CHAPTER 5
ULTRAFINE PARTICLES AND BLACK CARBON MEASUREMENTS

Chapter 5. Ultrafine Particles and Black Carbon Measurements

5.1.Ultrafine Particle Measurements at Fixed Sites

5.1.1. Background on UFP Measurements

There is increasing evidence in the public health community that exposure to ultrafine particles (UFPs) may be associated with certain health effects, including neurological, respiratory and cardiovascular health endpoints.[1] While substantial effort has been made to characterize the health risks associated with exposure to PM from vehicles[2], information about the health effects of UFPs is still emerging. These very small particles (< 0.1 µm in diameter) primarily consist of organic material, soot, secondary ions, and trace elements and typically have different chemical composition than larger PM size fractions, PM_{10} (particles with a diameter less than 10 µm) and $PM_{2.5}$ (diameter less than 2.5 µm). [3,4]

[1] U.S. Environmental Protection Agency. (2019). U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, Dec 2019). Washington, DC: U.S. Environmental Protection Agency

[2] Health Effects Institute (2010) "Traffic-Related Air Pollution: A Critical Review of Literature on Emissions, Exposure, and Health Effects", http://pubs.healtheffects.org/getfile.php?u=553.

[3] Daher, N., Hasheminassab, S., Shafer, M. M., Schauer, J. J., Sioutas, C. (2013). Seasonal and Spatial Variability in Chemical Composition and Mass Closure of Ambient Ultrafine Particles in the Megacity of Los Angeles. Environ. Sci. Process. Impacts, 15 (1), 283–295.

4 Shirmohammadi, F., Hasheminassab, S., Saffari, A., Schauer, J. J., Delfino, R. J., Sioutas, C. (2016) "Fine and Ultrafine Particulate Organic Carbon in the Los Angeles Basin: Trends in Sources and Composition", Sci. Total Environ. 541, 1083–1096.

UFPs comprise a majority (~90%) of the number of airborne particles in the atmosphere.[5,6] For this reason, total particle number concentration (PNC; i.e., number of particles per cubic centimeter of sampled air) is typically used as a proxy for UFP concentration. UFPs are emitted from nearly all fuel combustion processes, including diesel, gasoline, and jet engines. UFP nucleation and growth mechanisms are not fully understood, but it is clear that vehicle exhaust is a major contributor to UFPs in urban areas.[7] Consequently, people living nearby highly trafficked roadways and other sources of combustion-related pollutants (e.g., airports, refineries, and railyards) may be exposed to high levels of UFPs in addition to other air toxics.

[5] Stanier, C., Khlystov, A., Pandis, S. (2004a) "Ambient aerosol size distributions and number concentrations measured during the Pittsburgh Air Quality Study (PAQS)", Atmospheric Environment 38, 3275–3284.

[6] Zhang, Q., Stanier, C., Canagaratna, M., Jayne, J., Worsnop, D., Pandis, S., Jimenez, J. (2004) "Insights into the chemistry of new particle formation and growth events in Pittsburgh based on aerosol mass spectrometry", Environmental Science and Technology 38, 4797–4809.

[7] Guo, S., Hu, M., Peng, J., Wu, Z., Zamora, M. L., Shang, D., Du, Z., Zheng, J., Fang, X., Tang, R., Wu, Y., Zeng, L., Shuai, S., Zhang, W., Wang, Y., Ji, Y., Li, Y., Zhang, A., Wang, W., Zhang, F., Zhao, J., Gong, X., Wang, C., Molina, M., Zhang, R. (2020) "Remarkable nucleation and growth of ultrafine particles from vehicular exhaust", Proceedings of the National Academy of Sciences, 117(7), 3427–3432.

Federal, state, and local regulatory efforts have been focused on reducing the mass concentration of PM in the ambient air with current PM regulations focused on PM_{10} and $PM_{2.5}$. Compared to the body of literature for PM10 and PM2.5 health effects, there are few long-term human health studies examining exposures to UFPs,[8] as this species is not typically measured in monitoring networks throughout the U.S. Generally, there is little or no correlation between ambient particle numbers and mass;[9,10,11] therefore, measurements of ambient particle number concentrations serve to complement PM mass measurements. UFPs have a relatively short lifespan and their concentrations are strongly dependent on local sources and atmospheric conditions. Thus, their number concentrations can vary significantly on short temporal and spatial scales.[12,13,14,15] The MATES V UFP measurement efforts serve to characterize UFP concentrations in community areas that are generally not close to sources. Therefore, these measurements represent general background concentrations of UFPs, but do not reflect UFP exposures for residents who live close to major UFP sources.

[8] Ohlwein, S., Kappeler, R., Kutlar Joss, M., Künzli, N., & Hoffmann, B. (2019) "Health effects of ultrafine particles: a systematic literature review update of epidemiological evidence", International Journal of Public Health, 64(4), 547–559.

[9] de Jesus, A. L., Rahman, M. M., Mazaheri, M., Thompson, H., Knibbs, L. D., Jeong, C., Evans, G., Nei, W., Ding, A., Qiao, L., Li, L., Portin, H., Niemi, J.V., Timonen, H., Luoma, K., Petäjä, T., Kulmala, M., Kowalski, M., Peters, A., Cyrys, J., Ferrero, L., Manigrasso, M., Avino, P., Buonano, G., Reche, C., Querol, X., Beddows, D., Harrison, R.M., Sowlat, M.H., Sioutas, C., Morawska, L. (2019) "Ultrafine Particles and PM2.5 in the Air of Cities around the World: Are They Representative of Each Other?", Environ. Int. 129, 118–135.

[10] Saha, P. K., Sengupta, S., Adams, P., Robinson, A. L., Presto, A. A. (2020) "Spatial Correlation of Ultrafine Particle Number and Fine Particle Mass at Urban Scales: Implications for Health Assessment", Environmental Science and Technology, 54 (15), 9295–9304.

[11] Sardar, S.B., Fine, P.M., Yoon, H., et al. (2004) "Associations between particle number and gaseous co-pollutant concentrations in the Los Angeles Basin", Air and Waste Management, 54: 992-1005.

[12] Kozawa, K. H., Fruin, S. A., & Winer, A. M. (2009) "Near-road air pollution impacts of goods movement in communities adjacent to the Ports of Los Angeles and Long Beach", Atmospheric Environment, 43(18), 2960–2970.

[13] Shirmohammadi, F., Sowlat, M. H., Hasheminassab, S., Saffari, A., Ban-Weiss, G., & Sioutas, C. (2017) "Emission rates of particle number, mass and black carbon by the Los Angeles International Airport (LAX) and its impact on air quality in Los Angeles", Atmospheric Environment, 151, 82–93.

[14] Zhu, Y., Hinds, H.C., Kim, S., et al. (2002a) "study of ultrafine particles near a major highway with heavy-duty diesel traffic", Atmospheric Environment, 36 (27): 4323-4335.

[15] Zhu, Y., Hinds, H.C., Kim, S., et al (2002b) "Concentration and size distribution of ultrafine particles near a major highway", Journal of Air and Waste Management Association, 52: 1032-1042.

5.1.2. UFP measurements during MATES V

The purpose of the MATES program is to conduct a series of studies to assess cancer risk from exposure to toxic air contaminants in the South Coast Air Basin (SCAB). These studies are the result of air toxics monitoring, development of toxic emissions inventories, regional modeling, and health risk evaluations. Continuous UFP concentration measurements began in MATES IV (July 2012 – June 2013), even though they are not technically specified as air toxics. The sampling period for all fixed stations was one year, beginning on May 1, 2018 and ending April 30, 2019. MATES V monitoring stations include Anaheim, Burbank Area, Central Los Angeles (Central LA), Compton, Huntington Park, Inland Valley San Bernardino (Inland Valley SB), Long Beach, Pico Rivera, and Rubidoux, and West Long Beach. Additional details about the monitoring sites, their characteristics, and sampling protocols are provided in Chapter 2.

