Local Scale Spatial and Temporal Air Pollution Gradients in the Los Angeles Area

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Supported by the California Air Resources Board

Outline

- Introduction: health effects, methods and background
- Extended freeway plumes in the early morning
- Classifying days based on their propensity to high levels of primary pollutants
- Differences in pollutant concentration between neighborhoods
- Summary

Multiple Pathways to Increased Morbidity and Mortality are Associated with Proximity to Traffic for Adults

Mortality

- Holland - living near roadways doubled risk of death from heart or lung disease.
  (Hoek, G. et al. (2002) Lancet 360: 1203-1209.)
- Canada - living near roadways increased the risk of death due to stroke and cardiovascular disease by 40%.
  (Finkelstein, M. M. et al. (2005) J. Epidemiol. Comm. Health 59: 481-487)

Heart Attack

- Germany - the risk of a myocardial infarction was tripled by exposure to traffic in the previous hour. (Peters, A. et al. (2004) N. Engl. J. Med. 351: 1721-1730.

Other Effects

- Increase in a variety of adverse health outcomes including type II diabetes, asthma, respiratory symptoms.

Multiple Pathways to Increased Morbidity in Children are Associated with Proximity to Traffic

Prenatal Impacts

- Los Angles - women living near high heavy duty traffic areas were at increased risk of premature delivery and low birth weight babies (Ritz and Co-workers, UCLA)

Asthma Prevalence and Respiratory Symptoms

- Southern California - prevalence of asthma among children was associated with several indicators of exposure to traffic including proximity of the home to a freeway (USC Childrens health study)

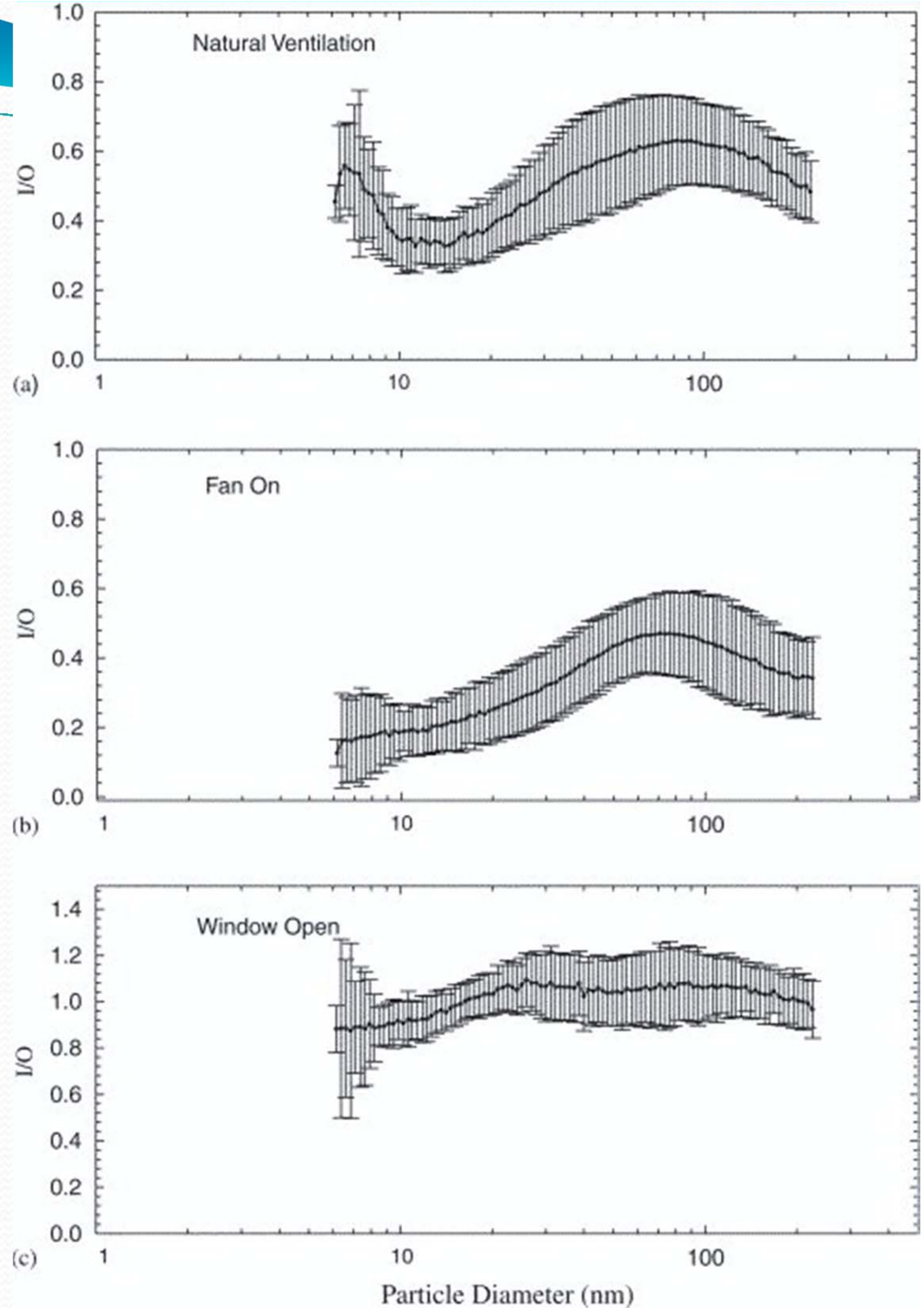
Childrens' Lung Development

- Southern California – Exposure to elevated indicators of diesel exhaust is associated with poorer lung development and lower overall lung function, conditions that are largely irreversible (USC Childrens health study)

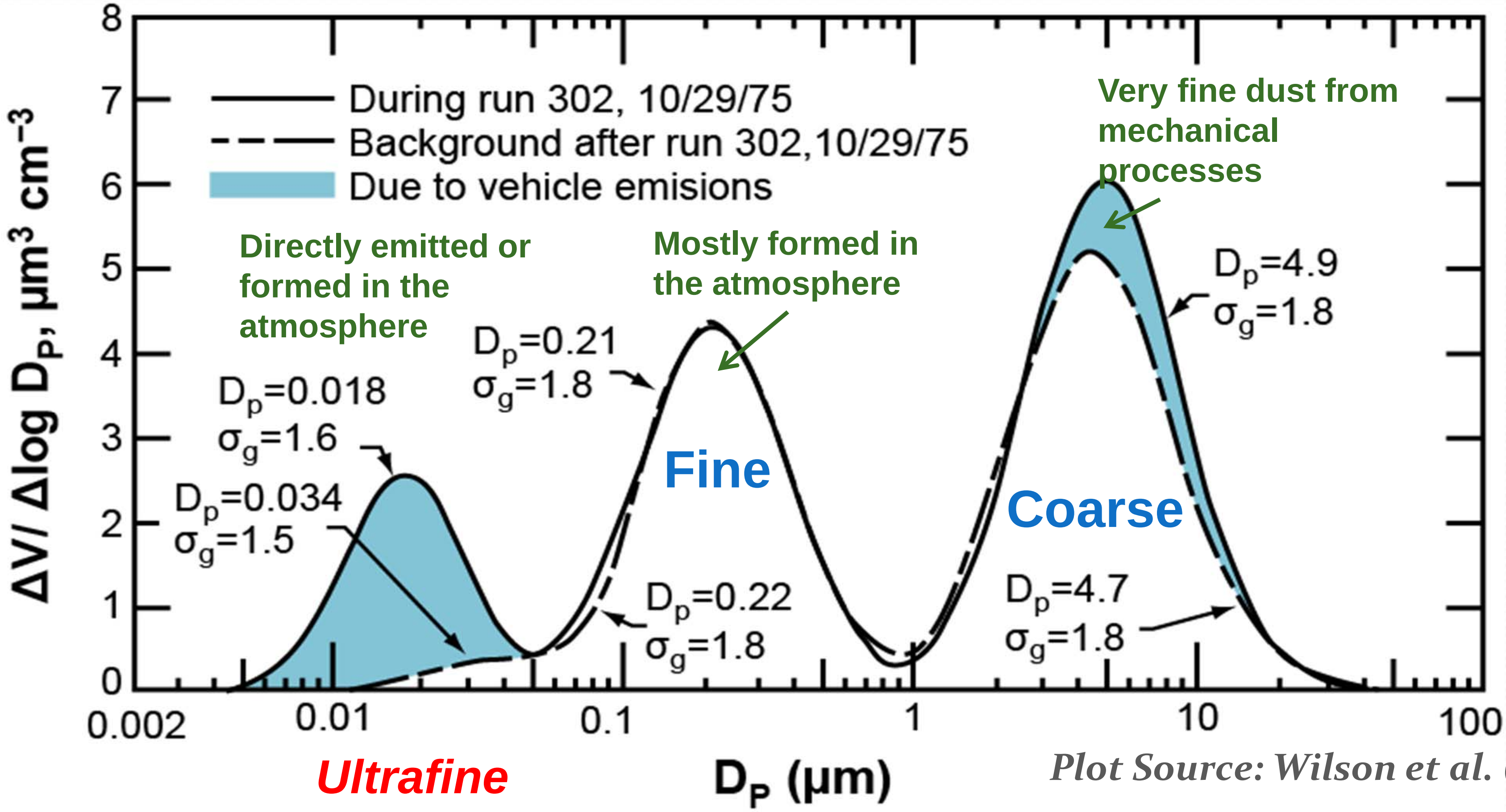
Penetration of Ultrafine Particles into Indoor Spaces is Significant.

I/O = indoor/outdoor concentrations

Zhu, Hinds et al., J. Aerosol Sci. 2005, UCLA Sepulveda & Sawtelle student housing



Size distribution of atmospheric particles



Plot Source: Wilson et al. (1977)

- **Mostly from vehicular emissions highly concentrated on UFP region: ~80% of the total number conc. but negligible in mass conc.** *[Kumar et al., 2010]*
- **Formed generally by condensation in the diluting exhaust plume (semi-volatile hydrocarbons and hydrated sulfuric acid)** *[Shi et al., 2000]*

Measurements

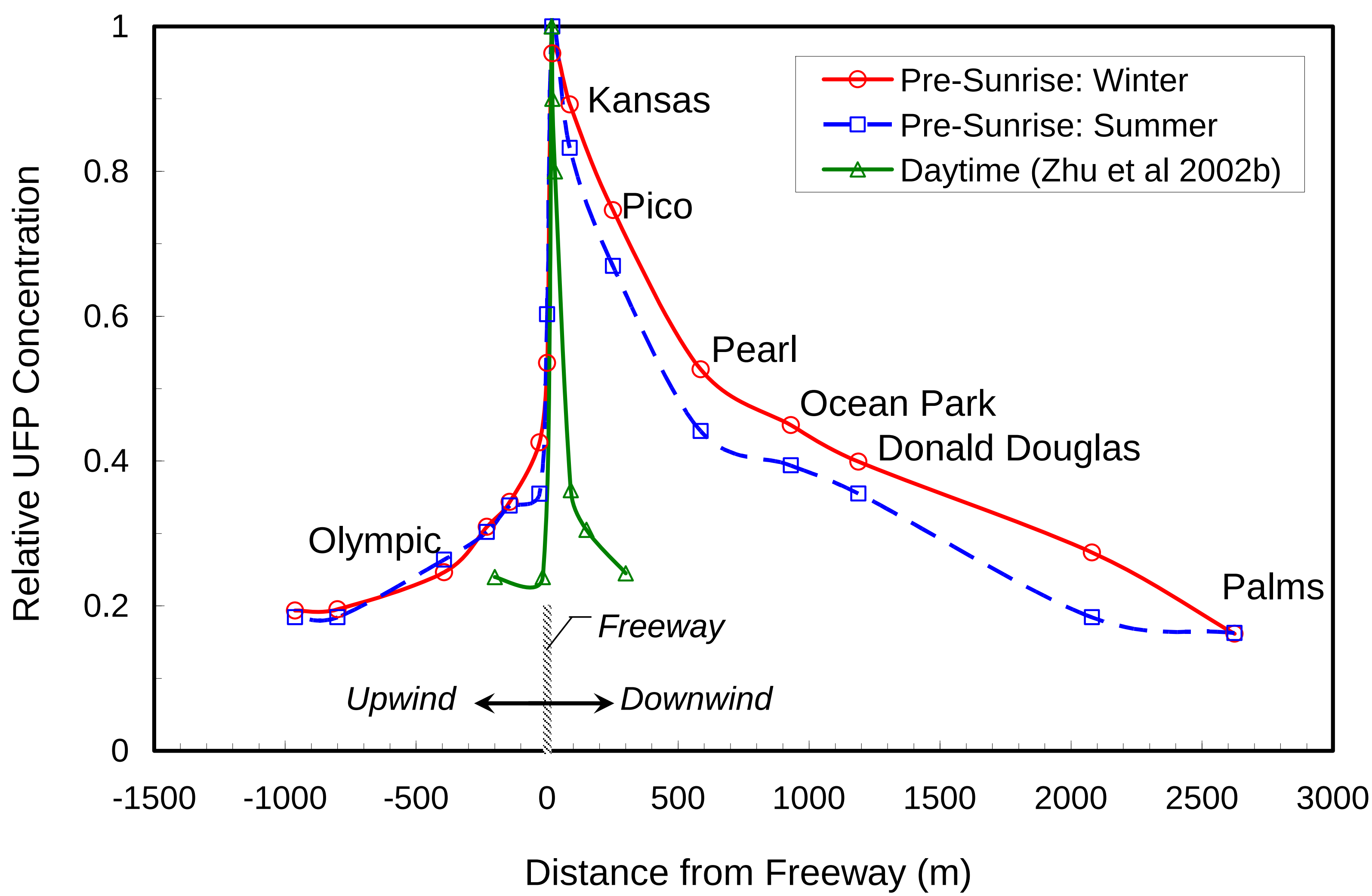
Instrument	Measurement Parameter
CPC (TSI, Model 3007)	UFP number concentration (10 nm ~ 1μm)
FMPS (TSI, Model 3091)	Particle size distribution (5.6~560 nm)
DustTrak (TSI, Model 8520)	$PM_{2.5}$ and PM_{10} mass
EcoChem PAS 2000	Particle bound PAHs
LI-COR, Model LI-820	CO_2
Teledyne API Model 300E	CO
Teledyne-API Model 200E	NO
Sonic Anemometer (Vaisala)	Temperature, Relative humidity, Wind speed/direction
Garmin GPSMAP 76CS	GPS
SmartTether™	Vertical profiles of temperature, *RH*, wind speed/direction
KciVacs video	Video record

ARB's Toyota RAV4 electric vehicle

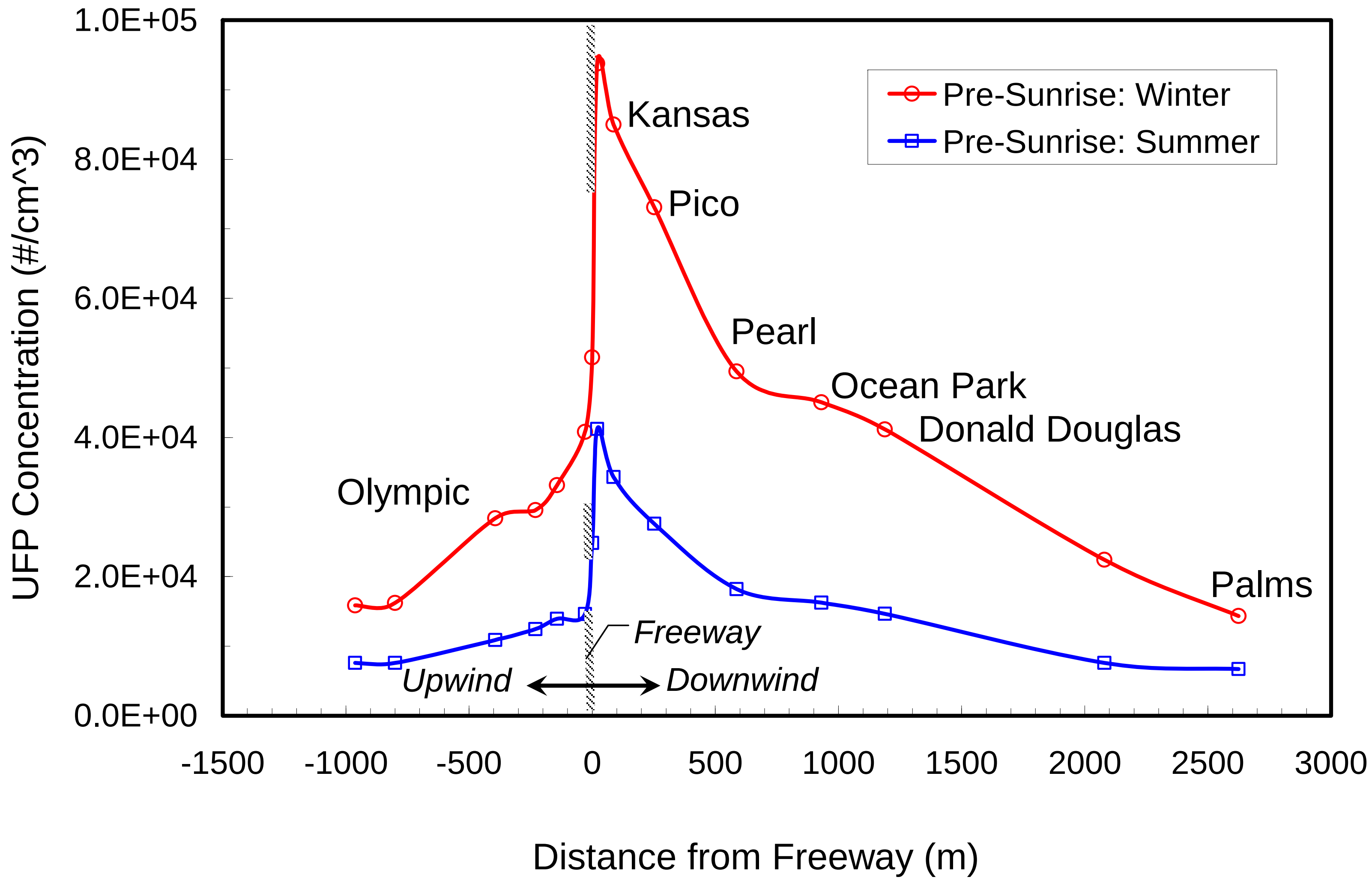
SmartTether™

Factors controlling freeway plumes in the early morning

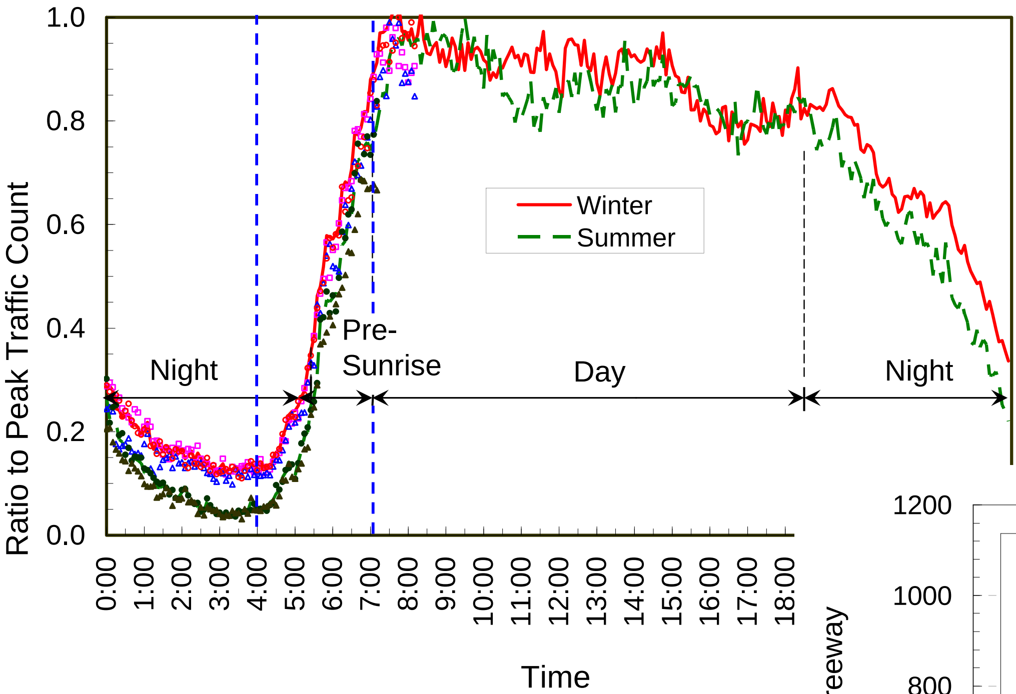
The Freeway Imprint is Many Times Larger Before and Just After Sunrise (normalized data)

