USC Urban Trees Initiative

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Research Brief: Distribution of Air Quality Across Los Angeles Using the Carbon Census Network

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The Challenge

Air Quality (AQ) includes gaseous compounds (ozone, carbon monoxide, nitrous oxides) and particulate matter (PM) — both are very sensitive to the pattern of wind movement throughout the city but also have different emission sources and removal mechanisms. Thus, predicting the distribution and concentration of AQ constituents in space and time is complicated. The influence of urban vegetation on AQ is also complicated (and discussed further in another Brief), but certainly, the 'built' and 'natural' environments of Los Angeles influence AQ on a neighborhood scale. Trees add many, many benefits to urban settings: shade at street level, cooling via transpiration, esthetic qualities, increased biodiversity, pollutant and CO_2 uptake, etc. Before we can attribute firm AQ benefits to urban vegetation, we need to know neighborhood-scale concentrations of various pollutants.

The Research

The USC Urban Trees Initiative (USC Trees) partnered with the City of Los Angeles to meet the challenge of documenting and interpreting urban AQ. Led by Will Berelson, Jinsol Kim, Pietro Vannucci and Thaomy Vo from USC's Dornsife Earth Sciences, the team deployed a dozen Carbon Census sensors throughout mid-city (whereby CalEnviroScreen has only one PM sensor for this entire region). These sensors have an orientation aligned with the airflow patterns in L.A., primarily from West to East (see Figure 1), which allows for a unique approach to modeling contaminant emissions. These sensors straddle mid-city, across the intersections of four major freeways, and extend to regions eight km west of downtown, surrounded by more suburban environments.

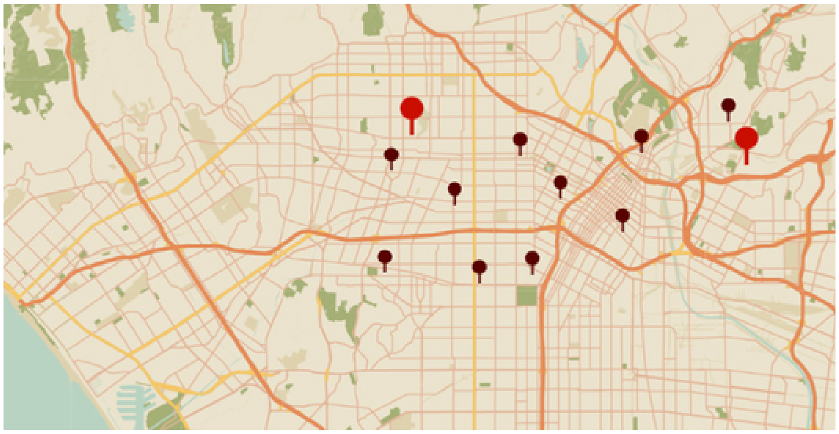

Figure 1: Left: The location of Carbon Census sensors in central Los Angeles. Two red pins denote the location of Murchison Elementary School (on the right, east side) and Third Street Elementary School (on the left, west side). PM data for these schools are presented below. **Right:** The sensor box (foreground) deployed on a school rooftop.

Background on PM

Particulate matter is composed of solids and liquid droplets suspended in air and is classified by their diameter. Particles that are 2.5 microns or less are considered fine particulate matter ($PM_{2.5}$) and are of special concern as their size allows these particles to be inhaled and deposited deep in the lungs, leading to respiratory and cardiovascular diseases and even premature death (Correia et al., 2013, Fang et al., 2013, Kim et al., 2015). Children, older adults, and those with preexisting lung or heart disease are the most vulnerable demographics (Sacks et al., 2011, Cadelis et al., 2014).

