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Inferring the Sources of Fine and Ultrafine Particulate Matter at Downwind Receptor Sites in the Los Angeles Basin Using Multiple Continuous Measurements

Philip M. Fine, Si Shen, and Constantinos Sioutas
University of Southern California, Department of Civil and Environmental Engineering, Los Angeles, California

Recent studies that have found increased health effects of atmospheric ultrafine particulate matter (PM) have refocused attention on particle number rather than particle mass concentrations as a relevant measurement of PM pollution. As part of the Southern California Supersite program, ambient particle characteristics were measured over 13 months at three different sites in the eastern portion of the Los Angeles Basin: Riverside, Rubidoux, and Claremont, CA. The sites represent receptor locations that are influenced by local particle sources as well as advection from the more intense particle sources upwind closer to Downtown Los Angeles. An SMPS/APS tandem system was employed to collect continuous particle size distributions, from which particle number and mass concentrations were calculated. An aethalometer provided continuous particulate elemental carbon (EC) concentrations. Results show no meaningful correlation between particle number and mass, indicating that fine particle standards may not be effective in controlling ultrafine concentrations. Diurnal patterns show a morning traffic peak indicated by increases in particle mass, number, and EC. Afternoon periods in the warmer months are characterized by high number counts while mass and EC remain low, suggesting the formation of new particles by photochemistry. Particle mode diameters range from 30 nm up to above 100 nm, a result not seen in most other studies of particle size distributions in other urban or rural areas where mode diameters are generally less than 50 nm. Evidence is presented that the observed ultrafine particle concentrations and size distributions are influenced by long-range advection and photochemical processes as well as vehicular emissions, which have been previously assumed to dominate day-to-day ultrafine particle levels.

INTRODUCTION

Epidemiological studies have demonstrated a strong link between ambient particulate matter (PM) concentrations and health effects (Dockery et al. 1992, 1993, 1996). Particle toxicity has recently been found to be higher for smaller-sized particles on a per unit mass basis (Oberdörster and Utell 2002; Li et al. 2002a). This has focused increasing attention on fine ($PM_{2.5}$) and ultrafine (particles with diameters less than about 0.1–0.2 μm) particulate matter. However, it is not clear whether it is particle number, mass, surface area, or chemical constituent concentrations that pose the greatest health risk.

Gravimetric techniques are most commonly used for the monitoring of PM for regulatory purposes (McMurry 2000). Such filtration and impaction methods require manual operation, often do not provide immediate results, and have very limited temporal resolution. It is often necessary to collect samples over one or more days for accurate analysis. These methods are more prone to sample contamination due to the manual handling and transportation of filters and substrates. Furthermore, long sampling periods can increase sampling artifacts due to volatilization and adsorption of labile PM species such as ammonium nitrate and semivolatile organic compounds (Appel et al. 1984; Coutant 1977; Hering and Cass 1999).

Many continuous instruments that are available or in development can provide real-time or near real-time measurements of PM number concentration, mass concentration, size distribution, and chemical composition. For example, scanning mobility particle sizers (SMPS; TSI Inc.) and aerodynamic particle sizers (APS; TSI Inc.) are widely used to measure number concentrations and size distributions continuously (Harrison et al. 2000; Shen et al. 2002). Instruments that measure particle mass concentrations near continuously include the tapered element oscillating microbalance (TEOM; Rupprecht and Patashnick, Albany, NY, USA), the beta attenuation monitor (BAM; Met One Instruments, Grants Pass, OR, USA), the Continuous ambient mass monitor (CAMM; Thermo Andersen, Smyrna, GA, USA), and nephelometers such as the DataRAM (Chung et al. 2001). Semicontinuous PM carbon and nitrate monitors have also been developed that measure total or size-segregated mass concentrations at 10–30 min intervals (Fine et al. 2002).

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Address correspondence to Constantinos Sioutas, University of Southern California, Department of Civil Engineering, 3620 South Vermont Ave., Los Angeles, CA 90089. E-mail: sioutas@usc.edu

In an urban environment, there are generally two main contributors to the PM concentrations: primary or direct emissions from particle sources and secondary PM formed by photochemical or physical processes in the atmosphere. The air at a downwind receptor location will contain particles emitted from local sources, as well as particles emitted or formed far upwind that have aged during transport. The combination of several continuous or semicontinuous instruments, in addition to providing cheaper and faster monitoring of particle parameters with potential acute health effects, can prove to be useful in helping to determine particle sources (primary versus secondary and local versus advected). Shi et al. (2001) used the temporal data provided by a condensation particle counter (CPC) to identify periods of nucleation events. Lawless et al. (2001) used the near-continuous data obtained from an SMPS and an optical counter to distinguish between primary and secondary contributions to $PM_{2.5}$ in Fresno, CA. These studies focused on one specific location. The spatial variation of aerosol characteristics within a city has also been examined. Kim et al. (2002) were able to identify periods of photochemistry and advection based on the continuous data provided by the SMPS and Aethalometer in Downey and Riverside, CA. Buzorius et al. (1999) conducted experiments at a series of sites in Helsinki, Finland in order to investigate the transport of aerosol traveling from source sites to receptor sites. Ruuskanen et al. (2001) conducted monitoring in three different European cities using continuous monitors to describe differences among the sites as well as diurnal variations of particle mass and number concentrations.

The literature on systematic monitoring of the physical and chemical characteristics of ultrafine particles—typically defined as those having diameters below 0.1 μm, although this definition has been extended to often include particles as large as 0.2 μm (Zhang and Wexler 2002)—in either urban or rural settings has not been as abundant as that for $PM_{2.5}$ or PM_{10}, mainly because current regulation does not target the concentration of these particles. Nevertheless, there has been rapidly increasing epidemiological and toxicological evidence linking respiratory health effects and exposures to ultrafine particles. Epidemiological studies conducted by Heyder et al. (1996) and Peters et al. (1997) have demonstrated a stronger association between health effects and exposure to ultrafine particles as compared to fine or coarse particles. A study by Pekannen et al. (1997) showed associations between fine and ultrafine particles and the incidence of asthma in children. More recent studies by Li et al. (2002a, b) demonstrate that when epithelial cells from human airways were exposed to the different modes of atmospheric PM on an equal mass basis, ultrafine PM caused a greater degree of response.

Most of the studies examining the size distributions of PM were conducted in urban areas in which the vast majority of ultrafine PM originate from primary sources (Harrison et al. 2000; Morawska et al. 1998; Hughes et al. 1998; Tier 1997; Woo et al. 2001), thus their diurnal concentration profiles match those of local vehicular sources. The majority of these studies were also intensive in nature, for a period ranging from a few weeks to a few months. Depending on the lower detectable particle size of the condensation counter used to detect ultrafine particles, these investigations indicated that the size distribution of a "typical" ultrafine aerosol has a number mean or mode diameter in the range of 20–40 nm, and over 90–99% of particle counts are associated with particles below 100 nm.

The work presented in this article intends to add to the body of information on continuous spatial and temporal variations in aerosol parameters such as number, mass, size distribution, and chemical composition in different locations and seasons in one of the most unique air basins of the U.S., the Los Angeles basin (LAB). The research described here is part of the activities of the Southern California Supersite, a large monitoring program funded by the US Environmental Protection Agency (EPA). One of the main objectives of this program is to conduct research that contributes to a better understanding of the measurement, sources, size distribution, chemical composition, physical state, spatial and temporal variability, and health effects of suspended PM. In order to study the geographical and seasonal variation of PM, the primary sampling site was designed to move to a new location within the LAB every 6–12 months. A better understanding of the sources and formation mechanisms of PM with respect to spatial, diurnal, and seasonal variability will help to design future control strategies for PM as well as refine the parameters used in epidemiological studies that attempt to link particulate levels and observed health effects.

The PM data presented in this article were generated over a 13-month period at three different locations within the LAB by the Southern California Particle Supersite Program. All three sites, located towards the east of the LAB, can be considered downwind receptor sites and are associated with some of the highest $PM_{2.5}$ concentrations in the U.S. (Christoforou et al. 2000). The sources and formation mechanisms of PM in these sites are also of particular interest. Unlike a typical urban environment, these sites are influenced by local primary sources, the advection of primary but aged particulate emissions from areas situated upwind, and the formation of secondary aerosols in the atmosphere. Riverside and Rubidoux, downwind of ammonia emissions from the dairy farms in Chino, are located along the "ammonia trajectory" described by Hughes et al. (2000). Claremont, however, is not affected by this strong ammonia source and is considered to be on the "traffic trajectory" (Pandis et al. 1992). The data collected by three near-continuous instruments (SMPS, APS, and Aethelometer) are used to infer information on sources and formation mechanisms at each location as well as their prevalence over different times of day and different seasons.

