Baltimore Supersite: Highly time- and size-resolved concentrations of urban $PM_{2.5}$ and its constituents for resolution of sources and immune responses

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Abstract

Protection of public health from the effects of air particulate matter (PM) requires measurements and methods that assess the PM chemical constituents, physical properties, and their sources. Sampling was conducted at three sites in the Baltimore area: a source-oriented (industrial) area in south Baltimore (FMC site), and two receptor area sites (Clifton Park and Ponca Street). FMC measurements were made for the initial 1-month of the project; Clifton measurements lasted for about 2 months, while measurements at Ponca Street lasted for about 9.5 months. Pollutant samples were collected at intervals ranging from 5 min to 1 h using semi-continuous monitors for $PM_{2.5}$ mass, sulfate, nitrate, elemental and organic carbon, particle number size distributions (10–20,000 nm), CO, NO_x, O_3, 11 metals, and mass spectra of individual particles, throughout the project. In addition to standard meteorological measurements, a 3D-sonic anemometer and a LIDAR system were operated during selected periods as were a rotating drum impactor with 3- to 6-h resolution and a filter/PUF sampler for 3-h measurements of organic compounds. Standard speciation and FRM mass measurements were also made. This report describes the types of measurements that were made at the various sites of the Baltimore Supersite program as well as presents the summary statistics for some of the PM measurements that have been made. The measurements of aerosol mass, major components, and size distribution data for the three sites are compared. Results show comparable PM concentrations at Ponca Street and Clifton Park. Increased variability was observed at Ponca Street.
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1. Introduction

The goal of the Baltimore Supersite was to conduct special, detailed, and extensive high-quality, chemical and physical characterizations of urban aerosol particles in support of three priority goals: (1) development of state implementation plans (SIPS), (2) setting of national ambient air quality standards (for particulate matter $(PM)_{2.5}$, and possibly its constituents or alternate indicators); and (3) evaluation and field testing of advanced measurement technology and methods to facilitate their transition to the monitoring arena. Goal 1 encompasses the development of data needed to substantially improve knowledge of source/receptor relationships. Goal 2 encompasses the development of monitoring data and samples to support health and exposure studies, and health risk assessments. Implicit in this goal is the improvement of knowledge of relationships between PM and its toxic and epidemiologic effects on humans. A critical aspect to achieving such improvements lies in the application of advanced technologies (Goal 3) to provide far higher temporal resolution and far richer speciation of PM constituents than can be achieved by either EPA's traditional compliance monitoring networks or its Speciation Trends Network (STN) Program. In addition, a key component of our project is the application of biological assays as potential metrics of human health response.

Baltimore is a populous and industrialized, mid-Atlantic, deepwater port city, located 50 km north of Washington, DC, and 150 km east of the Appalachian mountains. Baltimore is a major transportation thoroughfare between populous southern and northern cities. It is located at the southern end of the greater northeastern "megalopolis" extending from the Baltimore/Washington region to Boston. This corridor is highly important as it contains most of the major northeastern US cities and the single largest concentration of the US population.

Baltimore is an excellent choice for studying (a) the properties of local, regional, and inter-regionally transported aerosol emissions affecting urban air quality and (b) investigating our hypotheses regarding aerosol age, time-resolved sampling, and toxicological response. Like much of the northeast, PM air quality in Baltimore is heavily influenced by secondary sulfate formed during transport of sulfur emissions from the heavily industrial Ohio River Valley (Gordon, 1988) that lies > 300 km to the

west. Air traveling from the Ohio River Valley is orographically projected by the Appalachians facilitating cloud processing and concomitant heterogeneous conversion of sulfur dioxide to sulfate, providing a more aged/processed aerosol which can be differentiated from local emissions by particle size (Dodd et al., 1991; Wu et al., 1994), and by chemical composition (e.g., S:Se ratio, Gordon, 1988; and the presence of hydroxy methane sulfonic acid, Neubauer et al., 1996). Few point sources, however, lie to the west at relatively short distances from Baltimore. The most notable ones are one oil- and one major coal-fired power plant, which lie 60 and 200 km due west, respectively. The limited near-range sources allow the observation of mainly aged/processed inter-regionally transported aerosol during west winds that dominate the region's climatology along with the local emissions that will be characterized by higher temporal variability due to shifting plumes from point sources and the diurnal patterns of mobile source emissions.

The city is also influenced by urban emissions in Washington, DC, and a cluster of coal-fired power plants, and municipal and sludge incinerators along the Potomac River extending 50–90 km southwest of Baltimore. Locally, most of the Baltimore's industry is concentrated in the $125 km^2$ area comprising South Baltimore and Dundalk (Fig. 1), just a few kilometers from the center of the City, and immediately adjacent to populous neighborhoods.

The south Baltimore/Dundalk area contains > 40 industrial facilities, including 16 chemical manufacturing plants; five bulk materials shipping terminals; two medical waste, one municipal, and one sludge incinerator, six land fills for storage of domestic and industrial, including hazardous, waste; the nation's largest yeast plant, a rendering plant, an automotive painting plant, and a major steel plant.

