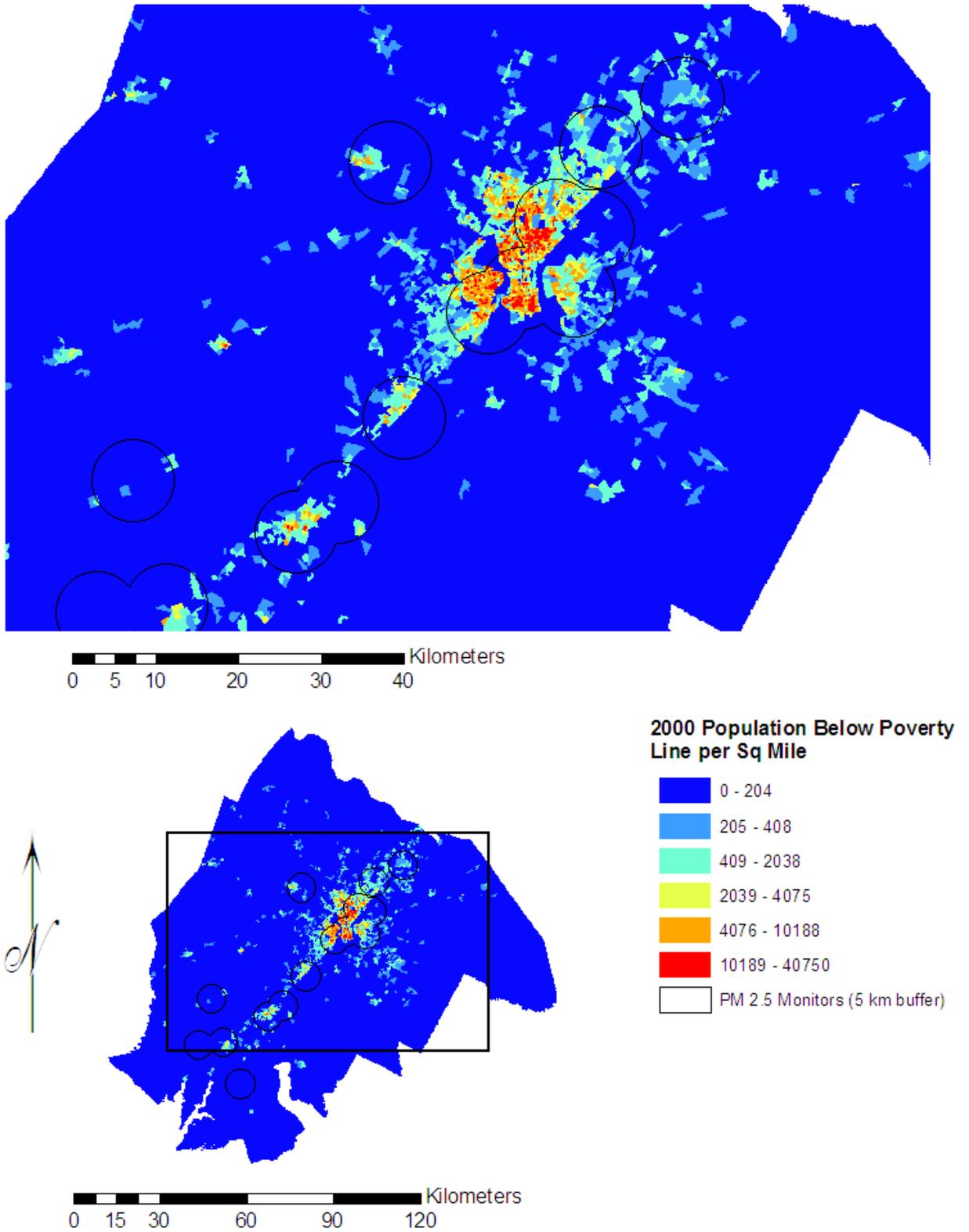
Figure A-237. PM_{2.5} sampler distribution in comparison with number of individuals below the poverty line, Philadelphia, PA.
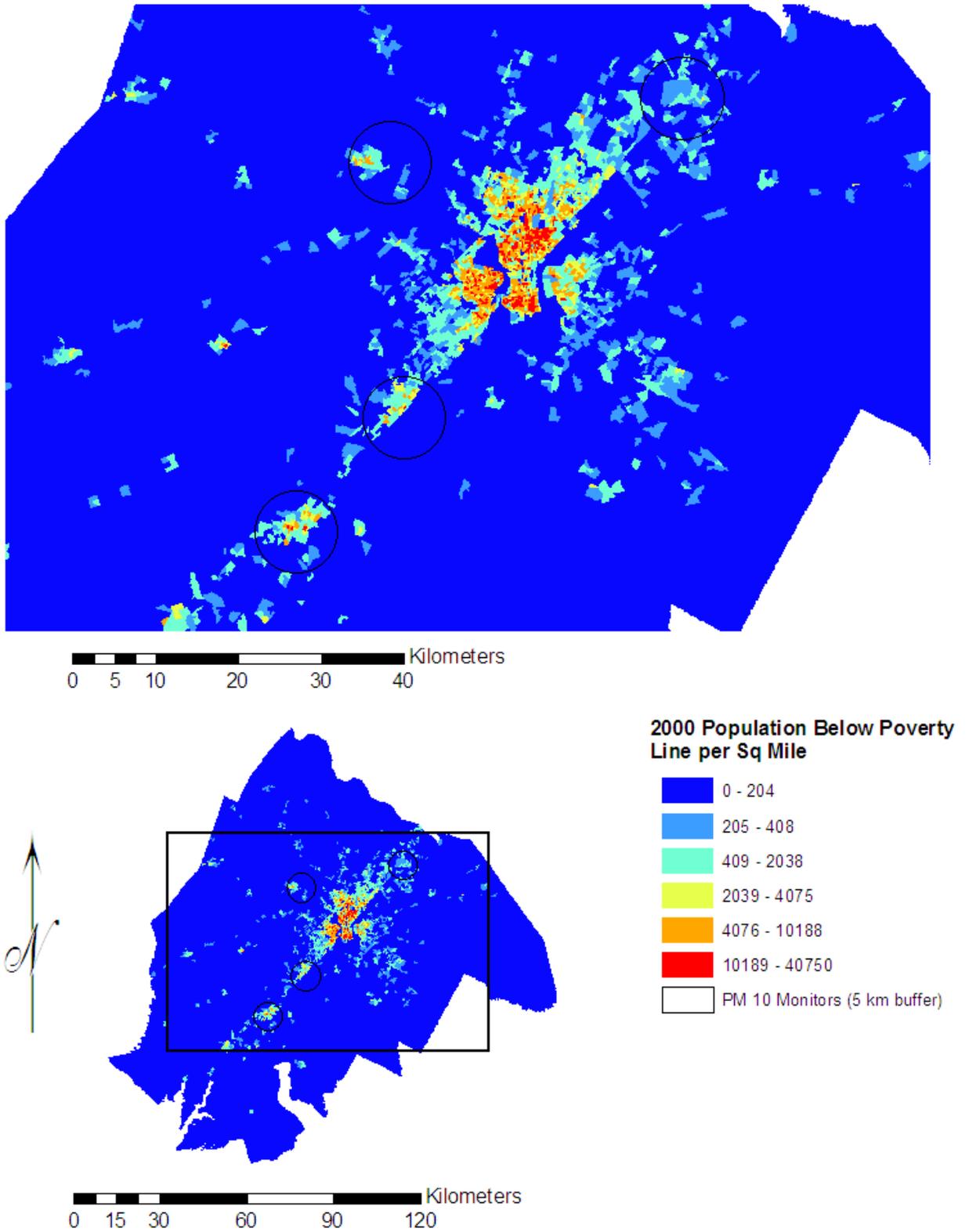
Figure A-238. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Philadelphia, PA.
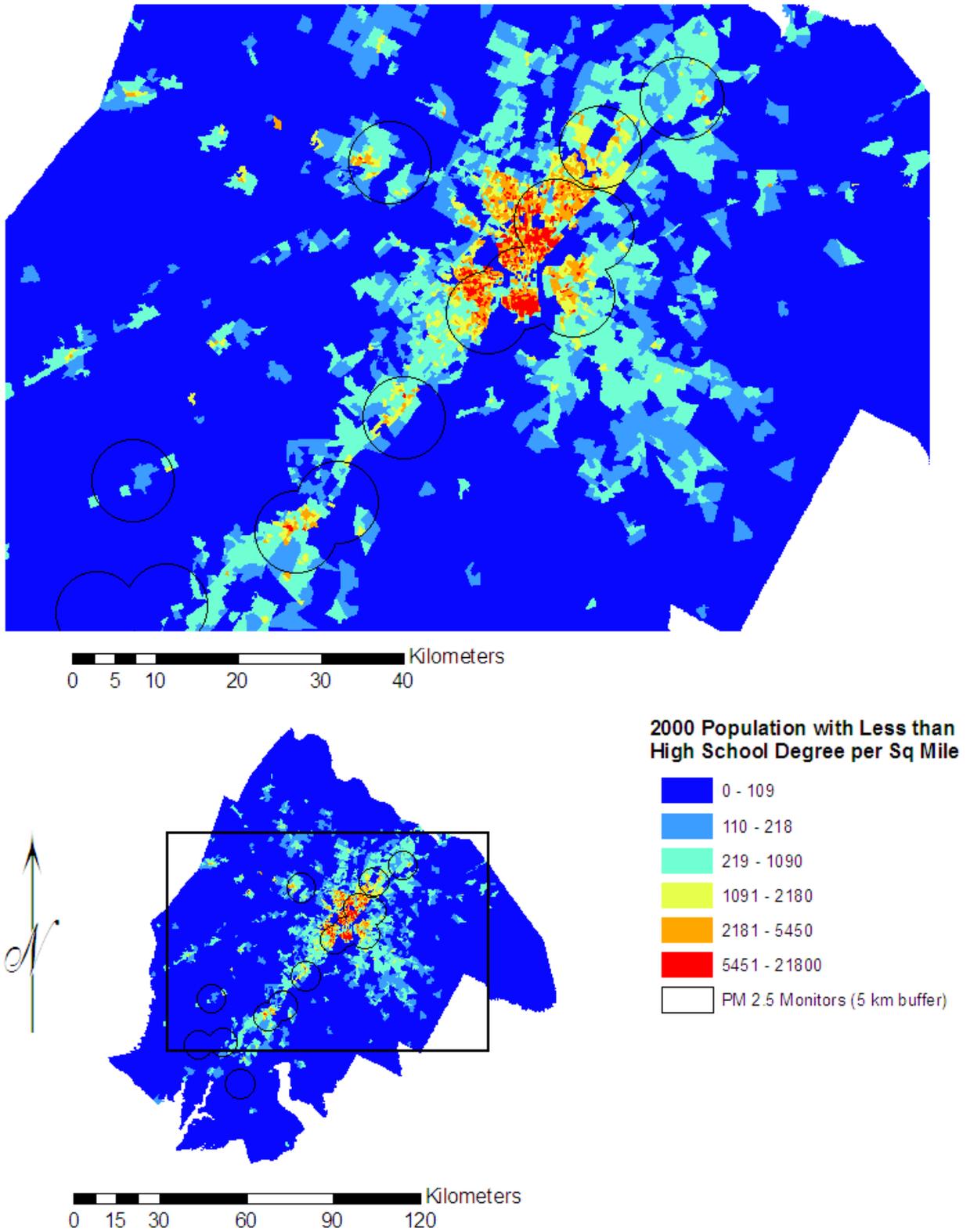
Figure A-239. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Philadelphia, PA.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 109
- 110 - 218
- 219 - 1090
- 1091 - 2180
- 2181 - 5450
- 5451 - 21800
- PM 10 Monitors (5 km buffer)
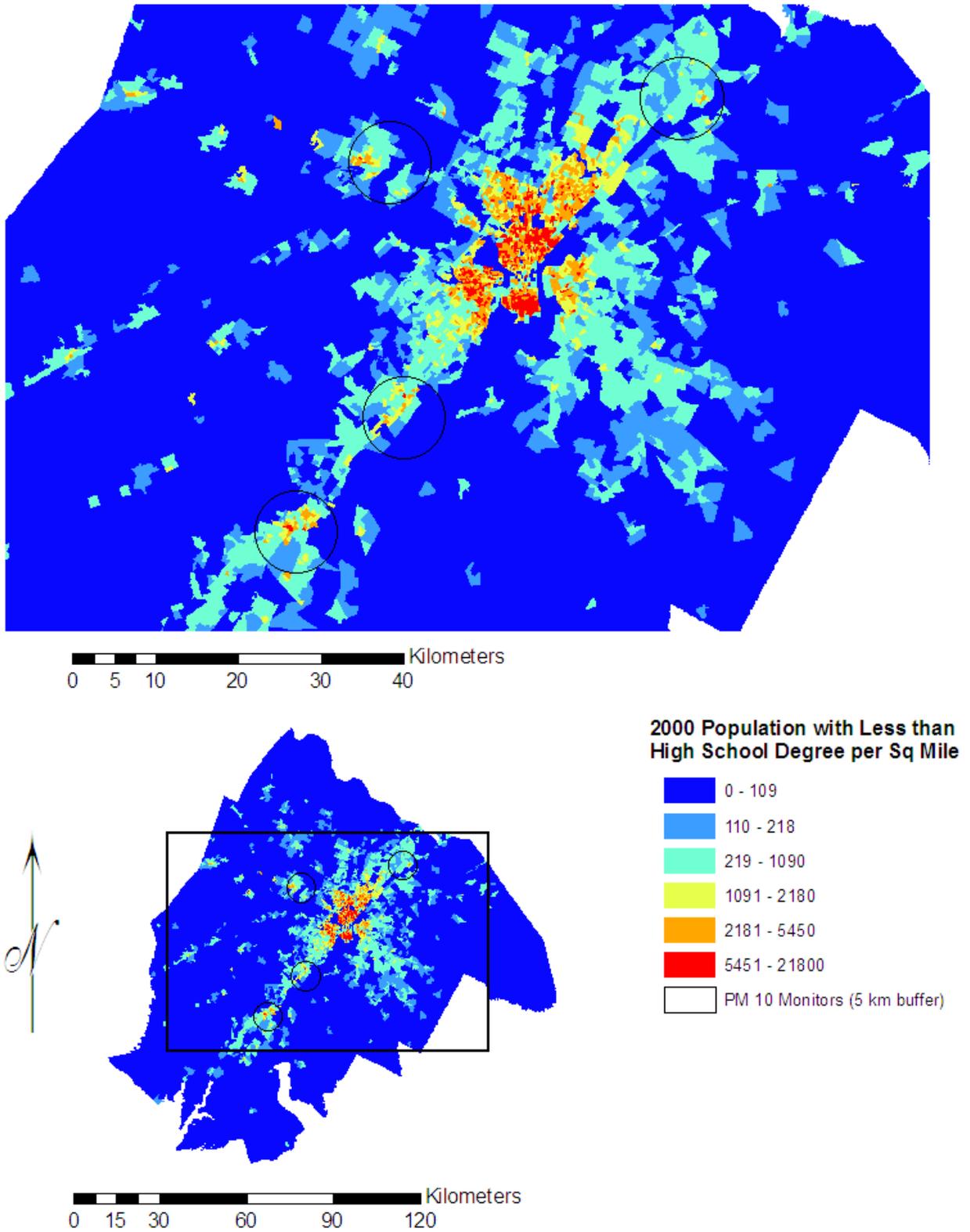
Figure A-240.   PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Philadelphia, PA.
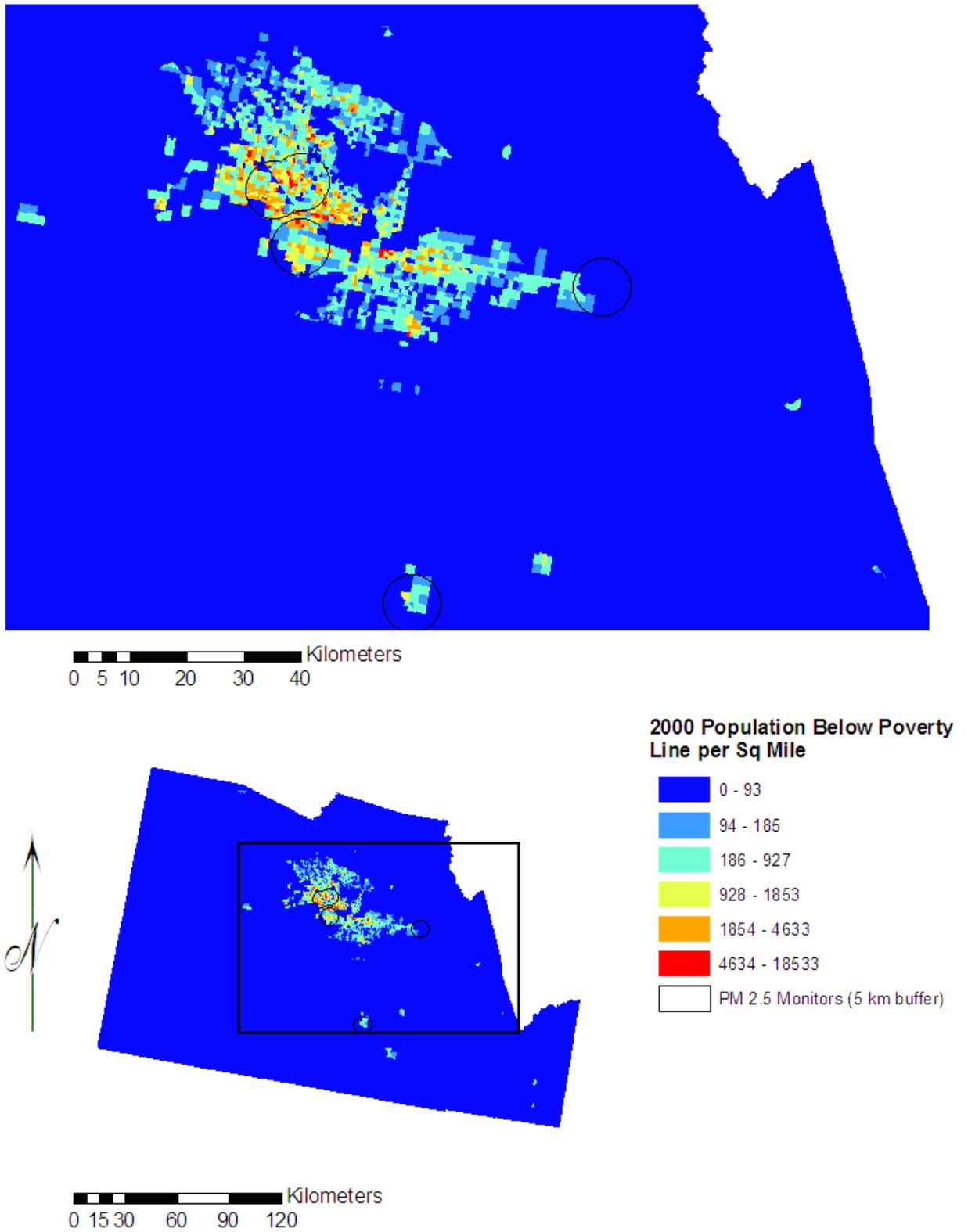
Figure A-241. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Phoenix, AZ.