METHODS

Sampling Sites

The ambient aerosol characterization data were collected through a mobile aerosol laboratory operated by the Southern

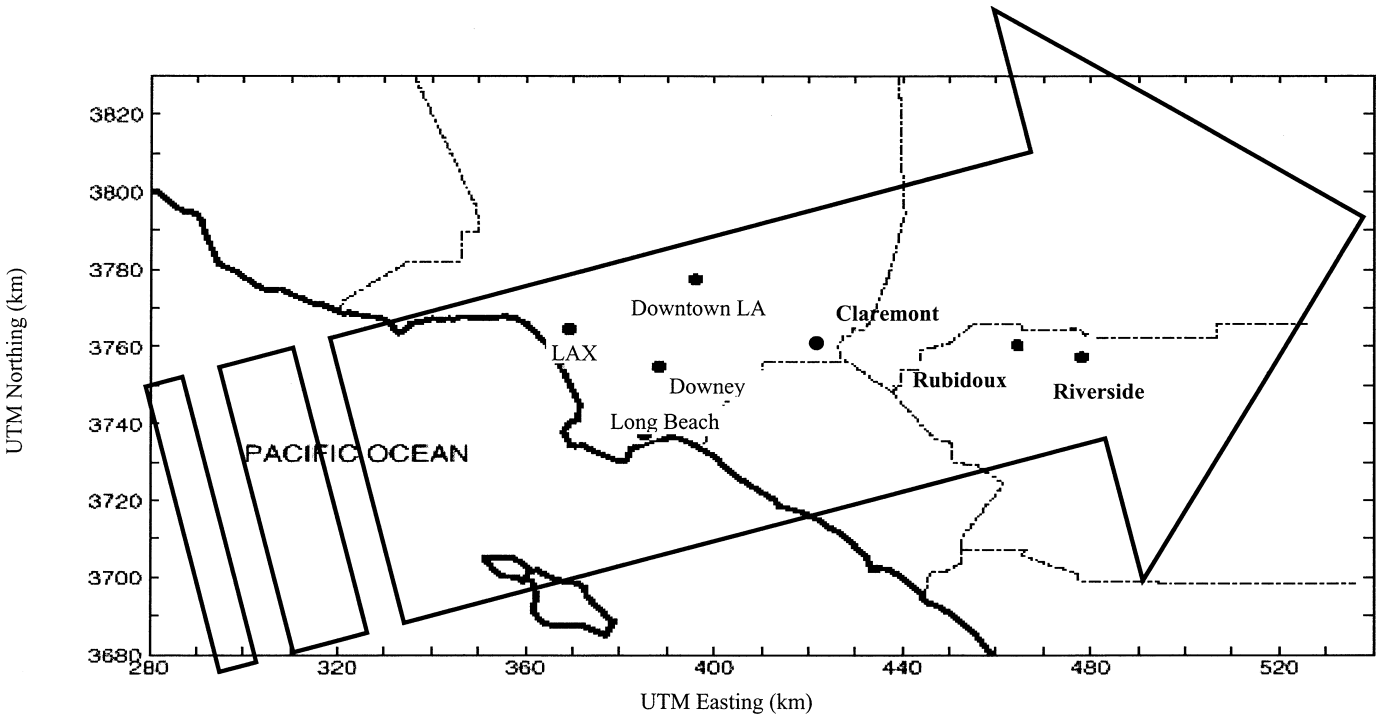

Figure 1. Locations of sampling sites (Riverside, Rubidoux, and Claremont) in the Los Angeles Air Basin: the large arrow shows the overall direction of wind during the daytime.

California Supersite. The sampling platform was designed to be mobile in order to examine the seasonal differences in ambient particle characteristics over the geographically large area of the LAB. The sampling locations considered in this work are Rubidoux, Riverside, and Claremont over the period of February 2001 to March 2002 (Figure 1).

The Rubidoux sampling site is located approximately 100 km inland from the Pacific Ocean and 80 km east from Downtown Los Angeles. It is immediately upwind of a nearby freeway. A substantial fraction of $PM_{2.5}$ in that area originates from the western portion of the LAB and arrives after aging for several hours in the atmosphere. It is also 25 km downwind of significant ammonia emissions from the Chino-area dairy farms, and thus is affected by secondary ammonium nitrate formation Rubidoux often has very high particulate nitrate concentrations (Christoforou et al. 2000).

The Riverside site is located within the facilities of the Citrus Research Center and the Agricultural Experiment Station of the University of California, Riverside. It is approximately 8 km east of the Rubidoux site, and, similar to Rubidoux, aged particles advected by the westerly winds to the Riverside area contribute largely to the ambient $PM_{2.5}$. Located on a similar trajectory as the Rubidoux site, Riverside is also influenced by the upwind stationary ammonia emissions in the Chino area.

Claremont is located in a residential neighborhood approximately 50 km east of Downtown Los Angeles, at the foothills of the San Gabriel Mountains. The site is also influenced by aged, advected aerosol from the west, but without the intense upwind ammonia source that affects Rubidoux and Riverside.

Instrumentation

Several near-continuous instruments were employed at each location as part of the activities of the Southern California Supersite. A scanning mobility particle sizer (SMPS; 3936, TSI Inc.) and an aerodynamic particle sizer (APS; 3320, TSI Inc.) were used in tandem to determine the number size distribution of particles with diameters between 14.1 nm and 2.5 μm. Data reduction and analysis of the SMPS/APS output was performed using the Aerosol Instrument Manager software (version 4.0, TSI Inc., St. Paul, MN, USA). Measurements were taken with a scanning time of 15 min each. The mass concentration of the PM is calculated from the SMPS/APS size distributions, assuming density of 1.6 g/cm^3 and an algorithm described in greater detail by Sioutas et al. (1999). A recent study by Shen et al. (2002) conducted in the LAB showed that the $PM_{2.5}$ mass concentrations determined by SMPS/APS were in excellent agreement with those measured gravimetrically by other collocated time-integrated $PM_{2.5}$ samplers. The number mode diameter, i.e., the particle diameter corresponding to the peak number concentration, was also determined from the SMPS/APS size distributions.

A dual-beam aethalometer (Anderson RTAA-900, Andersen Instruments Inc.) was used to determine $PM_{2.5}$ elemental carbon concentrations with a time interval of 5 min. The aethalometer uses the optical attenuation of 880 nm wavelength light to

measure "black" carbon mass concentrations as particles are collected on a quartz fiber filter strip. For comparison purposes, 1 h averages were calculated from all semicontinuous data.

RESULTS AND DISCUSSION

Hourly $PM_{2.5}$ number and mass concentrations were calculated from the SMPS/APS data for the entire study period. The relationship between these two metrics of particle pollution, displayed in Figure 2, shows very low correlation ($r^2 = 0.18$). Correlation between mass and number is also not evident when data are divided by season, site, time of day, and day of the week. Woo et al. (2001) did not find any correlation between number and volume (related to mass by an assumed constant density) over a 13-month period in Atlanta, Georgia. Since number concentrations are driven primarily by ultrafine particles less than about 150 nm in diameter, which in turn make up a low percentage of the total $PM_{2.5}$ mass, correlation would not be expected unless the shape of the particle size distribution remains relatively constant. As described below, this is not the case for the current study. These findings are also very important from a regulatory perspective because they imply that controlling ambient $PM_{2.5}$ mass via national air quality standards may not necessarily reduce human exposure to the ultrafine particles that have recently been shown to have toxic effects (see introduction).

The effects of the day of the week on the measured number, mass, and elemental carbon concentrations are shown in Figure 3. Data from all three receptor sites over all seasons are included in daily averages. Number, mass, and elemental carbon are all generally higher on weekdays, particularly during the middle of the week, and follow a similar weekly pattern. The trend in elemental carbon, which is emitted primarily from diesel engines, suggests that the weekly trends are in fact related to vehicle emissions. Certain industrial emissions might also be lower on weekends. The exception is Monday, which, for all three measurements, is associated with lower concentrations than the other weekdays. Furthermore, Saturday's average mass concentrations appear to be quite similar to weekday levels. Our three sampling sites are receptor sites downwind of the high concentration of sources in the western part of the LAB, and air parcels can take up to 24 h or more to travel inland to our sampling locations. Monday's lower levels, and perhaps Saturday's higher mass levels, might be explained by respectively lower and higher emissions of particles and particle-formation precursor gases the day before. Similarly, Woo et al. (2001) measured lower particle number concentrations for particles between 0.1 and 2 μm on Sunday and Monday versus the rest of the week in Atlanta. Overnight stagnation and transport effects will depend on the specific meteorology, sampling location, and source distribution of a particular area. At a minimum, the