In addition to industrial sources, emissions from traffic traveling through and around Baltimore each day adds to the area's air pollution problems. The primary north–south transport corridors travel through and around Baltimore including I-95 and its local tributaries (I-895 and I-695), and the major railroad traffic along the eastern seaboard. There are emissions from some 30,000 heavy diesel vehicles that use the City's three major toll facilities (Ft. McHenry, Harbor Tunnel, and Key Bridge) each day. One of the Baltimore measurement sites was located adjacent to I-895 and the City's bus fleet maintenance yard and would be expected to provide
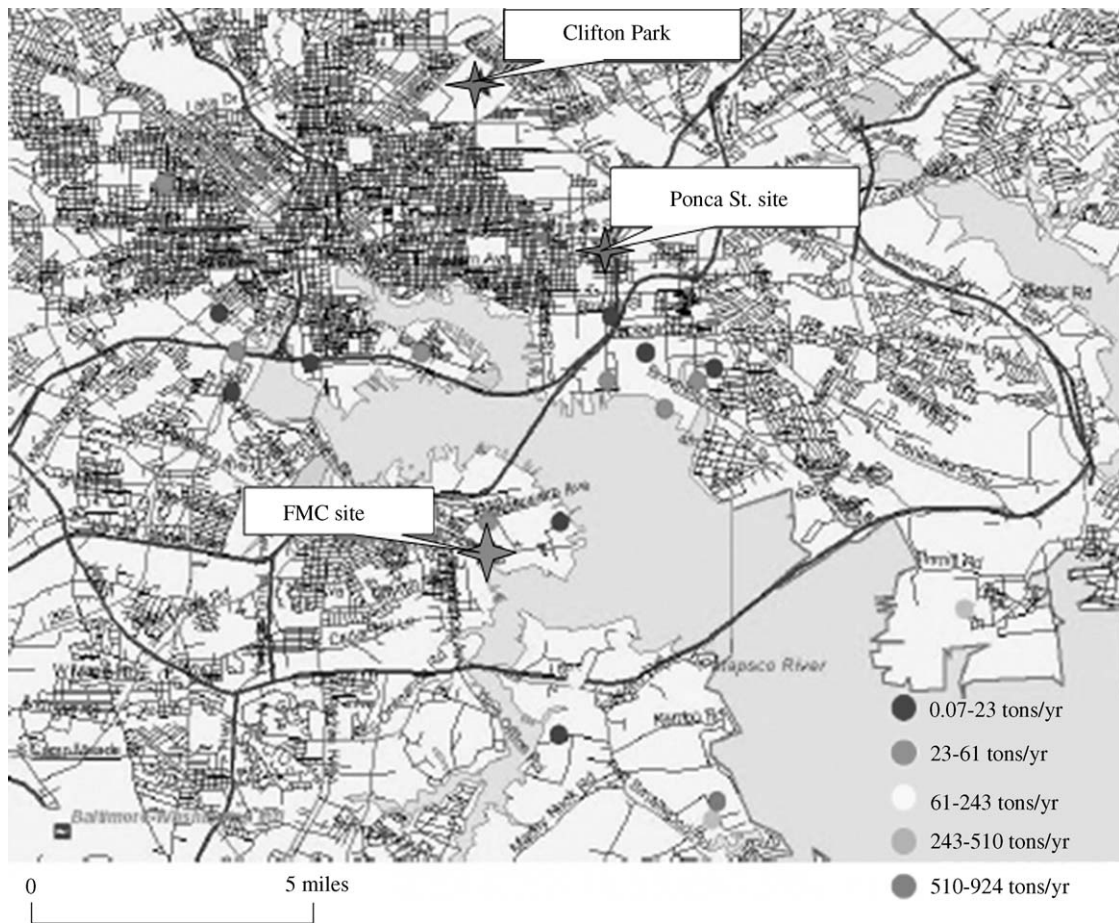
Fig. 1. Map of Baltimore showing the major PM_{10} sources and the three sampling sites, FMC, Clifton Park, and Ponca Street.

a good location for studying traffic related pollution.

Mean and maximum PM_{10} concentrations in south Baltimore (Fairfield) substantially exceed those observed in rural and suburban areas of Maryland by as much as 50%. In 1997, the mean values were $31\,\mu g\,m^{-3}$ at Fairfield vs. $17–20\,\mu g\,m^{-3}$; the maximum value at Fairfield was $86\,\mu g\,m^{-3}$ vs. $50–70\,\mu g\,m^{-3}$ at rural and suburban sites (Maryland Department of Environment (MDE) and Air Management Administration, 1998). Total aerosol carbon concentrations in summer range from 2 to $10\,\mu g\,m^{-3}$ (Suarez, 1998), about 20% of this is elemental carbon, the remainder is characterized as organic carbon by thermal-optical analysis (Birch and Cary, 1996).

During the AEOLOS intensive of August 1995, concentrations of Ca, Cr, Hg, Ti, Cl, Mn, Mo, Sb, and Zn measured in east Baltimore during winds

from the direction of the BRESCO municipal incinerator, exceeded those measured upwind of the City by from 10- to >20-fold. Note that Sb, Zn, Hg, Cr, and Cl are highly enriched in incinerator emissions and that CMB modeling attributes major fractions of the aerosol burden of these elements to incinerators in Maryland (Gordon, 1988; Ondov and Wexler, 1998). In samples influenced by winds from the Bethlehem Steel plant and sources in Hawkins Point, Cr, Fe, Mn, Sb, V, and Zn concentrations exceeded those outside the city by from 4- to 10-fold. Lastly, Baker (1999) has observed 10-fold enrichments in PAH concentrations in the Curtis Creek area, presumably due to the high density of motor vehicles in the area. While there may be other factors, the percentage of obstructive pulmonary disease deaths in the south Baltimore region is nearly 1.7-fold greater than for the whole of the city (BCHD, 1995).

Thus, Baltimore clearly offered a rich "laboratory" for studies of air pollution and health. Its industrial character, now-aged inner-city housing, and heavy traffic pose diverse environmental exposures for the City's population. The intensity and magnitude of its diverse sources in proximity to densely populated areas leads to a complex matrix of chemical exposures. These conditions have led to heightened community concerns over their environment and its impact on health. Because air pollutant transport vectors are so affected by complicated interactions of sea breeze, drainage flows, heat island, mesoscale circulations, and prevailing westerly winds, source-based modeling is extremely difficult. This further accentuates the need for detailed receptor modeling data and improved measurement methodology in order to understand the origins and variability of the Baltimore urban aerosol.