MATES V UFP data was collected using Teledyne Advanced Pollution Instrumentation (TAPI) Ultrafine Particle Monitors, Model 651. This monitor is a laminar flow condensation particle counter (CPC) that uses water to grow UFPs to a larger, detectable size. UFPs are grown through condensation in a controlled super-saturation environment to larger sizes and then counted using a photodetector. These CPCs can provide the total number concentration of particles between 7 nm and 0.5 µm and were operated with a cyclone restricting the upper size limit to approximately 600 nm. The CPCs were operated continuously with 1-minute time resolution. Given that the vast majority (~90%) of particles fall within the UFP size range, the PNC provided by the CPC is used herein as a proxy for UFP concentration. Additional technical details on this CPC model and the results of a test evaluation conducted by South Coast AQMD and UCLA prior to the beginning of MATES IV are reported in Lee et al.[16] For further information and maintenance instructions, please refer to the TAPI Ultrafine Particle Monitor Model 651 Operation Manual and the standard operating procedure document for this instrument (South Coast AQMD SOP00143).

[16] Lee, E.S., Polidori, A., Koch, M., et al. (2013) "Water-based condensation particle counters comparison near a major freeway with significant heavy-duty diesel traffic", Atmospheric Environment, 68: 151-161.

5.1.3. Results and Discussion of UFP Measurements

Initial results are focused on overall MATES averages with diurnal, day of week, and seasonal variations in the following section. The MATES V UFP means and confidence intervals (error bars) for each site and the SCAB (10 site average) are shown in Figure 5-1. Ultrafine particle concentration mean and 95% confidence interval for each site and the South Coast Air Basin (10 site average). The annual average UFP concentrations for each site range from 12,182 particles/cm^3 to 22,658 particles/cm^3, with an overall SCAB concentration of 15,971 particles/cm^3. The UFP concentrations vary significantly from site to site, with the highest annual averages measured at West Long Beach and Huntington Park. These sites show mean UFP concentrations considerably greater than what was observed over the entire SCAB and are the only sites that show mean concentrations greater than 20,000 particles/cm^3. Rubidoux, an inland receptor site, shows the lowest annual UFP concentration average. Inland Valley San Bernardino, the other inland receptor site, shows relatively high UFP concentration compared to the Rubidoux location. UFP concentrations observed at the MATES designated sites are significantly lower than those observed at all South Coast AQMD near-road monitoring stations where annual average UFP concentrations exceed 29,000 particles/cm^3 (see Appendix VII). The levels observed in the South Coast Air Basin are generally higher than what is seen on a national average, but comparable with other metropolitan areas such as Boston and Pittsburgh.[17]

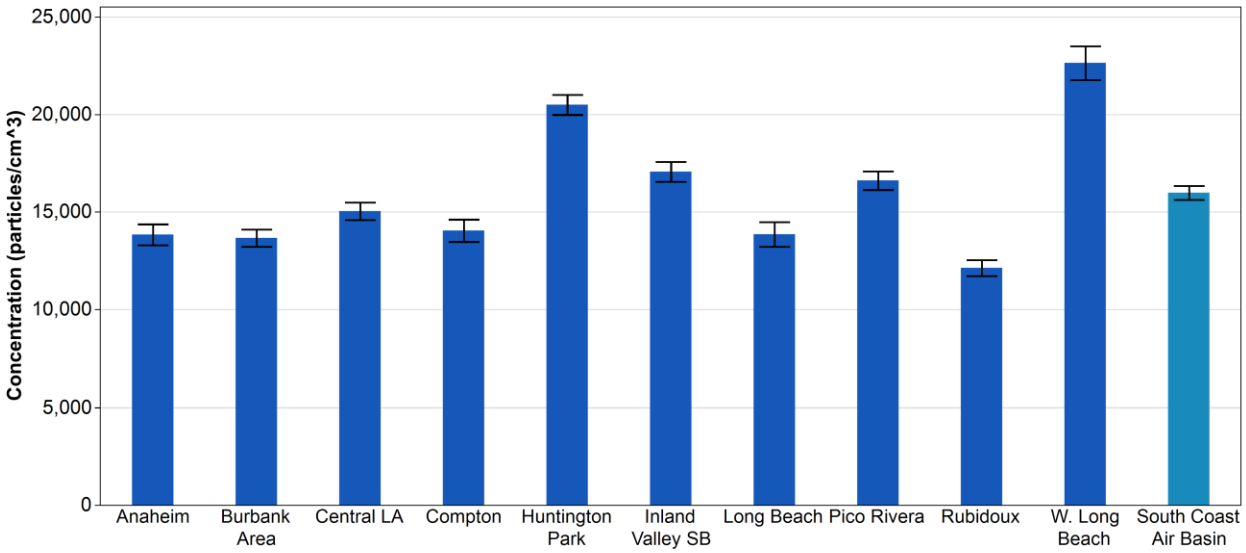

Figure 5-1. Ultrafine particle concentration mean and 95% confidence interval for each site and the South Coast Air Basin (10 site average)

[17] Presto, A.A., Saha, P.K., Robinson, A.L. (2021). Past, Present, and Future of Ultrafine Particle Exposures in North America. Atmospheric Environment: X, https://doi:org/10.1016/j.aeaoa.2021.100109.

The box and whisker plots in Figure 5-2. Box plots showing the daily average minimum, first quartile, median, third quartile, and maximum values at each site and SCAB (10 site average) for both MATES IV and V summarize the minimum, first quartile, median, mean, third quartile, and maximum daily average UFP concentrations at each site in MATES IV and V. The plot indicates that the Anaheim, Burbank Area, Central L.A., Inland Valley San Bernardino, and Rubidoux sites were characterized by a relatively low UFP variability during MATES V. West Long Beach station shows a much higher maximum concentration compared to the other sites during MATES V. The maximum daily concentration observed at Huntington Park is greatly reduced in MATES V compared to MATES IV, although the decrease in the average concentration is much more modest. Comparing the average UFP concentrations between measurement periods shows that there is no consistent trend in the average concentration observed at each site between MATES IV (July 2012 – June 2013) and MATES V (May 2018 – April 2019). The average concentration at each site is similar between the two measurement periods; however, the direction of change differs between sites. Three sites show small increases in average UFP concentration (Anaheim, Inland Valley SB, Rubidoux), while the other seven sites show a modest decrease (Burbank Area, Central LA, Compton, Huntington Park, Long Beach, Pico Rivera, W. Long Beach). This observation, coupled with a decrease in primary particle emissions from diesel sources (e.g., black carbon; see Appendix VI), suggests that primary particles from non-traffic related sources and/or secondary particle formation may be of higher relative importance to the concentration of UFPs measured in MATES V than to those measured in MATES IV.

