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Airborne Fine and Ultrafine Particles Near the World Trade Center Disaster Site

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Documentation of the airborne fine and ultrafine particles produced by the terrorist attack on the World Trade Center (WTC), particularly while fires were burning, was essential for evaluating the risk of adverse health effects in people who live and work in this area. We collected airborne particles for 3 months at a site about 400 m east of the former WTC.

Ultrafine particles were collected by deposition onto small detector chips for morphometric analysis by atomic force microscopy. Some chips were coated with an iron nanofilm for detection of strong acids. A condensation nucleus counter and two impactors measured particle number concentrations and size distributions.

Collected particles exhibited a variety of globular forms, and most appeared to be agglomerates. No ultrafine acid particles were detected. Particle number concentrations ranged from below 1×10^4 cm^{-3} to about 5×10^4 cm^{-3}. Occasional peaks reached values over 7×10^4 cm^{-3}.

The average total mass concentration was about 17 μg/m^3 in mid-October, about half that value in November, and as low as 5 μg/m^3 in mid-December. Particle size distributions were mostly bimodal. The mass concentration of very fine particles (0.1 μm to 0.29 μm) ranged from 4.3 μg/m^3 to 0.7 μg/m^3, and the ultrafine ($d < 0.1$ μm) ranged from 1.46 μg/m^3 to nondetectable after 5 November 2001.

Some backup filters from the October sampling sessions were analyzed for organic and elemental carbon (OC/EC) and polyaromatic hydrocarbons (PAH). About 70% of the total carbon was organic. The PAH levels ranged from 10 to 1500 ng m^{-3}.

Overall, our data for particle mass and number concentrations did not differ substantially from data we had collected in Manhattan the previous year. The dominant organic compounds found in these samples are those most common in urban environments. These data do not suggest, but cannot rule out, an unusual risk of adverse health effects from the number, or mass, of the fine ambient particles.

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BACKGROUND

Documentation of the airborne fine and ultrafine particles in the aerosol produced by the terrorist attack at the World Trade Center (WTC), particularly during the time that the fires were burning at the site, was essential for evaluating the potential risk of adverse health effects in people who live and work in this area. Fires erupted at the twin WTC towers after each was struck by a hijacked, fully fueled passenger jetliner on the morning of 11 September 2001. As a result of the fires and structural damage, both towers collapsed shortly afterwards, bringing down nearby buildings and releasing great clouds of debris and smoke. Thousands of people were killed. Fires continued to erupt during subsequent rescue efforts, and later as debris was cleared. New York City authorities declared the fires to be extinguished on 20 December 2001. A sampling station was set up as close to "ground zero" as possible and at the earliest possible time access to the site could be arranged. The sampling site was located at the New York University Downtown Hospital (NYUDH) about 4 blocks (400 m) east of the former WTC site (Figure 1). These samples were taken simultaneously with a large array of PM_{10}, $PM_{2.5}$, and Aethelometer samples collected by other NYU researchers. The data obtained from these samples and reported here contribute to a comprehensive picture of the airborne particles reaching this site from the WTC.

Particles derived from combustion form largely by condensation of volatile materials and grow by further coagulation of the primary particles, although some primary particles are released

Figure 1. Military reconnaissance picture of the World Trade Center site. The sampling site at the New York University Downtown Hospital is indicated by the dot near the bottom, right of center.

directly. The resultant airborne particles are thus found in the ultrafine- and fine-size modes. The particle sizes will be below about 700 nm in diameter, and most of the particles will have diameters below about 200 nm (USEPA 1996). Under normal circumstances, particles less than 200 nm represent about 90% of the number of airborne particles but, on average, only about one half of one percent of the total airborne particulate volume and mass (John 1993). Yet there is evidence that suggests they have an important role in health decrements associated with ambient particulate matter (PM), and very recent evidence has also shown that ultrafine particles are associated with human mortality (Wichmann et al. 2000).

Although the precise mechanism of ultrafine-particle–induced lung injury is not clear, it is known that they are biologically very reactive, and even low concentrations may elicit effects. Candidates for especially active components of the PM include the number of ultrafine particles and the concentration of H^+. There is some toxicological evidence supporting both of their roles in health decrements, consistent with known mechanisms of toxicity. In the case of the fires that took place at the WTC, a large variety of products of incomplete combustion, some of which are likely to be harmful, would also be expected in the ultrafine fraction. Incomplete combustion was evidenced by the ongoing eruptions of fires as pockets of smoldering debris were exposed to air. Ultrafine particles have a very high deposition efficiency in the respiratory tract, they may penetrate the epithelium more efficiently and be cleared less effectively by macrophages (Oberdörster et al. 1992) than larger particles, with unphagocytozed particles penetrating to the interstitium in a few hours. Oberdörster et al. (2000) recently reported that nonreactive (carbon and platinum) ultrafine particles do not appear to cause inflammation in young healthy rats. Thus, it is

also important to be able to distinguish the components, e.g., acidic and organic components, from the total ultrafine number concentration for appropriate exposure assessment and risk estimation, as well as for epidemiological studies.

This article presents our measurements of the particle number concentration in the twelve weeks following the attack on the WTC, together with the results of our examination of particles collected on iron nanofilm and silicon detectors, the measured airborne particle size distributions, estimates of the mass concentration of ultrafine particles, and some measurements of organic and elemental carbon in the collected particles.