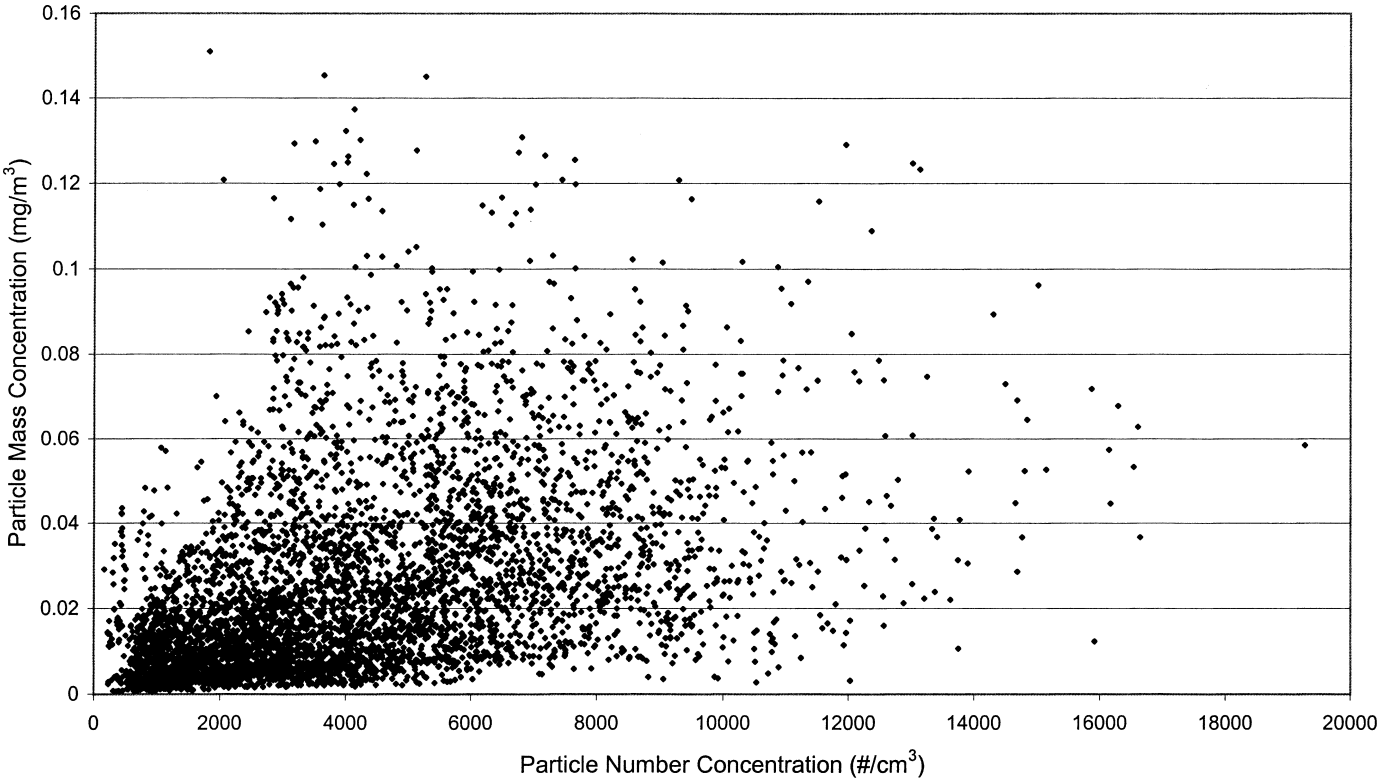

Figure 2. Particle number and mass concentration correlation in Riverside, Rubidoux, and Claremont, CA (February 2001 to March 2002).

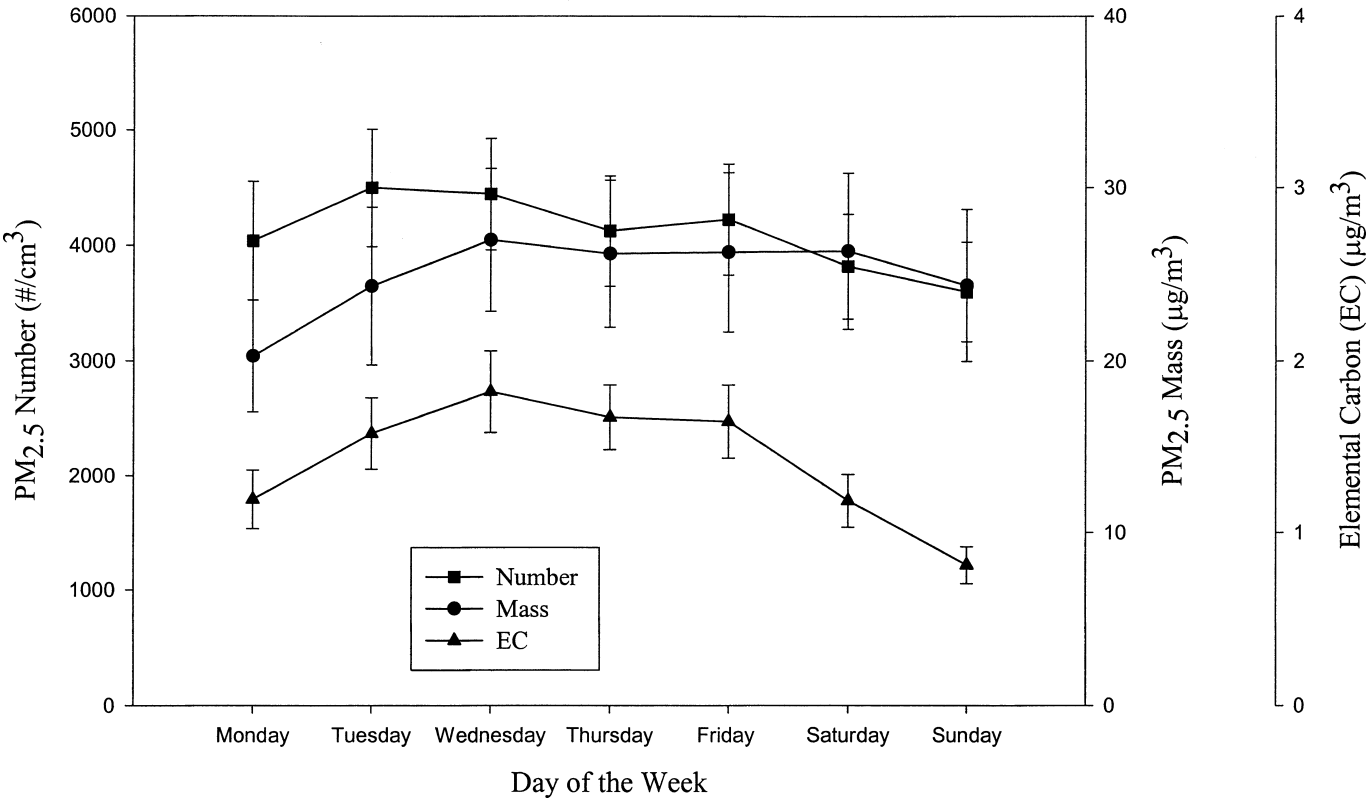

Figure 3. $PM_{2.5}$ particle number, mass, and EC concentrations during different days of the week in Riverside, Rubidoux, and Claremont, CA (February 2001 to March 2002).

results in Figure 3 suggest our receptor sites may be sampling air parcels that were over the LAB the day before, and thus contain at least some well-aged aerosol.

Rubidoux and Riverside

Rubidoux and Riverside, California are located approximately 20 km apart downwind of the Chino dairy farm ammonia source. Sampling was conducted in Riverside from February 2001 to May 2001 and then from June 2001 to August 2001 in Rubidoux. Figures 4 and 5 show the diurnal profiles of monthly averaged $PM_{2.5}$ number and mass concentration measured by SMPS/APS as well as elemental carbon mass concentration measured by the Aethalometer.

For all four months in Riverside, rush hour traffic emissions are the dominant source in the morning, as shown by the steep increase in particle number, mass, and elemental carbon (EC) concentrations (Figure 4). The primary source of EC in the LAB is diesel engines (Schauer et al. 1996), and thus EC can be used as an indicator of traffic emissions. Since number counts are high, indicating a fresh aerosol, and since wind speeds are generally low in the morning, the traffic source is presumably local to the sampling location. The high mass concentrations in the morning, relative to the evening rush hour levels, may be a result of the low mixing height during morning hours (Kim et al. 2002). As the day progresses the temperature increases, causing the inversion height to rise. With the exception of February, the particle mass concentration and EC mass concentration decrease steadily between 3 pm to 8 pm, while particle number concentration continues to increase. (The February evening peaks in mass and elemental carbon may be due to a seasonal and local source, such as residential wood burning, that decreased in strength by March.) When number counts dominated by ultrafine particles increase relative to particle mass, which is dominated by larger particles, the particle size distribution must necessarily shift toward smaller particles. Thus, the evening pattern corresponds to a general decrease in the particle mode diameter as seen in Figure 6.