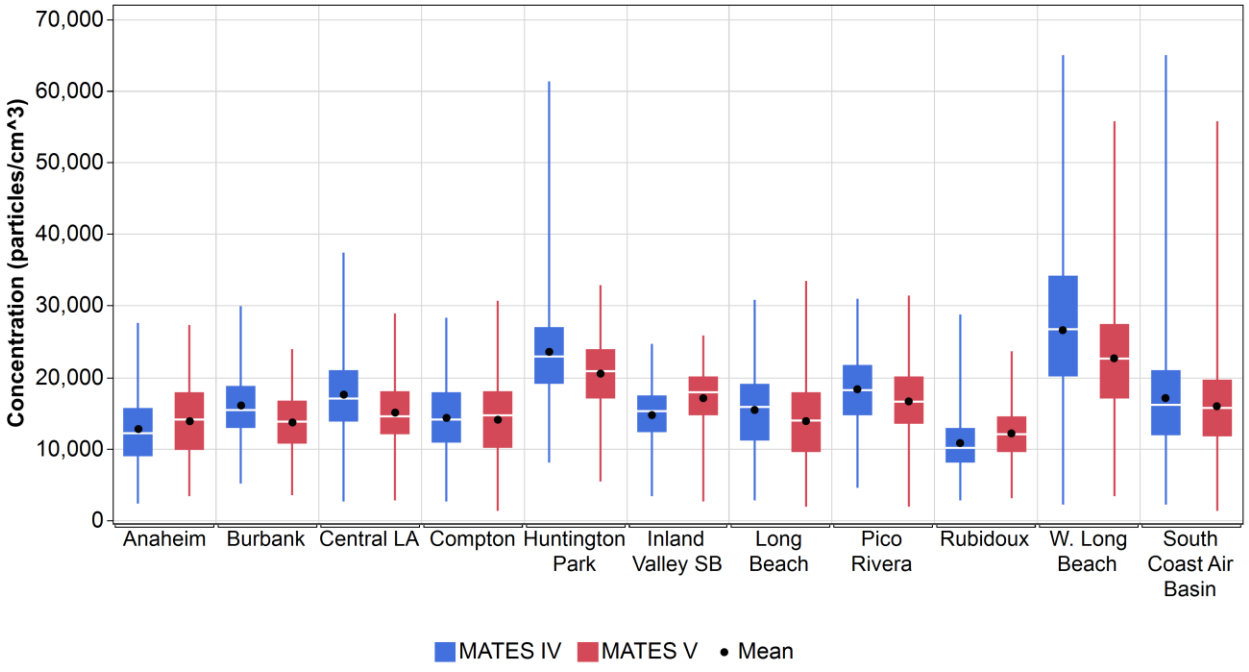

Figure 5-2. Box plots showing the daily average minimum, first quartile, median, third quartile, and maximum values at each site and SCAB (10 site average) for both MATES IV and V

5.1.4. Diurnal, day of week, and seasonal variations in UFP measurements

The effect of traffic emission sources and meteorological factors is reflected in the diurnal profiles by day of week (Figure 5-3). UFP concentrations in urban environments have been shown to closely follow the temporal variation in traffic density, with highest levels observed on weekdays during rush hours. UFP can also be formed by photochemical reactions in the atmosphere, particularly in photochemically-active sunnier seasons. This is often reflected in a mid-day peak associated with secondary particles. Moreover, the boundary layer in early mornings is much shallower than afternoon hours, which causes a lowering of the "mixing height," less atmospheric transport and dilution, and thus a consequent increase in near ground concentrations. As a result, during the early morning, there is a pronounced UFP enhancement during weekdays, likely due to emissions associated with rush hour traffic combined with a lower atmospheric boundary layer height in early mornings. As the day progresses and the atmosphere is heated, the mixing height rises, leading to a dilution and subsequent decrease of traffic emissions. Around noon, a second peak emerges mainly due to the formation of secondary UFPs driven by photochemical reactions. The UFP concentration decreases towards the late afternoon and a third, less pronounced peak due to the trapping of overnight emissions by the nocturnal inversion layer emerges in the early evening. The lowest UFP averages are typically observed on Sundays, which is consistent with previous studies.[18,19,20] Conversely, the highest average UFP level is observed on Fridays (see Appendix VII). While daily concentrations tend to be slightly lower on the weekends, especially on Sundays, the maximum hourly concentrations for each day (around noon) are not lower on the weekends despite lower traffic volumes. This suggests that secondary UFP production (i.e., photochemical reactions) and/or additional UFP sources other than traffic are important contributors to particle number concentrations.

[18] Sabaliauskas, K., Jeong C., Yao, X., et al. (2013) "Cluster analysis of roadside ultrafine particle size distributions", Atmospheric Environment, 70: 64-74.

[19] Sioutas, C. (2011) "Fine-Scale Spatial and Temporal Variability of Particle Number Concentrations within Communities and in the Vicinity of Freeway Sound Walls", University of Southern California

[20] Tiwary, A., Namdeo, A, Pareira, A. (2012) "Spatial Variation on Personal Exposure of Parking Attendants to Traffic Emissions in an Urban Conurbation", The Open Atmospheric Science Journal, 6: 78-83.

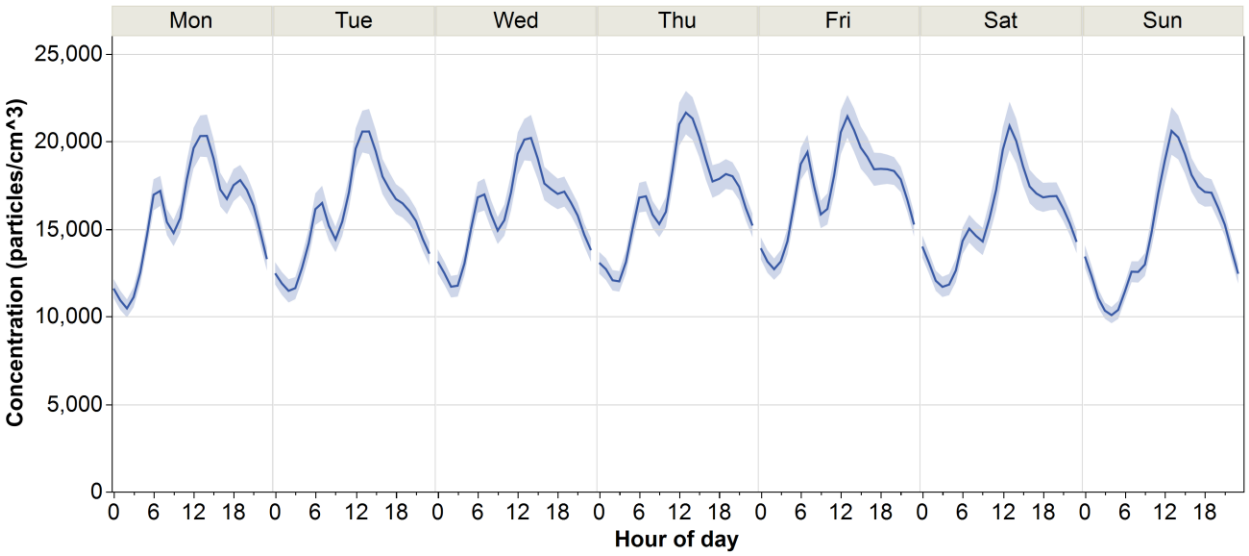

Figure 5-3. Diurnal profiles ultrafine particle concentration by day of week in the South Coast Air Basin. Error bands represent 95% confidence intervals. The hour of day times are shown for Pacific Standard Time (PST) and not adjusted for daylight savings time