2000 Population Below Poverty Line per Sq Mile

- 0 - 93
- 94 - 185
- 186 - 927
- 928 - 1853
- 1854 - 4633
- 4634 - 18533
- PM 10 Monitors (5 km buffer)
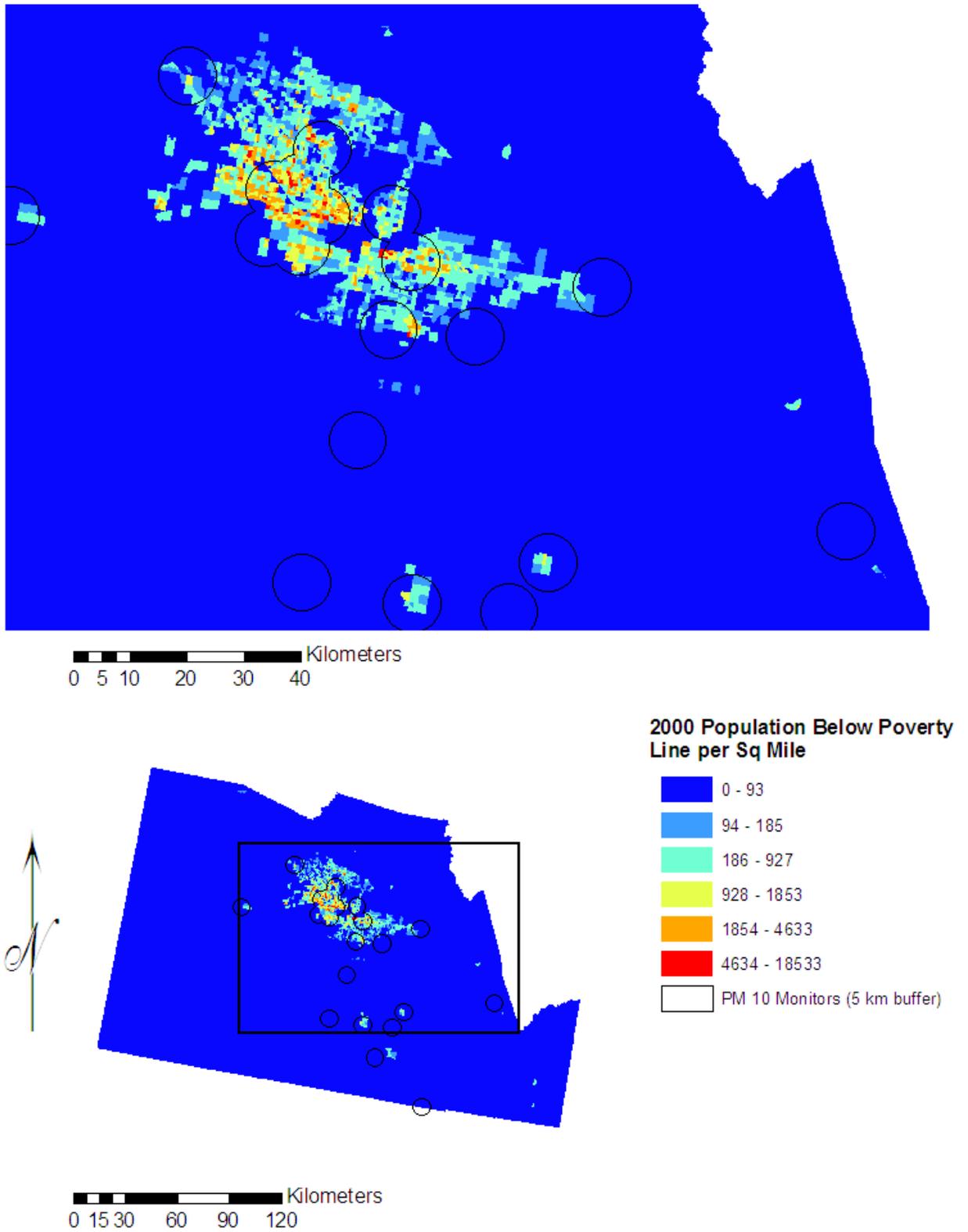
Figure A-242. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Phoenix, AZ.
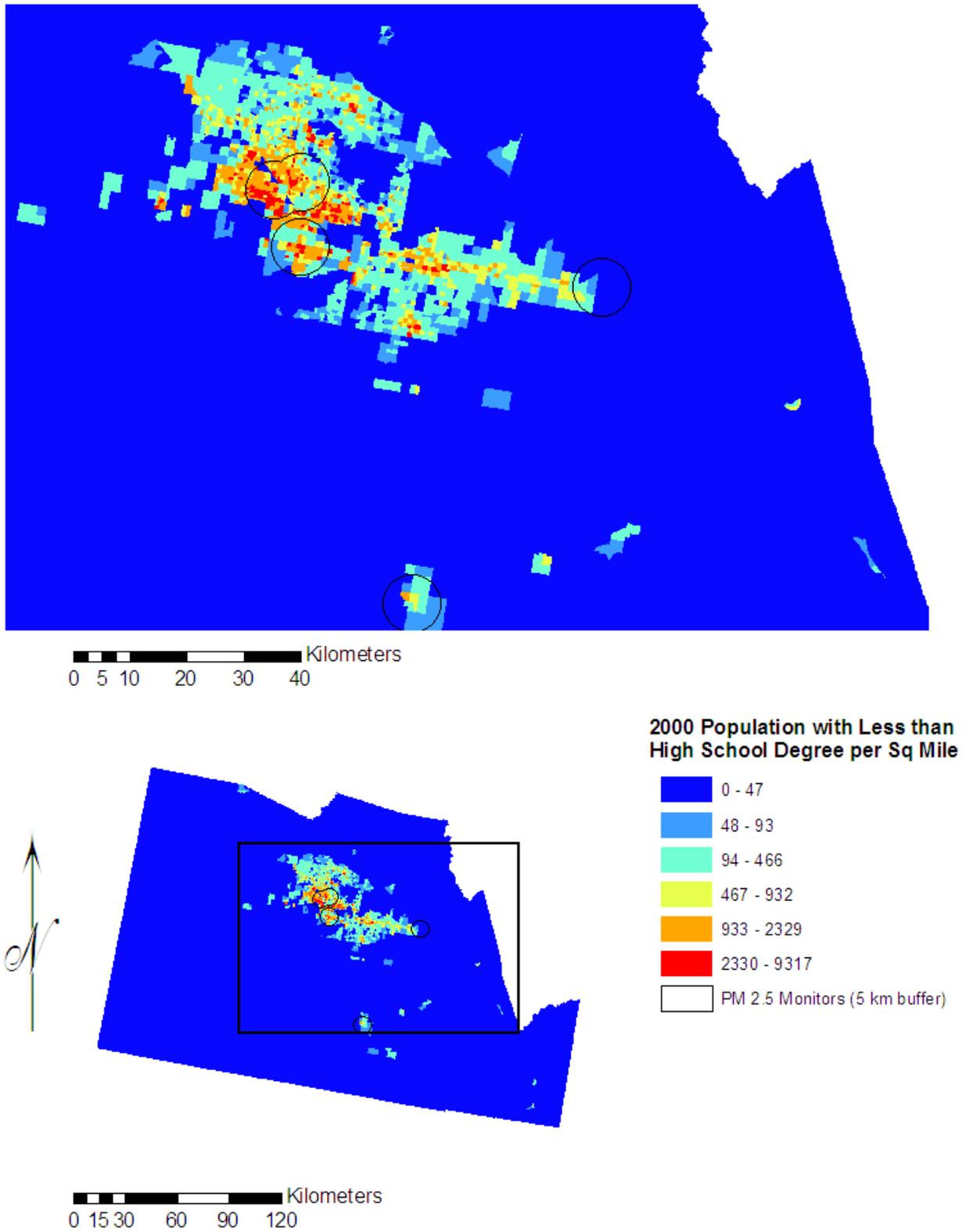
Figure A-243. PM2.5 sampler distribution in comparison with number of individuals having less than high school education, Phoenix, AZ.