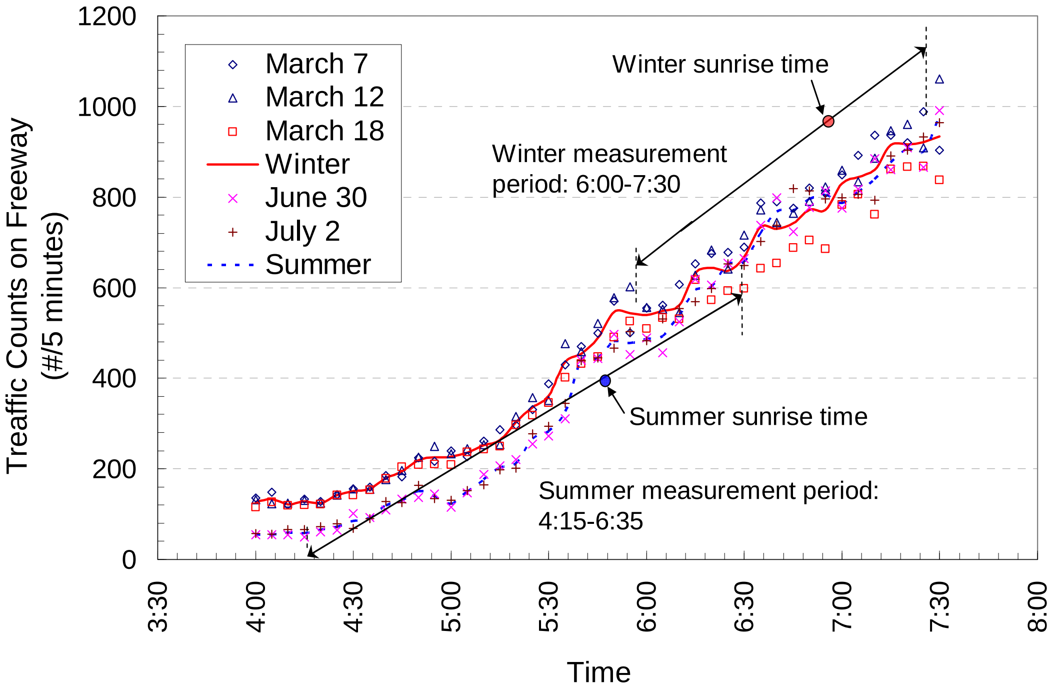


Santa Monica: Summer is Cleaner; why?



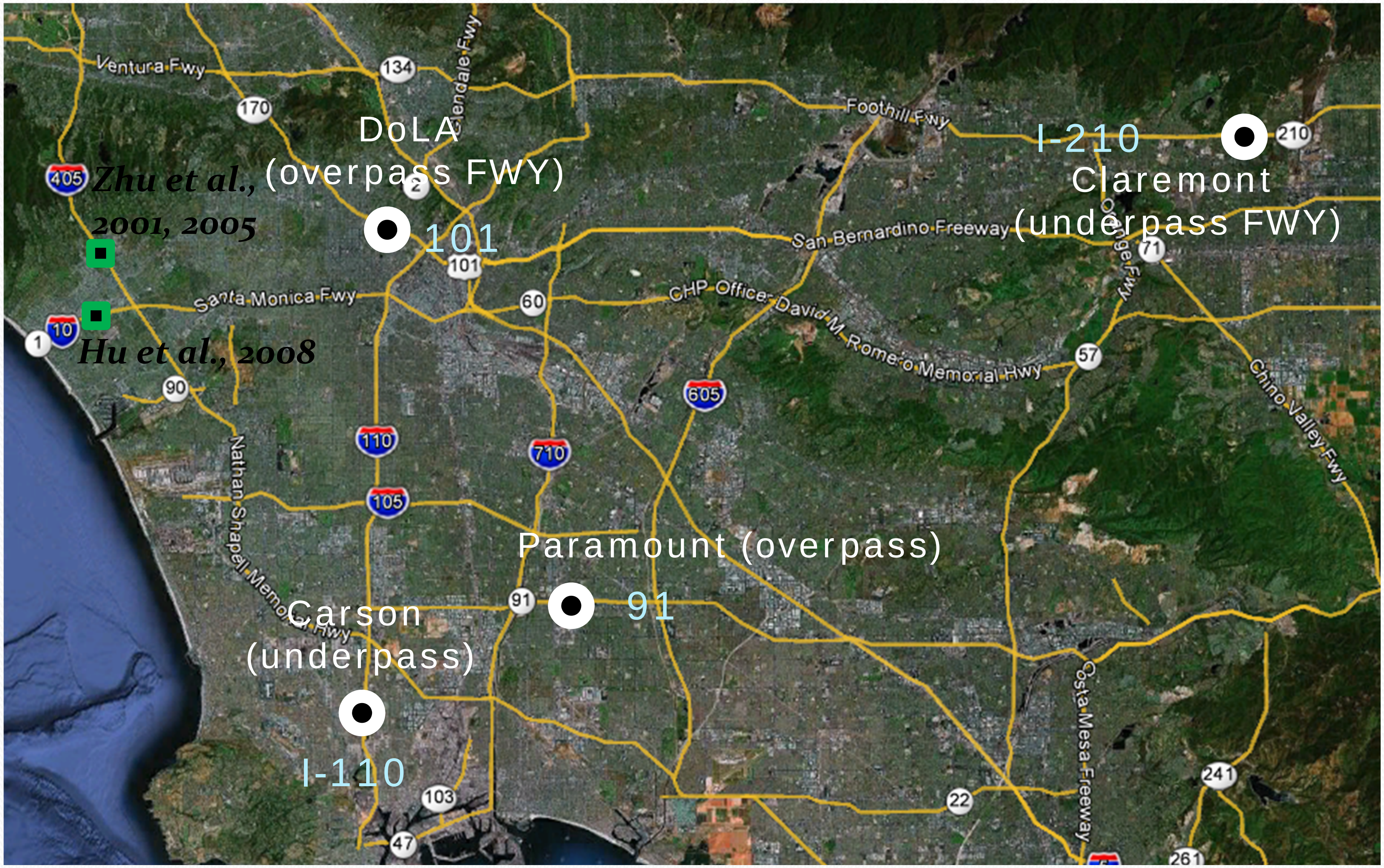
Traffic Counts Increase Rapidly in the Early AM



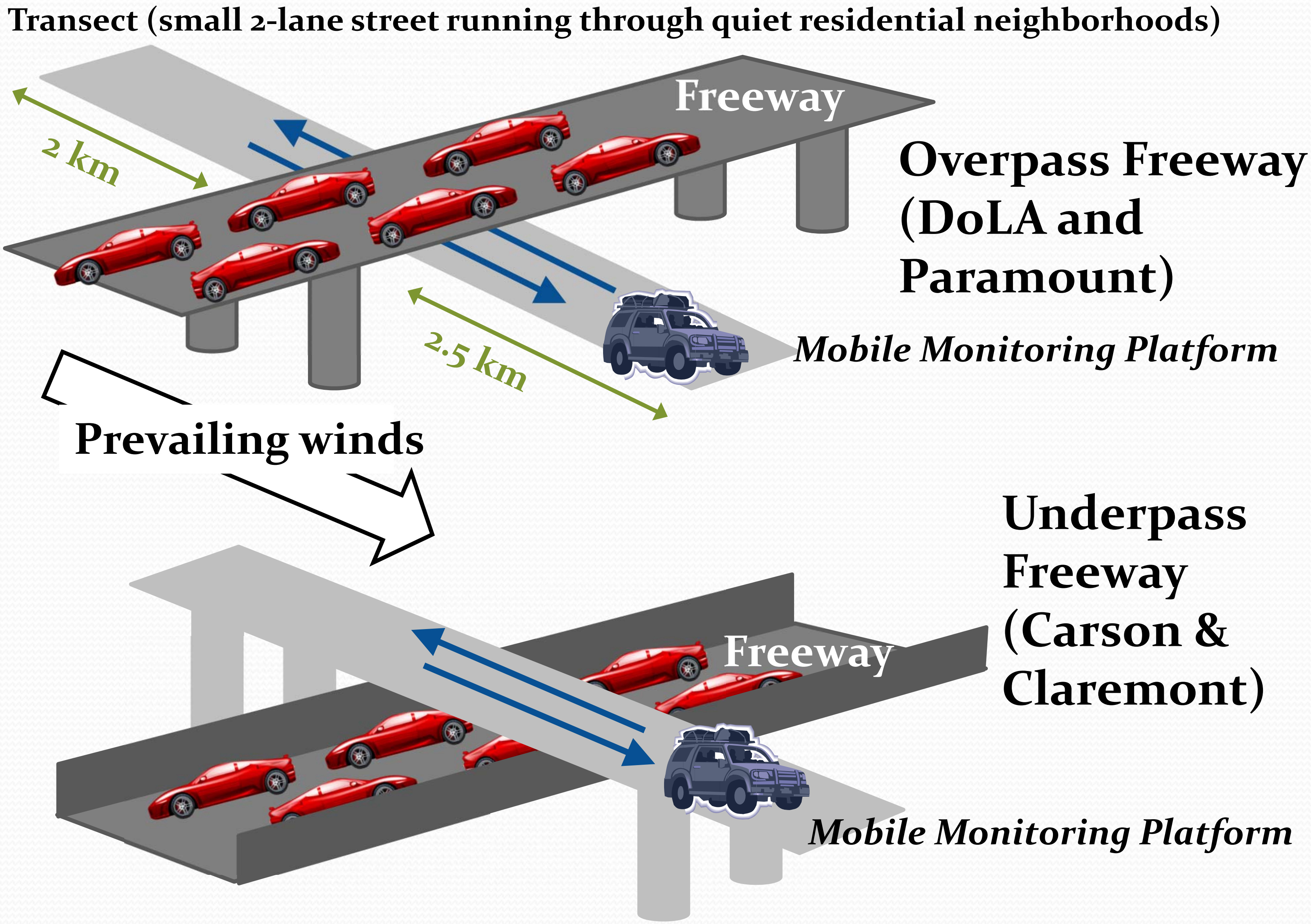


Summer is cleaner because there is less traffic during the pre-sunrise period

Sampling Area and Transects

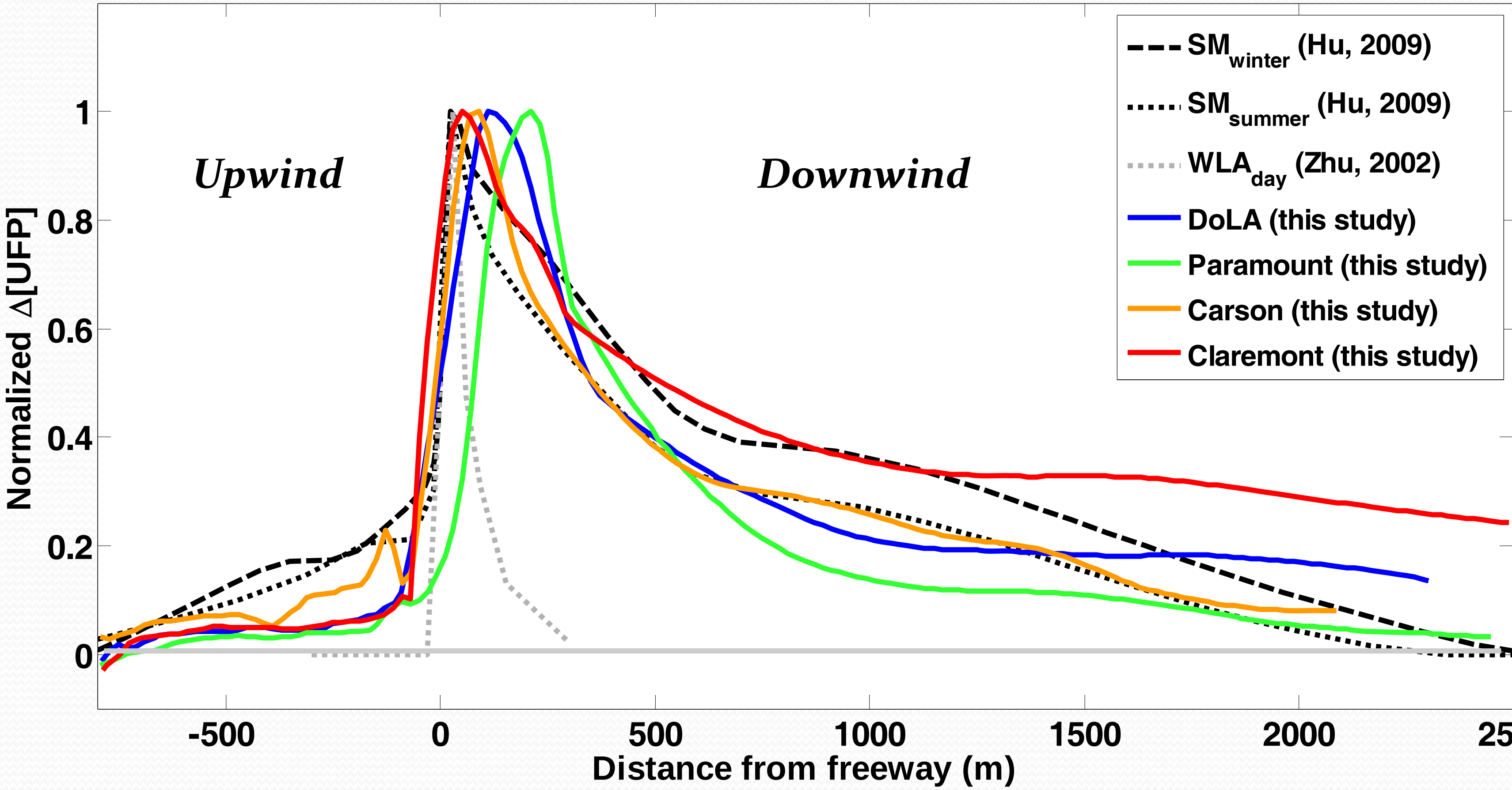


Transects



Transect (small 2-lane street running through quiet residential neighborhoods)
Freeway
2 km
Overpass Freeway (DoLA and Paramount)
2.5 km
Mobile Monitoring Platform
Prevailing winds
Underpass Freeway (Carson & Claremont)
Freeway
Mobile Monitoring Platform

Wide Impact Area Downwind of Freeways

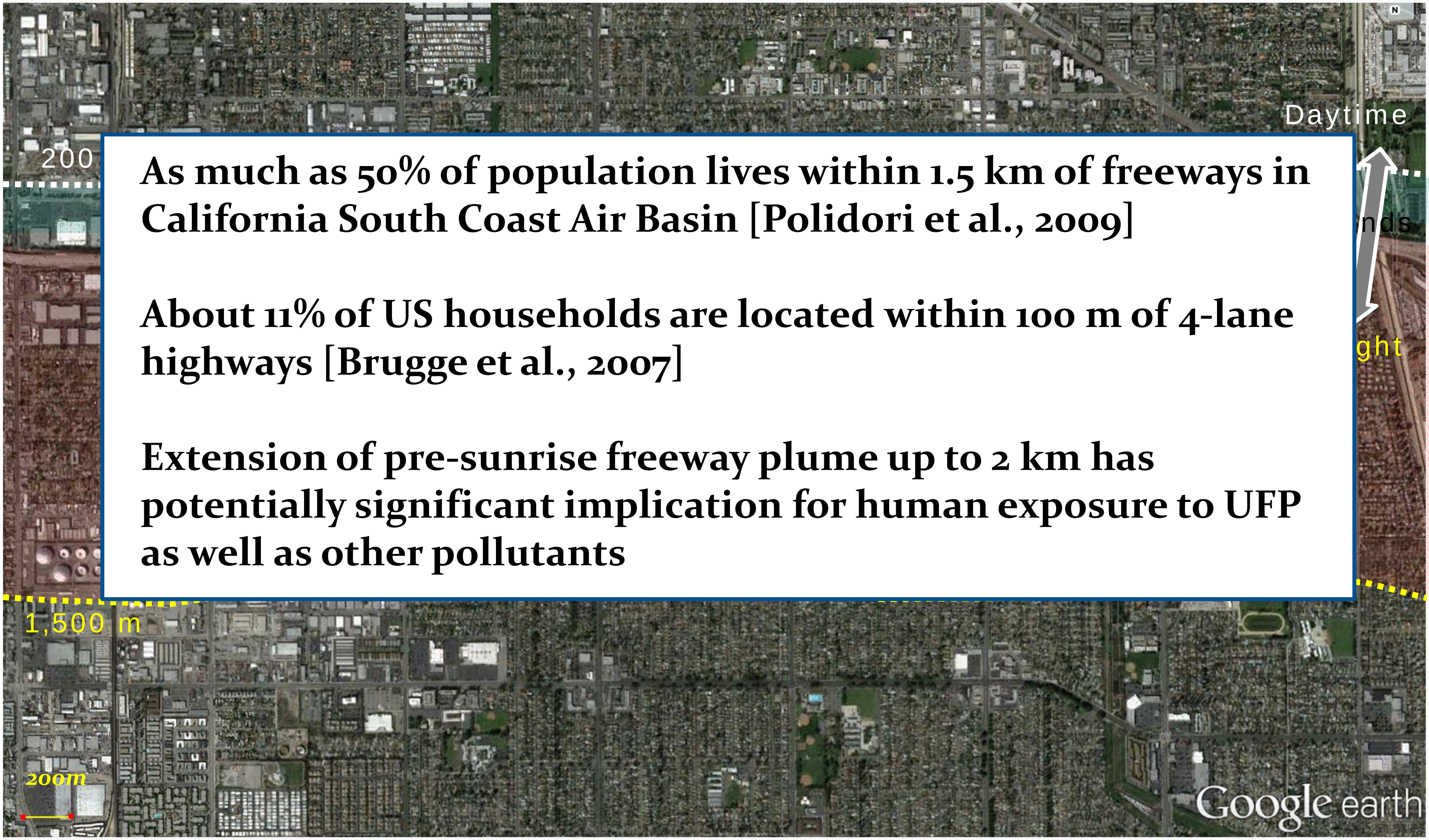


$$\Delta[UFP] = [UFP] - [UFP]_{bkgnd}$$

$$\text{Normalized}\,\Delta[UFP(x)] = \frac{\Delta[UFP(x)]}{\Delta[UFP]_{peak}}$$

