School bus pollution and changes in the air quality at schools: a case study

Chunlei Li,†[a] Quyen Nguyen,[a] Patrick H. Ryan,[a] Grace K. LeMasters,[a] Henry Spitz,[b] Megan Lobaugh,[b] Samuel Glover[b] and Sergey A. Grinshpun*[a]

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Millions of children attending US schools are exposed to traffic-related air pollutants, including health-relevant ultrafine aerosols generated from school buses powered with diesel fuel. This case study was established in a midwestern (USA) metropolitan area to determine the concentration and elemental composition of aerosol in the vicinity of a public school during morning hours when the bus traffic in and out of the adjacent depot was especially intense. Simultaneous measurements were performed at a control site. The ambient aerosol was first characterized in real time using a particle size selective aerosol spectrometer and then continuously monitored at each site with a real-time non-size-selective instrument that detected particles of 20 nm to >1 μm. In addition, air samples were collected with PM2.5 Harvard Impactors and analyzed for elemental composition using the X-ray fluorescence technique (for 38 elements) and thermal-optical transmittance (for carbon). The measurements were conducted during two seasons: in March at ambient temperature around 0 °C and in May when it ranged mostly between 10 and 20 °C. The particle number concentration at the test site exhibited high temporal variability while it was time independent at the control site. Overall, the aerosol particle count at the school was 4.7 ± 1.0 times (March) and 2.2 ± 0.4 times (May) greater than at the control site. On some days, a 15 min-averaged particle number concentration showed significant correlation with the number of school bus arrivals and departures during these time intervals. On other days, the correlation was less than statistically significant. The 3 h time-averaged particle concentrations determined in the test site on days when the school buses operated were found to be more than two-fold greater (on average) than those measured on bus-free days at the same location, and this difference was statistically significant. Overall, the data suggest a possible association between the number of detected aerosol particles and the school bus traffic intensity. Analysis of the filter samples collected at the school site between 6:00 and 9:00 AM revealed higher concentrations of elemental carbon as compared to the control site (2.8 ± 0.9 times in March and 3.1 ± 1.1 times in May). The data collected in this case study suggest that school buses significantly contribute to exposure of children to aerosol pollutants (including diesel exhaust particles) in the school vicinity.

Introduction

Air pollutants from traffic exhaust are associated with adverse respiratory health effects, especially in children. Children are particularly susceptible to the harmful effects of air pollution as their lungs are undergoing growth through to early adulthood. Children also breathe approximately 50% more air per kilogram of body weight than adults and often spend considerable time outdoors.[1–3] Among various traffic pollutants, diesel exhaust particles (DEP) exhibit a respirable size fraction with a peak size in the ultrafine range (<0.1 μm) that is capable of penetrating the lower airways.[4] Due to high levels of elemental carbon (EC) and carcinogenic pollutants, such as metal and polycyclic aromatic hydrocarbons (PAHs),[5–7] DEP is considered to be a probable human carcinogen.[2] In addition, DEP has been linked to numerous respiratory health effects including decreased lung function,[8] respiratory tract inflammation and irritation,[9] and persistent wheezing and asthma.[10,11] There is no established safe level of exposure to DEP for children, especially those with respiratory illnesses, such as asthma.

Several studies worldwide have addressed the health risk for children attending schools located near busy roadways.[12–20] Concentrations of air pollutants, including particulate matter (PM), have been measured at different distances from highways.[21–24] A recent study conducted by the University of Cincinnati team revealed that over 30% of public school students in major US metropolitan areas are regularly exposed to traffic emissions as their schools are located within 400 m of these highways.[25]

In addition to traffic on major roadways, children are often exposed to air pollutants generated by school buses, especially during arrival and dismissal times when dozens of buses may arrive and depart from the school within a short time. Bus drivers often allow engines to idle for considerable time periods in cold weather thus increasing emissions. In the US, nearly 600 000 school buses transport 24 million children to and from school daily with more than 99% of the buses using diesel fuel.[26] Diesel

[a]*Department of Environmental Health, University of Cincinnati, Cincinnati, OH, USA. E-mail: sergey.grinshpun@uc.edu*
[b]*Nuclear & Radiological Engineering Program, College of Engineering, University of Cincinnati, Cincinnati, OH, USA*
† On leave from Fudan University, Shanghai, People's Republic of China.

