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Spatial distribution of noise and particulate matter near two major freeways in Los Angeles, California: correlations and influencing factors

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by

Pu Yang

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ABSTRACT OF THE THESIS

Spatial distribution of noise and particulate matters near two major freeways in Los Angeles, California: correlations and influencing factors

by

Pu Yang

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2014

Professor Yifang Zhu, Chair

A-weighted equivalent continuous sound level (LeqA), ultrafine particles (UFP, particles with aerodynamic diameter < 100 nm) number concentrations, and fine particles (particles with aerodynamic diameter < 2.5 um) mass concentrations were measured simultaneously at increasing distances from the freeways on four streets in Los Angeles, CA, with or without sound wall, from February to June 2013. Correlations among UFP number concentrations, PM2.5 mass concentrations and LeqA were assessed by Pearson correlation coefficient. The impacts of wind direction, traffic volume and the presence of sound wall on PM2.5 mass concentrations, UFP number concentrations and LeqA were also investigated.

Moderate correlation(r ranges from 0.514 to 0.605, $p<0.05$) between LeqA and UFP number concentrations were observed under downwind conditions on all four streets. However, no correlation was found under upwind conditions. PM2.5 mass concentrations were correlated with

UFP number concentration, but not with LeqA. The sound wall was effective at blocking noise but its ability to block particulate matters needs further investigation. It suggests that the residents and workers who live or work at the dominantly downwind side of freeway are exposed to higher UFP yet similar noise levels when comparing with the situations at the upwind side of freeway. In addition, it is feasible to use the upwind side of freeway as a control for the two common confounders, particulate matters and noise, in epidemiological and occupational exposure studies. Data generated in this study may be used to study the independent and synergistic health impacts of noise and particulate matters near freeways, especially from an occupational exposure perspective for near roadside workers such as traffic directing personnel, gas station personnel and toll station workers.

The Thesis of Pu Yang is approved

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2014

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1. INTRODUCTION

Near-freeway environments are important from public health and environmental justice perspectives. It was estimated that approximately 11% of US households were within 100 m to a 4-lane freeway (Brugge et al., 2007). A survey conducted by the South Coast Air Quality Management District's (SCAQMD) revealed that approximately 2.3% of public schools in California were located within 150 m of high-traffic roads (greater than 50,000 vehicles per day), and an additional 7.2 % were within 150 m of medium traffic roads (25,000 – 50,000 vehicles per day) (Green et al., 2004). In addition, because the house prices in near-freeway communities are relatively lower, people in low socioeconomic status are more likely to live in there, which leads to an unequal share of air pollution and traffic noise burden (Association, 2001; Finkelstein et al., 2005).

Traffic-emitted air pollution causes multiple adverse health effects to near-freeway residents and workers. Many studies have found evidence that it decreases pulmonary function in children, especially for those who live less than 300 m away from freeways, and is associated with cardiovascular disease as well(Babisch et al., 2005; Brunekreef et al., 1997; Gauderman et al., 2007; Wjst et al., 1993). Long-term exposure of black carbon particles from mobile sources was found to be associated with decreased cognitive function among children (S. Franco Suglia et al, 2007). The distribution of traffic-emitted particulate matters in near-freeway environments has been studied extensively. Zhu et al. conducted systematic measurements of the concentration and size distribution of ultrafine particles (UFP) near two major freeways in Los Angeles, California (Zhu et al., 2002a; Zhu et al., 2002b). It was found that the relative concentrations of particle number, black carbon, and carbon monoxide tracked each other well. Within a 300 m range on the downwind side these pollutants' concentrations dropped exponentially as the distance from the freeway increased. The gradient of UFP from downwind freeway was less obvious at night than it in the daytime due to the differences in traffic and weather conditions (Zhu et al., 2006). For fine particles (PM2.5) and coarse particles (PM10), there was no observable concentration gradient in the vicinity of freeways (Zhu et al., 2006).

The traffic-emitted noise has been found to be associated with cardiovascular diseases such as hypertension and coronary artery disease (Babisch, 2008; Bluhm et al., 2007). Children are particularly vulnerable to the effects of noise because it can interfere with learning at a critical developmental stage. Exposure to traffic noise can cause decreased cognitive functions, such as reading speed, basic mathematics and memory among children (Stansfeld, 2005; Ljung 2009). A study focused on workers in the high traffic areas in Brazil found that 28% of near road traffic operators, technicians and wardens developed suspected noise-induced hearing loss and the prevalence was higher among those who worked in the noisier areas than among those working in areas with lower noise levels (Barbosa, 2005). The propagation of traffic-emitted noise has been studied for decades. Generally, the traffic noise decreases 4 dB when the distance from the freeway doubles (Alexandre, 1975). Because traffic noise is annoying, distracting, and associated with cardiovascular diseases, noise barriers such as sound walls have been widely used to mitigate the propagation of traffic-emitted noise near-freeways. Recent studies with sound walls suggest that, besides mitigating noise, the presence of sound wall may also modify the dispersion of air pollutants. According to a study conducted near interstate 710, Los Angeles, a recirculation cavity is formed 15 m downwind of the sound wall, resulting in a concentration deficit zone in the lee of the sound wall. As the downwind distance increases, particles and gaseous co-pollutant concentrations reach a peak at 80 – 100 m, where the plume of elevated traffic emissions sources reattaches to the ground (Ning et al, 2010). The study also acknowledged that factors such as meteorological conditions, design of roads, and vehicle-induced turbulence can all play important roles in affecting the dispersion of pollutants.