There are several possible explanations to explain the afternoon increase in number concentrations and decrease in mode diameters while the mass concentrations remain low. Increases in particle number at a fixed sampling location can arise from (1) decrease in mixing height, (2) increased activity of a local primary particle source, (3) long-range transport of an air mass with higher number concentrations, or (4) secondary particle formation in the atmosphere via homogeneous nucleation.

It has already been mentioned that the mixing height increases in the afternoon in these areas of the LAB, so the first explanation does not apply. The sites are not located immediately downwind

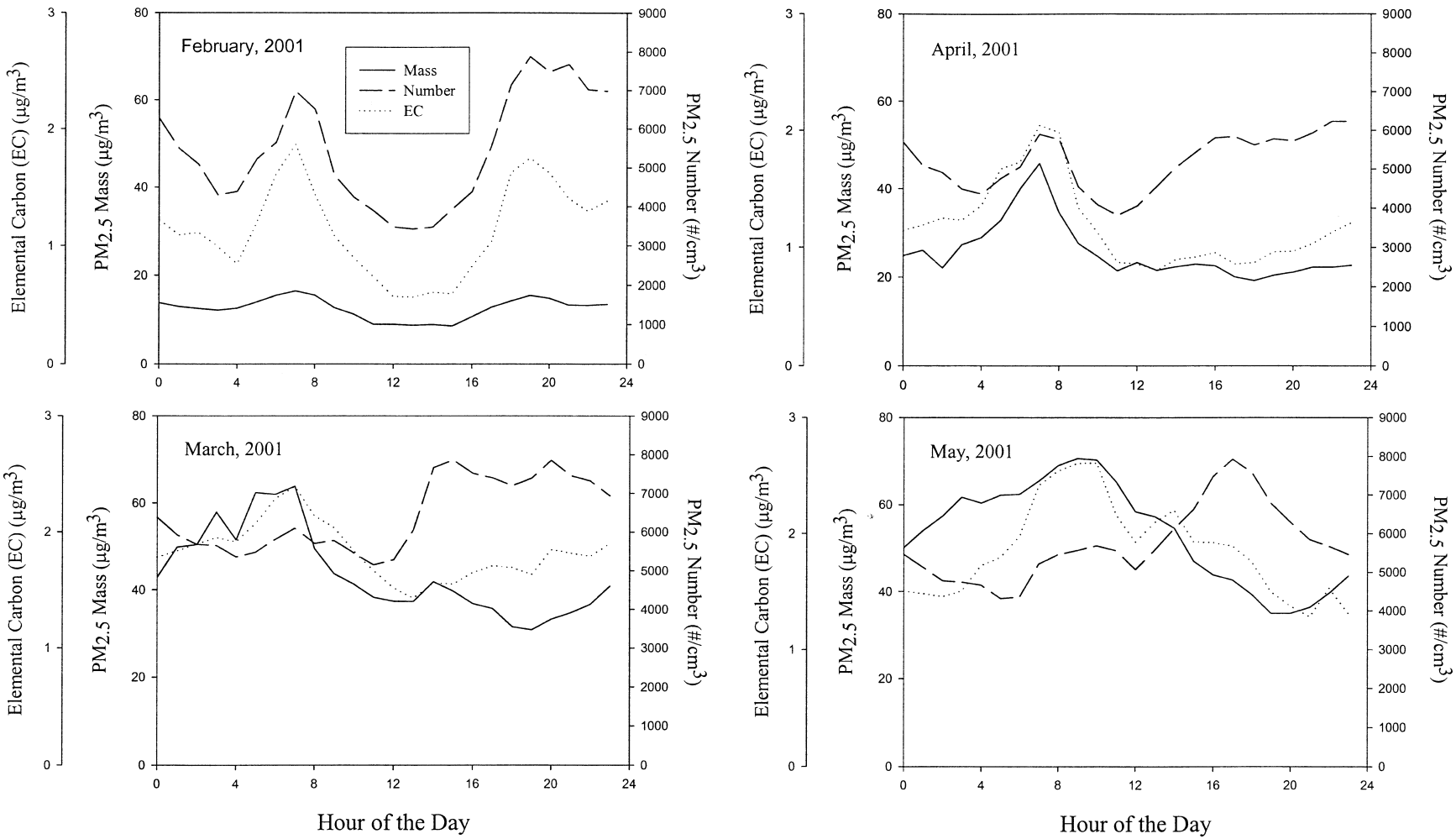

Figure 4. Diurnal profiles of $PM_{2.5}$ particle number, mass, and EC mass concentrations in Riverside, CA.

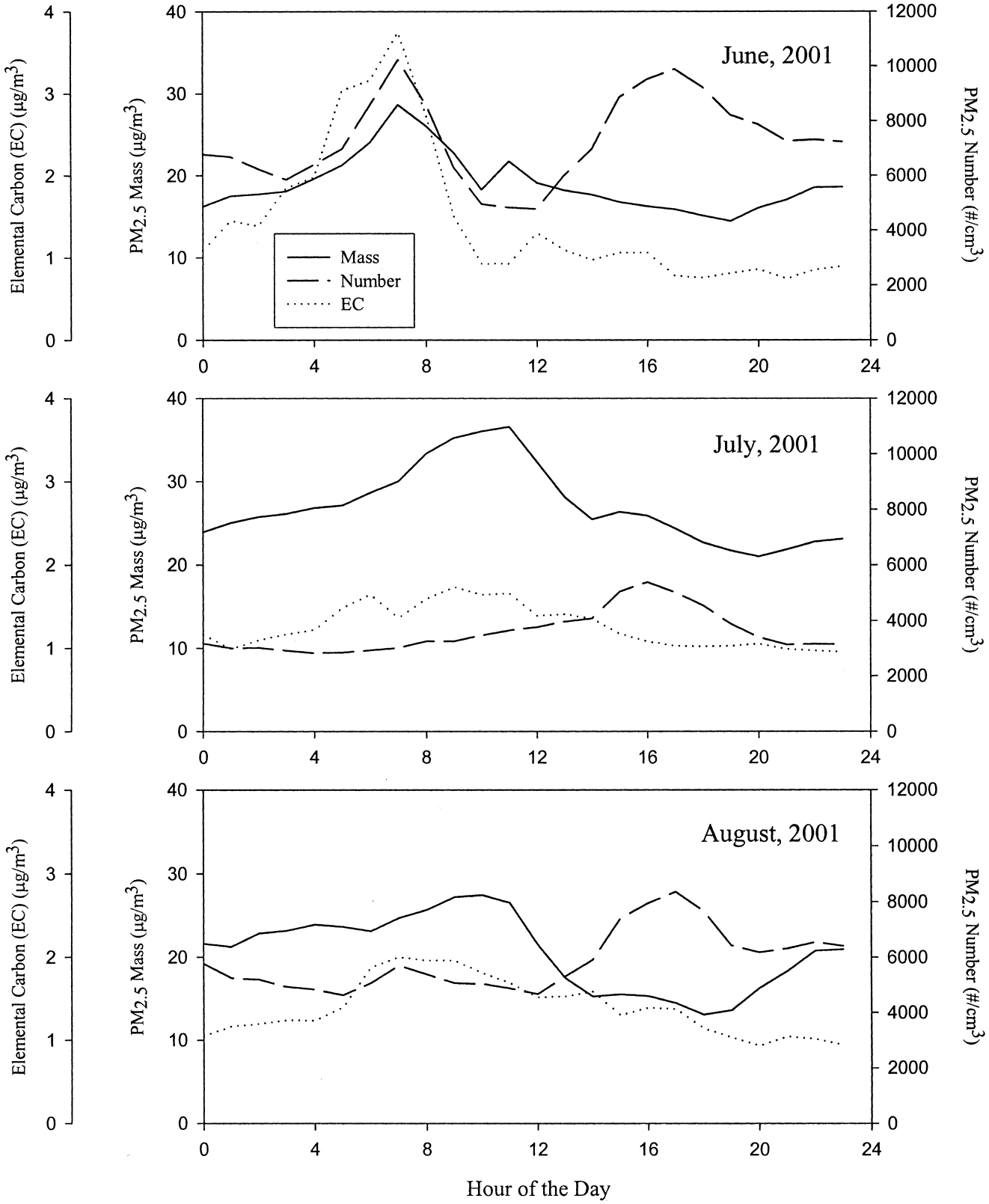

Figure 5. Diurnal profiles of $PM_{2.5}$ particle number, mass, and EC mass concentrations in Rubidoux, CA.