There is also a strong public health rationale for studying air pollution in Baltimore based on cancer, environmental justice, and asthma. Baltimore cancer rate (year 1996–2000), with an overall incidence rate of 54.9 per 10,000, significantly exceeds the national average of 47.3 per 10,000 (Cigarette Restitution Fund Program, 2003). At the same time, Baltimore city is ranked among the highest (at the census tract level) for cancer causing air toxins of mobile source origin including 1,3-butadiene (7th), benzene (4th), polycyclic organic matter (27th) and diesel exhaust (61st) (US Environmental Protection Agency (US EPA), 2002). Moreover, there is evidence to suggest that this excess risk falls disproportionately on Baltimore's economically disadvantaged communities of color identifying a serious environmental justice concern (Apelberg et al., 2005). In addition to cancer, air pollution poses an asthma risk to populations represented by Baltimore City's urban, predominantly African-American communities (Eggleston et al., 1999).

An advanced monitoring program was implemented that was highly-focused on the development of improved source–receptor relationships and that featured highly time-resolved measurements of PM constituents and encompassed an innovative surrogate health-effects concept, to extend the source–receptor paradigm to encompass correlation of the surrogate to PM sources and component species. Specifically, we have applied assays for cytokines and reactive oxygen species (ROS) to PM samples in a manner analogous to EPA Integrated Air Cancer Study's use of mutagenicity assays to apportion mutagenic contributions from sources which ultimately lead to improved estimates of cancer risks from air pollution sources (Cupitt et al., 1994; Lewtas et al., 1992).

The project further encompassed detailed (i) aerosol organic compound identification and analysis (ii) collection of multiple gram quantities of $PM_{2.5}$ for archival storage and more detailed chemical and physical characterizations, (iii) mapping of Baltimore's wind fields and aerosol concentrations, including plumes from discrete sources, (iv) advanced factor analysis (FA) and multivariate calibration algorithms for source apportionment, data reduction, hypothesis testing, and data quality analysis and method intercomparisons, (v) continuous/semi-continuous monitoring of mass, sulfate, nitrate, elemental and organic aerosol carbon (EC and OC, respectively), aerosol number concentration distribution, and light scattering using commercially available instruments, (vi) semi-continuous elements in aerosol sampler (SEAS) and rotating drum impactor (RDI) measurements for quantitative determinations of size spectra of elemental PM constituents; (vii) measurements of Federal Reference Method (FRM) mass, EC, OC, and elemental composition via standard 24-h monitors, and (viii) criteria and PAMS gases (VOC, aldehydes, SO_2, NO_X, O_3, CO), and (ix) integration with toxicological and epidemiological field studies.

A large number of samples has been collected and continue to be analyzed by the Supersite investigators. A series of papers is being developed from these data to present the results of the various studies. This paper describes the basic information about the Baltimore Supersite such as what measurements were made at the various locations around Baltimore as well as summary statistics for some of the measurements that have been made to date, thus providing an introduction to other papers in the special issues and those to follow. Herein, size distribution and chemical composition data are reported and discussed.

2. Measurements

To meet the objectives of the Baltimore Supersite, measurements were made at three different sites (Fig. 1) over different time periods. The initial measurements were made in the Brooklyn area (FMC Site). This site is located in an area of multiple sources where it was expected that the

combination of high time resolution measurements and detailed meteorology would permit the development of source specific emissions signatures that could be used in conjunction with the subsequent measurement campaigns. A 20-day study was conducted at this site beginning on 16 May 2001 using a subset of the eventual full complement of instruments (see Table 1).

The sampling systems were then moved to Clifton Park. Measurements were begun on 30 June 2001. Additional measurement systems were available at this site and they are listed in Table 1. Unfortunately sampling was stopped on 14 September 2001 when much of the equipment was destroyed by a fire at the site. Other problems, such as the failure of some of the instruments, prevented the full opera-

tion of all instruments during the July 2001/summer intensive. Thus, a new site needed to be developed and the equipment base re-established.

The new site was established at Ponca Street (Fig. 1) and began operation in early February 2002. Typically, measurements for SMPS, semi-continuous nitrate, speciation monitor, CO, NO, NO_x, O_3, wind direction and speed, and solar insolation, were started in early February, 2002, while measurements for APS, semi-continuous sulfate, and semi-continuous EC/OC, were started in mid-February. This site was operated until 1 March 2003. Due to the long period over which this site was operational, most of the instruments listed in Table 1 ran for sufficient time to provide a rich data set with multiple time resolution.

Table 1
Instruments deployed at the baltimore supersite sites

	FMC	Clifton Park	Ponca Street
Dates of operation	16/05–15/06, 2001	30/06–14/09, 2001	06/02–01/03, 2003
Particle size measurements			
SMPS[a]	X	X	X
APS (TSI Model 3320)	X	X	X
CSAS[b]	X	X	
Semi-continuous methods			
OC/EC	R&P[c] 5400	R&P 5400	Sunset Lab
Nitrate	R&P 8400n	R&P 8400n	R&P 8400n
Sulfate	R&P 8400s	R&P 8400s	HSPH design[d]
SEAS	Metals	Metals and cytokines	Metals and cytokines
Mass	30 °C TEOM with SES	TEOM (R&P 1400a)	30 °C TEOM with SES
Gas monitors	CO, NO_x, SO_2, O_3	CO, NO_x, SO_2, O_3	CO, NO_x, O_3
Meteorological variables			
Wind speed and direction	Hourly	Hourly	Hourly
Relative humidity	Hourly	Hourly	Hourly
Solar insolation	—	Hourly	Hourly
Sonic anemometer	u, v, w components	u, v, w components	u, v, w components
LIDAR	Episodically during daylight hours	Episodically during daylight hours	Episodically during daylight hours
Integrated measurements			
FRM mass (RAAS samplers)	Daily	Daily in July 2001; every third day otherwise	Daily in July 2002; every third day otherwise
Speciation monitor (RAAS samplers)	Daily	Daily in July 2001; every third day otherwise	Daily in July 2002; every third day otherwise
Aerosol organic compounds	None	None	3 h high volume samples in July and November 2002; February 2003
Single-particle mass spectrometer	None	None	RSMS III.

