Near-Road Mitigation Measures and Technologies

November 21, 2013

Agenda

9:00 a.m.	**Welcome** *Barry Wallerstein, Executive Officer, SCAQMD*
9:10 a.m.	**Overview of Pollutants Found in the Near-road Environment** *Suzanne Paulson, Professor, Dept. of Atmospheric and Oceanic Sciences, UCLA*
9:35 a.m.	**Overview of Health Effects Due to Exposure to Near-road Pollutants** *Rob McConnell, Associate Professor. Division of Occupational and Environmental Health, USC*
10:00 a.m.	**On-Road Motor Vehicle Emission Control Programs** Zero or near-zero emission tailpipe control technologies, regulatory and incentive programs, future goals and efforts *Mike McCarthy, Manager, Advanced Engineering Section, CARB*
10:30 a.m.	**Break (10 minutes)**
10:40 a.m.	**Exposure Mitigation I – Roadway Characteristics and Barriers** Effects of sound walls/noise barriers, vegetation, and roadway features on near-road exposure *Rich Baldauf, Physical Scientist/Engineer, U.S. EPA* *Akula Venkatram, Professor, Dept. of Mechanical Engineering, UCR* *Marko Princevac, Associate Professor, Dept. of Mechanical Engineering, UCR* *Cathy Fitzgerald, Scientist, The Planning Center* *Frank Di Genova, Scientist; Sierra Research*
12:30 p.m.	**Lunch (60 minutes)**
1:30 p.m.	**Exposure Mitigation II – Near Roadway Environment Features** Effectiveness of buffer zones, building and in-cabin air filtration, and other similar strategies in reducing air pollution exposure near roadways *Paul Roberts, Executive Vice President, STI* *Andrea Polidori, Manager, Quality Assurance Branch, SCAQMD* *Yifang Zhu, Associate Professor, Dept. of Environmental Health Sciences, UCLA*

2:30 p.m. **Planning and Policy Discussion**

Moderator: *Philip Fine, Assistant Deputy Executive Officer, Science & Technology Advancement, SCAQMD*

Panelists: *Connie Chung, Supervising Regional Planner, LADRP*
David Vintze, Manager; Planning and Research Division, BAAQMD
Huasha Liu, Director, Dept. of Land Use and Environmental Planning, SCAG
Mike McCarthy, Manager, Advanced Engineering Section, CARB
Terry Roberts, Director, American Lung Association

3:45 p.m. **Wrap-Up/Closing Remarks**

Participating Agencies / Institutions / Organizations

American Lung Association
BAAQMD – Bay Area Air Quality Management District
CARB – California Air Resource Board
LADRP – Los Angeles Department of Regional Planning
SCAG – Southern California Association of Governments
SCAQMD – South Coast Air Quality Management District
Sierra Research
STI – Sonoma Technology, Inc.
The Planning Center
UCLA – University of California, Los Angeles
UCR - University of California, Riverside
USC – University of Southern California
U.S. EPA – U.S. Environmental Protection Agency

Back to Agenda

Spatial Heterogeneity of Roadway Pollutants in Los Angeles

Wonsik Choi,[1] Shishan Hu,[2] Meilu He,[1] Kathleen Kozawa,[2] Steve Mara,[2] Scott Fruin,[3] Arthur Winer[1] and **Suzanne Paulson[1]**

[1]UCLA

[2]California Air Resources Board

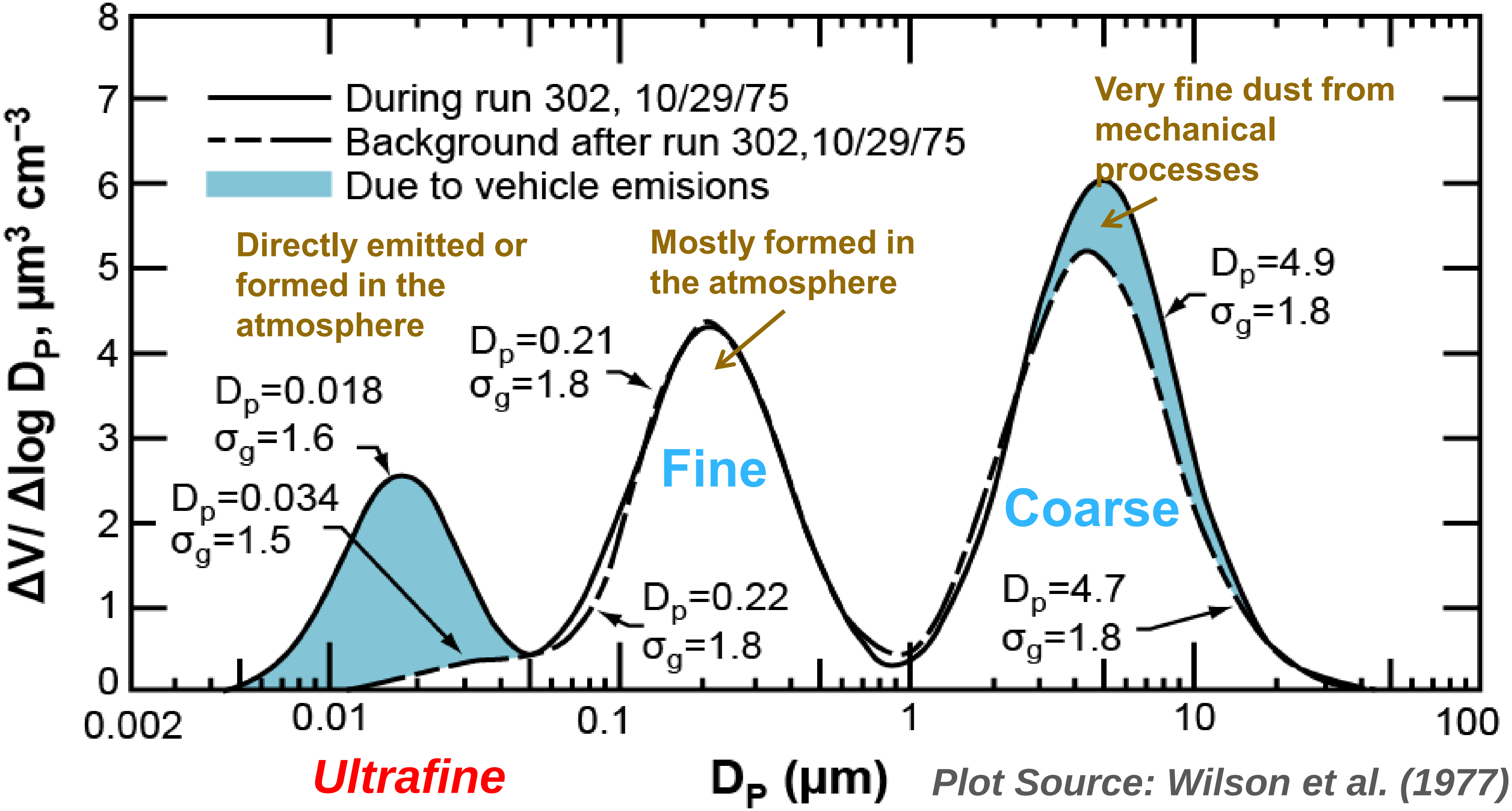
[3]USC

Supported by the California Air Resources Board

Outline

- Roadway pollutants and their daytime decay curves
- Early morning plumes
- Inter-neighborhood variations in pollutants

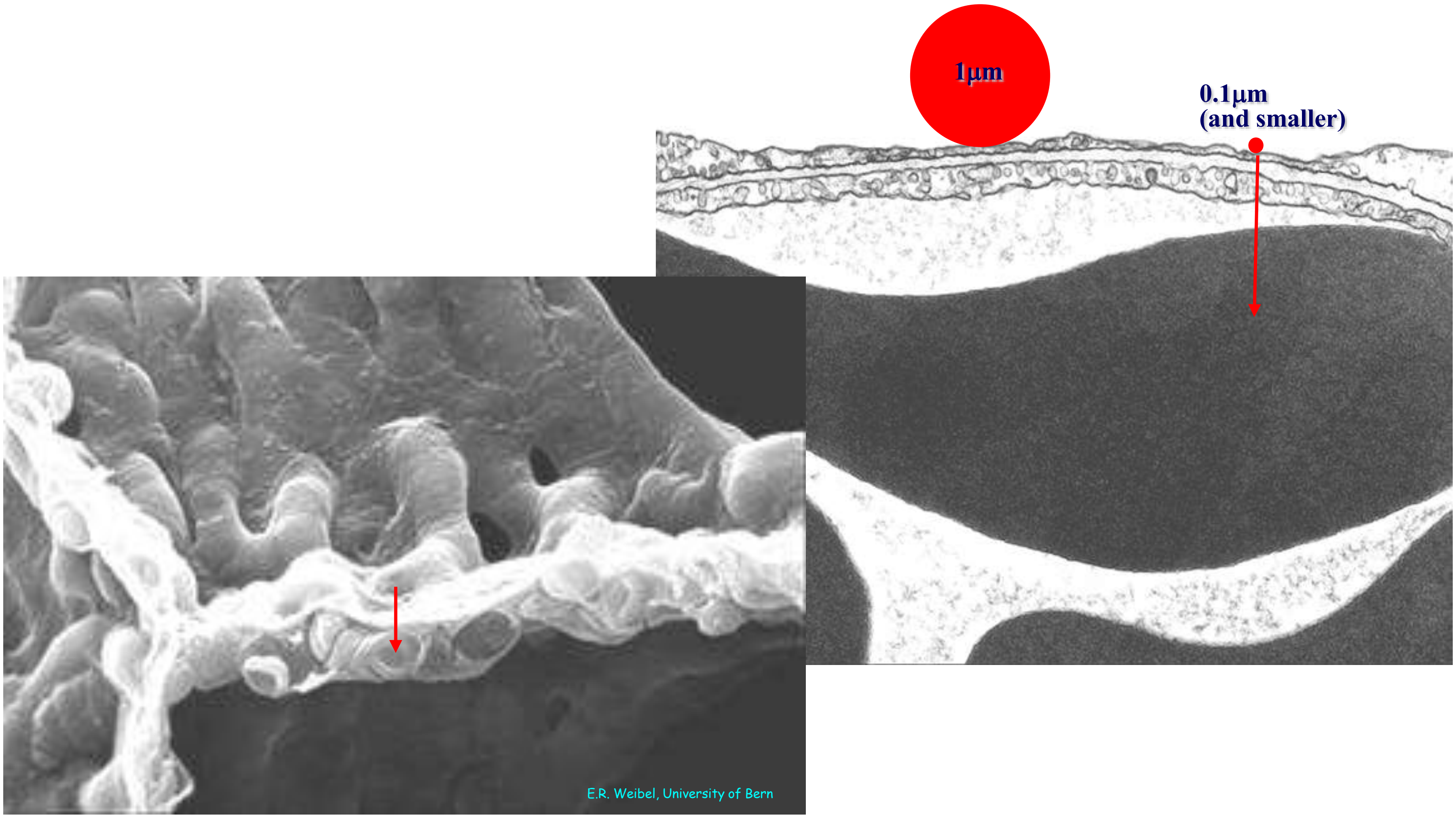
Size Distribution of Atmospheric Particles



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]***

TRANSLOCATION FROM AIR TO BLOOD



Courtesy of Peter Gehr, U. Bern

Pollutants & Measurements

Measurement Parameter
Particle Number (10 nm ~ 1μm), but dominated by ultrafine particles
Particle size distribution (5.6~560 nm)
$PM_{2.5}$ and PM_{10} mass
Particle bound PAHs
Black Carbon
CO_2
CO
NO, NO_2
Temperature, Relative humidity, Wind speed/direction
GPS
Vertical profiles of temperature, *RH*, wind speed/direction
Video record
-------- Wish List -------------
Speciated Volatile Organics
Particle Chemical Composition

ARB's electric vehicle

SmartTether™

Pollutant Concentrations Near Roadways Vary A LOT

- Fleet emissions
  - Traffic density, fleet composition, driving conditions
- Atmospheric Dispersion
  - Wind speed and direction, atmospheric stability, vehicle wakes, topography
- Built Environment
  - Roadway geometry, buildings, soundwalls, other nearby roadways & vegetation
- Observed Roadway Pollutant Spatial Distributions Also Depends on the relationship between the **Peak and Background Concentrations**.

Observed decay of pollutants depends on the difference between the peak and background concentration

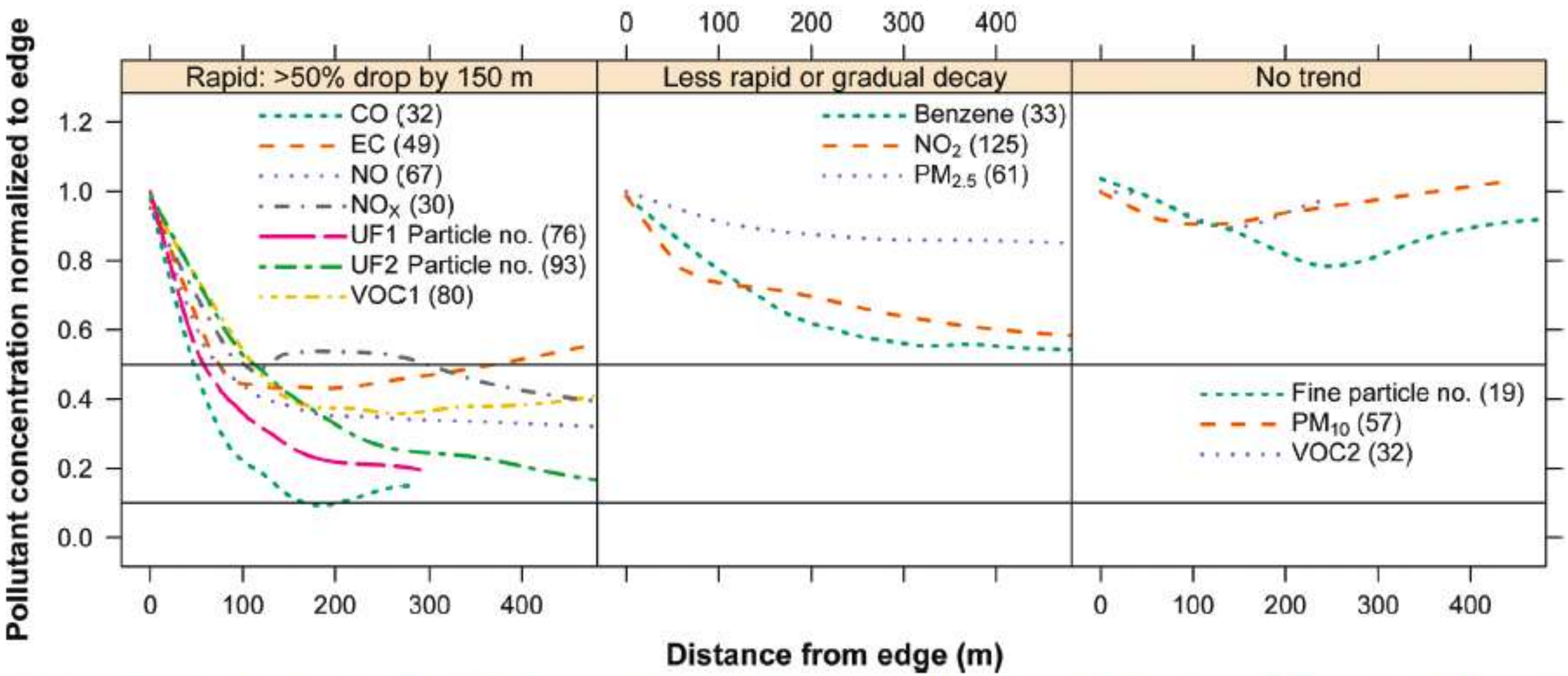
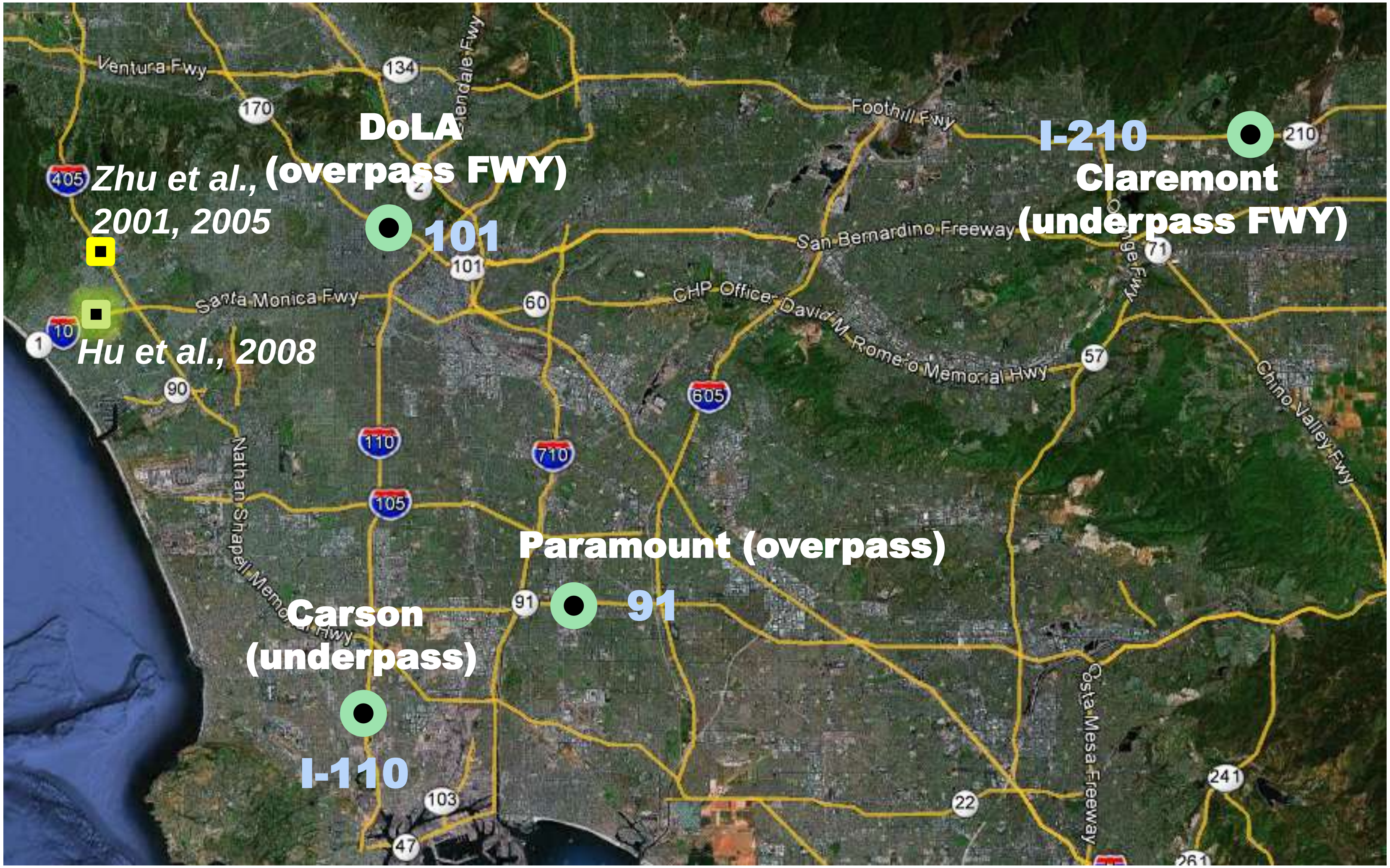


FIGURE 3. Local regression of edge normalized concentrations on distance. The horizontal black lines show a reduction from the edge-of-road concentration of 90% (at 0.1) and 50% (at 0.5). A loess smoother (alpha = 0.70, degree = 1) was fitted to pollutant data which was placed in one of three groups. The regression sample size, n, is given in parentheses after each pollutant. The n includes an estimated (not in the literature) edge-of-road value to facilitate normalization.

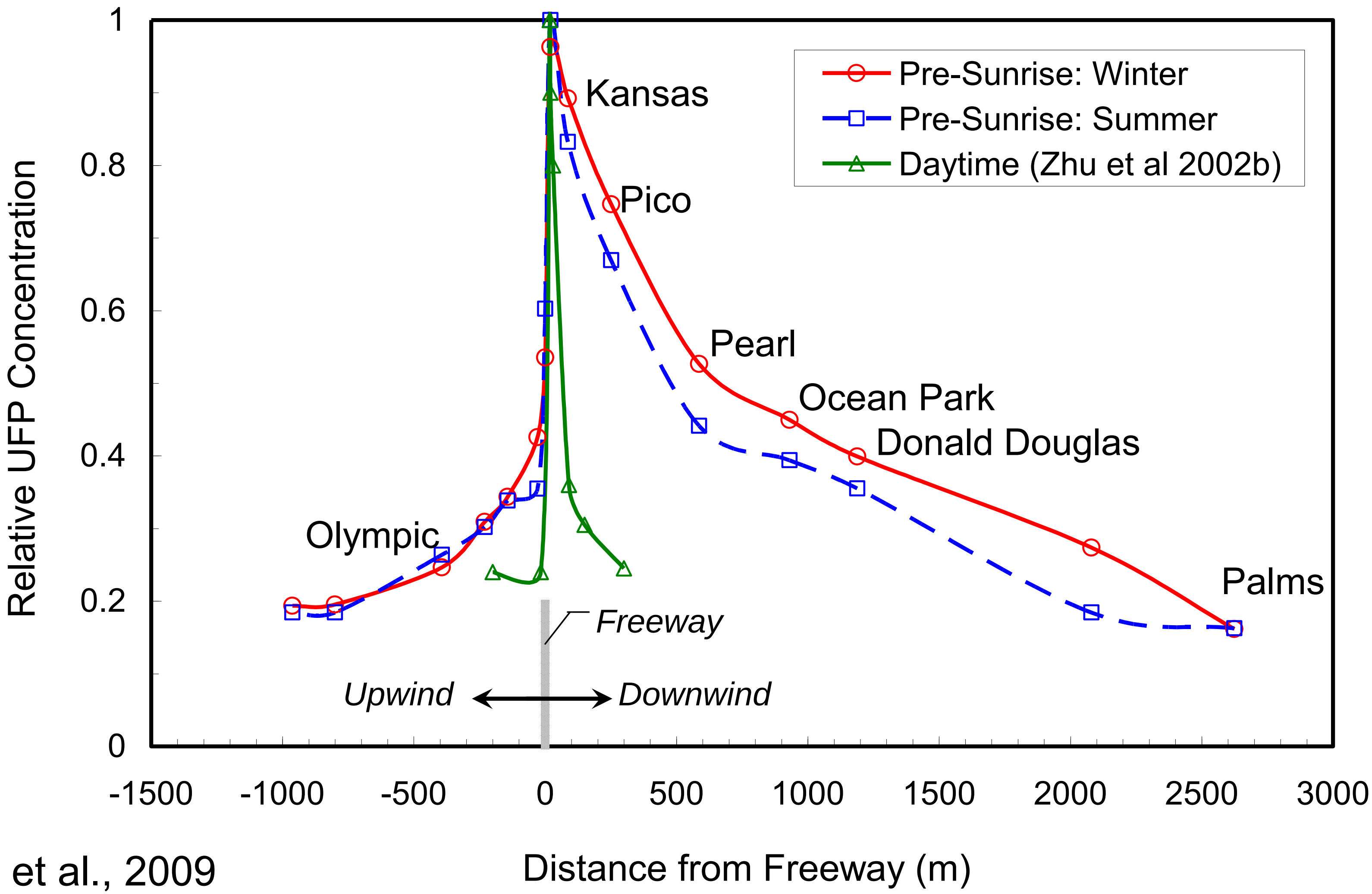
Karner et al., ES&T 2011

Freeway plumes in the early morning

Sampling Area and Transects

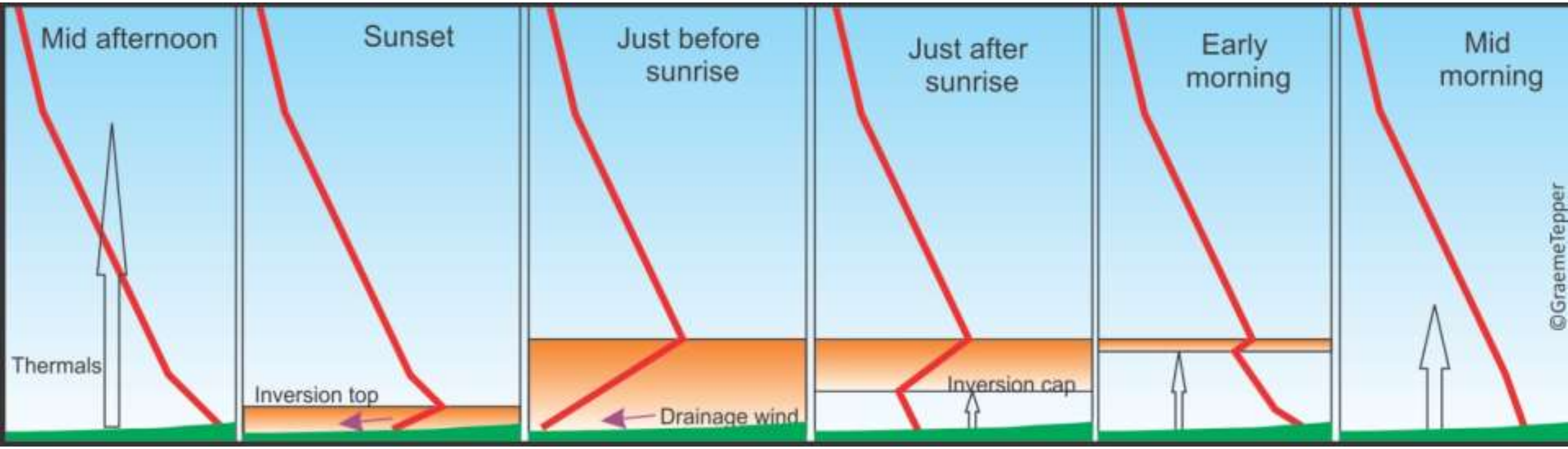


The Freeway Imprint is Many Times Larger Before and Just After Sunrise (normalized data)



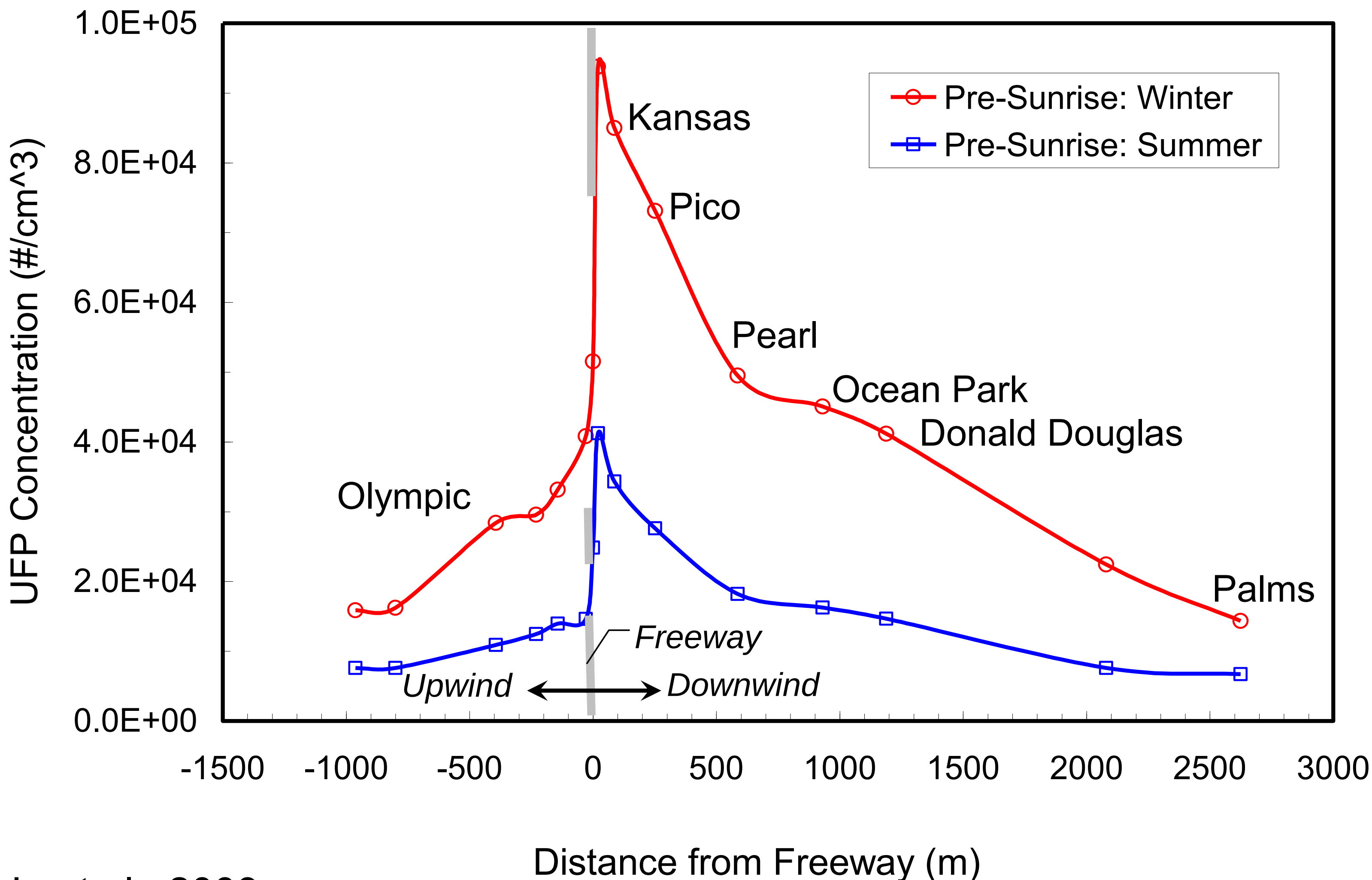
Hu et al., 2009

The Atmosphere Strongly Traps Pollution Near the Surface in the Early Morning



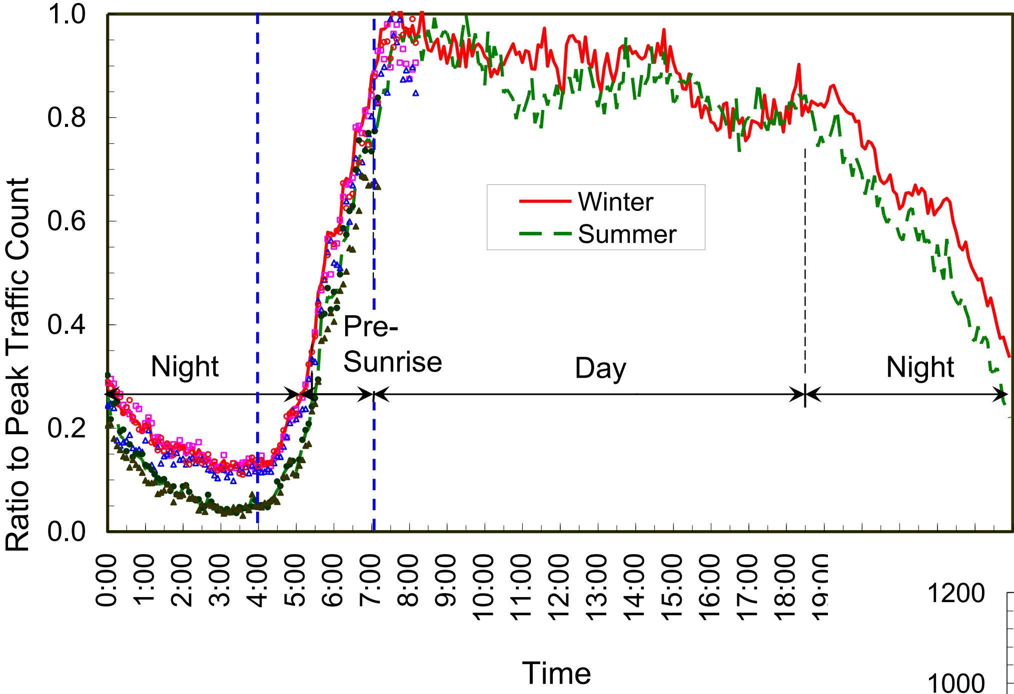
Red line indicates temperature profile

Santa Monica: Summer is Cleaner; why?