Legend:

2000 Population with Less than High School Degree per Sq Mile

- 0 - 47
- 48 - 93
- 94 - 466
- 467 - 932
- 933 - 2329
- 2330 - 9317
- PM 2.5 Monitors (5 km buffer)

2000 Population with Less than High School Degree per Sq Mile

- 0 - 47
- 48 - 93
- 94 - 466
- 467 - 932
- 933 - 2329
- 2330 - 9317
- PM 10 Monitors (5 km buffer)
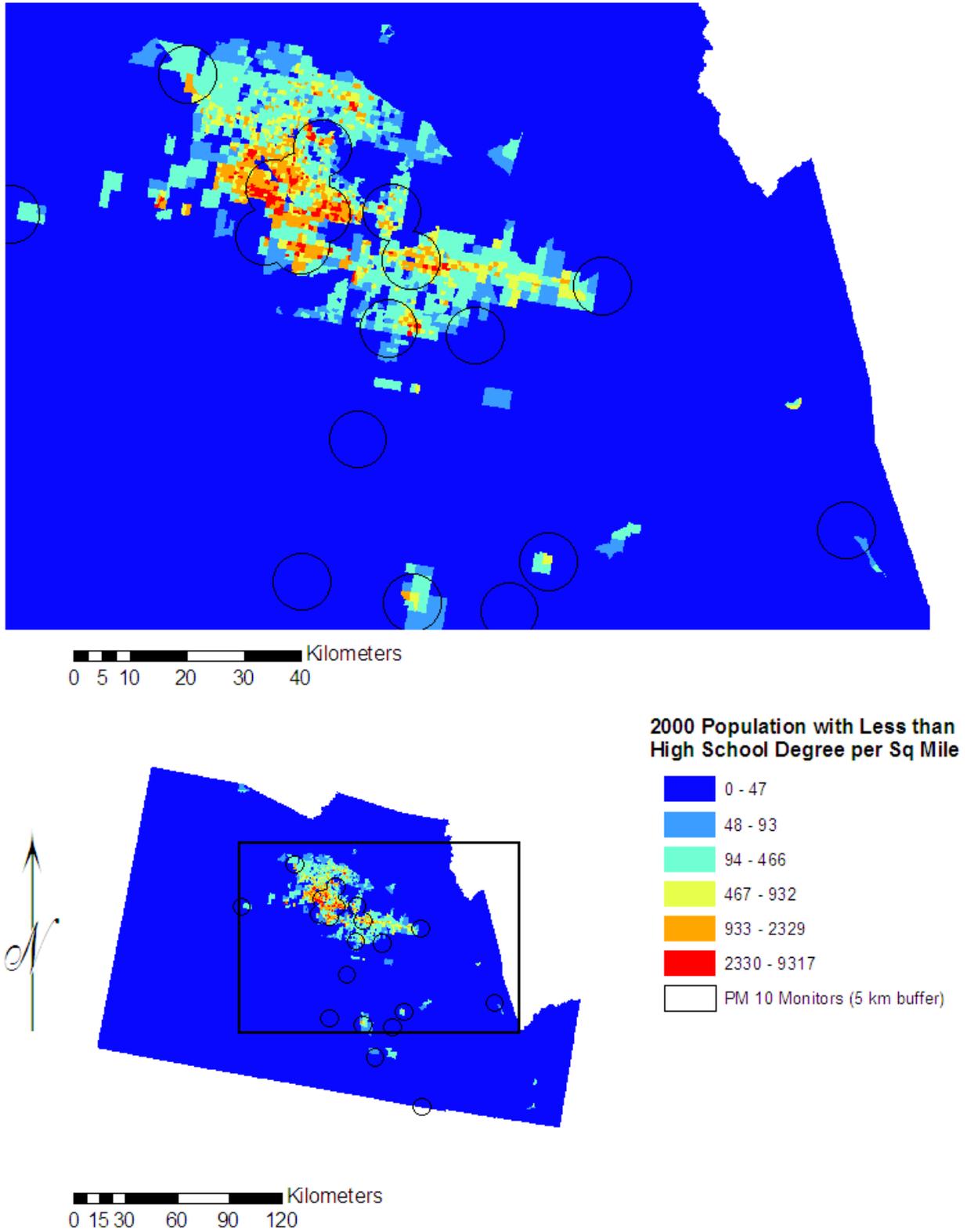
Figure A-244.   PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Phoenix, AZ.