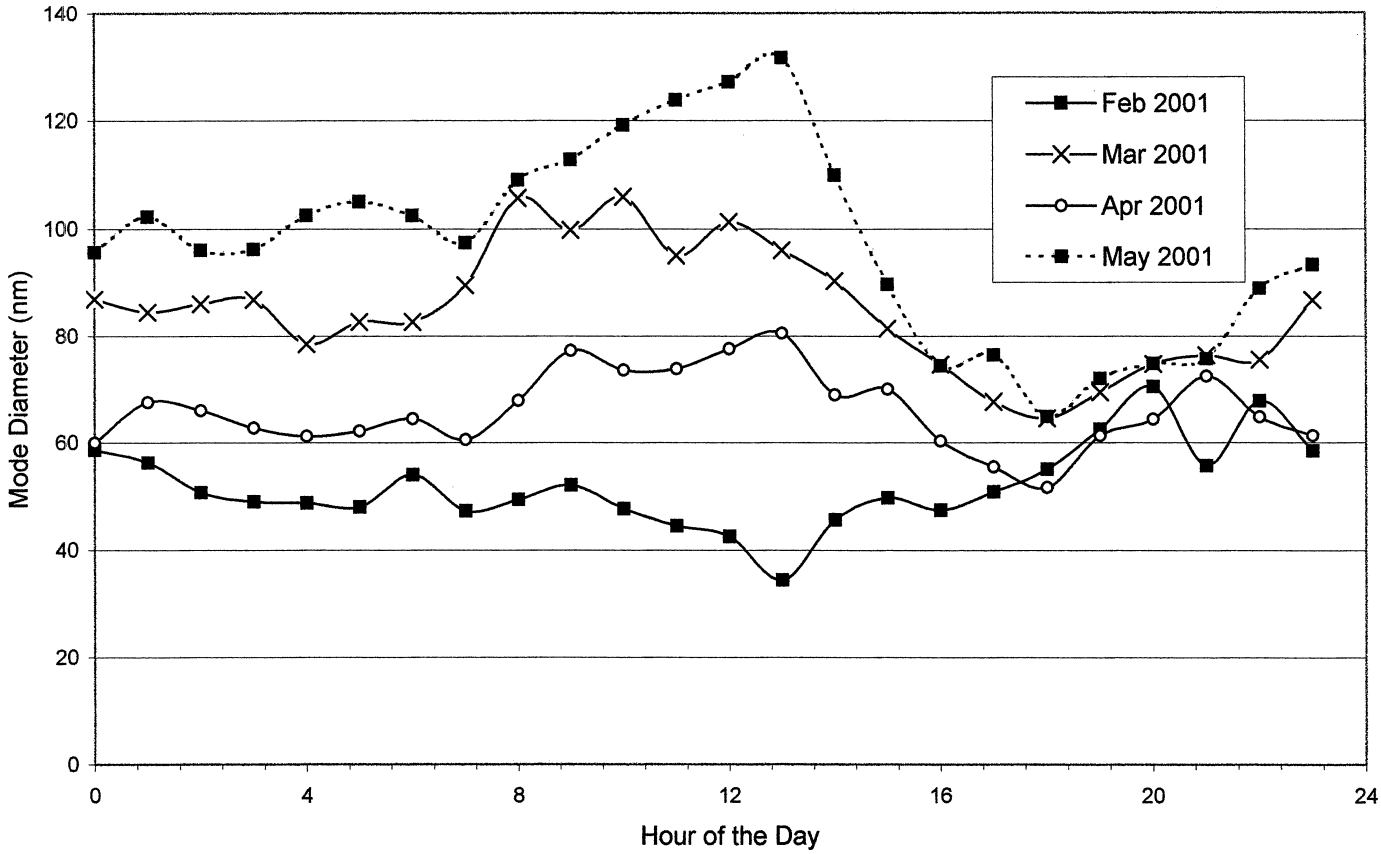

Figure 6. Monthly averaged mode diameters in Riverside, CA.

of a known particle source, such as a freeway or major road. Zhu et al. (2002a, b) showed that the influence of a freeway with respect to particle number is insignificant beyond 100–150 m downwind of a freeway. Wind data show that transport times from the nearest major road or freeway are too long for the number concentrations at the sites to be influenced by very local traffic sources. Wind speeds peak in the afternoon, but usually about 2 h before the number concentrations reach their maxima. Furthermore, EC levels do not track the increase in particle number, thereby indicating that this increase is not associated with a traffic or diesel source. Thus, it is unlikely that the observed pattern is due to vehicular emissions. An additional, nontraffic, local source can be practically ruled out due to the similarities between Riverside and Rubidoux, as well as the consistency (almost every day) and the persistency (5 h) of the increase in particle number concentrations.

Another source of particles could be the advection of polluted air masses from the Los Angeles area. It has already been shown that our three sites could be influenced by the previous day's emissions. However, advected, and thus aged, aerosols are generally larger in diameter (Zhang and Wexler 2002), and thus increases in particle number should be accompanied by larger mode diameters and higher mass concentrations. Figures 4–6 demonstrate that mass concentrations remain low while particle diameter decreases rather than increases. Ruling out the advection of aged aerosol, the final explanation for the observed trend is photochemical formation of new particles.

The observed decrease in the mode diameter of the particle size distribution in the afternoons indicates a freshly formed aerosol (Figure 6). Many observations of nucleation events show the presence of particles below 10 nm in diameter (O'Dowd et al. 1999, 2001; Shi et al. 1999) in remote locations. It should be noted that the minimum diameter measured by our instrumentation was about 15 nm. Woo et al. (2001) describe different nucleation events in urban Atlanta, some with most particles below 10 nm, but others with particle modes at around 20–30 nm. The proposed explanation of photochemical formation is also consistent with the afternoon onset of the particle number increase when increased solar irradiance produces high photochemical activity. Furthermore, with the yet unexplained exception of July, the afternoon increase in number is more pronounced in the warmer months than in the cold month of February. Most nucleation events have been observed in remote locations with very low background particle concentrations (O'Dowd et al. 1999, 2001). The low background levels are thought to provide too low a surface area for supersaturated vapors to condense, and thus nucleation is favored. However, events have been documented in urban areas with higher particle mass and surface area

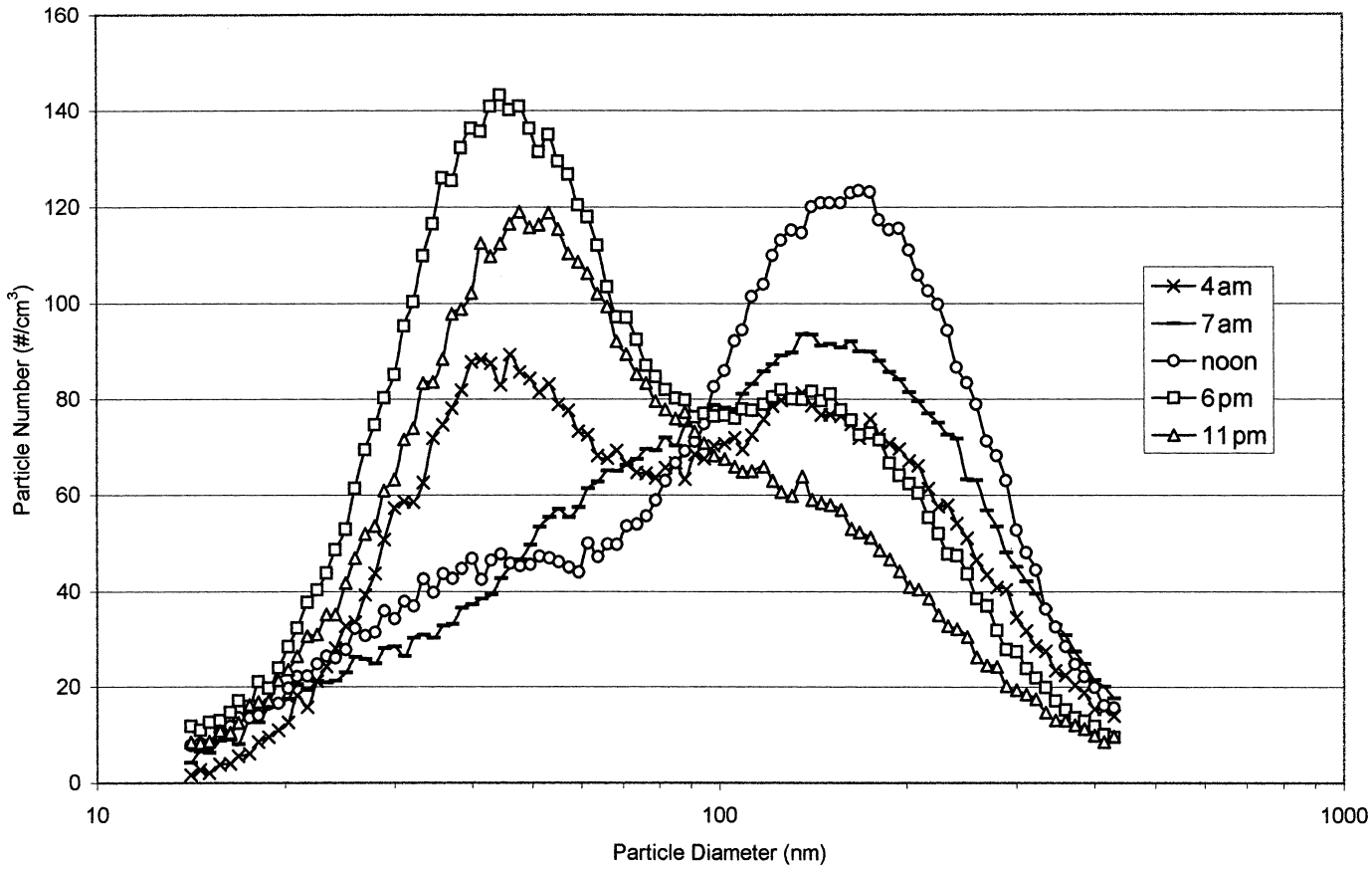

Figure 7. Size distributions in Riverside, CA (16 May 2001).

concentrations (Woo et al. 2001; Harrison et al. 2000). Our data show that the calculated surface area concentrations generally track the mass concentrations and thus decrease in the afternoon when particle numbers increase. This decrease in surface area would also theoretically favor new particle formation.