Because both air pollution and noise from traffic are associated with cardiovascular disease and decreased cognition among children, a couple of studies have investigated the correlation between air pollution and noise (Beelen et al., 2009; Gan et al., 2012). Data suggest there are independent effects of air pollution and noise, but the degree of correlation is still unclear. Several studies used model assessment to investigate the correlation between traffic-emitted air pollutants and noise on the metropolitan scale (Gan et al., 2012; Van den Hooven et al., 2012). Field measurements were relatively sparse and limited to urban area and the street canyon (Foraster et al., 2011; Kim et al., 2012; Weber, 2009). A substantial correlation between traffic-related noise and air NO2, was observed and the correlation varies with complex local characteristics (Can et al., 2011). No studies have measured the effects of sound wall on the propagation of traffic-emitted air pollutants and noise concurrently.

The two objectives of this study are (1) to assess correlations among three traffic-emitted pollutants: UFP, $PM_{2.5}$, and noise, and (2) to investigate how the presence of sound wall impacts these correlations. This study provides a better understanding about the propagation of these three pollutants in near-freeway environments, with or without the presence of sound wall. The results from this study may help future studies to investigate the independent and synergistic effects of UFP, PM2.5 and noise.

2. EXPERIMENTAL METHODS

2.1 SITES DESCRIPTION

The field measurements were conducted on four streets in Los Angeles, CA from February to June 2013. The site map is shown in Figure 5. The 405 site, referring to the Constitution Avenue in Westwood of Los Angeles, CA, is located 6.4 km east of Santa Monica Bay. The Interstate 405 runs from north to south at 330 degrees, with the Los Angeles National Cemetery on its eastern side and the Veterans Affair facility on its western side. Several measurements of air quality have been conducted at this site (Zhu et al., 2002b; Zhu et al., 2004; Zhu et al., 2006). Sampling locations in this study were set on both sides of Interstate 405 along the Constitution Avenue, which is perpendicular to and runs through Interstate 405 by a tunnel underneath.

The 710 site, a collective name for the three test sites on Gotham Street, Quinn Street, and Southern Avenue, is located in South Gate City of Los Angeles County 26 km east of the Pacific Ocean. Interstate 710 runs north to south at 10 degrees with all three streets on the eastern side. Gotham Street and Quinn Street are 200 m apart and both behind a 4 m high sound wall. There is a residential community between the two streets. Southern Avenue is about 1.6 km south of Quinn Street, and is not equipped with a sound wall. It is located in an industrial area with a parking lot on the south side and a public storage place and an asphalt processing company on the north. Several measurements of air quality have been conducted at these three streets too (Ning et al, 2010).

2.2 SAMPLING SCHEDULE

Twenty sampling sessions were conducted on nine different days from February to June 2013. The details of each test session are listed in Table 1. For the 405 site, the sampling sessions were scheduled at different hours of the daytime to cover different traffic and meteorological conditions. For the 710 site, the sampling sessions were scheduled during both daytime and nighttime to capture different meteorological conditions. Each sampling session was about 1.5 - 2 hours long. Traffic volume data collected during each sampling session are listed in Table 1.

2.3 METEOROLOGICAL DATA

Wind speed, wind direction, ambient temperature, and relative humidity were obtained from near-by weather stations operated by National Weather Service (Weather Underground, Inc. Ann Arbor, MI). Data during each sampling session were retrieved from two weather stations, one for the 405 site (weather station ID: KCALOSAN56) and the other for the 710 site (KCADOWNE4). The locations of these two weather stations are also shown in Figure 5 a.

2.4 TRAFFIC DATA

The traffic volume data were obtained from the California Department of Transportation Performance Measurement System (PeMS). Station (ID 717799) is located about 1 km north of the 405 site. This station only records the traffic count on the north bound lanes of Interstate 405 so the raw data were doubled to approximate the total traffic volume on Interstate 405. Station (ID 717989) for the Gotham and Quinn Street sites is located on the ramp that connects the Interstate 710 and Firestone Boulevard, about 900 m north of Gotham Street. Station (ID 774359) for the Southern Avenue site is located on Interstate 710, 300 m south of the Southern Avenue Site.

