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Seasonal and Spatial Trends in Fine Particulate Matter

Seasonal Trends of Concentration and Size Distribution of Ultrafine Particles Near Major Highways in Los Angeles

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Ultrafine particles (diameter <0.1 μm) have been suggested as a possible causative agent for the observed increases in mortality and morbidity with increases in particulate matter (PM) concentration. Zhu et al. conducted systematic measurements of the concentration and size distribution of ultrafine particles in the vicinity of Interstate 405 (mostly gasoline traffic) and Interstate 710 (large proportion of heavy-duty diesel traffic) in Los Angeles during the summer of 2001. The present study compares these measurements with those made at the same locations in the winter of 2001–2002. Particle number concentration and size distribution in the size range from 6 to 220 nm were measured by a condensation particle counter (CPC) and a scanning mobility particle sizer (SMPS). Measurements were taken at five distances downwind from the freeway. At each sampling location, concentrations of carbon monoxide (CO) and black carbon (BC) were also measured by a Dasibi CO monitor and an aethalometer, respectively. Average temperatures were about 7 degrees Celsius higher in summer than in winter. Wind directions are the same for both seasons, wind speeds are slightly higher in summer. Traffic densities were not statistically different between summer and winter for both the 405 and 710 freeways. The decay rates of CO and BC are slightly greater in summer than in winter for both freeways, suggesting a weaker atmospheric dilution effect in winter. Particle number concentration in the size range of 6–12 nm is significantly higher in winter than in summer. The associated concentration in that size range decreased at a slower rate in winter than in summer. The surface area concentrations in the size range of 6–220 nm are consistently higher in summer for all sampling locations. These results suggest that wintertime conditions favor greater particle formation, possibly due to increased condensation of organic vapors. These data may be useful to estimate exposure to ultrafine particles in the vicinity of major highways for epidemiological studies and to evaluate the adverse health effects of such particles.

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INTRODUCTION

Epidemiological studies have linked particulate matter (PM) exposure to increases in mortality and morbidity (Dockery et al. 1993; Schwartz 1991; Vedal 1997). However, it is not clear from these studies whether the mass concentration (Osunsanya et al. 2001) or the number concentration (Penttinen et al. 2001; Peters et al. 1997) is the underlying cause of the health effects of PM exposure. Some argue that particle surface contaminants, such as transition metals, contribute towards ill health (Fubini et al. 1995; Gilmour et al. 1996), while others argue that the physical characteristics (e.g., number, size, shape, and aggregation properties) are the determinants of health effects (Berube et al. 1999). Particle deposition in the various regions of human respiratory system depends strongly on particle size and shape by the complex action of aerosol deposition mechanisms (Hinds 1999), with the greatest fractional deposition occurring in the deep lung between 5 nm and 100 nm. In the ultrafine particle size range, deposition efficiency increases significantly as the particle size decreases (Jaques and Kim 2000; Yeh et al. 1997).

Current air quality standards only regulate the mass of particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$) and less than 10 μm (PM_{10}). These mass-based concentrations are primarily dominated by particles greater than 0.1 μm. However, in an urban environment ultrafine particles represent over 80% of particles in terms of number concentration (Morawska et al. 1998), but their mass concentration is insignificant compared with larger particles. Thus, number concentration, together with the size distribution of ultrafine particles are important metrics for determing the deposition and fate of urban aerosols.

Emission inventories suggest that the majority of fine and ultrafine particles found in the urban atmosphere come from engine combustions (Hitchins et al. 2000; Schauer et al. 1996; Shi et al. 1999). Particles generated by vehicle exhaust have been reported in the size range of 20–130 nm for diesel engines (Morawska et al. 1998) and 20–60 nm for gasoline engines (Ristovski et al. 1998). Zhu et al. (2002a, b) conducted measurements of particle number concentration and size distribution near two major freeways in Los Angeles, California. Measurements at both freeways showed rapid decrease in particle number concentration and significant changes in particle size distribution with increasing distance downwind from the freeway for particles in the size range of 6 nm to 220 nm.

Strong seasonal changes have been reported for the concentration and size distribution of ultrafine particles (He et al. 2001; Kim et al. 2002; Kittelson 1998). Kim et al. (2002) concluded that the highest ambient levels of primary pollutants such as ultrafine PM, CO, and NO_2 are generally observed during the winter months due to surface temperature inversions in coastal regions and the generally weak onshore flow (sea breeze) in the Los Angeles Basin. Warmer temperatures in the Los Angeles Basin are characterized by higher temperature differences between the coastal regions and inland valleys, thus creating a stronger onshore flow (Kim et al. 2002). In general, the concentration of particles in vehicle exhaust in the nuclei mode is nearly one order of magnitude greater for an ambient temperature of 15°C than it is for 25°C (Kittelson 1998).

Zhu et al. (2002a, b) conducted comprehensive ultrafine particle studies near two of the busiest freeways in the Los Angeles basin, Interstate highways 405 and 710. Sampling near freeway 405 took place between 15 May through 18 July 2001. Sampling near freeway 710 took place between 30 August through 27 October of the same year. Both periods have moderately high temperature and humidity in the Los Angeles basin. The average temperature during this sampling period was 30°C, and the average relative humidity was 66%. The focus of the present study is to evaluate ultrafine particles in the vicinity of freeways under winter conditions in the Los Angeles Basin and to investigate the degree to which differences in atmospheric conditions, such as temperature, humidity, and atmospheric mixing depth, affect the characteristics of ultrafine particles.