The mechanisms of homogeneous nucleation remain poorly understood. The most common theoretical mechanisms that have been suggested for homogeneous nucleation in the atmosphere are a binary sulfuric acid/water reaction and a ternary reaction involving sulfuric acid, water, and ammonia (Korhonen et al. 1997, 1999; Kulmala et al. 1998). Although sulfuric acid concentrations in the LAB are relatively low, the previously mentioned strong ammonia source upwind of these sites may play a role in particle formation. There is insufficient data to conclusively prove that particle nucleation is occurring regularly in the LAB, but the data presented here strongly suggest the possibility.

In general, the mode diameter of $PM_{2.5}$ in Riverside increases as the year progresses from colder to warmer seasons. This may be the result of the increased daylight hours forming more secondary organic semivolatile vapors that can condense onto newly formed aerosols. Furthermore, wind speeds and onshore flow also increase in the warmer months, leading to increased advection of polluted air parcels from the western LAB. The month of February has the smallest particles with a mode diameter near 50 nm (Figure 6). In the afternoons of this month, there is an increase in particle number and elemental carbon concentrations (Figure 4), suggesting the influence of vehicle emissions. The month of May has the highest mode diameter throughout the day, reaching a peak around 1 pm (Figure 6).

Figure 7 shows selected hourly particle size distributions over the course of a day in Riverside. May 16, 2001, a day towards the end of the sampling period in Riverside, was chosen as an example of a warmer, photochemically active sampling day. At 4 am, the size distribution shows a bimodal distribution with modes at 45 nm and 140 nm. As the day continues through 7 am and noon, the concentration of the larger mode increases and the smaller mode decreases or disappears. The larger mode is most likely indicative of an aged and grown aerosol reaching the site by advection. By 6 pm, the smaller mode near 40 nm has reappeared, presumably due to photochemical formation of fresh aerosol. The 40 nm mode decreases but persists through midnight, with the decrease possibly attributable to coagulation processes.

Figure 5 shows the diurnal distribution of $PM_{2.5}$ particle number, mass, and EC concentrations in Rubidoux. Rubidoux is geographically similar to Riverside in many aspects. Both sites are

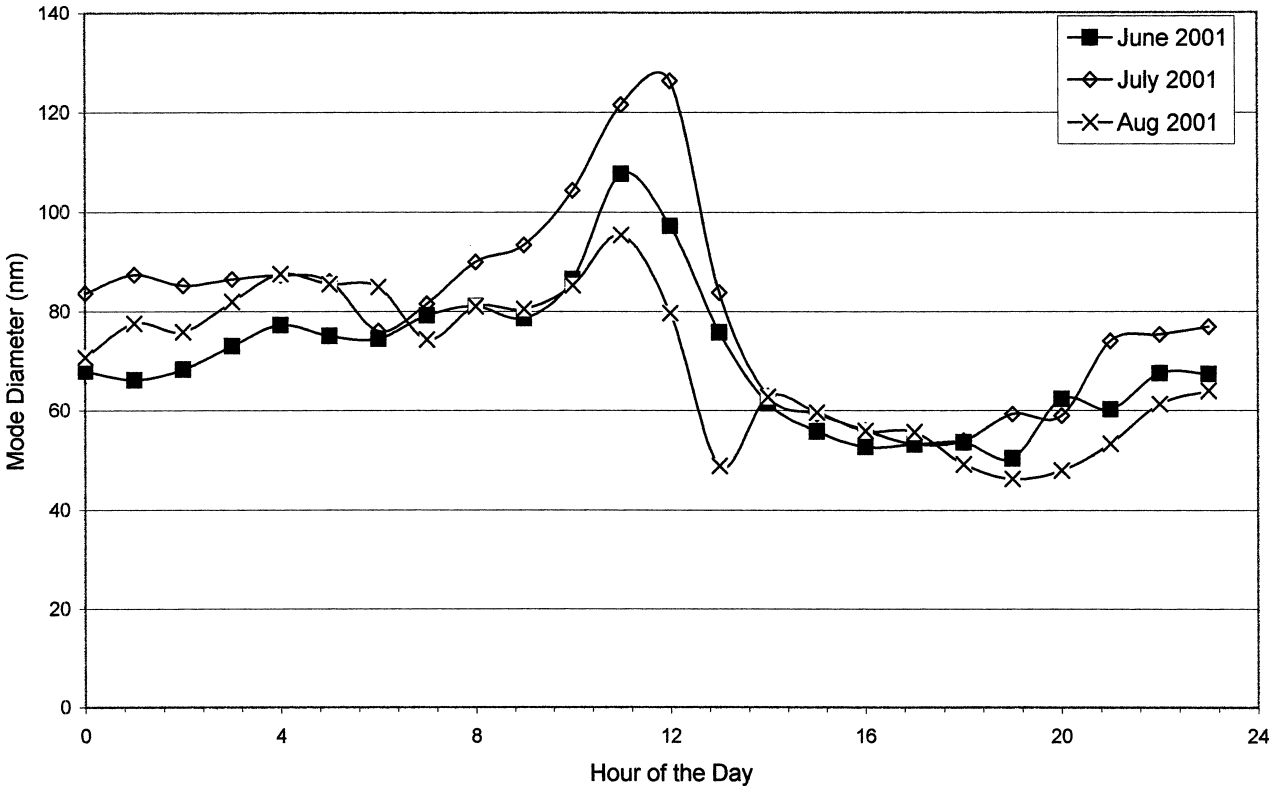

Figure 8. Monthly averaged mode diameters in Rubidoux, CA.