2.5 NOISE, UFP, and $PM_{2.5}$

The 5-minute A-weighted equivalent continuous noise level, LeqA, was measured by a Quest 2900 Sound Level Meter (3M, St. Paul, MN). The sound level meter was calibrated with a Quest Noise Calibration Source (100dBA Standard, 3M, St. Paul, MN) on each sampling day. A type 2 microphone was used in this sound level meter, which causes an uncertainty of ±1.0 dB in the final readings. UFP and $PM_{2.5}$ were measured by a portable Condensation Particle Counter (CPC 3007) and a Dusttrak Aerosol Monitor Model 8520 (Dusttrak), both manufactured by TSI Inc. (Shoreview, MN). Both the CPC 3007 and the Dusttrak were manufacturer-calibrated and a zero-check was performed on each sampling day. For the Dusttrak, all the readings were normalized by a factor of 2.4 to compensate the difference in the light-scattering property between the real environmental particles and the lab calibration standard particles (Quiros et al., 2013). This correction does not affect the results of the correlation calculations. All the instruments were constantly faced to the site during the sampling session.

The sampling locations were set at different distances to the freeways along each street. For the 405 site, the sampling locations were 45, 75, 105, 165, and 285 m away from the center line of Interstate 405, on both sides. For the 710 sites, the sampling locations were on the eastern side of Interstate 710 only, 15, 45, 75, 105, 165, and 285 m away from the center line. At each sampling location, 5-min concurrent measurements on UFP, $PM_{2.5}$, and LeqA were conducted. Previous studies have shown that the average of 5-min sampling was representative for the noise and particulate matters concentrations (Allen et al., 2009; Ntziachristos et al., 2007).

2.6 DATA ANALYSIS

After removing the outliers following the standard method (ASTM E178, 2008) , the geometric means of UFP and $PM_{2.5}$ of each 5-min measurement were calculated. To calculate the average of LeqA in each 5 minutes, the direct readings from the sound level meter were log-transform averaged. The Pearson Correlation Coefficient, r, and its statistical significance, *p*, were used to assess the correlation among average LeqA and average concentrations of UFP and $PM_{2.5}$.

3. RESULTS

3.1 METEOROLOGICAL AND TRAFFIC CONDITIONS

As shown in Table 1 and Figure 2, The 405 site and the 710 site, approximately 20 miles apart from each other, had similar meteorological conditions during all sampling days. The wind speed and direction generally followed the typical diurnal change pattern in the southern California coast area: the wind speed during night and early morning was low (mostly 0 - 2 m s^{-1}) and the majority of wind directions ranged from 0 to 150 degrees (Figure 2a). The late morning, afternoon, and early evening wind directions were usually between 150 to 270 degrees (Figure 2b) and the wind speeds were much higher. Therefore, the meteorological data were divided into two groups: nighttime (21:00 -08:59) and daytime (09:00 - 20:59), as shown in Figure 6. For the 405 site, all the sampling sessions were conducted during the daytime, which made the western side of Constitution Avenue always upwind and eastern side downwind, as shown in Figure 2 a. For the 710 site, the daytime sampling sessions were under upwind condition while all the nighttime sessions were under downwind conditions, as shown in Figure 6 b.

Based on the traffic volume data in Table 1, the daytime traffic volume was generally 6 - 8 times higher than that in nighttime, and the percentage of heavy duty truck was 30% during daytime and 5% at night. On Interstate 710 which connects the Long Beach port to downtown Los Angeles, the heavy duty truck percentage sometimes peaks to about 30% from midnight to 2 am. No sampling sessions in this study covered this time frame, therefore leading to a relatively low average value of heavy duty truck percentage. The effect of traffic composition on the near-freeway environment requires future studies.

3.2 405 SITES RESULTS

The LeqA, UFP, and $PM_{2.5}$ concentrations along Constitution Avenue are shown in Figure 7. The LeqA decreased as the distance to the center of Interstate 405 increased on both upwind (western) and downwind (eastern) sides. Although the drop of LeqA was obvious, the curves at each side of Interstate 405 were roughly asymmetric. On the western side, the LeqA peaked at location 105 m instead of 45 m away from Interstate 405. This may be caused by the different environment on each side of Interstate 405; the western side was mainly surrounded by concrete buildings where noise could be reflected and there is a parking lot with some random noise. Those factors could impede the noise decay in the western side while the eastern side is mainly embedded by grass and trees which have the ability to absorb sound.

The UFP concentrations measured on the downwind (eastern) side of Interstate 405 showed an obvious gradient while those at the upwind (western) side did not. The PM2.5 mass concentrations, as expected, showed no obvious gradient on either side and the concentrations on each side were similar. These findings are highly consistent with the two studies conducted at the same site (Zhu et al., 2002b; Zhu et al., 2006). These data were also in support for the hypothesis that the direct contribution to particle mass concentration by traffic emission near-roadway is small (Zheng et al., 2002; Zhu et al., 2006).