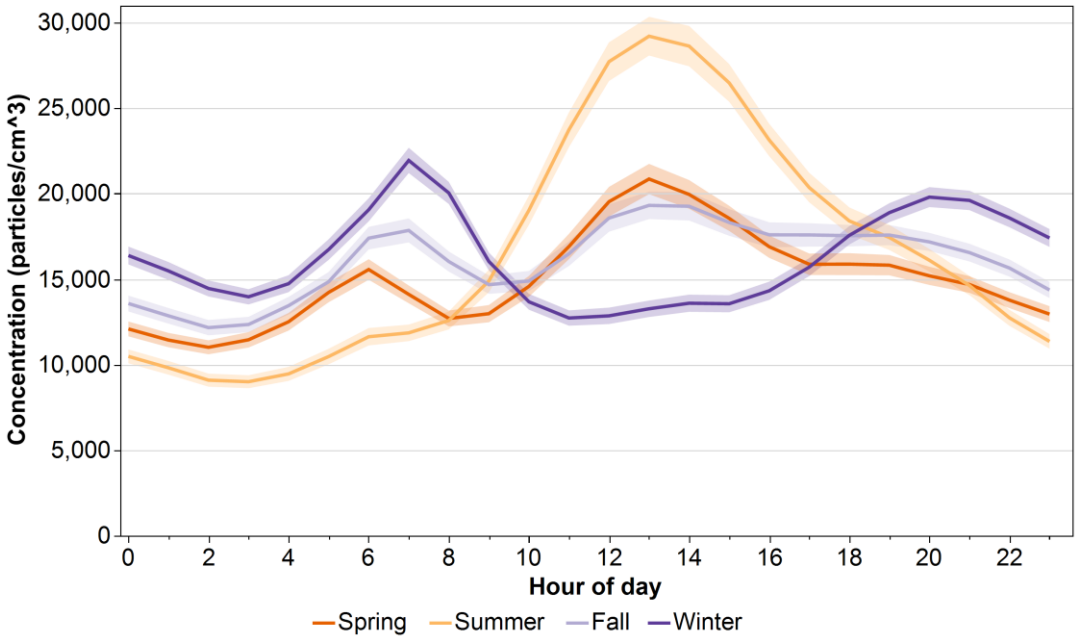

Figure 5-4. Seasonal diurnal profiles of ultrafine particle number concentration in the South Coast Air Basin (10 site average). Error bands represent 95% confidence intervals

While the overall SCAB diurnal profiles provide some information about the factors that influence the UFP concentrations in the region, these profiles are highly dependent on the season. Diurnal UFP profiles are averaged by season to characterize these variations (Figure 5-4. Seasonal diurnal profiles of ultrafine particle number concentration in the South Coast Air Basin (10 site average). Error bands represent 95% confidence intervals). Seasons are divided into winter (December-February), spring (March-May), summer (June-August), and fall (September-November). The winter profile is characterized by two peaks and is distinctly different from the diurnal profile observed in the summer. Traffic emissions generated during the morning commute in the winter produce a peak during rush-hour (6:00 to 9:00) that extends until late morning. As the temperature increases in the afternoon, the mixing height rises and the UFP concentrations drop, reaching a minimum around noon or early afternoon. When evening approaches, the nocturnal inversion layer causes an elevation in particle number count, producing a peak that persists throughout the late evening hours. Previous studies by Singh et al. (2006)[21] and Wang et al. (2012)[22] have found similar wintertime diurnal trends. In addition to the nocturnal inversion layer, the evening rush-hour traffic likely also contributes to the winter season evening peak, since the inversion layer is already reforming during the evening traffic hours. In contrast, the summer months do not show these traffic-related peaks and instead show a large midday peak (10:00 to 17:00) related to secondary formation of UFP through photochemical reactions. In these months, the inversion layer reforms or lowers later in the evening and the mixing layer is shallow, so the traffic peak is finished before the mixing is significantly restricted. Spring and fall diurnal patterns show intermediate profiles between those observed in winter and summer with both morning/evening peaks and a midday photochemical peak. Comparable spring and fall diurnal profiles are also observed in previous studies conducted in the SCAB.[23] Although there is consistency between the diurnal profiles observed here and in previous studies, seasonal diurnal profiles vary significantly by site (see Appendix VII).

[21] Singh, M., Phuleria, H.C., Bowers, K., et al. (2006) "Seasonal and spatial trends in particle number concentrations and size distributions at the children's health study sites in Southern CA", Journal of Exposure Science and Environmental Epidemiology, 16: 3-18

[22] Wang, Y., Hopke, P.K., Utell, M.J. (2012) "Urban-Scale Seasonal and Spatial Variability of Ultrafine Particle Number Concentrations", Water Air and Soil Pollution, 223: 2223-2235.

[23] Sioutas, C. (2011) "Fine-Scale Spatial and Temporal Variability of Particle Number Concentrations within Communities and in the Vicinity of Freeway Sound Walls", University of Southern California

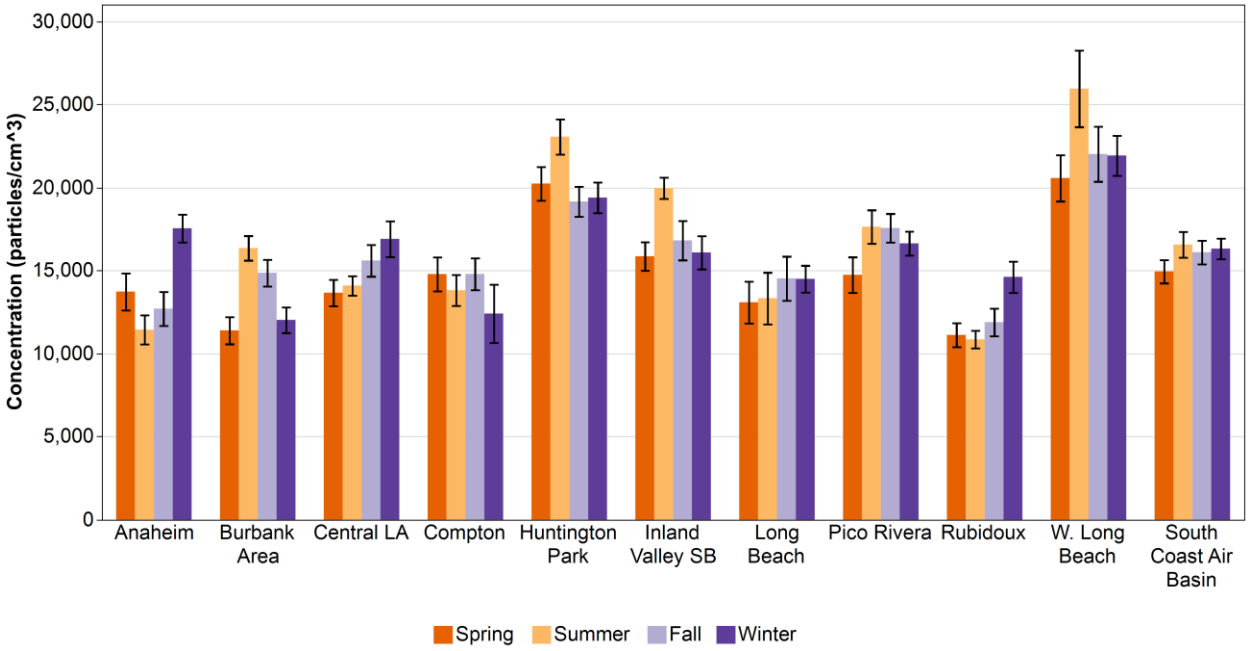

Figure 5-5. Average seasonal particle number concentration for each site and in the South Coast Air Basin (10 site average). Error bars represent 95% confidence intervals

The previous section discussed the overall trends of UFP concentrations observed in the South Coast Air Basin (i.e., all ten MATES V sites averaged together). However, since UFP concentrations are highly spatially variable, it is important to consider the differences between sites as well (Figure 5-5. Average seasonal particle number concentration for each site and in the South Coast Air Basin (10 site average). Error bars represent 95% confidence intervals). The highest average UFP levels observed for all seasons are in West Long Beach. In most instances, the highest average particle number concentrations at all sites are observed during the winter or summer months. In the wintertime, emissions from primary sources dominate the UFP concentrations due to stagnant atmospheric conditions. In addition, the coastal region experiences surface-based temperature inversions and weak onshore wind flow during this time of the year, leading to increased UFP levels near coastal regions. During the summertime, increased UFP concentrations inland are influenced by local emission sources, long-range advection of upwind sources due to a strong onshore flow and enhanced photochemical activity. UFP concentrations have decreased in winter for many sites going from MATES IV to MATES V, although summer concentrations have remained relatively constant (see Appendix VII). Overall, variations in UFP concentrations based on season and time of day depend on site location, meteorology, and the proximity/location of UFP sources and their precursors. See Appendix VII for a more detailed examination of wind direction and potential sources on UFP concentrations by site.