EXPERIMENTAL METHODS

The sampling program began on 20 September 2001 with the deployment of 4 ultrafine diffusion monitors in a meeting room on the second floor of the NYUDH with windows that faced the WTC site. The diffusion monitors were replaced on 28 September 2001 by an electrostatic aerosol sampler (EAS; Model 3100, TSI Inc., St. Paul, MN) in which airborne particles are efficiently precipitated onto the detectors. The EAS was preceded by a Mercer impactor (MI; In-Tox Products, Albuquerque, NM). A condensation Nucleus Counter (CNC; Model 3020, TSI Inc., St. Paul, MN), and a Micro-orifice uniform deposit impactor (MOUDI; MSP Technology, St. Paul, MN) were also added to the site (Figure 2). The inlets for the CNC and MI-EAS system were each 3.2 mm (0.125 inch) diameter metal tubing fitted with raincaps, extending about 0.5 m from the building wall on the second floor of the NYUDH. The inlet for the MOUDI was 7.75 mm inside diameter (0.305 inch) stainless steel tubing, fitted with a raincap, extending about 1.0 m from the building.

The ultrafine diffusion monitors (UDMs) deployed for the first week of sampling are low-flow diffusion monitors developed in our laboratory for the collection of time-integrated samples of ultrafine ambient particles. The UDM is a flat, rectangular aluminum channel, 1.0 mm high and 50 mm wide. The monitor has depressions cut to hold multiple 5 mm × 5 mm detectors flush with the inner surface. Two units are 500 mm and two are 95 mm in length. For outdoor sampling, the inlet of the UDM penetrated a slit cut through a temporary panel fitted to the window of the meeting room. Air was drawn through each monitor by a low-flow pump at a flow rate of 200 $cm^3\ min^{-1}$. Flows were checked each day with a calibrated flow meter (triCal, BGI Inc., Waltham, MA). The particles entering the monitor deposit by diffusion onto the walls of the channel. Two iron nanofilm detectors and one nonreactive (silicon) detector are placed side by side in the cut receptacle on the lower wall. After sampling, detectors are stored under nitrogen. The iron nanofilm detectors are used to quantitate both the total number of particles and those particles that are acidic.

Six sample sets, consisting of six detectors each, were collected in the UDMs. The detector surface is analyzed topographically by atomic force microscopy (AFM) to view and enumerate the particles and the acid reaction sites (Cohen et al. 2000). Briefly, the detectors are scanned using a noncontact mode in

Figure 2. Sampling equipment deployed in a second floor storage room at the NYUDH. Inlets extended from the window. Shown are the MOUDI, MI, CNC, and EAS. Samplers of other investigators are at right.

which the cantilever oscillates above the surface at a distance where Van der Waals forces interact with the surface to modify the oscillation frequency. A morphometric image of a 10 μm × 10 μm scan results. The acid particle sites are distinguished by their signature ring around a central elevated site. An extensive field test of the detectors under ambient conditions indicated that, once formed, the acid reaction sites are stable (Cohen et al. 2003). Particles with other distinguishing morphometry can be recognized and evaluated by comparison with standard sources, e.g., *The Particle Atlas* (McCrone and Kelly 1973). The airborne concentration, C_a, in particles per cm^3 represented by the deposited particles is given by $C_a = N/EV$, where N is the net average number of particles counted per 100 μm^2, E is the deposition efficiency on the scan area (calculated value = 7.7×10^{-10} for 50 nm diameter particles), and V is the volume of air sampled (cm^3).

The CNC operated at a flow of 300 cm^3 min^{-1}. Number concentration measurements were recorded by both a chart recorder, and a data logger (Model 2101, Telog Instruments Inc., Rochester, NY). The data logger averaged concentrations over a set time interval of 1 h. The time interval was later adjusted to provide 15 min averages.

The MI and EAS formed a single sampling combination. The MI preceded the EAS to remove particles larger than 0.46 μm in aerodynamic diameter; the remaining particles followed the airstream to the EAS. Within the MI particles were collected on 5 impaction stages. At the operating flow rate, cut-off diameters were 6.32, 3.26, 1.68, 0.88, and 0.46 μm. The glass substrates on the collection stages were weighed before and after exposure on an electrobalance (Model G-1, HAUG-BIEL, Switzerland) for the last 12 exposure periods. The net weights were used to determine the mass median aerodynamic diameter (MMAD) of the ambient particles. Fifteen sets of samples were collected. Each sample represents an integrated collection over approximately 5 days.

The EAS is a two-stage electrostatic precipitator (one charging and one collecting stage) that deposits particles in a random and uniform manner onto a 2.5 cm × 12.7 cm collection surface for microscopic evaluation of the deposited particles. For this study, iron nanofilm detectors (described above) and glass microscope cover slips were placed over the collection area of the EAS to obtain uniform particle deposits. Counting the number of acid reaction sites, and the number of deposited particles per unit area of the surface allows determination of the number concentration of airborne acidic particles, total particles, and any specifically identifiable type of airborne particles (e.g., chain aggregates).

The MOUDI used in this study is an eight-stage cascade impactor. The nominal aerodynamic diameter cut points at a flow rate of 30 l min^{-1} are 15 (inlet), 3.2, 1.8, 1.0, 0.56, 0.29, 0.17, and 0.10 μm. This impactor is equipped with a rotation mechanism that rotates alternate stages to provide a nearly uniform deposit of particles on the collection substrates. Teflon filters (Zefluor, Pall Corp., Ann Arbor, MI), 47 mm in diameter, were used as impaction substrates. The same kind of filters were used as an afterfilter in order to collect particles with an aerodynamic diameter below 0.1 μm that penetrated the last stage of the impactor. A total of 10 sampling sessions, of 3 to 4 days each, were carried out at NYUDH from 28 September 2001 through 14 December 2001.