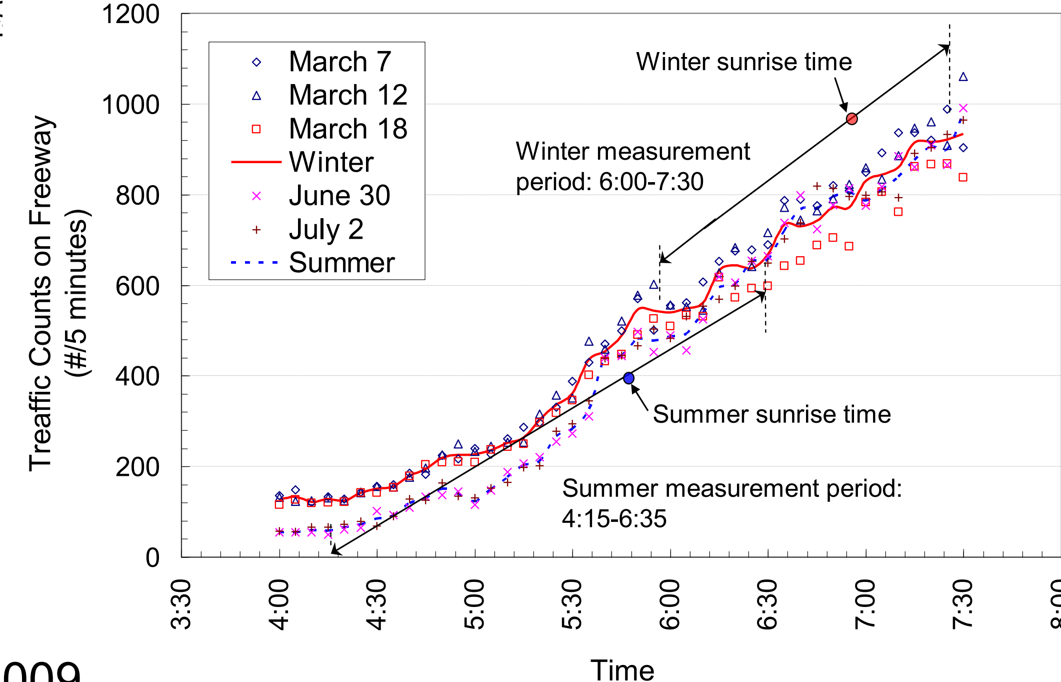


Hu et al., 2009

Traffic Counts Increase Rapidly in the Early AM

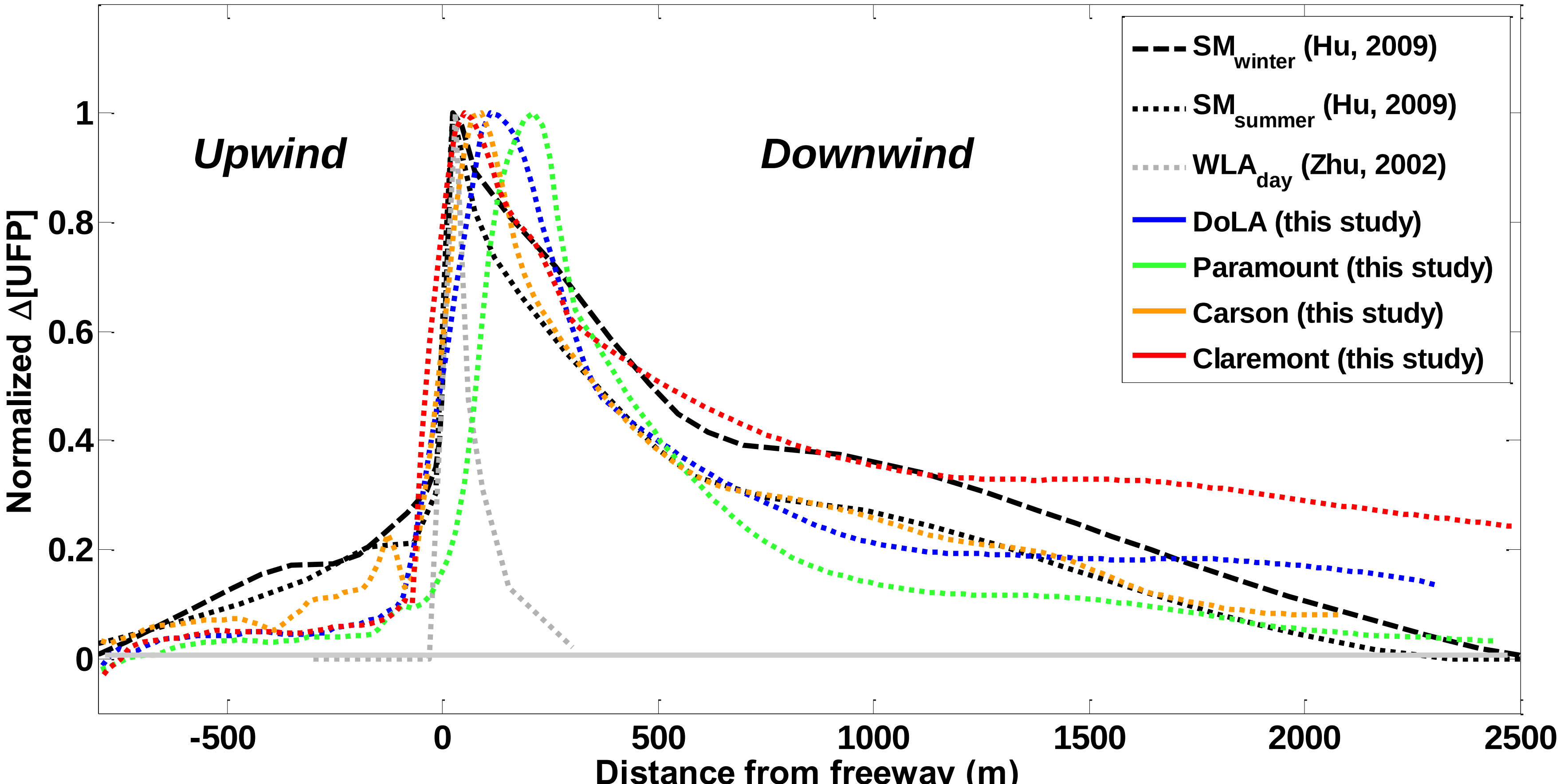


Summer is cleaner because there is less traffic during the pre-sunrise period



Hu et al., 2009

Early Morning Freeway Plumes at Other Locations in Southern California

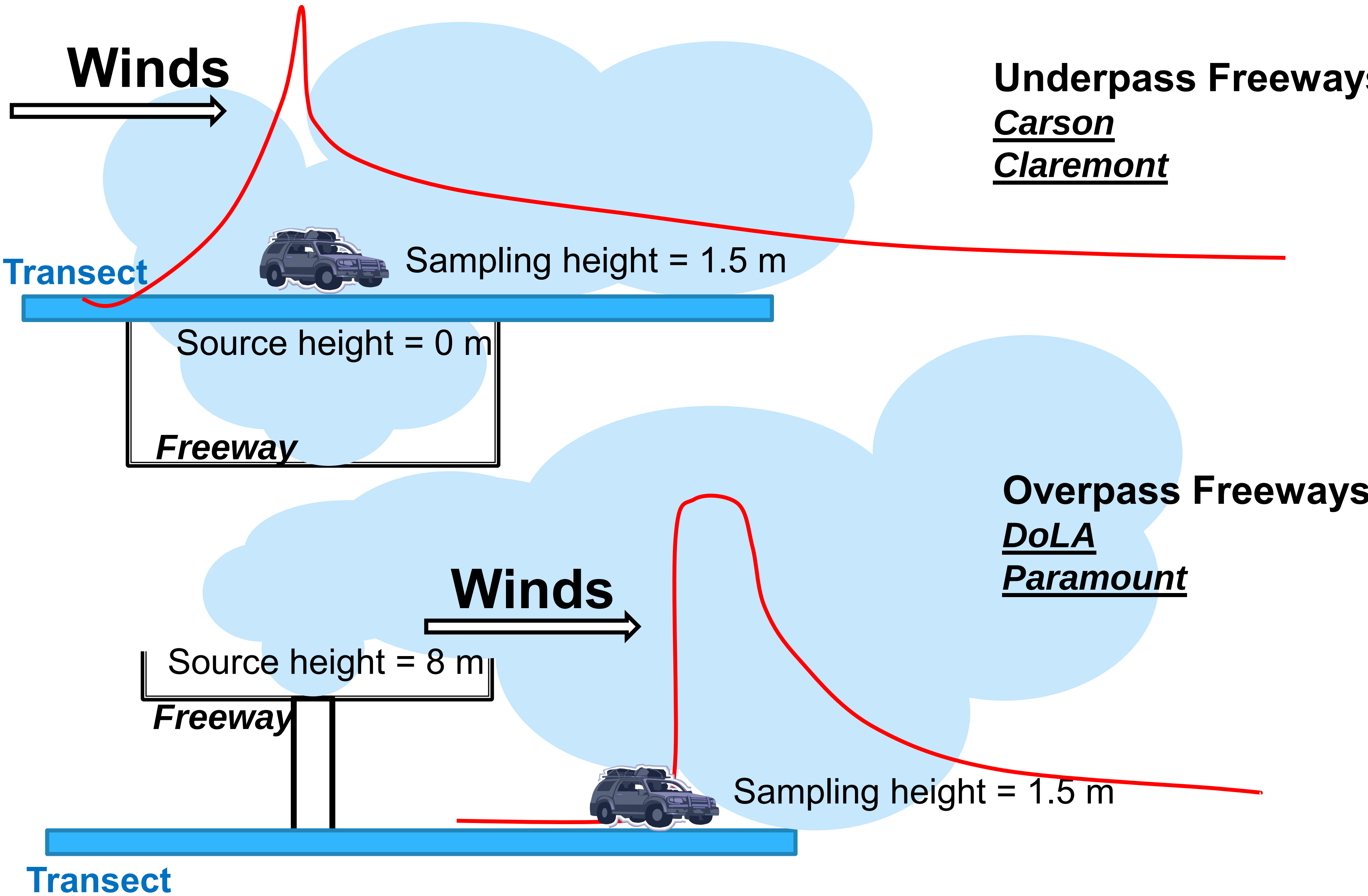


$$\Delta[UFP] = [UFP] - [UFP]_{bkgnd}$$

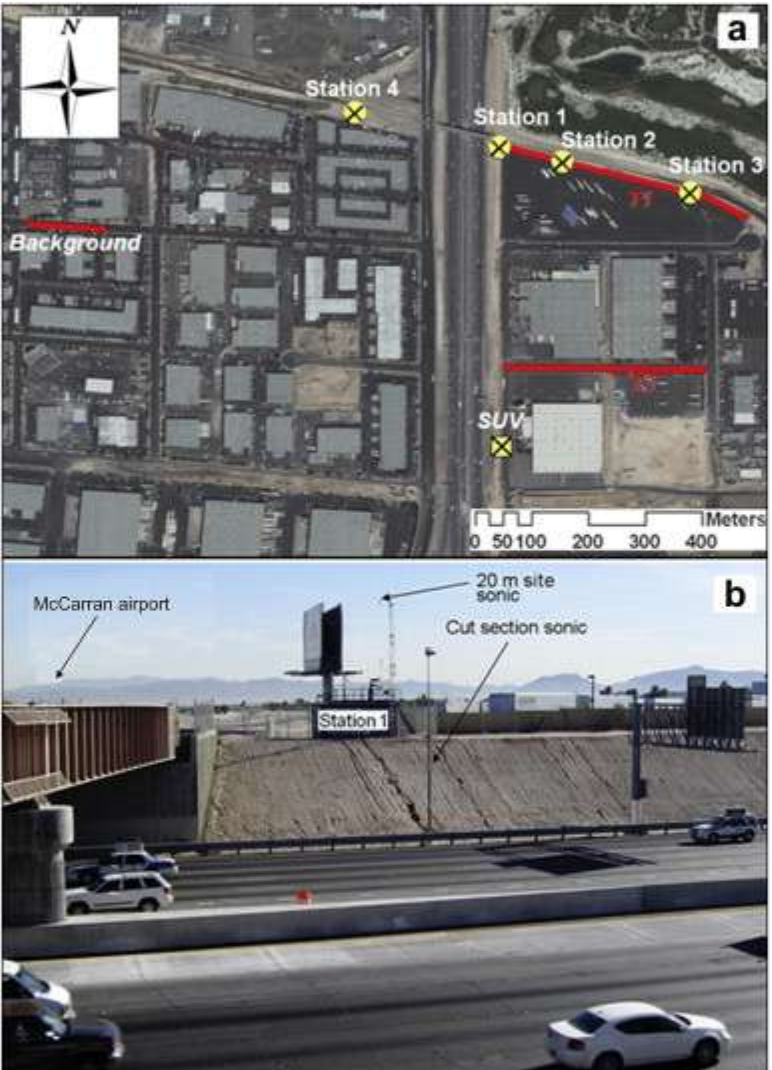
$$\text{Normalized } \Delta[UFP(x)] = \frac{\Delta[UFP(x)]}{\Delta[UFP]_{peak}}$$

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

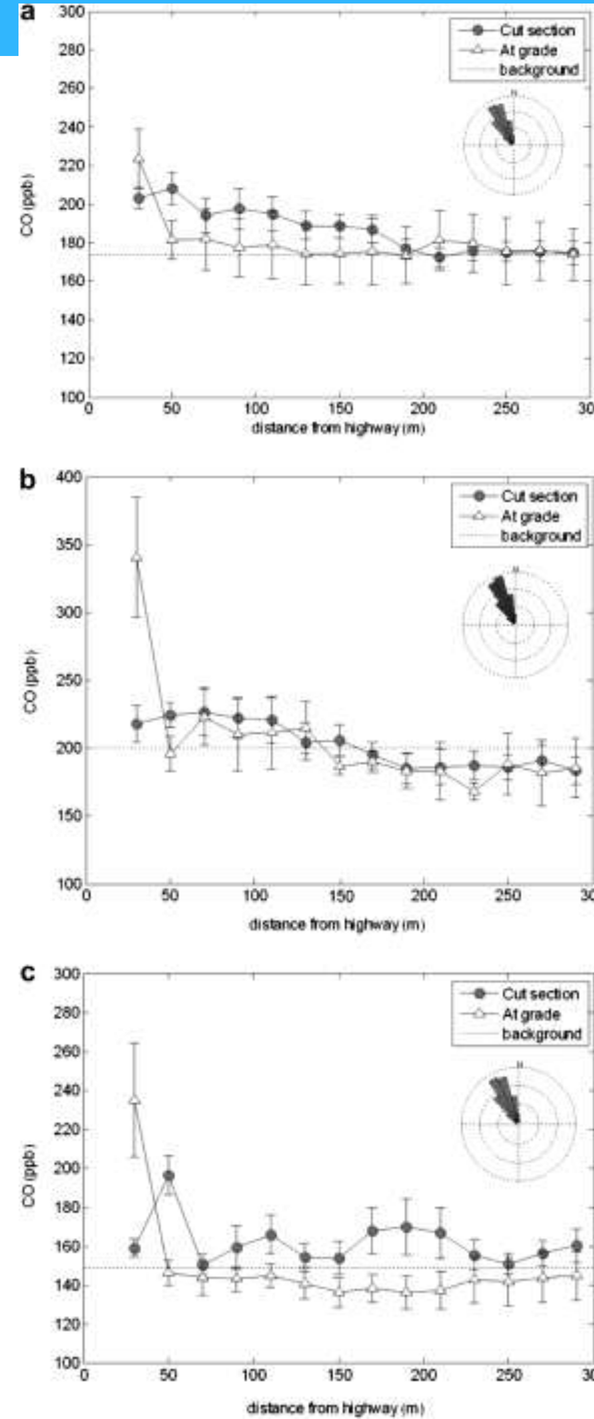
Freeway-Transect Geometry



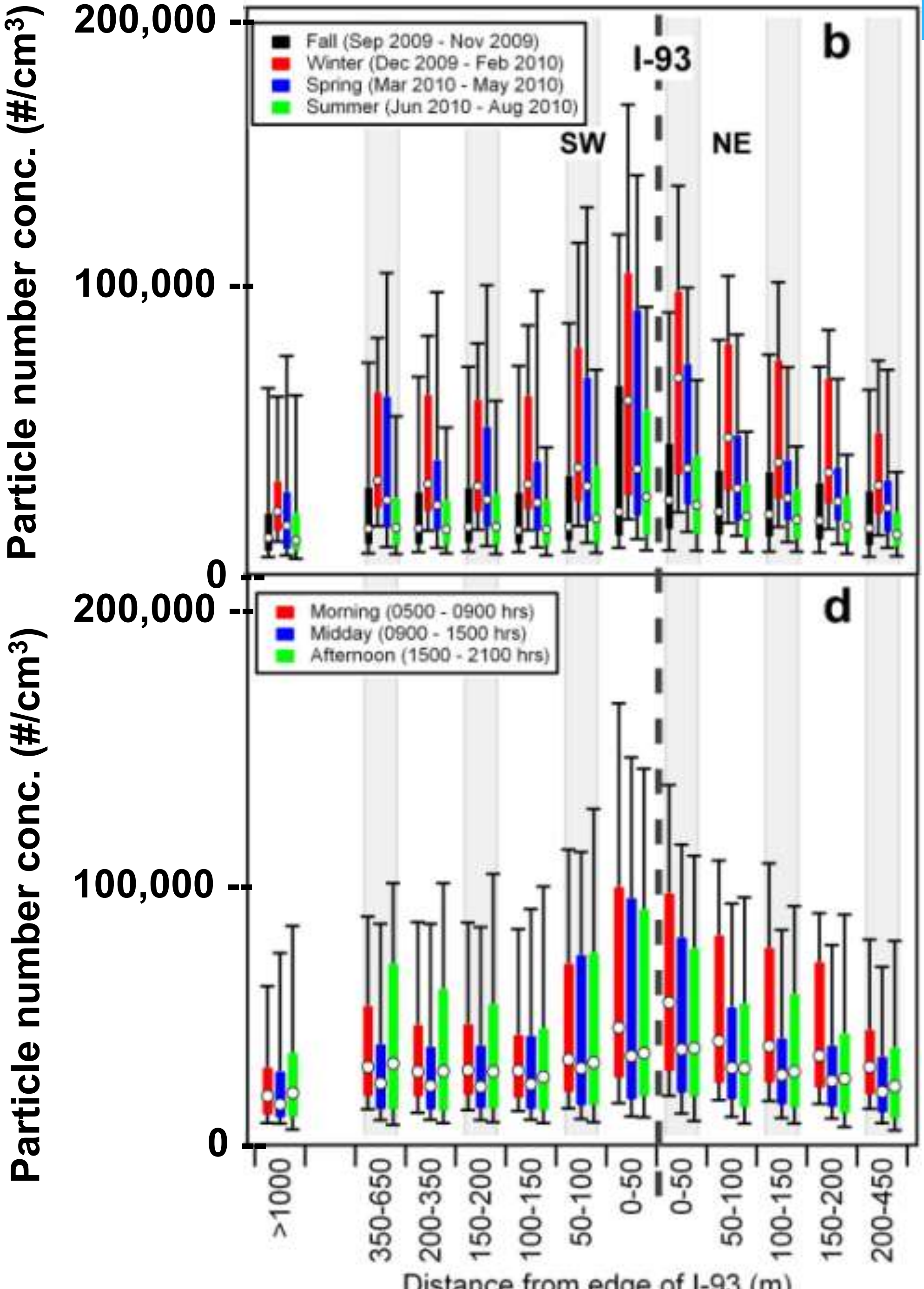
Impact of Freeway Geometry



Baldauf et al., Atmos. Environ 2013



Measurements from Sommerville, Massachusetts around I-93



Luz et al., Atmos Environ 2012

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

[Choi et al., submitted]

Gaussian Plume Dispersion model

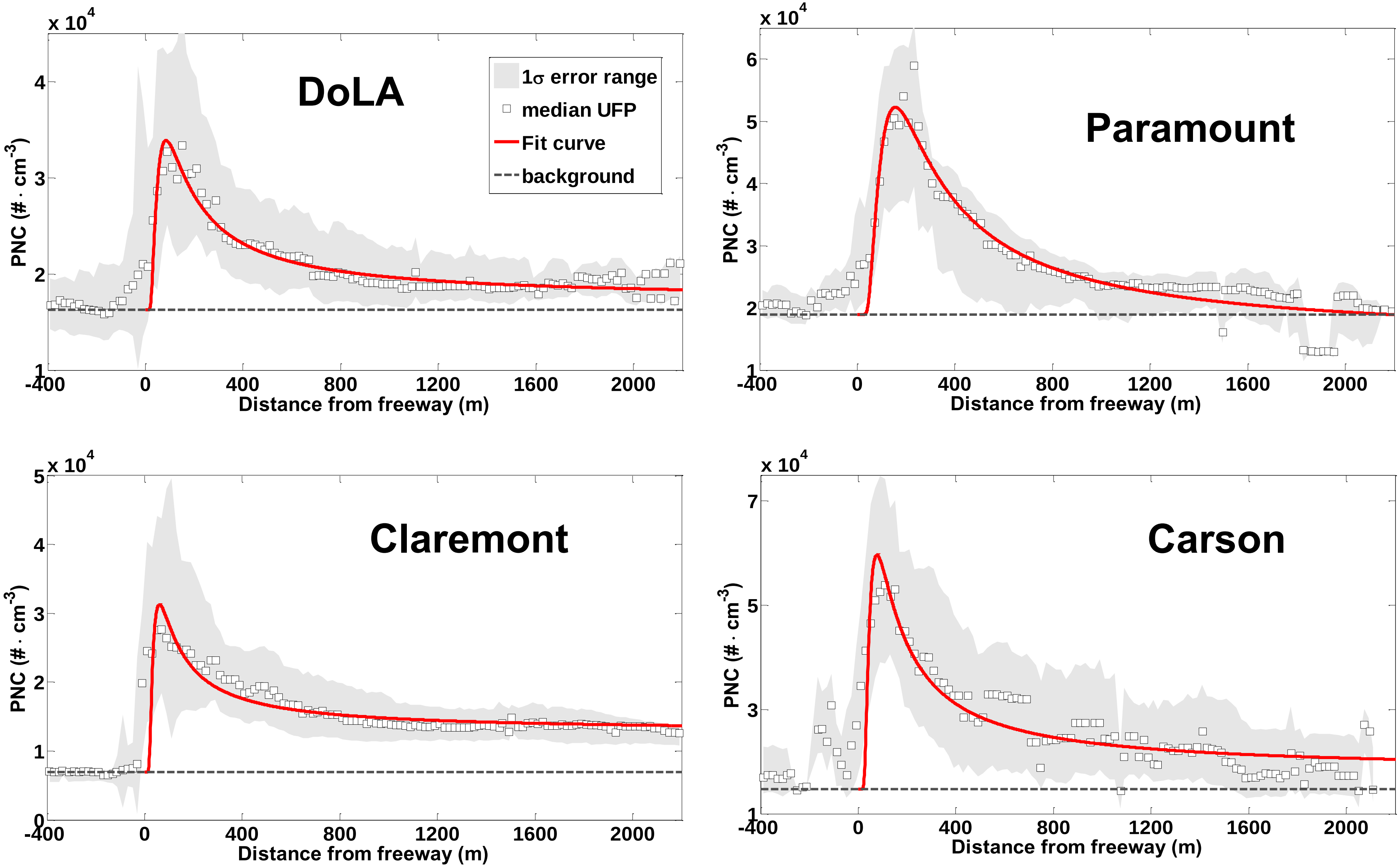
Q_c = Emission rate corrected with wind speeds
H = Source height
1.5m = Measurement height
σ_z = Dispersion parameter
x = Horizontal distance from the source

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

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

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* ($\# \cdot m \cdot cm^{-3}$)
q_{veh}	= *Particle number emission factor (PNEF)* ($\# \cdot mile^{-1} \cdot vehicle^{-1}$)
Traffic flow	= $vehicles \cdot s^{-1}$
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

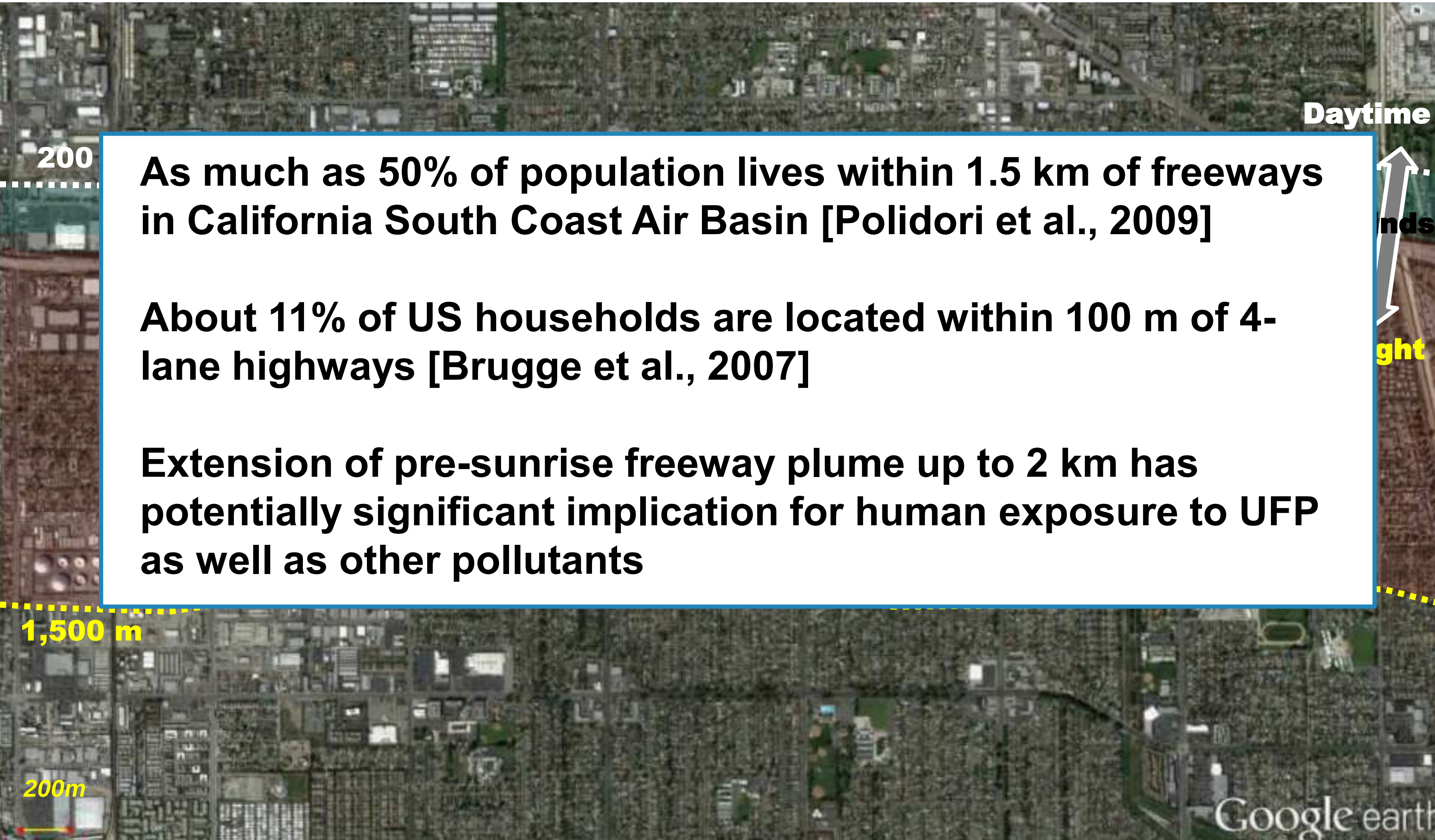
$$= \frac{\sqrt{2\pi} \times (8.12 \times 10^4) \times (0.64\, m/s + 0.2\, m/s) \times 10^6\, {cm^3}/{m^3} \times 300\, {s}/{5\,\text{min}}}{(680.2\, vehicles / 5\,\text{min})}$$

= 7×10^{13} particles·mi^{-1}·vehicle^{-1}

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

4.9×10^{14} particles·mi^{-1}·vehicle^{-1} in 2001 *[Zhu and Hinds, AE, 2005]*

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]

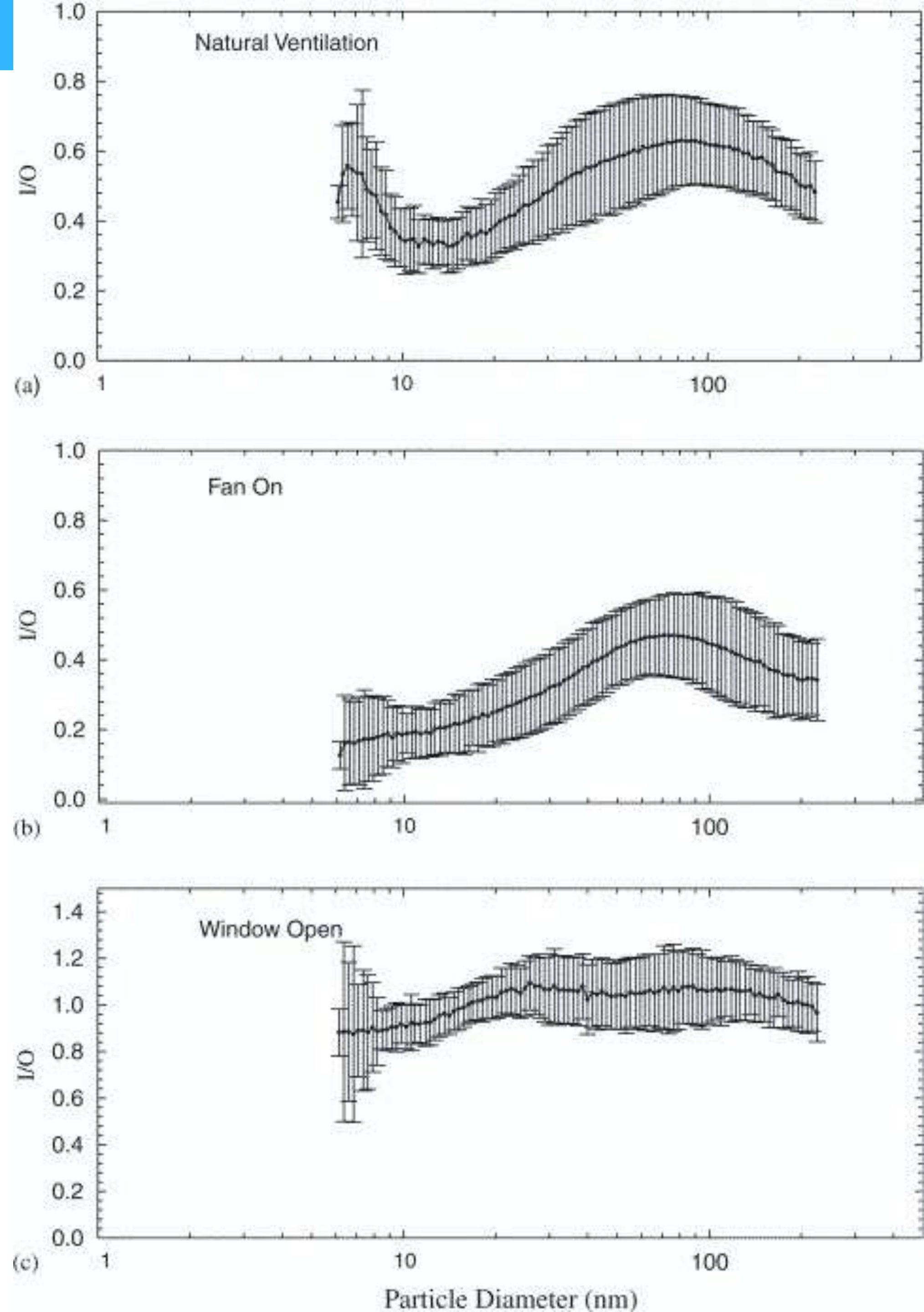
Extension of pre-sunrise freeway plume up to 2 km has potentially significant implication for human exposure to UFP as well as other pollutants

Paramount

Penetration of Ultrafine Particles into Indoor Spaces is Significant

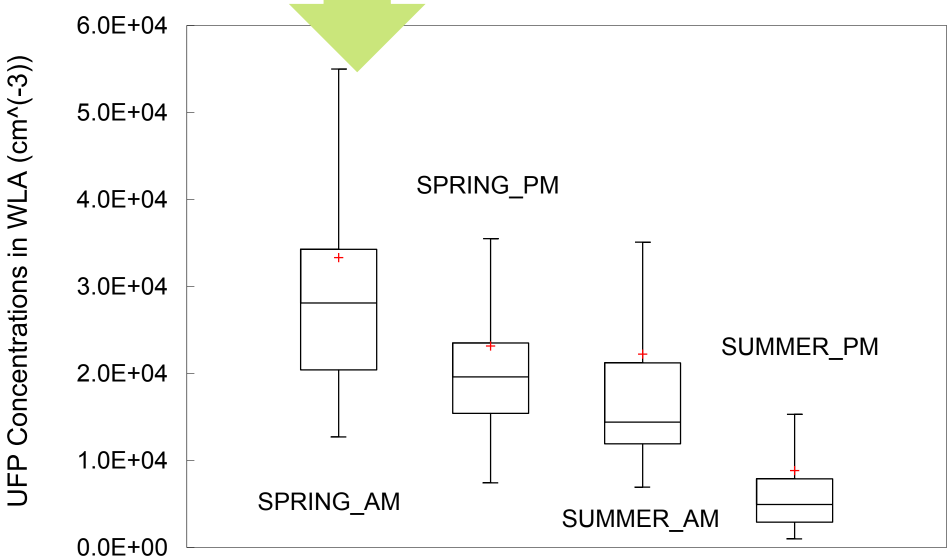
Avg. Indoor/Outdoor for particle number concentration was 0.95. For 18 homes in Massachusetts during summer (1900 – 1949 construction) Fuller et al., 2013 J. Exp. Sci. & Env. Epi.

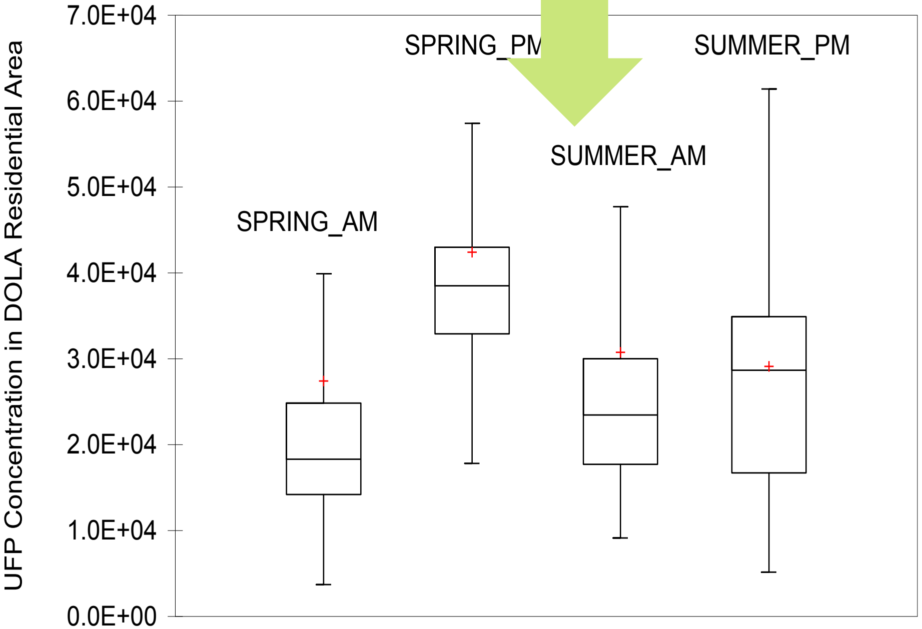
UCLA Sepulveda & Sawtelle student housing
Zhu et al., J. Aerosol Sci. 2005



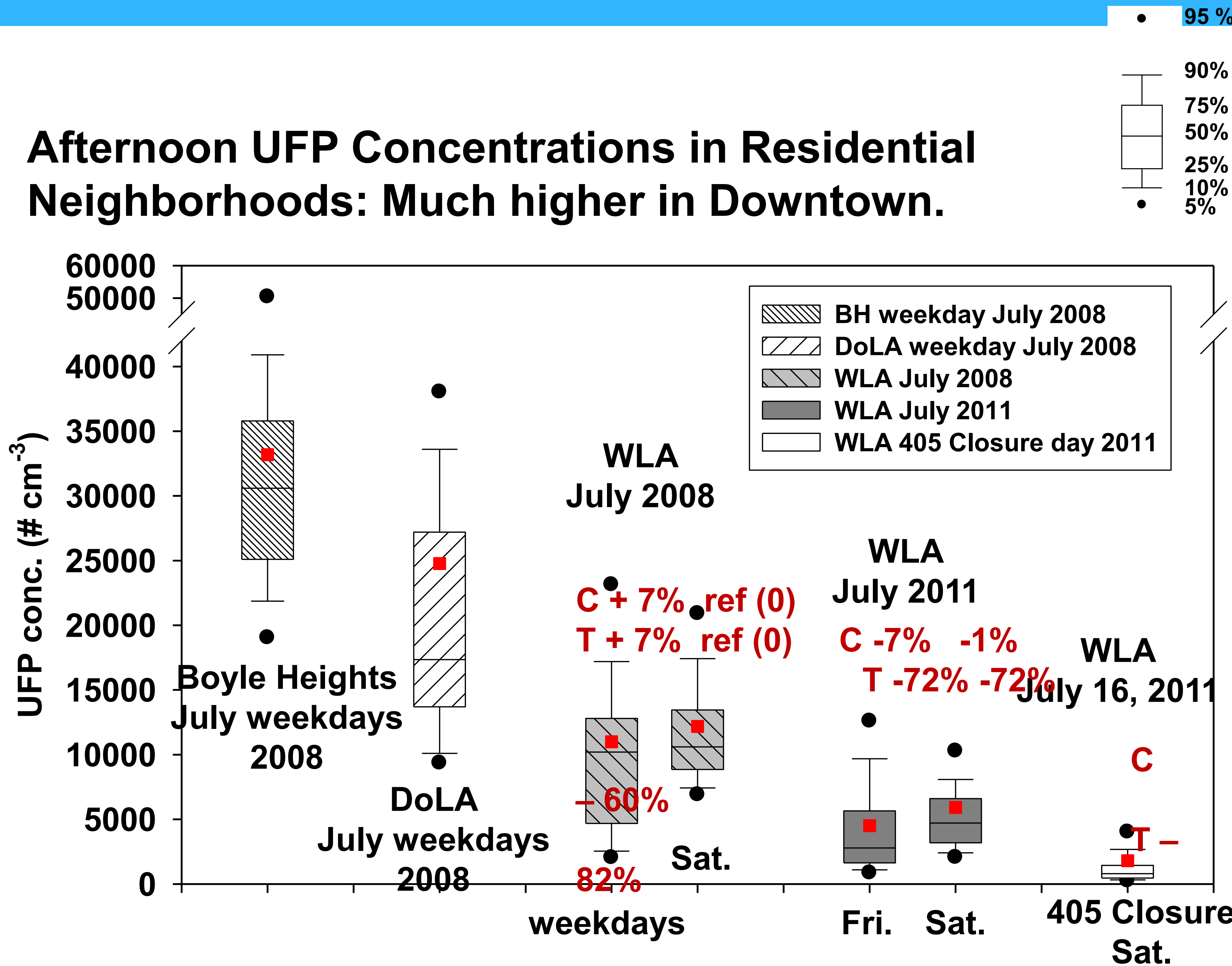
Air Quality in Several Los Angeles Neighborhoods

Temporal trends are quite area dependent.
(Data are for residential areas only.)