3.3 710 SITES RESULTS

The LeqA, UFP, and $PM_{2.5}$ measured from the 710 site are shown in Figure 8. At the 15 m locations, the Southern Avenue (without sound wall) showed an average LeqA of 69.7 dBA(SD=1.3), while the daytime averages of LeqA from Gotham Street and Quinn Street (with sound wall) were 64.5 dBA(SD=0.5) and 63.3 dBA(SD=0.8), respectively. Actually, as it shown in Figure 4, the LeqAs from Southern Avenue were constantly higher than those from Gotham Street and Quinn Street on all corresponding distances. This indicates that sound walls can effectively reduce the noise level in near-freeway environments. The noise decay patterns on Quinn and Gotham streets were similar to that of the 405 site, decaying within the 90 m distance and then flat out to background level while there is not a decay pattern in Southern Avenue because unlike the other two street, Southern Avenue is located in an industrial area with a parking lot on the south side and a public storage place and an asphalt processing company on the north. A slight increase of noise level was shown at the 285 m locations on all three streets because those locations are close to intersection with other streets and the measurements were somehow interfered.

For UFP, daytime sessions at all 710 sites showed similar decay-with-distance pattern, as found in 405 site on the downwind side. In nighttime sessions, due to the altered wind direction and low traffic volume, there is no concentration gradient. The UFP concentration in the nighttime was only about 25% of that in the daytime.

For $PM_{2.5}$, there was no obvious concentration gradient near the Interstate 710. The daytime and nighttime readings were not significantly different either. These observations are in agreement with those found at the 405 site.

4. DISCUSSION

4.1 CORRELATIONS BETWEEN LEQA AND PARTICULATE MATTER

The Pearson correlation coefficients and their significance levels are summarized in Table 2. Under upwind conditions on the Constitution Avenue, no statistically significant correlation was observed between any pairs among LeqA, UFP, and PM2.5. Under downwind conditions on the same street, LeqA-UFP and UFP-PM2.5 showed moderate but statistically significant positive correlations. Similarly, LeqA-UFP and UFP-PM2.5 were found moderately correlated on Gotham Street and Quinn Street. However, on Southern Avenue, the correlation between LeqA and UFP was not statistically significant at a p value of 0.09. Unlike the other three streets which are all in residential areas with very few traffic, Southern Avenue is located in an industrial area where random noise may occur. Therefore the measurement of noise and particulate matters may be interfered with.

More interestingly, no statistically significant correlation was found between LeqA and $PM_{2.5}$ in any sampling sessions in this study. The fact that LeqA and UFP are correlated with each other is easy to understand because both of them are directly emitted from vehicles and rapidly decay as they propagate in the air. On the other hand, UFP can grow into larger size particles by vapor condensation or coagulation with other particles and contribute to PM2.5 mass concentration (Hinds, 1999). This explains why UFP and PM2.5 may be correlated with each other too. However, there are also studies showing that UFP and PM2.5 may not necessarily be correlated because PM2.5 does not vary much in concentration by location or roadway, and is more influenced by specific encounters with high-emitting vehicles (Westerdahl, 2005). In terms of LeqA and UFP, there is no obvious mechanism to link the change of noise level and PM2.5 and the fact that the traffic-emitted noise was more correlated to smaller particles has also been demonstrated by Can et al.(2011).

4.2 EFFECTS OF SOUND WALL ON NOISE AND PARTICLE DISTRIBUTIONS

The presence of sound wall had a substantial impact on LeqA and UFP. As shown in Figure , the intercept of the linear regression between UFP and LeqA with sound wall (Figure a) was 52.9dBA and the 95%CI= (50.7, 55.2), while that without sound wall was 63.6 dBA and the 95%CI= (61.0-66.1). Therefore we conclude that the intercepts are significantly different. The slope also suggested that sound wall is more effective at blocking the traffic noise than its ability to block UFPs because assuming the same amount of UFP is reduced, the leqA decreases more in the situation with sound wall. In addition, as it shows in Table 2, the correlation of LeqA and UFP and the correlation of UFP and PM2.5 are statistically significant on Gotham and Quinn streets where sound walls exist, while those correlations are not significant on Southern Avenue where there is no sound wall. Therefore, a conclusion is reached that the presence of sound wall may enhance the correlation of LeqA and UFP and the correlation of UFP and PM2.5.

Meanwhile, the effect of recirculation cavity and concentration peak mentioned in the introduction part was not observed. Further studies will be needed to confirm the effect. To enhance the capability of UFPs mitigation in the near-freeway environment, adding large surface area by planting vegetation on the sound wall might be a potential solution (Hagler et al., 2012; Steffens et al., 2012) .

5. CONCLUSIONS

In this study, UFP number concentrations and noise levels were usually found to be positively correlated, under downwind conditions, within 300 m distance to two major freeways in Los Angeles, California. The only exception is on Southern Avenue, where measurement interference might have happened. PM2.5 mass concentrations were correlated with UFP number concentration, but not with the noise level. It suggests that the residents and workers who live or work at the dominantly downwind side of freeway are exposed to higher UFP yet similar noise levels when comparing with the situations at the upwind side of freeway. The sound wall has been demonstrated to be effective at blocking noise but its ability to block particulate matters needs further investigation.

The authors acknowledge that, even though the correlation between noise and UFP could be expected near other freeways, the slope of their linear relationship could be street-specific. Possible affecting factors include but are not limited to the road design, sound wall structure, building layout near freeway, composition of motorized vehicles, and meteorological conditions. The correlations identified in this study may not be applied to other streets without carefully examining all these factors.