2000 Population Below Poverty Line per Sq Mile

- 0 - 100
- 101 - 200
- 201 - 999
- 1000 - 1998
- 1999 - 4994
- 4995 - 19975
- PM 2.5 Monitors (5 km buffer)
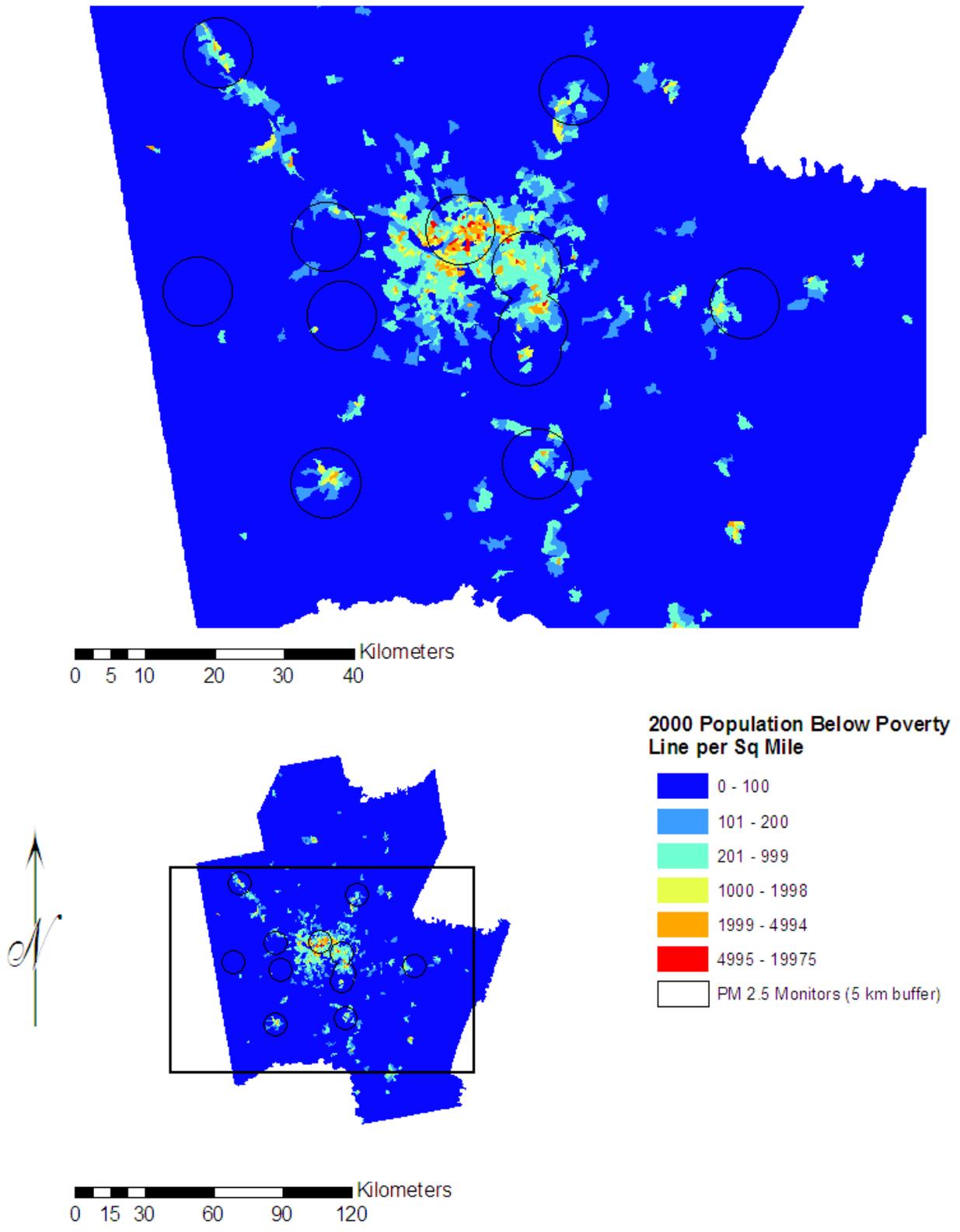
Figure A-245. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Pittsburgh, PA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 100
- 101 - 200
- 201 - 999
- 1000 - 1998
- 1999 - 4994
- 4995 - 19975
- PM 10 Monitors (5 km buffer)
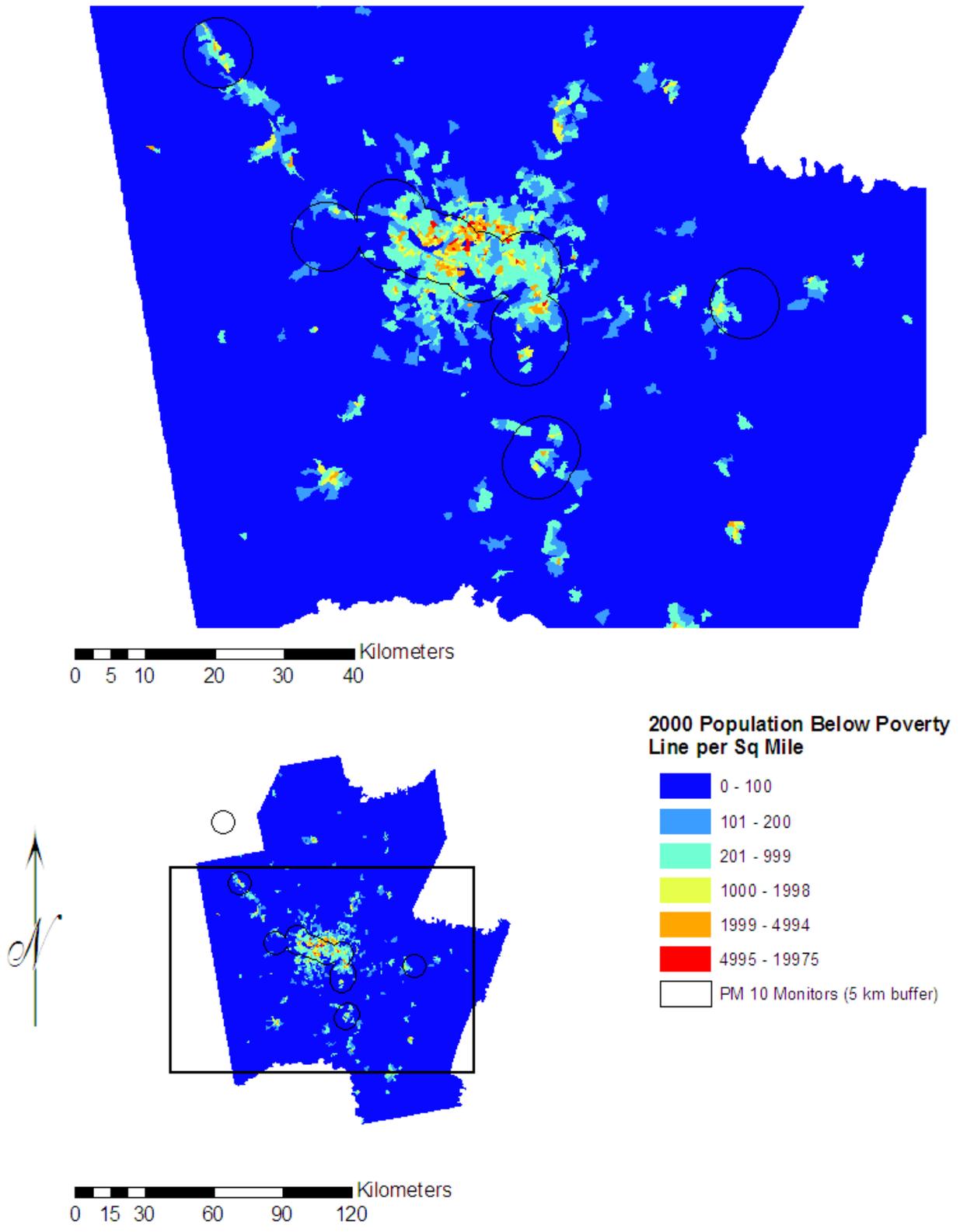
Figure A-246. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Pittsburgh, PA.
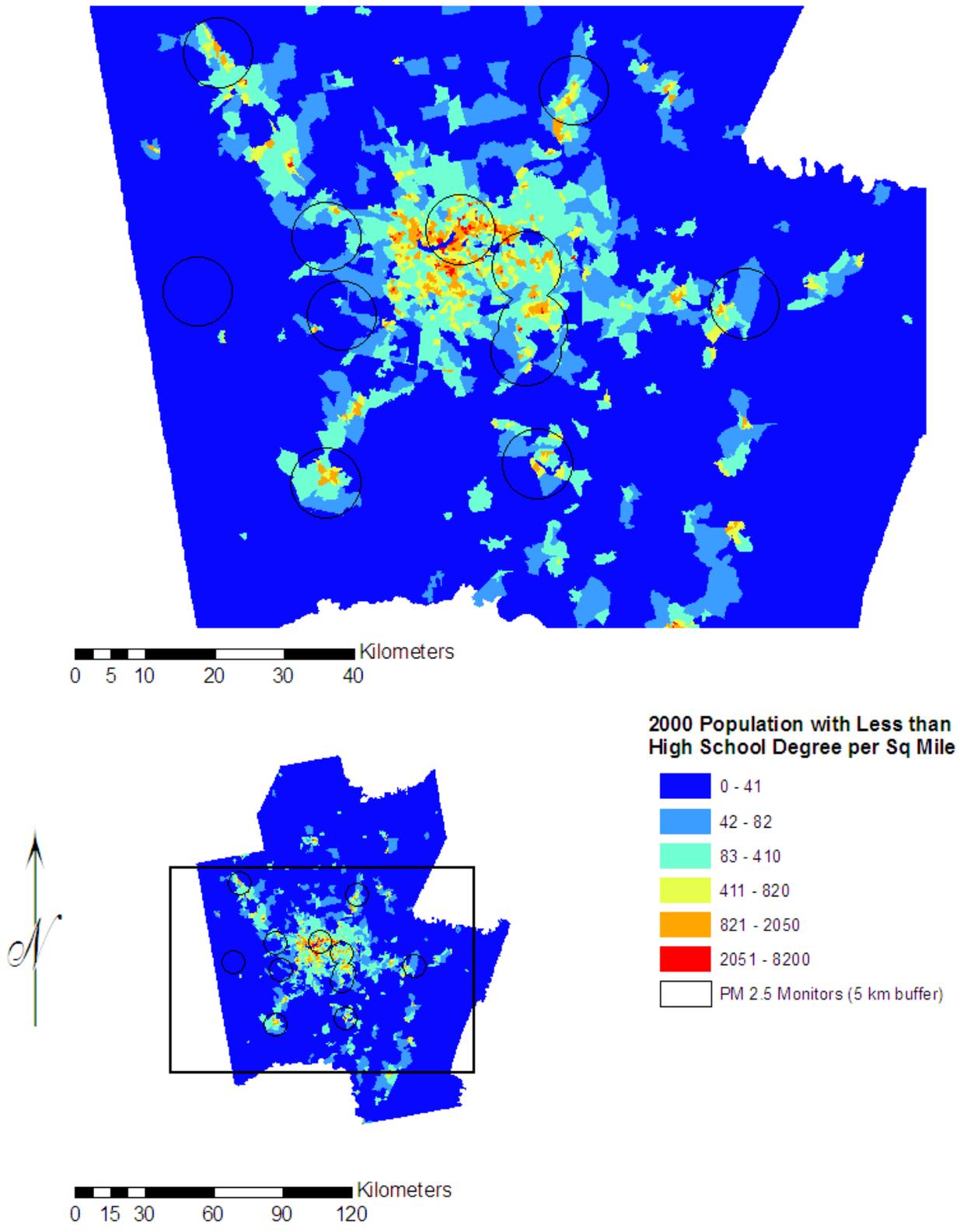
Figure A-247. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Pittsburgh, PA.
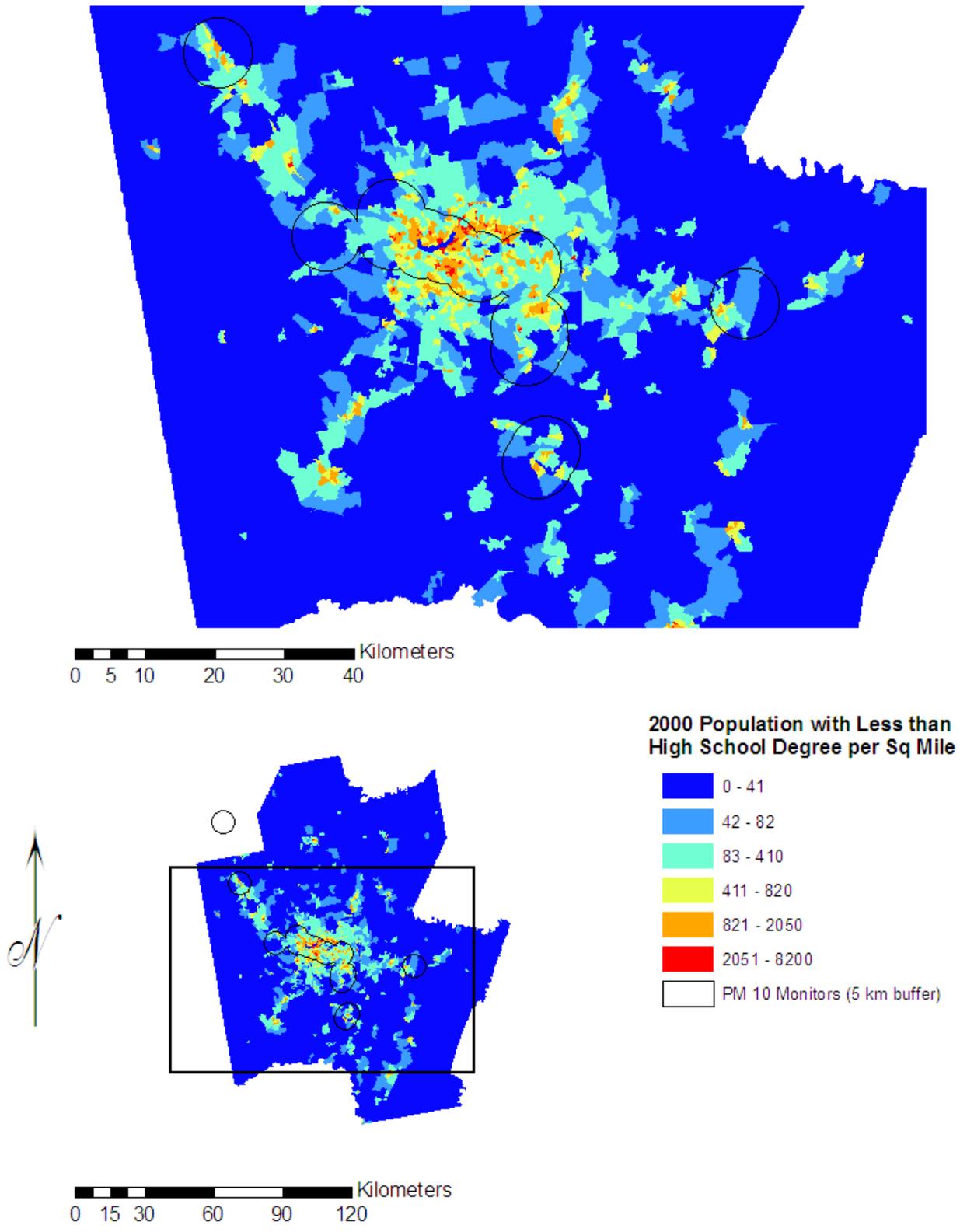
Figure A-248. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Pittsburgh, PA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 105