Traffic on Freeway 405 is dominated by gasoline-powered cars and light trucks, with less than 5% of vehicles being heavy-duty diesel trucks, while more than 25% of vehicles on freeway 710 are heavy-duty diesel trucks. At both locations, particle number concentration and size distribution in the size range from 6–220 nm were measured along with CO and black carbon (BC), upwind and as a function of distance downwind from the freeway.

EXPERIMENTAL

This study is a follow-up to nearly identical measurements published in Zhu et al. (2002a, b). The same sampling sites, instruments, and sampling protocol were used to ensure comparability of summer and winter ultrafine particle size distributions and number concentrations.

Description of Sampling Site

The present study was conducted at two locations representing different traffic composition. The first winter sampling location was the Los Angeles National Cemetery adjacent to the Interstate 405 freeway between 11 January to 20 January 2002. The second location was in the City of Downey along Southern Avenue between 14 January and 25 January 2002.

Freeway 405. Freeway 405 runs north and south along the western border of the Los Angeles National cemetery. Measurements were taken along Constitution Avenue, which runs perpendicular to the freeway. The site lies 6.4 km east of Santa Monica Bay and the Pacific Ocean. During the sampling period, a consistent sea breeze (northeastward from the ocean) starts in mid-morning, reaches its maximum early to mid-afternoon, and dies out in the early evening. Background measurements were taken at approximately 300 m upwind of the freeway, which is accessible through a tunnel under the freeway on Constitution Ave.

Major roads nearby the sampling site include Sepulveda Boulevard, which runs parallel and immediately adjacent to the freeway, and Wilshire Boulevard, which runs perpendicular to the freeway more than 0.8 km to the south. During the sampling periods, traffic on Sepulveda Boulevard was approximately 5% of that on the 405 freeway. For the usual wind direction (from southwest to northeast), traffic on Wilshire Boulevard had little influence on particle levels at the sampling site. The 405 freeway is about 30 m wide, including a 1 m wide median strip. The distance to each of the sampling locations is measured from the center of the median strip. During the sampling period, traffic density ranged from 200 to 270 vehicles/min passing the sampling site in both directions with approximately 5% being heavy-duty diesel trucks.

Freeway 710. The sampling location near the 710 freeway was chosen for its proximity to the freeway and lack of other significant ultrafine particle emission sources. Measurements were taken along Southern Avenue located perpendicular to the 710 Freeway and Garfield Avenue near the Los Amigos Country Club. The site lies 22.4 km east of the Pacific Ocean. Freeway 710 runs parallel to the Los Angeles River, generally north and south near the sampling site.

Several reasons make Southern Avenue ideal for this study. First, no other major roadways are near the sampling sites. Second, the sampling locations have minimal local traffic influence. Third, the only separation between the freeway and Southern Avenue is a metal chain link fence along the freeway. This allowed for measurements as close as 3 m from the closest lane of the freeway. Moreover, the upwind location is in a residential area that was easily accessible for upwind sampling.

During the sampling period, a fairly consistent eastward wind carries the freeway vehicular emissions directly to the sampling location. The 710 freeway is approximately 26 m wide including a 1 m wide median strip. As was done for the 405 freeway, the location of sampling sites for this study were measured from the center of the median strip.

A large percentage of the traffic on 710 freeway is heavy-duty diesel trucks. During the sampling period, traffic density ranged from 180 to 230 vehicles/min passing the sampling site in both directions, with approximately 25–30% being heavy-duty diesel trucks.

Sampling and Instrumentation

Meteorological data and total particle number concentration were measured at a fixed control site adjacent to both freeways. Carbon monoxide, black carbon, and ultrafine particle size distribution were measured at increasing downwind distance and upwind of the 405 and 710 freeways. Table 1 gives the sampling dates, times, and sites and summarizes the instruments that were used on each date. The weather station and one CPC were placed at a fixed downwind location near the freeways. Samples were taken at this control site throughout the experiment. All other applicable instruments were placed on a mobile laboratory cart and were moved together to sample simultaneously at each location. It takes about 10 min to complete sampling in one location and about 90 min to finish a set for all six sampling points. Three to four sets were performed on each sampling date.

Wind speed and direction were measured at the control site 6 m above the ground level. Wind data were logged into a computerized weather station over 1 min intervals (Wizard III, Weather Systems Company, San Jose, CA). Wizard III has a minimum detection limit of 0.4 m/s with an accuracy of ±0.2 m/s. A video camcorder was used to capture all lanes of the freeway throughout each measurement period. After each sampling session, traffic density was counted manually by playing back the videotape. Three 1 min samples were randomly selected from each 10 min interval for traffic counting.