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Table 1 Location, Time, and whether conditions of each sampling session

Street	Session	Date	Time	Wind speed (m/s)	Traffic volume (# vehicle/5 min)	Heavy duty truck flow volume (# vehicles/5 min)	Temperature (°C)	Relative humidity (%)
Constitution	1	February 12	15:50-17:05	5±3	792±48	n/a	19	24
	2	February 17	15:20-16:40	7±2	800±90	n/a	15	63
	3	March 10	09:30-11:00	7±3	909±54	n/a	20	42
	4	April 05	10:00-12:00	6±2	748±372	n/a	28	29
Gotham	1	April 06	13:10-13:47	12±2	917±36	41±2	21	51
	2	April 07	03:02-03:50	3±2	110±16	3±1	16	76
	3	April 11	14:46-15:24	7±2	804±122	80±12	28	32
	4	April 12	03:53-04:30	3±2	189±56	21±6	16	70
	5	June 29	14:40-15:20	6±2	861±48	35±2	36	32
	6	February 12	15:50-17:05	5±3	792±48	n/a	39	23
Quinn	1	April 06	14:05-14:51	4±1	932±36	39±2	19	57
	2	April 07	04:03-04:37	2±2	108±17	5±1	16	76
	3	April 11	15:34-16:21	5±2	981±35	69±2	25	41
	4	April 12	04:33-05:12	1±2	362±64	25±4	15	72
Southern	1	June 29	15:24-16:00	6±1	897±24	29±1	35	32
	2	June 29	16:24-17:05	4±2	874±49	17±1	35	31
	3	April 06	15:01-15:45	6±2	1129±97	34±3	21	54
	4	April 07	04:51-05:35	0±1	168±18	7±1	16	75
	5	April 11	16:32-17:26	5±1	1297±36	75±2	30	30
	6	April 12	05:37-06:15	1±1	988±117	68±8	15	70

Table 2 Pearson correlation coefficients between LeqA, UFP, and $PM_{2.5}$

Site	Street	Sound wall	Wind Direction	Pearson Correlation Coefficient*		
				LeqA - UFP	UFP - $PM_{2.5}$	LeqA - $PM_{2.5}$
405	Constitution Avenue	No	Upwind	0.261 (*p*=0.267)	0.127 (*p*=0.650)	-0.361 (*p*=0.817)
		No	Downwind	**0.514 (*p*=0.019)**	**0.722 (*p*=0.002)**	-0.409 (*p*=0.873)
710	Gotham Street	Yes	Downwind or no wind	**0.605 (*p*<0.01)**	**0.391 (*p*=0.032)**	-0.047 (*p*=0.195)
710	Quinn Street	Yes	Downwind or no wind	**0.515 (*p*<0.01)**	**0.662 (*p*<0.01)**	0.124 (*p*=0.513)
710	Southern Avenue	No	Downwind or no wind	0.359 (*p*=0.09)	-0.047 (*p*=0.148)	-0.238 (*p*=0.659)

* Bold font indicates statistically significant results ($p<0.05$)