[Choi et al., Atmos. Environ., 62, 318-327, 2012]

Night and Day



As much as 50% of population lives within 1.5 km of freeways in California South Coast Air Basin [Polidori et al., 2009]

About 11% of US households are located within 100 m of 4-lane highways [Brugge et al., 2007]

Extension of pre-sunrise freeway plume up to 2 km has potentially significant implication for human exposure to UFP as well as other pollutants

Paramount

Curve Fits to Observed Profiles to Extract Emission Factor and Dispersion Coefficients

[Choi et al., submitted]

Gaussian Plume Dispersion model

Q_c *= Emission rate corrected with wind speeds*
H *= Source height*
1.5m *= Measurement height*
σ_z *= Dispersion parameter*
x *= Horizontal distance from the source*

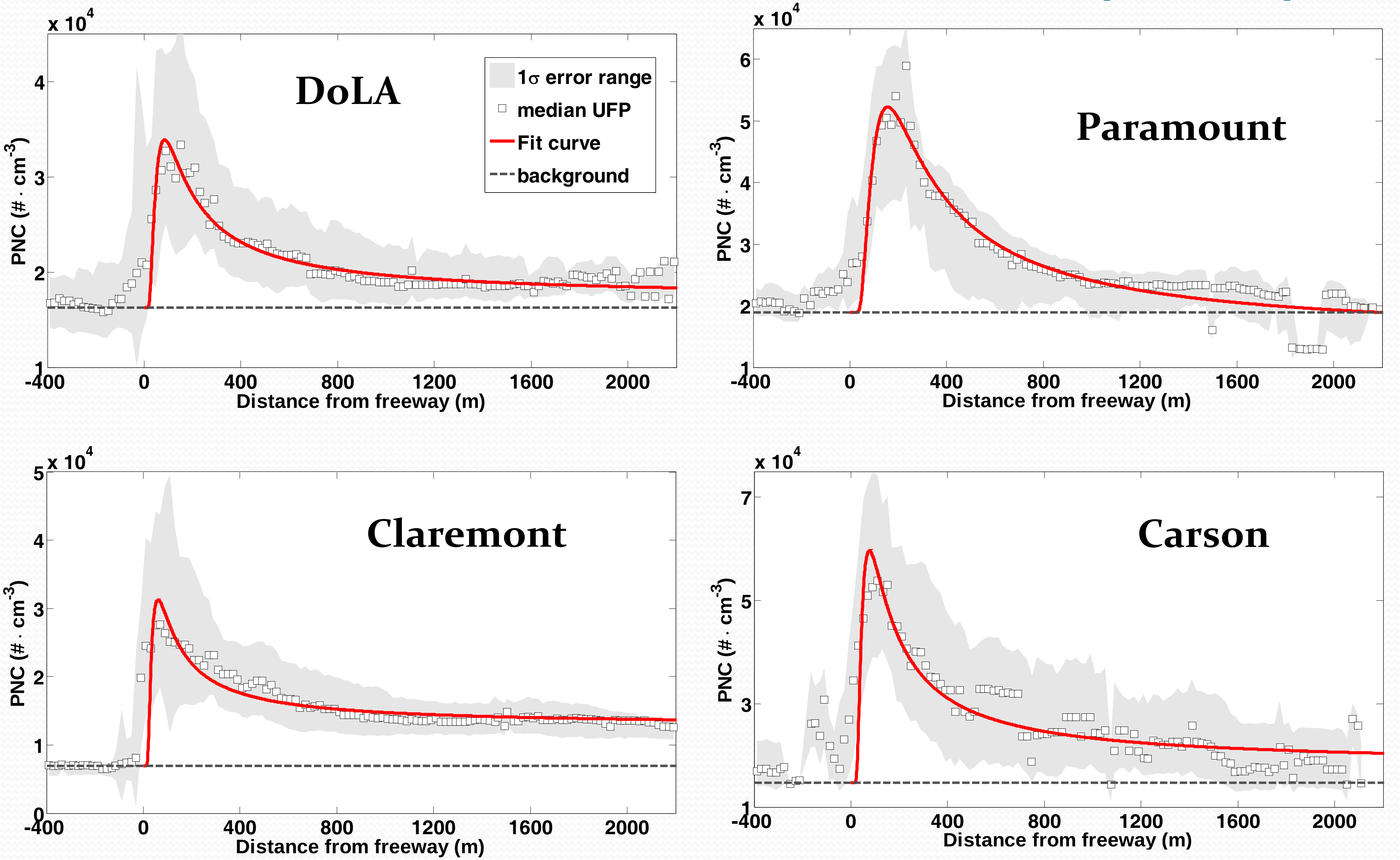
$$C(x,1.5m) = \frac{Q_c}{\sigma_z}\left[\exp\left(-\frac{(1.5m+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(1.5m-H)^2}{2\sigma_z^2}\right)\right]$$

References	Equation form	Land use	Stability Class	Dispersion coefficients
Briggs (1973)	$\sigma_z = \frac{\alpha \cdot x}{(1+\beta x)}$	Rural	E[a] (slightly stable)	α = 0.03, $\beta = 0.3\times10^{-3}$
		Rural	F[a] (moderately stable)	α = 0.016, $\beta = 0.3\times10^{-3}$
		Urban	E – F[a] (stable)	α = 0.08, $\beta = 1.5\times10^{-3}$

distance

Dispersion Parameter

The Model Fits the Observations Well ***(R^2 > 0.9)***



Estimating the Particle Number Emission Factor

$$Q_c = \frac{q_{veh} \times (\text{Traffic flow})}{2\sqrt{2\pi}U_e}$$

Q_c	= ***Wind speed-corrected Emission rate*** *(#·m·cm⁻³)*
q_{veh}	= ***Particle number emission factor (PNEF)*** *(#·mile⁻¹·vehicle⁻¹)*
Traffic flow	= *vehicles·s⁻¹*
U_e	= ***Effective wind speeds*** *[Chock, AE, 1978]* ***(wind speed + speed correction factor due to traffic wake)***

$$q_{veh} = \frac{\sqrt{2\pi}Q_c \cdot U_e}{(\text{traffic flow})}$$

with the mean values obtained from observations

$$= \frac{\sqrt{2\pi} \times (8.12\times10^4) \times (0.64\,m/s + 0.2\,m/s) \times 10^6\, cm^3/m^3 \times 300\, s/5\min}{(680.2\, vehicles/5\min)}$$

= 1.2×10^{14} particles·mi⁻¹·vehicle⁻¹

This is 15% of the Particle Emission Factor measured in West LA in 2001

8.3×10^{14} particles·mi⁻¹·vehicle⁻¹ in 2001 *[Zhu and Hinds, AE, 2005]*

Factors Controlling Plume Transport and Decay

$$C(x,1.5m) = \frac{Q_c}{\sigma_z}\left[\exp\left(-\frac{(1.5m+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(1.5m-H)^2}{2\sigma_z^2}\right)\right]$$

Horizontal distance from freeway

$$\sigma_z = \frac{\alpha \cdot x}{(1+\beta \cdot x)}$$

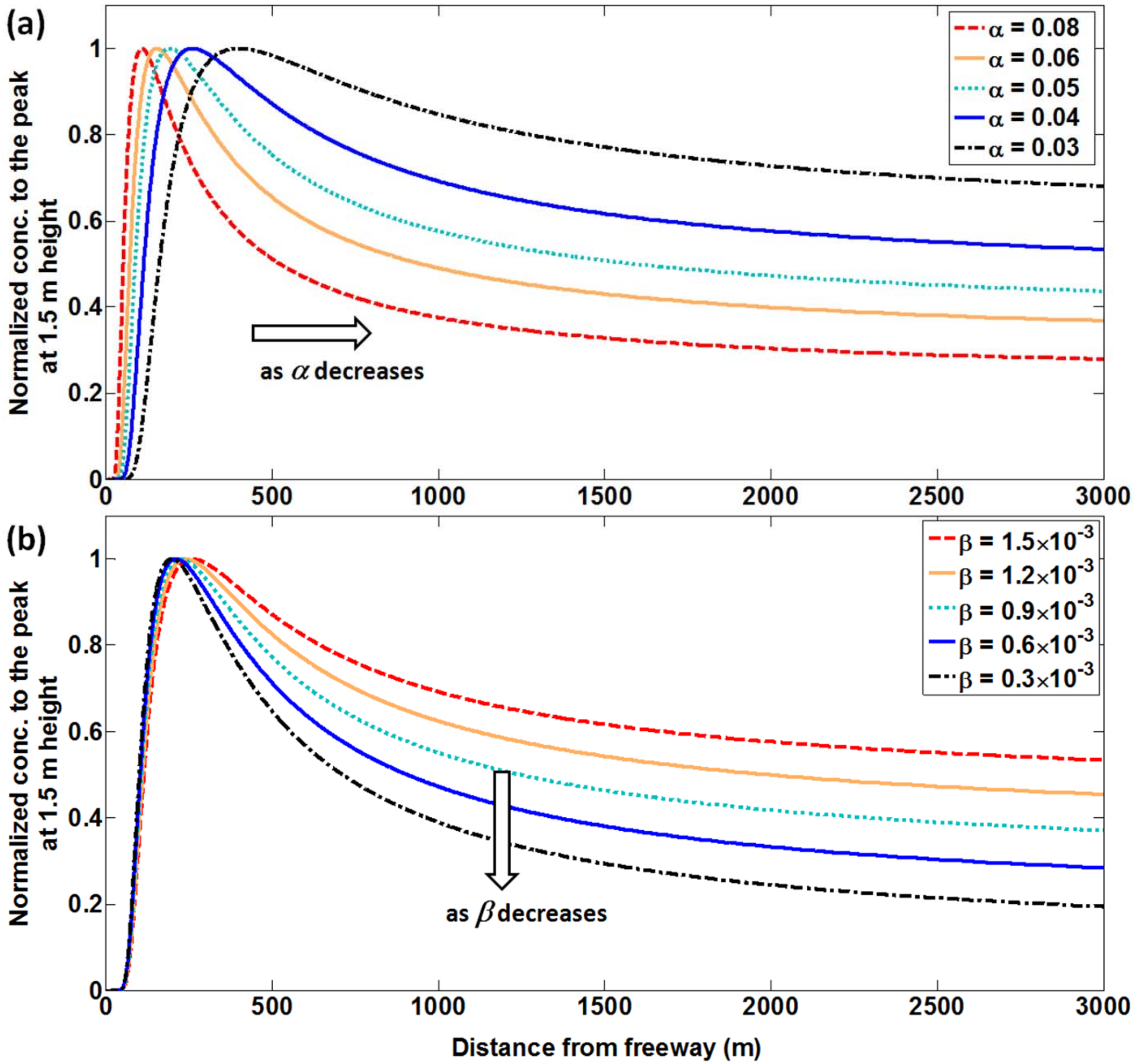
Dispersion Coefficients, α and β

Effects of Dispersion Coefficients on Plume Shapes

Coefficient related to plume transport and intensity

$$\sigma_z = \frac{\alpha \cdot x}{(1+\beta \cdot x)}$$

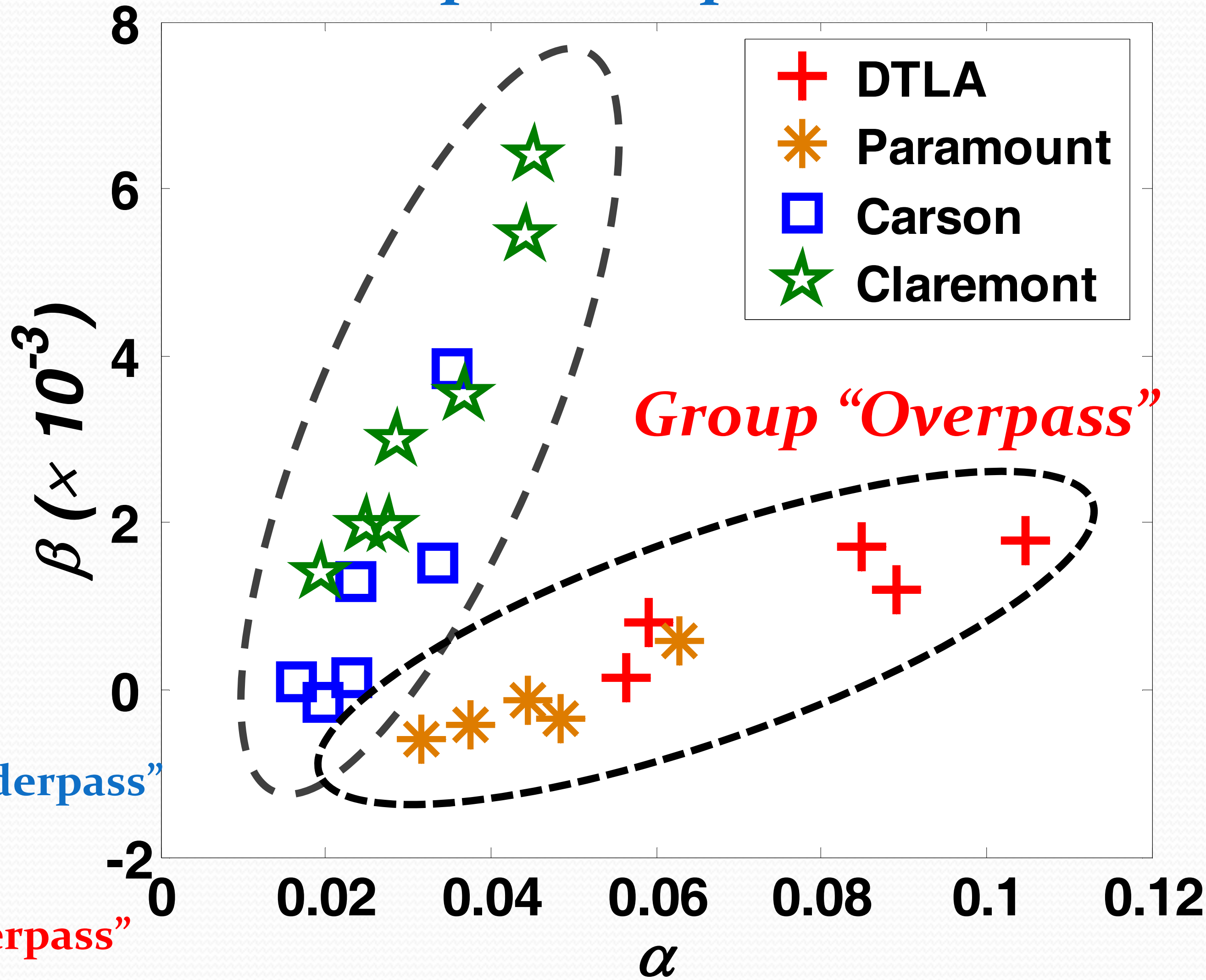
Coefficient related to plume dissipation



Observed Dispersion Coefficients, α and β

Strong Positive relationships between α and β depending on freeway-transect geometry

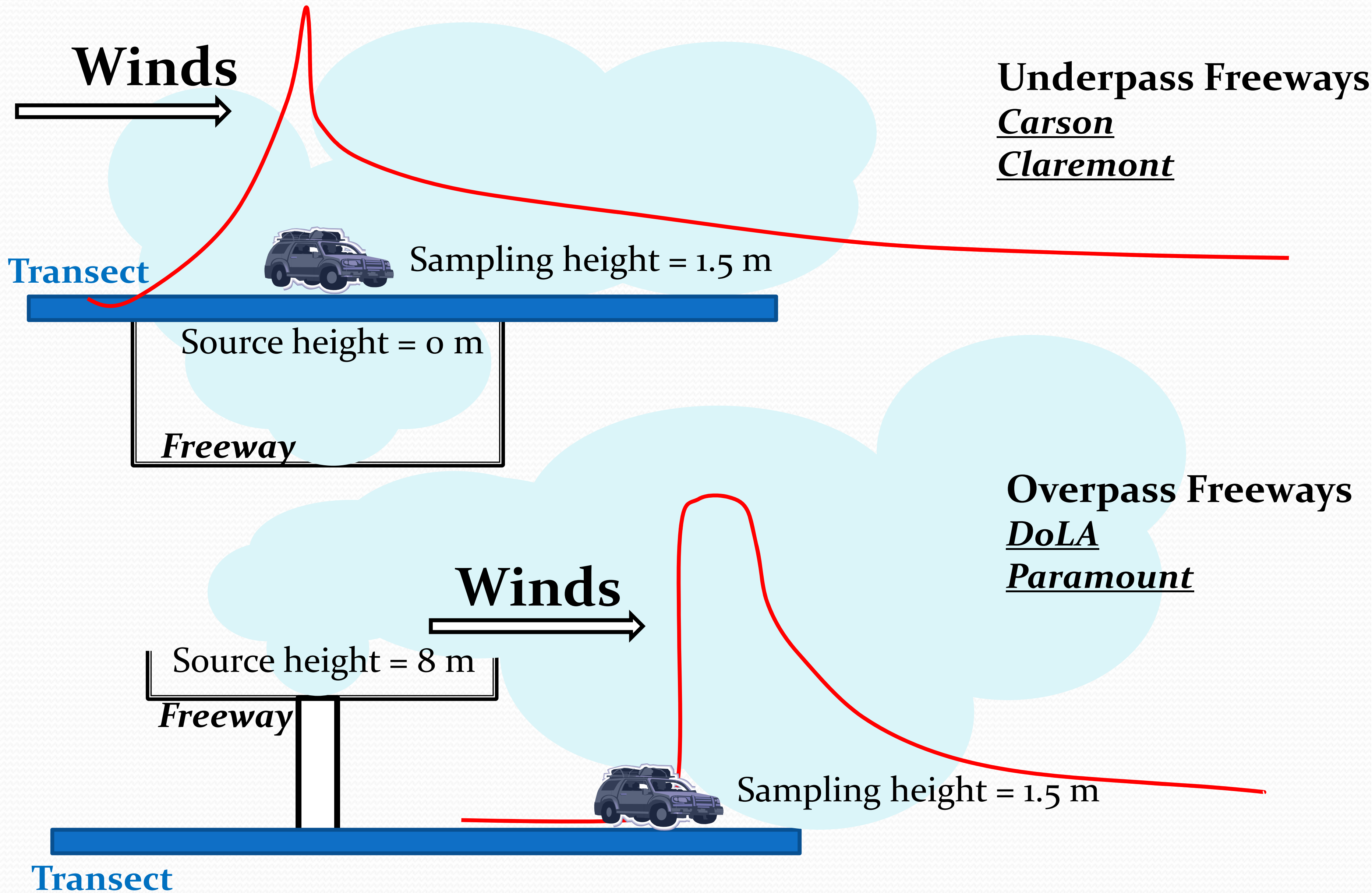
Group "Underpass"