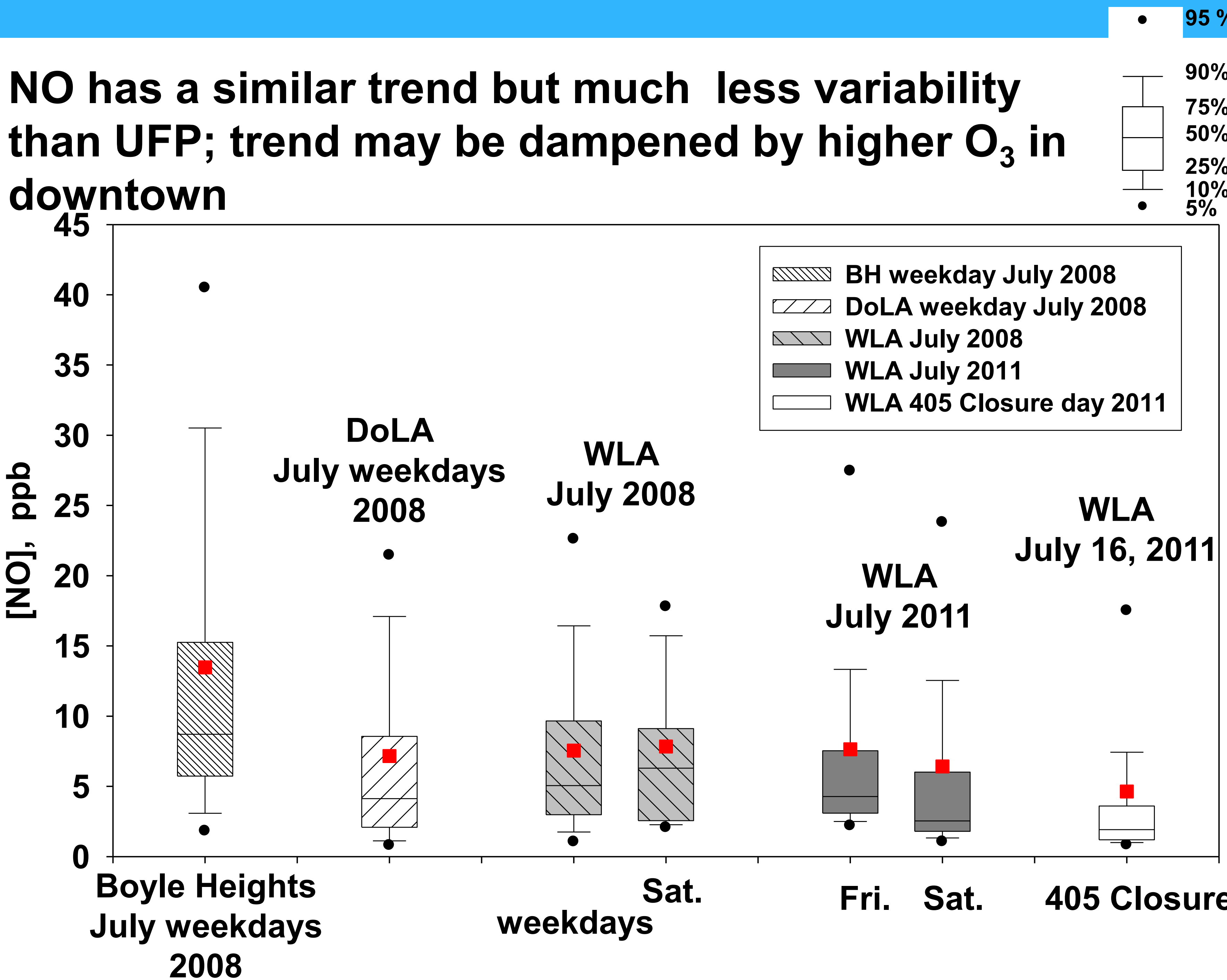


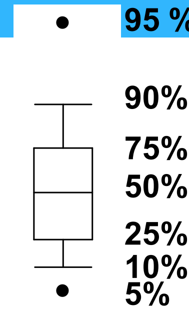


Afternoon UFP Concentrations in Residential Neighborhoods: Much higher in Downtown.

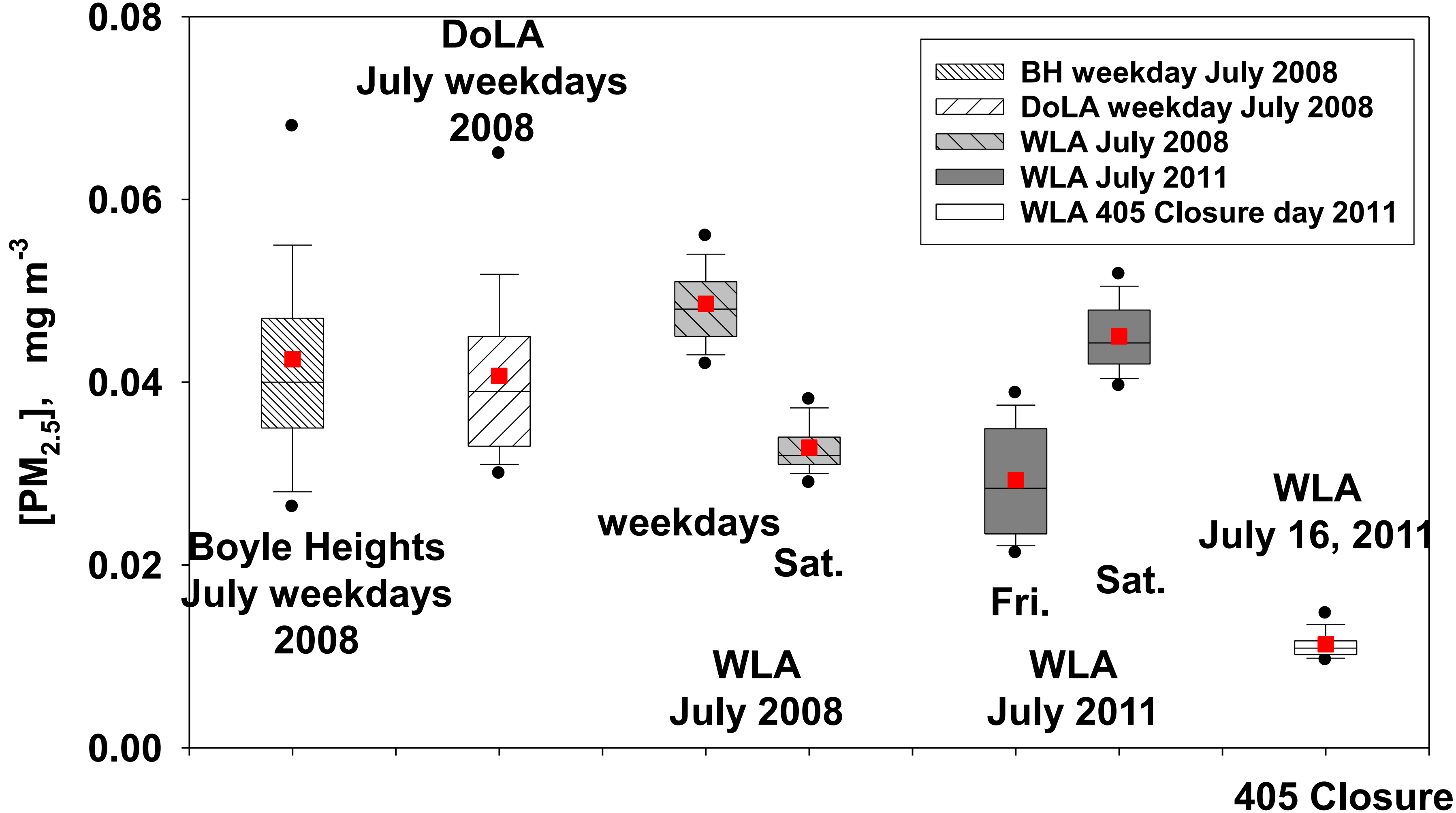


NO has a similar trend but much less variability than UFP; trend may be dampened by higher O_3 in downtown



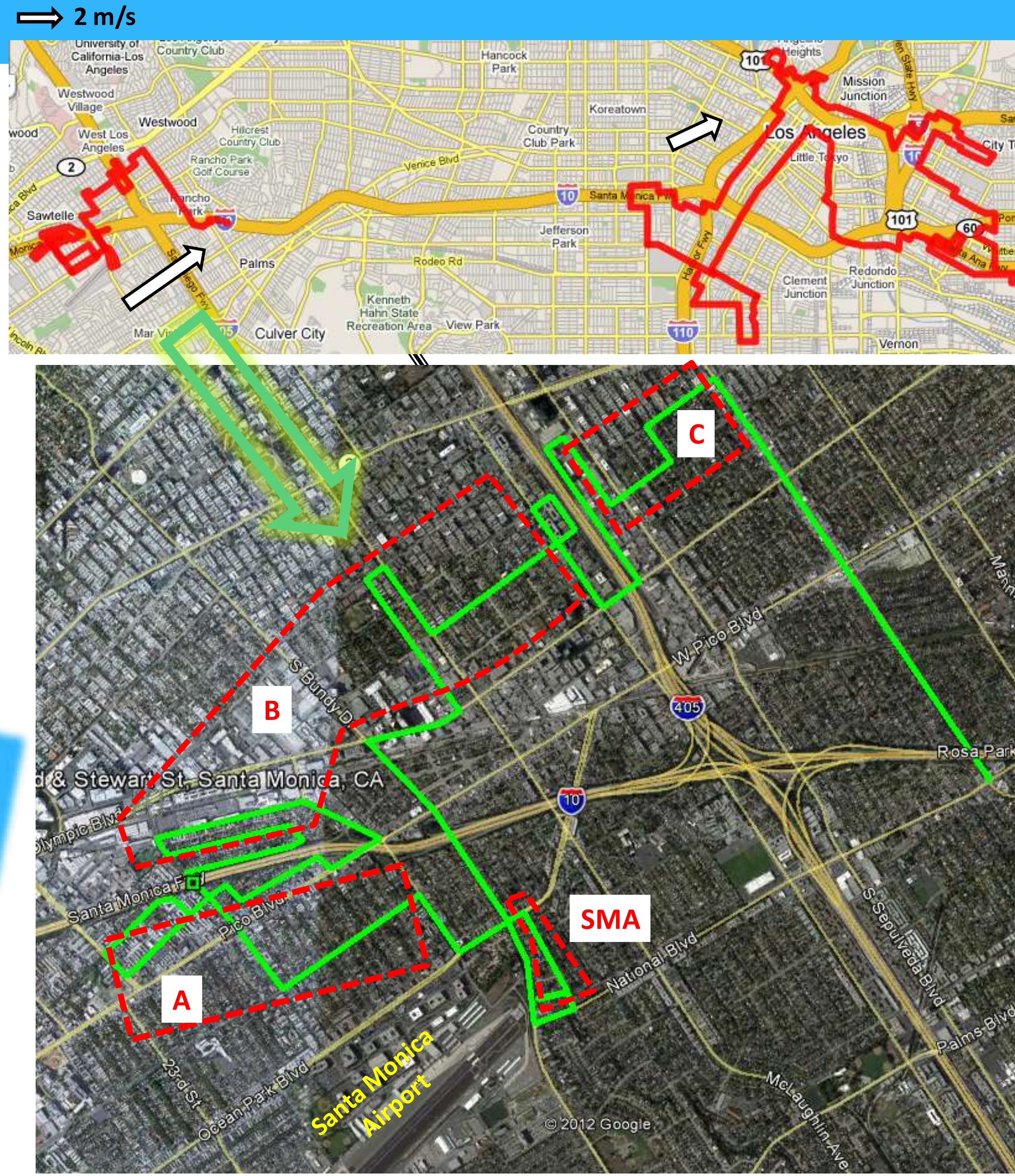


$PM_{2.5}$ was similar throughout except during "Carmageddon" (all afternoon data)

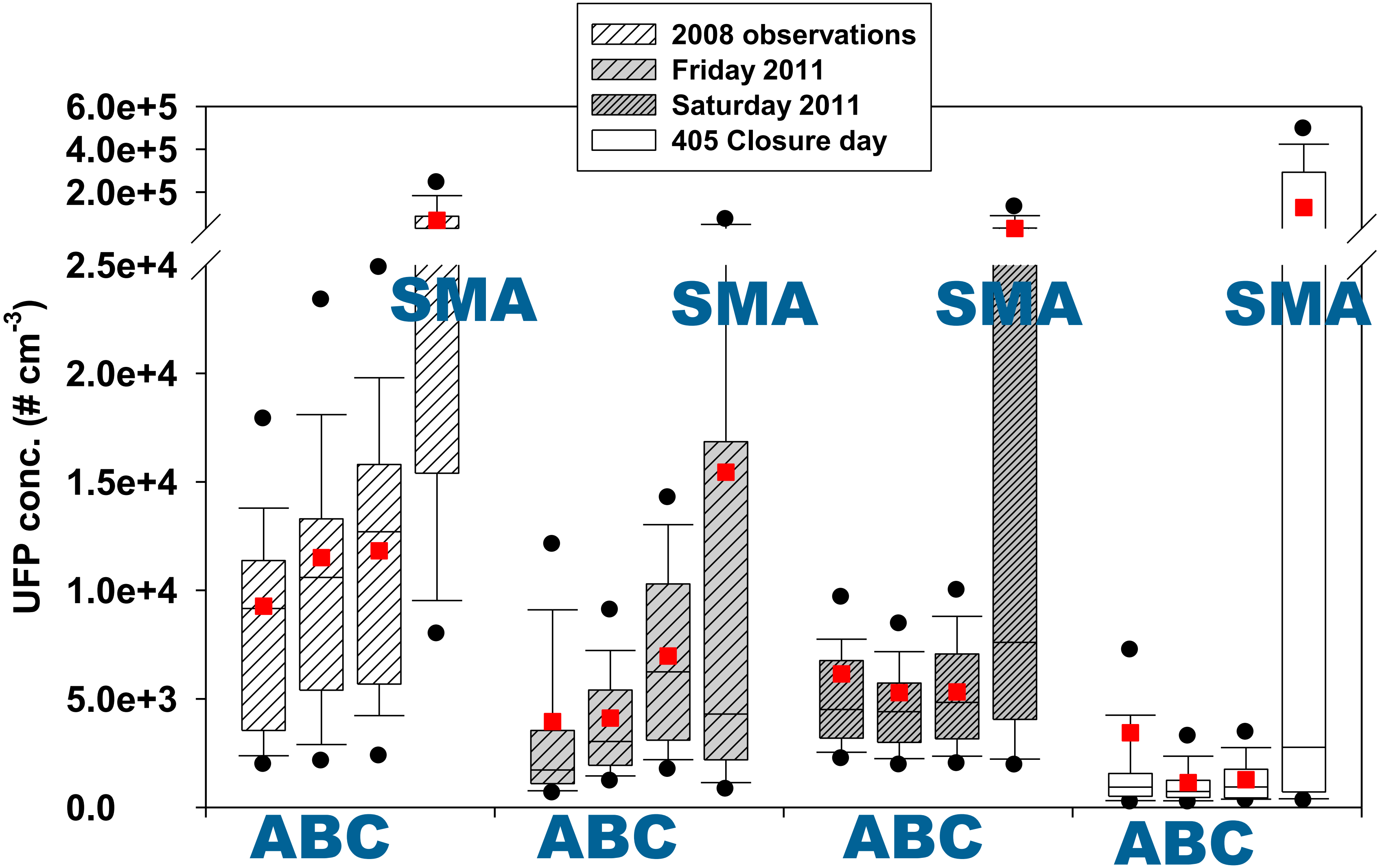


Neighborhood-Scale Air Quality in West Los Angeles

West Los Angeles residential measurement areas in 2008 and 2011



Ultrafine Particle Concentrations Vary Substantially between Neighborhoods



Summary

1. Freeway plumes are complex, and best traced by species with low urban backgrounds like ultrafine particles.
2. Early morning extension of freeway plumes far downwind (> 2 km) is a general phenomenon.
3. Data indicate a strong drop in emissions of ultrafine particles over the past decade.
4. Plume intensity as well as met. parameters control pollutant plume lengths downwind of freeways.
5. Behavior of UFP concentrations in neighborhoods is sufficiently complex as to be easy to explain but somewhat difficult to predict.

Thank you for your attention

The Credit is Really Due to:

Wonsik Choi
Shishan Hu
Hwajin Kim
Meilu He
Kathleen Kozawa*
Steve Mara*
Dilhara Ranasinghe
Karen Bunavage
Rodrigo Siguel

Juan De La Cruz
Vincent Barbesant
Arthur Winer

*California Air Resources Board

Supported by the California Air Resources Board, and the National Science Foundation

Back to Agenda

URBAN AIR POLLUTION AND CHILDHOOD ASTHMA:
Burden of Disease

Rob McConnell
Professor of Preventive Medicine
Keck School of Medicine
University of Southern California
November 21, 2013

Prior Evidence From Time Series and Panel Studies: Acute Effects

- Ozone and Particles Make Asthma Worse
  - More symptoms
  - More medications used
  - More respiratory illnesses
  - More clinic visits
  - More emergency room visits
  - More hospitalizations

Sarnat JA. Curr Opin Pulm Med. 2007; 13: 63-6.

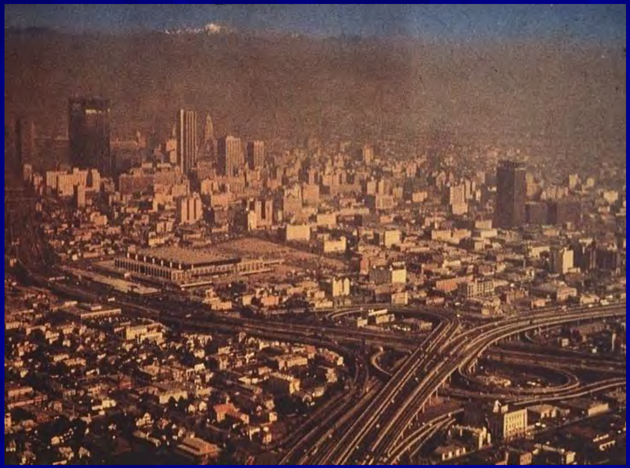
"Common Wisdom" About Air Pollution and Asthma

- Air pollution exacerbates asthma, but does not cause asthma (*Eder W, et al: The asthma epidemic, NEJM 2006;355:2226*)
  - Rates of asthma generally are not greater in communities with more regional air pollution

CHILDREN'S HEALTH STUDY RESEARCH QUESTIONS

- What is the health impact of increases in regulated regional pollutants?

- What is the health impact of increases in local near-roadway pollutants which are not currently regulated?



Regulated

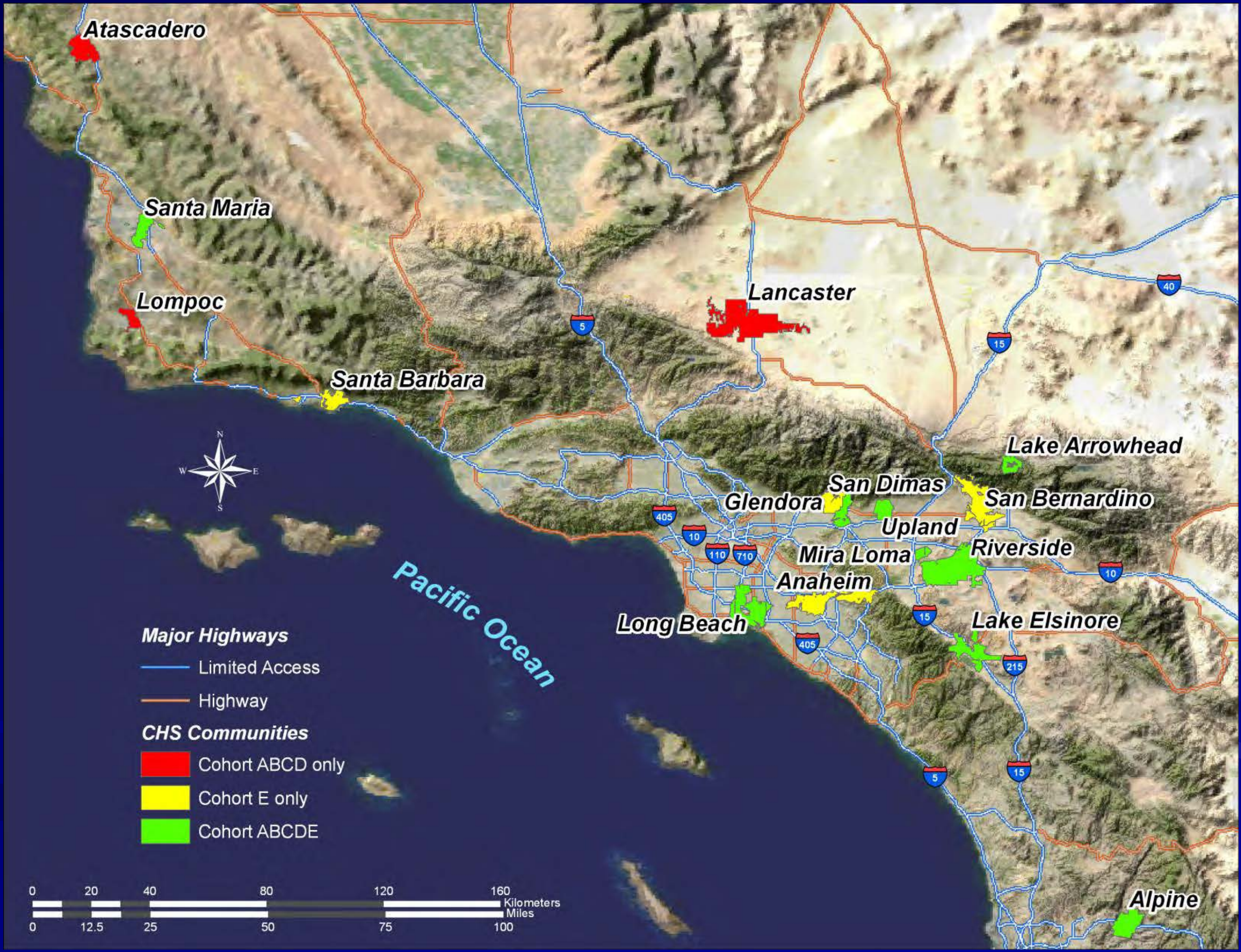
Largely Unregulated

"Common Wisdom" About Air Pollution and Asthma

- Emerging evidence indicates that near-roadway air pollution that varies within communities causes asthma
- We'd been looking at the wrong pollutant mixture!

Overview of Presentation

- Children's Health Study design
- Evidence for causal relationship of asthma with near-roadway exposure
- Cumulative impact of near-roadway and regional pollution on asthma exacerbation
- Some policy implications


Atascadero
Santa Maria
Lompoc
Santa Barbara
Lancaster
Lake Arrowhead
San Dimas
Glendora
San Bernardino
Upland
Riverside
Mira Loma
Anaheim
Long Beach
Lake Elsinore
Alpine
Pacific Ocean
Major Highways
Limited Access
Highway
CHS Communities
Cohort ABCD only
Cohort E only
Cohort ABCDE
0 20 40 80 120 160 Kilometers
0 12.5 25 50 75 100 Miles

CHS Cohorts (Year and Grade)

Cohort	N	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
A	938	10	11	12																	
B	937	7	8	9	10	11	12														
C	1,806	4	5	6	7	8	9	10	11	12											
D	2,081				4	5	6	7	8	9	10	11	12								
E	5,341										K	1	2	3	4	5	6	7	8	9	10
	11,103																				

MAIN OUTCOMES

- Lung function (spirometry)
- Asthma
- Respiratory symptoms (eg. bronchitis)
- Exhaled nitric oxide
- Respiratory school absences
- Carotid intima medial thickness, arterial stiffness, blood pressure
- Obesity, metabolic disease
- Epigenetic marks

Asthma Definition

- Lifetime MD asthma at study entry
  - Further characterized by age of wheeze onset or diagnosis
- New onset asthma
  - New report of MD asthma or severe wheeze
  - Nurse practitioner interview
  - Subset with skin prick test for allergy and exercise challenge for airway reactivity

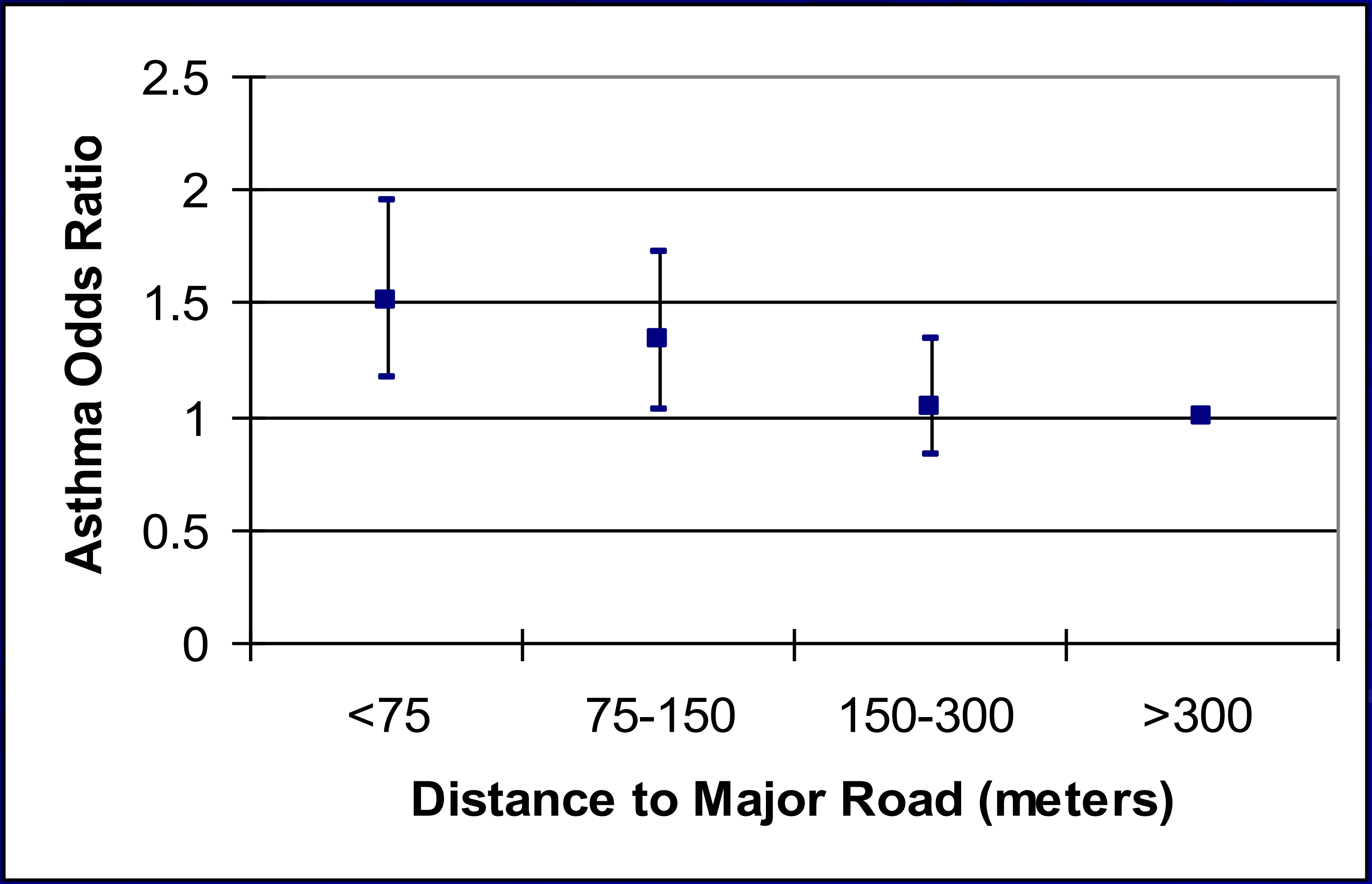
Exposure Assessment (Ambient)

- One Station Per Community
  - Ozone (hourly)
  - Nitrogen dioxide (hourly)
  - PM_{10} (houly) and $PM_{2.5}$ (2-week) mass
    - Chemistry (EC/OC, metals, PAHs)
  - Acid vapor (primarily nitric; 2-week)

Traffic Pollution Metrics

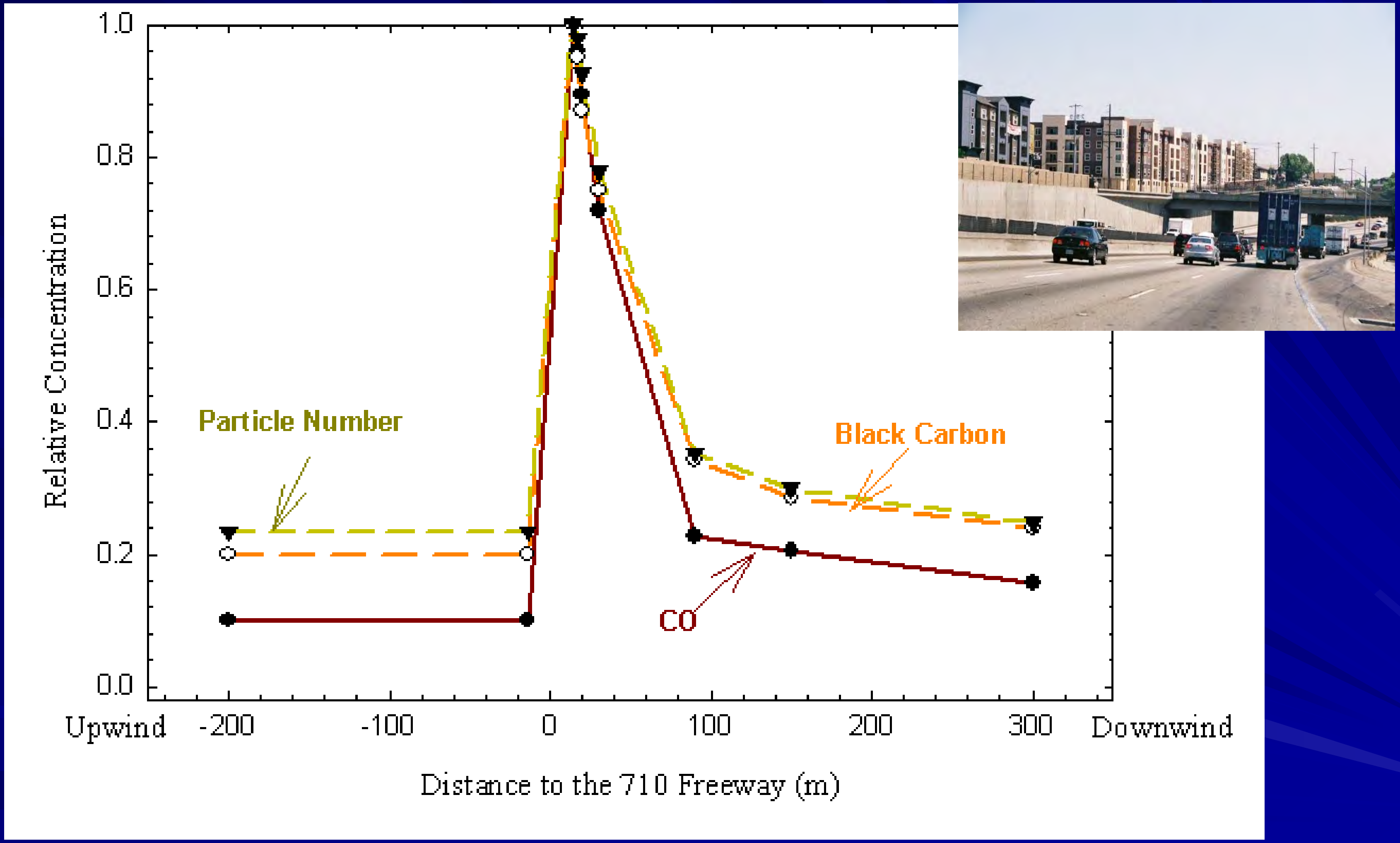
- Assigned to homes and schools
  - Distance to a freeway or major road
  - Average annual daily traffic density within 150 meters (distance weighted)
  - Modeled near-roadway exposure
    - CALINE4 line source dispersion model
  - Measured NOx, size-fractionated PM and PM composition at a sample of homes in each community
    - Used to develop prediction models

There is more asthma in children living within 150 meters of a major road



McConnell, et al, Environ Health Perspect 2006;114:766-772

Air Quality is Worse Near a Freeway



Other pollutants are also high near freeway (e.g. NO2, benzene,…)

(Zhu et al., 2002, 2006)

Incident Asthma and Traffic-Related Pollution (TRP) at School and Home

	Home		School		Combined[b]	
Traffic-related exposure[a]	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
Non-freeway TRP	1.51	(1.25-1.81)*	1.45	(1.06-1.98)	1.61	(1.29-2.00)*
Freeway TRP	1.12	(0.95-1.31)	1.08	(0.86-1.34)	1.12	(0.94-1.35)
Total TRP	1.32	(1.08-1.61)**	1.20	(0.91-1.58)	1.34	(1.07-1.68)

[a]Scaled to the IQR at homes for each metric
[b]Combined weighted for time at home and school
*P<0.001; **P<0.01

McConnell et al. Environ Health Perspect 2010, 118:1021-1026

Confounders

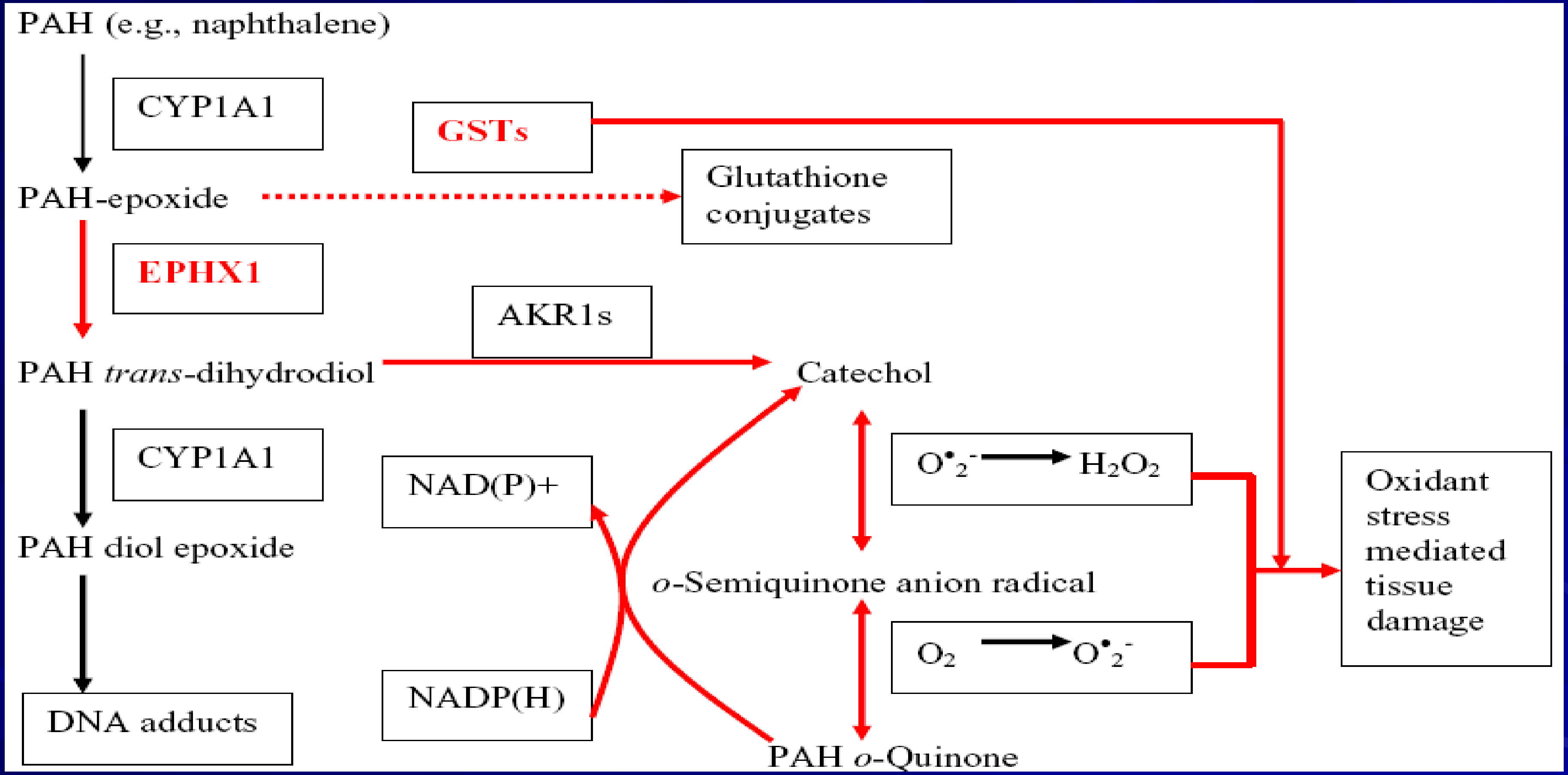
- Demographic characteristics
- Allergic symptoms, BMI, ultraviolet light exposure
- Family history
- SES
  - Parental education
  - Household income
  - By community (eg. census data, crime statistics)
  - By school (eg. school lunch, Title 1, ethnic mix, performance)
- Housing conditions
  - Pets, pests, mold, water damage
  - Second hand tobacco smoke exposure
- *In utero* tobacco smoke exposure

Biologically Plausible?