A Condensation Particle Counter (CPC 3022A, TSI Inc., St. Paul., MN, USA) and a Scanning Mobility Particle Sizer (SMPS 3936, TSI Inc., St. Paul., MN, USA) were used to measure particle number concentration and size distribution in the size range from 6–220 nm. The sampling flow rate of the SMPS was 1.5 lpm with a sheath flow rate of 15 lpm, which allowed measurement of particles as small as 6 nm. This also minimizes the diffusion losses of ultrafine particles during sampling. In order to avoid particle losses due to electrostatic forces, flexible, conductive tubing (Part number 3001940, TSI Inc., St. Paul., MN, USA) was used for the sampling lines. Aerosol Instrument Manager software (version 4.0, TSI Inc., St. Paul., MN, USA) was used for data reduction and analysis of the SMPS output. Measurements near 405 Freeway were taken 30, 60, 90, 150, and 300 m downwind and 300 m upwind from the center of the Freeway. Near the 710 Freeway, measurements were taken at 17, 20, 30, 90, 150, and 300 m downwind and 200 m upwind from the center of the Freeway. At each location, three SMPS samples were taken, with a scanning time of 180 s each. Details of the calibration of these instruments are given in Zhu et al. (2002a, b).

Black carbon (BC) and carbon monoxide (CO) concentrations were monitored simultaneously at each sampling location in addition to particle size distribution and the total number concentration. Data were averaged after collection over the time periods corresponding to the scanning intervals of the SMPS. BC concentrations were measured using a Dual Beam Aethalometer (Model AE-20, Andersen Model RTAA-900, Andersen Instruments Inc., Smyrna, GA, USA) at 5 min intervals. Concentrations of CO were measured by a near-continuous CO monitor (Dasibi Model 3008, Environmental Corp., Glendale, CA, USA) at 1 min intervals.

Power for the control site CPC and Weather Station was provided by a nearby office by means of an extension cord. A 1.2 kW gasoline-powered portable generator (Model EU 1000i, Honda Motor Co., LTD., Tokyo, Japan) was used to supply the electric power for other sampling instruments at each of the sampling locations. The generator was placed approximately 50 m downwind of each sampling location in order to avoid sample contamination. Measurements were taken at the control site with the

Table 1
Winter sampling dates, time, sites, and instruments used

Date	Time	Site	Instruments used
01/10/02	10:30–15:30	405	Aethalometer, CO monitor, CPC, weather station
01/11/02	10:30–16:00	405	CPC, SMPS, weather station
01/14/02	11:00–16:00	710	Aethalometer, CO monitor, CPC, weather station
01/16/02	10:00–16:00	405	Aethalometer, CO monitor, CPC, SMPS, weather station
01/18/02	10:30–16:30	405	Aethalometer, CO monitor, CPC, SMPS, weather station
01/21/02	11:00–16:30	710	Aethalometer, CO monitor, CPC, SMPS, weather station
01/25/02	10:30–16:00	710	CPC, SMPS, weather station

Table 2
Comparison of sampling conditions in summer and winter

	Summer	Winter
Temperature (Celsius)	30.3 ± 3.7[a]	23.2 ± 4.0
Relative humidity (%)	66.4 ± 14.8	43.1 ± 21.4
Wind speed (m/s)	1.36 ± 0.66	1.27 ± 0.67
Traffic density on 405 freeway (vehicles/min)[b]	231 ± 30	236 ± 27
Traffic density on 710 freeway (vehicles/min)[b]	203 ± 12	200 ± 11
Solar zenith angles (deg)*	25.1 ± 6.3	64.4 ± 1.4
Control CPC reading near 405 ($\times 10^{-5}$/cm^3)	1.16 ± 0.87	1.40 ± 1.09
Control CPC reading near 710 ($\times 10^{-5}$/cm^3)	1.22 ± 1.11	1.49 ± 1.12

*From Finlayson-Pitts and Pitts, Chemistry of the Upper and Lower Atmosphere, 2000, Academic Press. (Finlayson-Pitts and Pitts 2000) Table 3.9.
[a]Mean ± one standard deviation.
[b]Both directions combined.

generator on and off, and there was no detectable differences in ultrafine PM concentrations.

RESULTS AND DISCUSSION

Results, including ultrafine particles size distributions, CO and BC concentrations at increasing downwind distances from the 405 and 710 freeways in winter obtained in the present study, are compared to those reported by Zhu et al. (2002a, b), which were obtained at the same locations in summer.

Table 2 summarizes the mean and standard deviation for meteorological sampling conditions, total vehicles, and control CPC readings in summer and winter. Since the raw data did not meet the normality criteria for a t-test, the nonparametric Mann-Whitney rank sum test was used to compare sampling data for summer and winter. Test results show that the traffic density near the 405 and 710 freeways are not statistically different between summer and winter, while, temperature, relative humidity (RH), wind speed, solar zenith angle, and CPC readings are all significantly different, with p values less than 0.001. The temperature and RH for the 405 and 710 freeways in winter were not significantly different.

