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Puget Sound Clean Air Agency

2014 Chinatown International District Near-Road Study

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Executive Summary

Highway traffic is major source of pollution in the Puget Sound area and many highly-impacted communities. To improve our understanding of the impact of I-5 on the Seattle Chinatown – International District community, we conducted a special study in August and September of 2014. The study used regulatory monitors at the central site (10th and Weller [10&W]) which was adjacent to I-5, along with inexpensive, portable detectors (CairPol and MicroAeth), and passive collectors (Ogawa badges). We detected a strong diurnal and spatial pattern consistent with a significant source of pollution from I-5. At 10&W, carbon monoxide (CO) and black carbon increases peaked at about 300 ppb and 3 ug/m^3, respectively. The traffic pollution decreased with distance from I-5 and was close to background by 300 meters, which is consistent with most published studies. Further away, including at Bailey Gatzert Elementary, there was little detectable impact from I-5. Mobile monitoring suggested that local traffic and other sources could have measurable short term impacts on air quality over relatively localized areas, although the long term impact was not clear.

Background

Cars and trucks are major pollution sources in the Puget Sound. Together, on-road mobile sources emit more than half of the region's carbon monoxide (CO) and nitrogen oxides (NOx), about one third of all volatile organic compounds (VOCs), and about 10% of the fine particulate matter (PM). A substantial portion of the region's population lives in close proximity to the major highway sources. More than 100,000 people live within 100 meters of major highways, and more than 200,000 live within 200 meters. EPA's COBRA model suggests that at least 50-100 premature deaths occur per year due to pollution from highway transportation sources. Air quality researchers have increasingly targeted the near-road environment and identified a range of health impacts from known risks such as cardiovascular disease to potential toxic, childhood development, and neurological problems.

In response to the developing science, in 2010 EPA adopted an NO_2 near-road rule that established siting criteria and ambient standards. In 2014 the Washington State Department of Ecology established a near-road site at 10th and Weller to comply with the new NO_2 rule and to further investigate the near-road environment. The site also houses fine particle and black carbon instruments.

Previous work to identify sensitive populations and highly impacted neighborhoods had identified the Chinatown International District neighborhood as a priority community. In order to leverage data collected at the new 10th and Weller, we selected the adjacent neighborhood for an intensive monitoring campaign. The motivation for the study included the following scientific questions:

1. Can any relatively small, portable instrument quantify the gradient (above background) of the emissions from mobile sources on I-5 (including both gasoline and diesel vehicles)?

2. What are the concentrations of important air pollutants within 1km of the 10th and Weller near-road monitor (Chinatown International District neighborhood)? Are pollution levels generally less than at the near-road monitor?
3. Does Bailey-Gatzert Elementary School have any impact from I-5?
4. How do pollutants from mobile sources vary on the micro scale?

Composite plots from Karner et al. (2010) (Figure 1) suggest that the pollutants most likely to have a strong gradient near a roadway are CO, elemental carbon, NO, NOx, some VOCs, and ultrafine (< 0.3 um) particles.

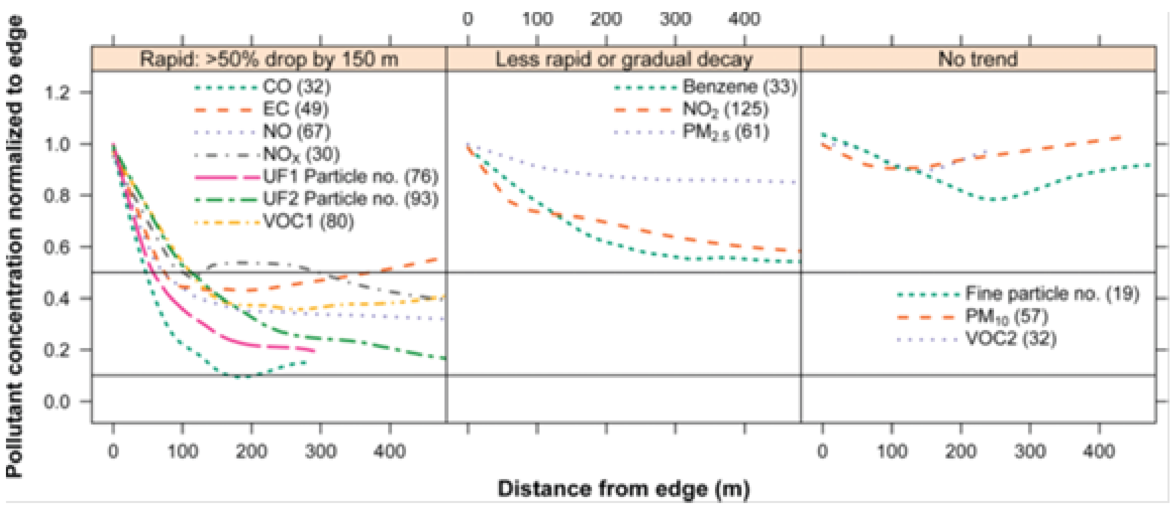

Figure 1 — From Karner et al., 2010. Gradients of pollution as a function of distance from the road. These are categorized as rapid decrease (left), gradual decrease (center), and no decrease (right). Karner, A., Environ. Sci. Technol. 2010, 44, 5334–5344.

The strong gradients are due to the peak concentrations (at edge or center of the road) being much higher than background, and plume dispersion (turbulent diffusion) reducing concentrations to near background within about 300m. Pollutants whose elevation in concentration is much greater than the background concentration, will decrease rapidly with distance from the highway. Pollutants whose peak elevation in concentration (enhancement above background) is a fraction of the background will appear to have little or no change. For this reason, based on the Karner et al. (2010), we would also expect benzene, NO_2, and PM2.5 have modest to small gradients, respectively. Fine particle number, PM10, and VOC2 had no clear gradient. A near-road gradient study is therefore not likely to find a strong gradient or spatial pattern if it relies on either PM2.5 mass or fine particle counts.

This study takes advantage of the standard regulatory instruments that are housed in the 10th and Weller (10&W) site, and several new portable technologies. The 10&W site included CO, NO_2, NO_x, black carbon, aerosol scatter, wind direction, and wind speed. A Radiance Research nephelometer was adapted for mobile (car based) monitoring. Three handheld devices were deployed for pole-mounted monitoring: CO CairClip, O_3+NO_2 CairClip, and black carbon MicroAethelometer. Integrated NO_2 and NOx concentrations were also measured using Ogawa badges mounted on poles at three central sites and four perimeter sites. Figure 2 shows a map of the study area and the locations of the samplers. The dates of data availability for the various monitors are shown in Table 1.