$\beta = 1.37\times10^{-1}\ \alpha - 1.86\times10^{-3}$
($R^2 = 0.74$) for group "Underpass"

$\beta = 3.45\times10^{-2}\ \alpha - 1.64\times10^{-3}$
($R^2 = 0.90$) for group "Overpass"

Freeway-Transect Geometry



Hypotheses

A strong positive relationship between dispersion coefficients α and β, and their variations are likely caused by:

(1) Meteorological conditions (Advection and turbulence)

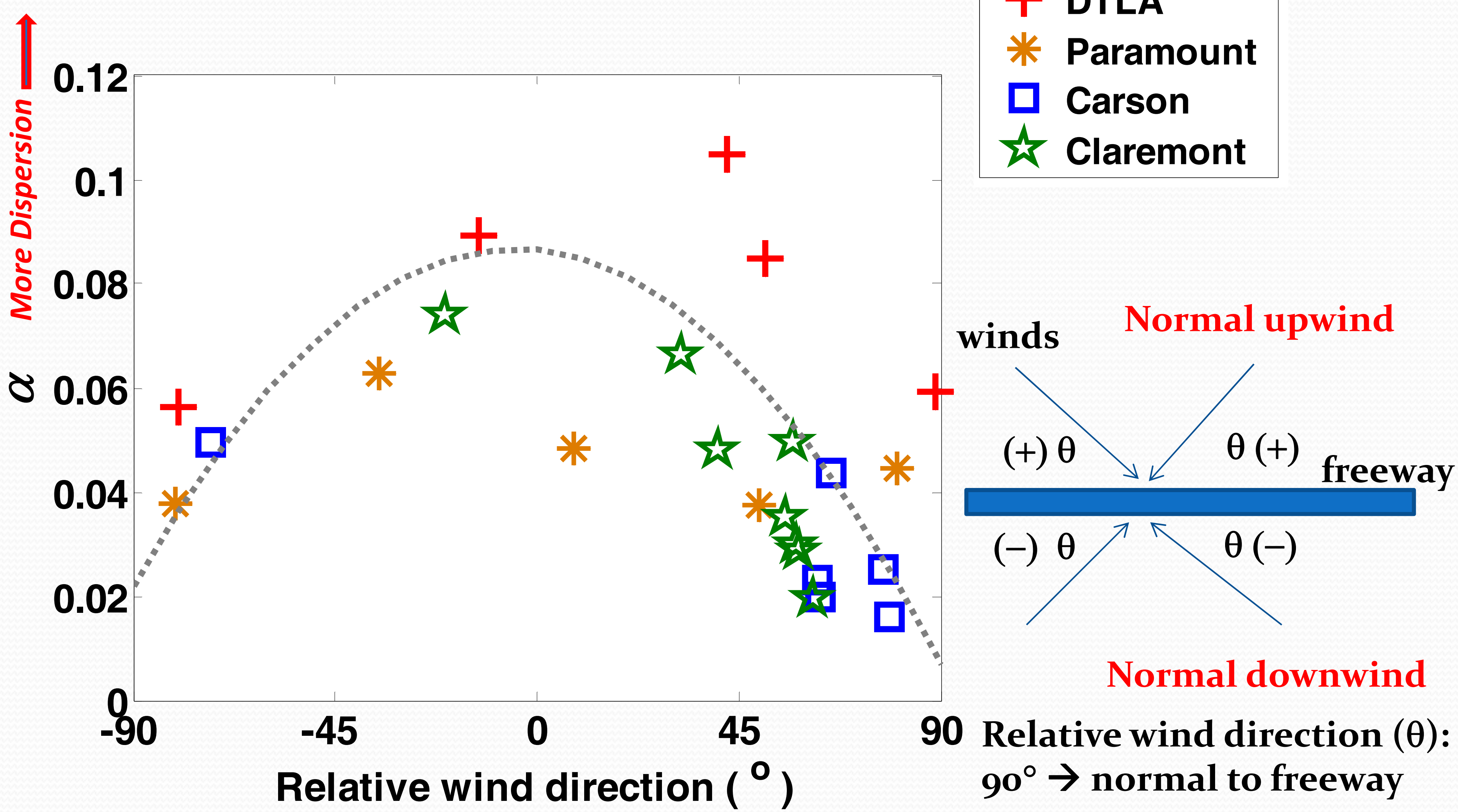
(2) Plume intensities (Conc. difference from the background)

$$\frac{dC(t)}{dt} = -K \cdot \left[C(t) - C_{bkgnd}\right]$$

[Dillon et al., JGR, 2002]

Hypothesis I: Winds Effects

Wind Direction



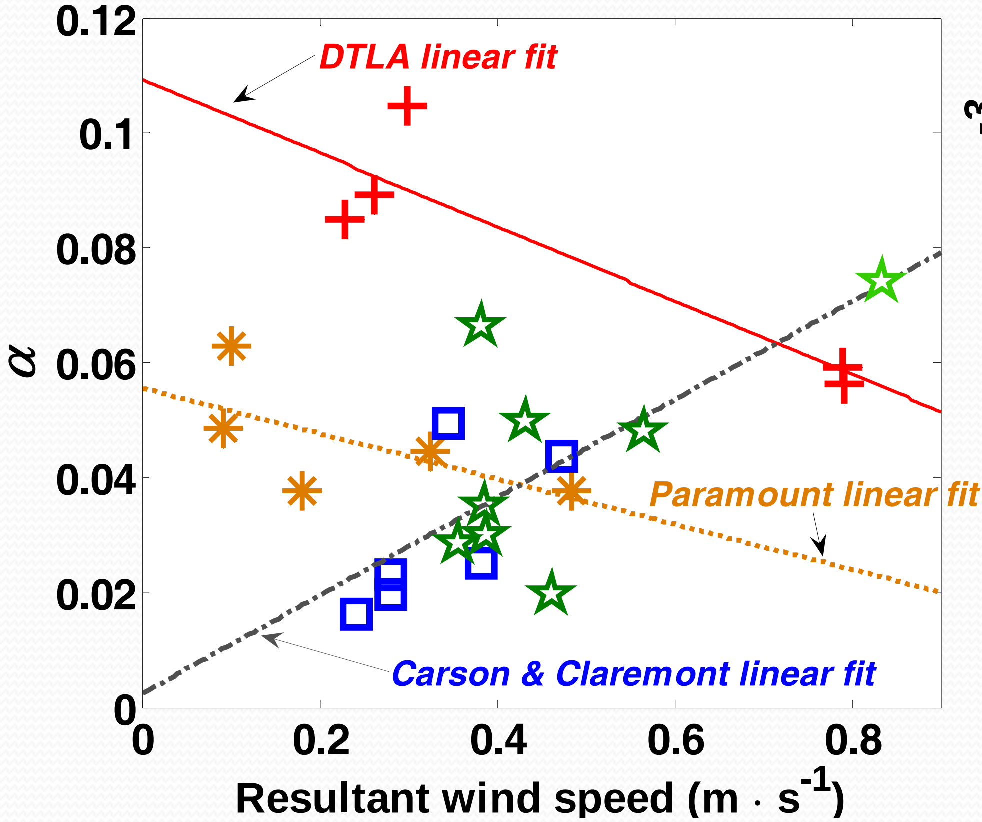
Relative wind direction (θ): 90° → normal to freeway

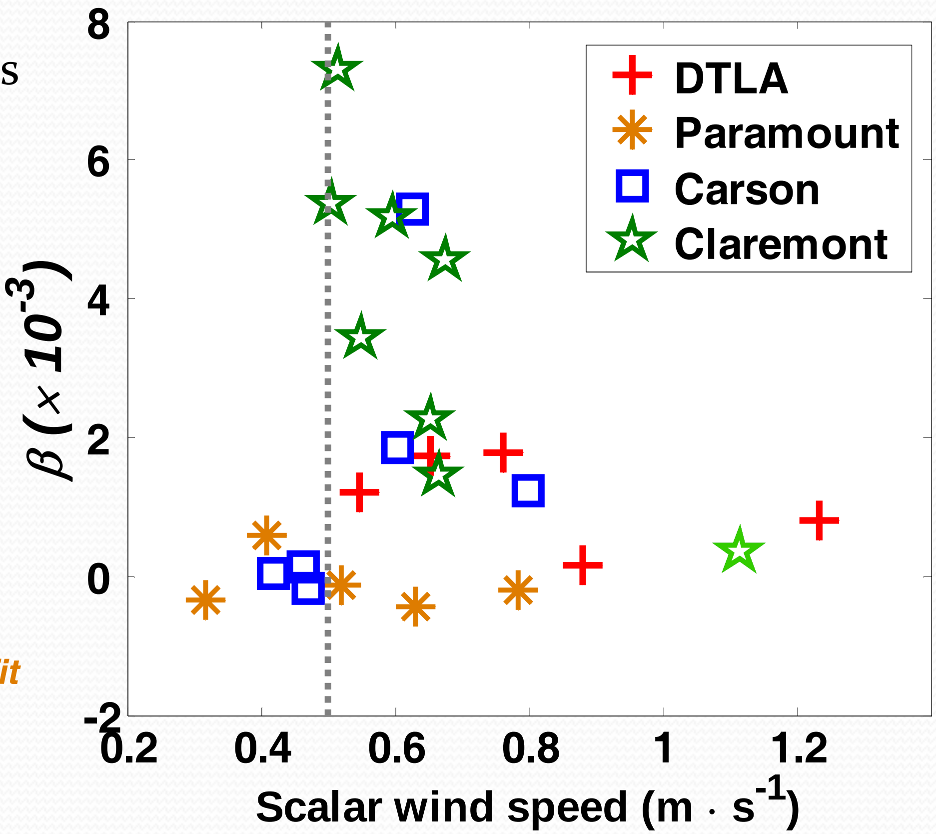
Hypothesis I: Winds Effects

DoLA & Paramount: Overpass freeways
Carson & Claremont: Underpass freeways

Wind Speed

- ❑ ***Negative correlation for overpass fwys***
- ❑ Less clear positive correlation for underpass fwys

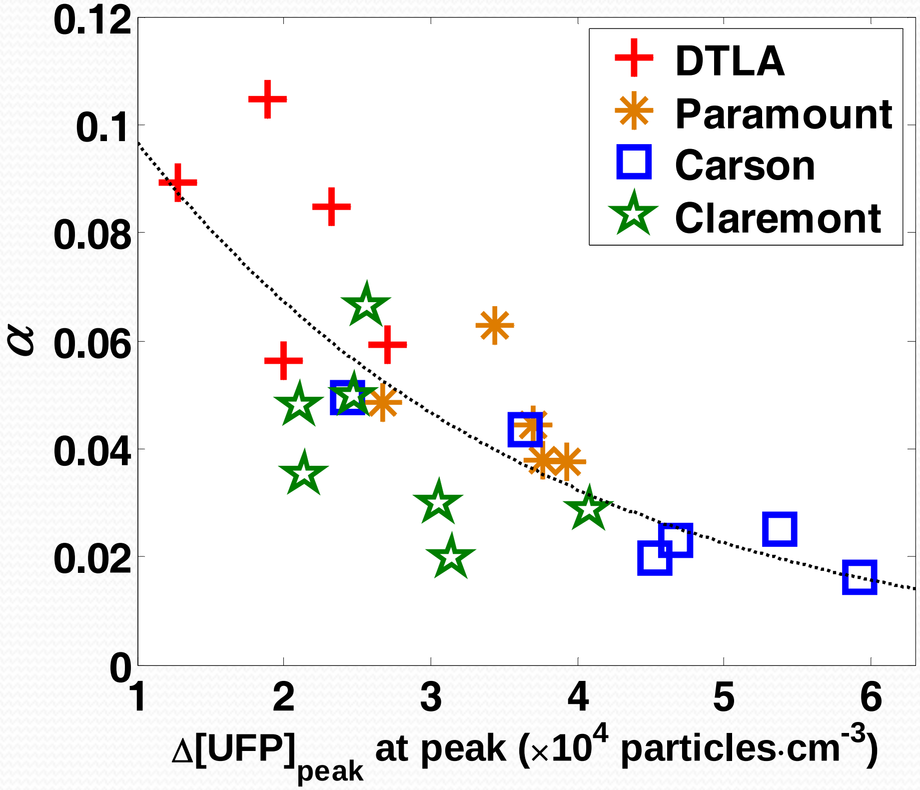




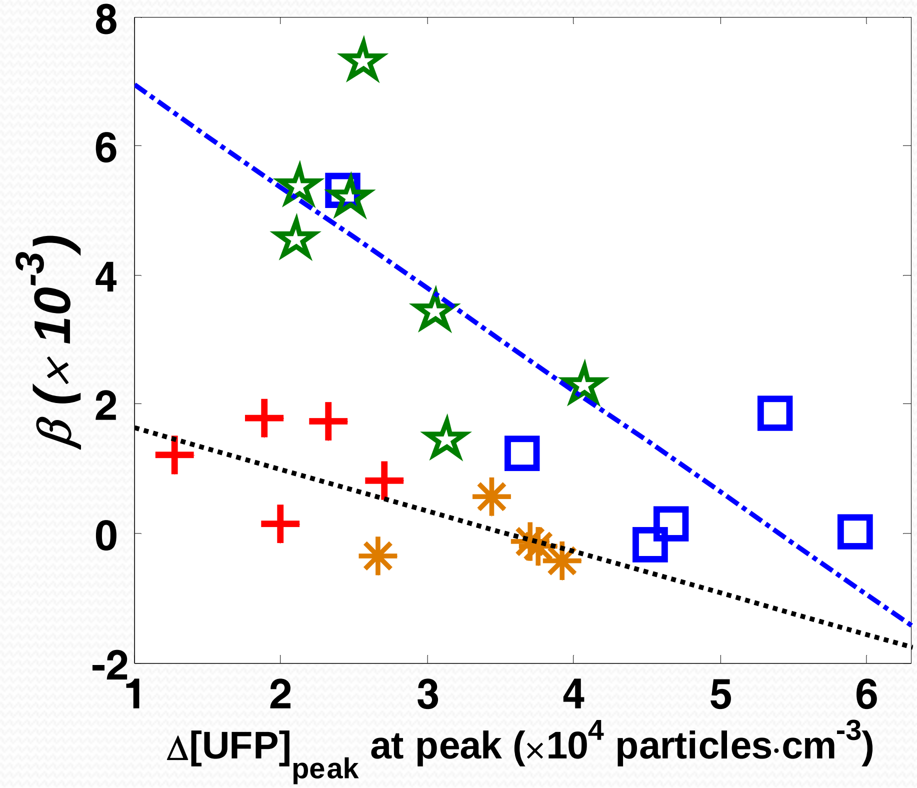
- ❑ No clear correlation for overpass fwys
- ❑ ***Negative correlation for underpass fwys (when scalar wind speed > 0.5 m/s)***

Hypothesis II: Effects of Plume Intensity

$$\Delta[UFP] = [UFP] - [UFP]_{bkgnd}$$ *Conc. difference from the background*



Plume intensity



Plume intensity

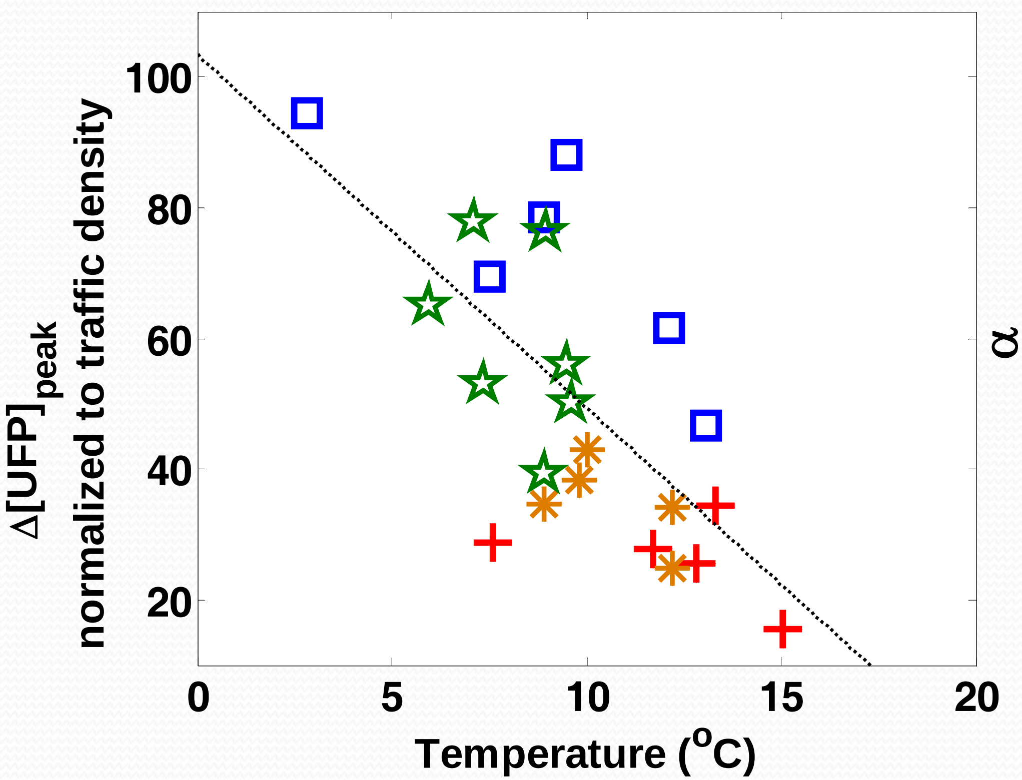
Hypothesis II: Effects of Plume Intensity