Figures 1a and b compare traffic volume in summer and winter on the 405 and 710 freeways. Error bars indicate one standard deviation. Freeway 405 passes through West Los Angeles and is considered one of the busiest freeways in the United States. More than 95% of vehicles on the 405 freeway were gasoline-powered (Zhu et al. 2002a). The average traffic volume per hour during the winter sampling period on the 405 freeway was: 13,100 cars, 360 light trucks, and 540 heavy-duty trucks, for a total of 14,000 vehicles. These values are not statistically different from those reported by Zhu et al. (2002a) in summer. Freeway 710, passing through the City of Downey, is considered a major truck shipping route in Southern California with about 25–30% of vehicles

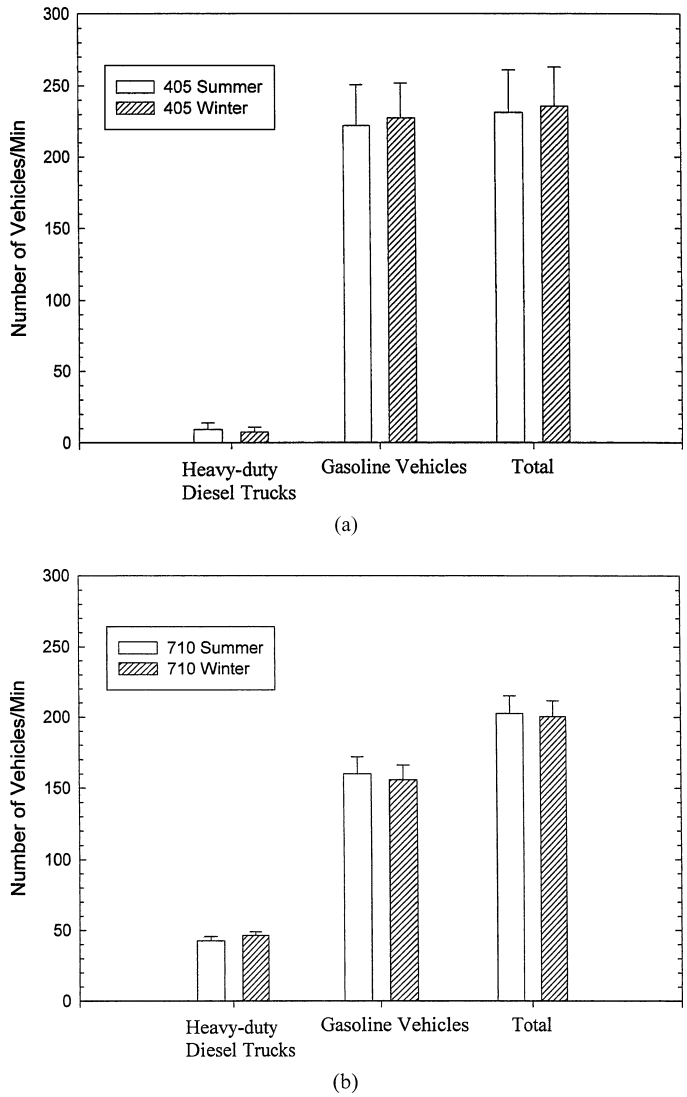

Figure 1. Traffic volume comparison in summer and winter for the (a) 405 and (b) 710 freeway. Bars indicate one standard deviation.

being heavy-duty diesel trucks (Zhu et al. 2002b). The average traffic volume per hour during the winter sampling period on the 710 freeway was: 8,450 cars, 840 light trucks, and 2,780 heavy-duty trucks, for a total of 12,000 vehicles. These values are also not statistically different from those reported by Zhu et al. (2002b) in summer near the 710 freeway.

Zhu et al. (2002a, b) reported that both wind speed and traffic density affected the characteristics of ultrafine particles near the 405 freeway, and the control CPC responded to these effects reasonably well. Thus, subsequent data for ultrafine particle analysis at increasing distances from the freeway were all normalized to the control CPC's reading. Details of the data normalization procedure are given by Zhu et al. (2002a, b).

Figures 2a and b show the ultrafine particle size distribution at different sampling locations near the 405 freeway in summer and winter, respectively. The horizontal axis represents particle

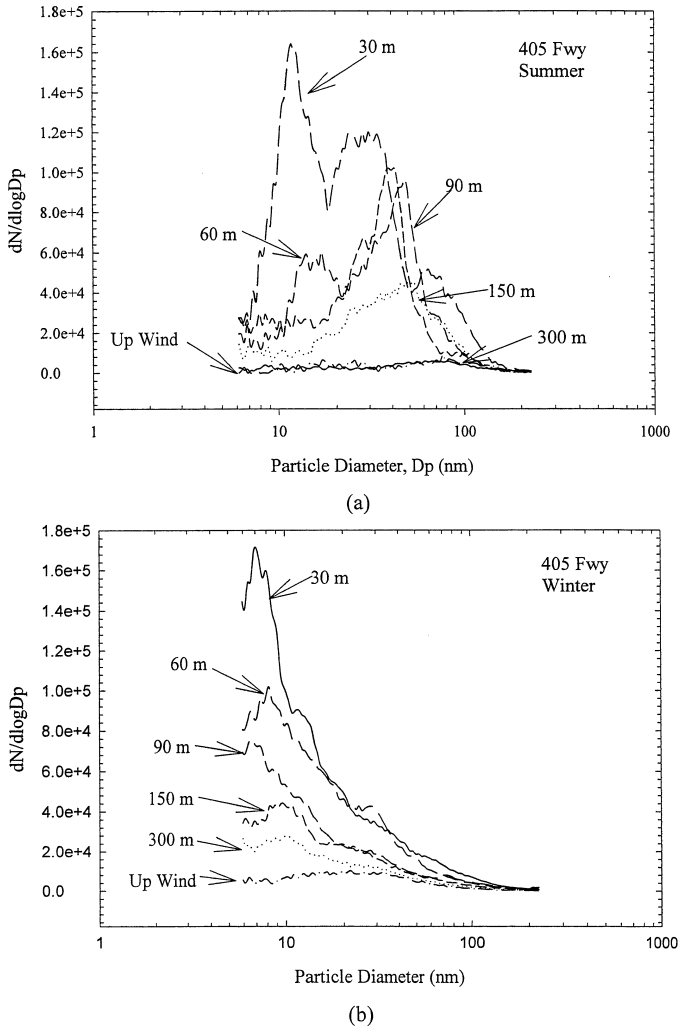

Figure 2. Ultrafine particle size distribution at different sampling locations near the 405 freeway in (a) summer and (b) winter.