A few prebaked quartz filters and teflon filters suitable for carbon and chemical organic analysis, and Fourier transformed infrared (FTIR) analysis, respectively, were available, so that a limited amount of analysis was possible for organic carbon (OC) and elemental carbon (EC).* Some of the filters were used to collect wipe samples of the highly diffusing particles that deposited on the upper surface of the diffusion monitor channel during the first sampling week (20 September through 25 September). Some of the quartz filters were used as backup filters of the MI-EAS system during measurements in October. The samples were stored under nitrogen in the laboratory, but it took several days before they were transported to storage. The quartz filters were analyzed for organic and elemental carbon (OC/EC) by thermal-optical transmittance analysis and for polycyclic aromatic hydrocarbons (PAH) by methods detailed in Offenberg et al. (2003). The teflon filters were analyzed by FTIR. The measured OC results were corrected for adsorbed OC that was measured a year later at the same location. The average adsorbed OC was 52% of the total OC.

RESULTS

Very few particles were seen in the 10 μm × 10 μm AFM scans of detectors exposed in the UDMs. The reason was the short total exposure times that resulted from sporadic power failures and other disruptions during the sampling sessions. As a result, counting statistics were poor, and the derived concentration data have high uncertainties; they ranged roughly from 1.3×10^3 to 34×10^3 particles per cm^3. A few scan areas had particles that could be visually compared with those observed when we sampled in Manhattan the prior year (Figure 3). There are no notable differences. The particles observed by this system are about 50–100 nm in diameter, although the scan process causes them to appear somewhat larger. The deposition efficiency for accumulation mode particles is very low in the UDMs, and we saw none on these samples. Additionally, we saw no acidic particles.

Particle number concentrations were measured with the CNC beginning 28 September 2001 (Figure 4). Hourly average number concentrations varied substantially (Figure 4a). Occasionally very high, short duration peaks are seen that reached values over 7×10^4 cm^{-3}. The daily average number concentrations (Figure 4b) ranged from below 1×10^4 cm^{-3} to about 5×10^4 cm^{-3}. There were 5 days between 28 September 2001 and 30 November 2001 when the daily average particle

*The prebaked filters were provided and analyzed through the generous cooperation of Dr. Barbara Turpin and Dr. John H. Offenburg of the Department of Environmental Sciences, Rutgers University, New Brunswick, NJ.

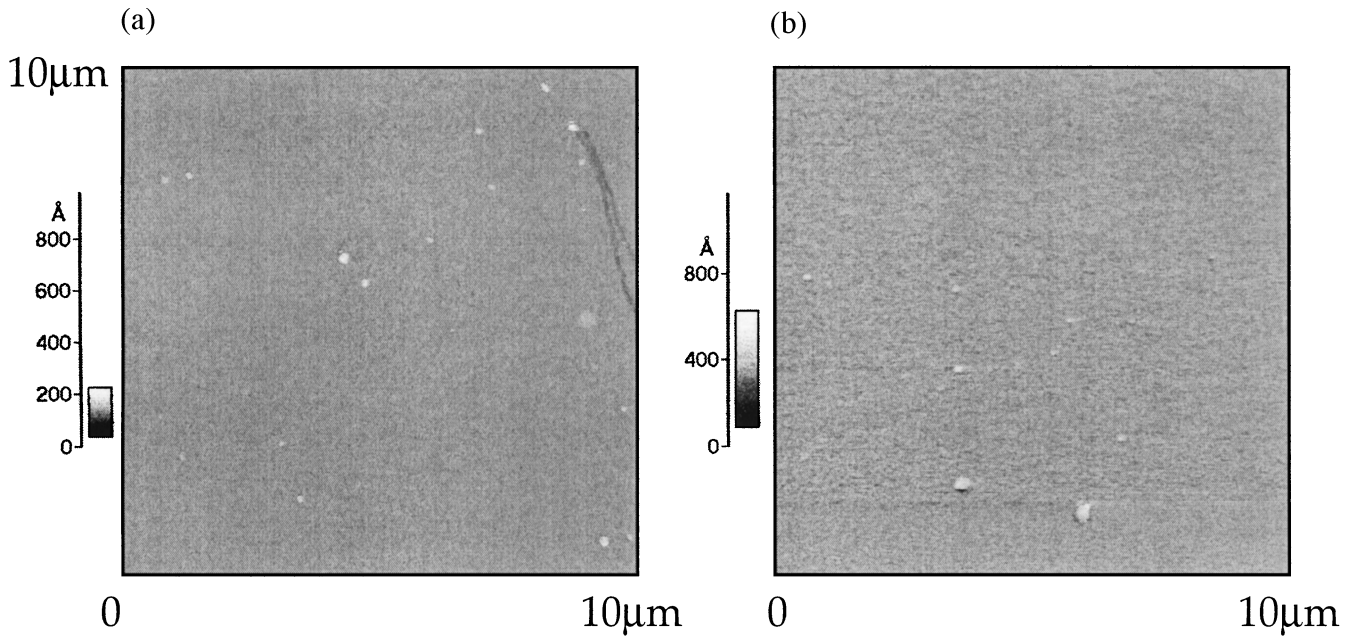

Figure 3. AFM images of particles collected in the UDM (a) at the NYU Medical Center in central Manhattan from 9–22 March 2000 and (b) at the NYUDH-WTC site from 19–21 September 2001. The gray scale indicates the height of the particle.