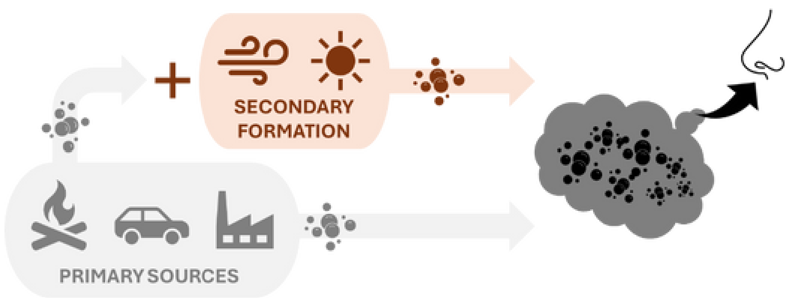

Figure 2: Primary and secondary sources of PM.

As depicted in Figure 2, PM can be emitted directly through processes like fossil fuel combustion (primary formation) or formed through chemical reactions in the atmosphere (secondary formation), and its dispersion can depend on wind speed and direction (Hasheminassab et al., 2014, Elminir, 2005). This makes PM difficult to control as its concentration can vary based on emission sources and meteorological conditions.

PM at two schools on either side of LA

In the Ramona Gardens neighborhood of East LA, Murchison Street Elementary School sits within a two-mile radius of three interstate highways. On the other side of the sensor array is Third Street Elementary School, situated away from highways in the Hancock Park neighborhood of West LA. Comparing the PM concentrations between these two schools, we hope to answer the following questions:

1. **Primary Sources:** How does the proximity of schools to pollution sources impact $PM_{2.5}$ exposure?
2. **Vulnerable Demographics:** When are school children most likely to be exposed to high levels of $PM_{2.5}$?

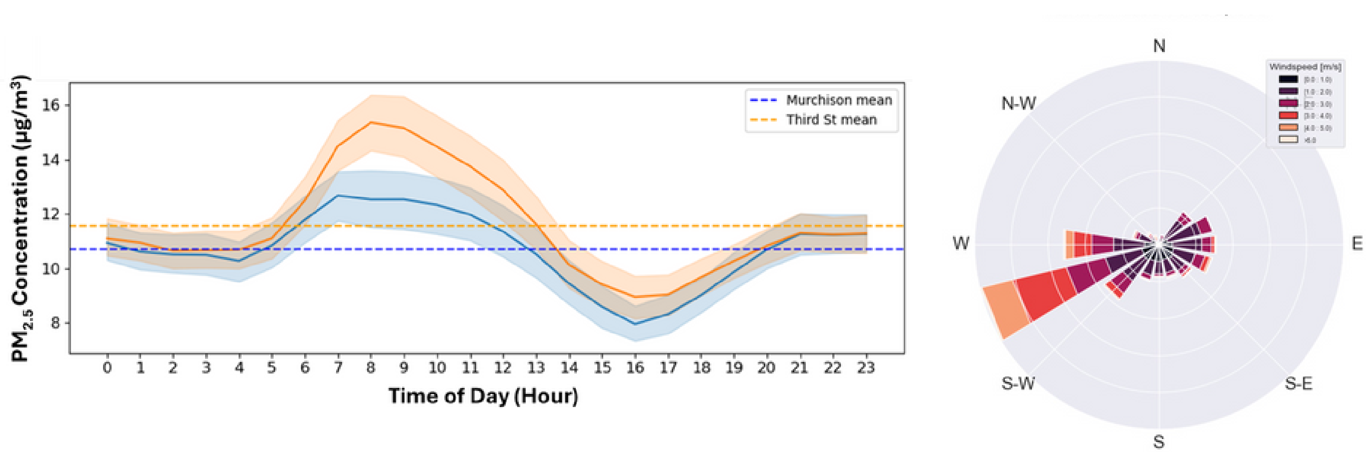

Figure 3: **Left:** Annual average $PM_{2.5}$ concentration for different hours of the day at two LAUSD schools across the year 2022. **Right:** Wind rose diagram showing wind direction frequency (length of wedge) and wind speed (color coded) over annual average in central Los Angeles. Wind is predominantly coming from the W, S-W.