[a]Consisting of a DMA, Kr-85 neutralizer, and CPC (TSI Inc. Models 3071, 3077, and 3010, respectively).
[b]Classical Scattering Aerosol Spectrometer, Model CSAS-100-HV (Particle Measuring Systems Inc., Boulder, CO)
[c]Rupprecht and Patashnick Co. Inc. Instruments, Albany, NY.
[d]Harvard School of Public Health Design.

Sampling start dates for other measurements made at the three sites of the Baltimore Supersite that are listed in Table 1 (i.e., SEAS, LIDAR, cytokine SEAS collections, etc.) may be obtained from the Supersite's progress reports that are available to the public online through the EPA's web site: http://www.epa.gov/ttn/amtic/baltprog.html. The data have also been loaded into the Supersite's data base (BSSB). Two-dimensional LIDAR images of relative particle concentration of all episodically taken data during the study period can be found in the LIDAR data archive at: http://www.jhu.edu/~dogee/mbp/supersite2001/lidar_data.htm. The meteorological data is available through: http://www.jhu.edu/~dogee/mbp/supersite2001/met_data.htm. Several publications have also been prepared, submitted or published detailing the analytical and sampling methods. An updated list of these publications is available through the Supersite's web site: http://www.chem.umd.edu/supersite/Datameet.htm.

3. Results and discussion

The particle size distribution data were subdivided into a series of size ranges: 10–50 nm, 50–100 nm, 100–500 nm, 500 nm–2.5 μm, 2.5–10 μm, and 10–20 μm. Generally, there were fewer instruments in operation for a shorter time at the FMC site. For example, no sulfate measurements were made. Also, due to problems mentioned earlier in this report, only limited measurements were made at Clifton Park. In the case of Ponca Street, most of the instruments listed in Table 1 ran most of the time that the site was in operation.

The particle number summary statistics are presented in Tables 2, 4, and 7 for FMC, Clifton Park, and Ponca Street sites, respectively. Fig. 2 shows a plot of the number concentrations for the six size ranges. The (cumulative) particle number distributions show an agreement over all the sampling sites. Four statistic tests (Cochran's C test, Bartlett's test, Hartley's test, and Levene's test) were applied to check for similarities, if any, between the standard deviations for each size bin among the three sites. The p values obtained were significantly less than 0.00001, indicating that there was a statistically significant difference amongst the standard deviations at the 95.0% confidence level. The F test was used to test for any similarities between the arithmetic means for all the size bins among the three sites. The test indicated a statistically significant difference between the means
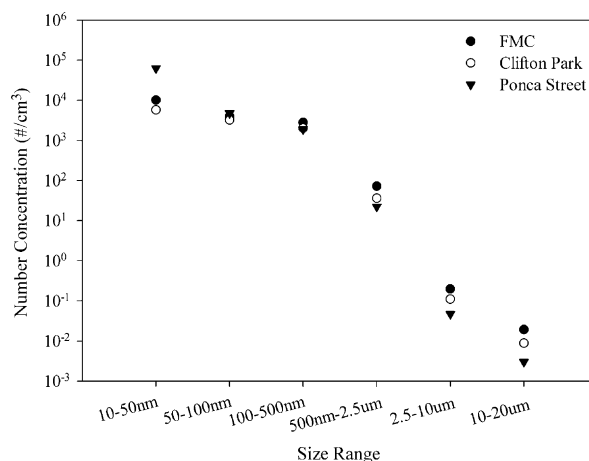

Fig. 2. Number distributions for all three sites based on arithmetic means.

indicated by the p-Value being much less than 0.05. The results from these tests imply that the values given in Tables 2–9 can be compared directly.

The chemical composition data obtained from the semi-continuous instruments are presented in Tables 3, 5, and 8. Tables 6 and 9 summarize data that were obtained from the Speciation Network sampler. A box-and-whisker plot of major component distributions for all the three sites is also given in Fig. 3.

3.1. $PM_{2.5}$ measurements

The distributions for the major components are shown in Fig. 3, where one immediately notes that nitrate, sulfate and total carbon are the predominant species contributing to the measured PM mass. The time series of nitrate, sulfate and OC concentrations (Fig. 4) illustrates the effects of winter, summer, and the Quebec Wildfire episodes, respectively, on the overall mass. The immediate effect of these episodes is to increase the variability in the data as can be seen in Tables 7–9. Also, the wildfire episode resulted in the elevation of the mean concentration of $PM_{2.5}$ mass observed at Ponca Street as reported by Park et al. (2005). Total mean aerosol carbon concentrations are $3.39 \pm 3.33\,\mu g\,m^{-3}$ (FMC), $5.24 \pm 1.54\,\mu g\,m^{-3}$ (Clifton), and $7.34 \pm 4.39\,\mu g\,m^{-3}$ (Ponca Street). These results are consistent with earlier findings by Suarez (1998) in which total aerosol carbon concentrations in summer ranged from 2 to $10\,\mu g\,m^{-3}$.