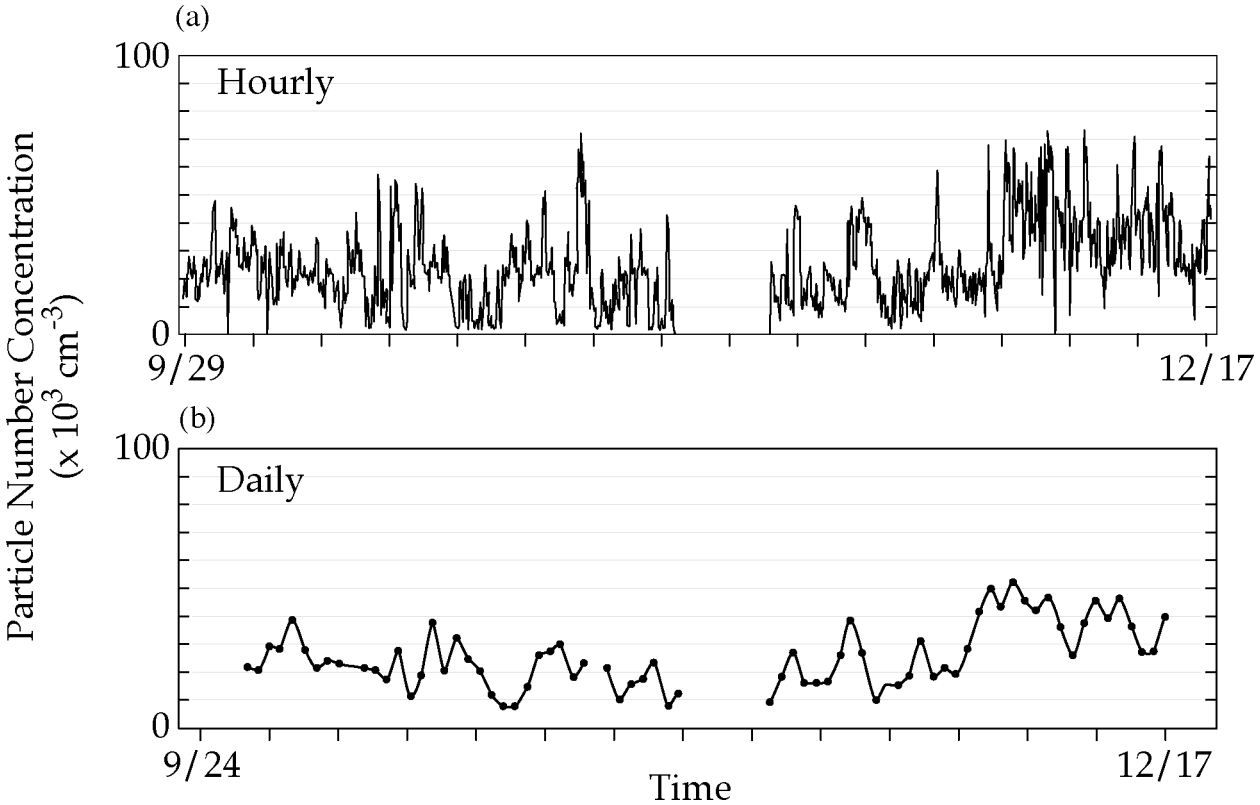

Figure 4. Particle number concentrations measured at the NYUDH (a) hourly averages and (b) daily averages.

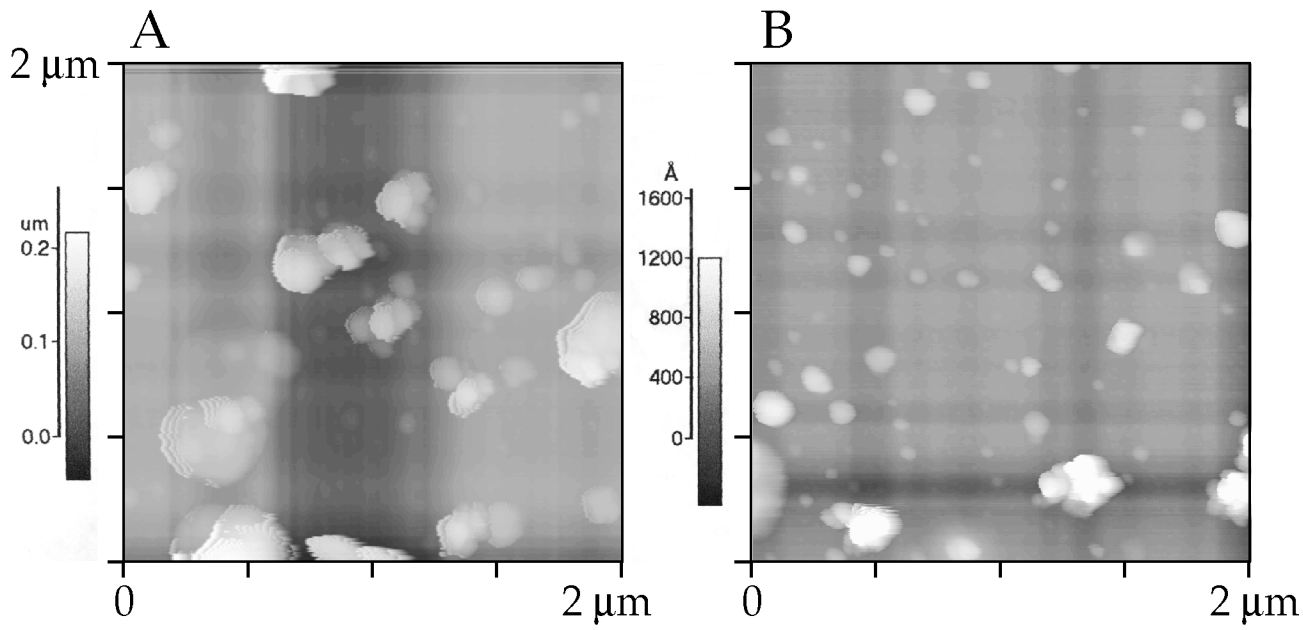

Figure 5. AFM images of particles collected in the EAS at NYUDH between (a) 17 and 22 days and (b) 60 and 66 days after 11 September 2001. The gray scale indicates the height of the particle.

concentrations exceeded 3×10^4 cm^{-3}. However, in December the concentrations increased and there were only 3 days on which the concentrations did not exceed 3×10^4 cm^{-3}.