- 106 - 209
- 210 - 1045
- 1046 - 2090
- 2091 - 5225
- 5226 - 20900
- PM 2.5 Monitors (5 km buffer)
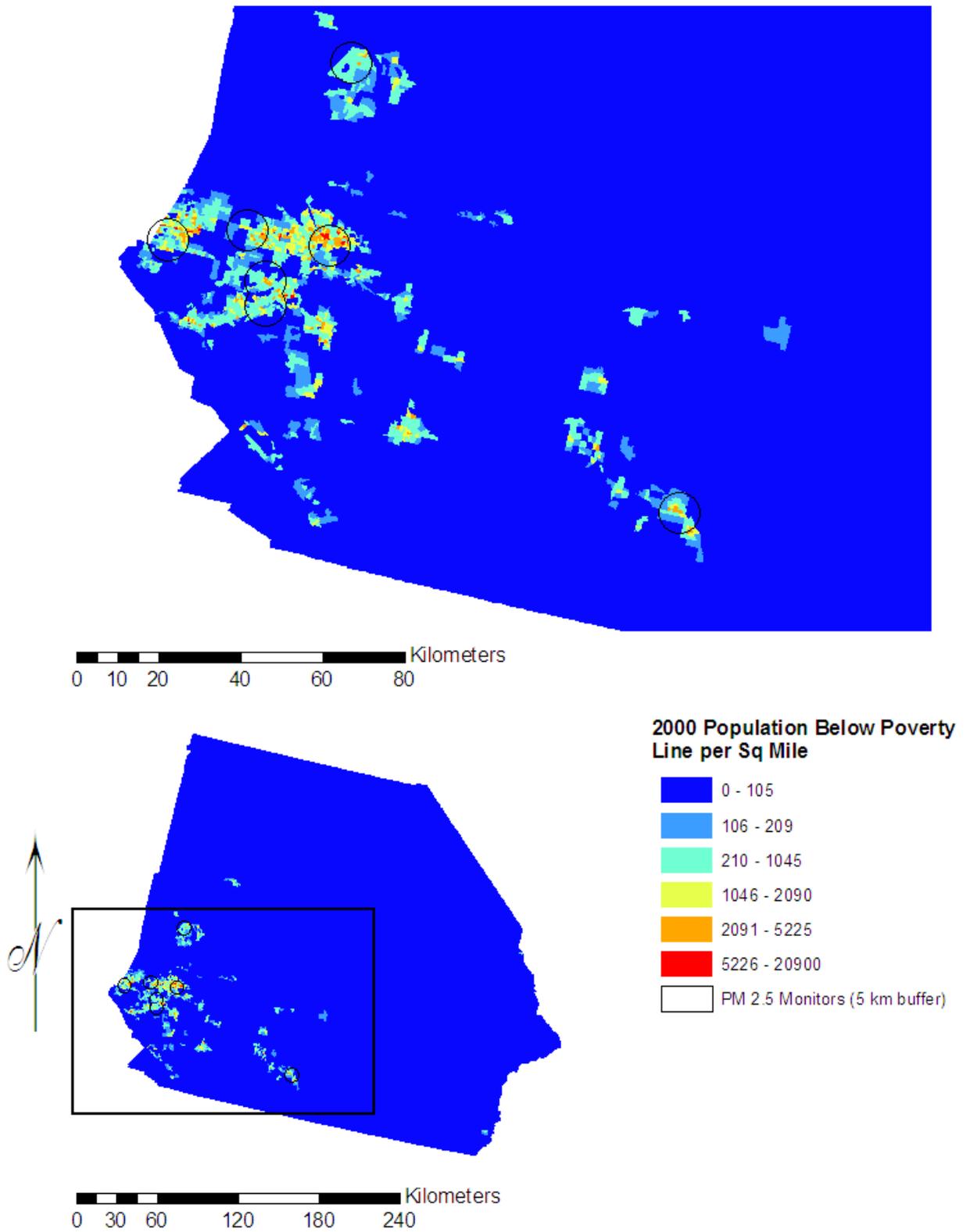
Figure A-249. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Riverside, CA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 105
- 106 - 209
- 210 - 1045
- 1046 - 2090
- 2091 - 5225
- 5226 - 20900
- PM 10 Monitors (5 km buffer)
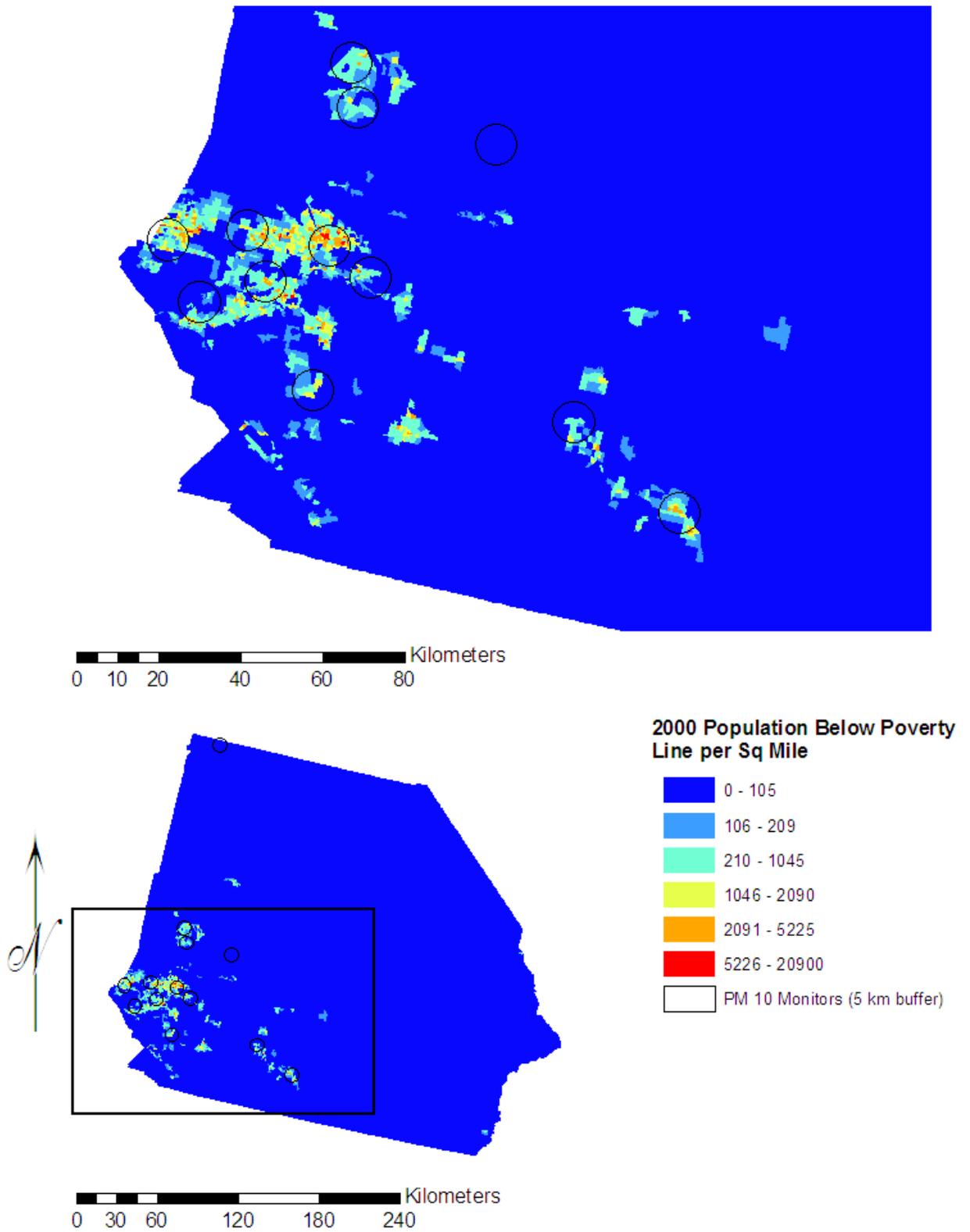
Figure A-250.   PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Riverside, CA.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 64
- 65 - 129
- 130 - 643
- 644 - 1285
- 1286 - 3213
- 3214 - 12850
- PM 2.5 Monitors (5 km buffer)
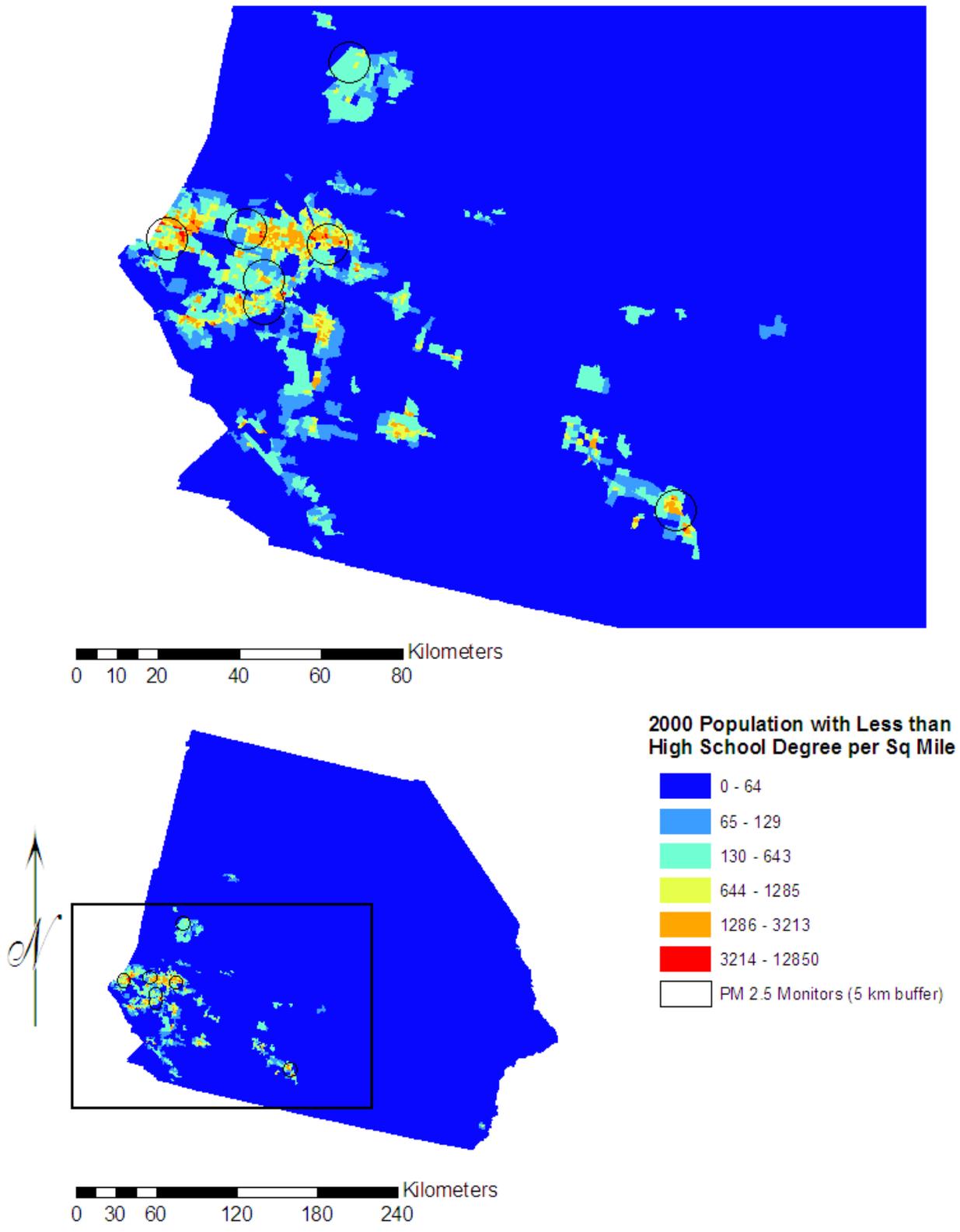
Figure A-251. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Riverside, CA.