size on a logarithmic scale, while the vertical axis represents normalized particle number concentration. The normalized ultrafine particle size distributions, in the size range of 6–220 nm at each distance from the freeway were averaged for all sampling dates (Zhu et al. 2002a). As shown in Figure 2a, three distinct modes were observed during the summer season, 30 m downwind from the freeway. The smallest mode, around 13 nm, shifted to a larger modal value of 16 nm, and the modal number concentration dropped to one third of the maximum concentration at 60 m downwind. Furthermore, this mode was not observed at greater downwind distances. Ultrafine particle concentration measured at 300 m downwind of the freeway was comparable to what was measured at the background location 300 m upwind of the freeway. The maximum number concentration that was observed near the freeway was about 25 times greater than that observed for the background location in summer (Zhu et al. 2002a). These results indicate that the freeway is a very strong local source of ultrafine particles. Figure 2b illustrates a different situation in the winter season. Only one dominant particle mode was observed for all sampling locations. At 30 m downwind from the 405 freeway, this mode occurred around 7 nm rather than the 13 nm found in summer, with a modal number concentration of 1.8×10^5 /cm^3. Contrary to the summer season, this mode also persisted at distances up to 300 m downwind of the freeway and did not shift to a larger size. Furthermore, although the modal concentration decreased significantly with increasing distance, it did not drop as fast as it did in summer. While this mode was not observed at downwind distances greater than 60 m in summer, it was observed at all sampling locations in winter. It is also of particular note that ultrafine particle concentrations measured at 300 m downwind of the 405 freeway were still distinguishable from background measurement in winter. These results suggest that the effect of atmospheric dilution is weaker in winter.

Figures 3a and b were prepared in the same way as Figures 2a and b, showing the ultrafine particle size distribution at different

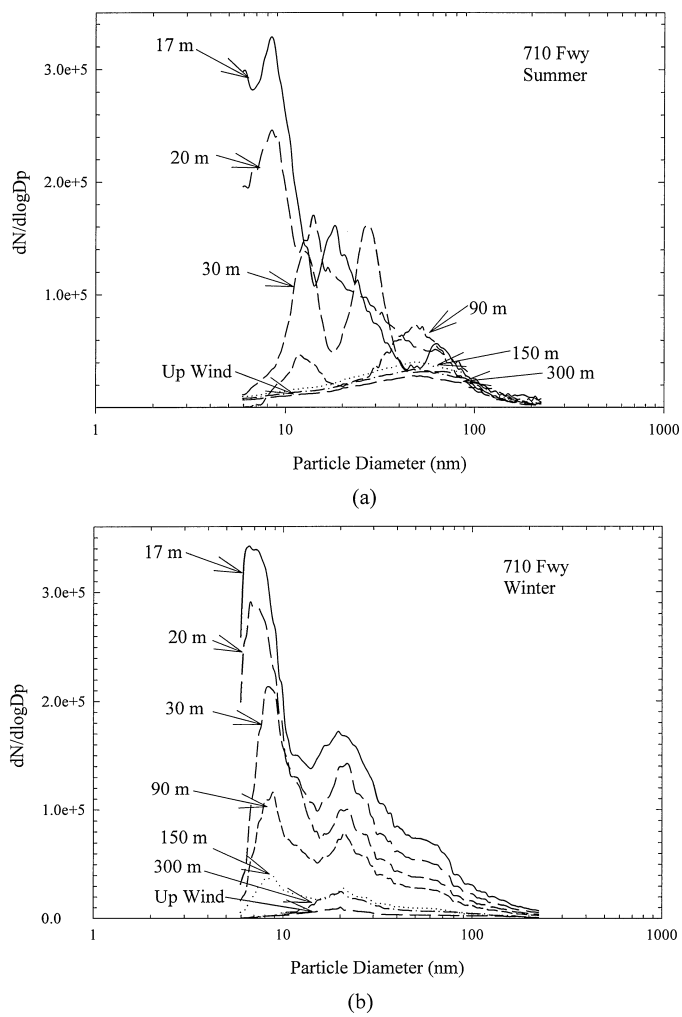

Figure 3. Ultrafine particle size distribution at different sampling locations near the 710 freeway in (a) summer and (b) winter.