Figure 2 — Map of study area and monitoring sites. The 10th & Weller site is the location of the fixed Near-Road Monitor which was established to comply with the Near-Road NO2 rule.

1) 10th & Weller Near-Road Monitor fixed site. 2) 14th & Main. 3) 8th & Weller. 4) 12th & King. 5) 5th & Dearborn. 6) 12th & Judkins. 7) 14th & Spruce 8) 18th & Weller.

#	Site	NO_2, NOx, Ogawa Badges	Carbon Monoxide	Black Carbon	Other
1	10th & Weller	Aug 27 - Sept 10, Sept 10 - Sept 24	Continuous - Trace CO Aug 27 - Sept 19 - CairPol 1 Aug 27 - Sept 19 - CairPol 2	Continuous - Aethelometer	Continuous - Ozone, NO, NO_2, Temperature, Wind Speed & Direction
2	14th & Main	Aug 27 - Sept 10, Sept 10 - Sept 24	Aug 27 - Sept 18 - CairPol	Aug 27 - Sept 4, Sept 8-13, Sept 15-18 - MicroAeth	-
3	8th & Weller	Aug 27 - Sept 10, Sept 10 - Sept 24	Sept 2-19 - CairPol	-	-
4	12th & King	Aug 27 - Sept 10, Sept 10 - Sept 24	Aug 27 - Sept 18 - CairPol	-	-
5	5th & Dearborn	Aug 27 - Sept 10, Sept 10 - Sept 24	-	-	-
6	12th & Judkins	Aug 27 - Sept 10, Sept 10 - Sept 24	-	-	-
7	14th & Spruce	Aug 27 - Sept 10, Sept 10 - Sept 24	-	-	-
8	18th & Weller	Aug 27 - Sept 10, Sept 10 - Sept 24	-	-	-

Table 1 — Monitoring sites, pollutants monitored, dates of data availability – instrument/method.

Concentration as a function of distance from highway or major traffic

Figure 3 shows the gradient in NOx and CO as a function of distance from nearest major traffic. In some cases, the nearest major traffic was not I-5. E.g. for site #5, the pole was located about 40 ft uproad (against the direction of traffic) of a bus stop on S. Dearborn where it intersects with Seattle Blvd. S. and the exit of the I-90 express lanes is about 40 m to the SW. Both NOx and CO decrease by about 50% (from above background) by 100 meters and are not distinguishable from background by 200 meters.

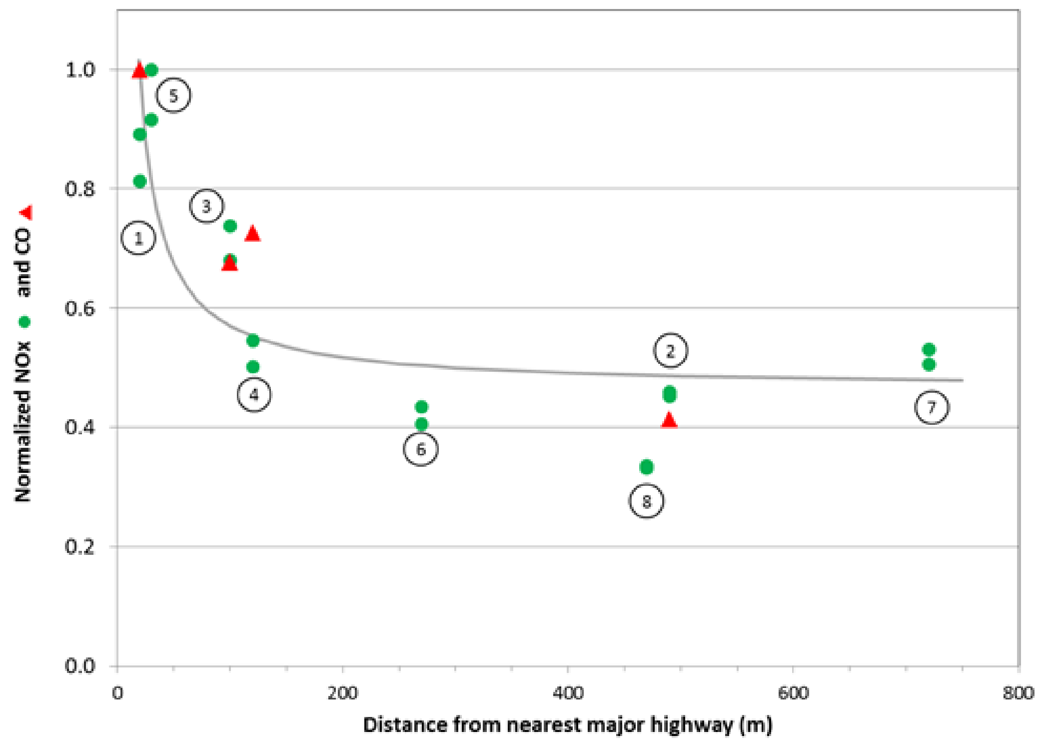

Figure 3 — Shows the gradient in NOx and CO as a function of distance from nearest major traffic. In some cases, the nearest major traffic was not I-5. E.g. for site #5, there was substantial traffic with about 50 meters from the exit of the I-90 express lanes and traffic along Seattle Blvd S. The gray line is a linear fit of the normalized concentration and 1/distance.

Diurnal patterns at the regulatory site

Figure 4 shows the average diurnal pattern of CO at four different sites, identified per Table 1. Note that both CO CairPol devices at 10 & Weller appeared to respond more slowly to the rise in CO in the morning and then build higher in the afternoon. This could be due to artifacts of the solid state CO detection method used in the CairPol devices. Also, the CairPol device at 14th & Main (site #2) appeared to be about 100 ppb lower than then all other devices. It is not clear at this time if this difference is an accurate reflection of different sources and dispersion or is an instrument bias, or some combination of both.