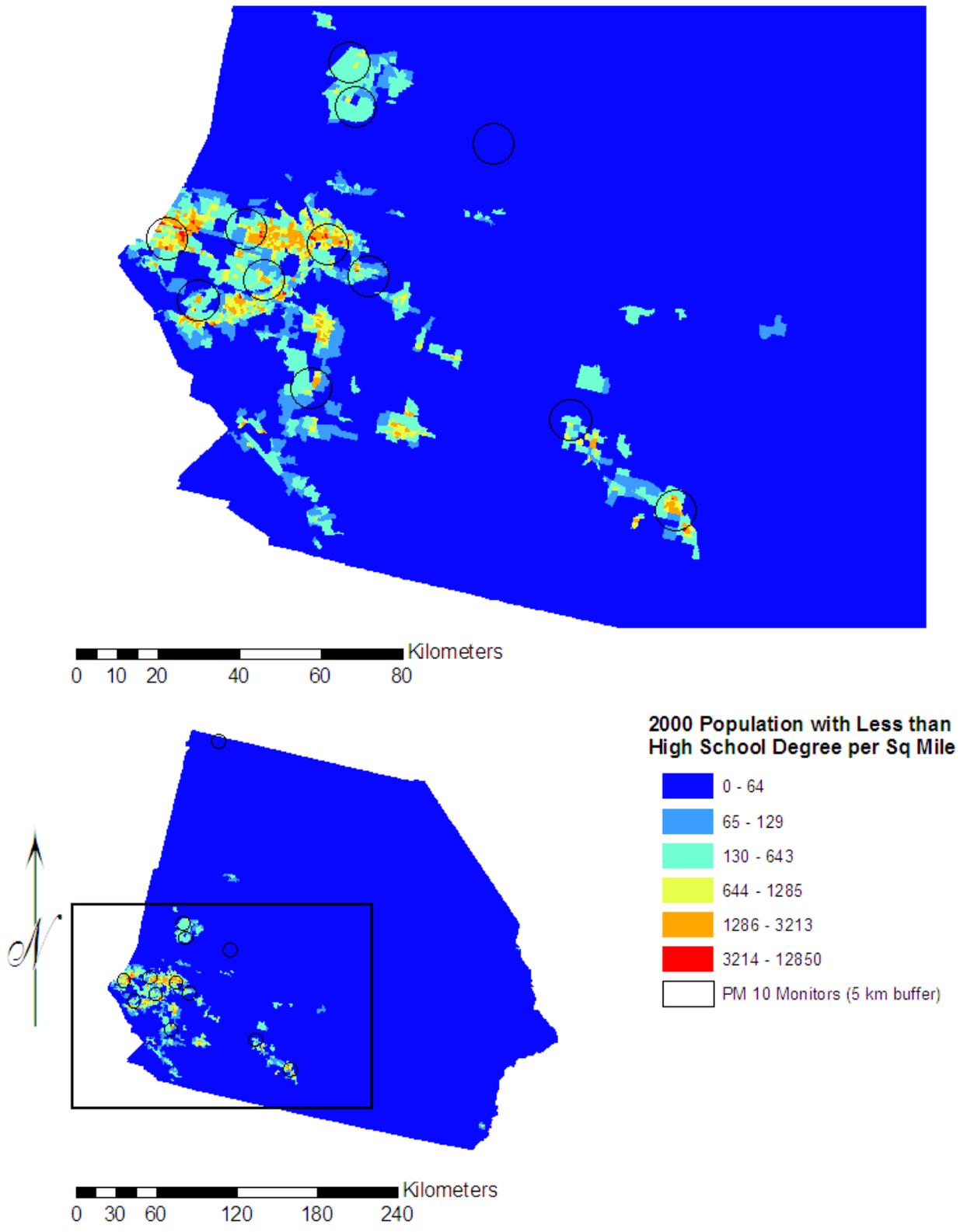
Figure A-252. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Riverside, CA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 81
- 82 - 163
- 164 - 813
- 814 - 1625
- 1626 - 4063
- 4064 - 16250
- ☐ PM 2.5 Monitors (5 km buffer)
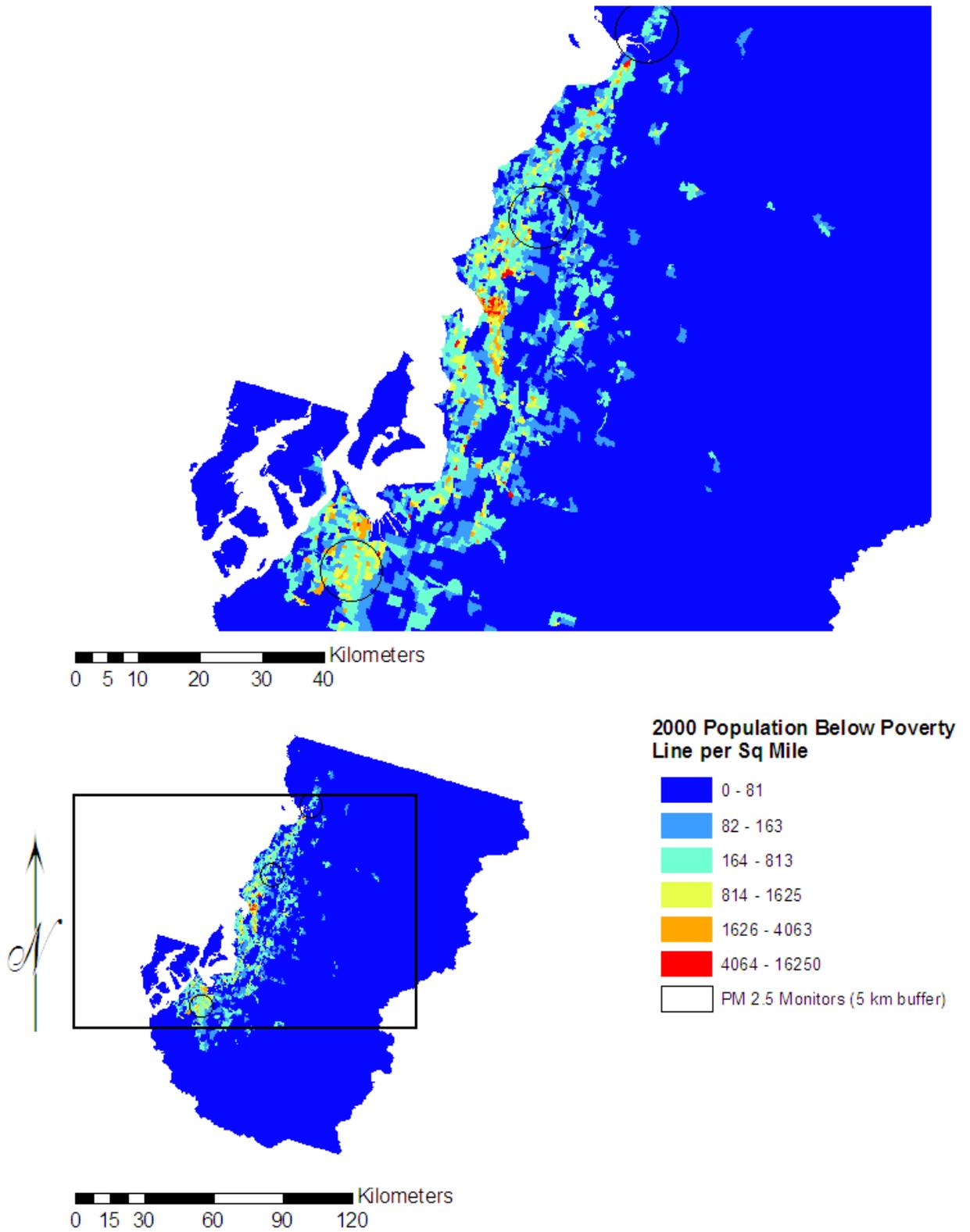
Figure A-253. PM$_{2.5}$ sampler distribution in comparison with number of individuals below the poverty line, Seattle, WA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 81
- 82 - 163
- 164 - 813
- 814 - 1625
- 1626 - 4063
- 4064 - 16250
- PM 10 Monitors (5 km buffer)
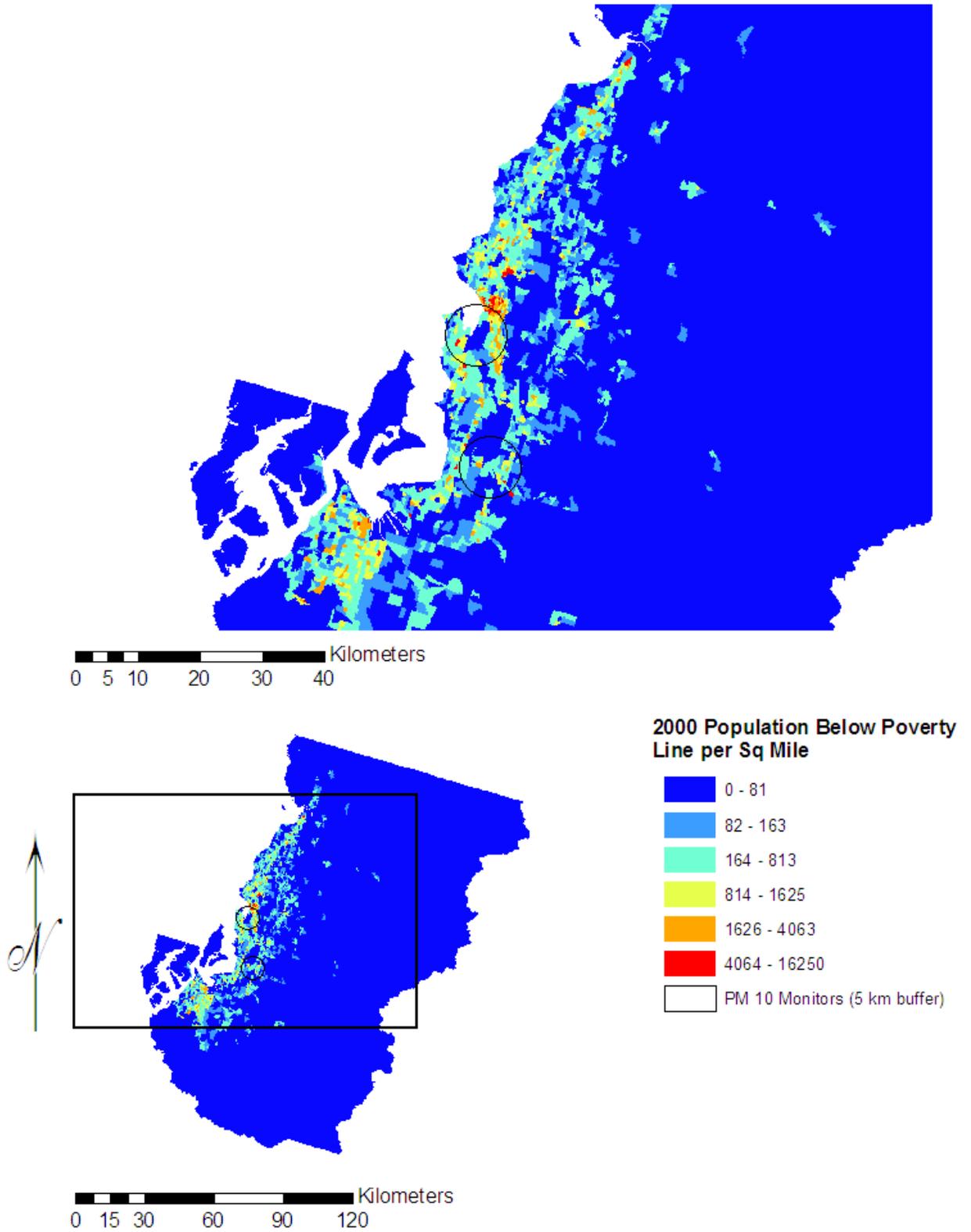
Figure A-254. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, Seattle, WA.
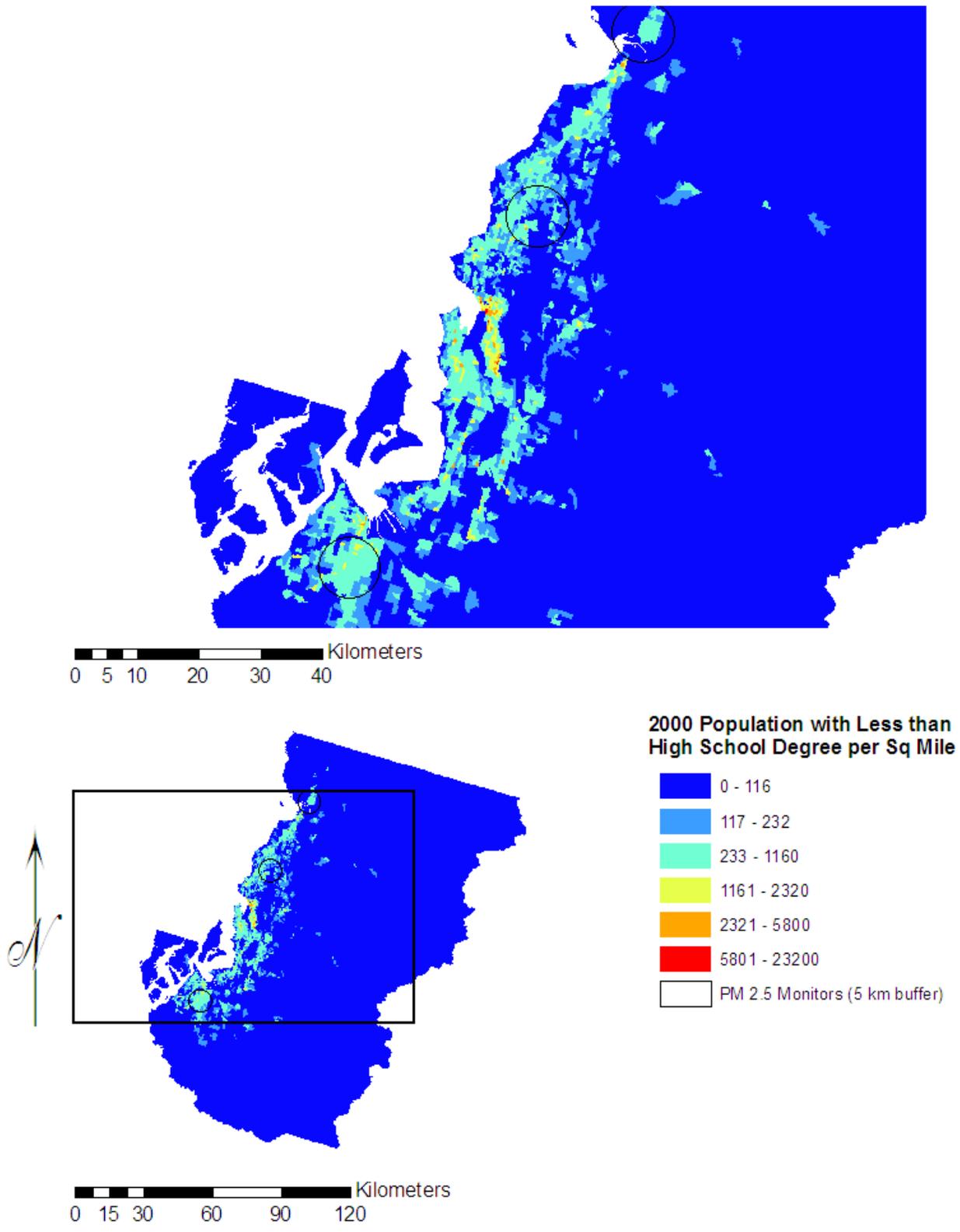
Figure A-255.   PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, Seattle, WA.