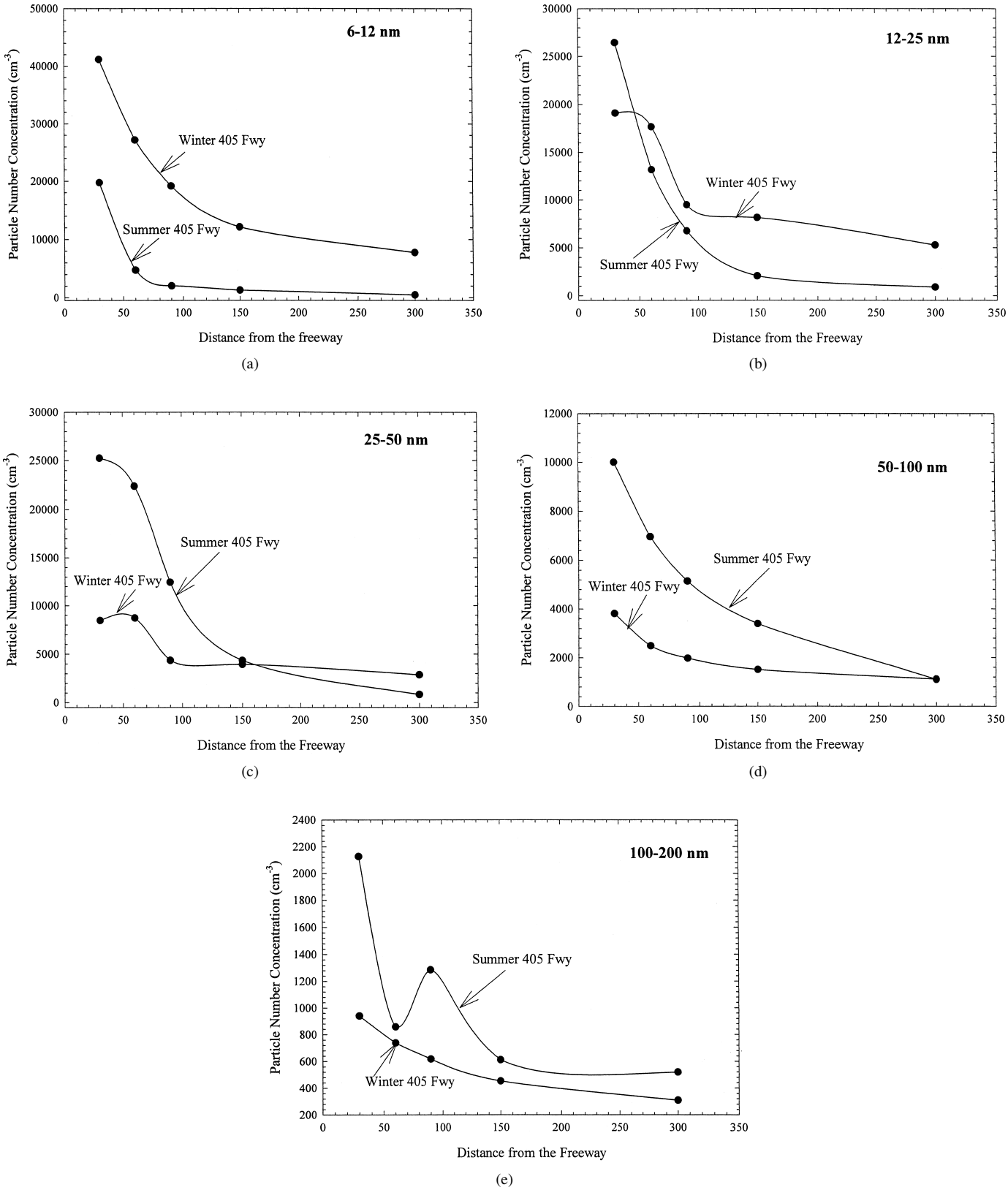

Figure 4. Comparison of decay of particle number concentrations in summer and winter in the size range of (a) 6–12 nm, (b) 12–25 nm, (c) 25–50 nm, (d) 50–100 nm, and (e) 100–200 nm near the 405 freeway.

sampling locations near the 710 freeway in summer and winter. For the predominant mode (diameter <10 nm), similar trends were observed. This mode shifted to a larger size range and disappeared after 90 m from the 710 freeway in summer. By contrast, in wintertime, this mode persisted up to 150 m downwind from the freeway. The decay in modal concentration with distance from the freeway was slower than that observed during the summer experiments. Contrary to what was observed near the 405 freeway, a second mode around 20 to 30 nm appeared in winter near the 710 freeway. This is presumed to be due to the much higher diesel emissions on the 710 freeway. As shown in Figures 1a and b, heavy-duty diesel trucks on the 710 freeway represent more than 25% of traffic, while on the 405 freeway they represent less than 5% (Zhu et al. 2002a, b). Average particulate matter emission rates for heavy-duty diesel trucks are about 0.4 g/mi (California Air Resource Board 2000) and for passenger cars are about 0.08 g/mi. (US Environmental Protection Agency 2000). This gives about 68% of PM emission from heavy-duty diesel trucks on the 710 freeway (Zhu et al. 2002a, b). Similar to the predominant mode, the second mode remained around 20 to 30 nm for all sampling locations and did not shift to a larger size significantly. Its modal concentration decreased more slowly in winter than in summer. These results are in excellent agreement with what has been observed near the 405 freeway and can be explained by weaker atmospheric dilution in the winter season.