- Oxidative stress and inflammation fundamental to the pathogenesis of asthma
- Ultrafine particulate matter has strong oxidant properties and generates inflammatory responses

Li N, et. al. Clin Immunol 2003;109:250-65

PAH, EPHX1, GST and Asthma



Salam M T et al. Thorax 2007;62:1050-1057

Results - EPHX1 Phenotypes and Asthma

EPHX1 phenotypes	**Lifetime asthma OR (95% CI)**
Low	1.0
Intermediate	1.07 (0.85-1.35)
High	**1.51 (1.14-1.98)**

EPHX1 Phenotypes & Asthma, Stratified by *GSTP1 Ile105Val*

EPHX1 phenotypes	***GSTP1 Ile105Val***		
	Ile/Ile	***Ile/Val***	***Val/Val***
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**
Low/intermediate	1.0	1.0	1.0
High	1.12 (0.74-1.70)	1.34 (0.92-1.94)	4.01 (1.97-8.16)
	P-interaction = 0.006		

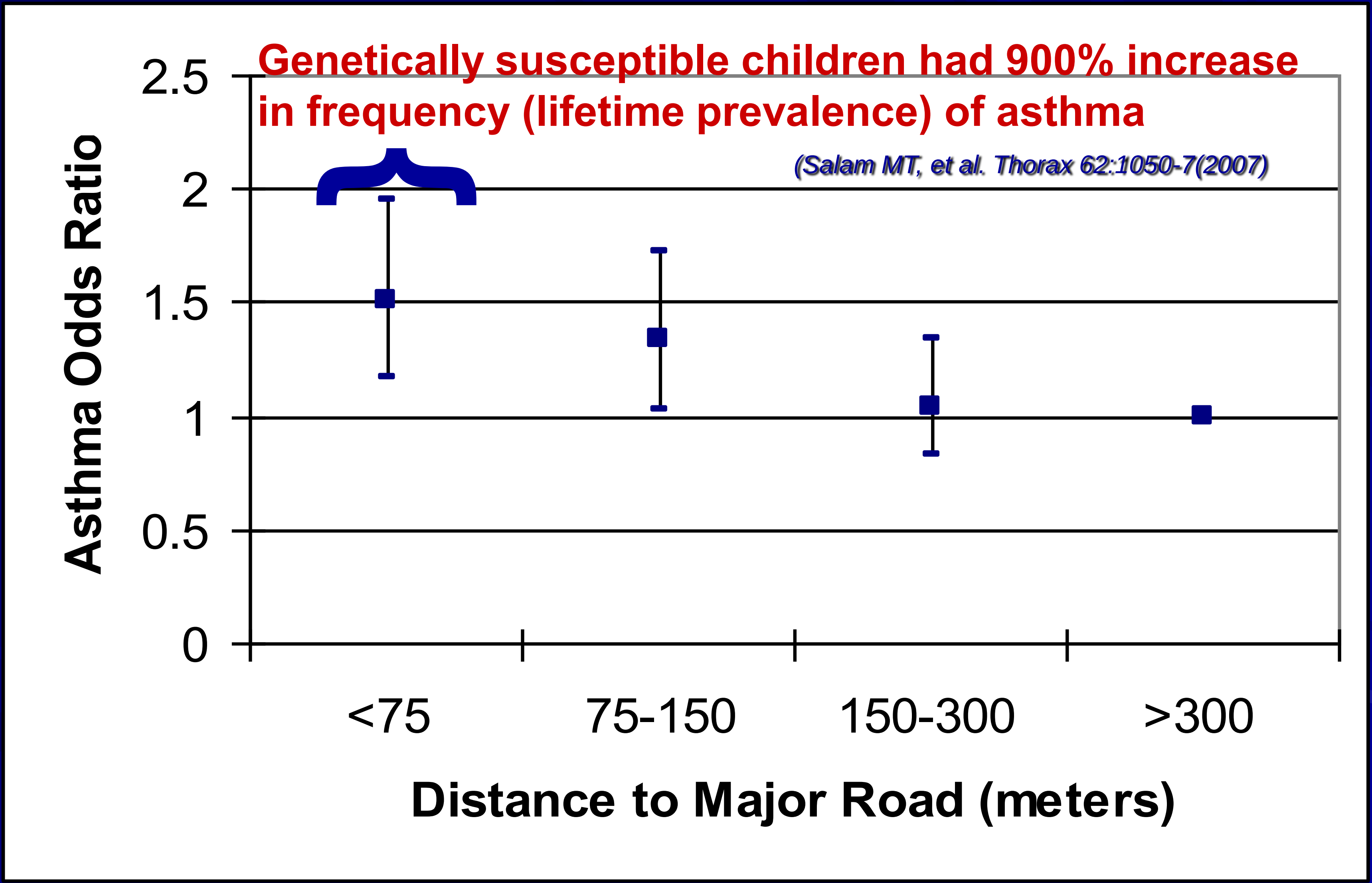
EPHX1 Phenotype and Asthma, Stratified by Residential Distance from a Major Road

EPHX1 phenotypes	**Residential distance from major road**	
	≥75m	**<75m**
	OR (95% CI)	**OR (95% CI)**
Low/intermediate	1.0	1.0
High	1.25 (0.93-1.69)	**3.24 (1.75-6.00)**
	P-interaction = 0.03	

Joint Effects of Traffic, EPHX1 Phenotypes, and GSTP1 Ile105Val on Asthma

Residential distance from major road	GSTP1 *Ile*105*Val*	EPHX1 phenotypes	Lifetime Asthma OR† (95% CI)
≥75m	*Ile/Ile*	Low/Intermediate	1.0
≥75m	*Ile/Val*	Low/Intermediate	1.19 (0.88 to 1.61)
≥75m	*Val/Val*	Low/Intermediate	0.94 (0.59 to 1.50)
≥75m	*Ile/Ile*	High	1.03 (0.61 to 1.71)
≥75m	*Ile/Val*	High	1.35 (0.85 to 2.15)
≥75m	*Val/Val*	High	**2.63 (1.34 to 5.18)**
<75m	*Ile/Ile*	Low/Intermediate	1.01 (0.60 to 1.69)
<75m	*Ile/Val*	Low/Intermediate	0.89 (0.54 to 1.44)
<75m	*Val/Val*	Low/Intermediate	1.46 (0.71 to 3.03)
<75m	*Ile/Ile*	High	1.71 (0.75 to 3.87)
<75m	*Ile/Val*	High	**2.61 (1.22 to 5.58)**
<75m	*Val/Val*	High	**8.91 (2.40 to 33.12)**
			P-interaction=0.04

Some children are more susceptible to near roadway pollution…



Summary Near-roadway Pollution Effects

- Pattern of genetic susceptibility seen in CHS hard to explain based on confounding
- Many studies in U.S. and in Europe show that living near busy roads and freeways has been linked to asthma

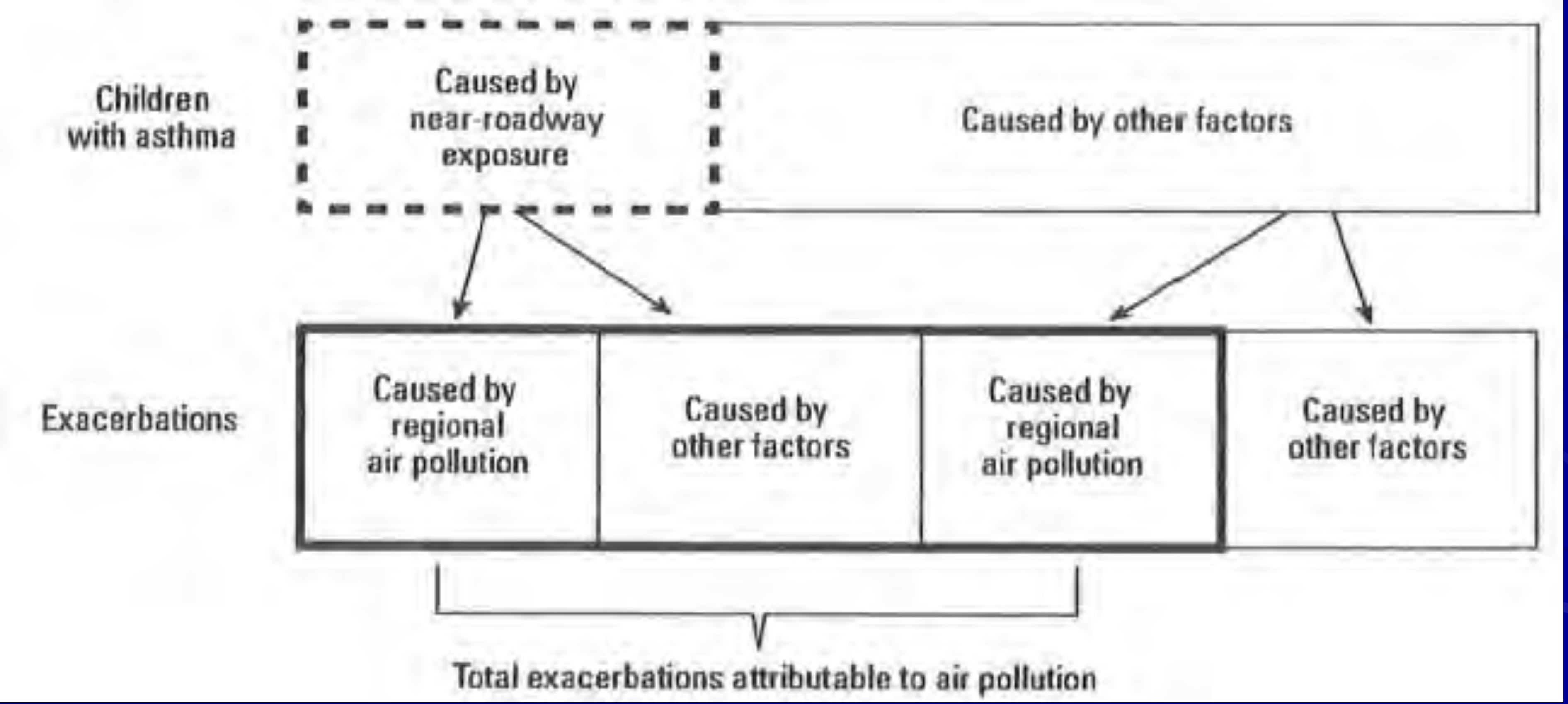
Anderson HR, Atmosphere & Health 2011, 1-10

What's the Cost of Inaction?

- Addressed by risk assessments and health impact assessments
- Generally examine only regional pollution effects.
- Potential enhancements:
  - Burden of local traffic proximity pollutants included
  - Provide estimates of burden of disease in high impact locations
  - Examine costs

Cumulative Near-roadway and Regional Pollution Effects

Framework for Risk Assessment



Kunzli, et al. Epidemiology 2008, 19:179-185

What’s the Cost of Inaction

- Number of childhood asthma cases attributable to traffic proximity
  - Long Beach – 1600 (9%)
  - Riverside – 690 (6%)

(Perez, Am J Public Health 2009)

Cumulative Regional and Near-roadway Burden of Asthma

	Baseline Estimate, No.	Attributable to Air Pollution, No. (95% CI)	Attributable to Other Causes,[a] No. (95% CI)	Total[b] No. Cases (95% CI)	Total[b] % (95% CI)
Bronchitis episodes among those with asthma	6767	3400 (1200, 4900)	310 (170, 530)	3700 (1700, 5100)	54.7 (25.1, 75.4)
Emergency room visits for asthma	10166	160 (20, 300)	930 (860, 1000)	1100 (950, 1200)	10.8 (9.3, 11.8)
Clinic visits for asthma	12410	500 (90, 860)	1100 (1000, 1200)	1600 (1200, 2000)	12.9 (9.7, 16.1)
Hospital admissions for asthma	264	30 (24, 35)	22 (20, 24)	51 (46, 57)	19.3 (17.4, 21.6)

(Perez, Am J Public Health 2009)

- Economic cost of pollution-attributable asthma exacerbation $18 million yearly
  - 2010 budget equivalent: 6% H&W Riverside County; 21% DHHS Long Beach
  - Per family 7-8% average HH income (5% is sustainable)

(Brandt , Eur Respiratory J 2012)

What's the Cost of Inaction (L.A. County)

- Number of asthma cases attributable to traffic proximity
  - Entire County using more complete exposure information:
    - 20,000 – 30,000 cases

Perez, et al. EHP 2012

Is Action Warranted to Prevent Childhood Disease?

- There is strong evidence that exposures within 500 feet of roadways with heavy traffic cause asthma and asthma exacerbation

Other Air Pollution "Cumulative Respiratory Impacts"

- Susceptibility, eg. Genetics, comorbidity
- Co-exposure effects, eg. Secondhand tobacco smoke and in utero exposure to maternal smoking

CHS Acknowledgments

- Ed Avol
- Kiros Berhane
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- Talat Islam
- Nino Kunzli
- Fred Lurmann
- John Peters
- Towhid Salam
- Duncan Thomas

- South Coast Air Quality Management District
- National Institute for Environmental Health Sciences
- US Environmental Protection Agency
- National Health, Lung and Blood Institute
- Hastings Foundation

Questions?

Back to Agenda

The Role of California's Motor Vehicle Control Programs in Reducing Near-Road Exposure

Michael McCarthy
California Air Resources Board

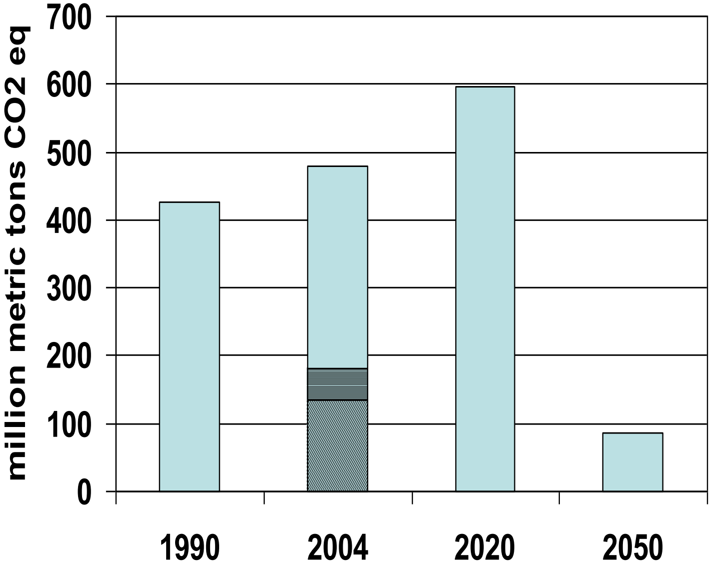
Near-Road Mitigation Measures and Technologies Forum
South Coast Air Quality Management District
November 21, 2013

Overview

- California's Air Quality Program
- Progress to Date
- Recent Regulations
- Future Plans

Mobile Source Priorities

- Meeting regional air quality needs
  - Ozone, PM2.5
- Achieving climate goals
  - 1990 levels by 2020
  - 80% below 1990 levels by 2050



- Reducing near-source exposure
  - Toxics (diesel PM, VOCs, metals)

Keys to Past Success

- Cleaner burning fuels
- New vehicle emission standards
  - Advanced aftertreatment technologies
  - Improved engine combustion
- In-use control programs

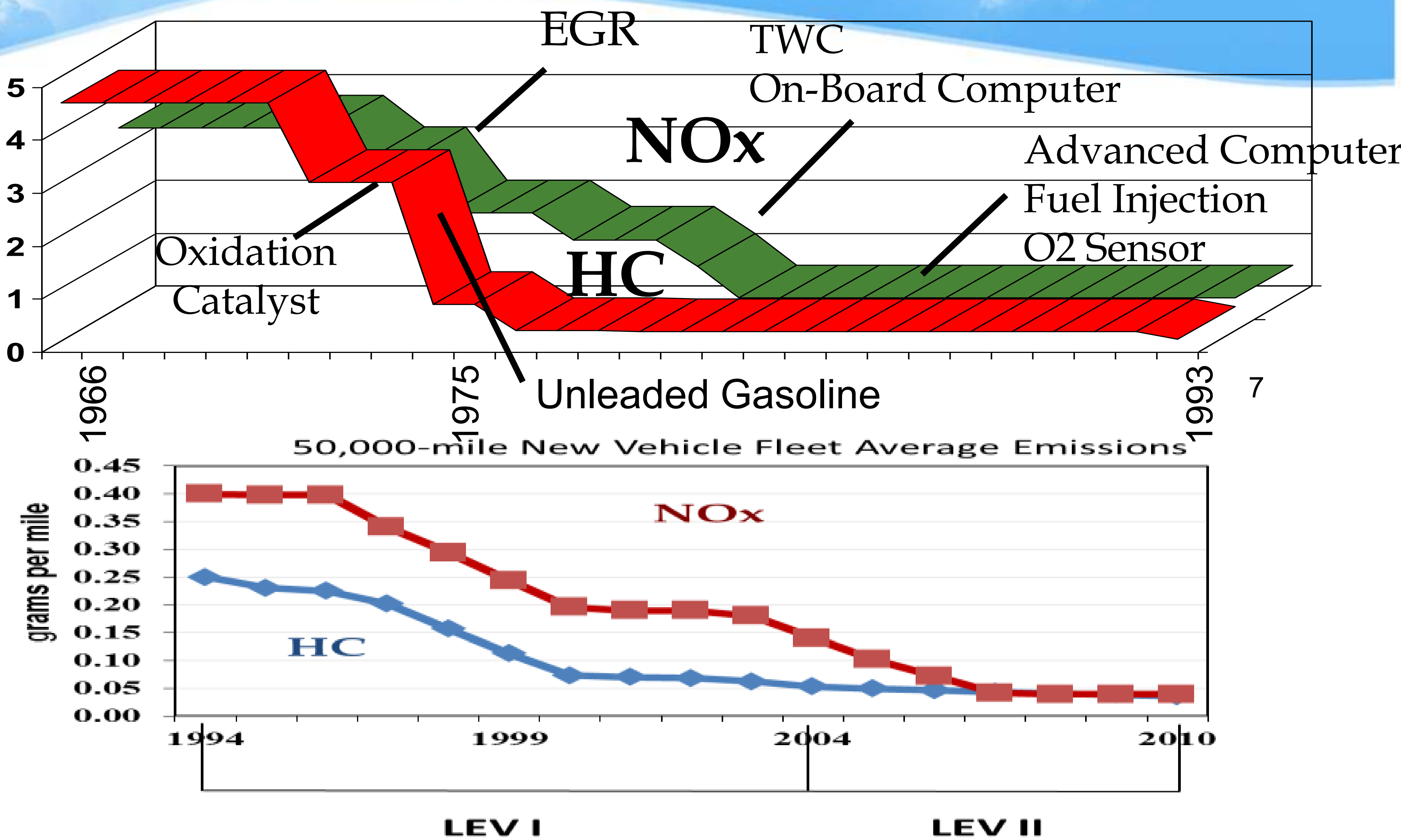
Cleaner Burning Gasoline

- Gasoline
  - 1992: Phase I
    - Eliminated lead
    - RVP reduced from 9.0 to 7.8 psi
    - Required 10% oxygenates
  - 1996: Phase II
    - Sulfur reduced from 151 to 30 ppm
    - RVP reduced to 7.0 psi
  - 2002: Phase III
    - Prohibited MTBE as oxygenate (replaced by ethanol)
    - Sulfur reduced to 15 ppm

Cleaner Burning Diesel

- Diesel
  - 1993: Phase I
    - Reduced sulfur to 500 ppm
      - Lower SO_2 and sulfate emissions
    - Reduced aromatic hydrocarbon to 10%
      - Lower PM and NOx emissions
  - 2006: Phase II
    - Sulfur reduced to 15 ppm
      - Enables effective aftertreatment (PM, NOx)
      - Heavy- and light-duty diesel vehicles

Light-Duty Emission Standards



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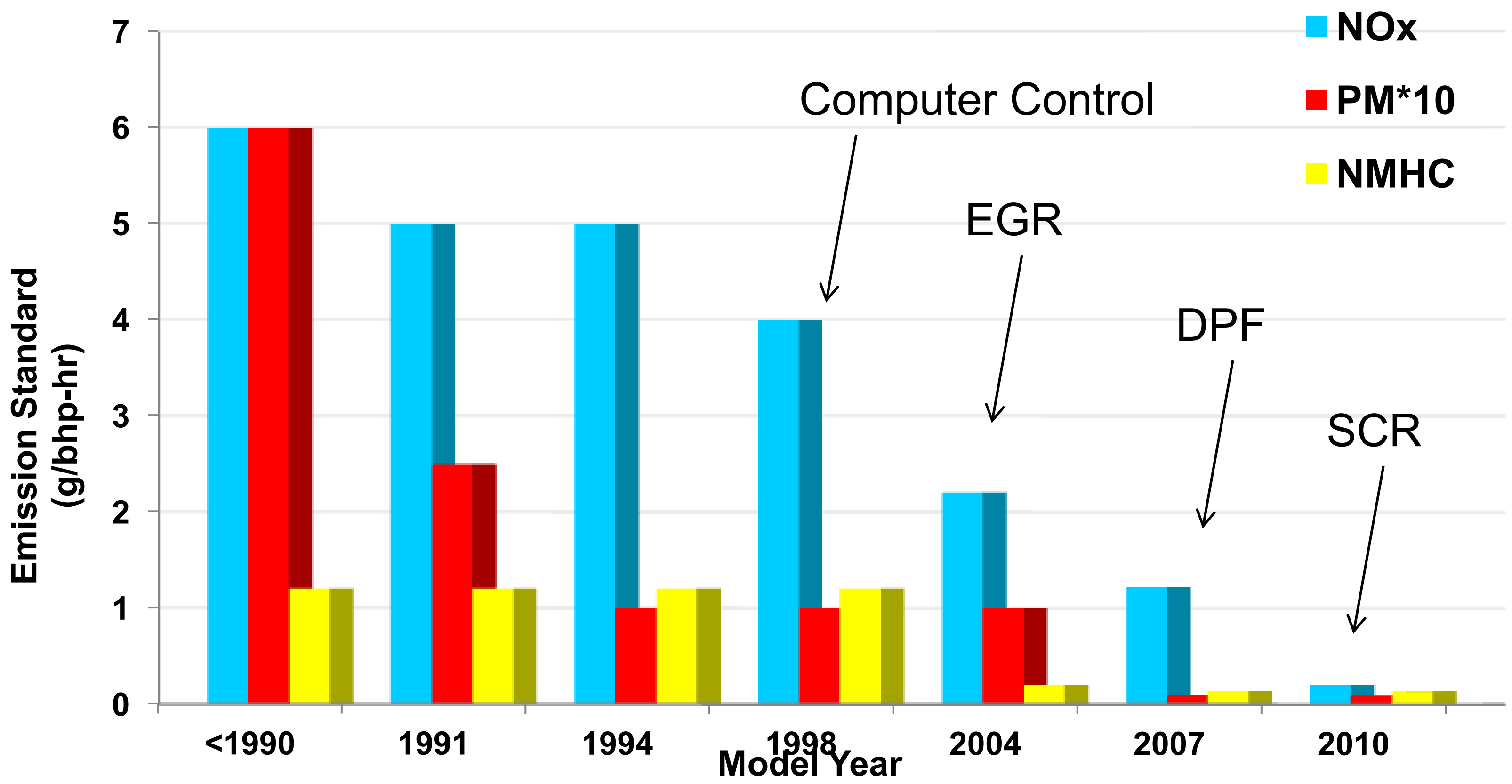
Heavy-Duty Emissions Standards

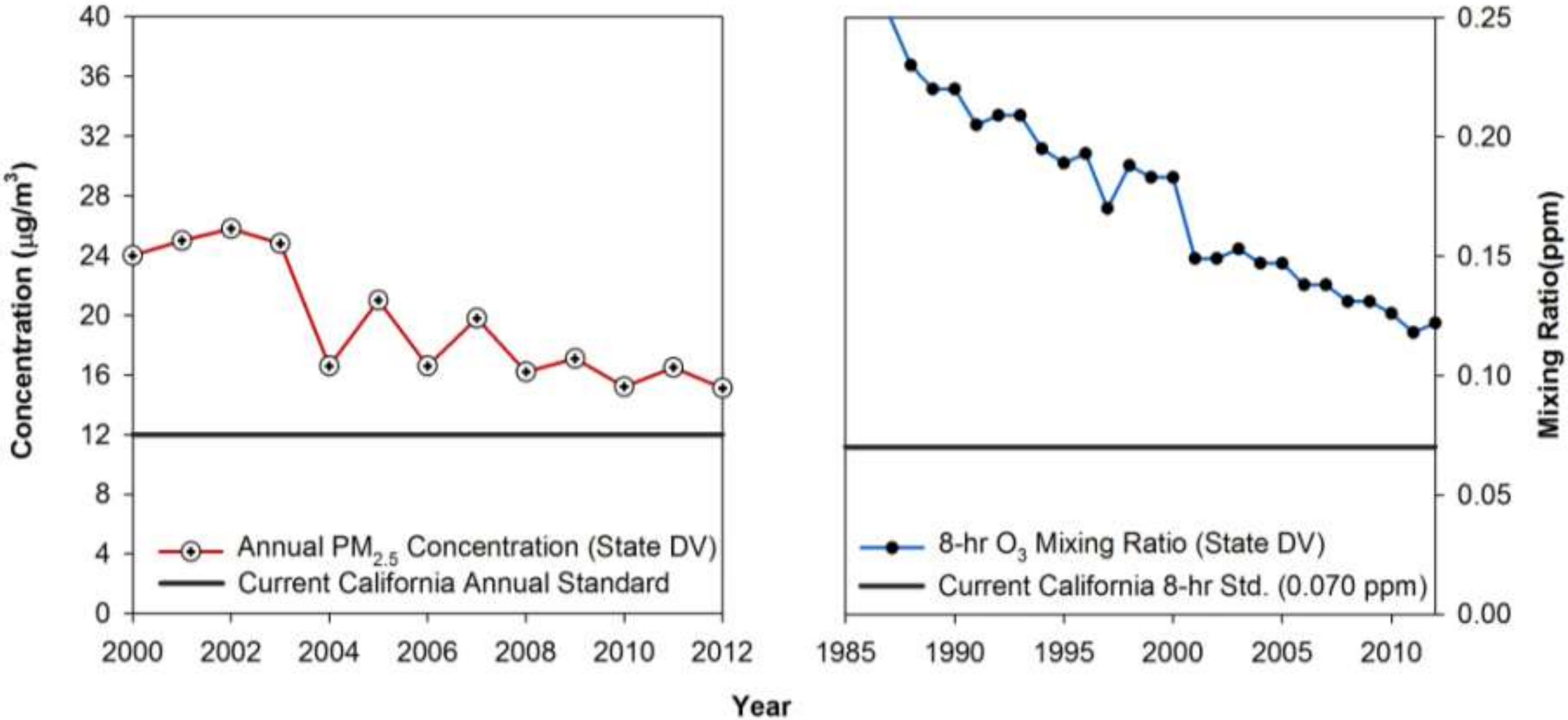


Overview

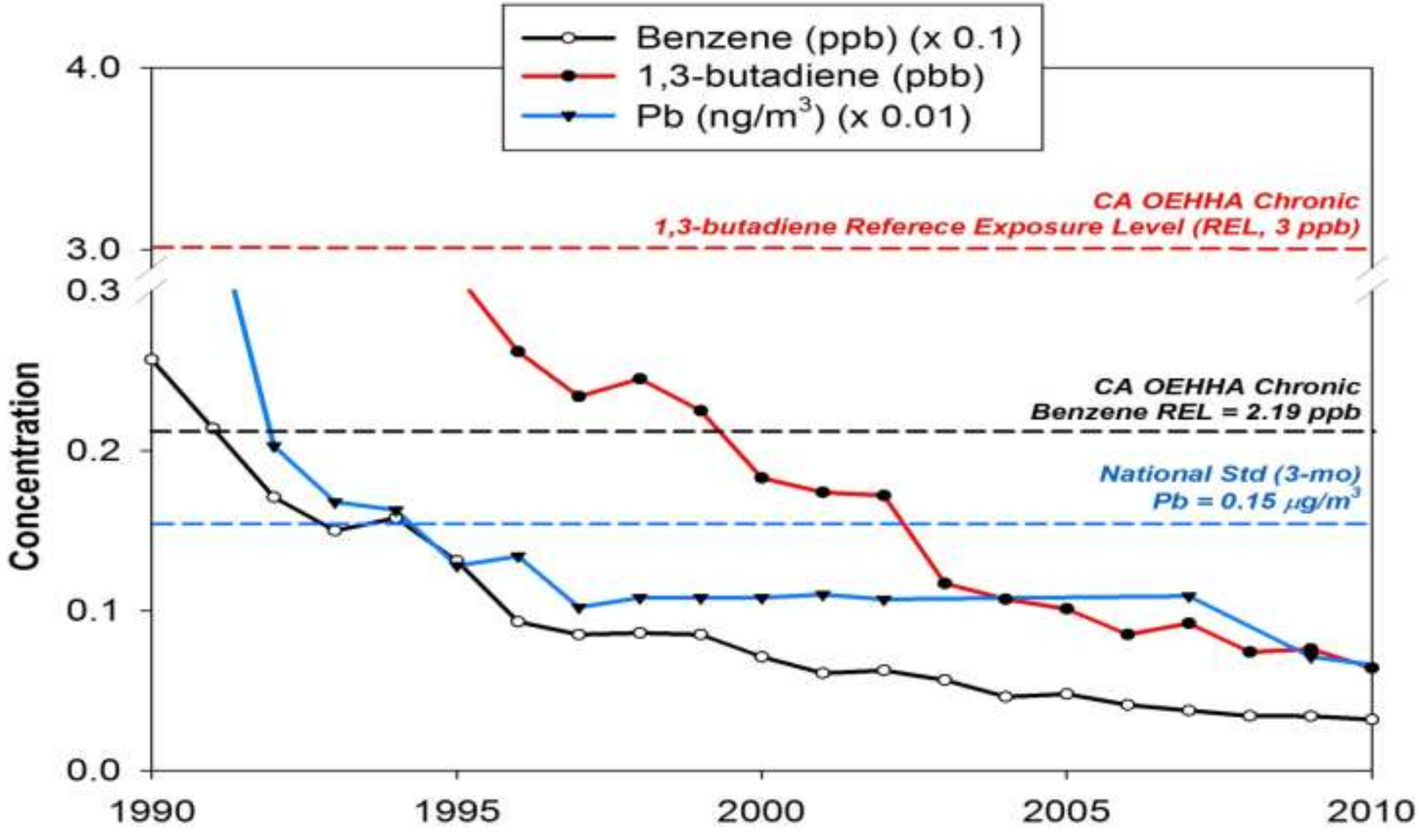
- California's Air Quality Program
- Progress to Date
- Recent Regulations
- Future Plans

Trends in Ambient PM2.5 and Ozone

South Coast Air Basin

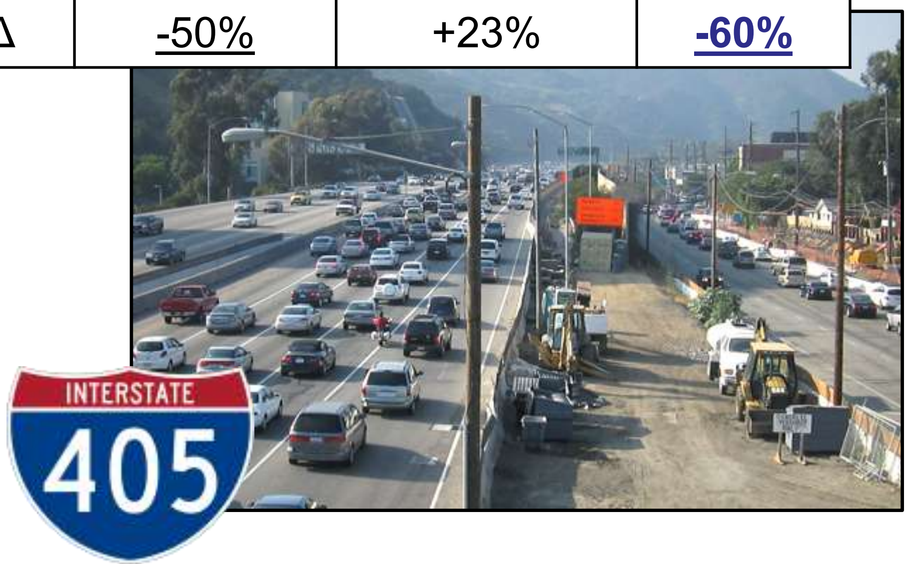


Ambient Toxics Trends
Statewide



Reductions in Near-Roadway Ultrafines

	Downwind - Upwind (Δ #/cm³)	I-405 Flow (vehicles/hr)	# UFP / vehicle
2001	1.1×10^5	13,900	8.1
2011	5.5×10^4	17,100	3.2
Δ	-50%	+23%	**-60%**



- UCLA I-405 freeway study
- Light and heavy duty fleet
- ~60% reduction in per-vehicle ultrafine emissions between 2001 and 2011
- Attributed to newer car and truck fleets, cleaner burning fuels

Quiros et al. (2013). Air quality impacts of a scheduled 36-h closure of a major highway. Atmospheric Environment 67(0).