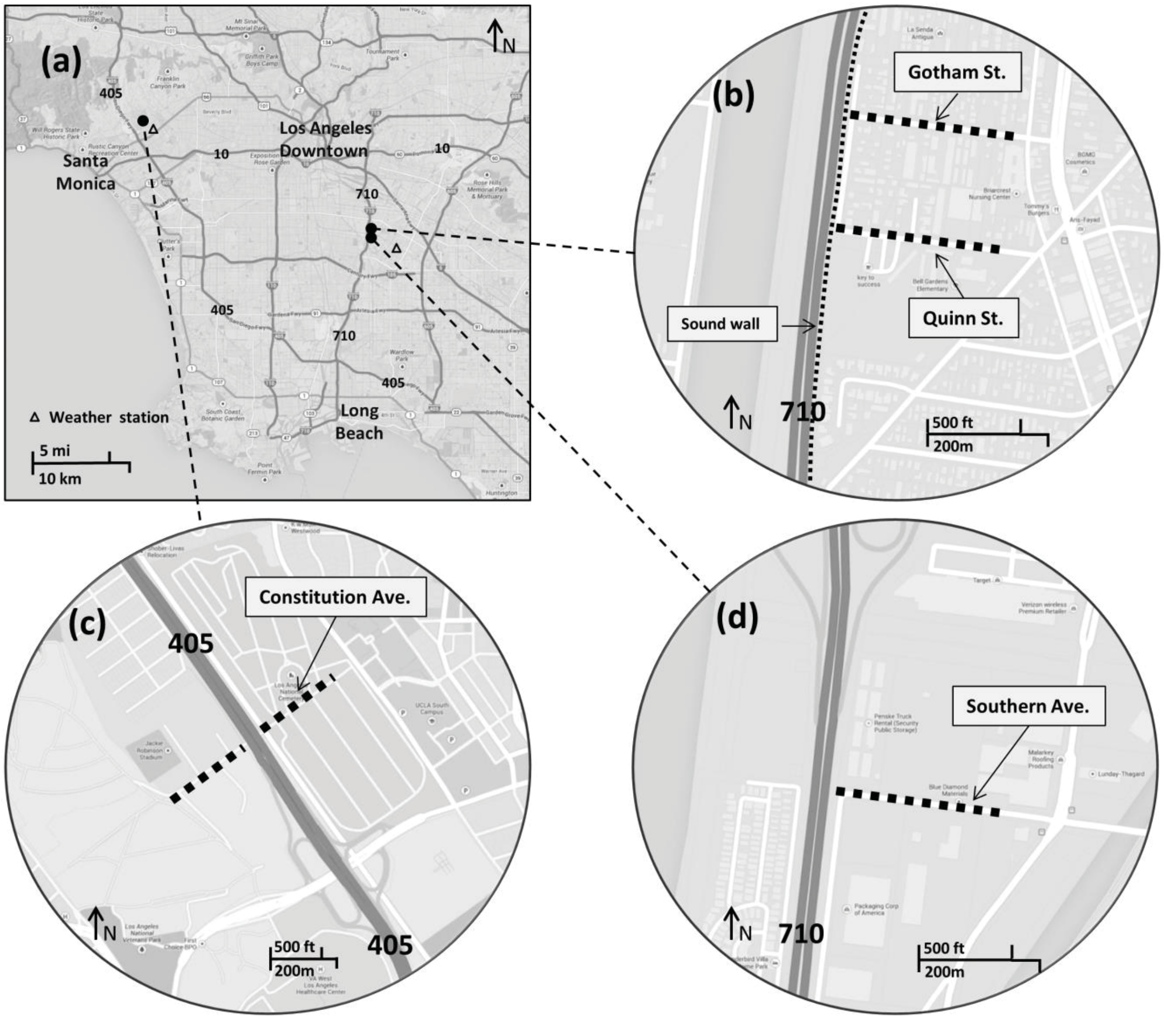

Figure 5. Maps of sampling locations. Panel (a) shows the locations of each site and near-by weather stations. Panel (b), (c), and (d) show the details of each street, as labeled individually.

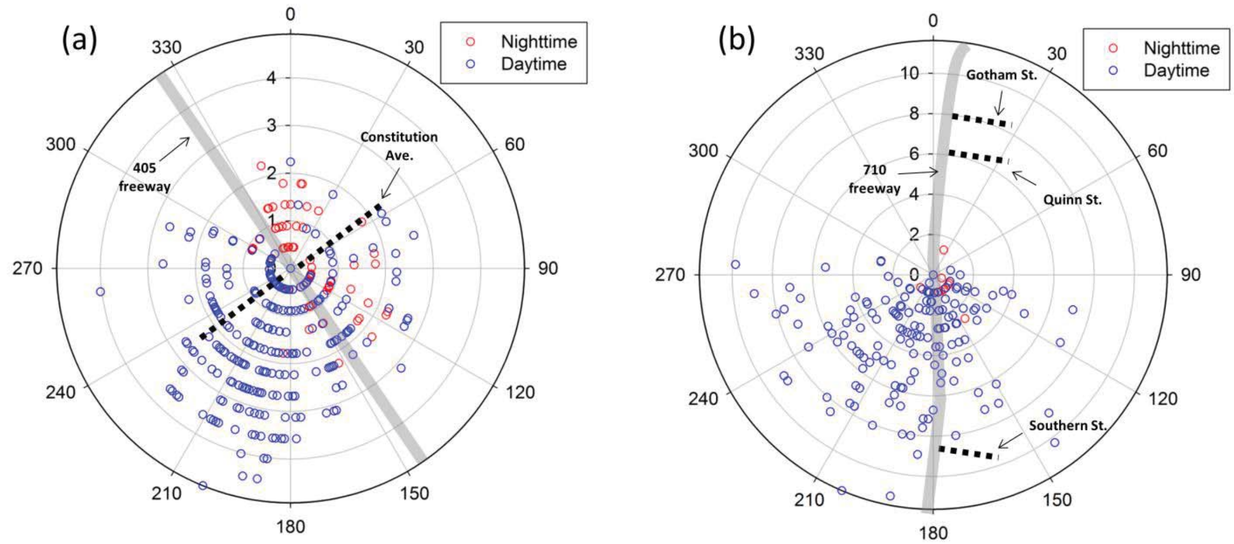

Figure 6. Wind direction and speed during the sampling days at (a) the 405 site and (b) the 710 site.