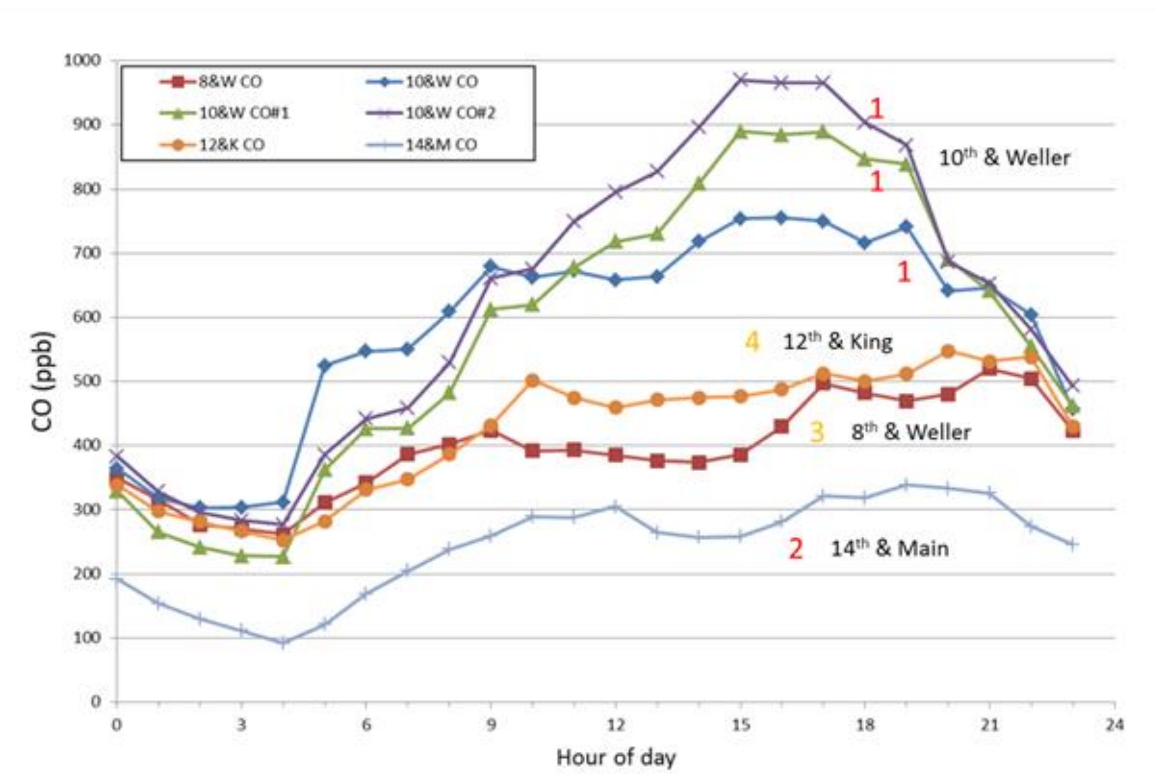

Figure 4 — Shows the average diurnal pattern of CO at four different sites, numbered per Table 1. Note that both CO CairPol devices at 10 & Weller appeared to respond more slowly to the rise in CO in the morning and then build higher in the afternoon. The 14th & Main CairPol device may have a negative offset.

The diurnal patterns are consistent with our expectation of the strongest source in the area being traffic (mostly I-5 and I-90) and the influence dropping exponentially with distance.

Concentrations as a function of wind direction

Figure 5 shows a wind pollution “rose” plot at 10th & Weller. Four pollutants, PM2.5, black carbon, NO, and CO are plotted as a function of wind direction, with the concentrations all normalized. As expected, the best tracers of highway mobile source pollution (the NO and black carbon, and to a lesser degree the CO) peak when the winds come from the WSW to WNW, which matches the location of I-5 just to the west. Correspondingly, the lowest pollution levels were observed when the winds were from the ESE to NNE, which would have pollution from only arterial and neighborhood traffic.

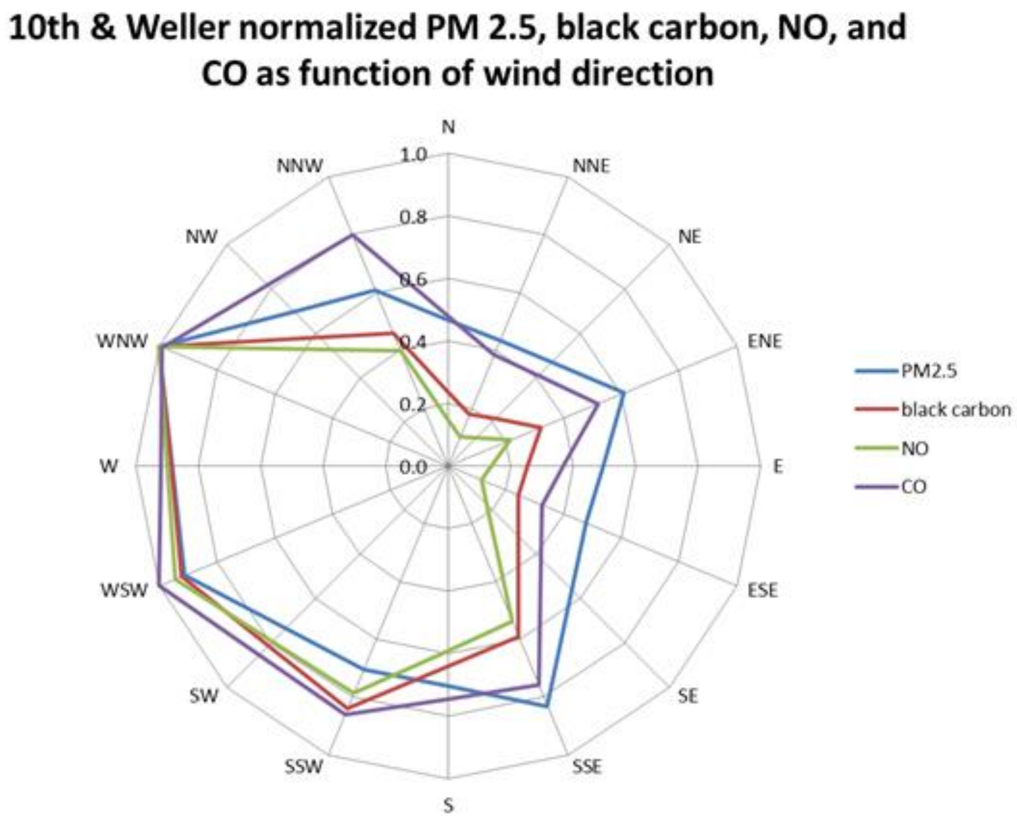

Figure 5 — Shows the normalized concentration of PM2.5, black carbon, NO, and CO as a function of wind direction. Black carbon and NO are generally good tracers of mobile sources and particularly heavy duty diesel. CO is also a good combustion tracer and so also shows a consistent directional pattern. PM2.5 has a weaker directional trend as would be expected (e.g. Figure 1 [Karner et al., 2010]).