Table 2
Particle number concentrations (number cm^{-3}) for the FMC site

Size range	Arithmetic mean	Arithmetic std deviation	Geometric mean	Geometric std. deviation
10–50 nm	10119	92287	6126	2.68
50–100 nm	3975	24621	2524	3.06
100–500 nm	2813	31121	1602	2.70
500 nm–2.5 μm	73	139	23	4.89
2.5–10 μm	0.197	0.300	0.125	2.37
10–20 μm	0.0193	0.0407	0.0097	2.93

Table 3
Concentrations (μg m^{-3}) for the components at the FMC site measured using the semi-continuous instruments

Component	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
TEOM	19.03	11.42	15.55	2.00
Nitrate	0.87	1.04	0.43	3.69
EC	1.46	1.54	1.16	1.82
OC	1.93	1.89	1.63	1.62
TC	3.39	3.33	2.83	1.66
Al	0.01217	0.0274	0.00606	3.53
As	0.00069	0.00076	0.00039	3.11
Cd	0.00288	0.00604	0.00086	5.38
Cr	0.00091	0.00142	0.00045	3.29
Cu	0.00232	0.00277	0.00141	2.81
Fe	0.00846	0.01467	0.00137	8.39
Mn	0.00149	0.00261	0.00057	4.32
Ni	0.00389	0.00540	0.00254	2.46
Pb	0.00828	0.01158	0.00471	2.91
Se	0.00189	0.00128	0.00147	2.22
Zn	0.01745	0.01700	0.01284	2.14

Table 4
Particle number concentrations (number cm^{-3}) for Clifton Park

Size range	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
10–50 nm	5823	6728	4035	2.42
50–100 nm	3232	2713	2345	2.37
100–500 nm	2032	1985	1519	2.17
500 nm–2.5 μm	36.2	59.0	8.2	7.74
2.5–10 μm	0.111	0.088	0.078	2.86
10–20 μm	0.0089	0.0081	0.0061	2.58

Thermal-optical analysis (Birch and Cary, 1996) characterized about 20% of this total carbon as elemental carbon. At Ponca Street, the mean elemental carbon concentration is about 15% of the mean total carbon. The highest monthly average OC, 10.77 μg C m^{-3}, was observed in July, primarily caused by the Canadian Quebec forest fire event (July 6th and 8th). The highest monthly EC average, 1.50 μg C m^{-3}, occurred in November because of increased traffic congestion and the cold and stable atmospheric conditions (Park et al., 2005a, b).

With the exception of S, an element that was found to be highly correlated with sulfate (Ogulei et al., 2005), the highest average elemental concentrations were obtained for Na at Clifton Park

Table 5
Concentrations ($\mu g\,m^{-3}$) for the components at Clifton Park measured with the semi-continuous instruments

Component	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
TEOM	16.44	11.90	11.75	2.63
Nitrate	1.00	1.25	0.59	2.82
Sulfate	6.65	0.27	4.09	3.16
OC	2.58	6.31	2.11	1.64
EC	0.89	0.85	0.73	1.83
TC	3.47	6.48	2.92	1.60
Al	0.00819	0.01228	0.00586	2.27
As	0.00084	0.00059	0.00063	2.28
Cd	0.00016	0.00016	0.00011	2.44
Cr	0.00019	0.00027	0.00012	2.40
Cu	0.00267	0.00460	0.00167	2.41
Fe	0.01498	0.01687	0.00997	2.44
Mn	0.00207	0.00241	0.00140	2.29
Ni	0.00252	0.01899	0.00089	3.10
Pb	0.00190	0.00254	0.00103	3.20
Se	0.00238	0.00226	0.00168	2.31
Zn	0.01038	0.01099	0.00724	2.31

Table 6
Concentrations ($\mu g\,m^{-3}$) for Clifton Park obtained from the 24-h integrated samples collected with the speciation network sampler

Species	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
TEOM	16.82	7.49	15.26	1.58
NO_3^-	0.741207	0.538331	0.597590	1.954218
SO_4^{2-}	5.091862	2.955773	4.281886	1.872535
NH_4^+	1.531857	1.123331	1.145822	2.412328
K^+	0.050138	0.027819	0.046295	1.434644
Na^+	0.135672	0.091785	0.103782	2.251940
EC	0.519270	0.189425	0.485569	1.460126
OCX	2.237568	0.805610	2.105492	1.428556
OC	4.725561	1.441398	4.508323	1.374905
TC	5.244831	1.543000	5.016530	1.364173
Al	0.015644	0.030362	0.012571	4.483893
Sb	0.003212	0.005045	0.003828	3.067854
As	0.000779	0.000960	0.000875	2.849431
Ba	0.029199	0.024575	0.026578	3.127738
Br	0.002969	0.002217	0.002353	2.273531
Cd	0.001295	0.002468	0.001830	2.950401
Ca	0.039441	0.020052	0.035830	1.528476
Ce	0.024330	0.032246	0.030857	2.456542
Cs	0.007698	0.011386	0.006535	5.203814
Cr	0.001217	0.001473	0.000943	1.949806
Cu	0.002372	0.001237	0.002044	1.820564
Eu	0.000038	0.000199	0.001055	1.000000
Ga	0.000271	0.000437	0.000628	2.094182
Au	0.001450	0.002162	0.002293	2.495616
Hf	0.004268	0.007258	0.006273	4.099076
In	0.002206	0.002454	0.001842	2.844434
Ir	0.003298	0.002938	0.004029	1.742197
Fe	0.069312	0.034232	0.062417	1.581822
La	0.018918	0.030267	0.016264	5.424250
Pb	0.002356	0.002327	0.003075	2.034176

Table 6 (*continued*)

Species	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
Mg	0.012708	0.013454	0.022379	1.431763
Mn	0.002459	0.001485	0.002428	1.746691
Hg	0.001138	0.001525	0.002145	1.715810
Mo	0.001009	0.001476	0.001874	2.281866
Ni	0.004298	0.002117	0.004019	1.619145
Nb	0.000442	0.000843	0.001049	2.303064
P	0.000038	0.000199	0.001051	1.000000
K	0.037876	0.038779	0.027374	2.188111
Rb	0.000363	0.000637	0.000975	1.800999
Sc	0.000237	0.000422	0.000757	1.612165
Se	0.002000	0.002421	0.001489	3.089060
Si	0.094681	0.078307	0.078085	1.761358
Ag	0.003342	0.003723	0.003241	2.752135
Na	0.255183	0.095576	0.234972	1.549886
Sr	0.000679	0.001235	0.000856	2.670251
S	1.738083	1.020756	1.452066	1.910063
Ta	0.034219	0.015200	0.034581	1.483086
Sn	0.016175	0.006081	0.015700	1.511997
Ti	0.008805	0.006970	0.007336	1.788779
V	0.004183	0.003318	0.003464	2.242128
W	0.005588	0.006227	0.008259	1.948616
Y	0.000341	0.000655	0.000613	3.017107
Zn	0.009337	0.009506	0.006914	2.192562
Zr	0.000525	0.001000	0.000824	3.114589