5.1.5. Summary of UFP measurement results

Continuous real-time UFP measurements collected at ten South Coast AQMD monitoring sites during MATES V show high temporal and spatial variability. A variety of factors, such as the distance to the nearest emission source, type of emission source, traffic volume, wind speed, wind direction, relative humidity, and temperature (among other factors), can all influence the concentration, composition, and dispersion of UFPs. Atmospheric parameters can fluctuate rapidly throughout the day, therefore high time frequency data (hourly or faster) need to be used to examine diurnal UFP profiles. Despite the high spatial and temporal differences measured across the SCAB, the average diurnal UFP concentrations at most MATES V sites follow similar trends, with distinct peaks during the early morning commute, midday, and evening commute times. However, there are clear differences in the observed diurnal and seasonal profiles, with the absolute UFP concentrations dependent on the location of the specific monitoring site where measurements are taken.

Several traffic and meteorological factors contribute to the diurnal variability in the concentration of UFPs; these include:

- High traffic volume during the morning and evening rush hours lead to increased particle number concentration in most seasons.
- Mixing layer height, which can lead to increased particle number concentration when the layer is shallow in the evening and morning and decreased concentrations when the mixing layer height is higher during mid-day.
- High photochemical activity around noon, which favors secondary particle formation.

Meteorological factors modulate these diurnal profiles and contribute to the seasonal variability in the concentration of atmospheric PM and UFPs; these include:

- Lower mixing layer height and greater atmospheric stability in winter, which tend to increase particle levels by limiting vertical atmospheric mixing.
- Lower winter temperature, which leads to increased nucleation of volatile combustion products, particularly during morning rush hours.
- High photochemical activity in the summer, which favors secondary particle formation.

Due to these factors, the highest seasonal UFP concentrations are usually observed in the winter or summer months. As shown here and reported in previous studies, the ambient UFP concentration in urban environments is related to the temporal variation in traffic density, with high levels observed on weekdays during rush hours.[24,25,26] However, high photochemical activity during midday hours can also lead to very high UFP during the summer, oftentimes exceeding maximum hourly wintertime levels. Very high summertime UFP concentrations are likely indicative of nearby sources of precursor gases (e.g. volatile organic compounds and SO_2) which may react and nucleate secondary particles when photochemistry is active.

In addition to the variability observed between sites, there is no consistent trend in observed UFP concentrations across sites between the MATES IV (July 2012 – June 2013) and MATES V (May 2018 – April 2019) measurement periods. Despite decreases in diesel exhaust emissions, some of the MATES sites showed increases in average UFP concentrations during this time period. This suggests that any potential controls on particle number concentration may need to target UFP precursor gases in order to be effective in decreasing overall UFP levels. Measurements of UFPs at near-road sites are relatively new; these measurements are ongoing, but do show a decreasing trend in UFP concentrations, pointing to decreased levels from on-road traffic sources, such as trucks. Continued measurements are needed to make robust conclusions on the long-term trends and spatial patterns of UFPs.[27] Although our understanding of UFPs is increasing, additional information about UFP sources, precursors, and exposures would help improve the understanding of this type of pollution in the South Coast Air Basin.

[24] Hussein, T., Puustinen, A., Aalto, P., Makela, J., Hameri, K., Kulmala, M. (2004) "Urban aerosol number size distributions", Atmospheric Chemistry and Physics Discussions 4, 391–411.

[25] Morawska, L., Ristovski, Z., Jayaratne, E.R., et al (2008) "Ambient nano and ultrafine particles from motor vehicle emissions: characteristics, ambient processing and implications on human exposure", Atmospheric Environment, 42: 8113-8138.

[26] South Coast Air Quality Management District, 2015. "Multiple Air Toxics Exposure Study in the South Coast Air Basin (MATES IV)."

[27] Presto, A.A., Saha, P.K., Robinson, A.L. (2021). Past, Present, and Future of Ultrafine Particle Exposures in North America. Atmospheric Environment: X, https://doi:org/10.1016/j.aeaoa.2021.100109.

5.2. Black Carbon Measurements at Fixed Sites

5.2.1. Background on Black Carbon Measurements

A common goal of the MATES studies is to identify and quantify health risks associated with major known toxic air contaminants within the South Coast Air Basin (SCAB). Previous MATES studies assessed the carcinogenic risk due to exposure to air toxics and found that emissions from diesel powered engines accounted for 86% and 80% of inhalation air toxics cancer risk during MATES III and MATES IV, respectively.[28,29]

During diesel fuel combustion, multiple gaseous pollutants and particulate matter are formed due to the incomplete nature of the combustion process. Diesel particulate matter (diesel PM) is the major fraction of these emissions that are comprised of soot, organic compounds (OC), and trace amounts of inorganic compounds.[30,31,32] Soot particles are agglomerates of nanometric spherical particles, that are formed in the combustion engine under high heat-and-pressure and consists of mostly elemental carbon (EC) or black carbon (BC)[33], depending on the measurement method used (see Chapter 2 for details). The structure and properties of soot particles are like those of impure graphite. The organic fraction of diesel emissions consists of a large variety of organic compounds including volatile, and less volatile to non-volatile compounds, e.g. long-chain hydrocarbons originating from lubricating oils and polyaromatic hydrocarbons (PAHs). Due to the high temperature of the combustion process, the vapors of the organic compounds and soot particles cool down upon their emission to the atmosphere. When the mixture cools down, soot particles can absorb the OC vapors, i.e. a coating of OC is formed on the soot particles. Thus, significant quantities of potentially toxic organic compounds can accumulate on the carbonaceous particles. While soot may not be a major direct toxic component of fine particles ($PM_{2.5}$), it operates as a universal carrier of a wide variety of chemicals that cause adverse health effects.

[28] South Coast Air Quality Management District, 2008. "Multiple Air Toxics Exposure Study in the South Coast Air Basin (MATES III)."

[29] South Coast Air Quality Management District, 2015. "Multiple Air Toxics Exposure Study in the South Coast Air Basin (MATES IV)."

[30] Abu-Allaban, M., Rogers, C.F., Gertler, A.W., 2004. A quantitative description of vehicle exhaust particle size distributions in a highway tunnel. J. Air Waste Manage. Assoc. 54, 360–366.

[31] Lloyd, A.C., Cackette, T.A., 2001. Diesel engines: environmental impact and control. J. Air Waste Manage. Assoc. 51, 809–847.

[32] Wang, X., Wang, Y., Bai, Y., Wang, P., Zhao, Y., 2019. An overview of physical and chemical features of diesel exhaust particles. J. Energy Inst. 92, 1864–1888.

[33] BC and EC both refer to impure carbon particles resulting from combustion processes. While these terms are often used interchangeably, they are two methodologically-defined species that are measured using optical and thermaloptical methods, respectively.