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engines emit 10 times more particles per mile than conventional gasoline engines and 30–70 times more than gasoline engines equipped with catalytic converters.[27] To reduce the exposure of children riding the school bus to DEP, the US EPA supports programs such as the Clean School Bus USA. Considerable efforts towards reducing exposure to DEP are being made by retrofitting school buses with diesel oxidation catalysts, increasing the use of low-sulfur diesel fuel, and establishing anti-idling campaigns. Nonetheless, most students are still likely to be exposed to PM pollutants emitted by school buses.

While several investigators have measured PM2.5 inside school buses to characterize PM pollution levels,[28–30] there is a lack of information regarding children's exposure to aerosols produced by bus traffic in the school vicinity. In addition, as school bus traffic is not uniform over the 24 -h period, it is particularly important to assess the relevant short-term emission episodes during drop-off and pick-up. Therefore, the aim of this case study was to determine the concentration and elemental composition of respirable aerosol (PM2.5) particles in the vicinity of a public school during early morning commute hours when the arrival and departure of buses at the school was especially intense. Simultaneous measurements were performed at a control site in a rural-suburban location where all vehicular traffic, including school buses, was low. The particle number concentration (N) was measured at both sites in real time and the 3 h PM2.5 filter samples were collected and analyzed for diesel-relevant elements. Two field sampling campaigns were established to reflect two seasons with distinctly different ambient air temperatures.

Materials and methods

Two sampling sites—a test and control location—were selected in the Cincinnati (OH, USA) metropolitan area. The test site was established across the street from a suburban junior high school attended by approximately 950 students. Adjacent to the school is a bus depot operating approximately 75 diesel engine buses that serves one district consisting of three distinct communities. This depot also enables students to make bus transfers to schools outside the district. Thus, many of the buses make multiple round trips in the morning, noon, early and late afternoon. The school is also located approximately 120 m from the nearest interstate highway. The control site was selected in a rural suburban environment located about 4000 m from the nearest interstate highway with minimal vehicular traffic other than one school bus in the morning and afternoon.

Ambient air monitoring at the test and control sites was conducted at the same times and dates for five school days beginning at approximately 6:00 AM until 9:00 AM. The study included two main field sampling campaigns, in March (cold weather) and May (warm weather) of 2008. An additional air monitoring campaign was undertaken at the test site for three weekdays chosen over the December school break, when the school bus depot was not operational but the commuter traffic was ordinary. The latter test aimed at differentiating the car and the school bus exhaust contributions with respect to ambient particle concentrations.

A portable condensation nuclei counter (P-Trak, model 8525; TSI Inc., St. Paul, MN) was used at each site to determine the concentration of aerosol particles in the size range of 20 nm to >1 μm. Although this instrument has a time resolution as short as 1 s, it is not capable of providing size selective data. According to an earlier pilot monitoring effort that was undertaken by using a Wide Range Particle Spectrometer for characterizing the size distribution of ambient aerosol particles generated by diesel-powered school buses, over 99% of the particles by number were contained in the submicrometer fraction. The latter justifies our use of the P-Trak in this case study.

The P-Trak data were used to determine the time averaged particle concentrations for the entire sampling period (6:00 AM to 9:00 AM) at the test (N_{test}) and control ($N_{control}$) sites. The ratio, $N_{test} : N_{control}$, was also calculated for each day. The above concentrations were also integrated over sequential 15 min intervals. As no school bus traffic was observed at the test site during the first 15 min interval (6:00 AM to 6:15 AM), the time-averaged value obtained for this interval served as an internal control and was compared to the time-averaged value calculated for the period from 6:30 AM to 8:30 AM when the school bus traffic was intense. This comparison was performed for all daily data sets collected at the test site. Although the above-described internal control is useful, its value is somewhat limited because buses were idling in the depot before departure, especially in March.

Two Harvard-type PM2.5 impactors (Air Diagnostics and Engineering, Inc., Harrison, ME) were used to collect air samples at each site, one with a 37 mm Teflon membrane filter (Pall Corporation, Ann Arbor, MI) for elemental analysis using X-ray fluorescence (XRF) and the other with a 37 mm quartz filter (Whatman, Inc., Clifton, NJ) for carbon analysis using thermal-optical transmittance (TOT). The impactors provide a cut size of 2.5 μm at a sampling flow rate of 20 L min^{-1} and were calibrated before and after sampling using a flow meter (DryCal DC-Lite, BIOS International Corporation, Butler, NJ). Each impactor was placed on an aluminium tripod at a height of 1.5 m from the ground and at least 2 m away from any obstruction.[31] The number of school buses departing and returning to the depot was recorded manually. In addition, the vehicle count (beyond school buses) was recorded at the test site in 6 of 10 routine sampling days in March and May as well as in 3 days in December (with no school buses running).