Deposition efficiency in the EAS is high for all particle sizes. We used the MI as a precollector to remove particles greater than about 0.46 μm, which is the cut size of the last included stage. These detector samples show a high density of particles with a variety of globular forms. The presence of the larger (>0.2 μm) particles interferes substantially with the scanning process. Large particles cause mechanical discontinuities, because the vertical range of the AFM is quite restricted. Thus, analysis was limited to the scanning of small areas (less than 3 μm $\times$ 3 μm) for morphometric analysis. Figure 5 shows typical particles collected about 2 1/2 weeks (17–22 days; Figure 5a) and 8 weeks (60–66 days; Figure 5b) after the disaster. Most of the particles appear to be composed of agglomerates of smaller particles. Occasional single particles of about 30 nm are seen, and more of them, and fewer agglomerates, are seen in the later sample. These differ in character from the particles collected in prior sampling campaigns where we saw individual single unit particles almost exclusively. No fibrous particles were noted, and no acidic particles were detected.

Total ($d_a < 15$ μm) PM mass concentration for a sampling session was obtained by summing the concentrations measured in the individual size fractions. The average total mass concentration measured by both the MOUDI and MI was 17 μg m^{-3} in mid-October. It decreased to roughly half the value in November, and then to as low as 5 μg m^{-3} in mid-December (Figure 6). Individual MOUDI and MI samples cannot be directly compared because, although both operated over most of the 12 week sampling period, the start time and duration of the sampling sessions differed. The average total mass concentration for the different sampling sessions measured with the MOUDI ranged from 4.4 μ g m^{-3} to 22.7 μg m^{-3}. It did not exhibit any clear trend through time.

Partial mass concentrations were summed to compare two size fractions: (1) the very fine fraction, which includes the particles with aerodynamic diameter within the range of 0.1 μm to 0.29 μm; and (2) the ultrafine size fraction of particles with aerodynamic diameter smaller than 0.1 μm. Ambient mass

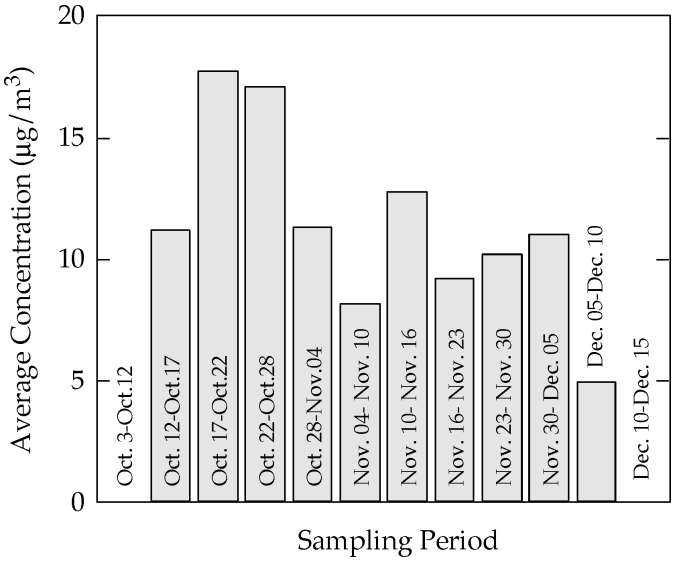

Figure 6. Average total mass concentrations measured at NYUDH (MI).

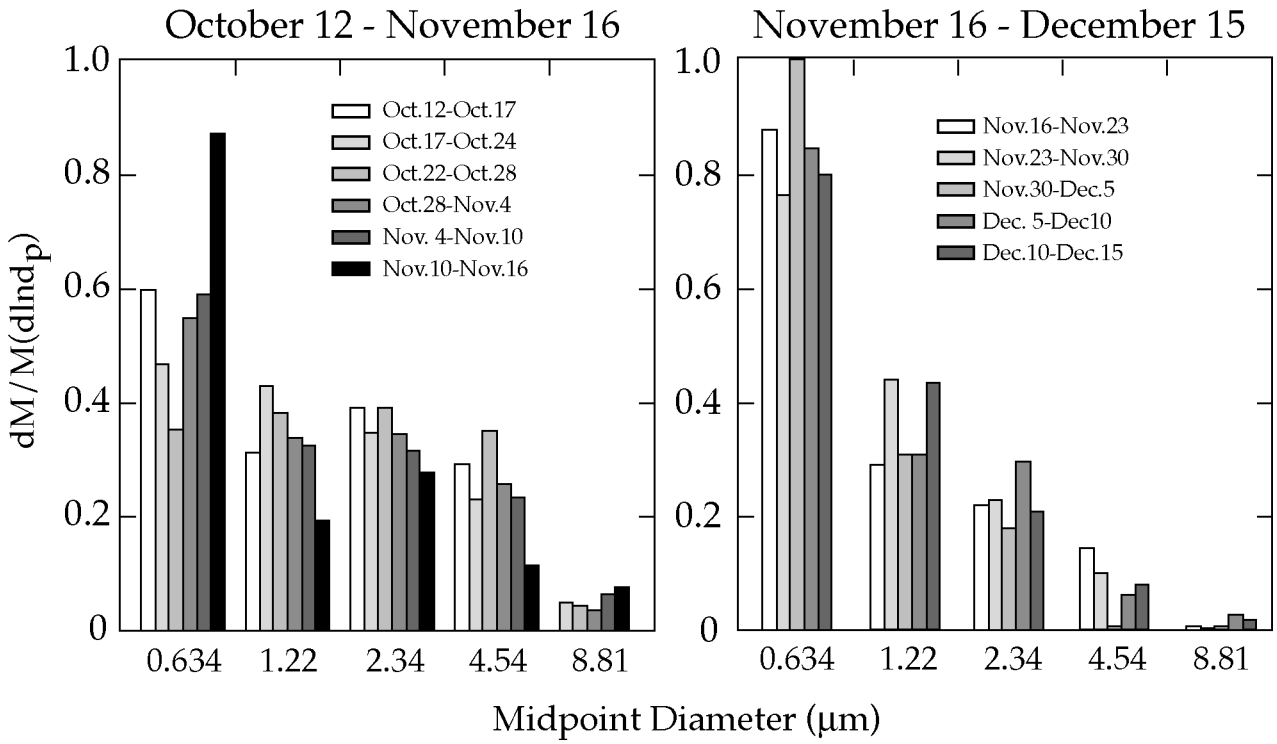

Figure 7. The mass weighted size distribution of the WTC aerosol measured with the MI for the different sampling sessions.