The presence of high fractions of soot within diesel exhaust is a unique property of this combustion source; therefore, in urban areas, soot is often considered a good proxy for diesel PM.[34] While the major source of soot in an urban area is diesel-powered vehicles, other sources, e.g., non-road mobile machinery, ship emissions, residential heating (such as wood-burning stoves), and open biomass burning (e.g., forest fires or burning of agricultural waste) also contribute to the observed levels. Although soot is currently unregulated, the implementation of national, state, and local regulations and programs to mitigate fine PM emissions and the toxic impacts of diesel emissions, often result in reduction of soot levels.

In MATES V, we examined the diurnal, daily, seasonal, and yearly variations of BC concentration and studied the temporal variations in BC concentrations. Spatial variations were also studied by comparing the collected BC data across each sampling site. These variations allow to identify potential source contributions throughout SCAB. Detailed information regarding the equipment used for BC sampling, the location of the sampling sites, data processing and the complete set of results are provided in Appendix VI to this report.

5.2.2. Black Carbon Measurements during MATES V

The Aethalometer (Magee Scientific, Berkeley, CA) is a photometer that provides a real-time readout of the BC concentration particles in an air stream. The operating principles of the Aethalometer are described in detail elsewhere.[35] Briefly, the instrument collects airborne particulate matter on a filter while continuously measuring the light transmission through the filter. The attenuation in light intensity is caused by light absorption of BC-containing particles that accumulate on the filter over time. This measurement needs to be post-processed to obtain ambient aerosol absorption coefficients which are then converted to BC concentrations. One drawback of this measurement method, inherent in all filter-based photometers, is the nonlinearity of the measurements due to PM loading on the filter media, which reduces the sensitivity of the measurements. Numerous studies have focused on developing algorithms to correct the Aethalometer non-linearity. The Magee Aethalometer model AE33 performs this correction automatically.

During MATES V, aerosol particles were sampled through a ¼" inlet with a $PM_{2.5}$ cyclone with a sampling flow rate of 5 $L \cdot min^{-1}$. The Aethalometers were operated in air-conditioned trailers. Typical maintenance operations included flow rate calibration, clean air zero test, filter taper replacement (once every two weeks in locations with high BC concentrations), and cleaning.

[34] Schauer, J.J., 2003. Evaluation of elemental carbon as a marker for diesel particulate matter. J. Expo. Sci. Environ. Epidemiol. 13, 443–453.
Schraufnagel, D.E. (2020) "The health effects of ultrafine particles", Exp Mol Med, 52, 311–317.

[35] Hansen, A.D.A., Rosen, H., Novakov, T., 1984. The aethalometer—an instrument for the real-time measurement of optical absorption by aerosol particles. Sci. Total Environ. 36, 191–196.

The sampling period for all fixed stations was one year, beginning on May 1, 2018 and ending April 30, 2019. MATES V monitoring stations include Anaheim, Burbank Area, Central Los Angeles (Central LA), Compton, Huntington Park, Inland Valley San Bernardino (Inland Valley SB), Long Beach, Pico Rivera, and Rubidoux, and West Long Beach. Additional details about the monitoring sites, their characteristics, and sampling protocols are given in MATES V Chapter 2. Further information on the instrument and detailed methodology and data validation procedures are available in Appendix III and Appendix V.

5.2.3. Black Carbon Results and Discussion

Overall, the annual average BC concentrations for each site range from 720 to 1213 ng/m^3, with an overall SCAB concentration of 1019 ng/m^3 (Figure 5-6. Black Carbon concentration average and 95% confidence interval for each site and the South Coast Air Basin (10 site average)**Figure 5-*6*.** Black Carbon concentration average and 95% confidence interval for each site and the South Coast Air Basin (10 site average)). The annual average BC concentration across the 10 sites in the SCAB is 22% lower than what was measured during MATES IV.

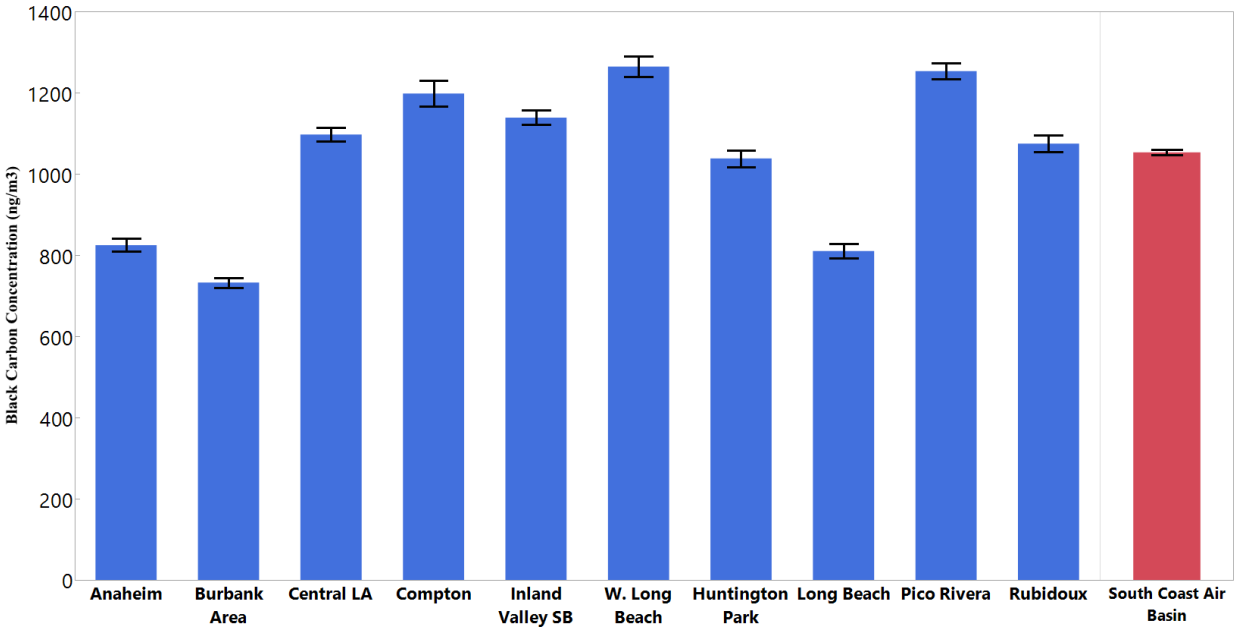

Figure 5-6. Black Carbon concentration average and 95% confidence interval for each site and the South Coast Air Basin (10 site average)

5.2.4. Spatial Variations of Black Carbon Measurements and Comparison with MATES IV

Figure 5-7. A comparison between the spatial distribution of BC levels during MATES IV and MATES V. *Refers to sites that have been relocated between the two study periods. presents the median and average BC concentration at each site for the duration of the study. Data is displayed based on six number values (in order from the bottom): minimum, 1st quartile, median, 3rd quartile, and the higher whisker equal to 3rd quartile plus 1.5 times of the interquartile range. Solid circles represent the annual average in each site. Figure 5-7. A comparison between the spatial distribution of BC levels during MATES IV and MATES V. *Refers to sites that have been relocated between the two study periods. demonstrates that the averaged BC levels was significantly reduced in comparison to MATES IV levels, in almost all sites. In addition, the median BC levels, and the range of measured levels (the box length) decreased as well.