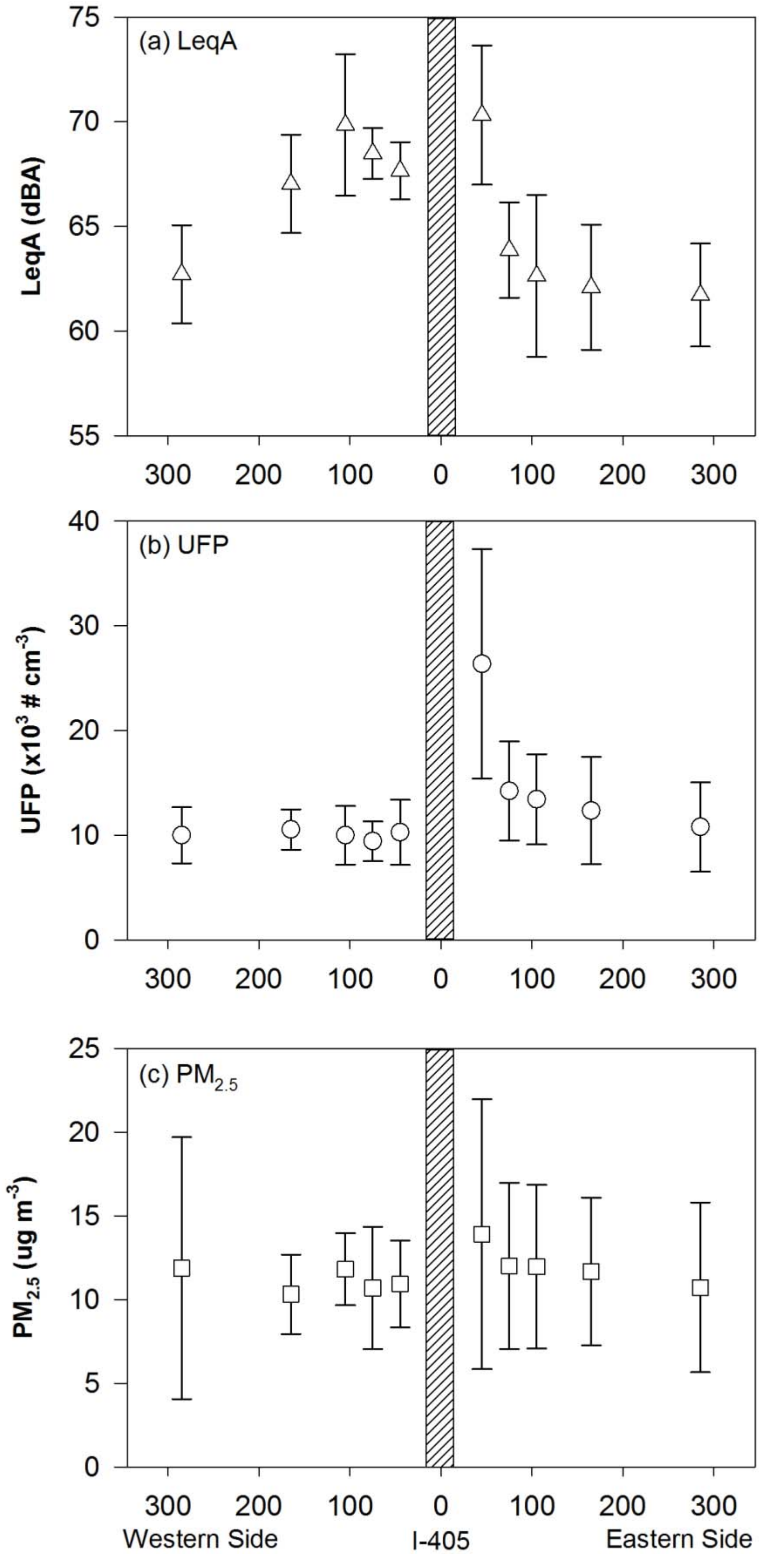

Figure 7. Noise level, ultrafine particles number concentration, and $PM_{2.5}$ mass concentration measured along Constitution Avenue.