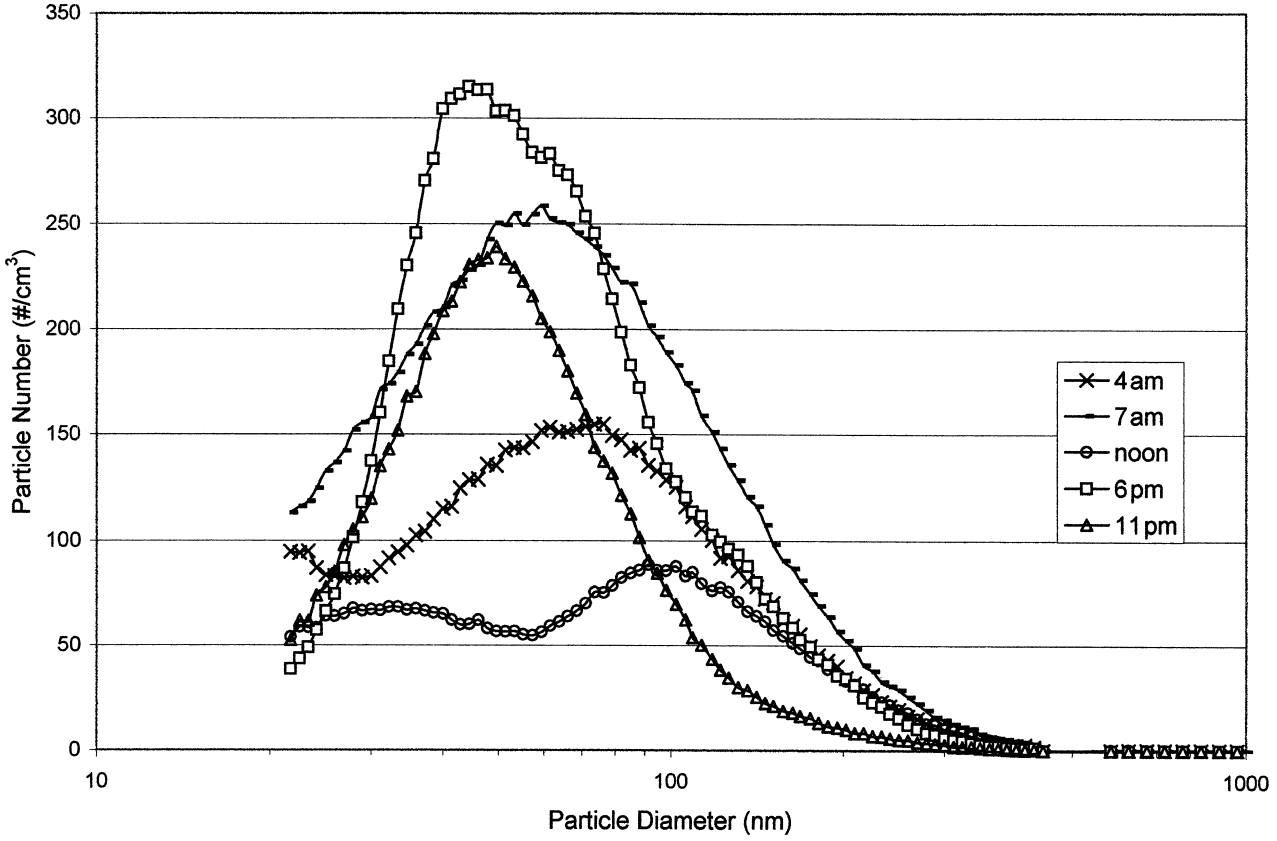

Figure 9. Size distributions in Rubidoux, CA (27 June 2001).

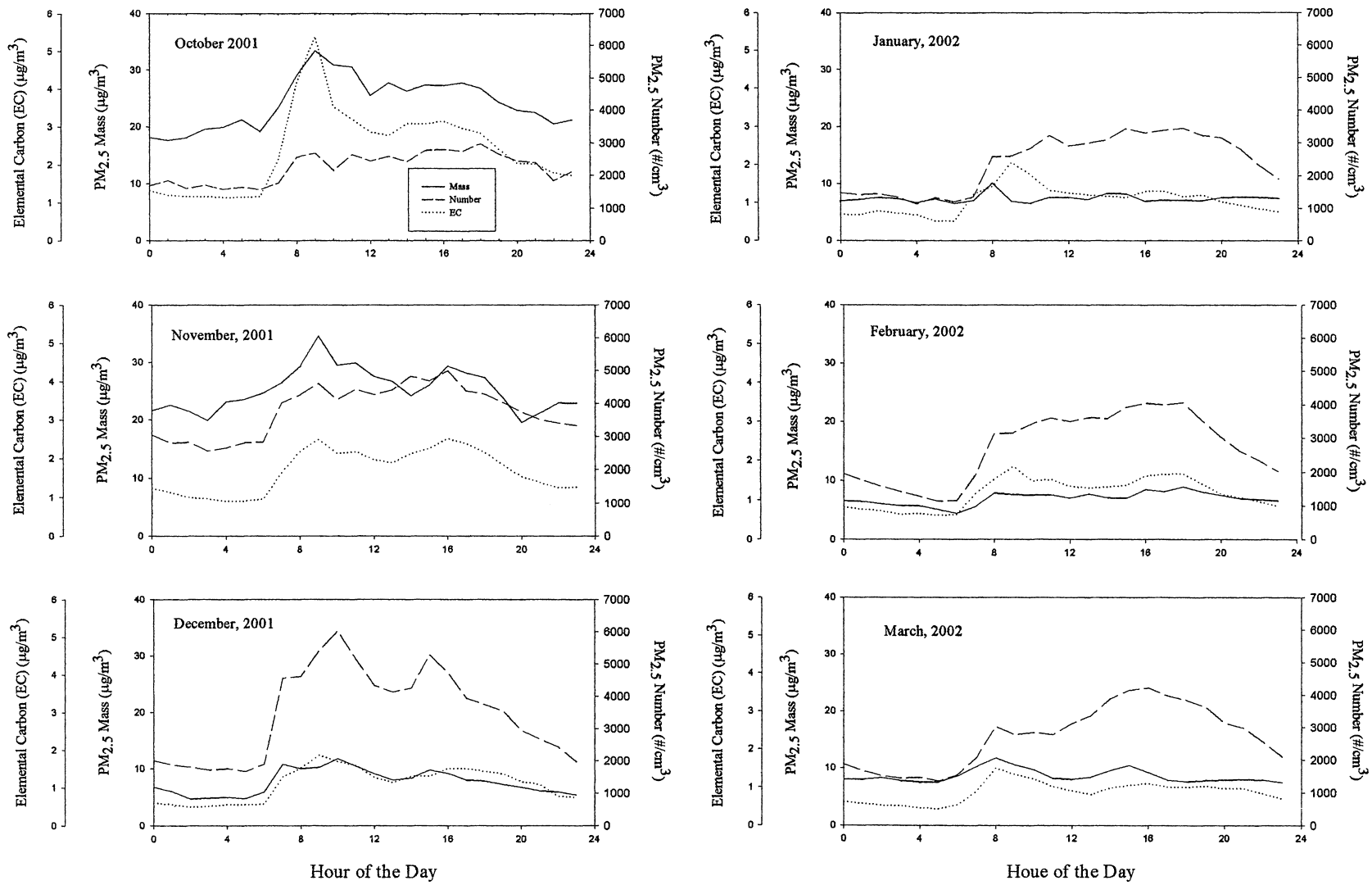

Figure 10. Diurnal profiles of $PM_{2.5}$ particle number, mass concentration, and EC mass concentrations in Claremont, CA.

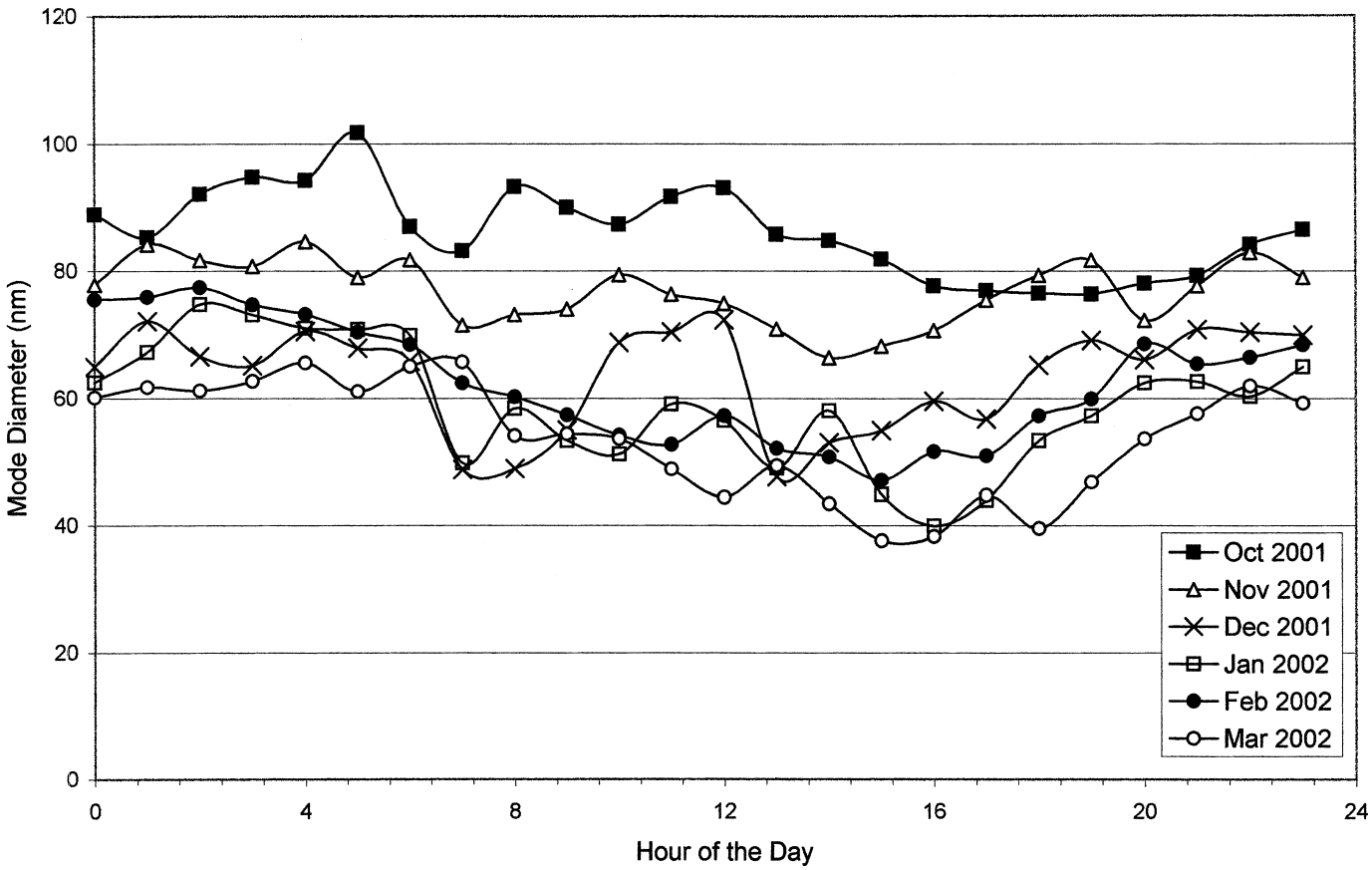

Figure 11. Monthly averaged mode diameters in Claremont, CA.