Five blanks of each filter were analyzed, including at least one field blank for each media. XRF analysis of the Teflon filters determined the mass concentration of Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Hg, and Pb. The quartz filters were analyzed by TOT for elemental and organic carbon analysis using the NIOSH–5040 method. Ambient temperature, barometric pressure, and wind characteristics were also recorded at the beginning and end of sampling for each day.

The average, standard deviation, and coefficient of variation of the daily time-integrated ratios, $N_{test} : N_{control}$, were calculated for both locations for the two sampling campaigns. Similarly, the ratios for elemental carbon (EC) and selected elements measured at both locations were calculated and averaged. The paired-sample t-test was applied to results obtained in March and May to investigate the presence of any seasonal effects on these measured data. Because of the cold weather in March, bus drivers began idling their engines earlier. Some idling was also

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observed in May. Therefore, the time averaged particle number concentrations for the periods 6:00 AM to 6:15 AM and 6:30 AM to 8:30 AM at both sites were compared using the paired-sample t-test. Since the distribution of the number of school buses with time was determined to be non-normal using the Kolmogorov–Smirnov test, a non-parametric Spearman correlation tested the association between the measured ambient particle count and the number of school buses observed at the test site. In addition, we examined, using regression modeling, linear relationships between the particle count and the number of school buses as well as the number of other vehicles (commuter traffic).

All statistical tests were performed using the SPSS 11.0 for Windows (SPSS Inc., Chicago, IL, USA). A p-value of <0.05 was considered to demonstrate statistical significance. Two-tailed p-values were used for all the analyses except for the correlation between the number of school buses and the particle number concentration, because we hypothesized that the particle number concentration would increase with an increase in the number of school buses.

Results and discussion

The total number concentration of particles measured with the P-Trak at the test site exhibited large fluctuation with time while the concentration at the control site was more constant (Fig. 1). The 3 h time-averaged particle concentration values were significantly

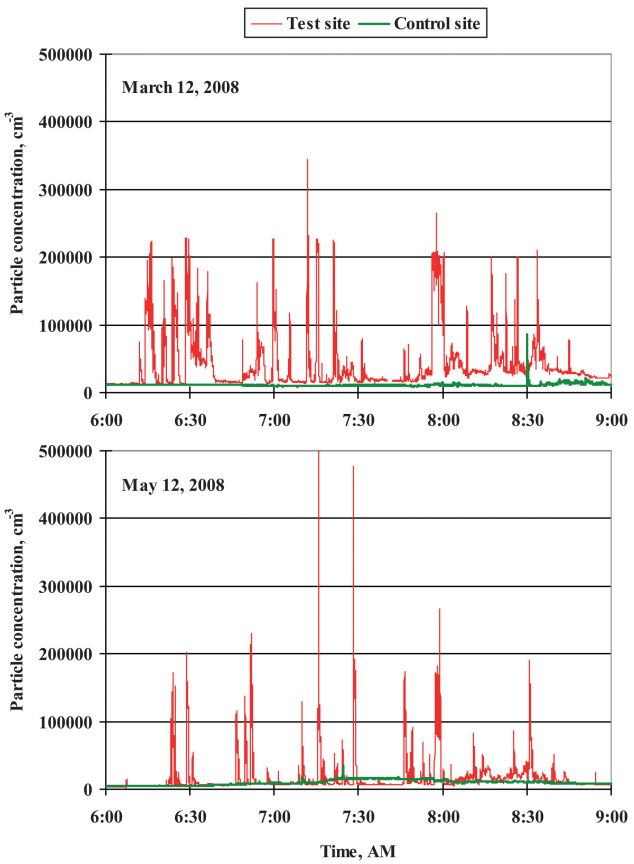

Fig. 1 Comparison of the particle number concentration ($d_p \geq 20$ nm) measured in 1 s intervals using a P-Trak for one period in March and May at the test and control sites.