Figure 6 shows a similar plot from the other CairPol CO sites. Both sites located to the east of I-5 (12th & King, 14th & Main) have the highest pollution levels when the winds were from the west, but the difference with respect to the other directions is much smaller than at 10th & Weller. The site located to the west of I-5, 8th & Weller, has nearly uniform pollution levels with respect to wind direction, with a minor spike to the SSE, and a minor dip to the SSW. These plots are consistent with the influence of I-5 being significantly weaker by about 100 m from the road.

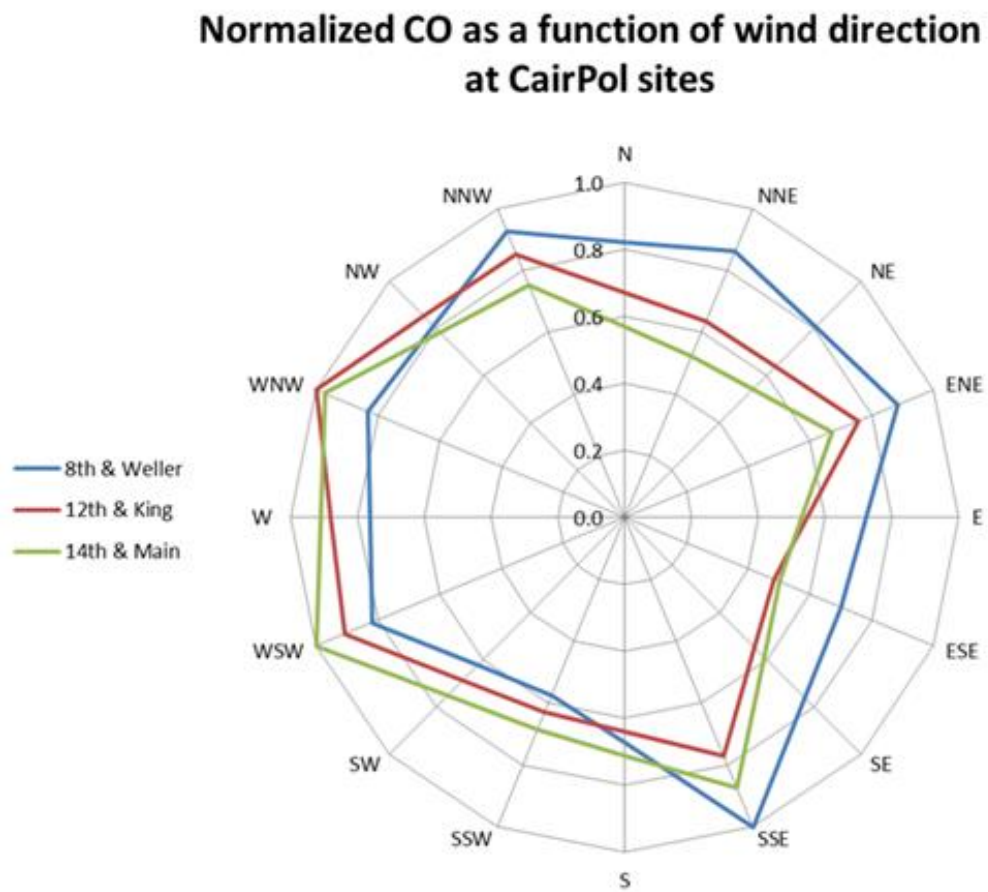

Figure 6 — Shows the directional dependence of CO measured at three sites, not including 10th and Weller. There is a weak directional dependence that is still consistent with I-5 as the major influence: 12th and King is to the east of I-5 and so has higher CO in the westerlies. 14th and Main also has higher CO from the westerlies which could be due to closer traffic on MLK Way, which was just to the west. 8th and Weller was more uniform which could be due to less frequent easterlies or other sources to the west.

Meteorological influences, time series and diurnal pattern

Figure 7 shows a time series at 10th & Weller of daily average PM2.5, NO, NOx, black carbon, wind speed, wind direction (scalar average), and temperature. The pollutants are fairly well correlated as daily averages, but do not exhibit any strong trend with temperature, wind speed, or wind direction. There was a fairly consistent diurnal wind pattern and so the wind direction (calculated as a scalar) is probably not a particularly meaningful metric. The pollution levels over this period were low to moderate with a few brief spikes.