Overview

- California's Air Quality Program
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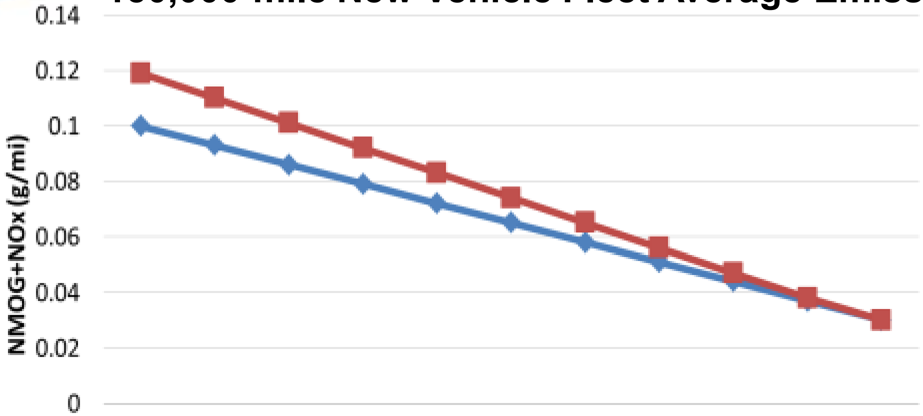
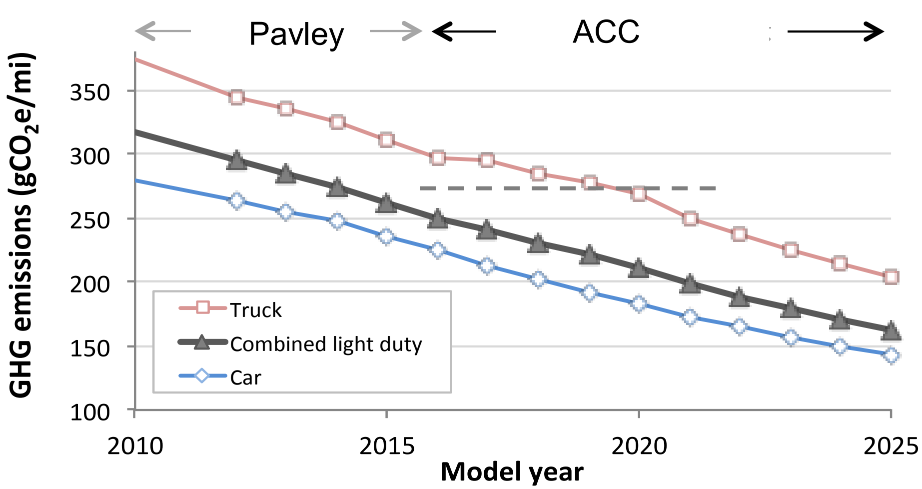
LEV III

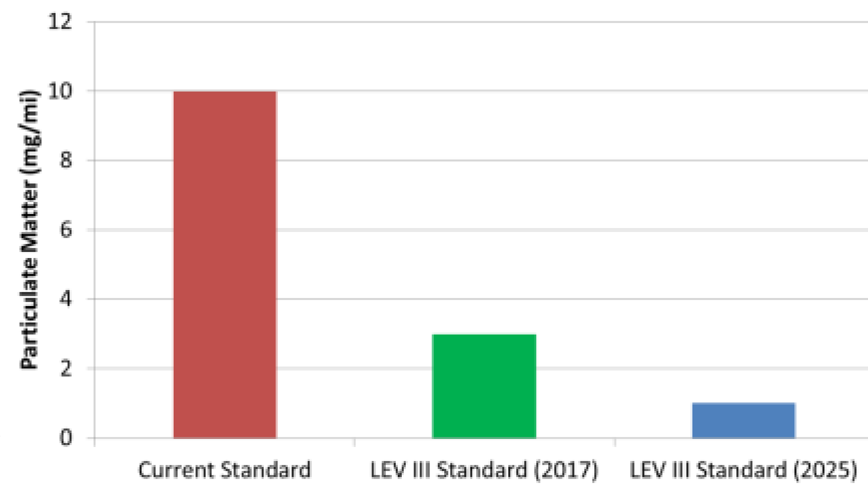
150,000-mile New Vehicle Fleet Average Emissions



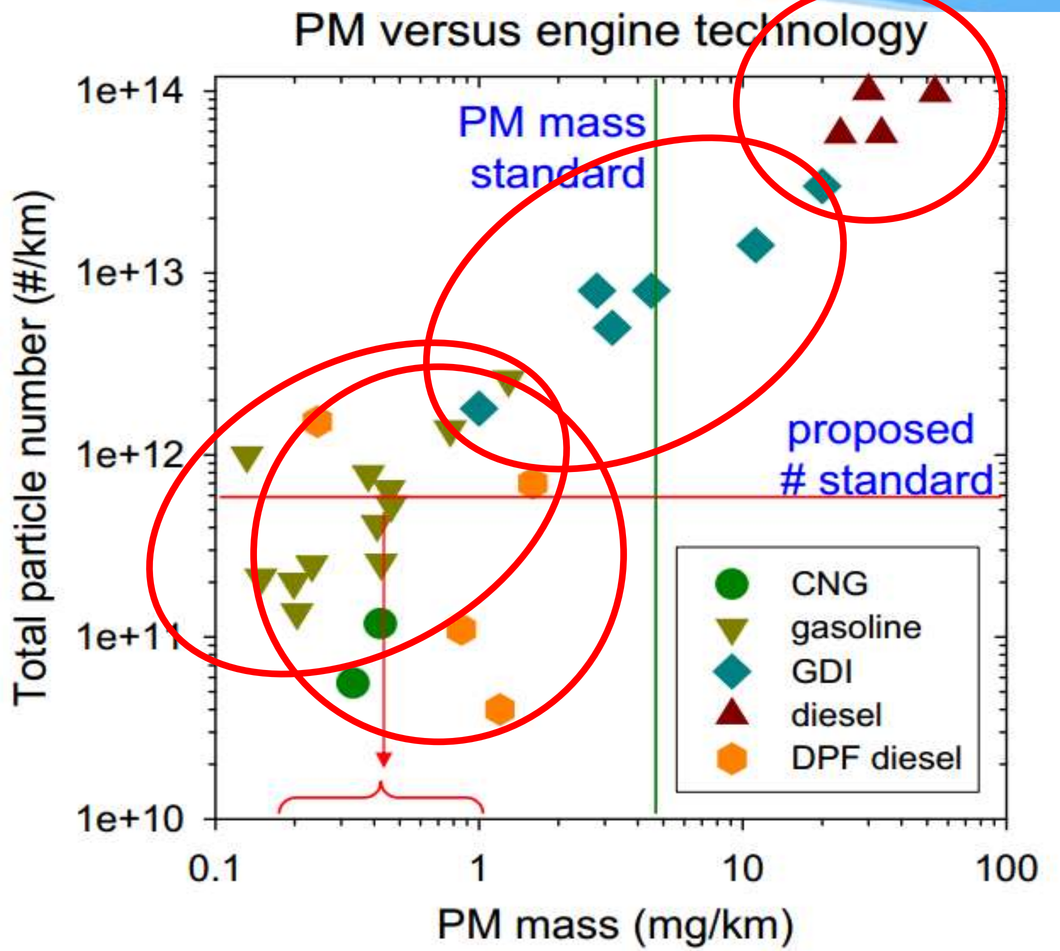
- 75% Reduction 2015-2025
- 34% GHG reduction from 2016 to 2025



LEV III Particulate Matter Standards

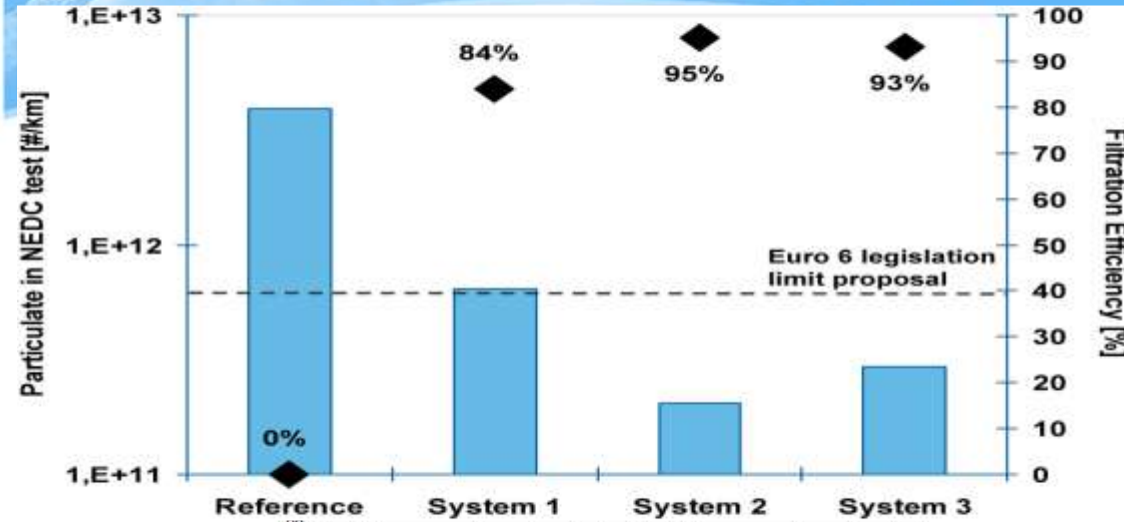


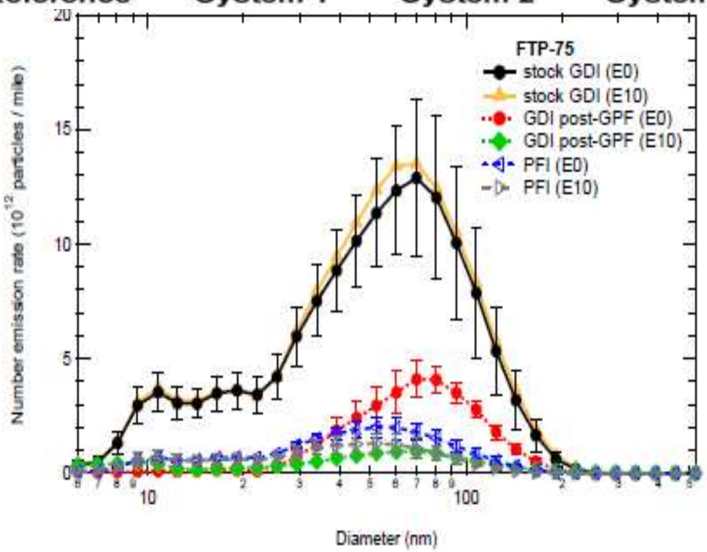
Interaction of Standards



Maricq, M. (2009). HEI Annual Conference. How are emissions of nuclei-mode particles affected by new control technologies and fuels?

Prototype Gasoline Particulate Filter





re 4: *Average particle number size distributions over the FTP-75 drive cycle for the GDI and PFI vehicles.*

- Catalyzed GPF can have significant reductions
  - SPN >23
- Impact across all sizes
  - SPN >4

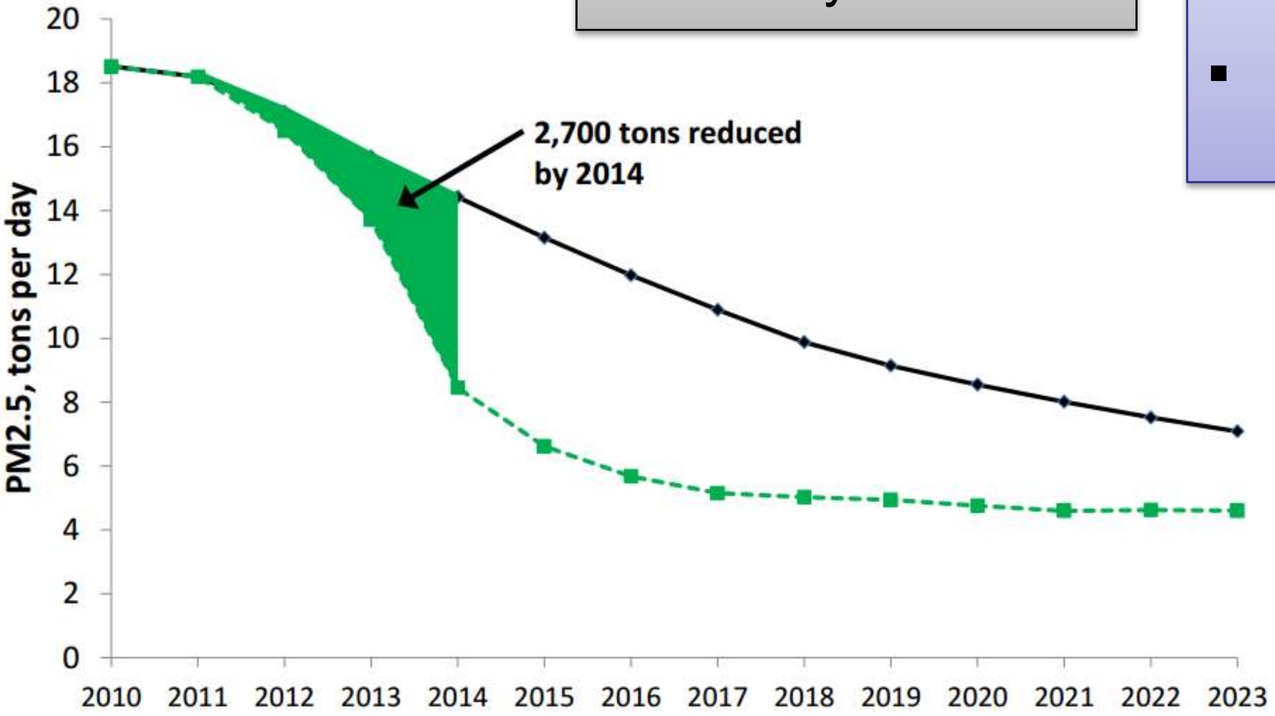
2012-01-1727
Evaluation of a Gasoline Particulate Filter to Reduce Particle Emissions from a Gasoline Direct Injection Vehicle.

2012-01-1244
Application of Catalyzed Gasoline Particulate Filters to GDI Vehicles

Truck and Bus Rule Reductions

Lighter trucks/buses:
- Upgrade to 2010 MY+ by 2023

Heavier vehicles **(>33,000 GVWR):**
- DPF required by 2014
- Upgrade to 2010+ engine by 2023



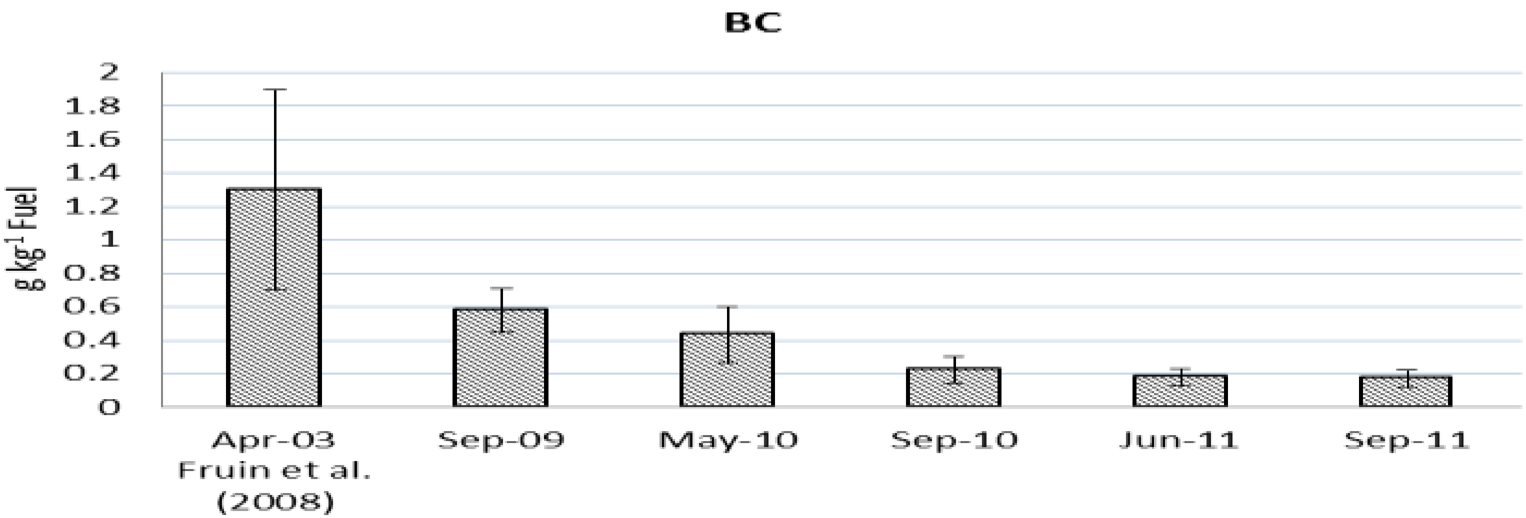
Localized Benefits Confirmed

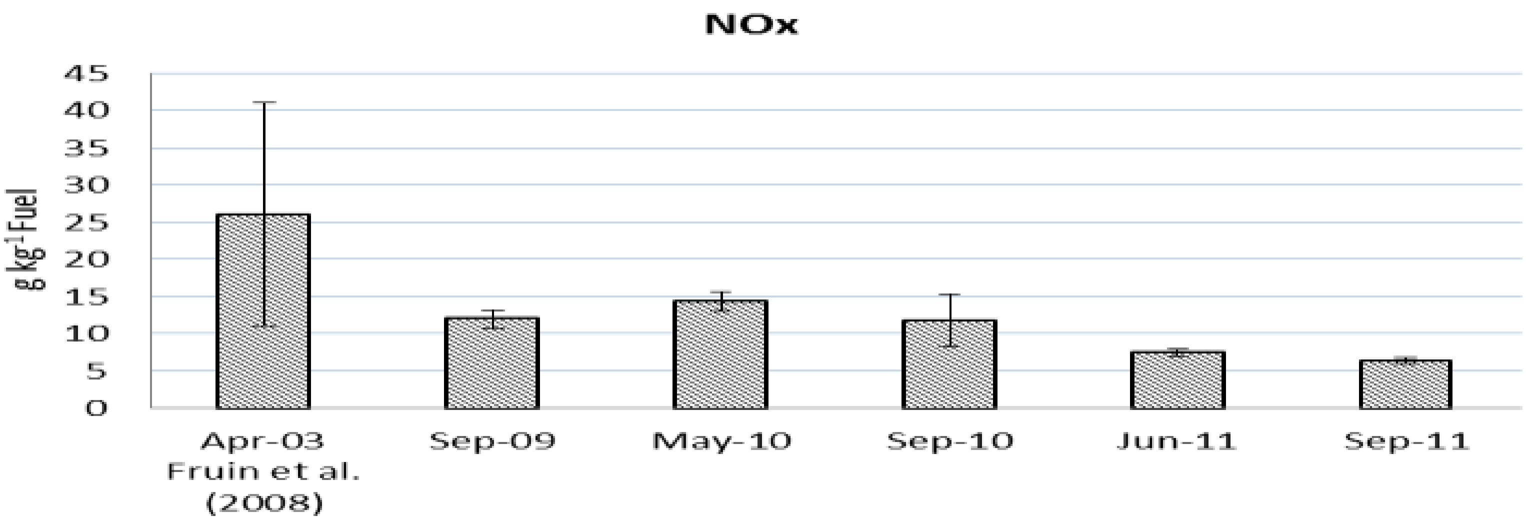
- July 2007 and July 2010 L.A./Long Beach study*
  - Measurements at busy intersections
  - Black carbon and NO_X levels reduced 50%
- November 2009 to June 2010 Oakland study**
  - Black carbon emissions reduced 54%, NO_X by 41%
  - BC reduction of 40% at Caldecott Tunnel took 9 years

* K.H. Kozawa and S.L. Mara (2010) Exposures at Busy Intersections: Effect of State/Local Regulations, CRC Mobile Air Toxics Workshop, Sacramento, CA, November 30-December 2.

** T.R. Dallmann, R.A. Harley, and T.W. Kirchstetter (2011) Effects of Diesel Particle Filter Retrofits and Accelerated Fleet Turnover on Drayage Truck Emissions at the Port of Oakland, *Environmental Science & Technology*, **45**, 10773-10779.

Mobile Platform Confirms Reductions in Emissions Near Ports





In-Vehicle Exposures

- In-Vehicle
  - Centerline of Road exposure > Roadside >> Ambient
- Examples of in-vehicle-to-ambient ratios
  - Benzene: 4-8x higher, 15-20% of total exposure (LA)[1]
  - Diesel PM: 5-15x, 30-55% of total exposure (CA)[2]
  - 1,3-Butadiene: 50-100x higher[3]

[1]Rodes, et al. (1998) [2]Fruin, et al. (2004) [3]Duffy and Nelson (1997)

Overview

- California's Air Quality Program
- Progress to Date
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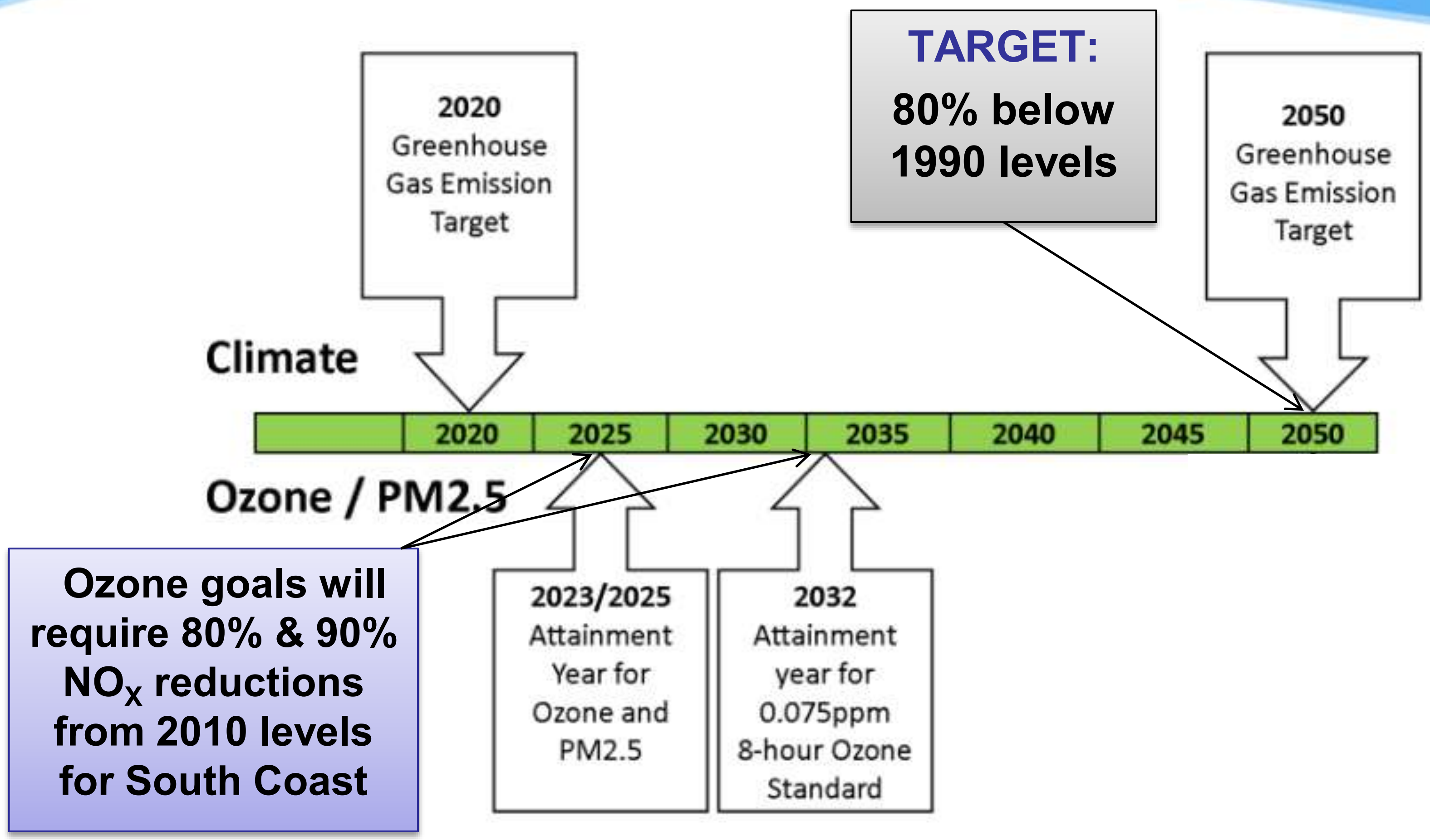
Future Challenges: Climate and Ozone Planning Horizons

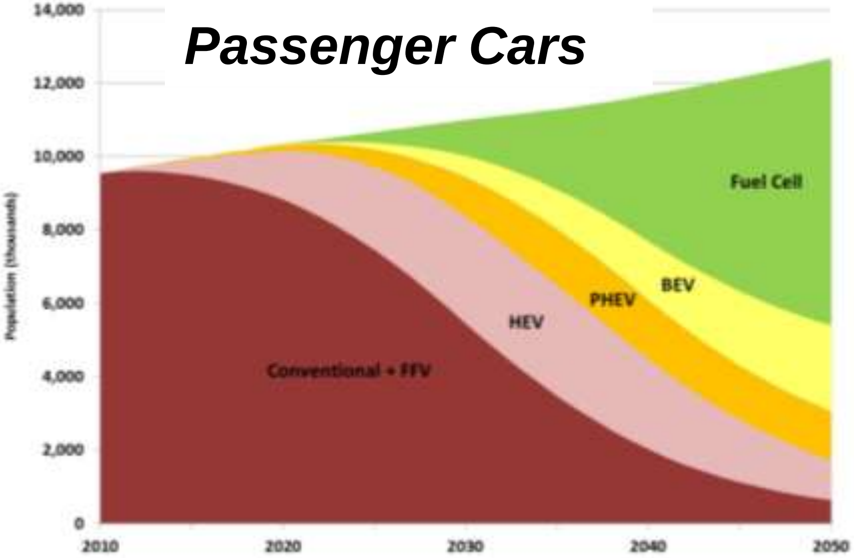


Keys to Meeting New Goals

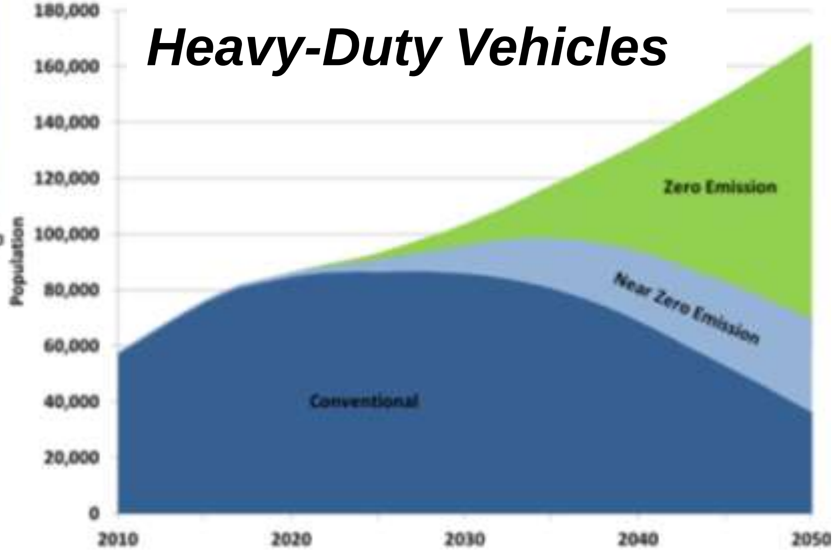
- Cleaner burning and lower carbon fuels
- New vehicle emission standards
  - Investigating 90% lower std for HD
  - Improve goods movement
  - Keep in-use vehicles as clean as possible
- Near-zero and zero-emission technologies
  - Both LD and HD

Transitioning to Zero-Emission Vehicles

Passenger Cars



Heavy-Duty Vehicles



Summary

- Current mobile source programs have significantly reduced near-road exposure
- Long term transition to zero- and near-zero emission technologies will provide additional near-road co-benefits
- Critical to further reduce and control combustion sources during transitional period

Back to Agenda

United States Environmental Protection Agency

Ambient Air Mitigation Strategies for Reducing Exposures to Traffic Emissions

Rich Baldauf, U.S. EPA

Nov. 21, 2013

South Coast Air Quality Management District Workshop

Diamond Bar, CA

United States Environmental Protection Agency

Background

- Evidence of increased health risks for populations spending time near large roadways
- Elevated concentrations of many pollutants near large roads
- Public health concerns have raised interest in methods to mitigate these traffic emission impacts
- Transportation and land use planning options include:
  - Vehicle emission standards and voluntary programs
  - Reducing vehicle activity/Vehicle Miles Travelled (VMT)
  - Buffer/exclusion zones
  - Use of roadway design and urban planning
    - Road location and configuration
    - Roadside structures and vegetation

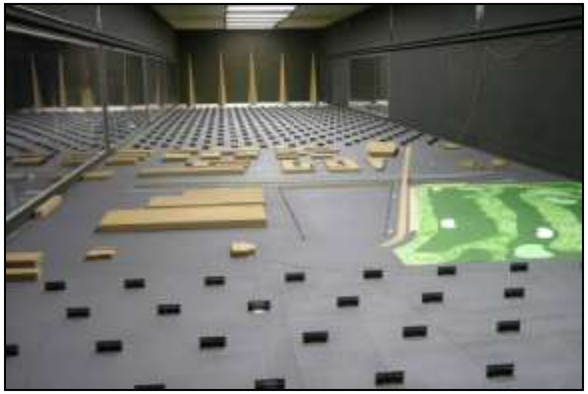
Why study roadside features?

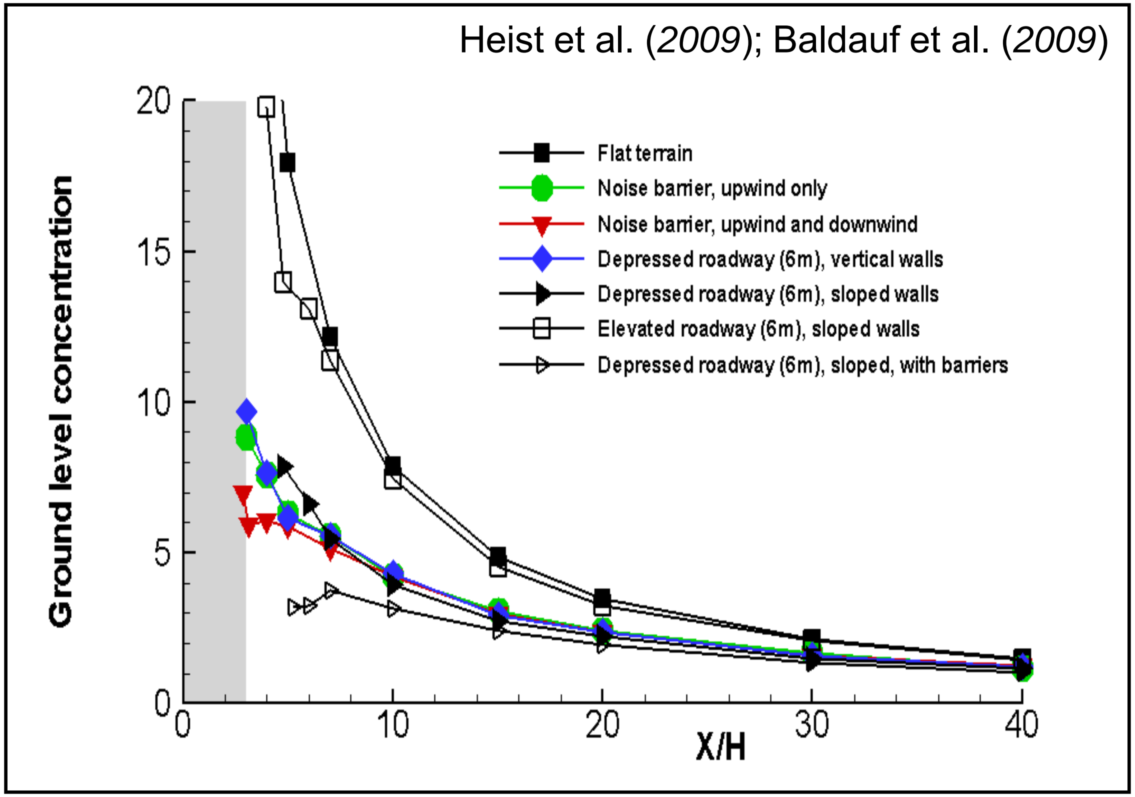
- Few other "short-term" mitigation options
  - Emission reductions take long to implement (fleet turnover required)
  - Planning and zoning involved in rerouting/VMT reduction programs
  - Buffer/exclusion zones may not be feasible
- Roadside features may already be present
- Roadside features often have other positive benefits

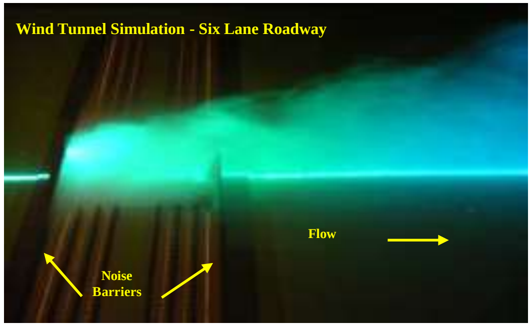
Research Methodology

- EPA has initiated research to examine the role roadside features (noise barriers, vegetation) may play in reducing near-road air pollutant impacts
- Using combination of modeling and monitoring to characterize the impact of noise and vegetation barriers on near-road air quality
  - Wind tunnel assessments
  - CFD modeling
  - Field studies (Raleigh, Chapel Hill, Idaho Falls, Detroit, Phoenix)
- Developing new model algorithms for evaluating impacts of roadside structures and vegetation
  - Determine potential mitigation opportunities
  - Air quality characterization
  - Exposure assessment and characterization

Roadway Configuration Effects



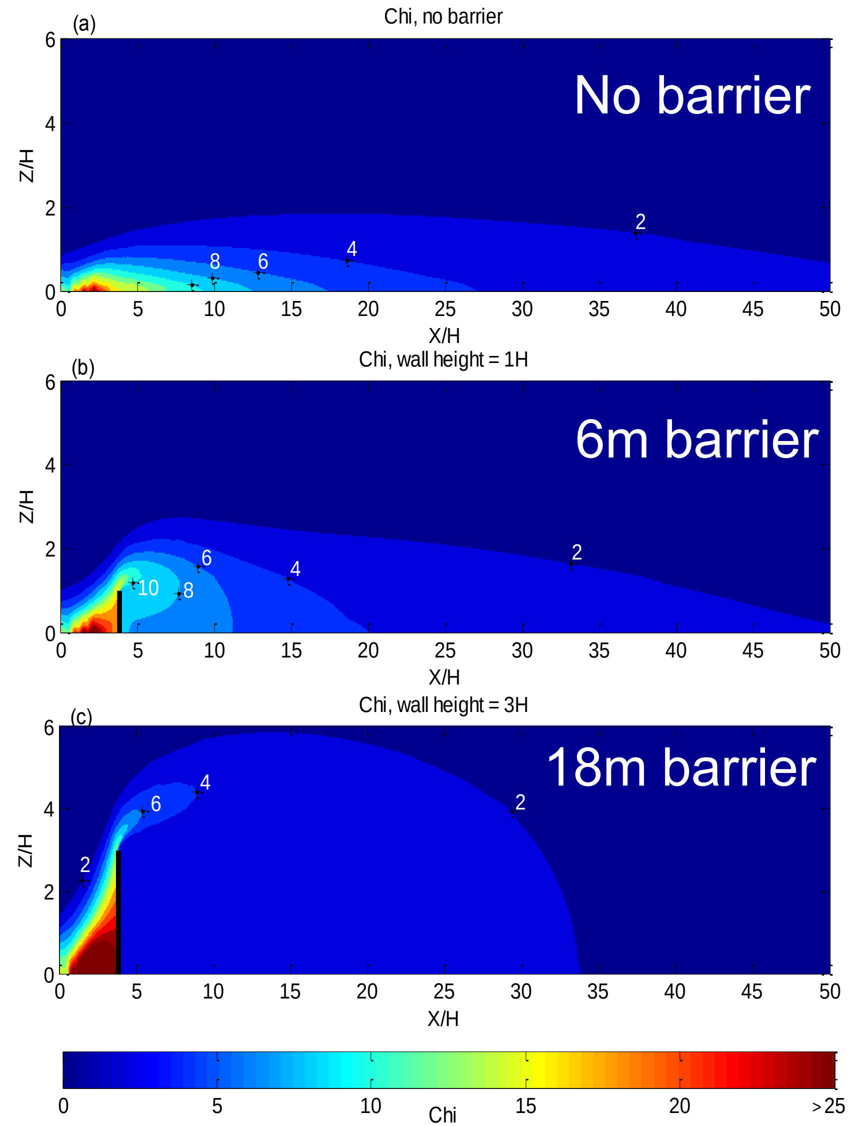




Wind tunnel simulations show roadway design effects on pollutant transport and dispersion. Highest levels occur with at-grade and elevated fill roads. Lowest levels occur with noise barriers and cut section roads

Noise Barriers

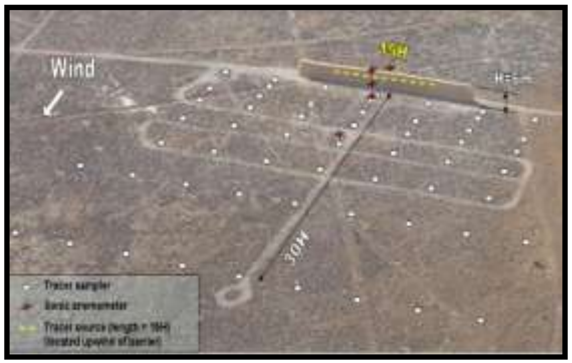
- CFD modeling suggest decreased concentrations downwind of barriers, but increased on-road concentrations
- Dispersion models being developed to quantify mitigation potential of barrier

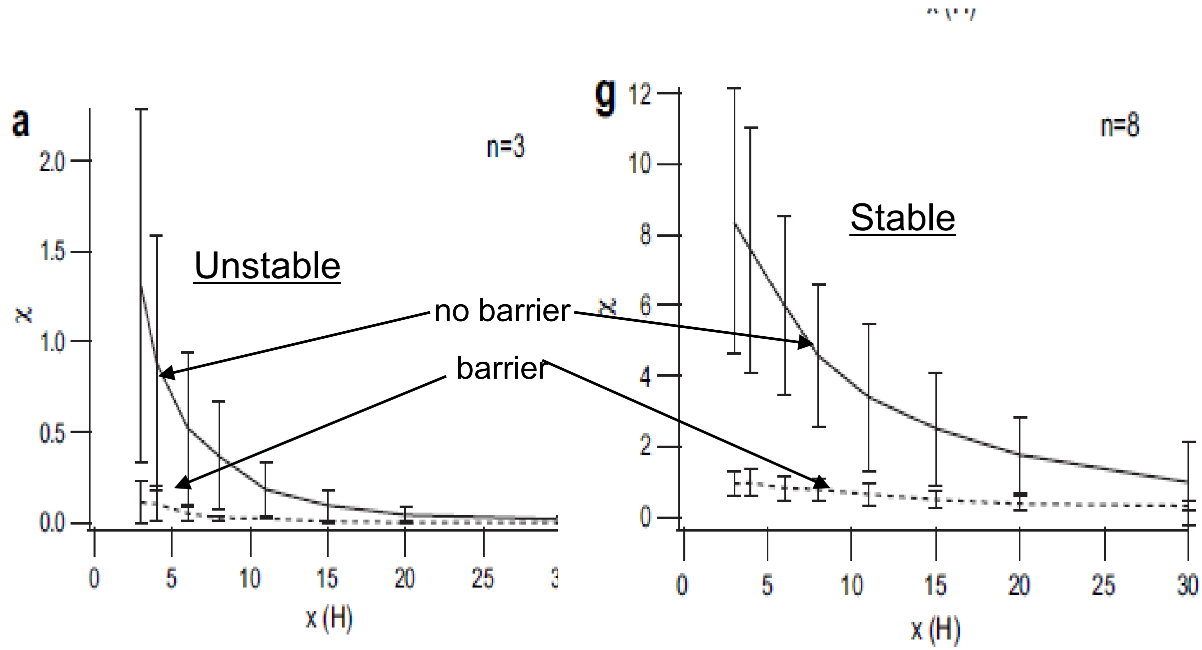


(Hagler et al. 2011)