Table 1 The average, standard deviation, and coefficient of variation for the test-to-control ratios of the particle number concentrations (N_{test} : $N_{control}$) as well as the PM2.5 mass concentrations of EC, S, Ti, Mn, Fe, Cu, As, and Pb, calculated from daily samples collected during the March and May

Ratio	March	May
N_{test} : $N_{control}$	4.7 ± 1.0 (CV_4 = 21%)	2.2 ± 0.4 (CV_5 = 18%)
EC_{test} : $EC_{control}$	2.8 ± 0.9 (CV_5 = 32%)	3.1 ± 1.1 (CV_5 = 35%)
S_{test} : $S_{control}$	1.3 ± 0.2 (CV_5 = 15%)	1.9 ± 1.8 (CV_5 = 95%)
Ti_{test} : $Ti_{control}$	6.8 ± 5.8 (CV_5 = 85%)	13.8 ± 22.1 (CV_5 = 160%)
Mn_{test} : $Mn_{control}$	2.7 ± 2.2 (CV_5 = 81%)	4.4 ± 3.9 (CV_5 = 89%)
Fe_{test} : $Fe_{control}$	3.5 ± 2.4 (CV_5 = 69%)	5.5 ± 5.1 (CV_5 = 93%)
Cu_{test} : $Cu_{control}$	3.6 ± 5.1 (CV_5 = 142%)	5.7 ± 7.8 (CV_5 = 137%)
As_{test} : $As_{control}$	1.7 ± 2.1 (CV_5 = 124%)	3.1 ± 2.6 (CV_5 = 84%)
Pb_{test} : $Pb_{control}$	2.2 ± 1.7 (CV_5 = 77%)	3.0 ± 5.3 (CV_5 = 177%)

higher (p <0.01) at the test than at the control site. The ratio of the particle concentrations at the test and control sites, N_{test} : $N_{control}$, integrated over the 5 day sampling period was as high as 4.7 ± 1.0 in March and 2.2 ± 0.4 in May (Table 1). The seasonal difference was found to be statistically significant (p = 0.01), suggesting higher particle emissions in March possibly related to increased engine idling in cold weather. The treatment of road surfaces in March by spreading salt to melt ice and snow is also expected to contribute. However, the day-to-day variability for the March data set (CV = 26%) was generally comparable to that obtained for the May data set (CV = 18%).

The particle size distribution measured with a WPS in our earlier pilot study conducted at a school location identified the presence of a considerable ultrafine particle size fraction. The school bus traffic was found to increase the local aerosol background across the entire range of particle sizes. The increase was shown to be statistically significant (p < 0.01) based on the paired-sample t-test. While the difference was especially high for the smallest WPS-measured particles (about 5-fold of the background level), we found no statistically significant effect of the particle size on the bus-associated aerosol concentration increase for the particle sizes in excess of ~25 nm (r = 0.15, p = 0.38).

Ratios of the concentrations of EC, S, Ti, Mn, Fe, Cu, As, and Pb at the test and control sites measured on the PM2.5 filters are listed on Table 1. These elements are related to bus emissions; several of them are also known as health-relevant. For example, Pb and As are exhaust-related compounds[32,33] and Cu, Fe, Mn, and Ti are traced to brake wear,[34] while S might mainly originate from fossil fuel combustion emission and its subsequently chemical transformation.[35] Table 1 also lists 5 day average values, standard deviations and coefficients of variation (CV) for these ratios. The level of EC, a tracer of DEP, was found approximately 3-fold higher at the school site as compared to the control test site: 2.8 ± 0.9 in March and 3.1 ± 1.1 in May. In contrast to the particle number concentration, no statistically significant seasonal difference was observed (p = 0.27) for the elemental concentrations. For example, the daily variability of EC was 32% and 35% for March and May, respectively.