Table 7
Particle distribution (number cm^{-3}) for Ponca Street

Size range	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
10–50 nm	63237	825884	37316	3.70
50–100 nm	4777	4082	4127	1.70
100–500 nm	1890	3630	1570	1.80
500 nm–2.5 μm	22.24	203.75	1.88	3.76
2.5–10 μm	0.0469	0.4419	0.0091	2.98
10–20 μm	0.0030	0.0852	0.0002	3.49

($0.255 \pm 0.096 \, \mu g \, m^{-3}$, respectively) and Fe at Ponca Street ($0.144 \pm 0.099 \, \mu g \, m^{-3}$, respectively). Being a port city, the high concentration of Na could be attributed to sea salt and the Fe could be coming from the Bethlehem steel plant. Using an advanced receptor modeling technique involving multiple time resolution samples, Ogulei et al. (2005) found significantly high $PM_{2.5}$ Fe contributions from steel plant emissions (82% of the apportioned Fe). The highly time-resolved data from the SEAS instrument permitted additional resolution of local point sources.

The concentrations of Ca, Cr, Hg, Ti, Cl, Mn, Mo, Sb, and Zn are higher at Ponca Street than Clifton Park. During the atmospheric exchange over lakes and ocean surfaces (AEOLOS) intensive of August, 1995, concentrations of Ca, Cr, Hg, Ti, Cl, Mn, Mo, Sb, and Zn measured in east Baltimore exceeded those measured upwind of the city by from 10 to >20-fold when winds blew from the direction of the BRESCO municipal incinerator. In samples influenced by winds from the Bethlehem Steel plant and sources in Hawkins Point, Cr, Fe, Mn, Sb, V, and Zn concentrations exceeded those outside the city by from 4- to 10-fold. Sb, Zn, Hg, Cr, and Cl have previously been found to be highly enriched in incinerator emissions and CMB modeling attributed major fractions of the aerosol burden of these

Table 8
Concentrations ($\mu g\,m^{-3}$) for the components at Ponca Street measured using the semi-continuous instruments

Species	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
TEOM	15.69	13.10	11.07	2.56
Nitrate	1.70	1.66	1.13	2.49
Sulfate	5.76	5.67	4.25	2.22
OC	1.61	2.43	1.07	2.66
EC	0.23	0.77	0.12	3.61
TC	1.84	2.80	1.20	2.75
Al	0.0561	0.0669	0.0412	2.0073
As	0.0006	0.0006	0.0004	2.9599
Cd	0.0004	0.0005	0.0002	2.4264
Cr	0.0006	0.0007	0.0004	2.6498
Cu	0.0059	0.0036	0.0049	1.8832
Fe	0.0691	0.0541	0.0573	1.9295
Mn	0.0073	0.0093	0.0046	2.4320
Ni	0.0035	0.0116	0.0011	4.1382
Pb	0.0072	0.0061	0.0048	3.0467
Se	0.0013	0.0010	0.0010	2.4745
Zn	0.0289	0.0266	0.0215	2.1193

elements to incinerators in Maryland (Gordon, 1988; Ondov and Wexler, 1998).

3.2. Particle count data

Fig. 2 indicates the relationships among particle number distributions measured at all the three sites. The mean number concentration of particles with aerodynamic diameter less than 0.1 μm was higher in Ponca Street whereas particles with sizes greater than 0.1 μm were predominant at the FMC site. This observation could in part be a result of the fewer measurements made at FMC site in comparison to Ponca Street. The proximity of the Ponca Street site to the interstate highway I-895 is more likely the reason for the higher small particle concentrations at Ponca Street (resulting from direct traffic emissions) (Zhu et al., 2002). However, there is much variability in the Ponca Street data as can be seen by the higher standard deviations (e.g., 8.25×10^5 particles cm^{-3} (Ponca Street) compared to 9.23×10^4 particles cm^{-3} (FMC) or 6.72×10^3 particles cm^{-3} (Clifton) for the 10–50 nm range). The high degree of variability suggests that there were significant influences from local sources. Particle numbers are dominated by the smallest particle sizes that contribute very little PM mass. The variability of the particle size distributions suggests local source emissions superimposed on a background of smaller numbers of transported larger particles.

Using their third-generation real-time single-particle mass spectrometer (RSMS III), Lake et al. (2004) found that many particles between 45 and 1250 nm in aerodynamic diameter contained both sulfate and nitrate, suggesting that these particles are acid neutralized. Also, using single particle measurements at Ponca Street, Tolocka et al. (2004) observed that number concentrations of ambient particles containing the elements vanadium, iron, arsenic and lead could exceed 10,000 particles cm^{-3} at the measurement site. Both of these observations suggest a significant contribution from both local and regional sources. In fact, Tolocka et al. (2005) report that almost 40% of particles in the Baltimore aerosol of size range 48–770 nm are internally mixed, consisting primarily of organic carbon, ammonium nitrate, and ammonium sulfate and that most of these particles are likely to be derived from regional sources. The remaining particles appear to be derived mainly from local sources and processes and include elemental carbon (almost 30%), ammonium nitrate ($>10\%$), and various metals ($>20\%$).