The Key Findings

1. There was no pollution proximity effect for schools near freeways due to rapid air mixing: Although we expected Murchison Street Elementary to experience higher PM levels due to its proximity to freeways, the difference in average $PM_{2.5}$ concentrations was less than 1.0 $\mu g/m^3$ (Figure 3) and the school furthest from freeways had higher average PM (11.6 $\mu g/m^3$) than the school closer to freeways (10.7 $\mu g/m^3$). *Statistically, these values are not different.* Previous studies have found that PM concentrations decrease as we move away from sources; PM may form from freeway traffic, but it is mixed throughout the atmosphere rapidly (Weijers et al., 2004). Although only 450 meters away from the nearest freeway, Murchison Elementary does not directly detect poor air quality generated by freeway traffic.

2. PM peaks in the morning, from 7 to 11 AM: This peak is a result of increased human activity that generates more PM and a low mixed layer height that keeps PM concentrated. In contrast, $PM_{2.5}$ is lowest in the afternoon despite increased human activity because the high mixing height dilutes PM (see Figure 3). *In terms of AQ, children's health, and outdoor exercise (recess), 1-4 PM is a good time for outdoor activities, 7-11 AM is not.*

3. L.A. air is generally well mixed, but PM patchiness and distribution occur during hotter temperatures: The similarity of PM concentration between a location towards West LA and one in East LA is surprising. By looking at pairs of sensors, different distances apart, we expect to see higher correlations between close sensors and poorer correlations between distal sensors. In January-February, April-May, and October-November, PM concentrations between sensors are closely correlated (see Figure 4). Measurements made for these time periods in the morning and afternoon have correlation coefficients of >0.7, very well correlated, showing well-mixed air throughout this portion of the city. Night-times and the July-August periods are different. These times show poorer correlations, suggesting PM patchiness and poor mixing. Clearly, lower winds in the evening yield more patchy PM distributions.

But July-August is markedly different. Daytime correlations during these summer months are lower than daytime correlations during other seasons and night-time correlations are much lower. Secondary PM production is related to heat, higher temperatures yield more local PM production, hence greater patchiness in its distribution. Generalizing, LA air pollution is well mixed through much of the city through much of the year, but not so much in the summer months.

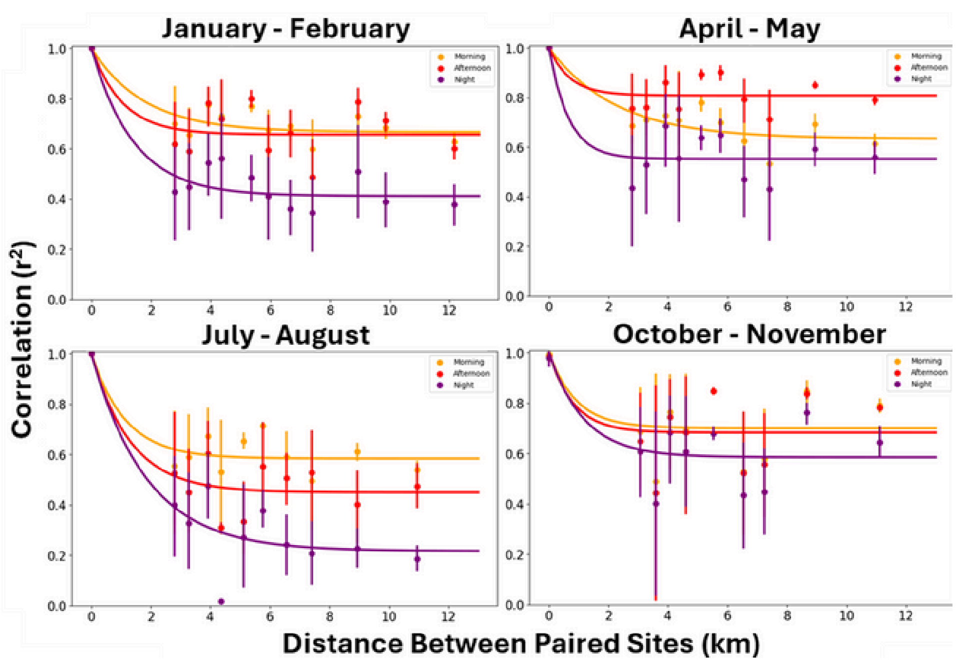

Figure 4: Correlations (y-axis) between sensors as a function of distance between sensors (x-axis) and time of day (colors) by season. Lower correlation values = more patchiness in PM.