concentration for the very fine size fraction (0.1 μm to 0.29 μm) ranged from 0.7 μg m^{-3} to 4.3 μg m^{-3}. The concentration for the ultrafine size fraction ranged from nondetectable to 1.46 μg m^{-3}. The ultrafine mass was not detectable in the last five samples, which were collected between 5 November 2001 and 14 December 2001.

The MMAD, calculated from the MI measurements, increased from about 1.2 μm to 1.75 μm the week of 22 October 2001 and then decreased to about 0.8 μm in November and December. The MI size distributions (Figure 7) show an ongoing reduction in the fraction of the mass collected on the upper stages, indicating that the decline in the total mass resulted from a decrease in the mass concentration of larger diameter particles. The MOUDI size distribution results demonstrated more clearly that for most samples, the size distribution is bimodal. One mode was present at a size fraction larger than 1.0 μm in diameter and a larger mode at a size fraction smaller than 1.0 μm in diameter. The two modal peaks were found within the range of 1.0 μm to 3.2 μm for the mode larger than 1.0 μm in diameter, and 0.29 μm to 1.0 μm for the submicrometer mode. However, samples collected at the later stage of this study demonstrated that overall, the submicrometer mode became more prominent, while the larger diameter mode diminished. The MMAD of the submicrometer mode was about 0.5 μm, which is in agreement with the MI results.

The backup filters (d < 500 nm) of the MI-EAS system from the October sampling sessions were analyzed for OC, EC, and PAH. Results, presented in Table 1, show that the mean and

Table 1
The concentrations of OC and EC, the ratio of OC to EC, the percent of OC of total carbon and concentration of the total PAH (sum of 37 compounds) measured in the MI-EAS backup filters (d_p < 500 nm) during October sampling sessions

Date	OC (μg m^{-3})	EC (μg m^{-3})	OC/EC	OC (%)	Total PAH (ng m^{-3})
10/03–10/08	1.30	0.44	3.0	77.5	510
10/08–10/12	1.44	0.75	1.9	71.9	616
10/12–10/17	0.96	0.45	2.1	73.2	1142
10/17–10/22	1.14	0.54	2.1	73.4	365
10/22–10/28	0.81	0.46	1.8	70.8	10
10/28–11/04	0.79	0.44	1.8	71.2	1497
mean ± SD	1.1 ± 0.3	0.5 ± 0.1	2.1 ± 0.5	73 ± 3	

standard deviation for the six sessions were 1.1 ± 0.3 μg m^{-3} and 0.5 ± 0.1 μg m^{-3} for OC and EC, respectively. The mean of the OC/EC ratio was 2.1 ± 0.5. About 70% of the total carbon was organic. The total PAH is a sum of 37 compounds. The measured PAH levels ranged from 10 to 1500 ng m^{-3}. The concentrations of the most abundant compounds, benzo[a]anthracene, phenanthrene, fluoranthene, pyrene, and chrysene/triphenylene, comprised 55% of the total. The wipe samples of lower plates of two UDMs on prebaked quartz filters show 96 ± 2% and 96.8 ± 0.9% of organic carbon. Wipe samples on teflon filters of the UDM top plates, qualitatively analyzed by FTIR, show mainly ammonium sulfate. Some carbonyl absorbance was also found, which is consistent with ambient samples.

DISCUSSION

The number concentrations of fine particles measured with the CNC were highly variable, which is typical in an urban enviroment. The concentrations are affected by local combustion sources which are numerous in such a setting. This sampling site overlooked a hospital parking area and a driveway that led to a building entrance. Although traffic to the lot was highly controlled, it is likely that motor vehicles carrying patients to and from the site exhausted particles that were detected at the second floor inlet. Official government limitations on traffic in the immediate vicinity of the disaster site and in the vicinity of the NYUDH continued throughout the sampling period. Nonetheless, traffic sources were clearly significant, as indicated by generally lower concentrations on weekends. The reason for the increase in the number concentration that we noted in December is unclear, but it likely results from resumption of more normal traffic in surrounding areas. Efforts to correlate concentrations with wind direction did not prove fruitful, probably because of the importance of local sources.

The particle number concentration measurements were compared with similar measurements made in Manhattan in the prior year. Measurements with the same instrument had been carried out in NYC in the winter of 2000 as part of an earlier research program. The NYC site was on the roof of a 14 story dormitory building at the NYU Medical School on First Avenue at 31st Street in Manhattan. The site is 3.0 miles north of the NYUDH. Figure 8 presents the particle number concentrations measured in Manhattan during a two week sampling campaign in the winter of 2000. There were high number concentrations of small particles measured after the WTC attack at NYUDH, but they are not too different from the values we previously measured in New York City.