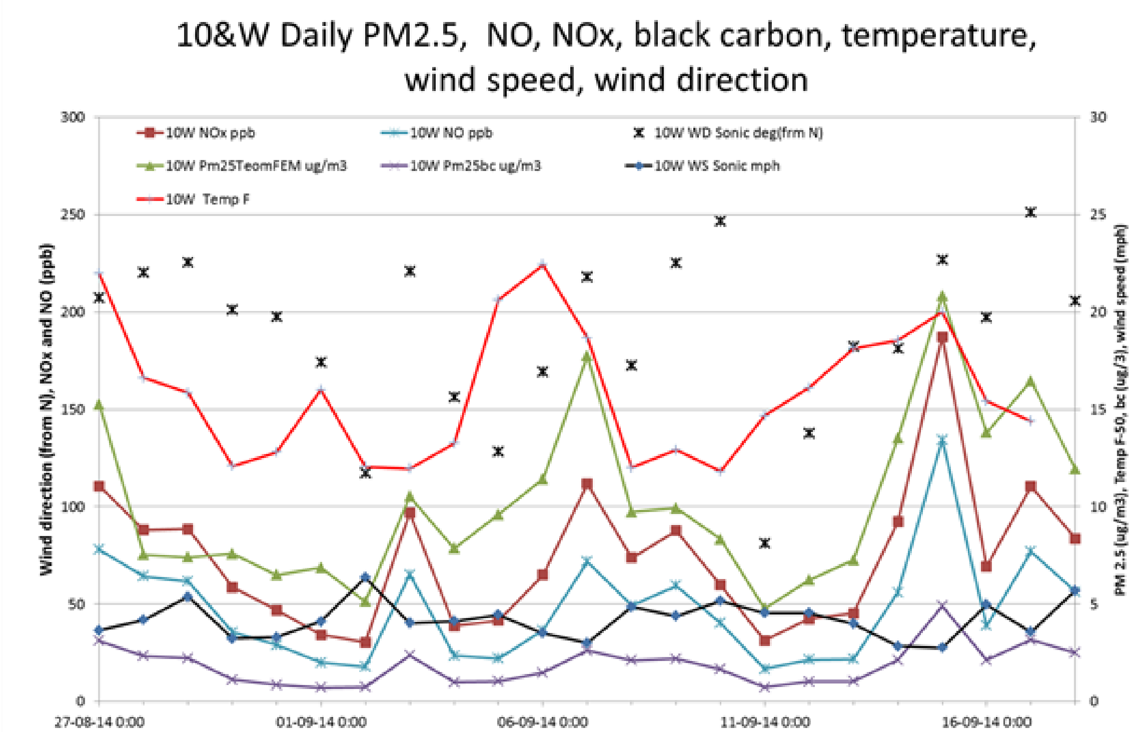

Figure 7 — Time series of daily PM2.5, NO, NOx, black carbon, temperature, wind speed, and wind direction. The temperature scale has been shifted to allow it to be plotted on the same axis. PM, NO, and NOx are modestly correlated. Wind speeds were generally light, and neither wind speed nor wind direction appeared to be correlated with any pollutant on a daily basis.

Figure 8 shows the diurnal pattern of the two pollutants and wind speed and wind direction at 10th & Weller. The pollutants are CO and black carbon, which are good proxies for the general highway pollution, and diesel pollution, respectively. On average, the wind speed increases throughout the day until midafternoon and then decrease to a minimum around midnight. The increase in wind speed through midafternoon should, all else equal, lead to decreasing impact from both CO and black carbon.

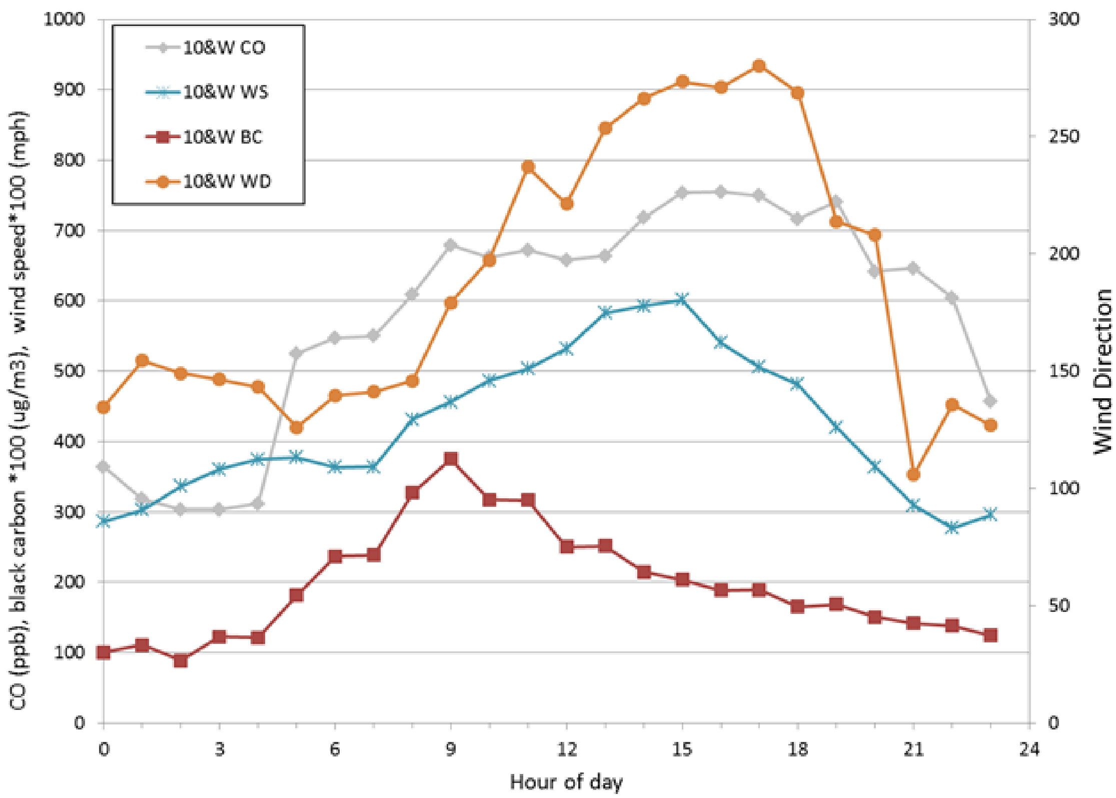

Figure 8 —Diurnal pattern of 10th and Weller (fixed site) monitors for carbon monoxide, black carbon, wind speed, and wind direction. The black carbon is a fair proxy for diesel traffic and the carbon monoxide for total vehicle traffic. In order to plot the values on the same vertical axis, the values of black carbon and wind speed have been multiplied by 100. The increase in wind speed through the day would likely lead to decreasing impact from both CO and black carbon. The shifting wind direction from SSE (~150) to W (~270) would likely increase the impact of mobile emissions of CO and black carbon from I-5. The peak time of the black carbon is consistent with a peak in diesel truck traffic in the morning that has been observed on other sections of I-5.

But the shifting wind direction, from SSE (~150) in the early morning, to W (~270) by midafternoon, would act to increase the impact of mobile emissions of CO and black carbon from I-5. The combined effect may be too complicated for a simple qualitative analysis, or there may be other factors that we have not identified. Nonetheless, the peak time of the black carbon is consistent with a peak in diesel truck traffic in the morning that has been observed on other sections of I-5. And, the CO peaking in the late afternoon or early evening would be consistent with the shifting of the wind direction in combination with morning and late afternoon peak traffic.

Correlations among parameters

Table 2 contains the Pearson's correlation coefficients for the daily average 10th & Weller data. The four best indicators of on-road pollution sources (CO, NOx, NO, and black carbon) are all well correlated ($r \geq 0.89$), PM2.5 is fairly well correlated to those four ($r \geq 0.81$) and 0_3+NO_2 is modestly well correlated with all of them ($r \geq 0.68$). There is a weak inverse correlation with wind speed, as would be expected for a source that is constant in time and not wind-speed dependent.