Zhu et al. (2002a, b) found that ultrafine particles from freeways in different size ranges behaved quite differently in the atmosphere. Figures 4a–e compare the decay characteristics of particle number concentrations near the 405 freeway in summer and winter in five size ranges, 6–12 nm, 12–25 nm, 25–50 nm, 50–100 nm, and 100–220 nm. In Figure 4a, for the particle size range of 6–12 nm particle number concentration was much higher in winter than in summer throughout the sampling distance. Kittelson et al. (2001) found in their on-road PM measurements that the number concentration of particles in the nuclei mode (10–20 nm) was nearly a factor of 10 greater for an ambient temperature of 15°C than for 25°C. This observation suggests that there could be significant differences in the formation of semivolatile nanoparticles between summer and winter, with lower atmospheric temperatures favoring the formation of a greater number of particles. This size range decays more slowly as a function of distance from the freeways in winter than in summer (Figures 3a and b), probably due to the decreased rate of dilution and coagulation during winter. For the next size range, 12–25 nm, Figure 4b shows that particle number concentration was higher in summer within 60 m downwind from the 405 freeway and was higher in winter for more distant sampling locations. Overall, particle number concentration in the 12–25 nm size range decayed faster in summer than in winter. The particle number concentration was much higher in summer than in winter for the larger size ranges (Figures 4c–e). The decay rates were also greater in summer than in winter for those size ranges.

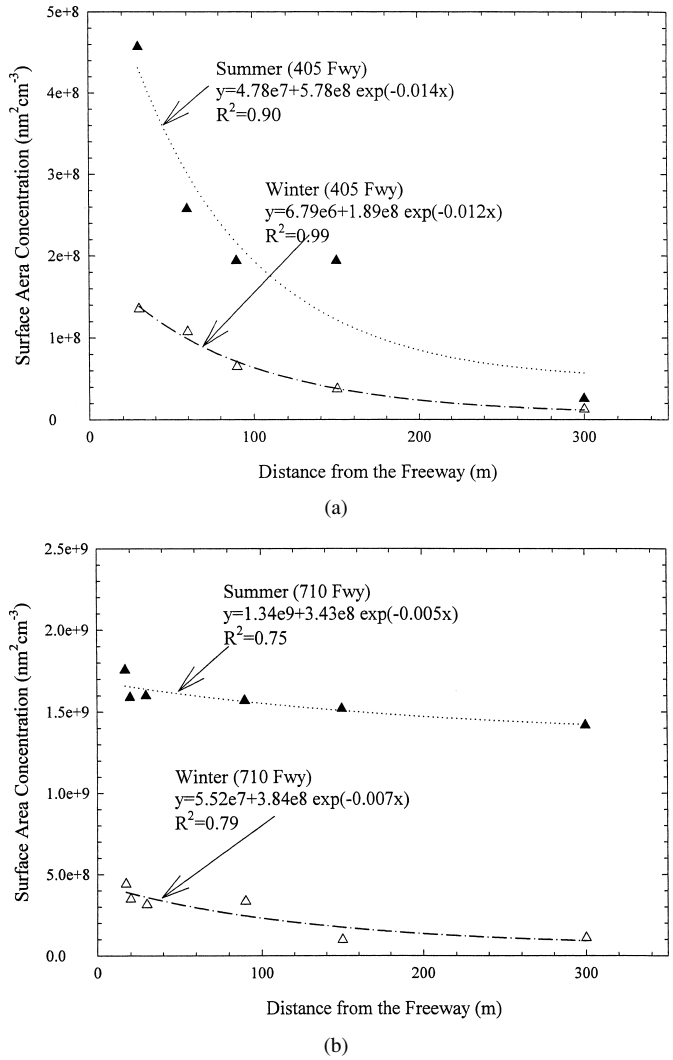

Figure 5. Decay curves of ultrafine particle surface area concentration in summer and winter near (a) the 405 freeway and (b) the 710 freeway.

Coagulation, a potentially important mechanism associated with aerosol aging in the atmosphere, appeared to be significant in the vicinity of the freeways in summer (Zhu et al. 2002a, b). The rate of collisions between two particles is directly related to collision surface area. Coagulation between nanoparticles and accumulation mode particle, which account for the majority of the aerosol surface area, is preferential to self-coagulation of these nanoparticles. Thus, nanoparticles will be scavenged by accumulation mode aerosols with their greater surface area (Hinds 1999). Figures 5a and b illustrate the decay curves of particle surface area concentration in summer and in winter, with distance along the wind direction from the 405 freeway and the 710 freeway, respectively. Surface area concentration was calculated from size-segregated SMPS data in the size range 6–220 nm. Each data point in the figure represents an averaged value for all measurements with the same wind direction. The

lines in the graph represent best-fitting exponential decay curves using SigmaPlot 2000 nonlinear curve fitting (SigmaPlot 2000). The best-fitting exponential decay equations and r-squared values are also given in Figure 5. As shown in Figure 5, for both freeways ultrafine particle surface area concentration remained much higher in the summer than in the winter for all distances downwind of the freeways. Based on the characteristics of coagulation, discussed above, these results suggest that coagulation should be stronger in summer than in winter. This argument is also corroborated by the faster decay rates of particles emitted by vehicles in summer than in winter.