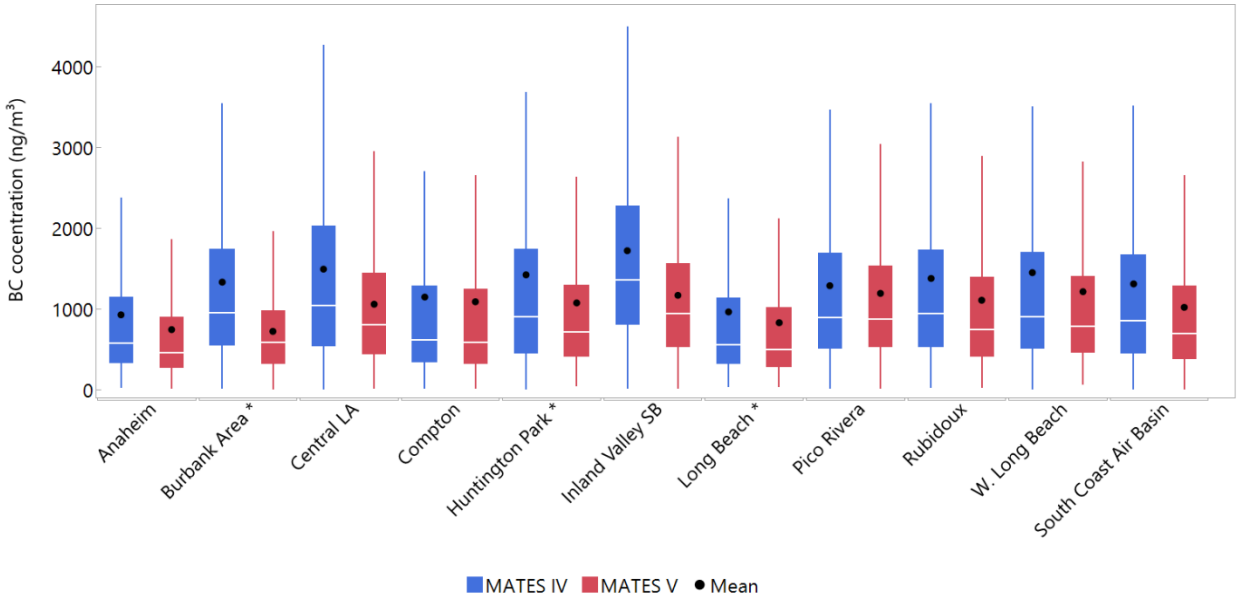

Figure 5-7. A comparison between the spatial distribution of BC levels during MATES IV and MATES V. *Refers to sites that have been relocated between the two study periods.

5.2.5. Comparison with Near-Road Sites

In addition to the MATES V sites, South Coast AQMD operates several near-road monitoring stations where BC levels are measured continuously. These sites include near-road stations in Ontario near CA-60 (60NR), Anaheim near I-5 (AHNR), Ontario near I-10 (ONNR), and Long Beach near I-710 (W710). BC concentrations measured at the near-road monitoring stations during the MATES V period are significantly elevated compared to the ten MATES V sites (Figure 5-8). BC concentrations measured at these near-road stations are, on average, about 60% higher than concentrations at the MATES V sites (Figure 5-8). These data point to the contributions of roadway sources, such as diesel truck emissions, to BC levels in locations where there are a large number of diesel trucks routinely traversing the area. The average daily volume of total traffic and truck traffic near these near-road sites is summarized in Table 5-1. Average volume of daily traffic and truck traffic* near the South Coast AQMD Near-Road monitoring sites for May 1, 2018-April 30, 2019.

Table 5-1. Average volume of daily traffic and truck traffic* near the South Coast AQMD Near-Road monitoring sites for May 1, 2018-April 30, 2019

Near-Road Monitoring Site	Average daily traffic (vehicles per day)	Average daily truck traffic (vehicles per day)
60NR (CA-60)	91,237	865
AHNR (I-5)	123,354	4,531
ONNR (I-10)	107,029	2,675
W710 (I-710)	95,852	10,092

* Traffic volume data was measured and reported by the CalTrans Performance Measurement System (PeMS) Data Source (https://dot.ca.gov/programs/traffic-operations/mpr/pems-source).

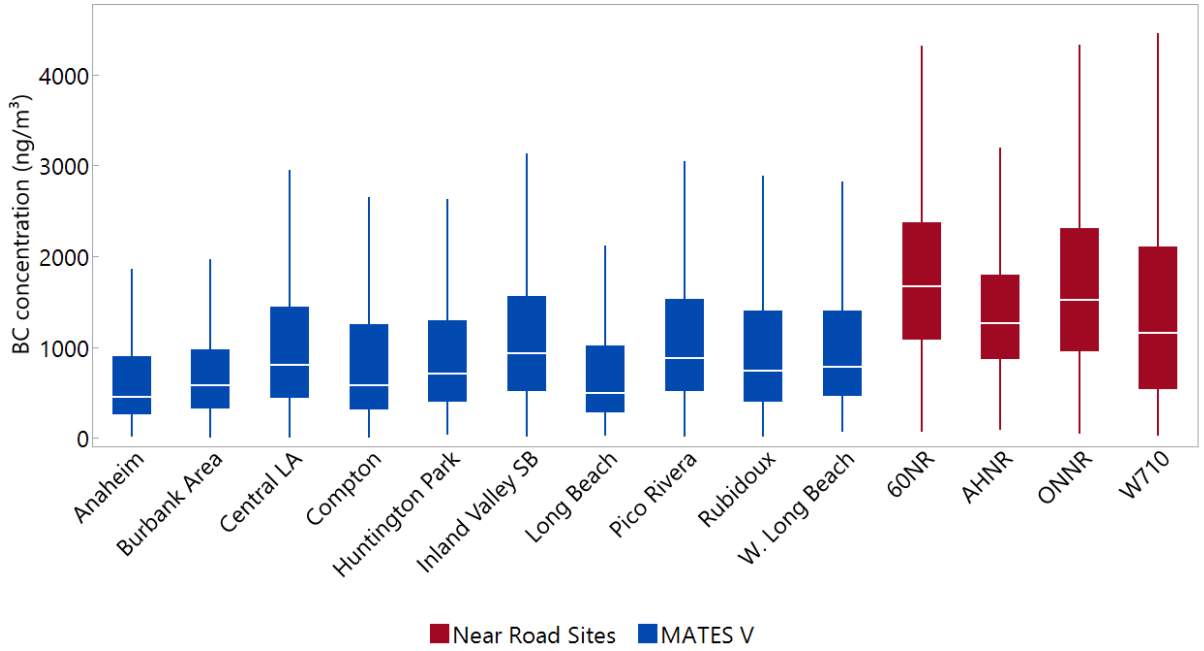

Figure 5-8. Boxplot comparison of BC concentrations between MATES V sites (blue) and near-road sites (red).

5.2.6. Diurnal Variations of Black Carbon Measurements

Typically, BC exhibits a distinct diurnal profile at most sites. BC is associated with primary combustion activities and is widely considered as one of the best indicators of local mobile sources (i.e. diesel emissions in urban environments). The 10-site average diurnal variation of BC concentrations (indicative of the typical diurnal BC trend in the South Coast Air Basin) is shown in Figure 5-9. The distinct increase in BC mass starts as early as 4:00 am. BC concentration reaches its maximum around 7:00 am and then decreases during the morning hours. This pattern is associated with rush-hour traffic during stagnant atmospheric conditions in the morning.

As the day progresses, the increased solar heating leads to greater dispersion of aerosols due to increased turbulent effects and deeper boundary layer. The dispersion of aerosols near the surface along with diminished traffic density in the afternoon results in a gradual decrease in BC concentrations in the late morning and early afternoon hours. The BC concentration continues to be relatively low until 4:00 pm and then increases again during the evening hours, partly because of the evening rush hour traffic. In addition, lower wind speeds at night and shallow inversion layer lead to a rapid decline in ventilation. Overnight, there is a progressive and strong reduction in the traffic density and BC generation; however, stable meteorological conditions and a lower boundary layer result in accumulation of BC near the surface until the next morning.