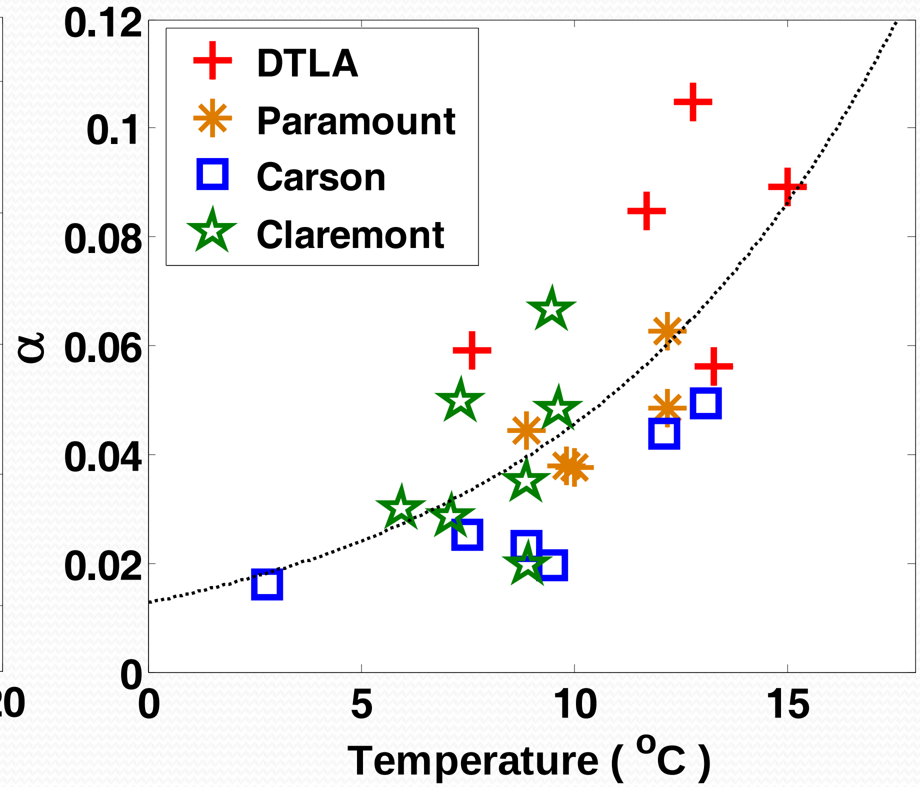
Temperature

Further supports the Hypothesis II

Temp. ↓

UFP emission ↑



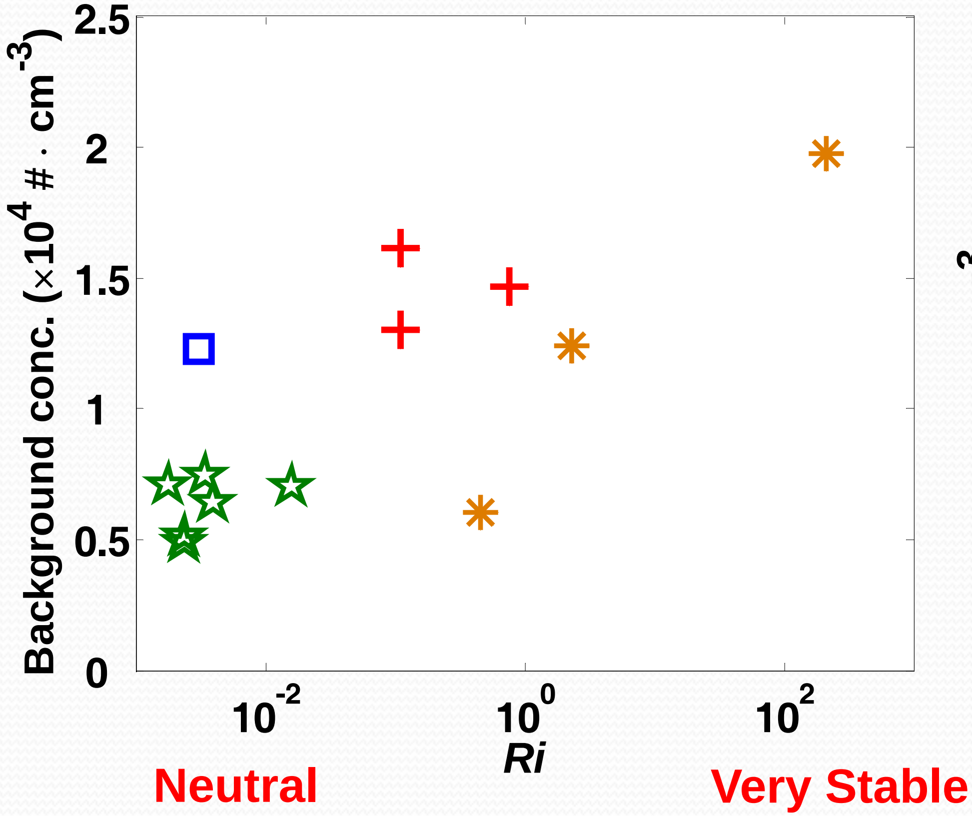


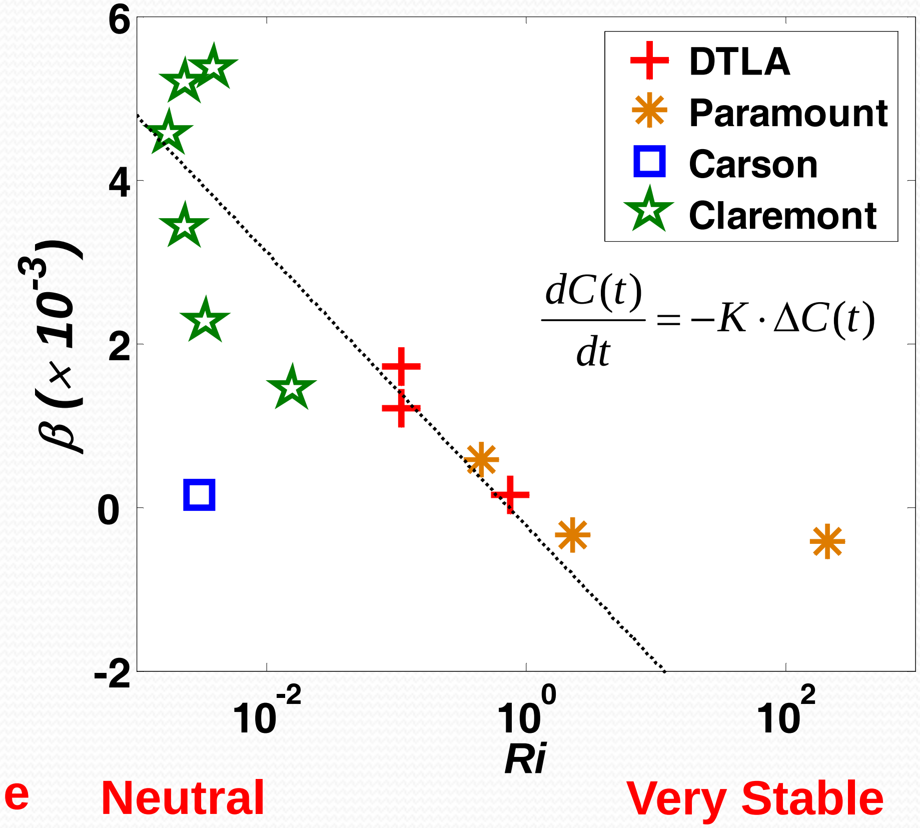
Hypothesis II: Effects of Plume Intensity

Vertical Stability (R_i #)

$$R_i \equiv \frac{g}{\overline{\theta}} \frac{d\theta}{dz} \cdot \left(\frac{dU}{dz} \right)^{-2}$$

$R_i > 0$: stable
$R_i = 0$: neutral
$R_i < 0$: unstable





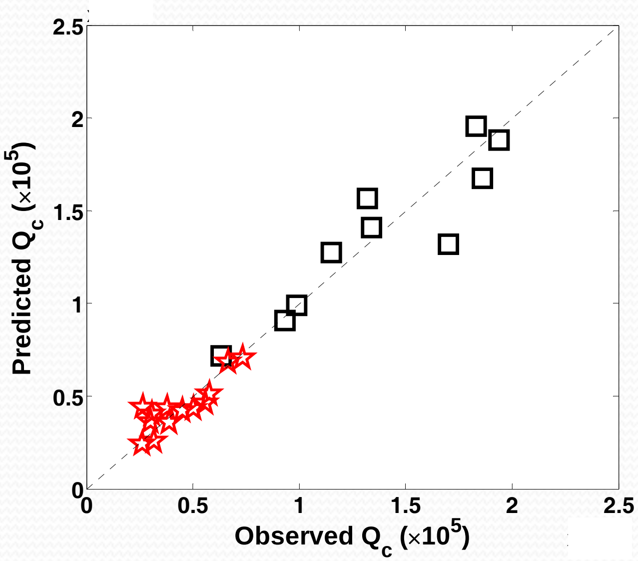
Prediction of Dispersion Coefficients

Multivariate Regression Model

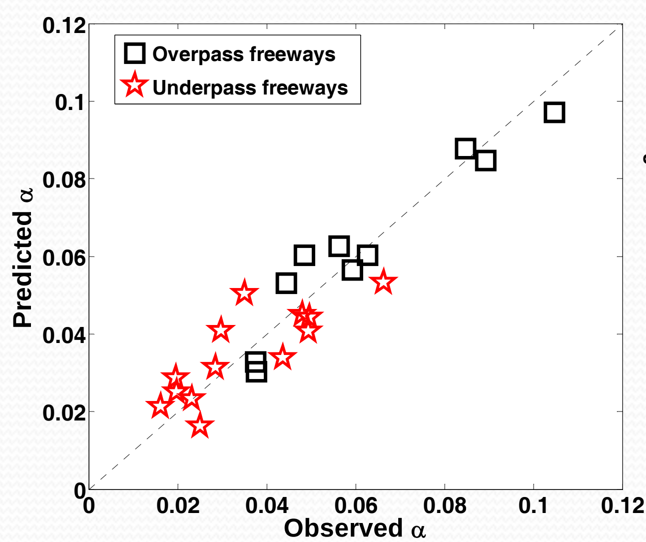
Q_c : *emission rate factor*
WD_{rel}: *relative wind direction to freeway*
T : *temperature*
WSR : *vector mean resultant wind speed*
RH : *relative humidity*
C : *correction factor*

$$Q_{c,j} = coef_1 \cdot Traffic_j + coef_2 \cdot \left|WD_{rel,j}\right| + coef_3 \cdot T_j + coef_4 \cdot WSR_j + coef_5 \cdot RH_j + C$$

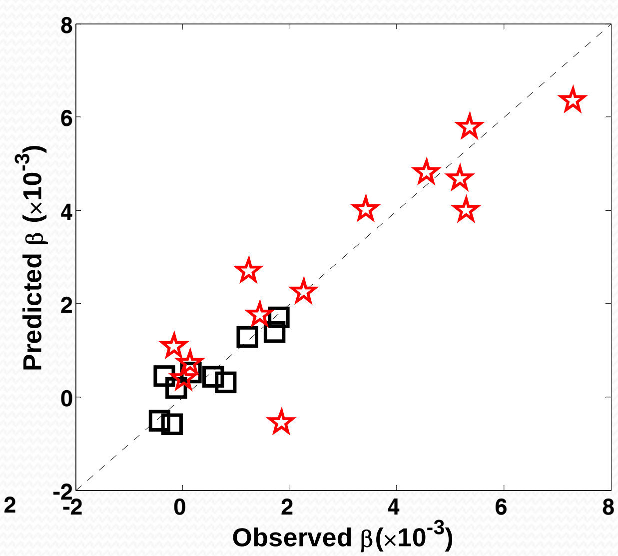
$$\alpha_j \text{ or } \beta_j = coef_1 \cdot Q_{c,j} + coef_2 \cdot \left|WD_{rel,j}\right| + coef_3 \cdot T_j + coef_4 \cdot WSR_j + coef_5 \cdot RH_j + C \qquad (j = 1,2,3,\ldots,k)$$



R^2 = 0.95



R^2 = 0.88

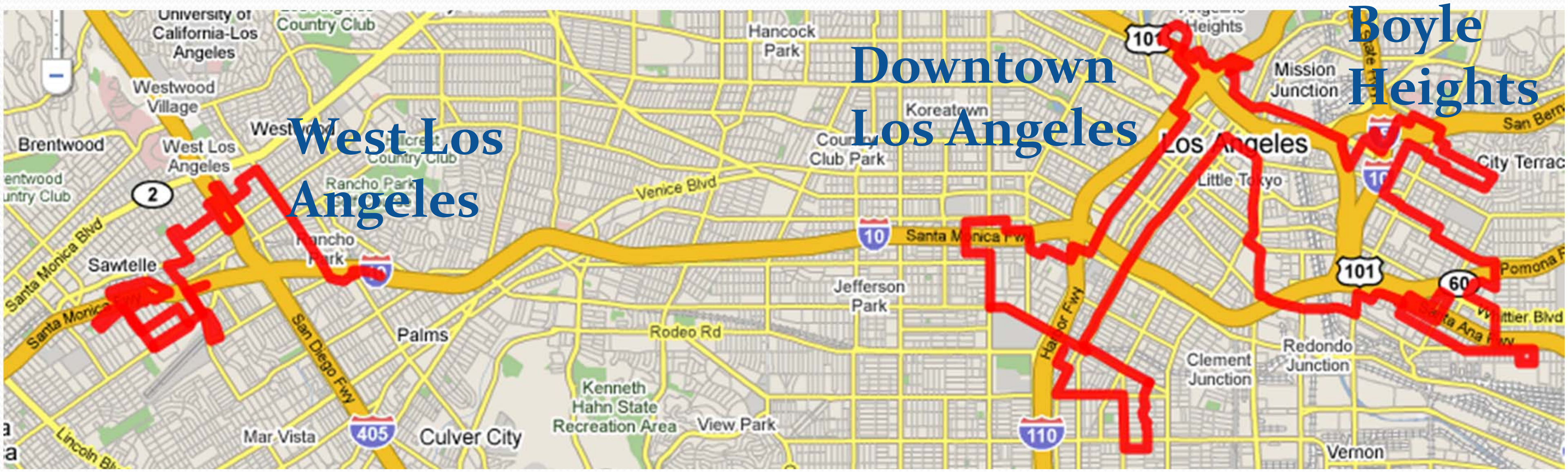


R^2 = 0.86

Summary I

1. **Pre-sunrise (or nocturnal) extension of freeway plumes far downwind (> 2 km) compared to daytime plume length (<300 m) is a general phenomenon in the SoCAB.**
2. **Curve fits using a Gaussian dispersion model solution allowed us to extract emission factor, and dispersion parameters directly from the observed UFP profiles.**
3. **From emission factor obtained from observed UFP profiles, estimated particle number emission factor was 1.2×10^{14} particles·vehicle^{-1}·mile^{-1}.**
4. **Plume intensity (*Δ[UFP]*) was an important factor to control pollutant plume length downwind of freeways under stable conditions as well as meteorological parameters, such as wind direction and speeds.**
5. **Based on strong correlations of dispersion coefficients with readily and routinely measurable parameters, plume shapes and areal impact can be predicted.**

Locations


West Los Angeles
Downtown Los Angeles
Boyle Heights
University of California-Los Angeles
Country Club
Hancock Park
Westwood Village
Brentwood
West Los Angeles
Koreatown
Country Club Park
Los Angeles
Mission Junction
City Terrace
Little Tokyo
Rancho Park
Venice Blvd
Santa Monica Fwy
Sawtelle
Santa Monica Blvd
Jefferson Park
Pomona Fwy
Palms
Rodeo Rd
Redondo Junction
Clement Junction
Kenneth Hahn State Recreation Area
View Park
Mar Vista
Culver City
Vernon
San Diego Fwy
Harbor Fwy
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10
405
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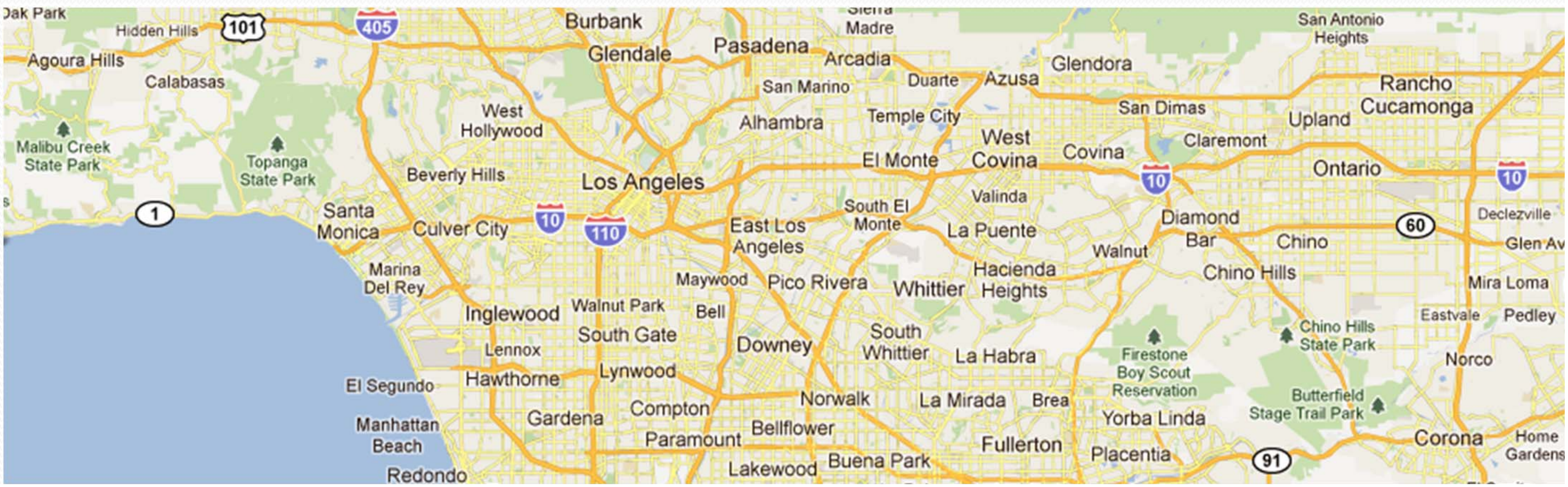
60
2