located along the nitrate/ammonia trajectory in the LAB. Upwind ammonia emissions, advection from downtown Los Angeles, and more local traffic emissions play important roles in the aerosol in Rubidoux. The mornings in Rubidoux are generally marked by vehicular emissions indicated by increases in EC concentration (Figure 5). In the afternoon, however, a pattern similar to that observed in Riverside is seen. High number concentrations corresponding to low mode diameters (Figure 8), low EC levels, and low mass concentrations may be the result of photochemical particle formation. Figure 9 shows a particle size distribution typical of a weekday in Rubidoux. The size distribution at noon exhibits a bimodal distribution with the smaller mode at 35 nm and another mode at around 100 nm. Particle number concentrations increase dramatically by 6 pm, and the distribution shows a mode at 45 nm indicative a newly formed aerosol.

Claremont

Sampling in Claremont, California occurred from October 2001 to March 2002. Figure 10 shows the diurnal profile of particle number, mass, and elemental carbon concentrations in Claremont during the entire sampling period. Similar to Riverside and Rubidoux, a clear influence of morning traffic is indicated by the increases in particle number, mass, and EC. Also similar to Riverside and Rubidoux, the mode diameter is generally higher over the first half of the day compared to the second half of the day, as seen in Figure 11. Figure 11 also shows a sharp decrease in particle mode diameter every month between 6 am and 8 am that generally corresponds to increases in elemental carbon and mass. This may be due to an unidentified local vehicular source close to the sampling site. The particle mode diameter in Claremont tends to decrease as the season progresses from warmer months to colder months. In Riverside, February has the smallest mode diameter relative to March, April, and May. In Claremont, January, February, and March have similar mode diameters and are much smaller than those in October. Thus, the same general pattern was observed at all three sites, with larger particle modes in the warmer months. The dominant particle source in the afternoon in Claremont from October 2001 to December 2001 is traffic, marked by the increase in particle, mass, and elemental carbon concentration, similar to that observed in the morning traffic hours. In January, February, and March 2002, particle numbers in the afternoon are high relative to mass and EC, which remain low. This may be the result of afternoon photochemical particle formation, as was observed in Riverside and Rubidoux. However, Claremont number

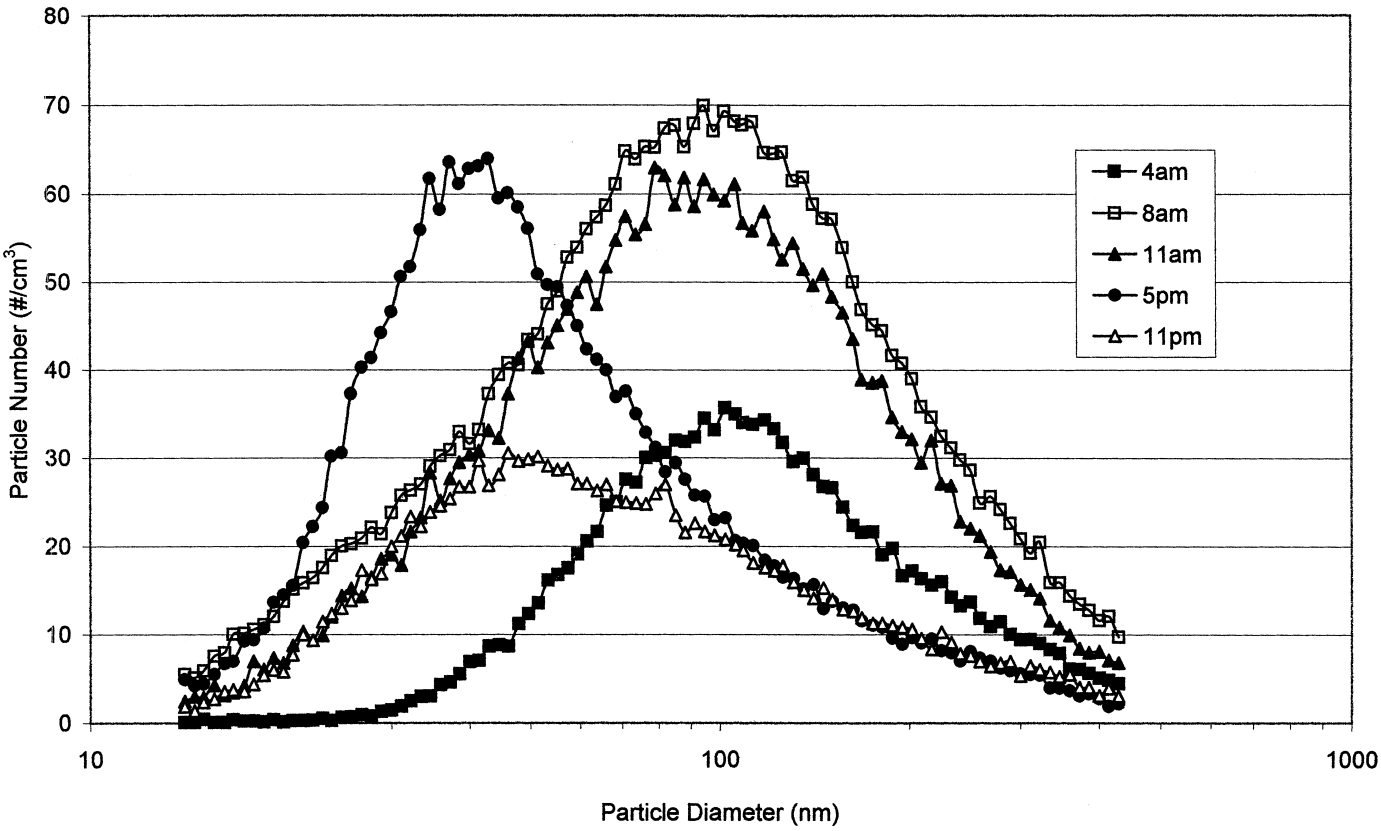

Figure 12. Size distributions in Claremont, CA (18 January 2002).

concentrations do not form a midday minimum like those seen at the other two sites. The increase in particle number concentration starts around 10 am, as opposed to noon in Riverside and Rubidoux, and it is not accompanied by increases in elemental carbon or mass. Figure 12 shows a particle size distribution from Claremont in January. The effect of photochemistry is not as pronounced in January in Claremont as it was in Riverside and Rubidoux, and no distinct smaller particle size mode appears in the afternoon. The observed mode diameters are around 70–90 nm for most of the day. The increase in smaller particles observed in the morning distribution may be due to traffic emissions, or the persistent local vehicle source mentioned above.

Differences in the observations between Riverside, Rubidoux, and Claremont may be due to the different geographical locations. Claremont is not located downwind of the strong ammonia source of the Chino dairy farms. It has been shown that vehicles can be an additional source of ammonia, but not at the strength observed for the Chino dairy farms (Fraser and Cass 1998). As suggested above, differences in ammonia concentrations may be affecting the degree to which particle nucleation occurs. Moreover, Claremont lies to the west of Rubidoux and Riverside, therefore polluted air parcels originating from urban Los Angeles could be arriving there a few hours earlier than in Rubidoux or Riverside.

CONCLUSION

In addition to the rush hour activity peaks of vehicle emissions, which have been typically considered the main source of ultrafine PM in urban areas, our results indicate that the diurnal and seasonal patterns in ultrafine particle concentrations and size distribution in these 3 receptor sites of the LAB are modulated by other equally important factors. These are (1) the afternoon peaking of photochemically generated particles, especially during the warmer months; (2) the trapping of overnight emissions by the nocturnal inversion; and (3) the downwind long-range transport of particles to receptor sites, originating in highly polluted urban or industrial areas of urban Los Angeles. These findings in turn suggest that ultrafine PM in highly polluted areas, such as the inland valleys of the LAB, do not necessarily display the same characteristics with those in other urban areas, i.e., having a number mean or mode diameter in the range of 20–40 nm, having 90–99% of particle counts associated with particles below 0.1 μm, and strictly following the diurnal trend of traffic sources.

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