Particle mass concentrations measured over the 12 sampling weeks ranged from about 4 to 23 μg/m^3 (averaged over 4–6 days). None exceeded the 24 h EPA Air Quality Index (AQI) or

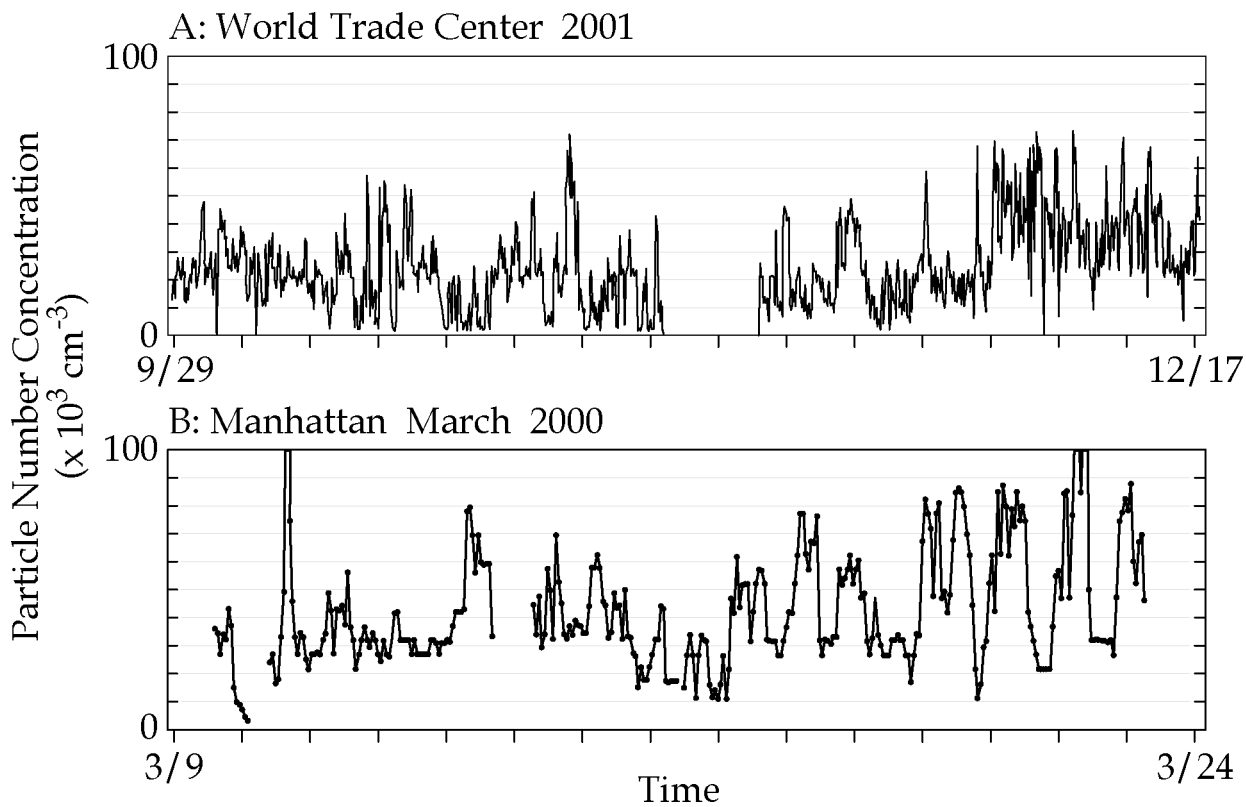

Figure 8. Particle number concentration (hourly averages) measured at (a) the NYUDH-WTC site and (b) NYU Medical Center in central Manhattan during Winter 2000.

the level of concern for susceptible subgroups of 40 $\mu g/m^3$. The size distribution showed a constant reduction in the large particle fraction of the mass, indicating that the reduction in the total mass resulted from a decrease in the mass concentration of larger diameter particles. This is consistent with data reported by others that showed very high concentrations of very coarse particles in surface-deposited dust collected soon after the destruction of the buildings (Lioy et al. 2002).

The results of the ultrafine and very fine size fractions were compared to mass concentrations we measured during an earlier study at a rural site located in Sterling Forest (SF), NY approximately 50 miles northwest of New York City. No background data was available for the WTC sampling location that could be used for comparison. During the SF study, a total of 20 samples were collected from April 1998 through September 1998 using the same MOUDI. Ambient mass concentrations at SF for the ultrafine size fraction ranged from 0.2 $\mu g\ m^{-3}$ to 3.2 $\mu g\ m^{-3}$. Ambient mass concentration for the very fine size fraction ranged from nondetectable to 3.5 $\mu g\ m^{-3}$. It is interesting that higher mean mass concentrations of ultrafine particles were measured at SF than at NYUDH; the mean and standard deviation of the concentrations are $1.1 \pm 0.8\ \mu g\ m^{-3}$ and $0.3 \pm 0.4\ \mu g\ m^{-3}$, respectively. For the very fine fraction, the mean mass concentrations measured at the two sites are very similar, $2.3 \pm 0.9\ \mu g\ m^{-3}$ for the SF site and $2.4 \pm 1.1\ \mu g\ m^{-3}$ for the NYUDH site.

The reason for the higher concentrations of ultrafine particles found in SF is that it is very likely that they were collected during a significantly warmer time period than the period of the NYUDH sampling. Ultrafine particles coagulate rapidly to form larger particles and move into the accumulation mode size range (Hinds 1999; Wexler at al. 1994) and are not likely to be transported long distances. Therefore, the sampled ultrafine particles are probably of local origin. Ultrafine particles at the sampling locations will either be emitted by local sources or be the product of local oxidation processes of PM precursors. Local oxidation of PM precursors, such as SO_2, is believed to involve reaction with ozone and hydrogen peroxide (Seinfeld and Pandis 1998; Martin 1984). These oxidation processes are rapid under high relative humidity (RH) conditions (McMurry and Wilson 1983). Photochemical production of both hydrogen peroxide and ozone reaches its peak during the afternoon of summer days, and higher concentrations of both hydrogen peroxide and ozone are measured during the summer than during the winter (Sakugawa et al. 1990). The ability of the atmosphere to hold water vapor increases exponentially with temperature. Atmospheric RH is generally higher during the warmer months of the year than during the colder months of the year. Overall, the conditions for oxidation of PM precursors are more favorable during the warmer months of the year. Clement et al. (2001) have also observed several events of ultrafine particle formation at the Hyytiälä forest in Finland. They concluded that vapor generated by photochemical reaction products from precursors emitted by the forest, can nucleate and condense to form ultrafine particles. Similar events were also observed at the SF site during sampling in 1999 and 2000. Therefore, it is reasonable to assume that the higher mass concentrations of ultrafine particles measured at SF are due to a higher degree of oxidation processes induced by the warmer weather conditions.