2000 Population with Less than High School Degree per Sq Mile

- 0 - 116
- 117 - 232
- 233 - 1160
- 1161 - 2320
- 2321 - 5800
- 5801 - 23200
- PM 10 Monitors (5 km buffer)
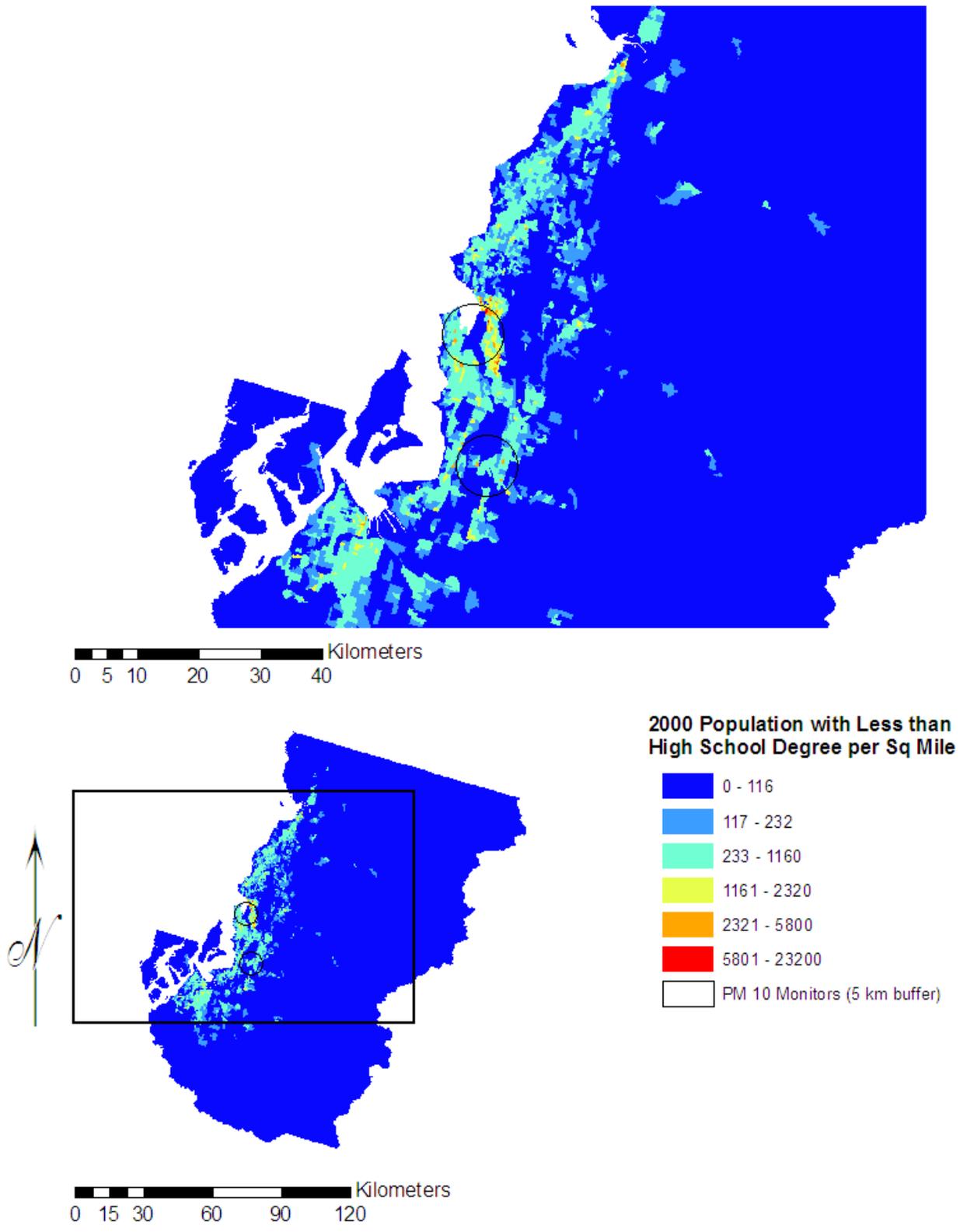
Figure A-256. PM$_{10}$ sampler distribution in comparison with number of individuals having less than high school education, Seattle, WA.

2000 Population Below Poverty Line per Sq Mile

- 0 - 59
- 60 - 119
- 120 - 594
- 595 - 1189
- 1190 - 2972
- 2973 - 11886
- PM 2.5 Monitors (5 km buffer)
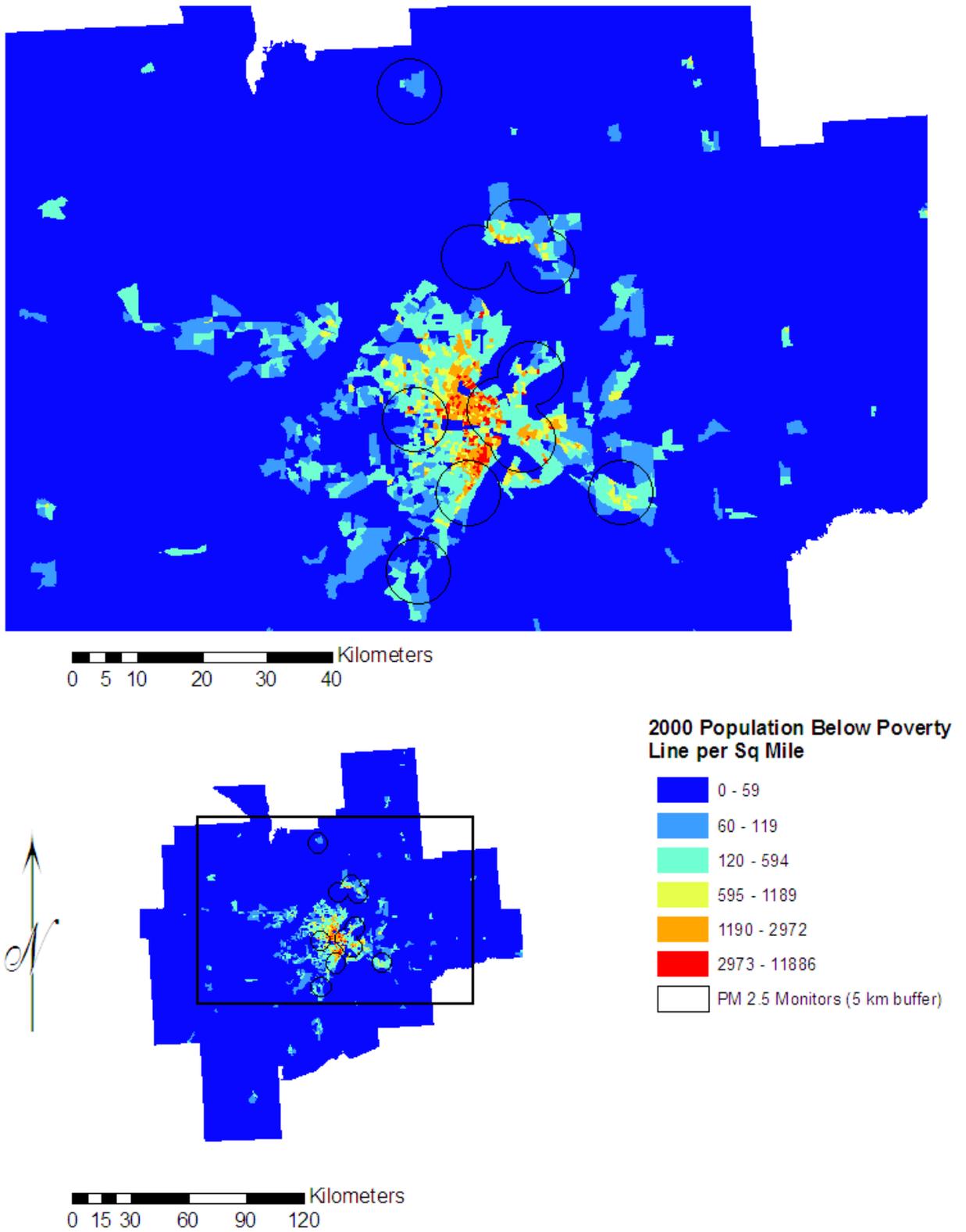
Figure A-257. PM₂.₅ sampler distribution in comparison with number of individuals below the poverty line, St. Louis, MO.
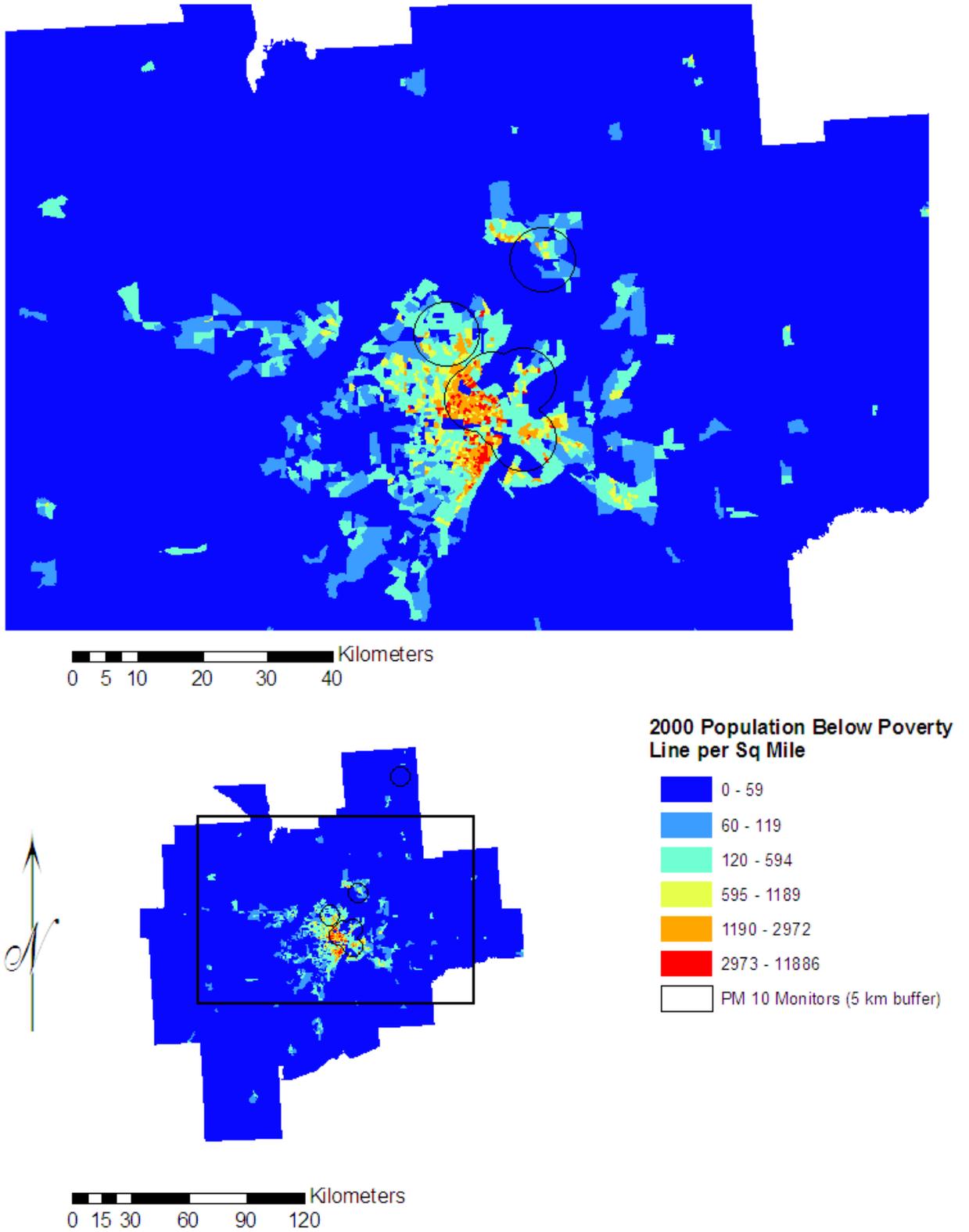
Figure A-258. PM$_{10}$ sampler distribution in comparison with number of individuals below the poverty line, St. Louis, MO.