4. Conclusion

This paper has laid out introductory information to which subsequent publications on the Baltimore Supersite study will refer. Summary statistics for PM measurements at three sites of the Baltimore Supersite have been presented. The results indicate

Table 9
Concentrations ($\mu g\, m^{-3}$) for Ponca Street obtained from the 24-h integrated samples collected with the speciation network sampler

| Species	Arithmetic mean	Arithmetic std. deviation	Geometric mean	Geometric std. deviation
TEOM	19.54	10.67	17.23	1.65
NO_3^-	1.999988	1.500681	1.504477	2.214190
SO_4^{2-}	5.289918	3.944535	4.355277	1.813890
NH_4^+	2.273088	1.356900	1.960013	1.723898
K^+	0.051487	0.078882	0.126295	1.466525
Na^+	0.199971	0.188108	0.153032	2.358092
EC	1.112320	0.583370	0.994670	1.588810
OCX	2.226322	1.010042	2.041492	1.512377
OC	6.224174	4.014752	5.452429	1.632910
TC	7.336496	4.388927	6.507818	1.595163
Al	0.025114	0.055032	0.022130	3.834176
Sb	0.005361	0.008386	0.005584	3.550509
As	0.001334	0.001508	0.001414	2.818735
Ba	0.029730	0.026458	0.023147	2.634823
Br	0.004919	0.003816	0.003763	2.234060
Cd	0.002657	0.004066	0.003262	2.756615
Ca	0.078093	0.053859	0.064986	1.845939
Ce	0.010260	0.019852	0.006806	4.692933
Cs	0.005410	0.008294	0.007504	2.878708
Cl	0.038588	0.137209	0.016130	5.184922
Cr	0.001655	0.001404	0.001466	2.192056
Co	0.000371	0.000642	0.000693	2.464175
Cu	0.005030	0.004581	0.003909	2.598500
Eu	0.002546	0.006585	0.003823	4.374954
Ga	0.000265	0.000508	0.000740	2.192903
Au	0.001696	0.001938	0.002128	2.398694
Hf	0.003579	0.007259	0.006952	2.976775
In	0.002211	0.003659	0.002995	3.025841
Ir	0.002269	0.002601	0.002765	2.255478
Fe	0.144377	0.099426	0.117154	1.915453
La	0.007120	0.013740	0.007764	3.120412
Pb	0.006030	0.004604	0.004803	2.291566
Mg	0.010372	0.030325	0.017927	3.826746
Mn	0.004079	0.003575	0.003273	2.243505
Hg	0.001455	0.001779	0.001743	2.461654
Mo	0.001515	0.002367	0.002240	2.610825
Ni	0.002510	0.002200	0.001948	2.401802
Nb	0.000683	0.001281	0.001217	2.482756
P	0.002969	0.005321	0.006355	2.559728
K	0.088779	0.088795	0.062970	2.262098
Rb	0.000537	0.000721	0.000719	2.630282
Sm	0.001054	0.002403	0.001636	3.300163
Sc	0.000279	0.000609	0.000770	2.367813
Se	0.002114	0.001795	0.001892	2.197813
Si	0.127067	0.114100	0.102587	1.824987
Ag	0.003236	0.004001	0.003395	3.388601
Na	0.075972	0.098293	0.118249	2.093735
Sr	0.001492	0.001942	0.001366	2.749690
S	1.809855	1.363245	1.484260	1.819937
Ta	0.012309	0.014611	0.010849	3.221045
Tb	0.000298	0.000956	0.001216	3.006754
Sn	0.010823	0.009851	0.010132	2.404102
Ti	0.010651	0.007275	0.008724	1.988729
V	0.004237	0.004165	0.003004	2.827194
W	0.002393	0.003514	0.003848	2.432702
Y	0.000523	0.000879	0.000818	3.075750
Zn	0.028606	0.034469	0.017335	2.625055
Zr	0.000899	0.001346	0.001285	2.605703
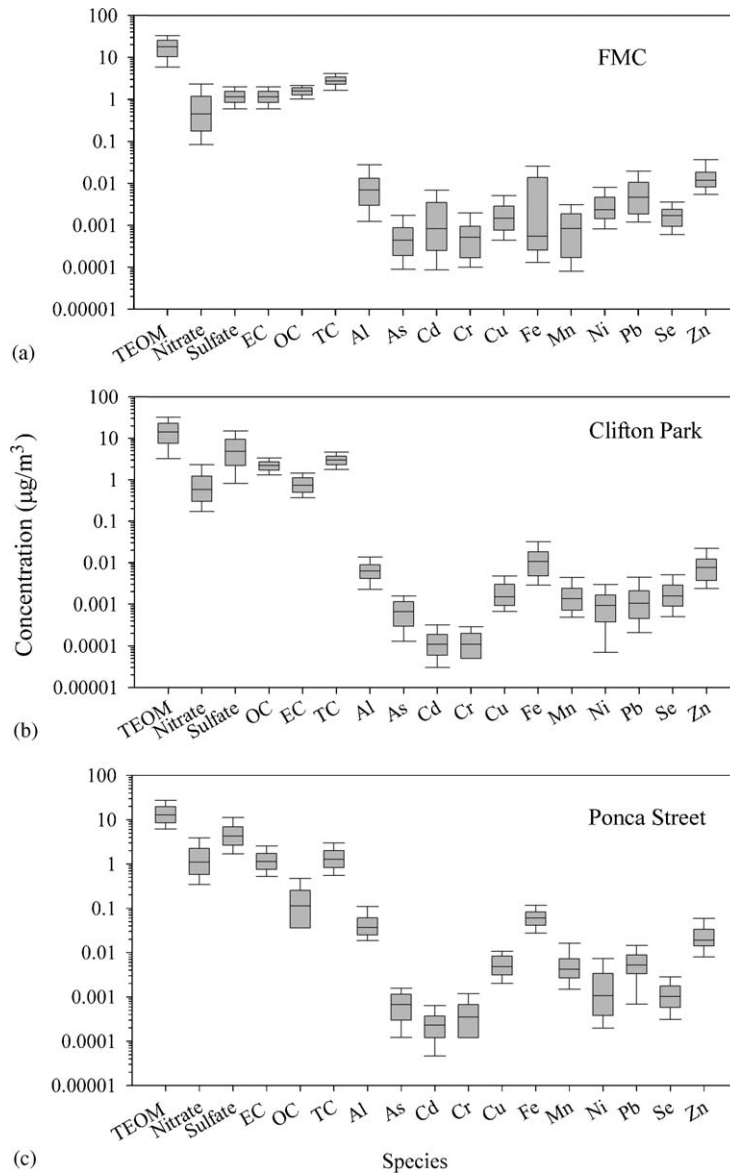
Fig. 3. Distribution of measured components (based on semi-continuous data) for the three sites.