The OC and EC concentrations measured in October 2001, namely $1.1 \pm 0.3\ \mu g\ m^{-3}$ and $0.5 \pm 0.1\ \mu g\ m^{-3}$ for OC and EC, respectively, are comparable to concentrations measured in Chicago—1.3 to 2.5 $\mu g\ m^{-3}$ for OC and 0.2 to 0.5 $\mu g\ m^{-3}$ for EC (Offenberg and Baker 2000)—and in Helsinki—2.2 to 4.2 $\mu g\ m^{-3}$ for OC and 0.9 to 2.1 $\mu g\ m^{-3}$ for EC with similar OC/EC ratios (Viidanoja et al. 2002). However, these values are for $PM_{2.5}$ while our samples consisted of particles less than 500 nm in diameter. Considerably higher concentrations have been reported in heavily polluted environments (Putaud et al. 2002; Viidanoja et al. 2002). Offenberg and Baker (2000) found the greatest proportion of carbonaceous material in the smallest particle fraction measured, $0.15 < d_{ae} < 0.45\ \mu m$. They also found a high percentage of organic carbon, 84%, in their samples, similar to ours. Since no reference samples were taken during this study to correct for the artifacts arising from adsorption of organic gases or evaporation of semivolatile compounds, the measured OC values were corrected with adsorbed OC values measured a year later at the same location. The OC adsorbed onto the filter was 52% ± 4% of the total OC.

In view of the average concentration of PAH of 5.7 ng m^{-3}, calculated from measurements made across the Hudson river at Liberty Science Center in Jersey City, NJ of 24 h TSP samples taken every 12th day between 5 July 1998 and 3 October 2001 (Gigliotti et al. 2000), all the concentrations except one measured during this study are very high. Although this event may have generated vast amounts of organic compounds due to the fires, the values seem excessive. Some of the PAHs were also generated by the vehicles serving the hospital. High PAH concentrations have been measured in urban areas, e.g., at street level in the center of Stockholm the sum of 14 PAHs ranged from 100 to 200 ng m^{-3}, the most abundant being phenanthrene, and in Gothenburg city center up to 64 ng m^{-3} (Boström et al. 2002).

Benzo[a]anthracene, phenanthrene, fluoranthene, pyrene, and chrysene/ triphenylene, comprised 55% of the total PAH in the samples. The same compounds were dominant in the bulk dust samples (Offenberg et al. 2003). These are the most common PAH species found in ambient air. Phenanthrene and fluoranthene are associated with diesel-fueled heavy-duty trucks and also domestic wood and oil burning. Fluoranthene and pyrene are the most important indicators for heavy diesel vehicles. Phenanthrene, anthracene, fluoranthene, pyrene, and chrysene are representative for all mobile sources and wood burning (Boström et al. 2002). Benz[a]anthracene has been found from burning of biofuels and coal (Venkataraman et al. 2002; Yang et al. 2002). Swartz et al. (2002) from the USEPA have reported finding indicators of fossil fuel emissions and markers for fuel oil degradation, e.g., pristane and phytane, of emissions of burning and

remnant materials, such as retene, and 1,3-diphenyl propane, which is associated with polyvinyl chloride materials, in the samples collected around the WTC site during 26 September to 20 October. Retene was also found in our samples in quantities of between 0.3% and 3.6%.

SUMMARY AND CONCLUSIONS

These data provide information on average mass and number concentrations, and size distributions measured at a site about 4 blocks east of the WTC for the three months following the terrorist attack. The measured particle mass concentration was generally less than half the EPA 24 h AQI limit of 40 μg m^{-3}. There was a general reduction in the monthly average that resulted from a decrease in the mass concentration of the larger diameter particles.

Ultrafine and very fine mass concentrations were not unusually high at the NYUDH sampling location. This is evident from the comparison with mass concentration from samples that had been previously collected at a rural location (SF), where the ultrafine particle mass concentration was higher. The higher concentrations at SF may be attributed to oxidation processes of PM precursors induced by the warmer weather conditions that prevailed during the SF sampling sessions.

There were high number concentrations of small particles throughout the 3 month sampling period, but they are not very different from values measured in New York City the previous winter. Morphometry of the fine particles collected soon after the collapse and major fire shows that most of the particles appear to be composed of agglomerates of smaller particles. Fewer agglomerates are seen in the later samples. We saw no ultrafine acid or fibrous particles. The agglomerates were different from the particles we collected in Manhattan the previous year, and from particles similarly collected in the Fall of 1999 at a rural site in Tuxedo, NY.

These data do not suggest, but cannot rule out, an unusual risk of adverse health effects from the number or mass of the fine ambient particles. The globular morphometry of the particles appear to confirm an origin different from the ambient samples we had previously examined. It is compatable with a source that produces a very high concentration of primary particles that undergo rapid agglomeration, such as a fire in which there is incomplete combustion of various materials. The OC and EC found in these samples are comparable to those measured in other urban areas, although the OC may be overestimated. The total PAH concentrations are high. The dominant compounds found in these samples are the ones that are the most common in urban environments.

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