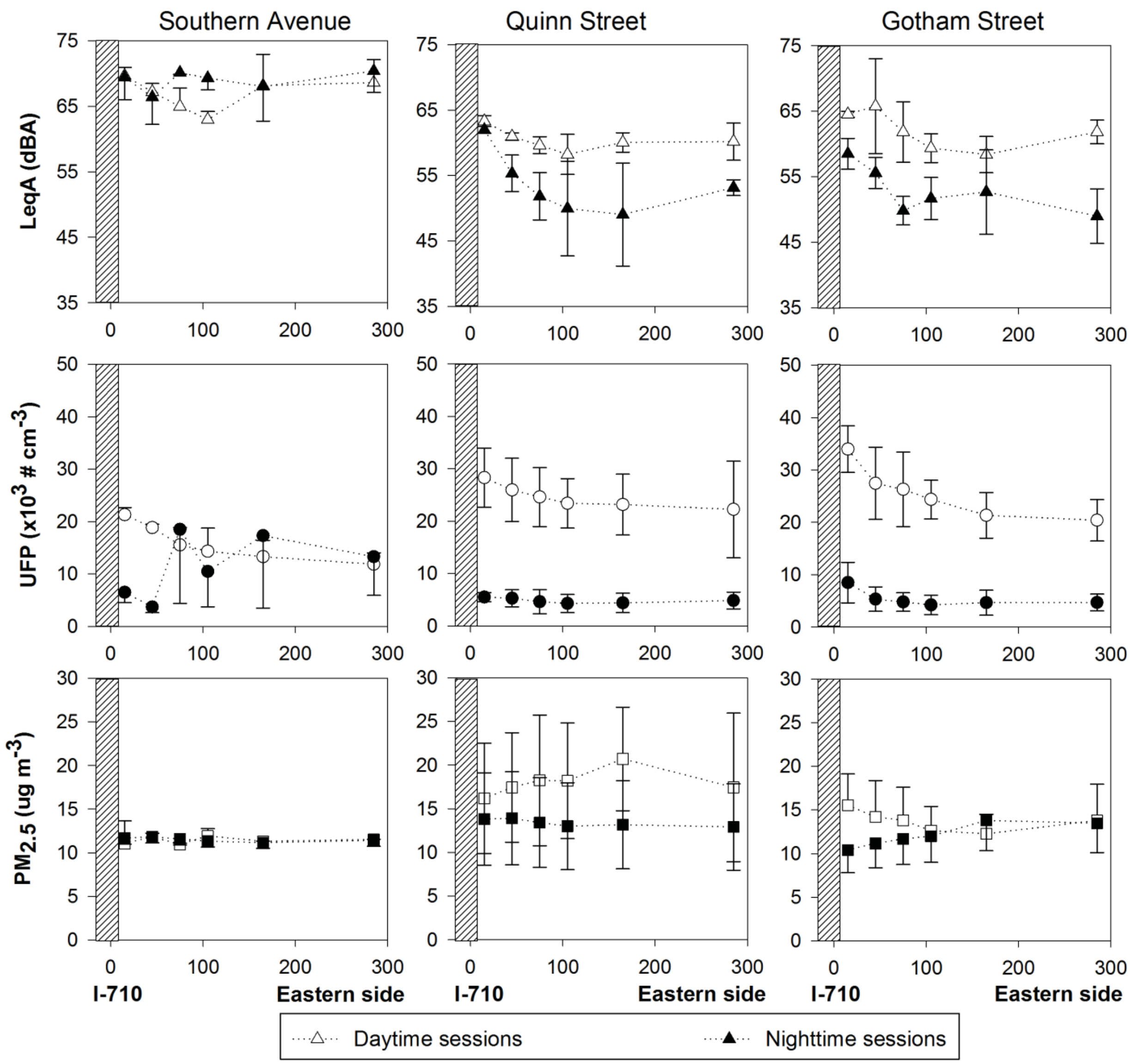

Figure 8 Noise level, ultrafine particles concentration, and $PM_{2.5}$ measured on 710 site.

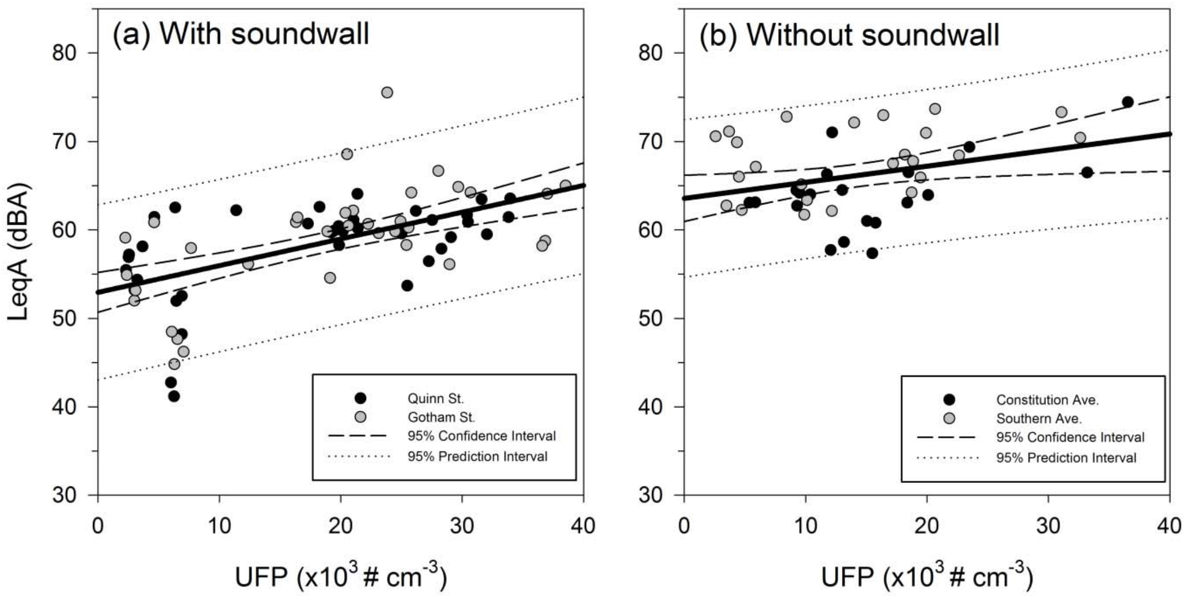

Figure 5 Correlation between particulate matter concentrations and noise level. For Constitution Avenue, only the eastern side (downwind) data were used. The linear regression and confidence interval are shown by the solid line and dotted lines, respectively.