	CO	*NOx*	*PM2.5*	*bc*	*NO*	*O3+NO2*	*WD*	*WS*	*NO2*	*uv*
NOx	0.93	1								
Pm2.5	0.84	0.86	1							
bc	0.89	0.98	0.87	1						
NO	0.90	0.99	0.82	0.98	1					
O3+NO2	0.68	0.73	0.81	0.73	0.70	1				
Wind Direction	0.60	0.66	0.52	0.65	0.67	0.46	1			
Wind Speed	-0.57	-0.45	-0.51	-0.32	-0.41	-0.41	-0.27	1		
NO2	0.95	0.96	0.92	0.92	0.92	0.77	0.59	-0.53	1	
uv	0.91	0.98	0.88	1.00	0.98	0.74	0.64	-0.36	0.94	1
Temp F	0.50	0.32	0.47	0.30	0.28	0.48	-0.07	-0.45	0.43	0.33

Table 2 — Pearson's correlation coefficients for the parameters measured at the 10th and Weller fixed site. The parameter abbreviations and full names are: CO (carbon monoxide), NOx (NO + NO2), PM2.5 (fine particles with diameters < 2.5 micron diameters), bc (black carbon), NO (nitric oxide), O3+NO2 (ozone + nitrogen dioxide), WD (wind direction), WS (wind speed), NO2 (nitrogen dioxide), uv (ultraviolet absorption). Correlations with magnitudes > 0.8 are highlighted in pink, correlations with magnitudes (absolute value) between 0.5 and 0.8 are highlighted in yellow.

Performance of the portable instruments

Figure 9 shows a time series at 10th & Weller of CairPol CO instruments compared to the regulatory CO monitor. Over this period, the CairPol sensors show a good correlation with the reference instrument and a similarly fast response. The CairPol sensors, however, appear to have some temperature dependence and may have some drift in the response slope (span) or offset. Considering the size [cylinder 3.5 cm diameter x 8 cm long (~1.5 inches x 3 inches)] and cost (~$1500) of the CairPol sensors, the performance is very good compared to the regulatory instrument.

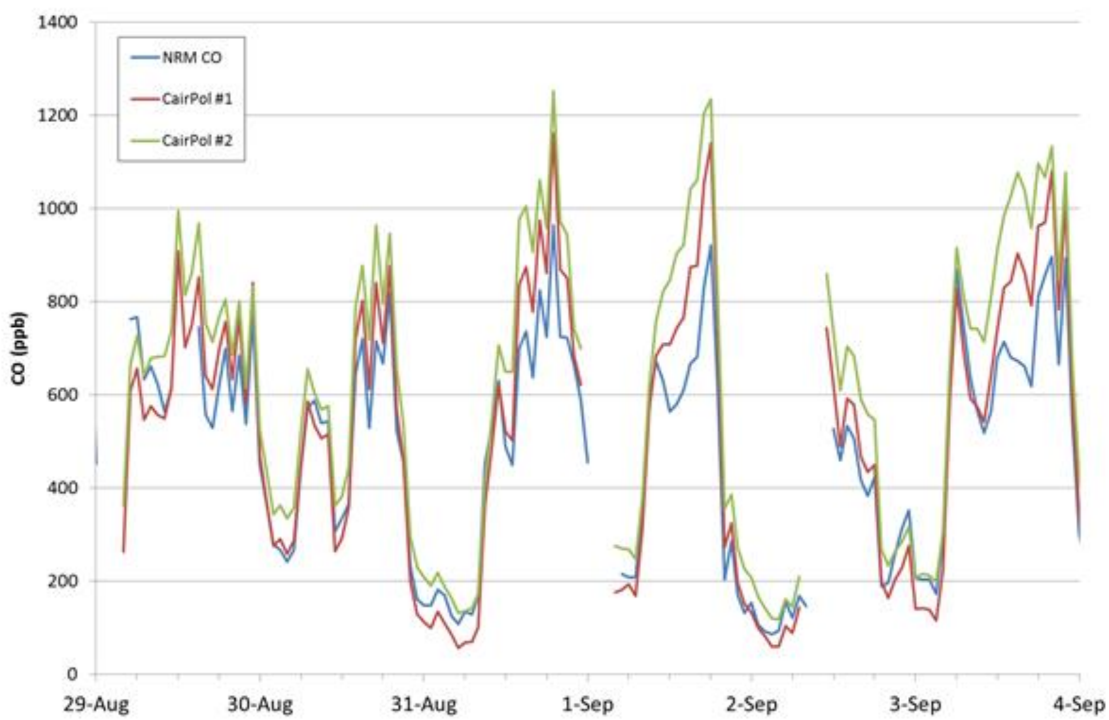

Figure 9 — Timeseries of collocated carbon monoxide (CO) data taken at the near-road monitor (NRM) site 10th & Weller. NRM CO indicates the CO data obtained from the regulatory approved CO instrument at the site. CairPol #1 and #2 are the two (portable and less expensive) CairPol sensors being tested. The CairPol sensors show a good correlation with the reference instrument and a similarly fast response. The CairPol sensors, however, appear to have some temperature dependence and may have some drift in the response slope (span) or offset.

Mobile Monitoring

Figure 10 shows the data availability for the mobile monitoring. Most of the runs consisted of two loops through the whole study area with the time divided approximately equally between quadrants. Technical problems prevented scattering and CO from being collected on the first two days of mobile runs.

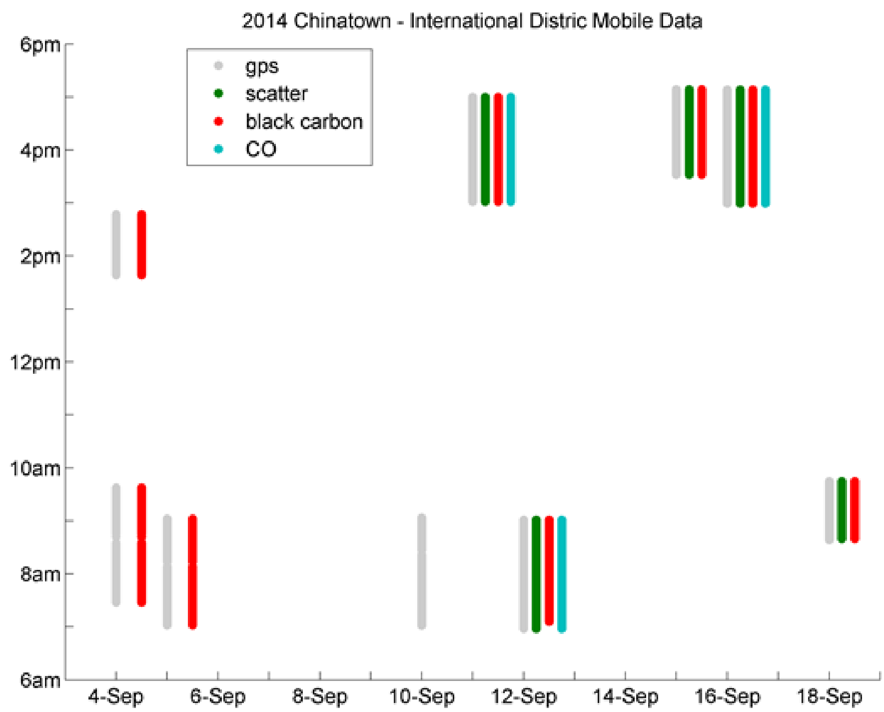

Figure 10 — Data availability for mobile runs. All CO data were collected with CairPol solid state sensors and all black carbon data were collected with a MicroAeth.