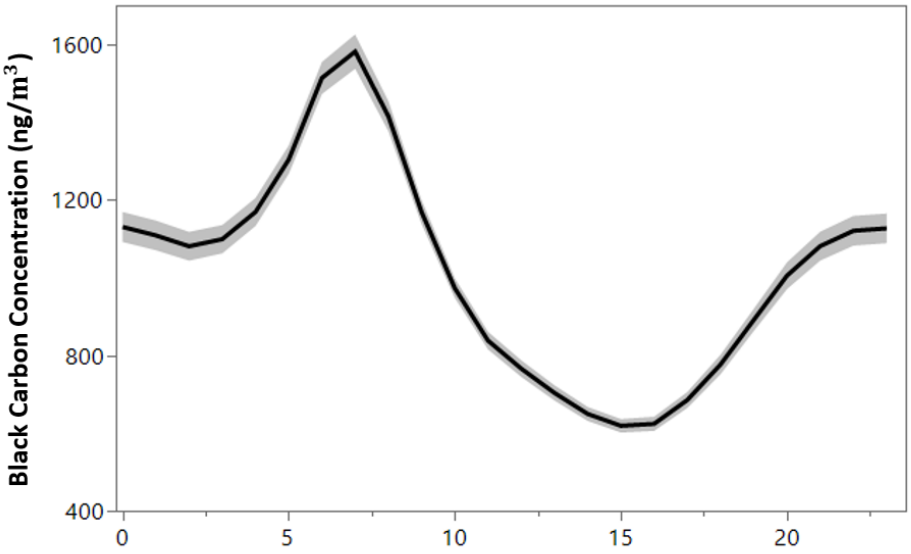

Figure 5-9. Diurnal variation of black carbon concentrations in the South Coast Air Basin during MATES V. Shaded area represents the 95% confidence level of the measurement.

5.2.7. Daily and Seasonal Variability of Black Carbon

Motor vehicle traffic, including diesel traffic, in particular, has a direct impact on ambient BC concentrations. At most locations, traffic density during weekdays is higher than on weekends. In addition, BC levels show a distinct seasonal dependence. Due to meteorological conditions, the boundary layer during the winter is much shallower than in the summer, resulting in an increase in the BC concentrations during the colder months. The daily and seasonal dependence is presented in Figure 5-9. For each season, the BC concentrations measured during weekdays is typically higher than on Saturdays and Sundays. We note that ash South Coast AQMD fire smoke advisory[36i] days were included in this analysis. Otherwise, if BC measurements during the active smoke advisories are excluded, BC levels during summer would have been ~10% lower.

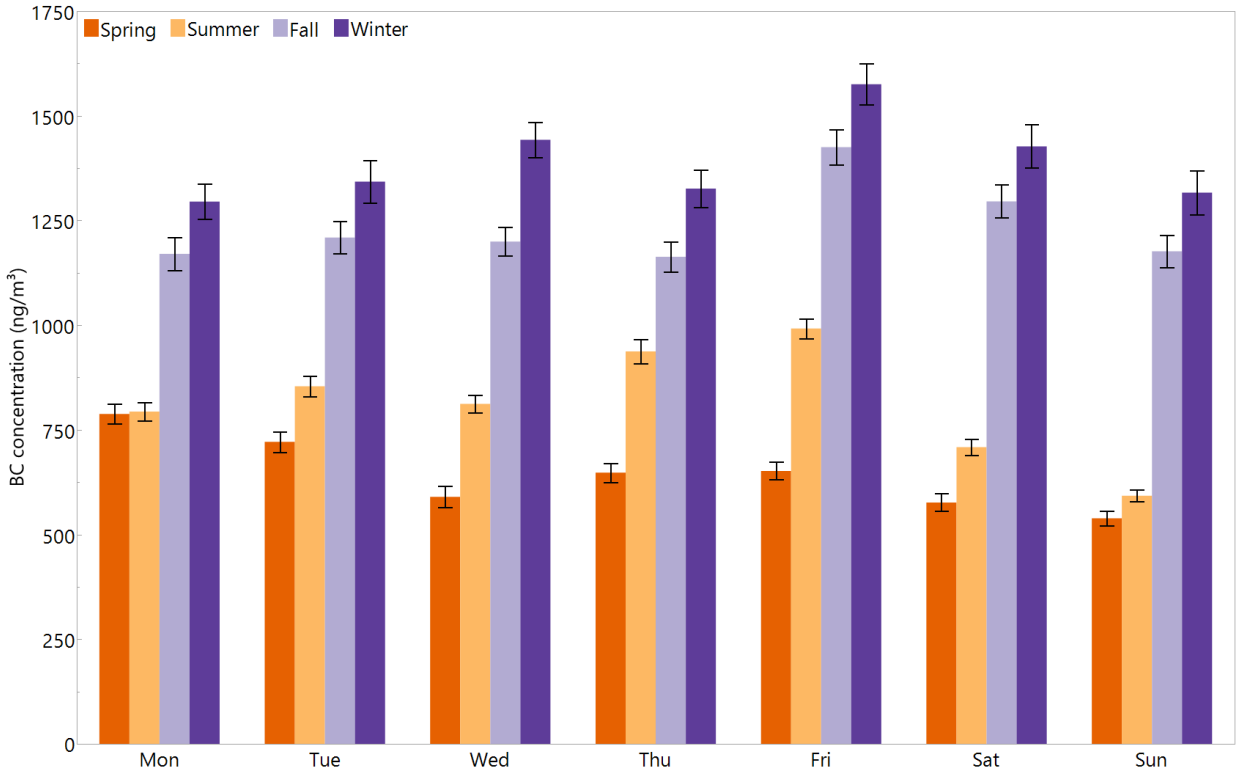

Figure 5-10. Seasonal day-of-week comparison of BC concentrations in the South Coast Air Basin during MATES V.

5.2.8. Summary of Black Carbon Measurements during MATES V

As part of MATES V, long-term measurements of BC concentrations were carried out from May 2018 to April 2019 in a network of 10 sampling sites located in the SCAB. These measurements were used to characterize the spatial and temporal variations in BC concentrations and their association to meteorology and local sources, most notably, vehicle traffic.

[36] http://www.aqmd.gov/home/air-quality/air-quality-advisories

The average levels of BC across the SCAB were 22% lower during MATES V (1019 ng/m^3) than they were during MATES IV (1319 ng/m^3). BC levels were significantly higher at sites located closer to traffic corridors.

BC levels show significant temporal variation on all scales, i.e. annual, seasonal, diurnal and weekday/weekend variations. A distinct diurnal cycle with a morning peak that is associated with increased traffic density during rush hours was observed at most sites. BC levels on weekdays were higher than during the weekend. These diurnal and day-of-week observations are associated with increased traffic density during rush hours and working days.

The seasonal variations are mostly affected by changes in meteorology and the boundary layer dynamics. This effect is particularly pronounced during the colder months when higher traffic density is coupled with a shallower mixing height. Moreover, biomass burning smoke may contribute to the observed elevated BC concentrations during the colder months. In general, local traffic sources, meteorological conditions, and boundary layer dynamics are the most important parameters influencing the BC concentrations.

Various regulations and emission reduction strategies can result in lower atmospheric concentrations of BC, either directly by reducing diesel emissions, or indirectly by reducing total PM emissions. Measures to mitigate BC will also reduce OC and PM emissions. Therefore, mitigating emissions of BC from diesel-engine and biomass burning sources would lead to a reduction in air toxic and PM exposure.