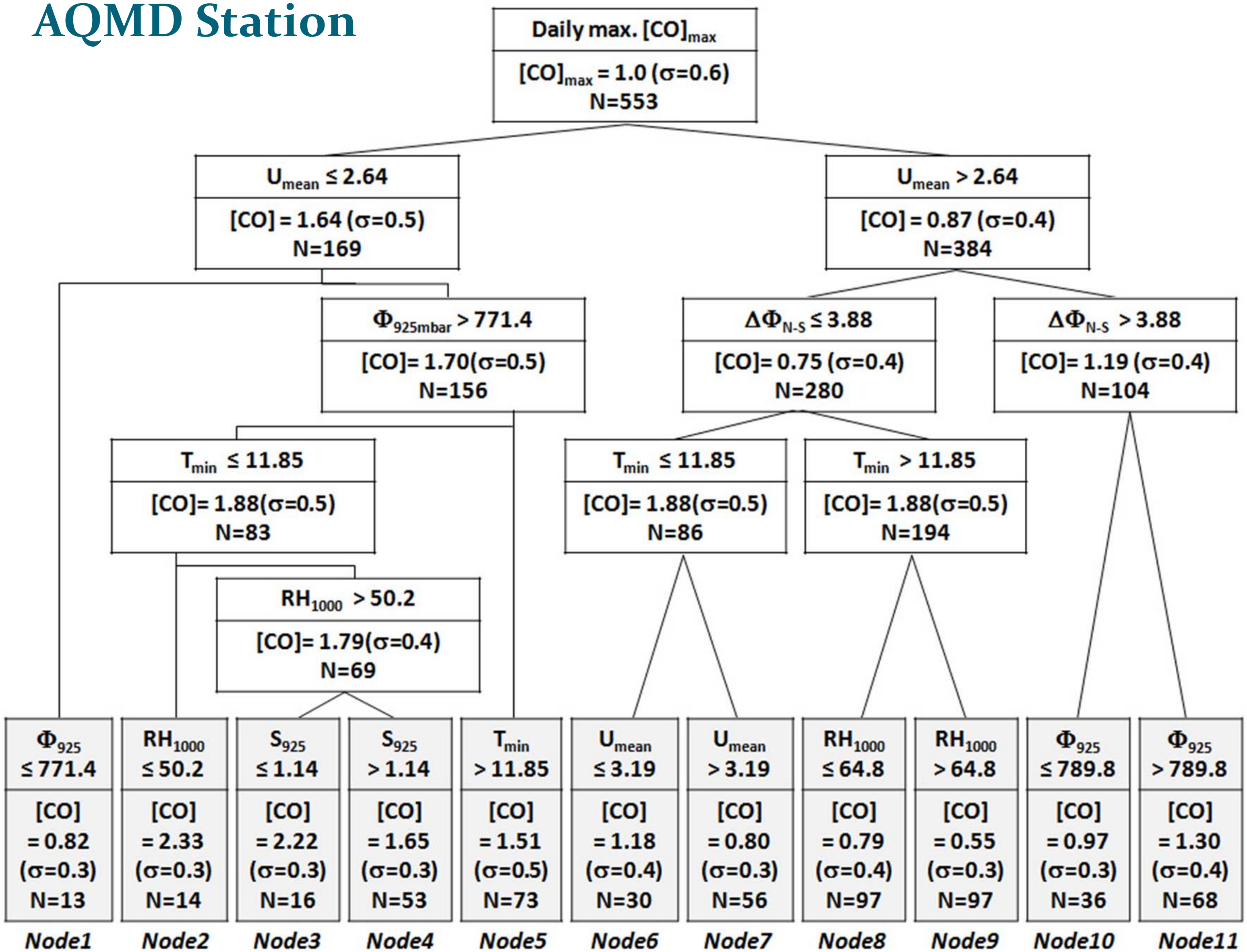

Hidden Hills
Burbank
San Antonio Heights
Agoura Hills
Calabasas
Glendale
Pasadena
Arcadia
Glendora
San Marino
Duarte
Azusa
Rancho Cucamonga
West Hollywood
Alhambra
Temple City
San Dimas
Upland
Malibu Creek State Park
Topanga State Park
Beverly Hills
West Covina
Covina
Claremont
Los Angeles
El Monte
Ontario
Valinda
Santa Monica
Culver City
South El Monte
Diamond Bar
Declezville
East Los Angeles
La Puente
Chino
Walnut
Marina Del Rey
Hacienda Heights
Chino Hills
Maywood
Pico Rivera
Whittier
Mira Loma
Inglewood
Walnut Park
Bell
Eastvale
Pedley
South Gate
South Whittier
Chino Hills State Park
Lennox
Downey
La Habra
Firestone Boy Scout Reservation
Norco
El Segundo
Hawthorne
Lynwood
Norwalk
La Mirada
Brea
Butterfield Stage Trail Park
Gardena
Compton
Yorba Linda
Manhattan Beach
Paramount
Bellflower
Fullerton
Corona
Home Gardens
Placentia
Buena Park
Lakewood
Redondo
101
405
1
10
110
60
91

Classification of Meteorology during Measurement Periods based on CART (Correlation and Regression Tree) analysis of primary pollutants

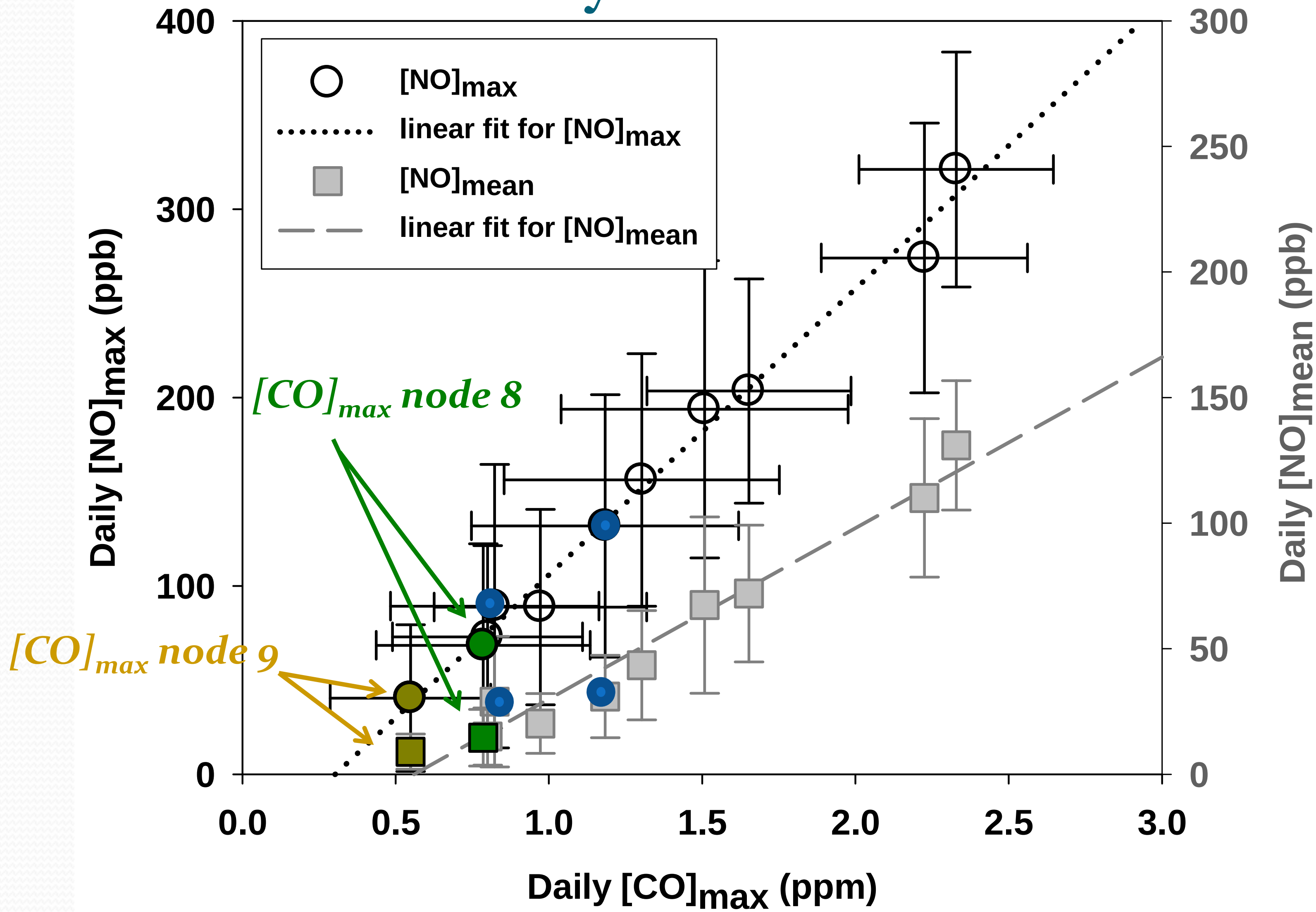
Meteorological variables considered in the CART model and their effects on atmospheric primary pollutant concentrations

	Meteorological variables	Importance on primary pollutant level
Upper-air (NCEP model)	• Geopotential heights (Φ) at 1000/925/850/500 mbar	Indicator of synoptic-scale weather pattern or vertical mixing height
	• Mean temperature (T) at 1000/925/850 mbar	A measure of the strength and height of the subsidence inversion
	• Stability ($T_{1000mbar} - T_{925mbar}$, $T_{1000mbar} - T_{850mbar}$)	Indicator of atmospheric stability
	• Thickness ($\Phi_{925mbar} - \Phi_{1000mbar}$)	Related to the mean temperature in the layer
	• Relative humidity at 1000 mbar ($RH_{1000mbar}$)	Indirect effect
	• Pressure gradient at 1000 mbar level ($\Phi_{north} - \Phi_{south}$, $\Phi_{east} - \Phi_{west}$)	Related to wind fields and ventilation strength
Surface observations (LAX)	• mean/min./max. temperature (T_{mean}, T_{min}, T_{max})	Indirect effects on air stability and emission rates from the engine
	• mean/max. wind speed (U_{mean}, U_{max})	Related to dispersion/ventilation strength
	• Relative humidity (RH)	Indirect effect
	• Mean surface pressure	Indicator of synoptic-scale weather

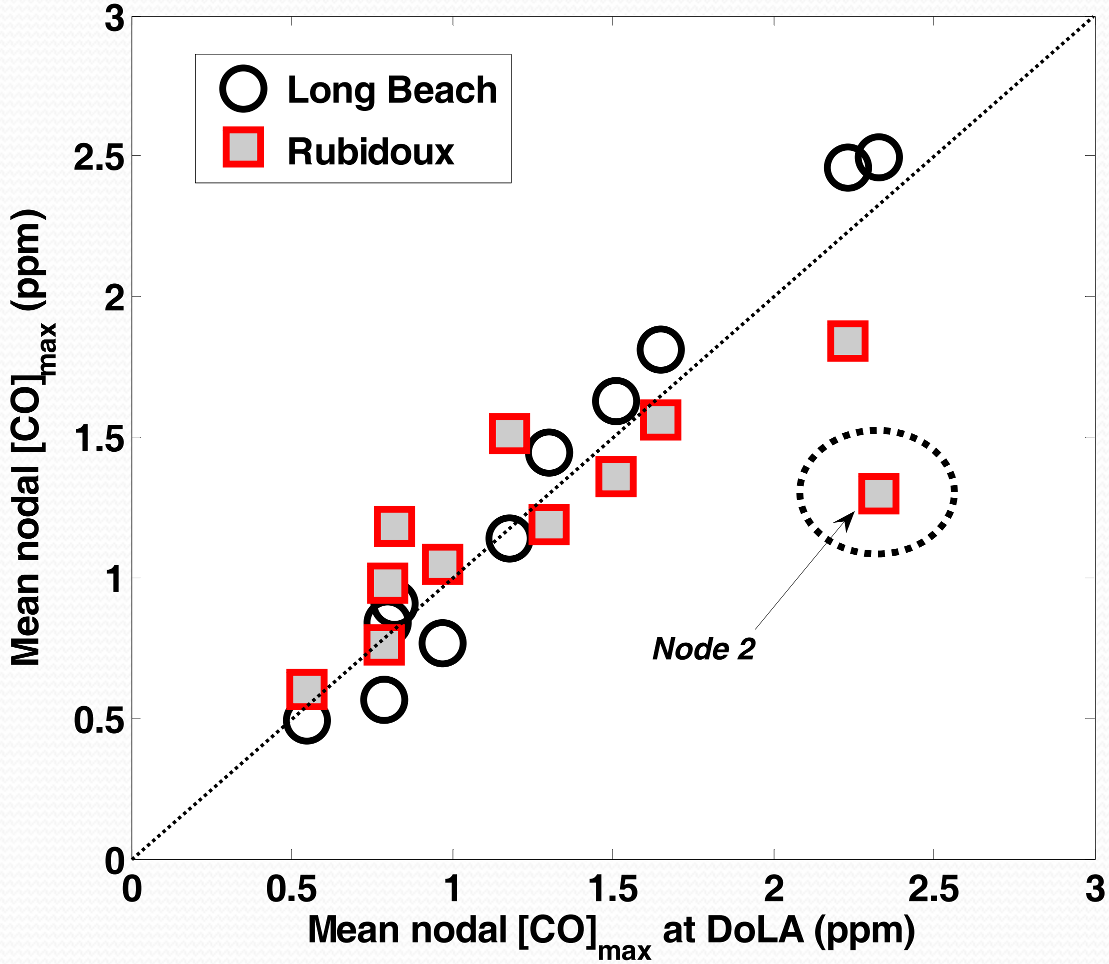
Regression Tree for $[CO]_{max}$ at the Downtown Los Angeles AQMD Station



Different pollutants at the same site are closely correlated.

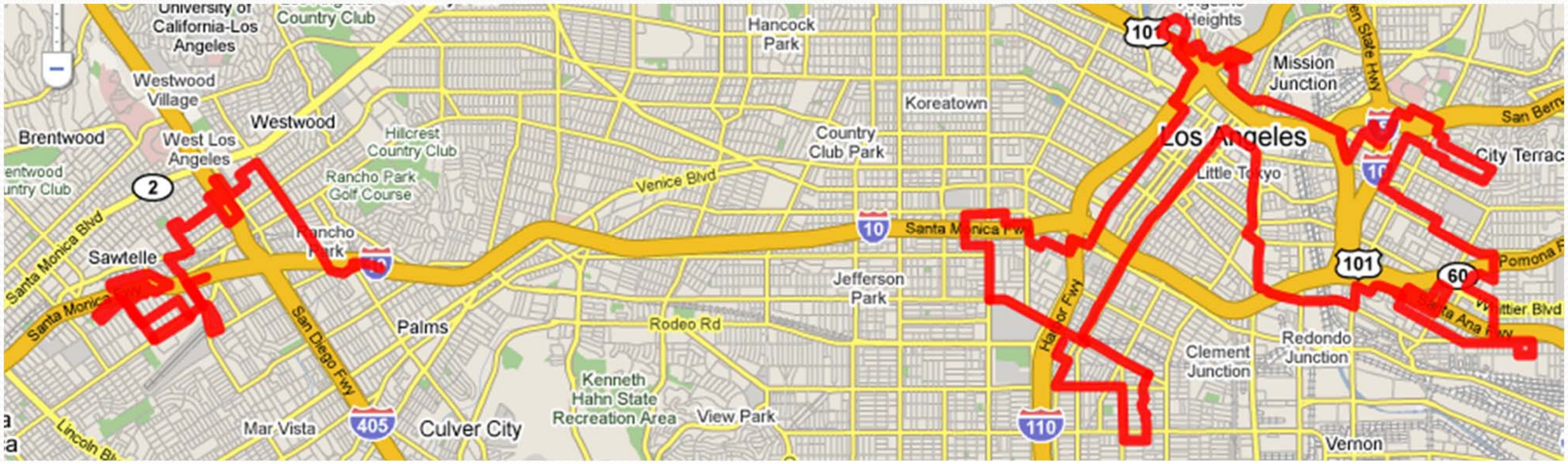


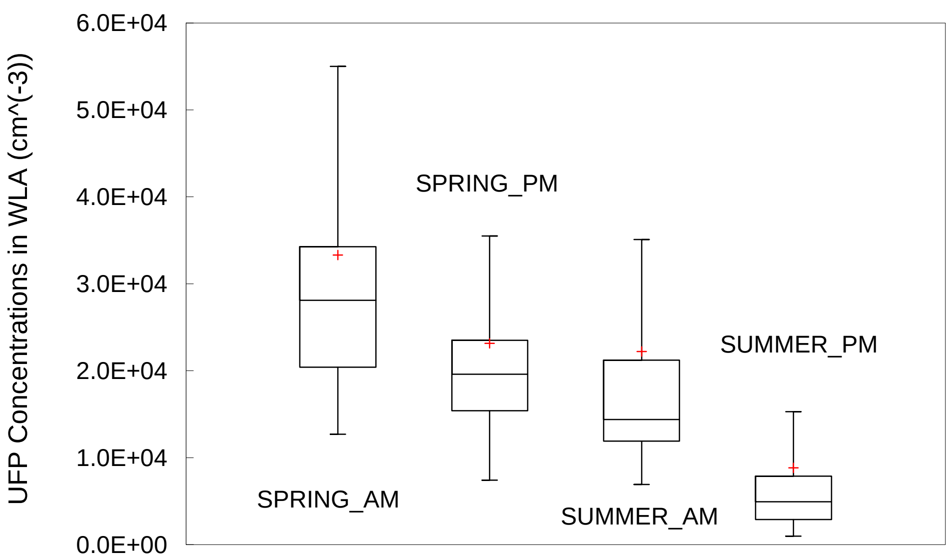
The Same Pollutants at Different Sites are also Closely Correlated.