Figures 11-13 shows mobile data averaged into a regular hexagonal grid with cells of 500 ft and 100 ft widths (2*apothem). The parameters plotted are, respectively, PM (scattering), black carbon, and CO. The color scale is the same for both cell sizes of each respective pollutant. But, the color scale doesn't correspond to any established air quality standard or health risk; it matches the range of the values of the 500 ft cells of each respective pollutant. For all of the pollutants, several of the cells in the 100 ft grid were outside of the range (below or above) of values from the 500 ft grids and so are colored light yellow and outlined in black.

These plots represent data collected from five runs (2 morning + 3 afternoon) of PM data, 8 runs (4 morning + 4 afternoon) with black carbon, and three runs (1 morning + 2 afternoon) with CO data.

In Figure 11, the highest pm levels were observed along the western edge of the mobile study area, which was along 4th Avenue. No other clear patterns or structures appear in either the 500 ft or 100 ft grids.

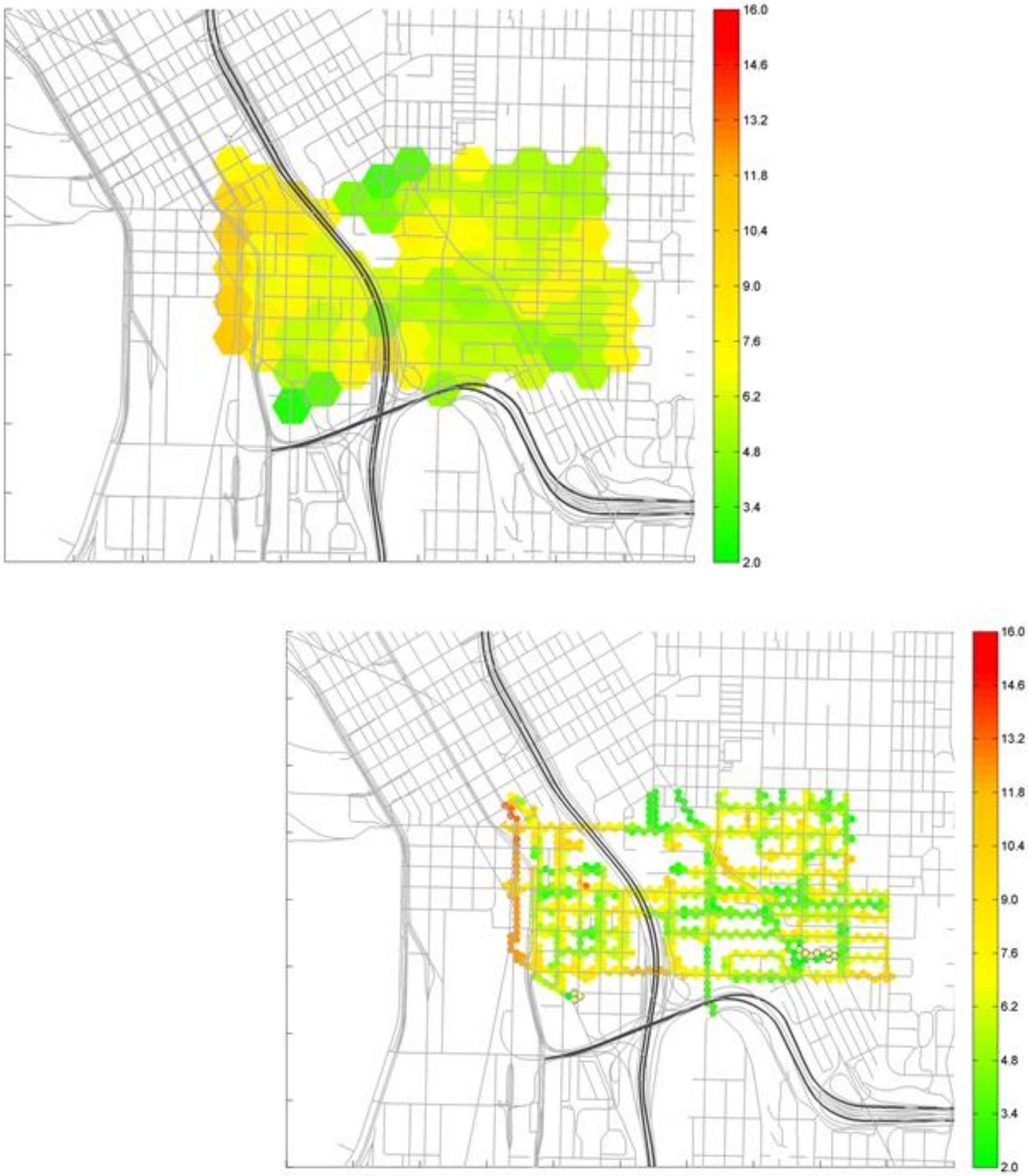

Figure 11 — Mobile monitoring results for PM (nephelometer) in ug/m3. 500 ft cells (top) and 100 ft cells (bottom).

In Figure 12, black carbon is highest near where S. Jackson St. crosses under I-5, and roughly in the area between 5th & Weller and 8th & S. Dearborn St. There does not appear to be a clear spatial pattern or gradient from I-5 observable in the black carbon data.