Noise Barrier Effects

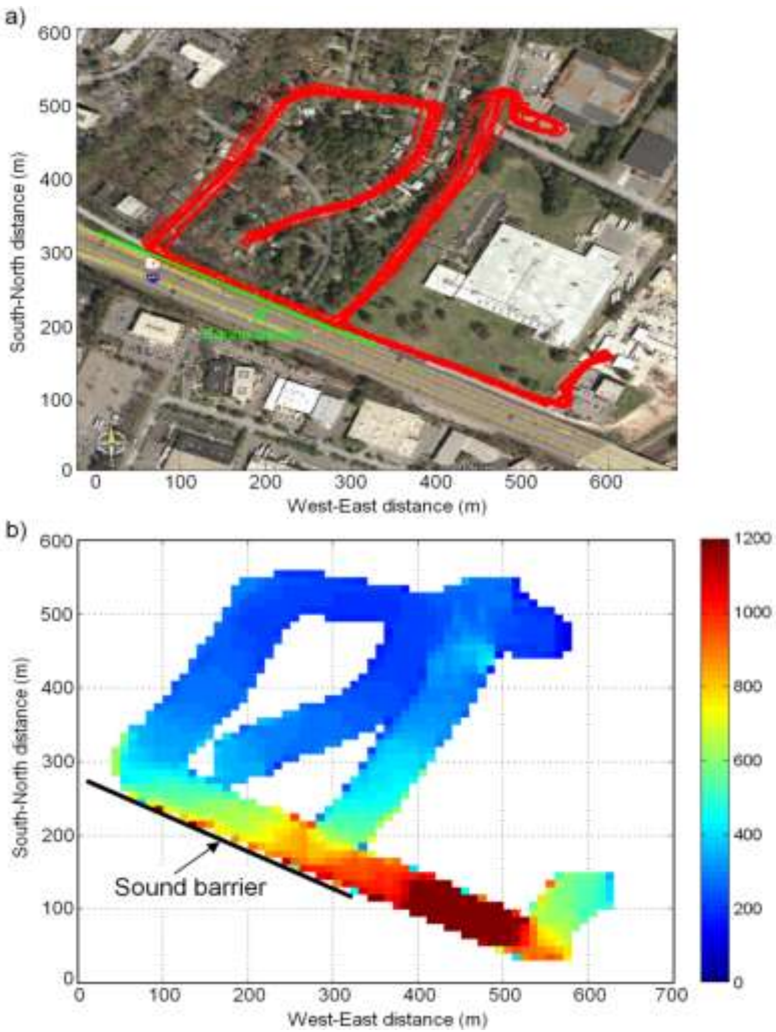
Tracer studies also indicate noise barriers significantly reduced downwind air pollutant concentrations under all stability conditions



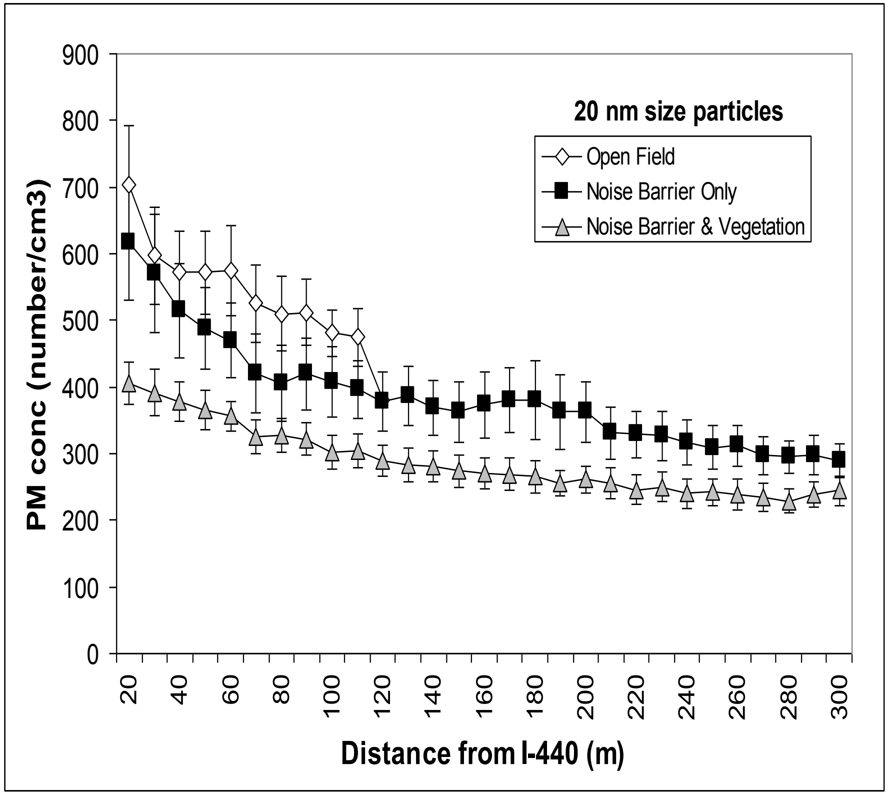


Finn et al., (2010)

Noise Barriers and Vegetation



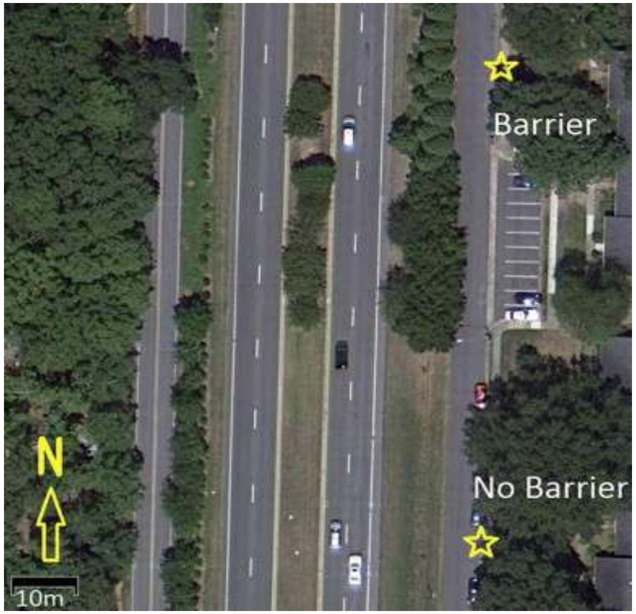
- Noise barriers reduced PM levels compared with a clearing
- Vegetation with noise barriers provided further PM reductions

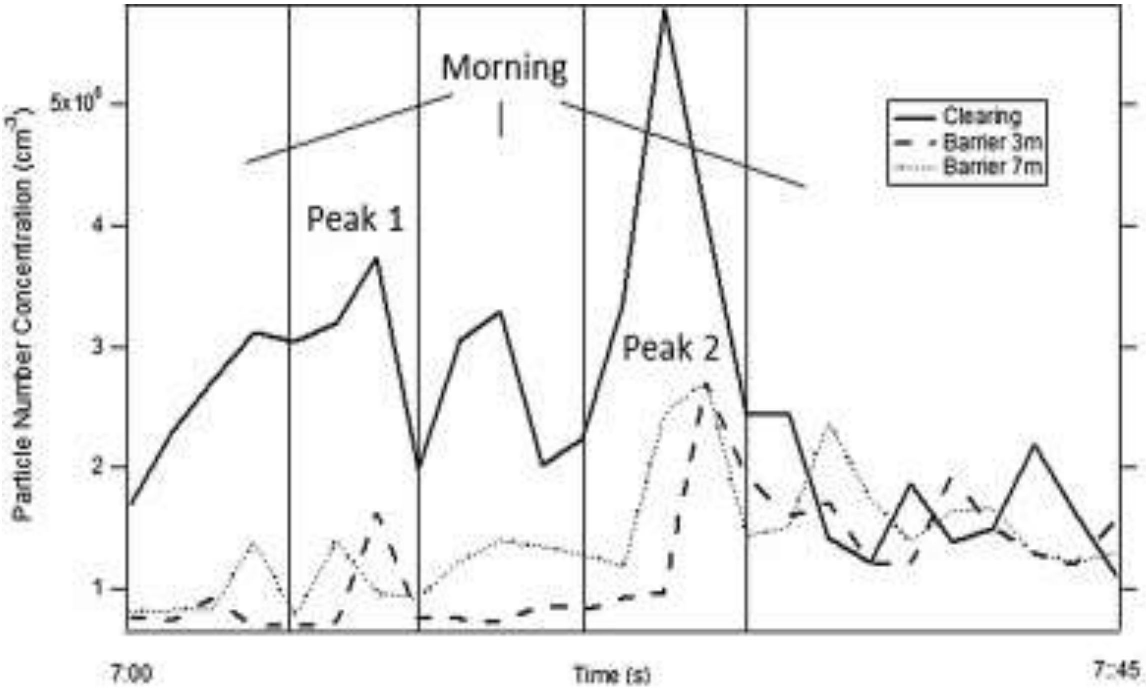


(Baldauf et al., 2008a; 2008b)

Vegetation Effects

Steffens et al. (2012)

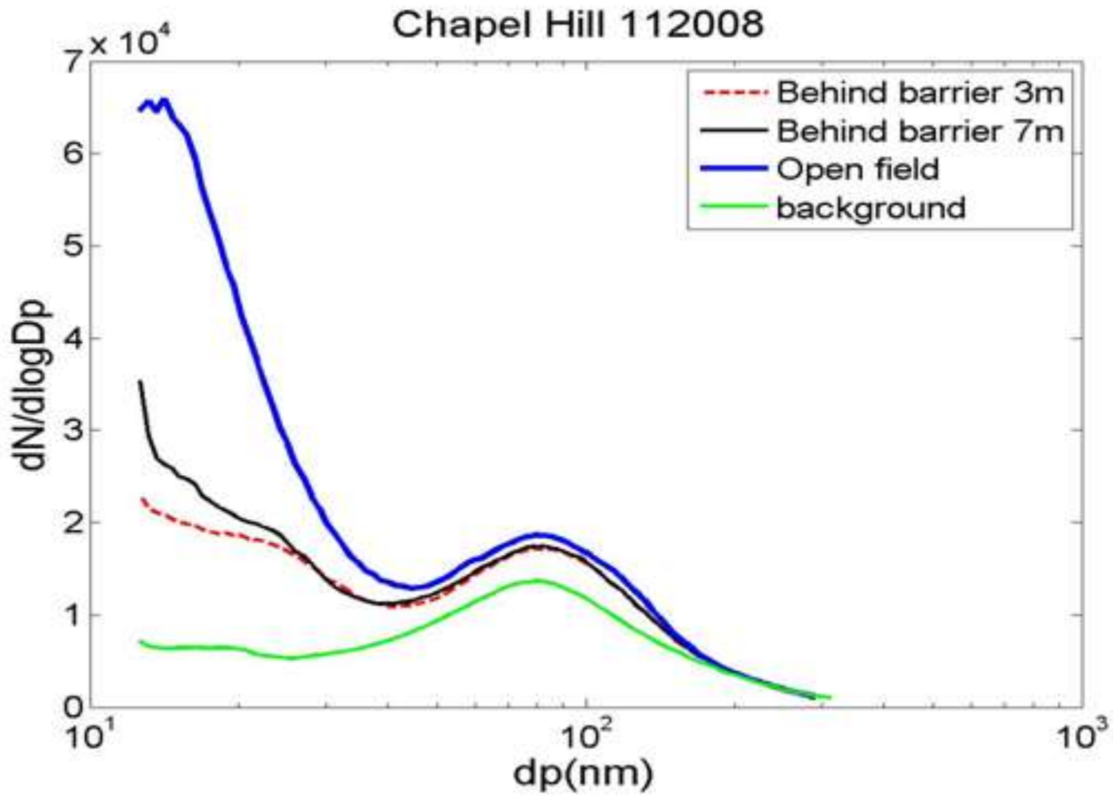




- Ultrafine PM number count generally reduced downwind of a vegetation stand
- Higher reductions most often occurred closer to ground-level
- Variable winds caused variable effects

Vegetation Effects

Khlystov et al (2012)

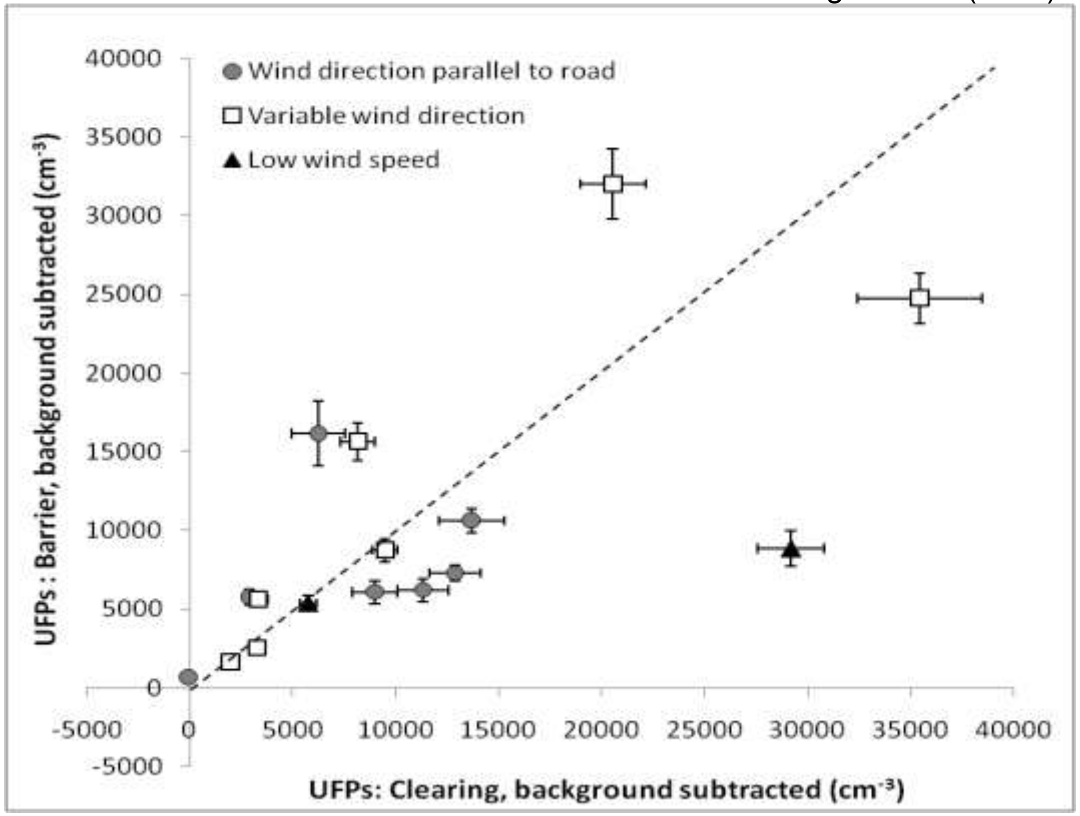


- Lower size fractions of PM most reduced downwind of the vegetation stand
- Effect most evident closer to ground-level

Vegetation Effects

- For thin tree stands, variable results seen under changing wind conditions (e.g. parallel to road, low winds)
- Gaps/dead trees may have led to higher concentrations
- Future research looking into effects of lower porosity/wider tree stands

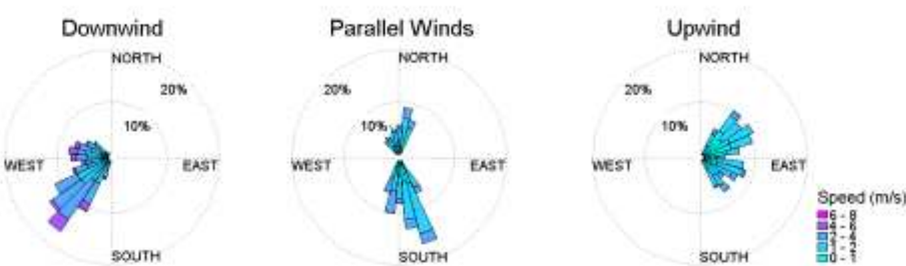
Hagler et al. (2011)

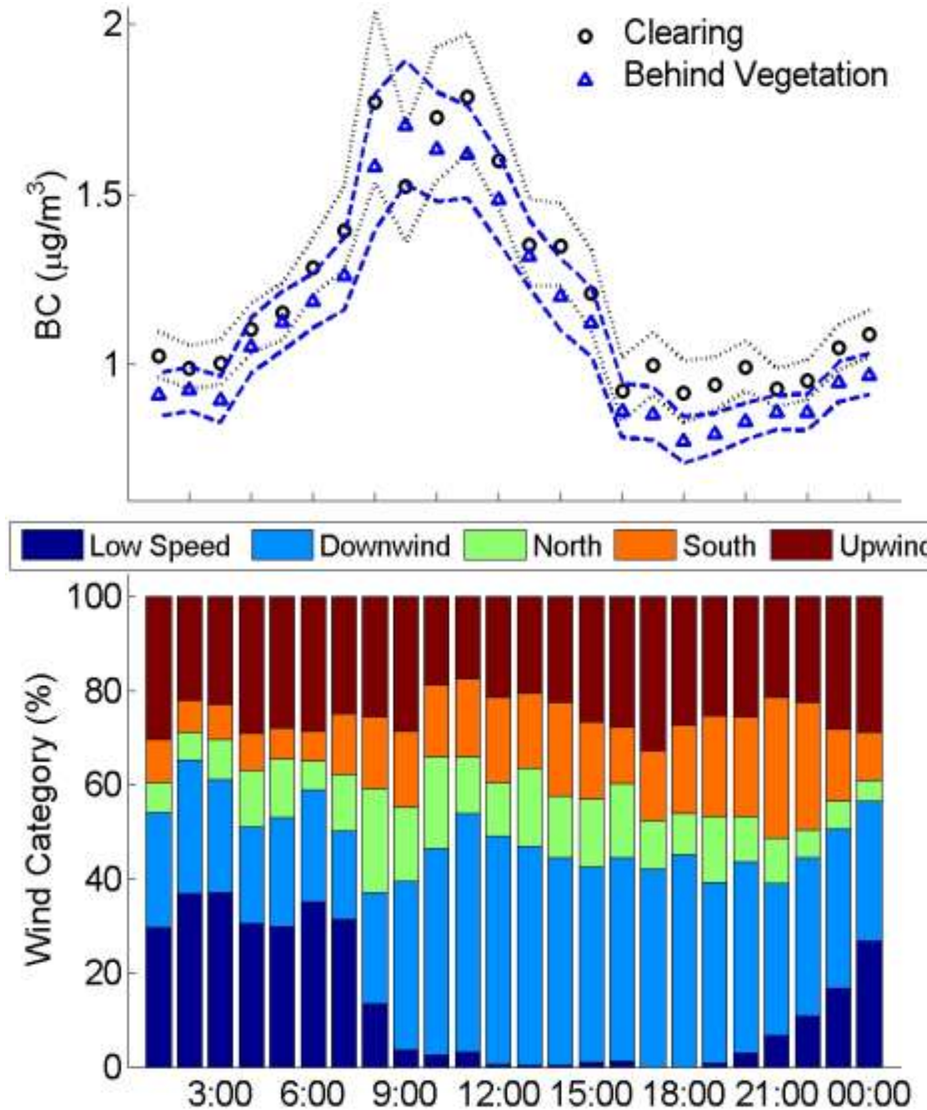


United States Environmental Protection Agency

Vegetation Effects

Vegetation on average resulted in 15% lower BC levels compared to concentrations in a clearing

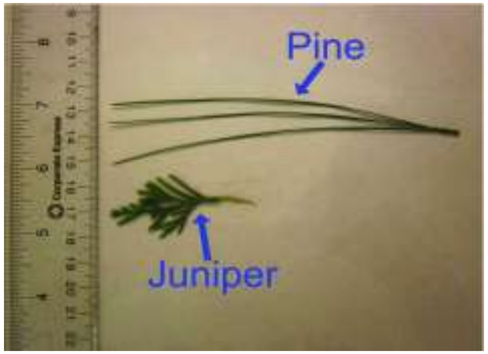




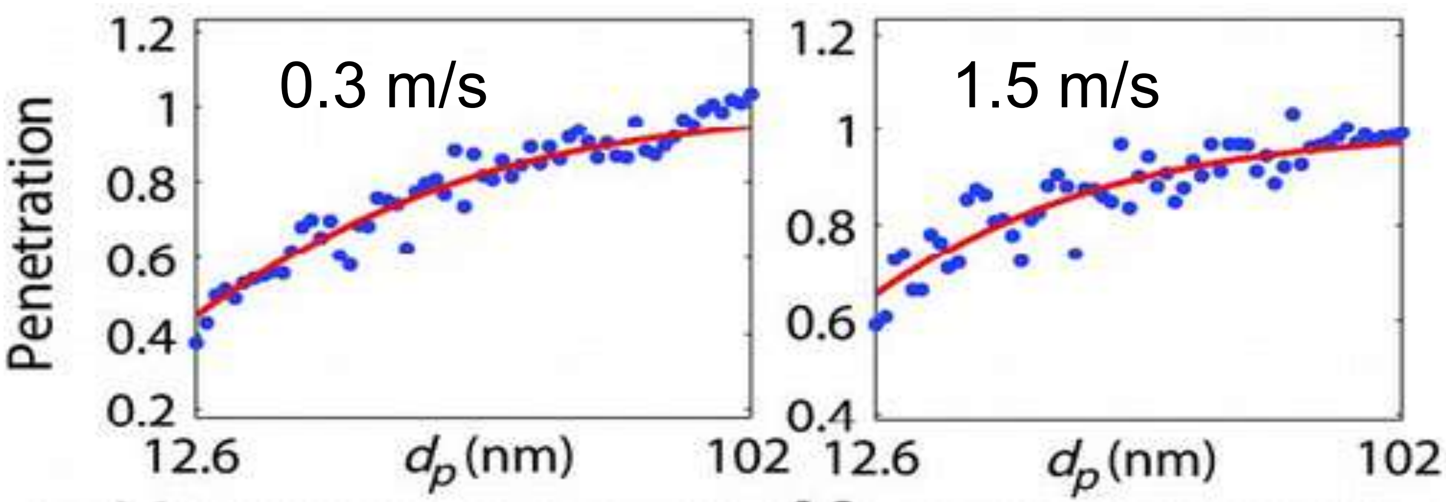
Brantley et al. (in prep)

Vegetation Effects

(Cahill et al., 2010)



- Smaller size fractions of PM have higher removal efficiency
- Removal increases at lower wind velocities
- Shape and size of branches/leaves affects removal



Summary

- Multiple options exist to mitigate traffic emission impacts on near-road air quality and population exposures
  - Reducing emissions
  - Reducing exposures
- Ambient air mitigation options focus on exposure reduction although some techniques may also remove air pollutants
- Each mitigation option has advantages and disadvantages in both short- and long-term air quality improvement and exposure reduction
- When implementing a strategy for reducing adverse health risks for near-road populations, a combination of these options should be considered
- Models will be important in evaluating mitigation options and designing future research studies

Summary – Noise Barriers

- Research shows the ability for noise barriers to reduce downwind pollutant concentrations near roads
- Design considerations are very important:
  - Generally, the higher the barrier, the higher the pollution reduction
  - Pollutants can meander around edges (sides and top), so areas desired for reduced concentrations should avoid edge effects

United States Environmental Protection Agency

Summary – Noise Barriers

- Design considerations are very important:
  - Pollutants can be trapped on the upwind side of the structure
    - May lead to increased concentrations on the road
    - "Upwind" sources in the area may cause increased concentrations under some wind conditions
  - Some studies suggest that the traffic plume from the road re-attaches further downwind of the barrier
    - May have higher concentrations at further distances (~150 m) with a barrier than without
    - Generally, overall concentrations are lower at these further distances, so reduced concentrations closer to the road with the barrier often outweigh the increased concentrations further away
    - Plume reattachment effect not seen in most studies

Summary - Vegetation

- Research shows the ability for roadside vegetation to reduce downwind pollutant concentrations near roads
- Design considerations are very important:
  - Generally, the higher and thicker the vegetation, the higher the pollution reduction
  - Pollutants can meander around edges or through gaps, so areas desired for reduced concentrations should avoid edge effects
  - Vegetation should be appropriate for the location of use
    - Native plants and trees preferred
    - Mature vegetation – trees take time to grow
    - Reasonable water use; water runoff control
    - Limited seasonal effects to ensure operational barrier year-round
    - Falling debris will not impact roadway

Summary - Vegetation

- Areas desired for reduced concentrations should avoid edge effects
  - Vegetation barrier should provide coverage from the ground to the top of canopy
  - Barrier thickness should be adequate for complete coverage so gaps are avoided
- Pine/coniferous vegetation may be a good choice
  - No seasonal effects
  - Complex, rough, waxy surfaces

Examples of full coverage, pine barriers

Summary - Vegetation

- Pollutants can meander around edges or through gaps
- Barrier thickness should be adequate for complete coverage to avoid gaps
  - No spaces between or under trees
  - No gaps from dead or dying vegetation; maintenance important

Examples of inadequate barriers due to gaps

Summary - Barriers

- Combination of noise and vegetative barriers may provide the most benefits
  - Increase potential for pollutant dispersion and removal
  - May be solid barrier with vegetation behind and/or in front
  - Use of climbing vegetation and hedges with solid barrier may also provide additional benefits
    - Field study results mixed
    - Vegetation on solid wall should extend enough to allow air to flow through

Examples of solid/vegetation barriers

Acknowledgements

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Thomas Long

FHWA

Victoria Martinez
Kevin Black
Mark Ferroni
Adam Alexander

USFS

David Nowak
Greg McPherson

NOAA

Dennis Finn
Kirk Clawson

For More Information

- Websites:
  - http://www.epa.gov/nrmrl/appcd/nearroadway/workshop.html
  - http://www.epa.gov/ord/ca/quick-finder/roadway.htm
- References

  - Baldauf, R.W., A. Khlystov, V. Isakov, et al. 2008a. Atmos. Environ. 42: 7502–7507
  - Baldauf, R.W., E. Thoma, M. Hays, et al. 2008b. J. Air & Waste Manage Assoc. 58:865–878
  - Baldauf, R.W., N. Watkins, D.K. Heist, et al. 2009. J. of Air Quality, Atmosphere, & Health. Vol. 2: 1-9
  - Baldauf, R.W., D.K. Heist,, V. Isakov, et al. 2012. Atmos. Environ. 64: 169-178
  - Brantley, H., P. Deshmukh, G. Hagler et al. 2014. Atmos. Environ. online
  - Finn, D., K.L. Clawson, R.G. Carter et al., 2010. Atmos. Environ. 44: 204-214.
  - Hagler, G.S.W., M-Y. Lin, A. Khlystov, et al. 2012. Science of the Total Environment, 419: 7-15
  - Heist, D.K., S.G. Perry, L.A. Brixey, 2009. Atmos. Environ. 43: 5101-5111
  - Khlystov, A., M-Y Lin, G.S.W. Hagler, et al. 2012. A&WMA Measurements Workshop, Durham, NC
  - Steffens, A., Y.J. Wang, K.M Zhang. 2012. Atmos. Environ. 50: 120-128

- Contact Information:

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Back to Agenda

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

USING ROADSIDE BARRIERS TO REDUCE NEAR-ROAD CONCENTRATIONS OF TRAFFIC RELATED POLLUTANTS

Akula Venkatram, Nico Schulte and USEPA collaborators
University of California, Riverside, CA

Overview

- Role of models in evaluating mitigation options
- Effects of sound barriers
- Effects of vegetative barriers
- Summary

Mitigation Options-Emission versus Exposure Reduction

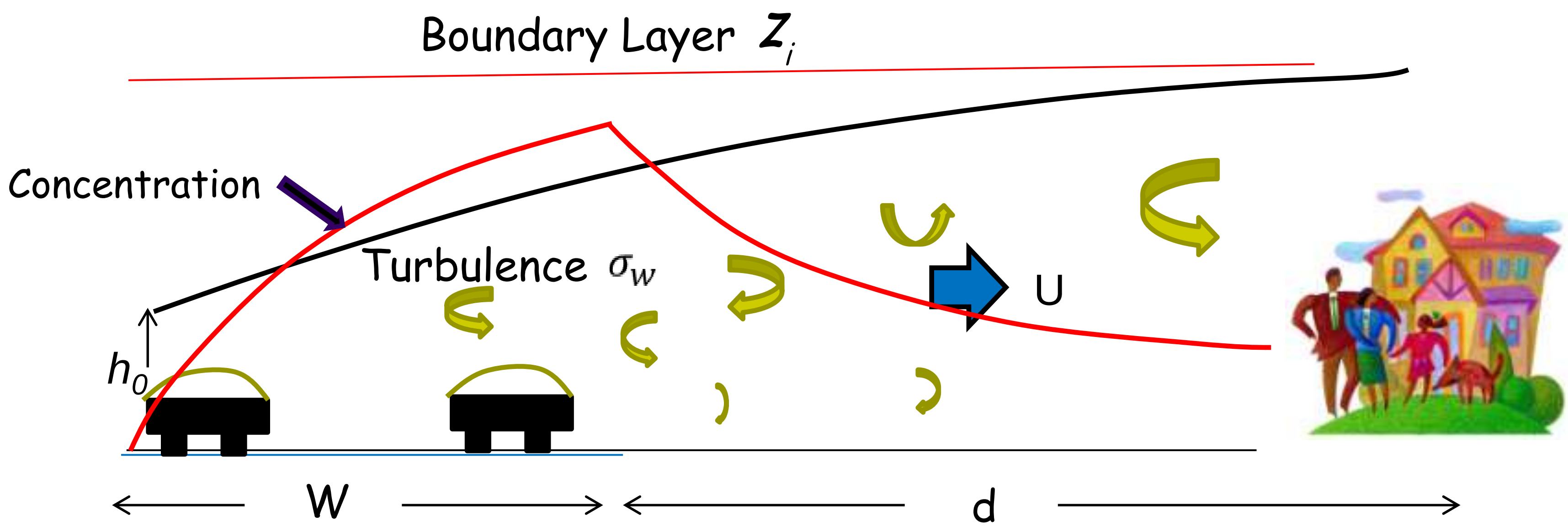
- Exposure Reduction
  - Buffer zones
  - Road geometry
    - Road width
    - Elevated or depressed roads
    - Covered roads
  - Dispersion and Removal structures
    - Solid barriers
    - Vegetative barriers

Models are essential for evaluating these mitigation options

Developing and Applying Models to Estimate the Impact of Roadway Emissions

- Obtain data from field studies and laboratory experiments
- Develop tentative model for dispersion from roads
- Evaluate model with data
- Improve model to reduce discrepancies between model estimates and observations
- Evaluated model becomes surrogate for reality
- Use model to conduct sensitivity studies that would be impossible in the real world.

Governing Processes



$$C = \sqrt{\frac{2}{\pi}} \frac{Te_f}{W} \frac{1}{\sigma_w} \ln\left(1 + \frac{\sigma_w W}{h_0 U + \sigma_w d}\right)$$

$$C_{min} = \frac{Te_f}{U z_i}$$

Field Studies and Models

Field and Laboratory Studies

- Dispersion of releases from sources close to the ground
  - Green Glow, Prairie Grass (1956)
- Field studies to understand road dispersion –GM tracer study (1980)- tracer released from 352 automobiles
- New road field studies
  - Caltrans (1980), Raleigh study (Baldauf et al., 2008), **Idaho Falls Study (2008, Finn et al. 2010)**

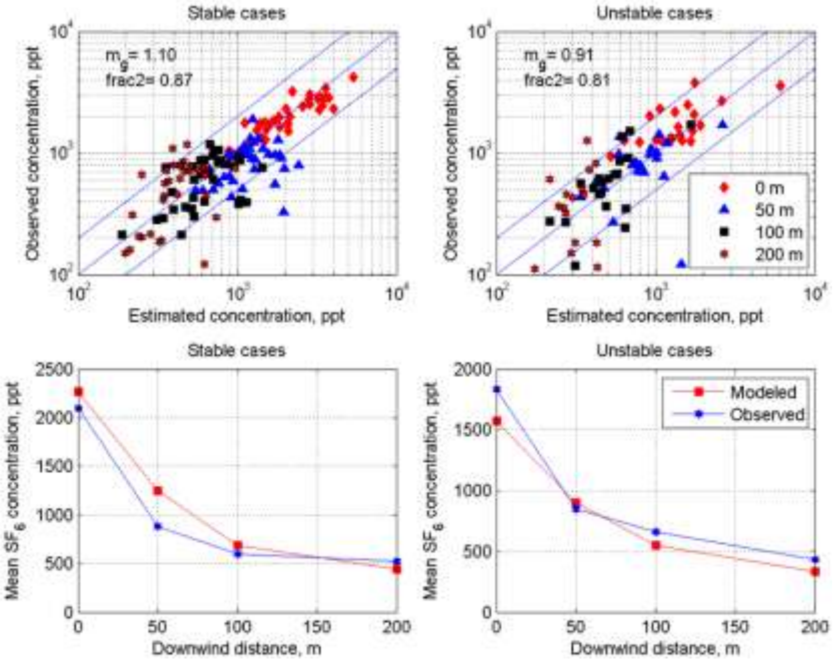
Models

- EPA Highway Model (1970s)
- CALINE Model (Benson, 1989)
- RLINE (Snyder et al., 2013)
- C-LINE (Barzyk et al, 2013)

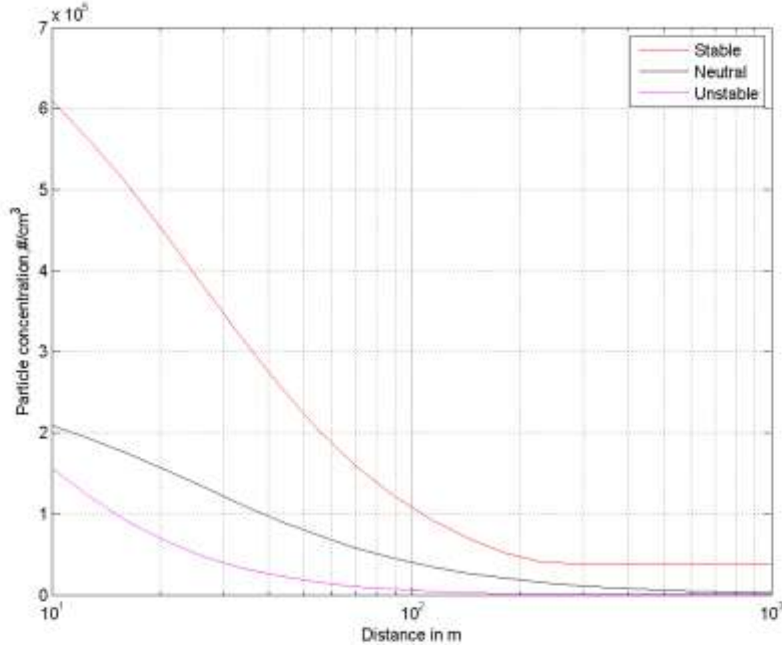
Development of RLINE

1. RLINE: A line source dispersion model for near-surface releases .
   *Atmospheric Environment, Volume 77, October **2013**, Pages 748-756*
   Michelle G. Snyder, Akula Venkatram, David K. Heist, Steven G. Perry, William B. Petersen, Vlad Isakov
2. Re-formulation of plume spread for near-surface dispersion
   *Atmospheric Environment, Volume 77, October **2013**, Pages 846-855*
   Akula Venkatram, Michelle G. Snyder, David K. Heist, Steven G. Perry, William B. Petersen, Vlad Isakov
3. Impact of wind direction on near-road pollutant concentrations
   *Atmospheric Environment, Volume 80, December **2013**, Pages 248-258*
   Akula Venkatram, Michelle Snyder, Vlad Isakov, Sue Kimbrough
4. Modeling the impact of roadway emissions in light wind, stable and transition conditions
   *Transportation Research Part D: Transport and Environment, Volume 24, October **2013**, Pages 110-119*
   Akula Venkatram, Michelle Snyder, Vlad Isakov
5. Estimating near-road pollutant dispersion: A model inter-comparison
   *Transportation Research Part D: Transport and Environment, Volume 25, December **2013**, Pages 93-105*
   David Heist, Vlad Isakov, Steven Perry, Michelle Snyder, Akula Venkatram, Christina Hood, Jenny Stocker, David Carruthers, Saravanan Arunachalam, R. Chris Owen
6. Estimating the height of the nocturnal urban boundary layer for dispersion applications
   *Atmospheric Environment, Volume 54, July **2012**, Pages 611-623*
   Sam Pournazeri, Akula Venkatram, Marko Princevac, Si Tan, Nico Schulte
7. Modeling the impacts of traffic emissions on air toxics concentrations near roadways
   *Atmospheric Environment, Volume 43, Issue 20, June **2009**, Pages 3191-3199*
   Akula Venkatram, Vlad Isakov, Robert Seila, Richard Baldauf
8. Analysis of air quality data near roadways using a dispersion model
   *Atmospheric Environment, Volume 41, Issue 40, December **2007**, Pages 9481-9497*
   Akula Venkatram, Vlad Isakov, Eben Thoma, Richard Baldauf
9. Approximating dispersion from a finite line source
   *Atmospheric Environment, Volume 40, Issue 13, April **2006**, Pages 2401-2408*
   Akula Venkatram, T.W. Horst
10. Using a dispersion model to estimate emission rates of particulate matter from paved roads
    *Atmospheric Environment, Volume 33, Issue 7, March **1999**, Pages 1093-1102*
    Akula Venkatram, Dennis Fitz, Kurt Bumiller, Shuming Du, Michael Boeck, Chandragupta Ganguly

Evaluation and Application



Tracer study conducted by Caltrans during the winter of 1981-82 along a 2.5 mile section of U.S. Highway 99 in Sacramento (Benson, 1989).