2000 Population with Less than High School Degree

- 0 - 49
- 50 - 98
- 99 - 491
- 492 - 982
- 983 - 2454
- 2455 - 9817
- PM 2.5 Monitors (5 km buffer)
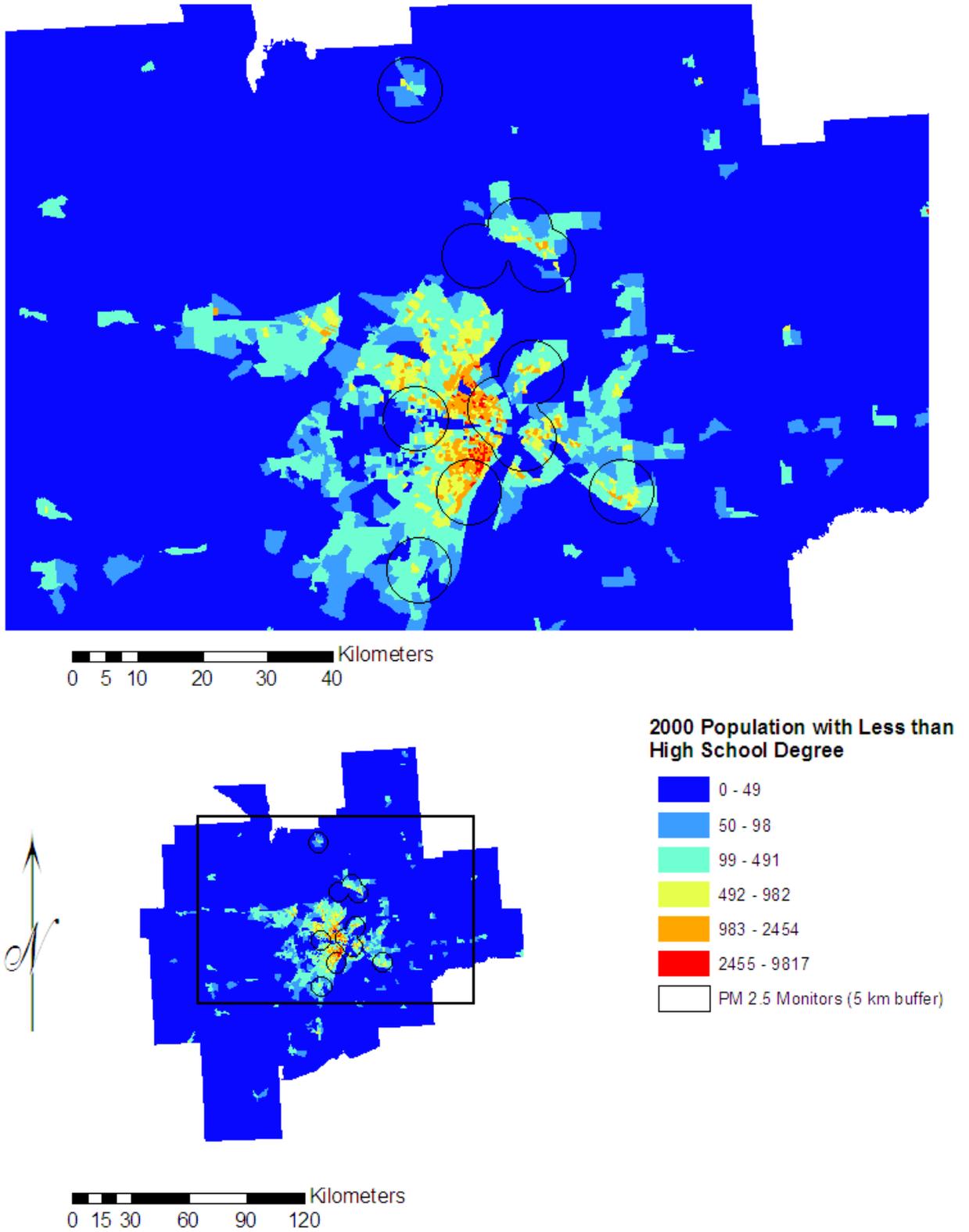
Figure A-259. PM$_{2.5}$ sampler distribution in comparison with number of individuals having less than high school education, St. Louis, MO.

2000 Population with Less than High School Degree

- 0 - 49
- 50 - 98
- 99 - 491
- 492 - 982
- 983 - 2454
- 2455 - 9817
- PM 10 Monitors (5 km buffer)
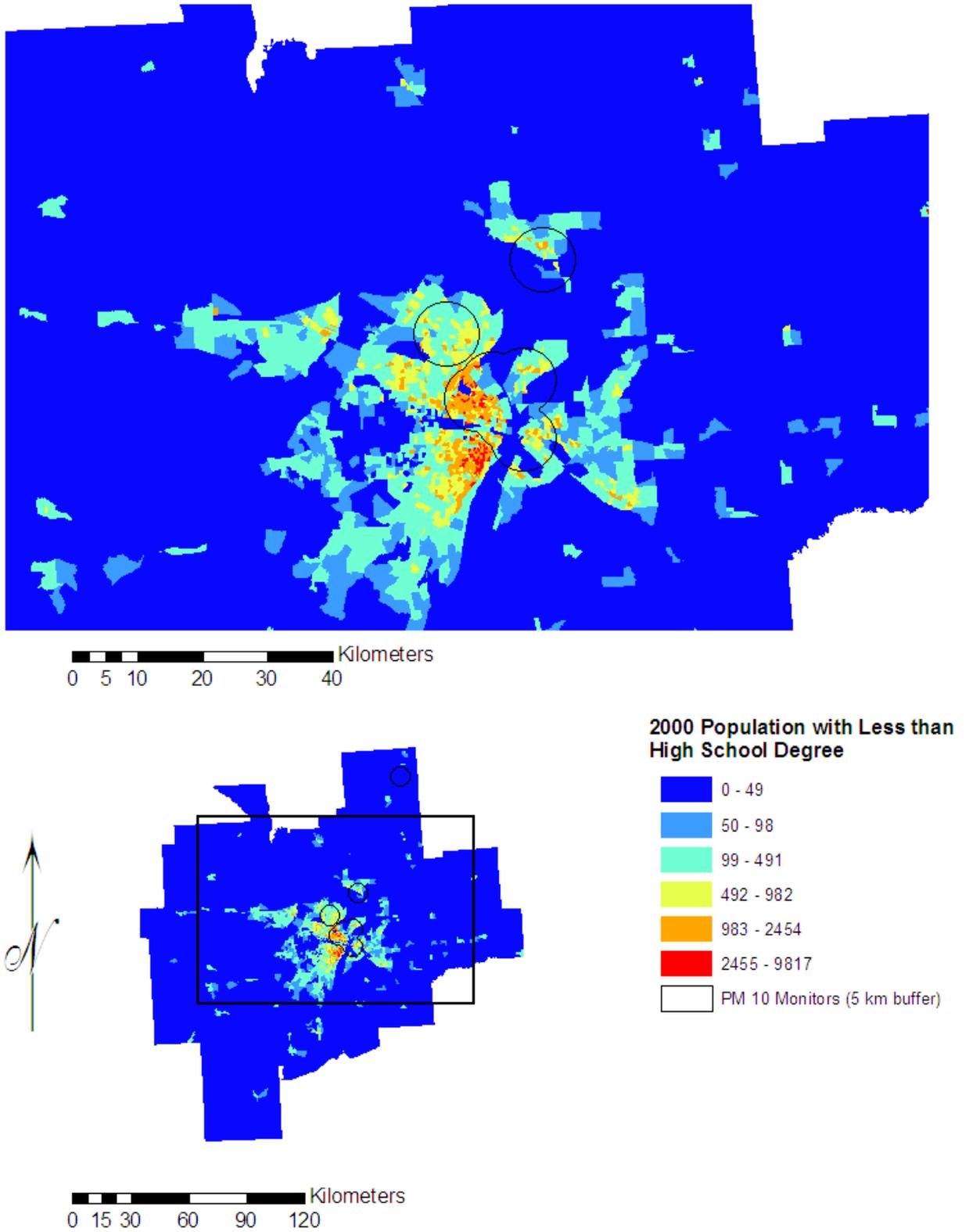
Figure A-260. PM₁₀ sampler distribution in comparison with number of individuals having less than high school education, St. Louis, MO.

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