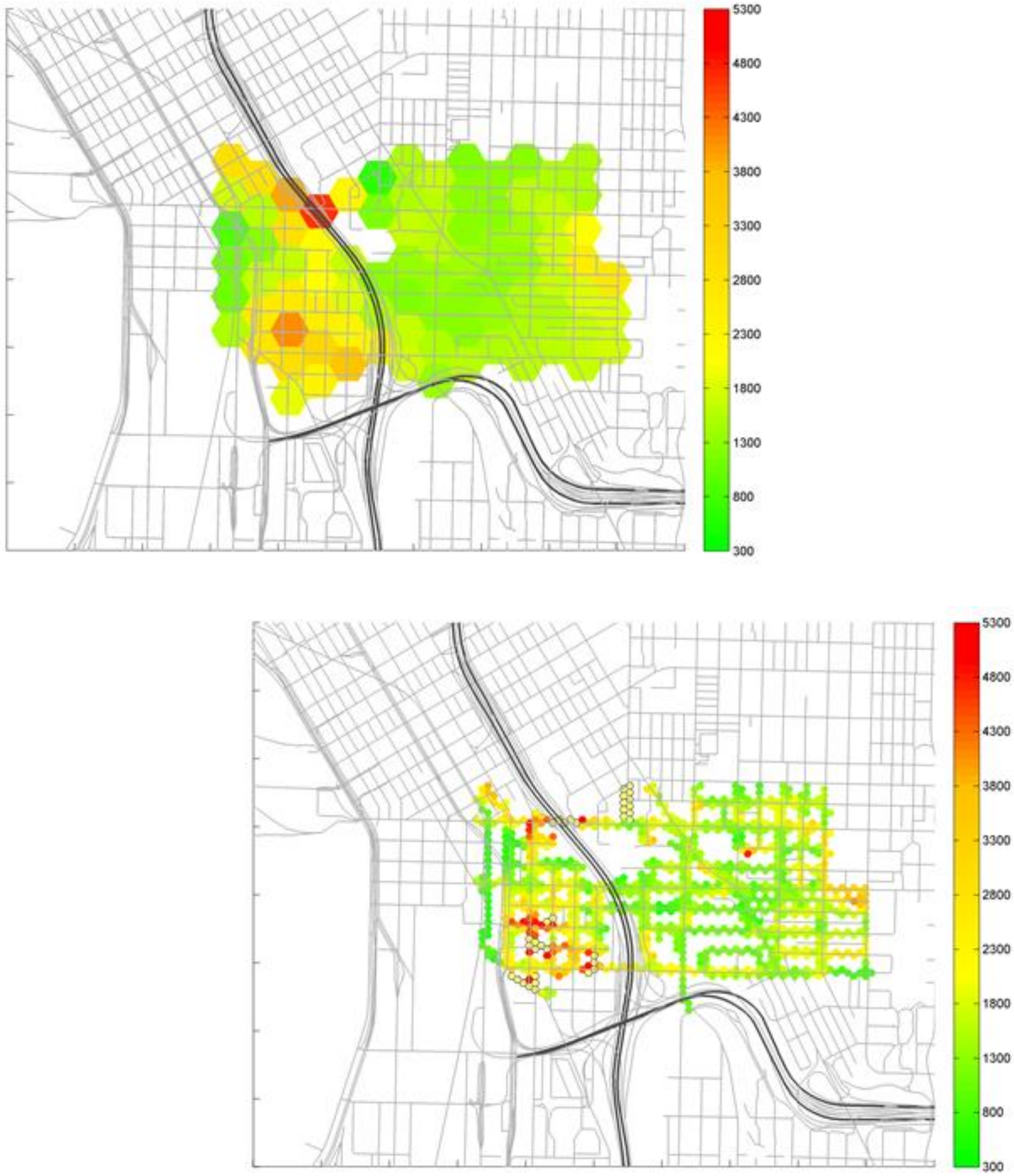

Figure 12 — Mobile monitoring results for black carbon in ug/m3. 500 ft cells (top) and 100 ft cells (bottom).

In Figure 13, elevated CO is observed in the south eastern portion of the study area and in a couple of isolated locations to the west of I-5. There does not appear to be a clear spatial pattern or gradient from I-5 that in observable in the data.

Figure 13 — Mobile monitoring results for CO in ppb. 500 ft cells (top) and 100 ft cells (bottom).

Analysis

The strong correlation (r=0.92) of PM and NO_2 at the 10^{th} & Weller site allowed the PM to be estimated at the sites that had Ogawa badges (and therefore NO_2). The estimate was made by applying the slope and intercept of the ordinary least-squares correlation between the NO_2 and PM at 10^{th} & Weller to the average NO_2 values at each site. This assumes that both the PM and NO_2 at the sites are dominated by, or occur in the same ratio as the 10^{th} & Weller site. All sites were < 8 ug/m^3 . For reference, the health-based annual average national ambient air quality standard for fine particles is 12 ug/m^3, and 6 of 8 sites were $\leq$ 6 ug/m^3.

Conclusions

Can any relatively small, portable instrument quantify the gradient (above background) of the emissions from mobile sources on I-5 (including both gasoline and diesel vehicles)?

The new technologies and sampling approach generally worked. The CairPol CO sensors appeared to respond fairly reliably with minimal noise and drift for an urban area with pollution in the moderate ranges. The CairPol's performance, considering its cost, size, and simplicity, is excellent. The second instrument tested, the MicroAethelometer, performed as advertised. But, the ambient concentrations were mostly near the instrument's detection limit, and so no spatial patterns were apparent. The pole-mounted approach with the CairPol detectors produced the best result for the costs and effort.

What are the concentrations of important air pollutants within 1km of the 10^{th} and Weller near-road monitor (Chinatown International District neighborhood)? Are pollution levels generally less than at the near-road monitor?

At the 10^{th} and Weller near-road monitor, the following suite of pollutants are closely correlated, so likely have a common source: CO, PM2.5, NOx, and black carbon. The diurnal pattern and wind direction pattern are both consistent with cars and trucks on I-5 as being dominant source of this pollution.

The pollution levels appear to drop off within a few hundred meters from I-5/I-90 exit, consistent with other reports of on-road mobile sources. Further away from I-5/I-90 exit, there also appeared to be some impact from neighborhood traffic, but to a much smaller extent. It's likely that pollutant concentrations in the Chinatown ID neighborhood (> 200 m from I-5/I-90) are generally lower than concentrations measured at the near-road 10^{th} and Weller site.

Does Bailey-Gatzert Elementary School have any impact from I-5?

Our sensors at Bailey Gatzert Elementary School indicated I-5 was unlikely to have more than a minor impact at the school. And, the fine PM, CO, and NOx concentrations appeared to be well below the National Ambient Air Quality Standards (NAAQS) if data collected during the study period can be extrapolated to the three year period needed to compare to the NAAQS.

How do pollutants from mobile sources vary on the micro scale?

The mobile monitoring produced some useful data, but it required more resources to collect and post-process the data than our fixed site samplers. Due to the small number of mobile runs (3 for CO, 5 for light scatter/PM, and 8 for BC) it is difficult to interpret the results (figures 11-13) and draw any strong conclusions.