overall higher concentrations of PM constituents at Ponca Street primarily attributable to its proximity to major emissions point sources and the extensive nature of the measurements. Owing to the few measurements made at FMC, comparisons between Ponca Street and Clifton Park data sets are more likely to be valid. The effects of winter, summer and the Quebec wildfire episode can be clearly seen from Ponca Street data in which much variability in the data is observed.

The PM summary statistics presented here do not include all data that have been obtained to-date. Statistics for gaseous species, VOCs, cytokine SEAS collections and meteorological measurements have specifically not been included. These and other statistics can be obtained from other publications by the Baltimore Supersite investigators that use these data to gain insights into the sources, transport and dynamics of the $PM_{2.5}$ aerosol in the Baltimore area. A list of these
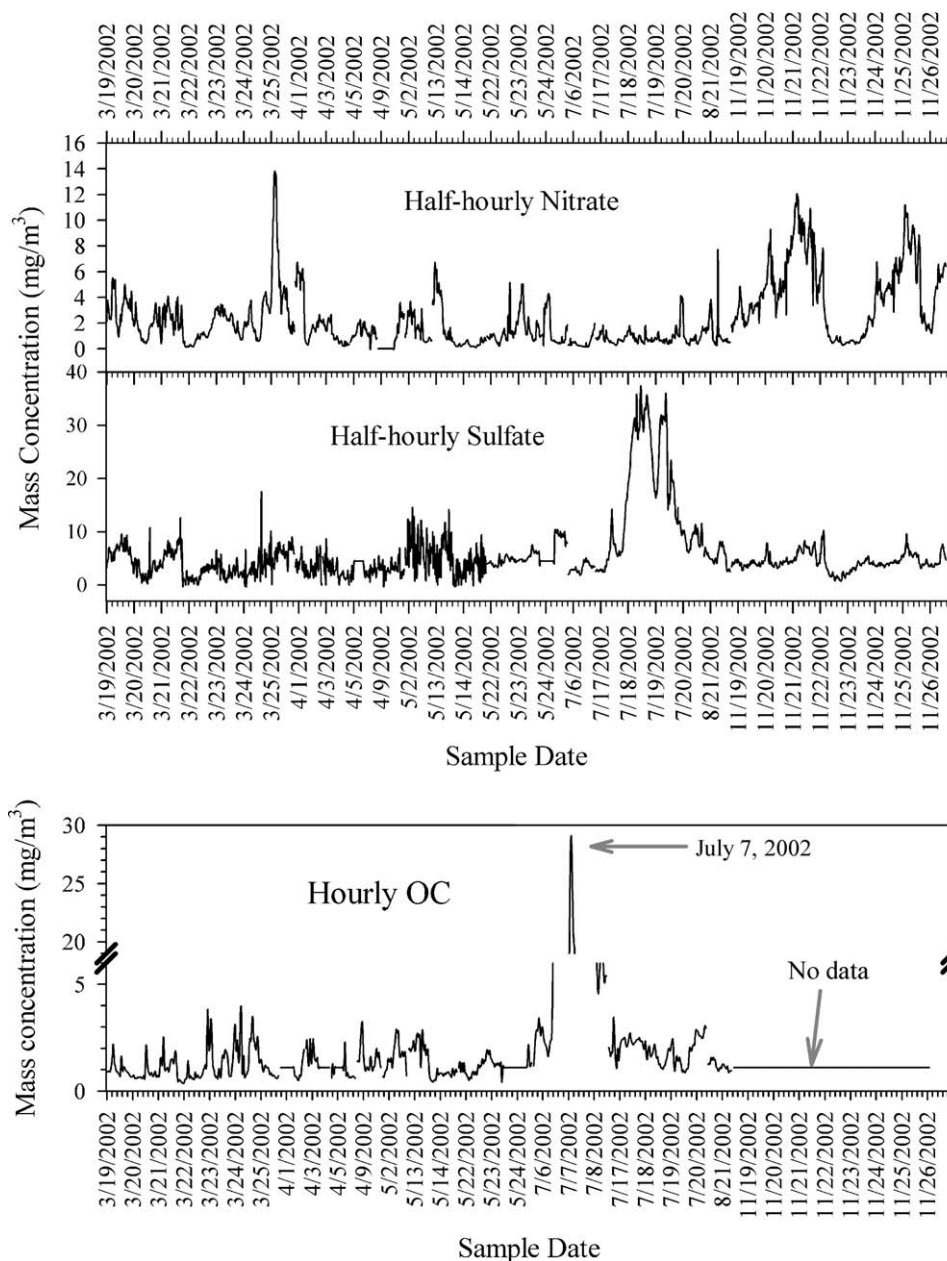
Fig. 4. Time series plots for nitrate, sulfate and OC at Ponca Street. Major ticks in the plots refer to 12:00 a.m. on the given date. The peak in sulfate can be attributed to summer sulfate. The OC peak corresponds to the Quebec Wildfire Episode.

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.atmosenv.2005.11.072.

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