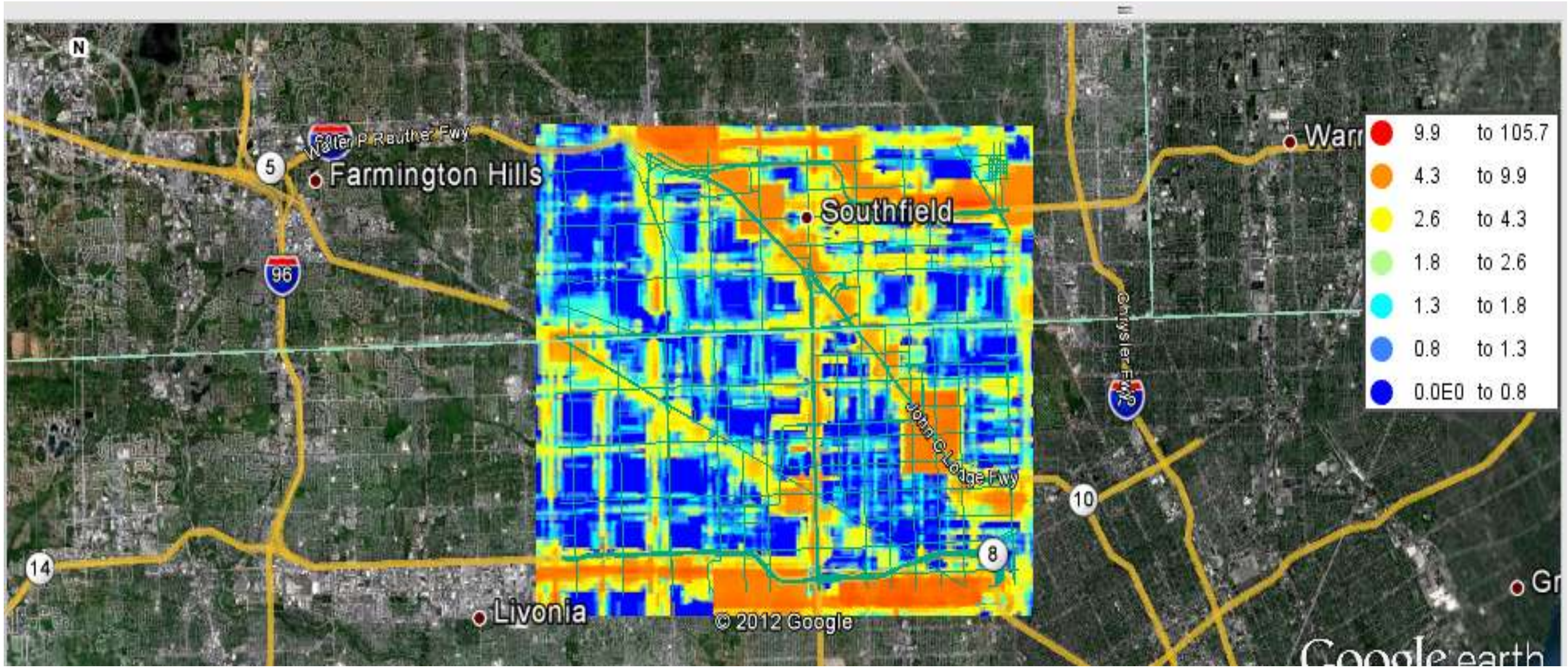
Impact of 10 lane freeway with traffic volume of 12000 cars/h

Buffer zones depend on
1. Traffic volume and composition
2. Road geometry
3. Prevailing meteorology

Application of RLINE

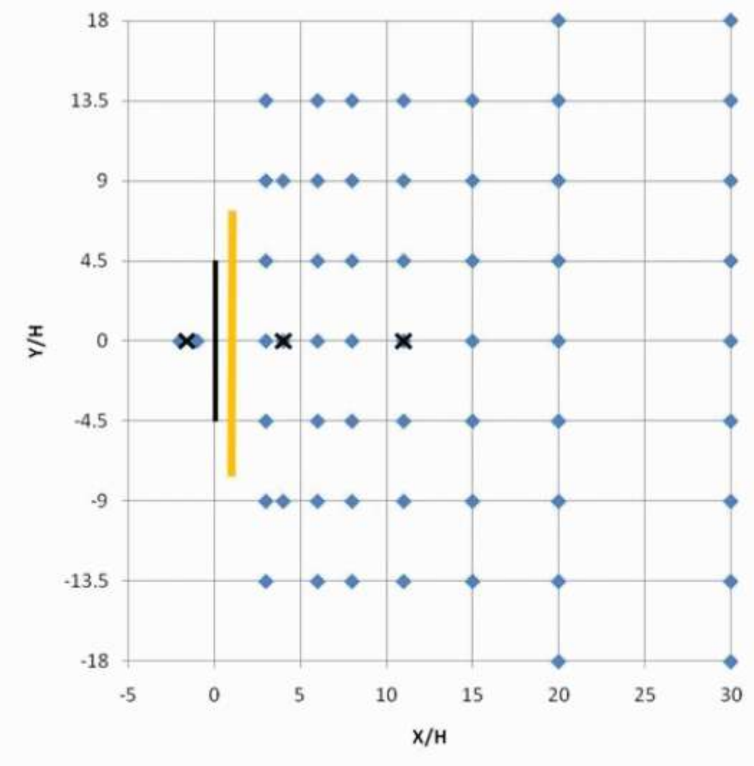
R-LINE algorithm is used in C-LINE, a decision support tool for evaluating effects of alternate transportation options on community health

EPA's C-LINE Tool



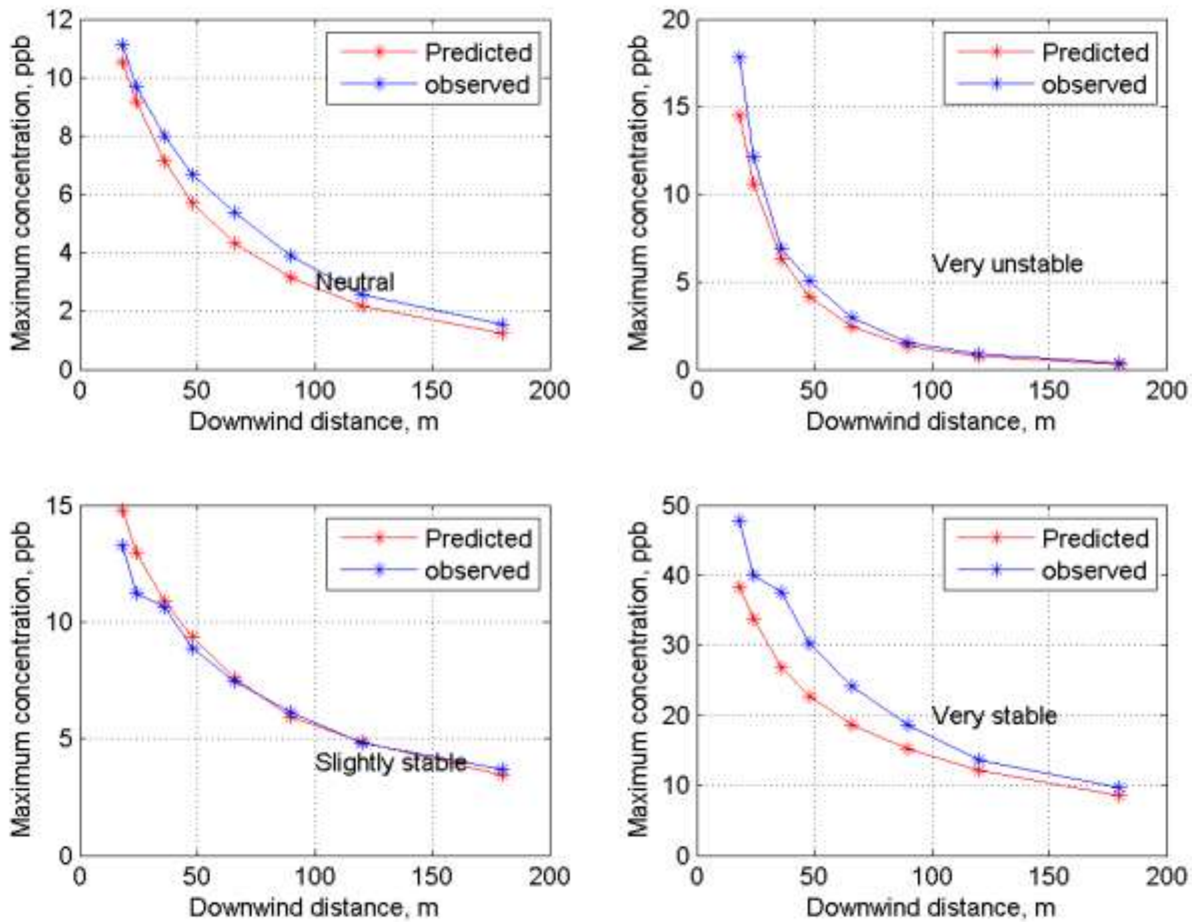
Barrier Effects-Idaho Falls Study

(Finn et al. 2010, AE, 44, 204-214)



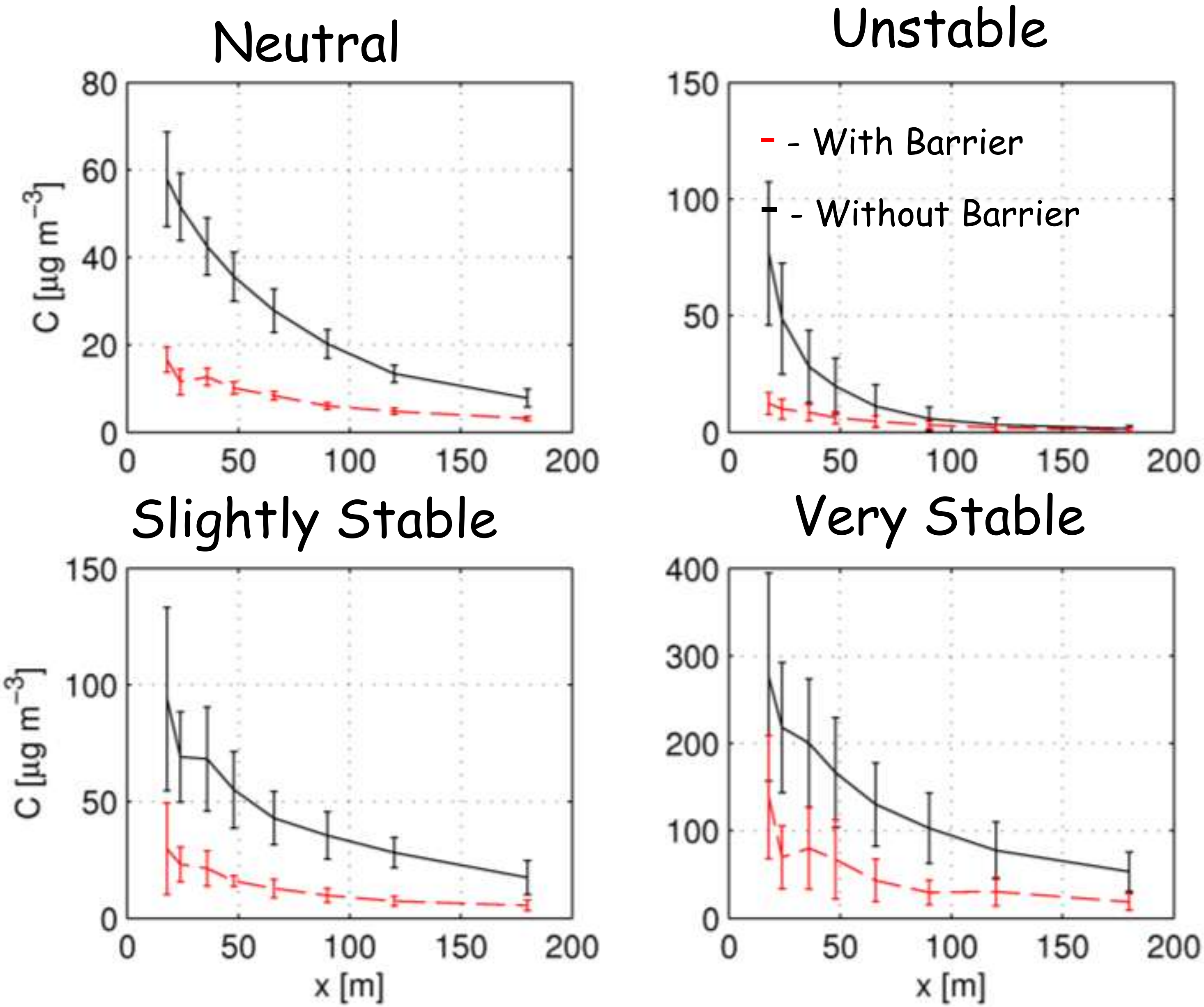
- SF_6 simultaneously released from two sources
- Concentrations measured at 56 receptors
- Spanned neutral, unstable, and stable conditions

Idaho Falls Flat Terrain



Idaho Falls Study

(Finn et al. 2010, AE, 44, 204-214)



Effects of Barriers on Concentrations

(Finn et al. 2010, AE, 44, 204-214)

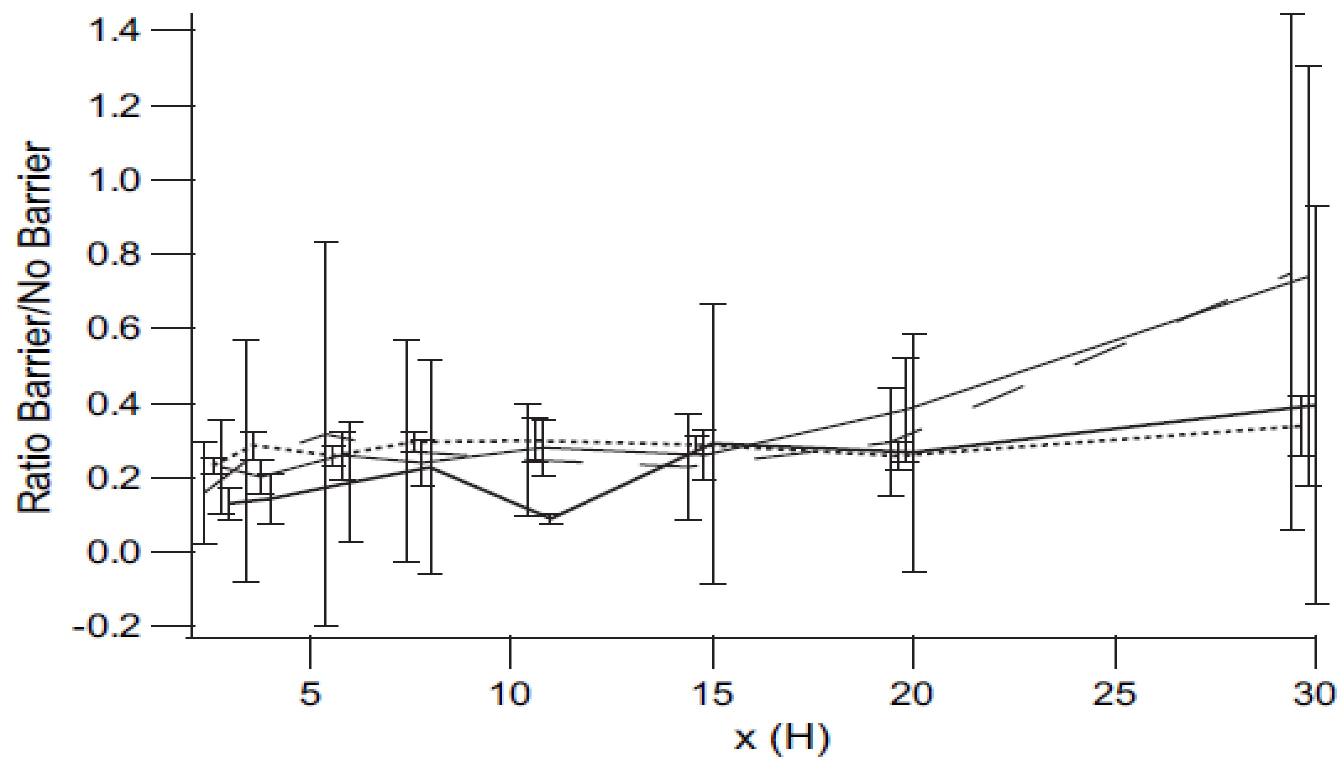
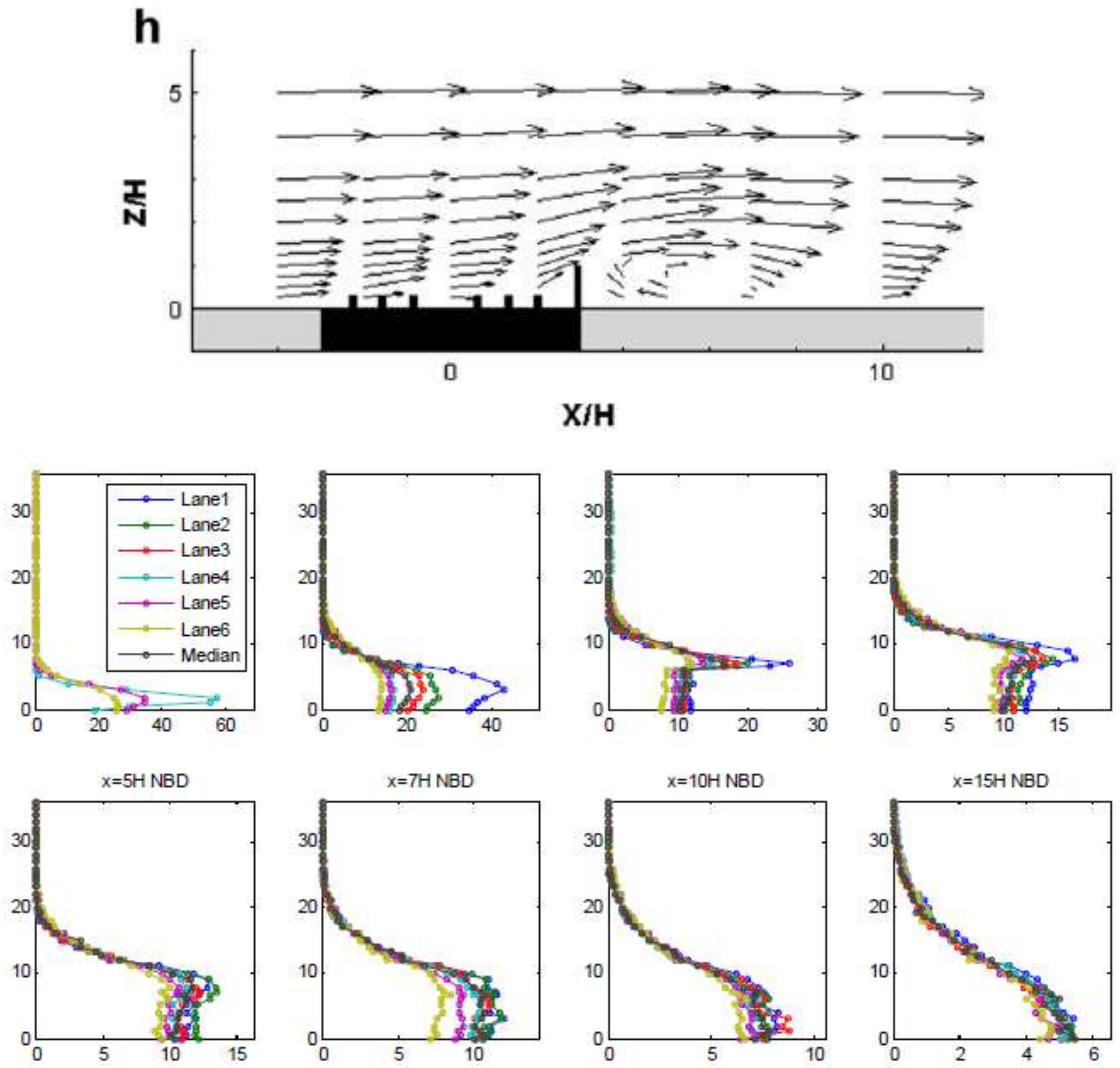


Fig. 9. Mean barrier/non-barrier normalized centerline concentration ratios for qualifying periods: unstable, bold; neutral, solid; weakly stable, dotted; stable, dashed. Error bars are standard deviations.

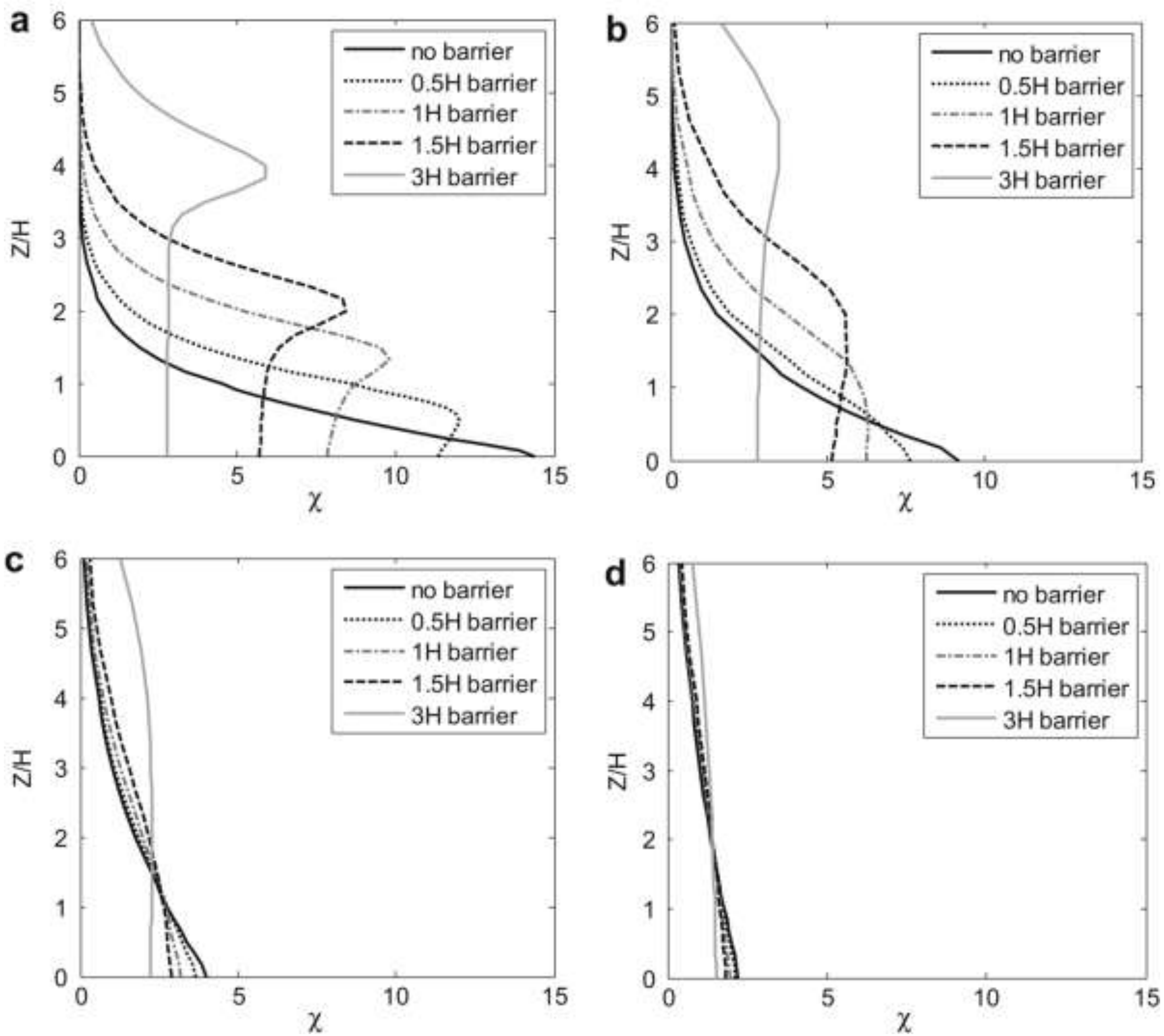
Barrier Effects

Wind Tunnel Results (Heist et al, AE, 43, 5101-5111)



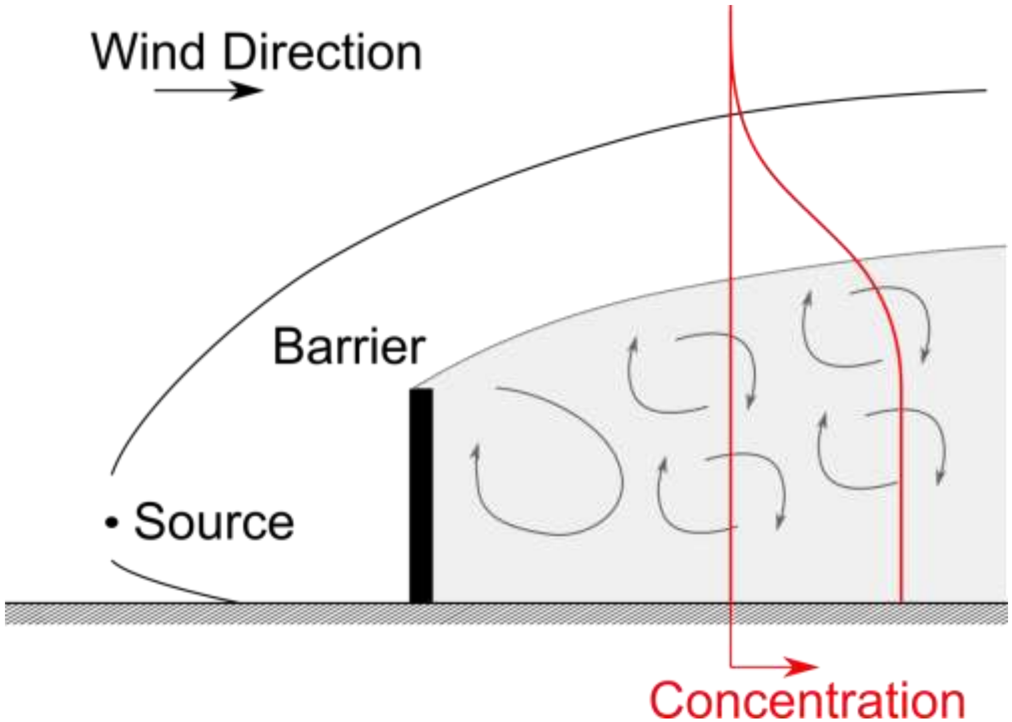
Barrier Effects CFD Simulation

(Hagler et al., 2011, AE, 45, 2522-30)



Mixed Wake Model

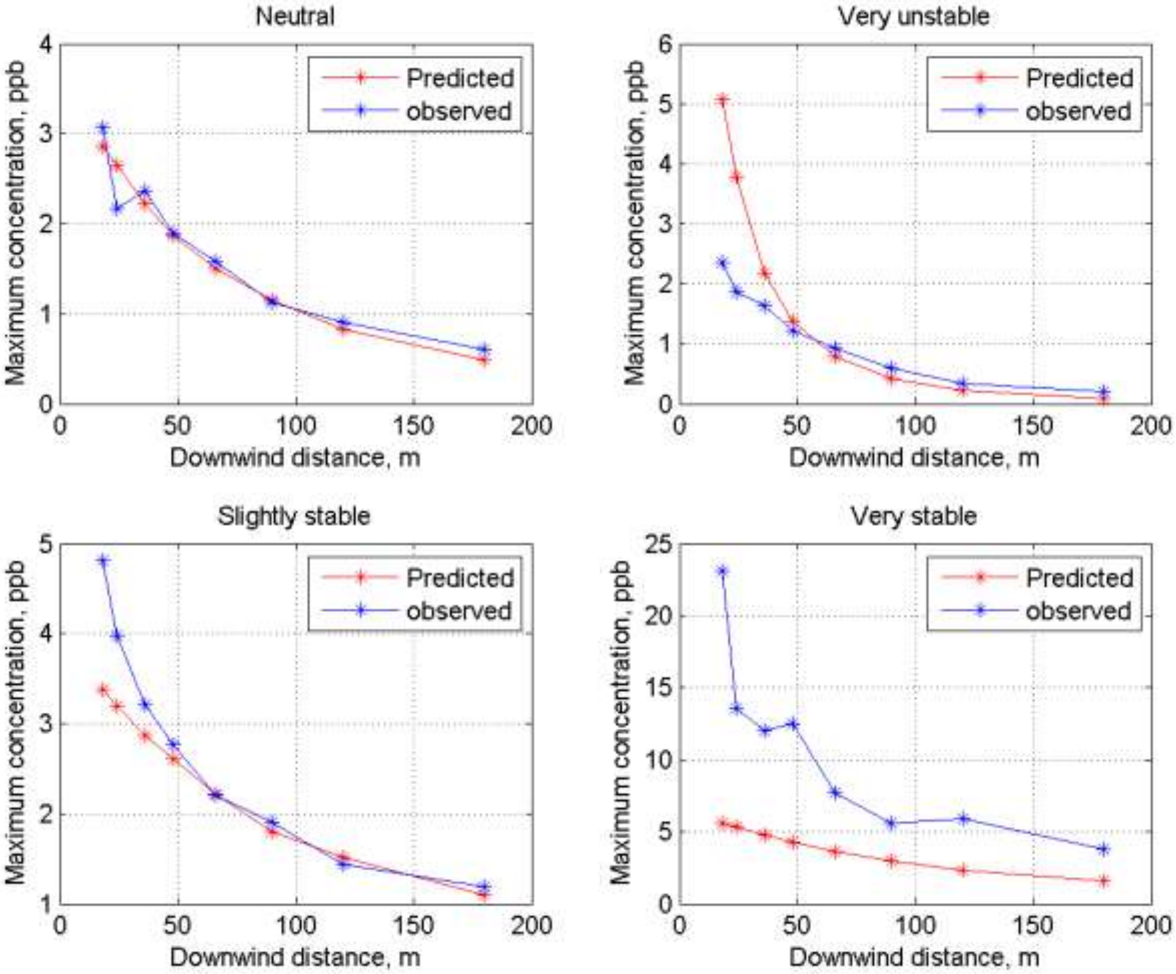
(Schulte and Venkatram, 2013, Harmo 15, May 6-9,Madrid, Spain)



- Concentration is <u>well mixed</u> over the height of the barrier, *H*
- <u>Vertical plume spread increased</u> by a factor α

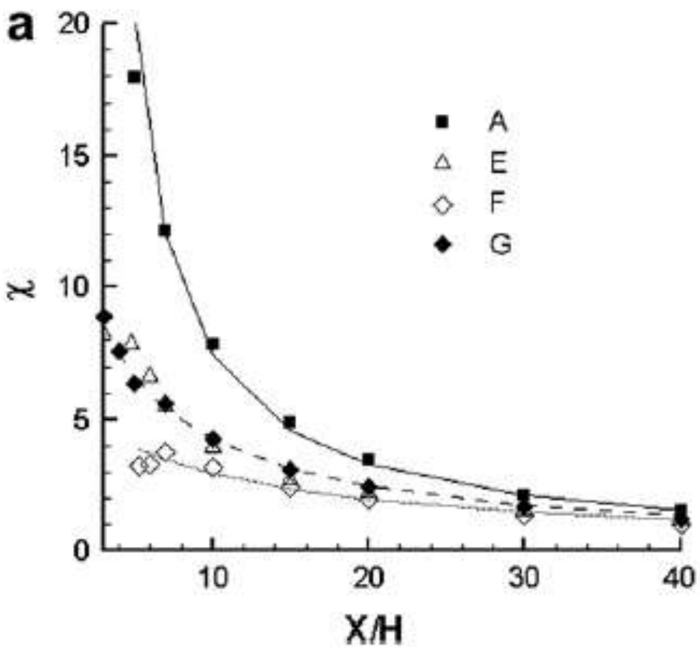
$$U\sigma_{zbarrier}(x) = U(z_{eff})\alpha\sigma_z(x) + U\left(\frac{H}{2}\right)\gamma\sqrt{\frac{\pi}{2}}H$$

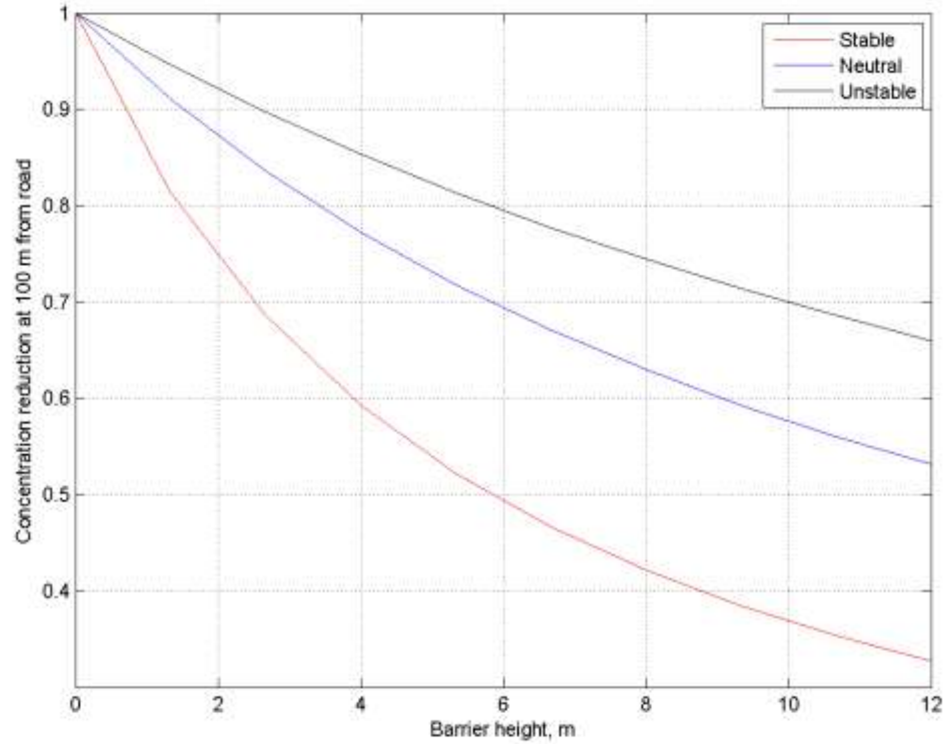
Idaho Falls with Barrier



Barrier Shifts the Source Upwind

(Heist et al, 2009,AE, 43, 5101-5111)





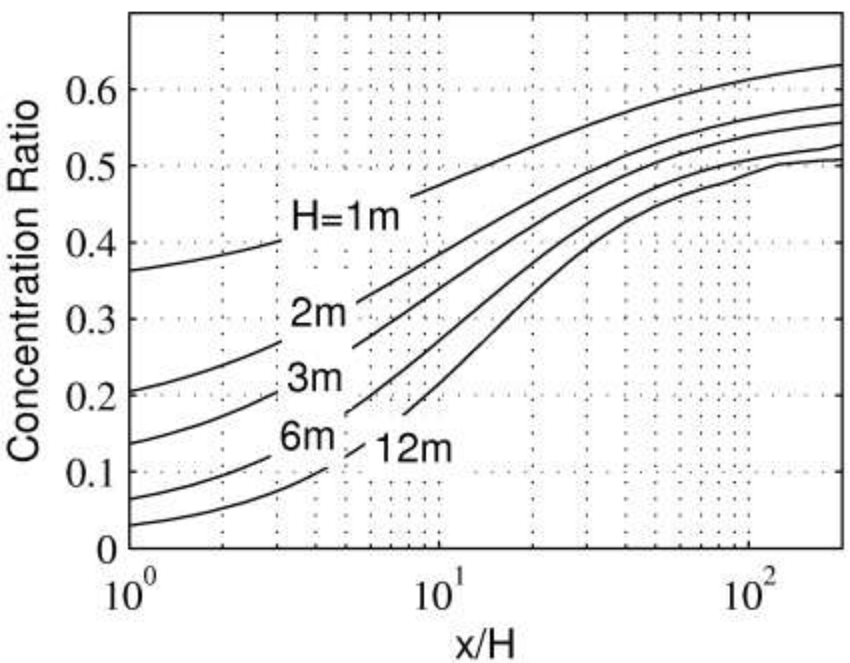
$$x_{eff} = h_0 \frac{U}{\sigma_w} + d$$