Elevated concentrations of EC and airborne particles serve as evidence that school bus emission had a predominant influence on the ambient aerosol in the vicinity of the test school. For other elements, the day-to-day variability was considerably higher preventing detection of seasonal differences. However, all the

average test-to-control ratios exceeded the unity and over 80% of the values showed a two-fold difference suggesting a greater presence of the diesel exhaust-relevant elements at the test *versus* the control site. Sulfur showed the highest concentration among all elements analyzed by XRF, but had the lowest ratio of test site to control site in both seasons among these nine traffic-related species. This finding indicates that sulfur was predominant in the background aerosol.[21]

Fig. 1 shows two representative profiles of the particle number concentration measured with a P-Trak with a time resolution of 1 s for the test and control sites on March 12, 2008 and May 12, 2008. A common occurrence throughout the field sampling campaign at the test site location was a low (background) particle number concentration during the first 15 min of sampling (6:00 AM to 6:15 AM) that increased substantially thereafter exhibiting a series of spikes as high as >500 000 cm^{-3} over the next 2.5 h and returning to background at approximately 9:00 AM. The time-averaged particle concentration observed between 6:30 AM to 8:30 AM, when school bus traffic was greatest, significantly ($p < 0.01$) exceeded the initial concentration observed between 6:00 AM to 6:15 AM before school buses departed from the depot at the test site even though bus idling was occurring during both periods. For example, the difference was 1.8 times on March 12 and 4.0 times on May 12. In contrast, the particle number concentration at the control site remained essentially constant throughout the measurement period. The coefficient of variation for the day-to-day 3 h average concentration value was 26% and ranged from 5886 on May 9 to 16 230 cm^{-3} on May 5, which reflects the differences in the ambient aerosol background. Thus, the particle count near the school was much higher than at the control site.

The temporal changes observed in particle concentration at the test site during the monitoring time were at least partially attributed to a non-homogeneous influence of school bus emission. Fig. 2 shows the aerosol concentrations measured over 15 min intervals at the test site with a P-Trak along with the number of school buses departing and returning over time to the depot. There is a small (8 min) difference between the initial points of the curves representing the March 12 and May 12 data sets. This discrepancy reflected a lack of synchronization in counting buses on these days. There is a positive Spearman correlation ($r = 0.52$, $p = 0.04$) exhibited on March 12 between the ambient particle count and the number of school buses and a less positive correlation ($r = 0.39$, $p = 0.11$) for observations on May 12. Overall, the p-values obtained for specific days ranged from 0.02 to 0.25 during the March and May sampling campaigns. While the statistically significant correlation between the 15 min averaged particle concentration and the number of school buses was not consistently observed over the ten sampling days, the data suggest that school buses were important sources of elevated PM pollutants at the test site, at least on some days. The lower correlations found for other days point to the influence of mobile and stationary PM sources, which were not related to the school buses. No lag time was introduced when analyzing the correlation between the particle concentration and the number of school buses since the sampling site was very close to the emission sources. This said, accounting for some lag time may nevertheless be appropriate for analyzing larger databases. Additionally, while the school chosen for this study was not located on a major

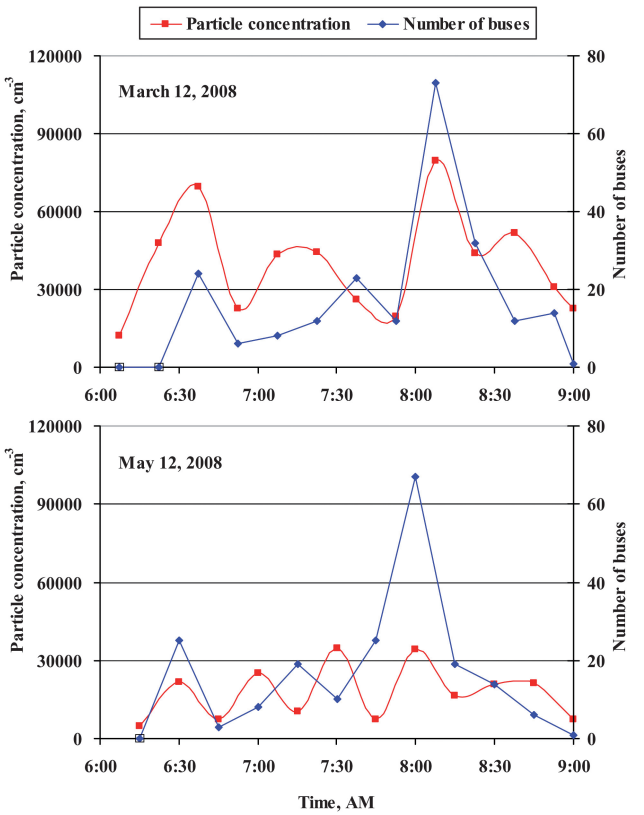

Fig. 2 Comparison of the particle number concentration ($d_p \geq 20$ nm) measured in 15 min intervals using a P-Trak with the number of school buses arriving and departing from the test site during one period in March and May.

road, increased local commuter traffic (other than school buses) was observed on this street, particularly between approximately 7.15 AM and 8.30 AM. However, no correlation was found between the particle concentration and the commuter traffic, except for one day in May.