From Figures 4 and 5 it can be seen that for lower ambient temperature there is a greater particle number concentration in the particle size range of 6–25 nm and a smaller number concentration in the 50–200 nm particle size range. This results in a greater total particle number concentration in winter as measured by the CPC (see Table 2). Although number concentration is lower in summer, the greater number of larger particles (50–200 nm range) gives a greater total surface area concentration in summer. In winter, the total particle number concentration is approximately 20% higher than it is in summer (Table 2). Although this should correspond to about 40% greater coagulation rate, this was not observed because atmospheric dilution has a much greater influence on the ultrafine particle aging process than coagulation. The effect of coagulation, in both summer and winter, is negligible compared to atmospheric dilution. The weaker wind and weaker vertical mixing in winter likely contribute to the slower decay of ultrafine particles. On the other hand, factors that influence coagulation rate may be different in summer and winter. For example, the percentage of fractal aggregates as compared to spherical ultrafine particles may differ between the two seasons. Since the coagulation kernel for fractal particles can be 10 times greater than that for spherical particles (Friedlander 2000), the coagulation of ultrafine particles may be controlled by the percentage of fractal aggregates.

Figures 6a and b compare the concentrations of CO and BC, respectively, in summer and winter with increasing distance from freeways 405 and 710. The decay rates for these two pollutants are slightly greater in summer than in winter for both freeways, which suggests that atmospheric dilution is stronger in summer. An additional factor for the lower decay rates in the winter may be the lower wind speeds during that period. According to classical Gaussian dispersion models, a pollutant's concentration is inversely proportional to wind speed at a given downwind distance from the emission source (Seinfeld and Pandis 1998). Since the average wind speed in winter is about 93% of that in summer, the dilution effect may be about 7% weaker in winter, assuming all other influencing factors are the same.

As seen in Figures 6a and b, the concentration of BC was significantly higher near the 710 freeway than the 405 freeway in both summer and winter. This is primarily due to the much higher heavy-duty diesel traffic composition on the 710 freeway (Zhu et al. 2002b). It is well known that diesel vehicles produce much more BC particles than gasoline vehicles (Burtscher et al. 1998; Kittelson et al. 2001; Weingartner et al. 1997). The emission of black carbon has been shown to represent as much as 80–90% of particulate from heavy-duty diesel vehicles (Lowenthal et al. 1994) and about 50% of PM2.5 in an urban environment (Ruellan and Cachier 2001). BC concentrations near the 710 freeway were not significantly different in summer as compared to winter.

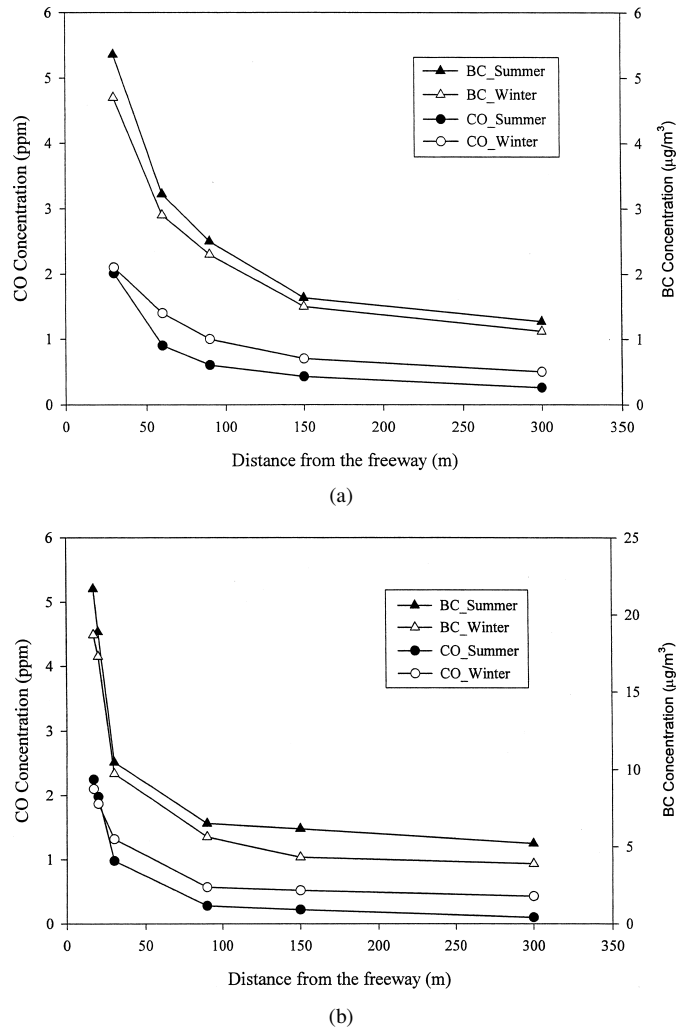

Figure 6. Comparison of CO and BC concentration decay in summer and winter near (a) the 405 freeway and (b) the 710 freeway.

CONCLUSIONS AND SUMMARY

The decay rate of CO and BC are slightly greater in summer than in winter for both freeways, suggesting a stronger atmospheric dilution effect in summer. Less dynamic changes in size distribution were observed in winter. Particle number concentration in the size range of 6–12 nm is significantly higher in winter than in summer. The associated modal concentration in that size range decreased at a slower rate in winter than in summer. The mode did not shift significantly to a larger size in winter as it

did in summer. The surface area concentrations in the size range of 6–220 nm are consistently higher in summer for all sampling locations.

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