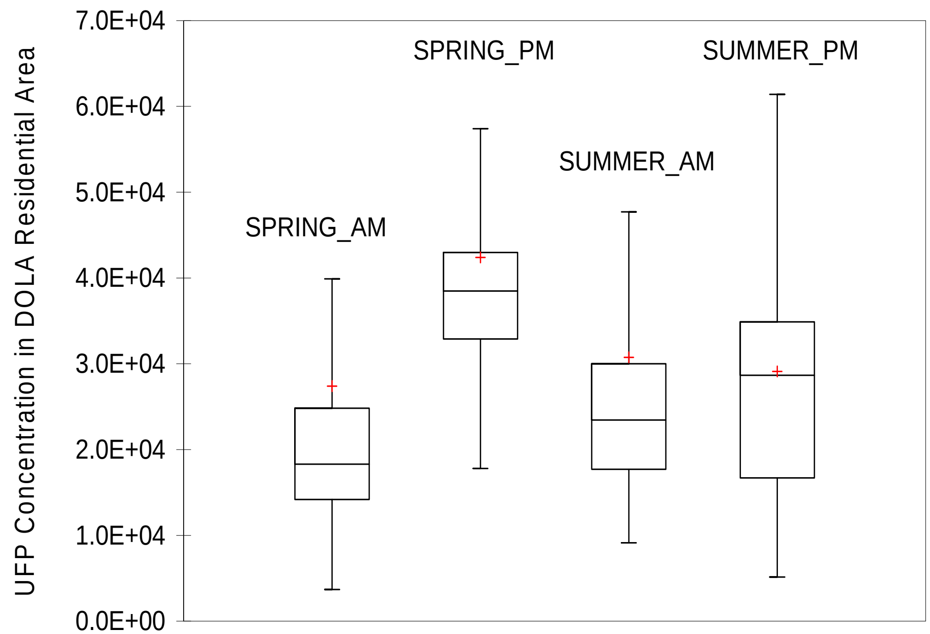


Air Quality in Several Los Angeles Neighborhoods

Temporal trends are quite different in different areas. Data are for residential areas only.

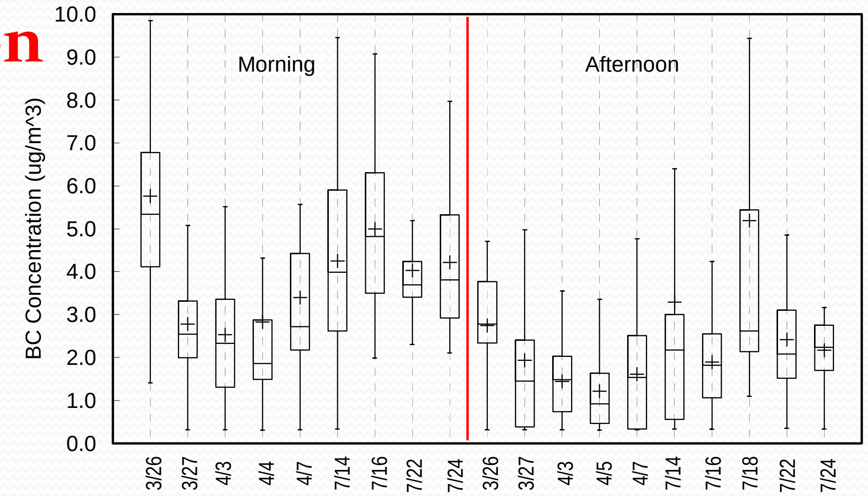


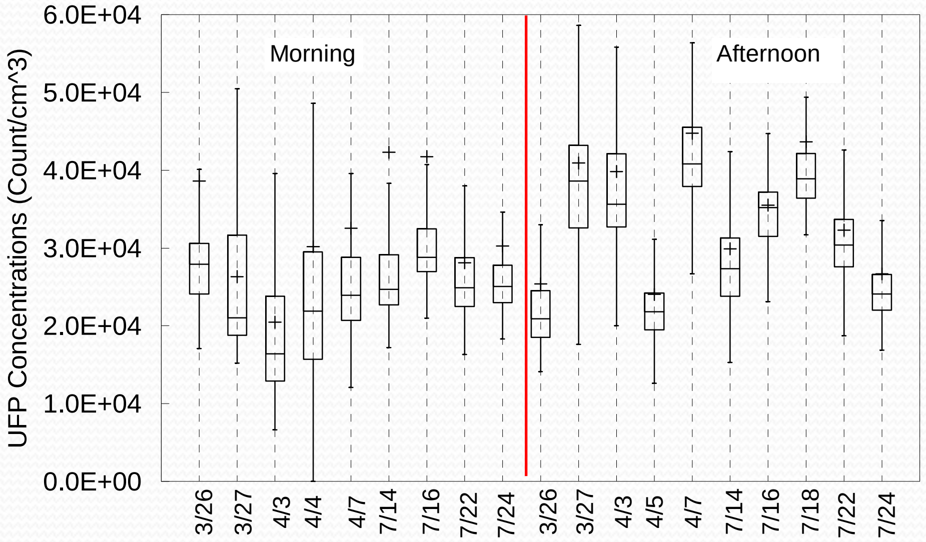




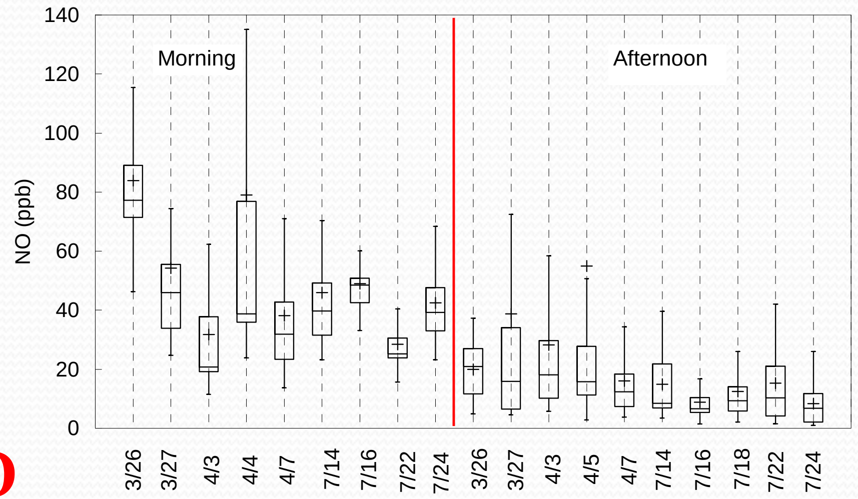
15 miles inland: UFP are higher in the afternoon while other 1° pollutants are lower

Black Carbon



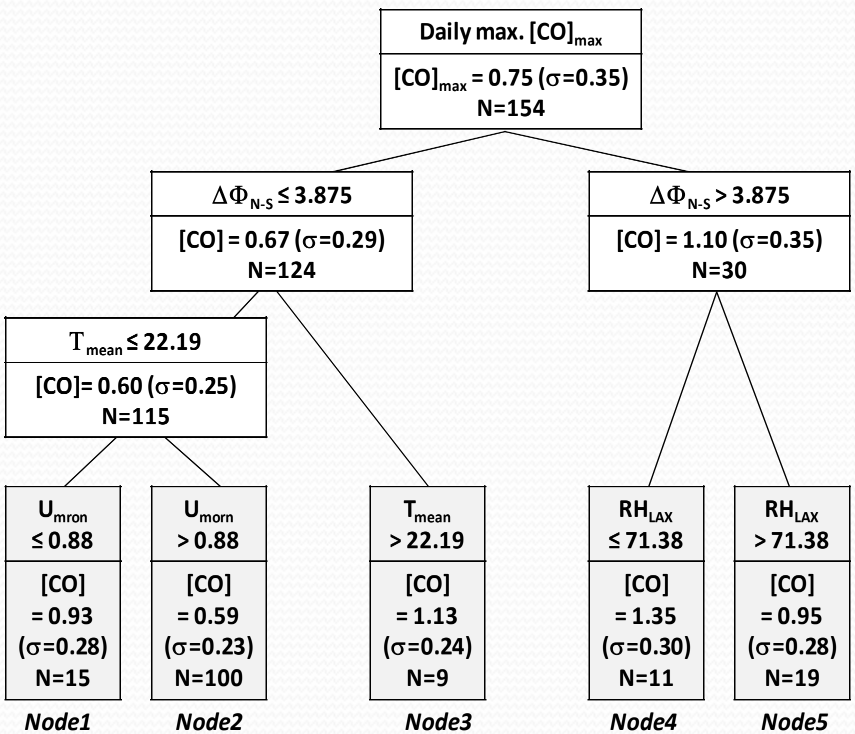


Ultra Fine Particles



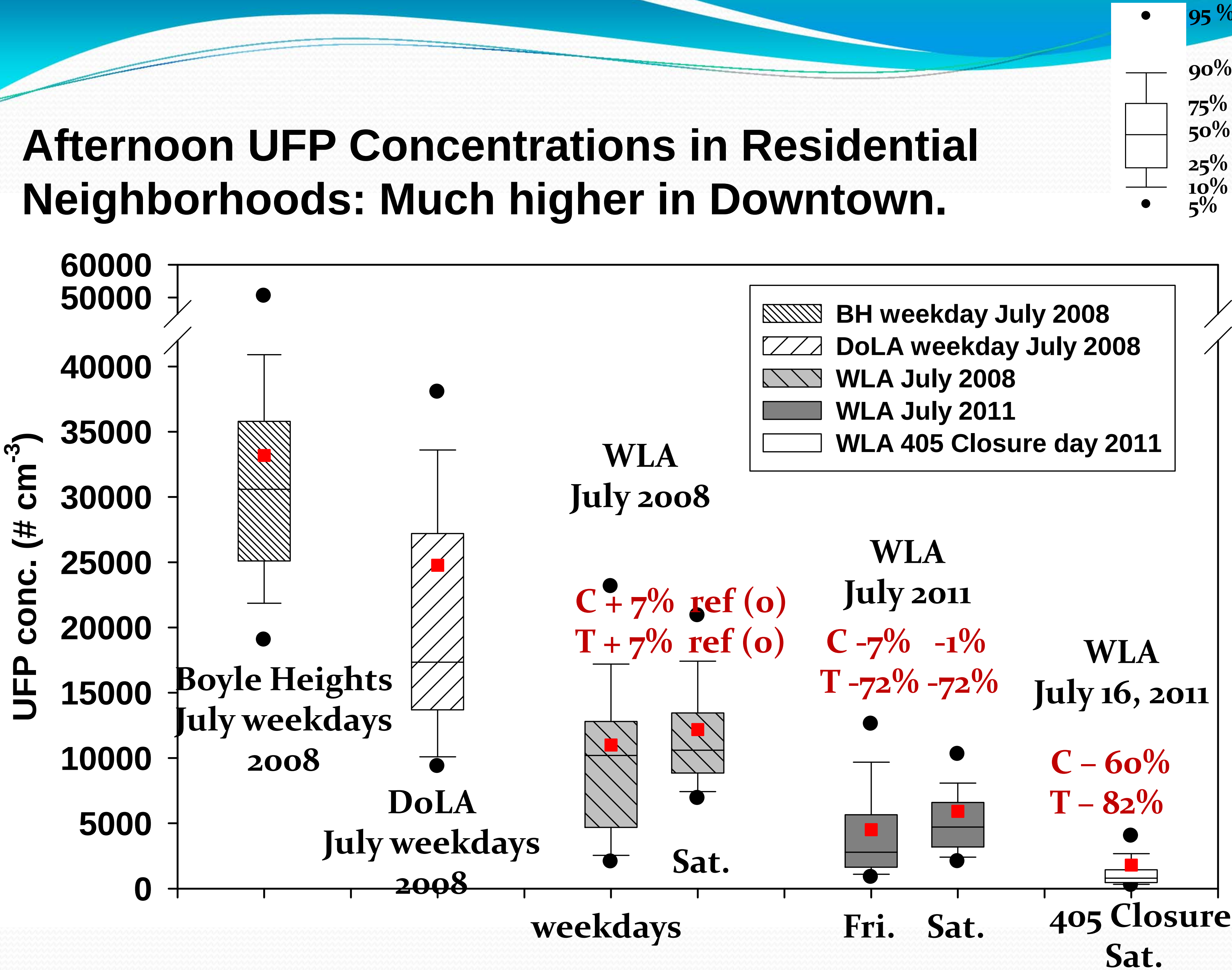
NO

Summer time regression tree for daily *$[CO]_{max}$* observed at Downtown LA (N. Main St.) for 2007 – 2009 (Jun. 21st to Sep. 21st). Choi et al. (2013).

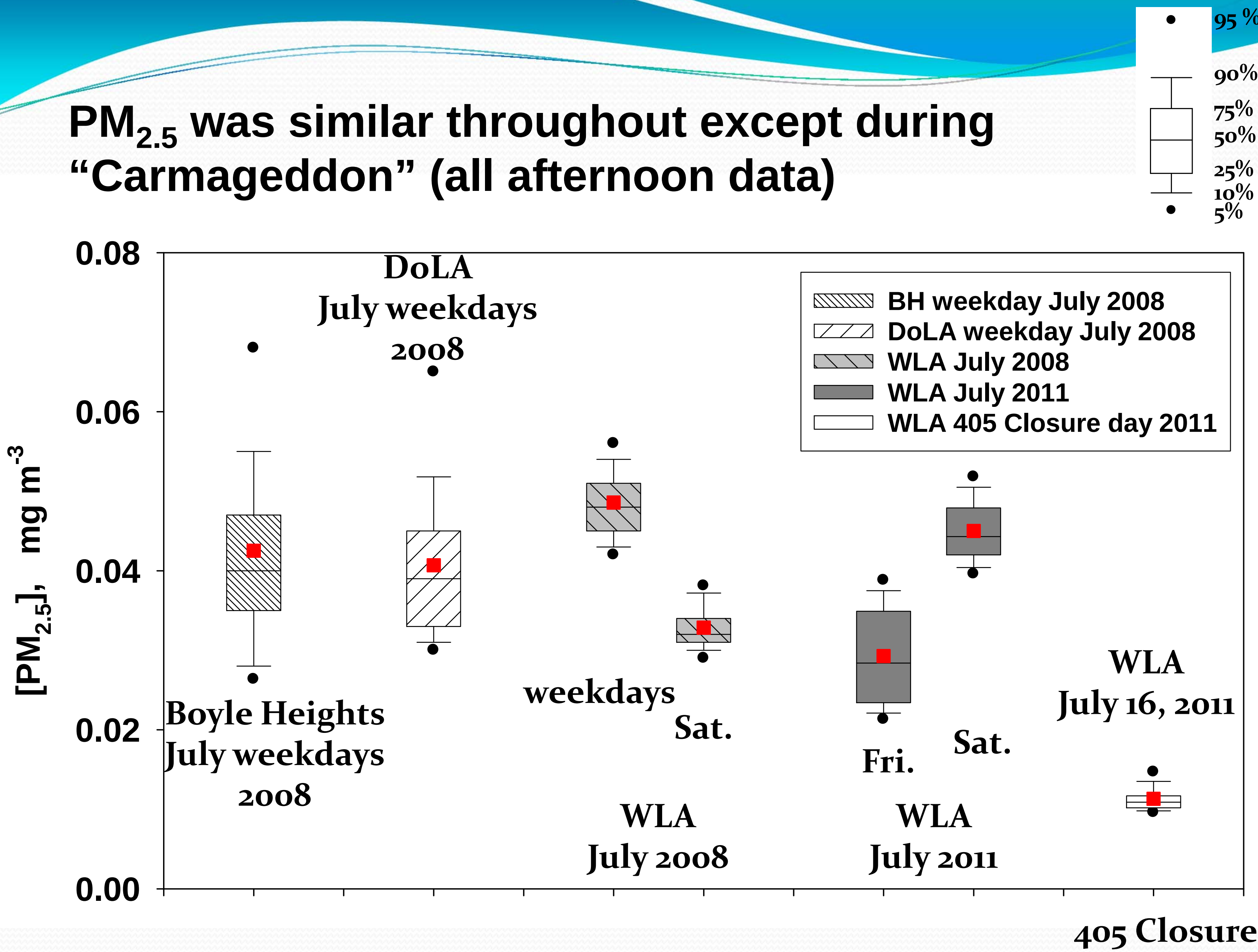


Area	Measurement Date (Time)	Day of week	Temp. (°C)	Relative humidity (%)	Wind speeds $(m \cdot s^{-1})$	Wind direction (°)	CART final node[a]
DTLA/ BH	07/14/2008 (14:00 – 17:00)	Mon.	27.6	41	2.6	240	2
	07/16/2008 (14:00 – 17:00)	Wed.	26.7	49	2.4	260	2
	07/18/2008 (14:00 – 17:00)	Fri.	24.6	61	2.9	250	2
	Mean (Std.)		26.3 (1.5)	50 (9)	2.6 (0.7)	250 (10)	
WLA	06/30/2008 (14:00 – 16:30)	Mon.	21.9	60	4.1	243	2
	07/08/2008 (14:00 – 16:30)	Tue.	20.7	73	5.1	240	5
	07/10/2008 (14:00 – 16:30)	Thu.	23.4	63	4.4	227	2
	07/12/2008 (14:00 – 16:30)	Sat.	23.9	63	4.3	240	2
	Mean (std.)		22.5 (1.5)	65 (5)	4.5 (0.6)	238 (13)	
WLA	07/08/2011 (12:00 – 14:00)	Fri.	22.6	70	3.9	233	2
	07/09/2011 (12:00 – 13:30)	Sat.	21.5	72	3.8	228	2
	07/10/2011 (12:00 – 13:30)	Sun	21.8	68	4.1	235	2
	07/15/2011 (13:30 – 15:00)	Fri.	21.3	57	4.6	245	2
	07/16/2011 (14:30 – 16:00)	Sat.	20.3	67	5.1	240	1
	07/17/2011 (13:15 – 14:45)	Sun	20.9	68	4.3	240	2
	07/22/2011 (14:20 – 16:00)	Fri.	20.9	66	4.8	233	2
	07/23/2011 (13:30 – 15:00)	Sat.	21.1	66	4.4	240	2
	Mean (std.)		21.3 (0.7)	67 (4)	4.4 (0.4)	237 (6)	