4. Trees play an incredible role in reducing CO_2 emissions in Los Angeles

The location of Carbon Census sensors through mid-city Los Angeles allows for a modeling approach that estimates fossil fuel and total CO_2 emissions from this region. On a one-year average, July 2021-July 2022, the hourly flux of CO_2 is modeled (see Figure 5). Fossil fuel-generated emissions in mid-city average 15 µmol CO_2/m^2 sec, yet total CO_2 emissions average 9 µmol CO_2/m^2 sec. Total CO_2 emissions are attenuated dramatically during mid-day. This must be due to the *net uptake of CO_2 via photosynthesis*.

Over 24 hours, urban vegetation consumes 33% of the fossil fuel CO emitted in this portion of the city. This region is not the most vegetated portion of Los Angeles and if trees are pulling the most weight in terms of CO_2 uptake, the trees in Los Angeles must be super-consumers of CO_2. They must be taking up CO at rates 5-20 times greater than do average trees growing in a forest. In this part of LA, urban trees are a huge CO sink.

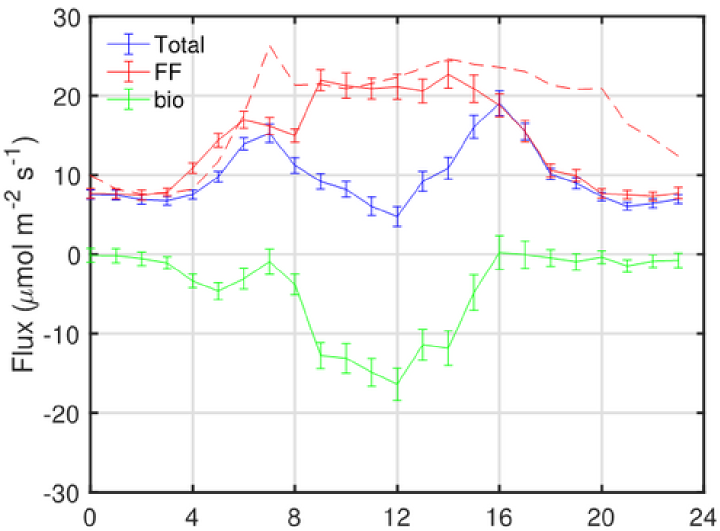

Figure 5: Analysis of hourly CO_2 emissions for July 2021-July 2022. Red line is fossil fuel emissions, blue line is total CO_2 emissions and green line is the difference between red and blue = role of vegetation. Red dashed line is a bottom-up synthesis of expected emissions in the area of our sensor array. That the red dashed line is close to the red solid line is evidence that our modelling approach is valid.

This analysis (Kim et al., 2024) provides Los Angeles City officials with a baseline emission flux against which changes in emission, targets set by city officials, can be quantified. Building out this array of sensors to incorporate a longer and broader swath of Los Angeles will allow for similar modeling and constraints on CO_2 emissions through more and less vegetated regions.

In Conclusion

The use of low-cost sensors in an array around Los Angeles provides powerful evidence of how pollutants move within the city and the important role urban trees play in mitigating CO_2 emissions. Although one expects air pollution to always be highest near the numerous L.A. Freeways, this is not observed. Buildings and urban vegetation can help create atmospheric turbulence that mixes air pollutants quite effectively. Use of array data combined with a model of air transport allows for estimates of emissions of important air quality parameters. Expansion of the sensor array will allow this analysis to incorporate a greater portion of the city.

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Research Methods

Concentrations of $PM_{2.5}$ along with sensor-specific temperature, relative humidity, and absolute humidity, were retrieved from the Carbon Census nodes stationed at Third Street Elementary and Murchison Street Elementary. To add more meteorological context, ambient temperature, boundary layer height, and u and v components of wind were taken from ECMWF Reanalysis v5 (ERA5), an atmospheric reanalysis model. The dataset spanned from January 1, 2022 to December 31, 2022, with readings recorded at an hourly interval.

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For More Information

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