The data recorded on March 12 in 15 min intervals were examined using simple linear regression. The number of school buses was significantly associated with the particle concentration ($p < 0.01$). No association, however, was observed between the number of commuter vehicles on the street and the particle concentration measured during these time intervals ($p = 0.90$). In addition, school buses and local commuter vehicles were entered as covariates in a multiple linear regression model using the same database. In this model, buses were significantly associated with the particle concentration ($p < 0.01$) while the other vehicles were not ($p = 0.09$). It was also acknowledged that the test site was located in a proximity to a highway. However, no attempt was made to relate the highway traffic count and the aerosol particle concentration determined over short time intervals. The number of vehicles on the highway per 15 min interval was not a subject of considerable variability between 6 and 9 AM; however, the type of vehicles and their speed were highly variable (unlike in the local commuter traffic). As the exhaust-related aerosol pollution is affected by these factors (not solely by the highway traffic count), it seems too simplistic to search for a relationship between the particle concentration and the number of vehicles on the highway during a specific time period.

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To further assess the contributions of buses *versus* other vehicles (mostly passenger cars), we compared the 3 h time-averaged (6 AM to 9 AM) particle concentration levels measured in March (with school buses and commuter traffic) and in December (school break, commuter traffic only). Three days with similar temperature, humidity and wind conditions were chosen in each of these two months, and the average particle concentration and the standard deviation were calculated for each set of three values. The average concentration in March, when the school buses operated, was found to be more than two times greater than on bus-free days in December. This difference, representing the contribution of the PM generated by the school bus exhaust in addition to the commuter traffic, has a strong statistical significance ($p < 0.01$). When measuring in the absence of school buses (December), an association between the particle concentration and the commuter traffic was observed in two of three monitoring days—the effect of which was evidently masked by the school bus influence on days the bus depot operated.

It is acknowledged that the meteorological conditions, particularly the wind speed and direction may affect the representativeness of the aerosol sample. In our study, however, the ambient air at the test site was almost always calm (with a wind speed below 1.5 miles h^{-1}), which makes the wind condition to be of a secondary importance for our findings. Generally, a more comprehensive investigation that would include meteorological factors, source apportionment, pollution–response time differentiation and a detailed commuter traffic component analysis should follow to establish more accurate relationships between the aerosol concentration and the school bus traffic intensity.

Conclusions

This case study was undertaken to determine the concentration and elemental composition of airborne particles in the vicinity of a public junior high school with an adjacent bus depot in the Cincinnati (OH, USA) metropolitan area during the early morning hours when school bus traffic is most intense. The school bus traffic was shown to significantly ($p < 0.01$) increase the local aerosol background across the entire range of particle sizes. The particle number concentration exhibited high fluctuations at the school with heavy bus traffic and were lower and relatively constant at the control site. The particle count at the school exceeded that at the control site by a factor of almost five fold in March when buses were continuously idling and over two fold in May. On some days, a 15 min-averaged particle number concentration showed significant correlation with the number of school bus arrivals and departures during these time intervals. On other days, the correlation was not statistically significant suggesting an increased influence of mobile and stationary PM sources, which were not related to the school buses. Not surprisingly, the 3 h time-averaged particle concentrations determined in the test site on days, when the school buses operated, were found to be significantly different and more than two fold higher, on average, than those measured on bus-free days. Overall, the data suggested an association between the number of detected aerosol particles and school bus traffic intensity. At the same time, the multiple regression model revealed no statistically significant association between the particle concentration and the commuter traffic intensity at the test site as it was likely masked by the school bus emission. Analysis of the filter samples collected at the test site between 6:00 and 9:00 AM revealed an elevated concentration of elemental carbon (2.8 ± 0.9 times in March and 3.1 ± 1.1 times in May) and other relevant elements (ranging from 1.7 ± 2.1 to 13.8 ± 22.1) as compared to the control site. The data suggest that school buses significantly contribute to the children's exposure to aerosol pollutants (including DEP) in the school vicinity.

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