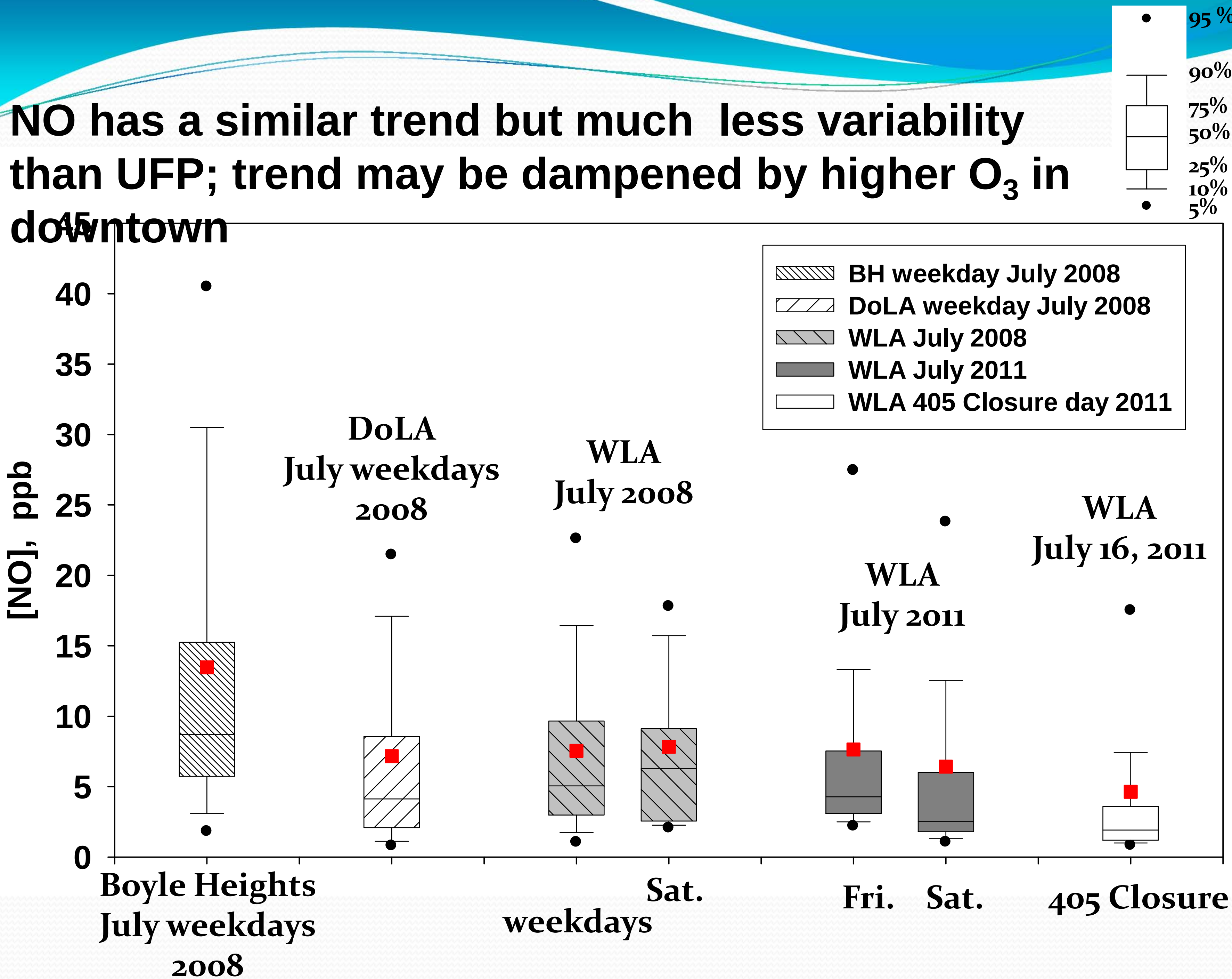
Afternoon UFP Concentrations in Residential Neighborhoods: Much higher in Downtown.



$PM_{2.5}$ was similar throughout except during "Carmageddon" (all afternoon data)

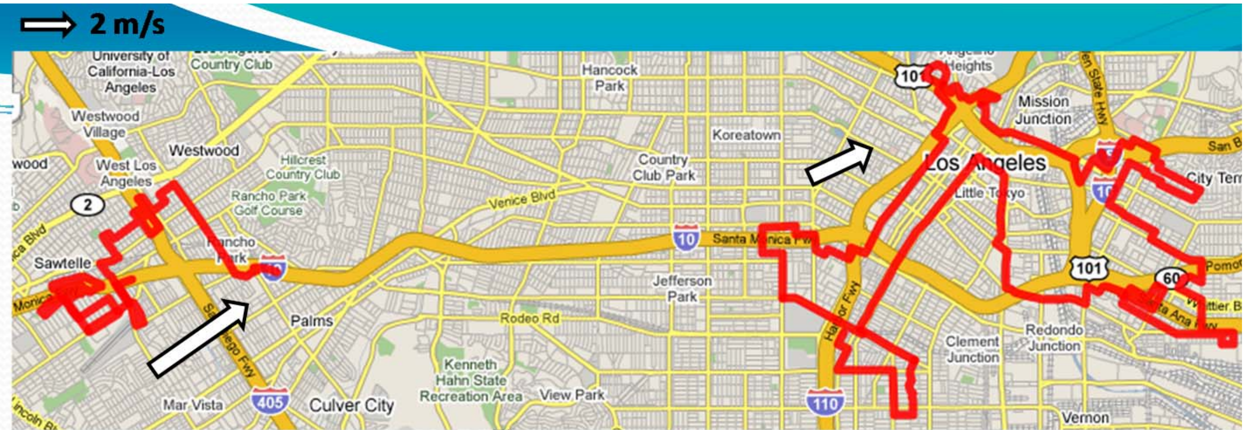


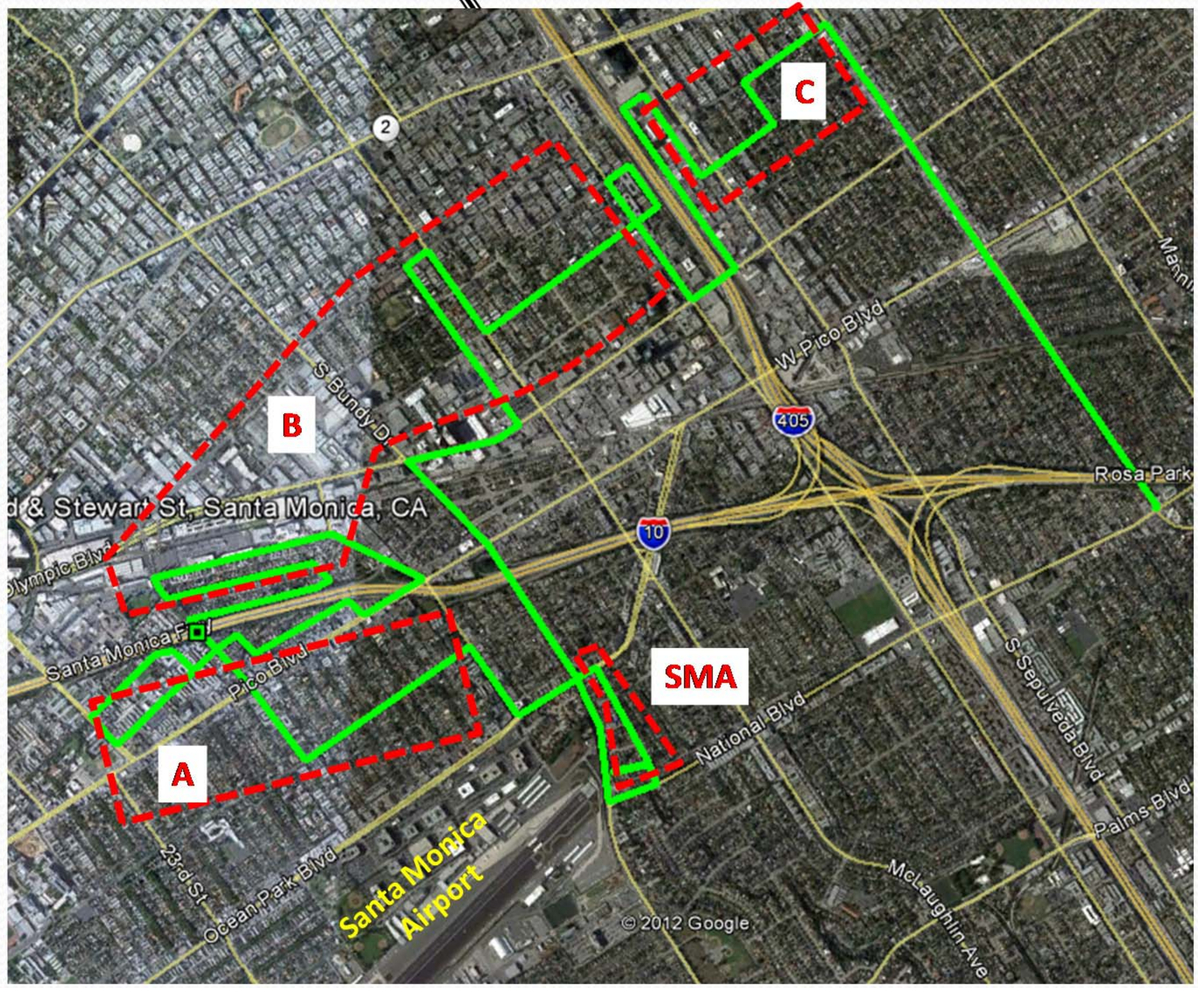
NO has a similar trend but much less variability than UFP; trend may be dampened by higher O_3 in downtown



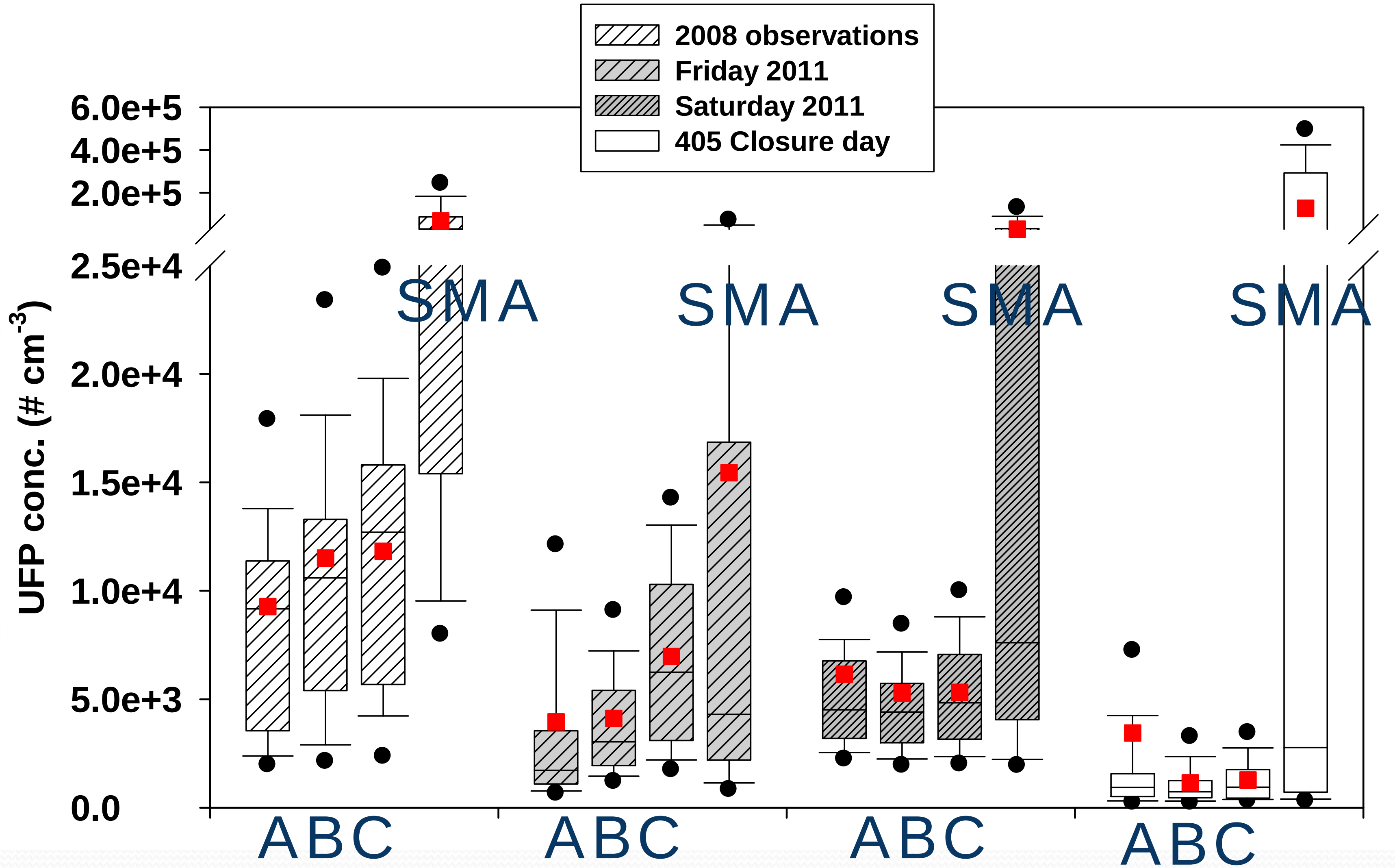
Neighborhood-Scale Air Quality in West Los Angeles

West Los Angeles measurement areas in 2008 and 2011





Substantial Variations in Ultrafine Particle Concentrations between Neighborhoods



Air Quality Benefits of emissions reductions (Daytime measurements)

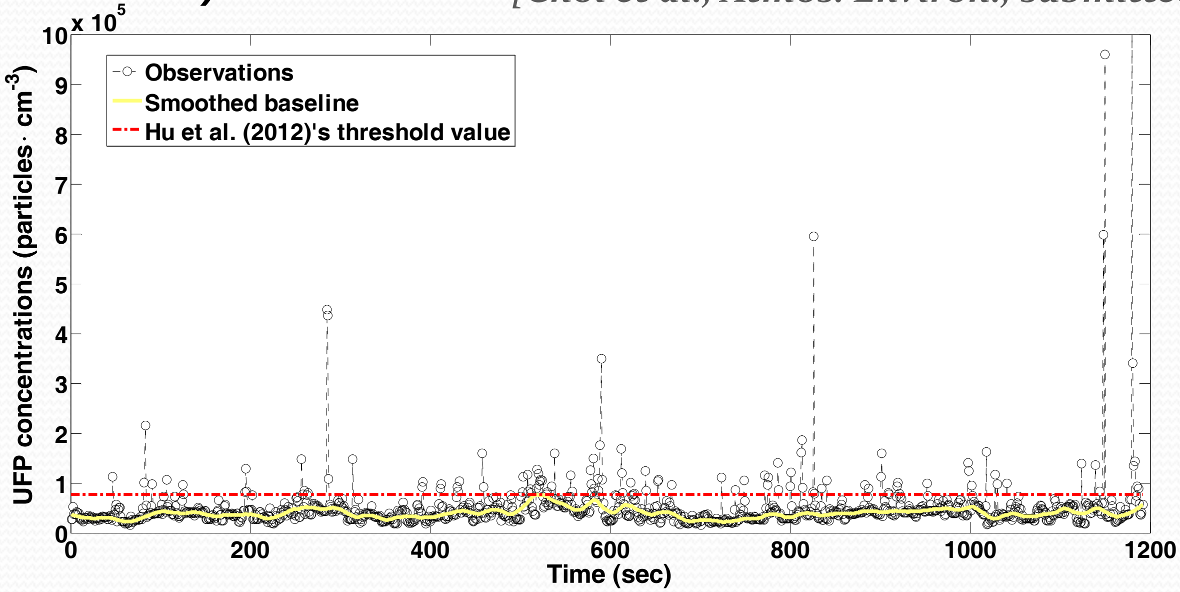
[Choi et al., Atmos. Environ., submitted

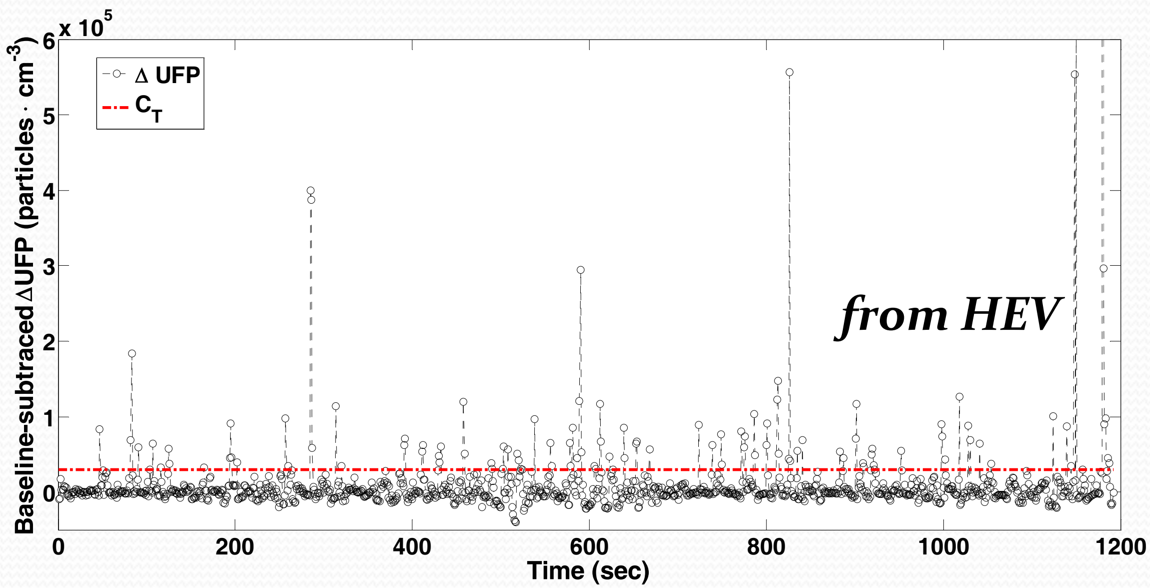
High emitting vehicles (HEV) effects on UFP levels

$$C_T = 3 \times \sigma_{\Delta UFP < C_T}$$

$$\%\ \text{time HEV were encountered} = \frac{N_{C>C_i}}{N_{total}}$$

$$\%\ \text{of total UFP from HEV} = \frac{\sum C_{C>C_i}}{\sum C_{total}}$$





6–8% of time HEV were encountered account for 17–30% of total UFP in residential neighborhoods

Less than 1% HEV of the fleet contributed to more than a third of total CO and HC emissions.

[Bishop et al., 2012]

Summary

- The regression tree (CART) analysis is helpful, but more resolution is desired.
- UFP are much more variable than other metrics like PM 2.5, black carbon and NO_x between neighborhoods.
- Particle concentrations are much higher in the afternoons in Downtown Los Angeles than in the coastal area, but more similar overall.
- Behavior of UFP concentrations in neighborhoods is sufficiently complex to be easy to explain but difficult to predict.

Summary III

1. **High emitting vehicles significantly contributed to total UFP distributions both on arterial roadways and in residential neighborhoods.**
2. **Roughly 30 – 70% traffic reductions in WLA during the "Carmageddon" period led to about 70% reductions in particulate pollution area-wide in WLA.**

Present case study makes clear the potential benefits for public health of achieving significant vehicle emission reductions through strategies such as HDDT retrofits, and transition to electric vehicles and alternative fuels such as natural gas. This study also showed the significant impact of HEV on total UFP concentrations, and hence, retrofits or earlier retirement of high-emitting vehicles can help improve urban air quality.

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