Barrier induced spread

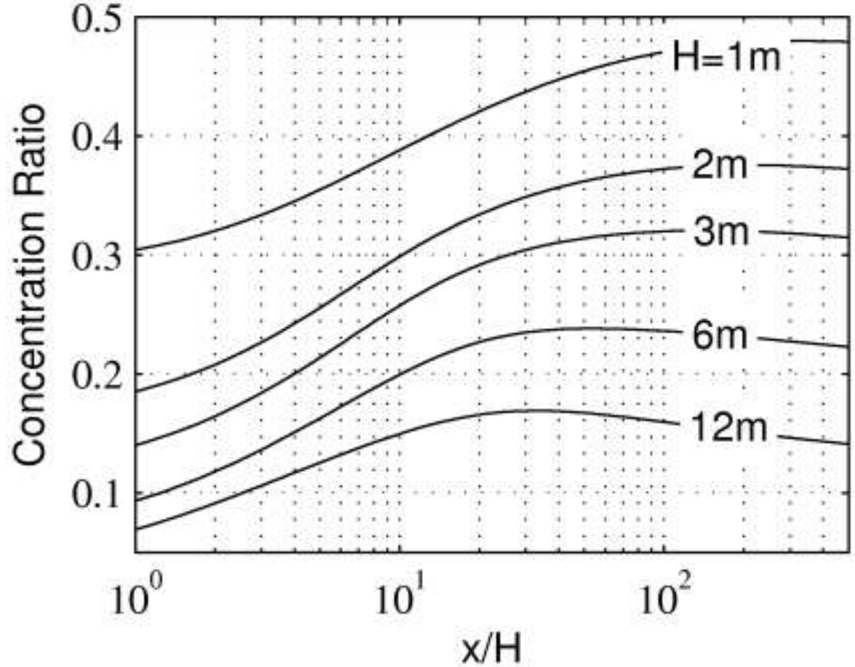
Atmospheric turbulence

Sensitivity to Barrier Height

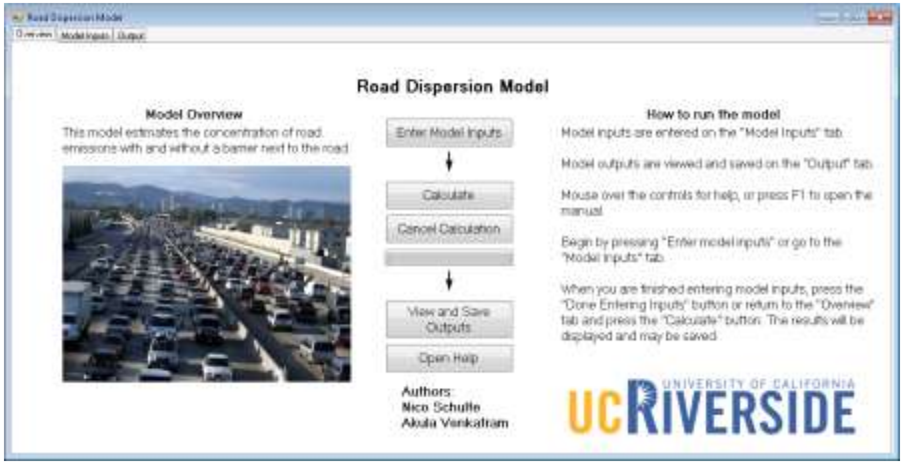
Unstable

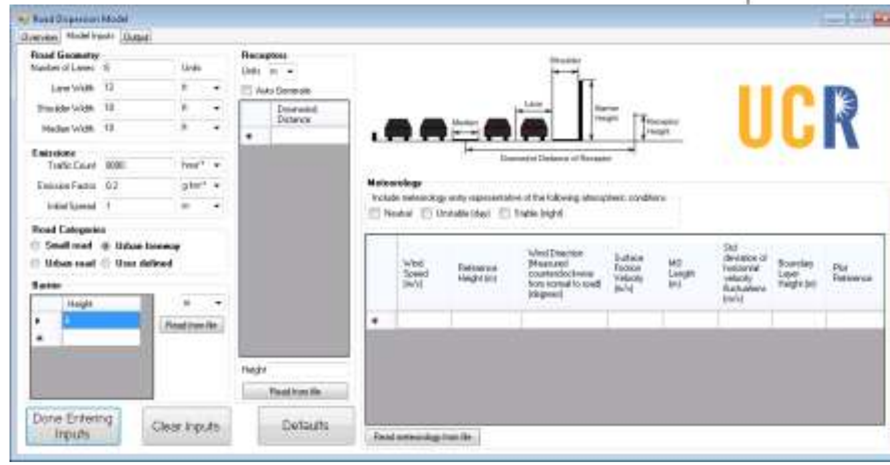


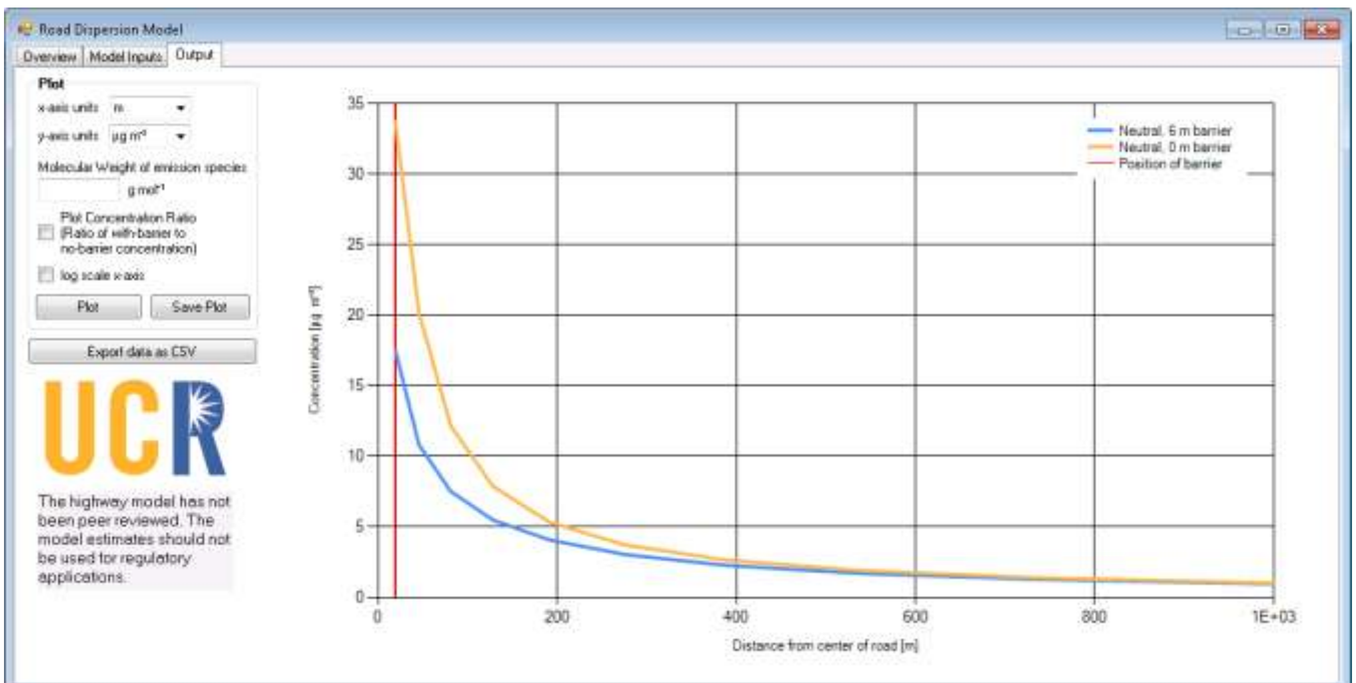
Stable



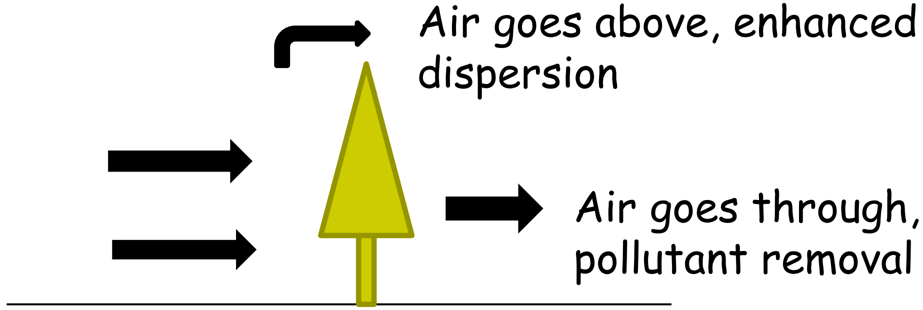
Windows Based Dispersion Model







Vegetative Barriers



Increasing deposition by increasing barrier thickness reduces flow through barrier and increases dispersion

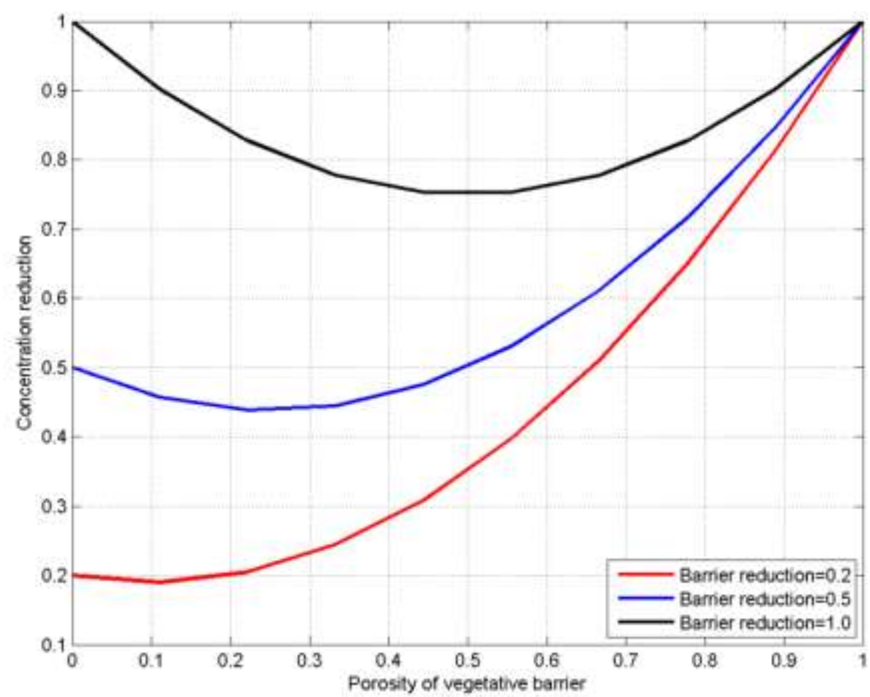
$$p = \exp\left(-\alpha X_{vegetation}\right)$$

$$r_{vegetation} = \left(1 - p^{n}\right) r_{barrier} + p^{1+n}$$

Vegetation can be beneficial in combination with solid barriers

Field studies are *inconclusive*

(Hagler et al., 2012, Sci. Tot. Environ., 419, 7-15)



Summary

- Sound walls reduce near-road exposure by enhancing vertical dispersion. Enhancement is proportional to barrier height.
  - Gaps: Low wind speeds, stable conditions, vehicle induced turbulence, vertical concentration distribution
- Vegetative barriers can be effective in combination with solid barriers. Models are preliminary. Need field studies to obtain better data.

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Funding Agencies:

- South Coast Air Quality Management District
- USEPA
- California Air Resources Board

Back to Agenda

UCR

Near Field Effects of Sound Barriers on Flow and Dispersion

Marko Princevac

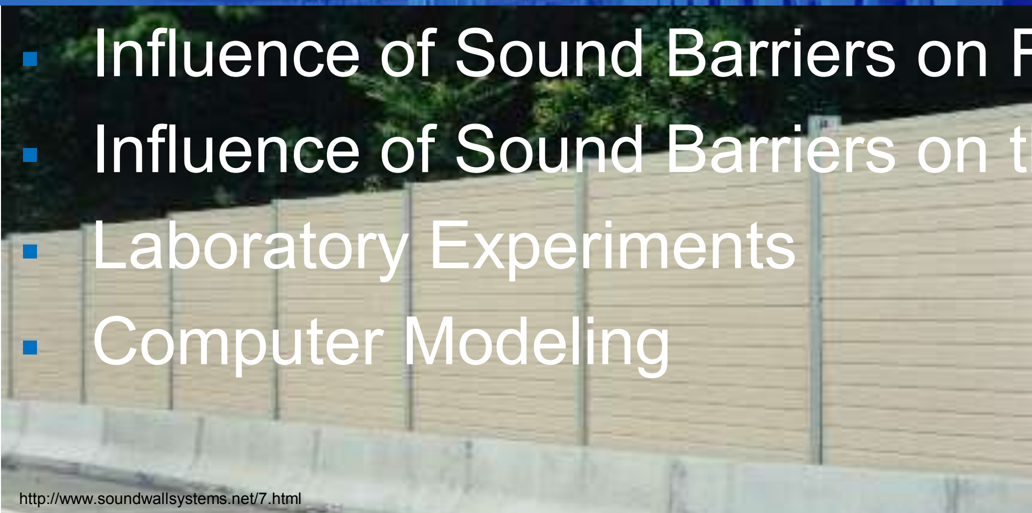
Brandn Gazzolo, Sam Pournazeri, Matti Azard, Trevor Brown, Raul-Delga Delgadillo, Trent Nash, Senyeung Shu

Total Project Cost to SCAQMD: $43,586

Introduction

UCR

- Influence of Sound Barriers on Flow
- Influence of Sound Barriers on the Dispersion of Pollutants
- Laboratory Experiments
- Computer Modeling



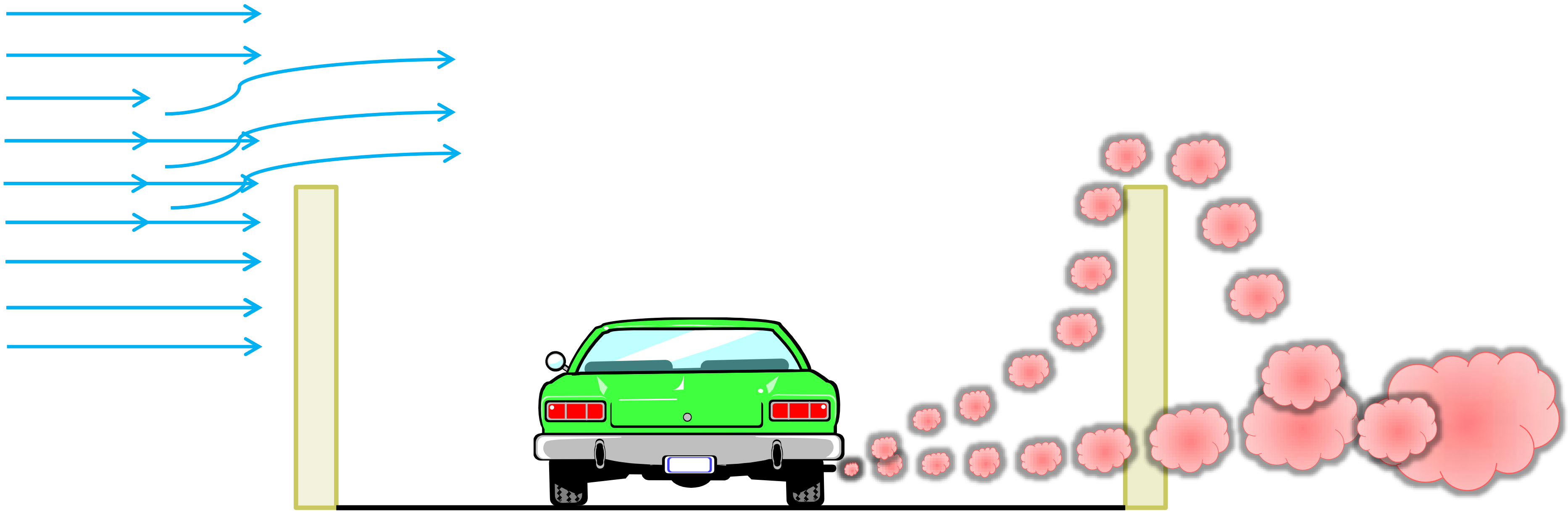
http://www.soundwallsystems.net/7.html

http://www.aaroads.com/forum/index.php?topic=2967.0

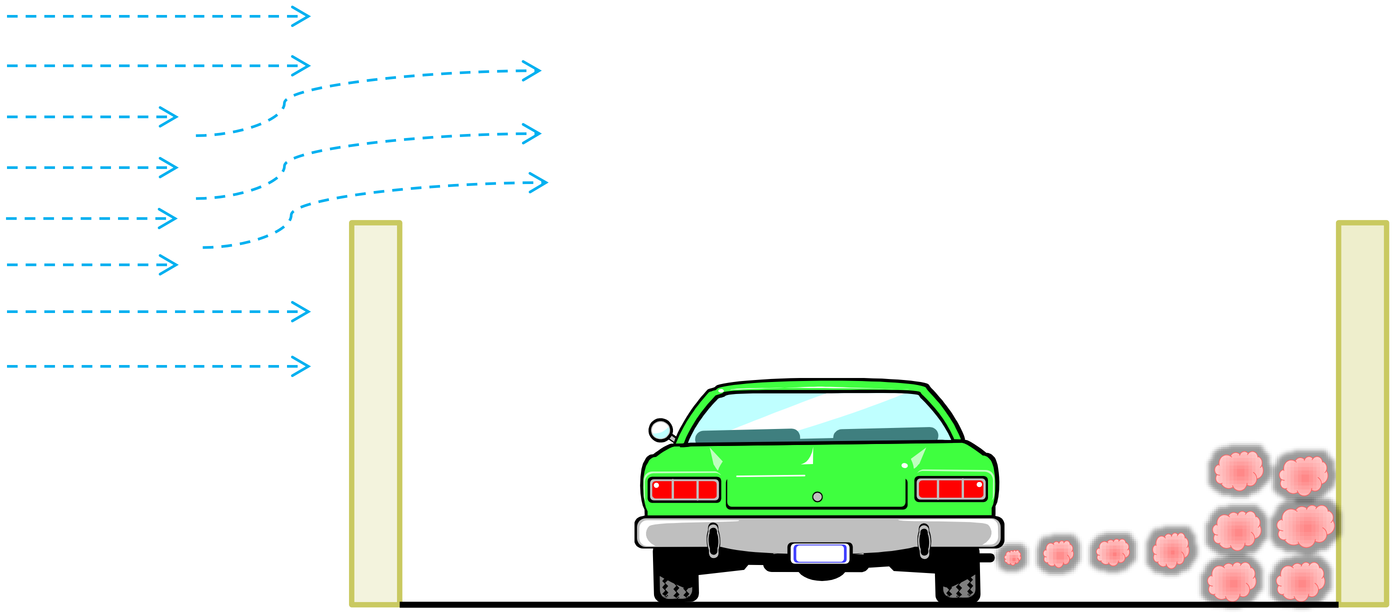
http://www.avtinc.net/barrier_walls/highway_barriers.html

http://www.gettyimages.com/detail/200171389-001/Photographers-Choice

Background

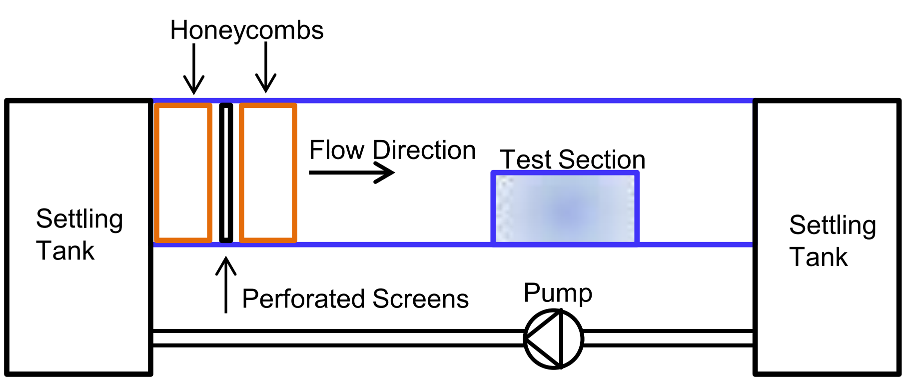


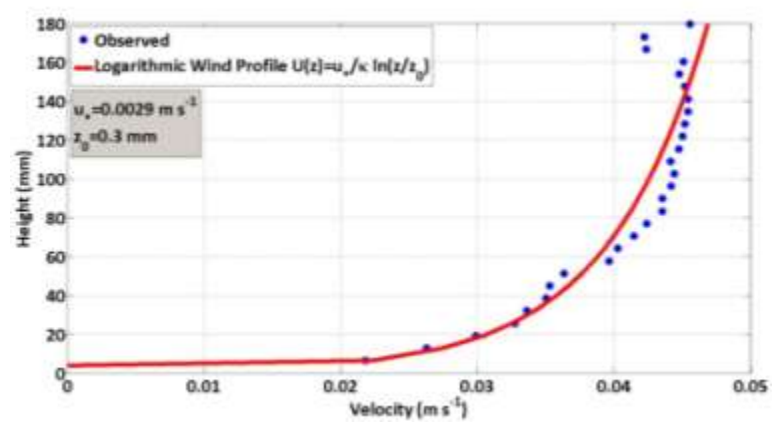
Background



Laboratory

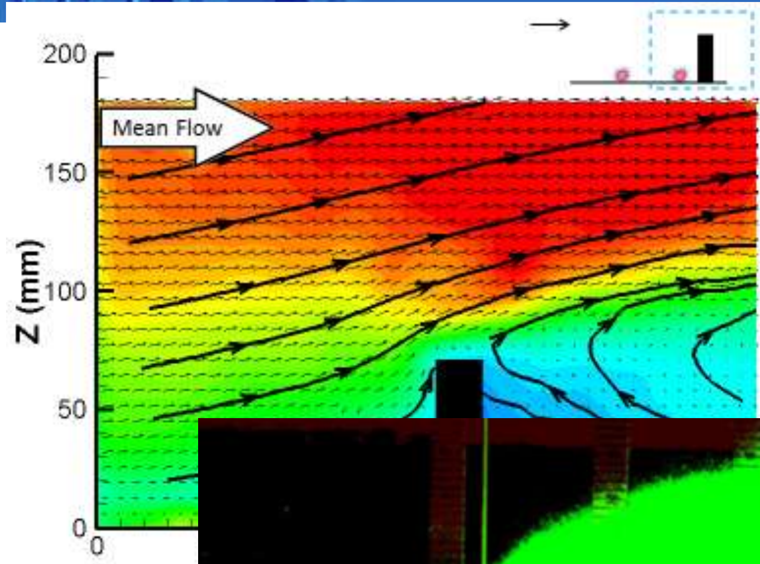
- Laboratory for Environmental Flow Modeling (LEFM)



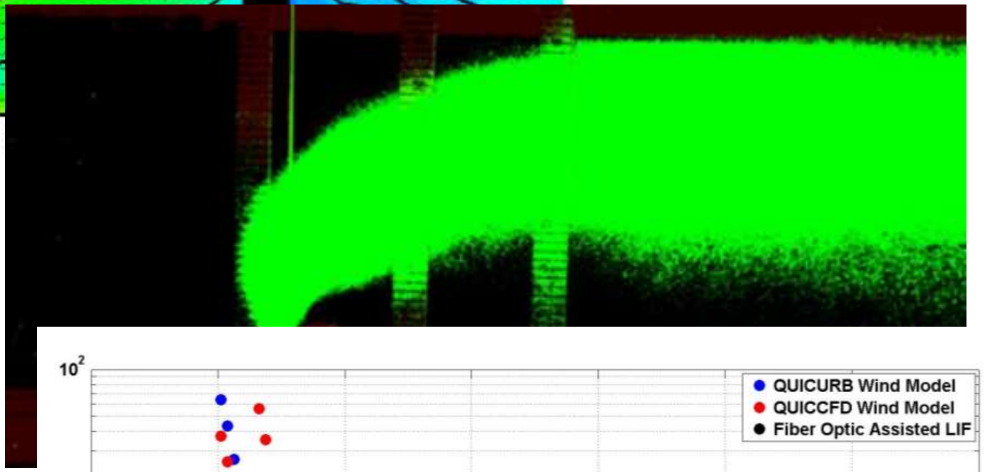


Experimental Products

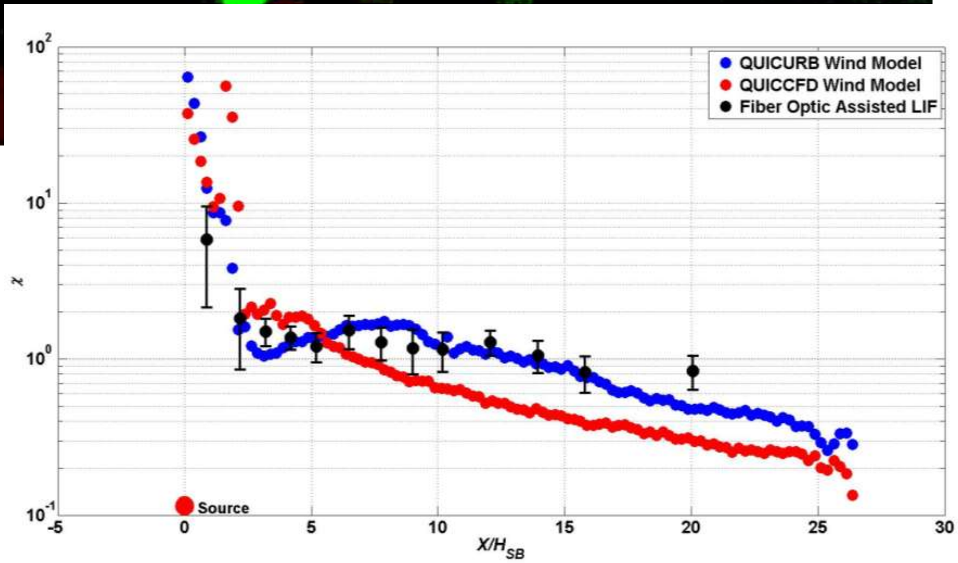
- Velocity Fields



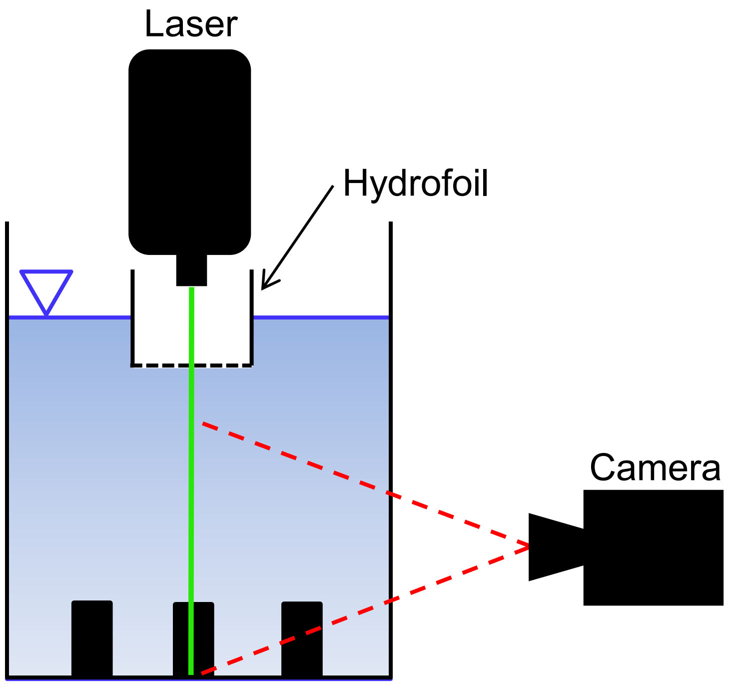
- Plume Visualizations



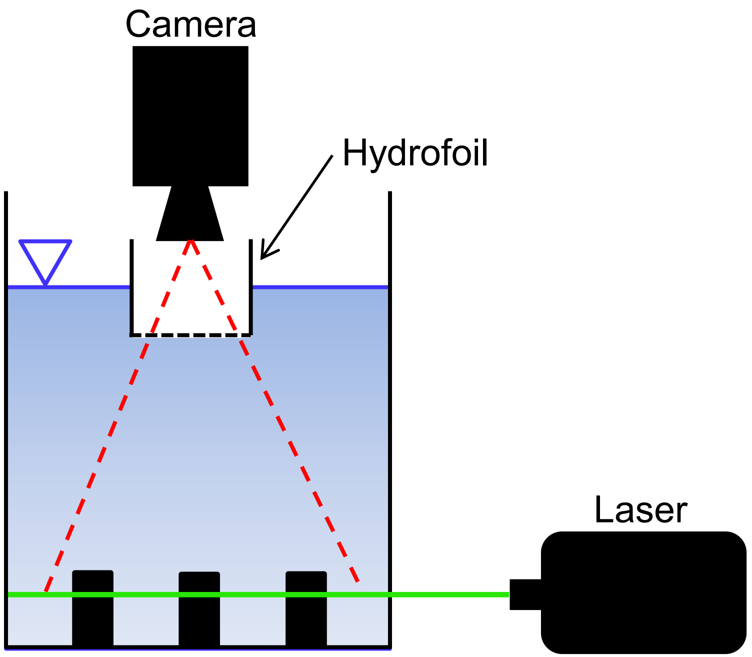
- Plume Concentration



Particle Image Velocimetry

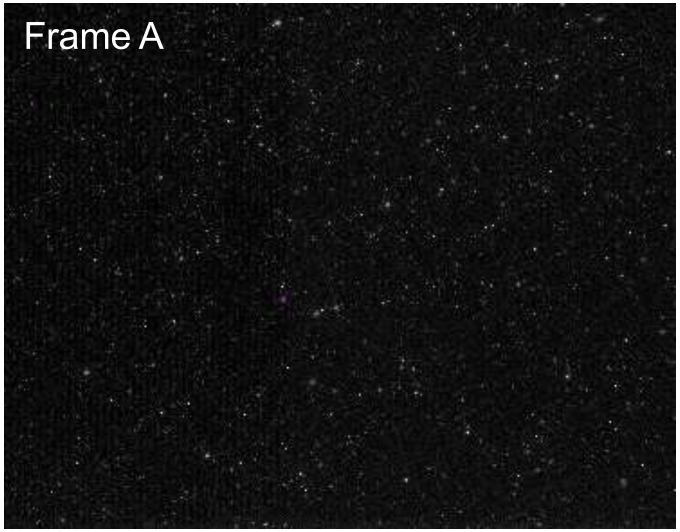


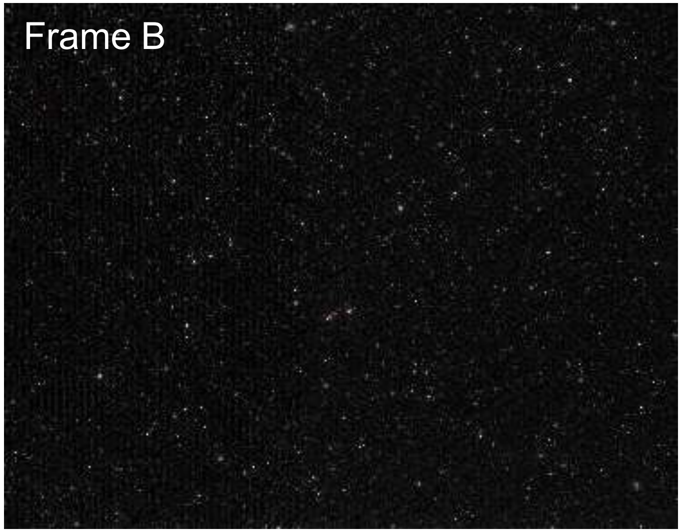
Vertical Plane

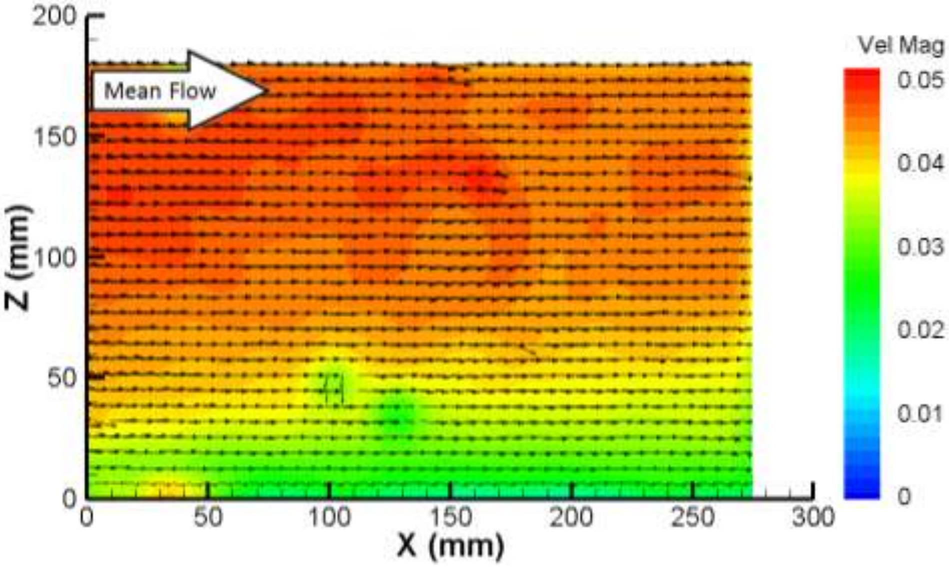


Horizontal Plane

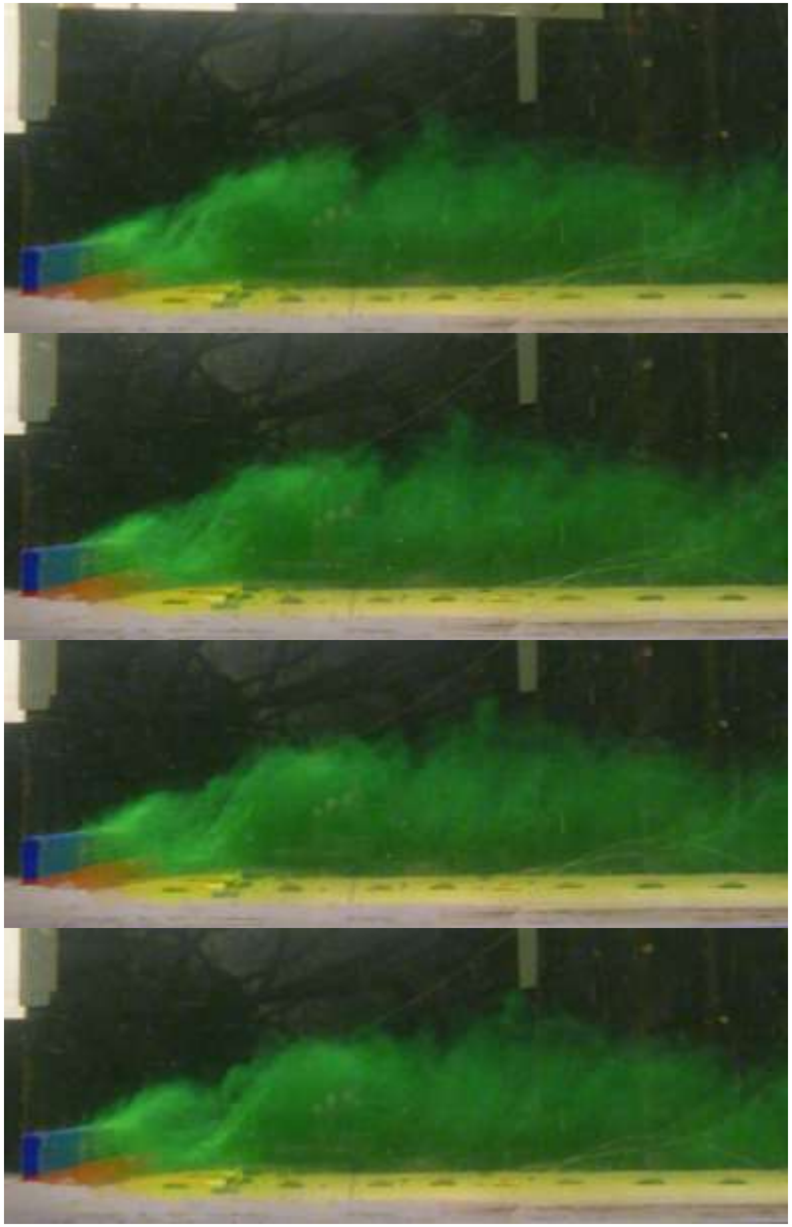
Particle Image Velocimetry

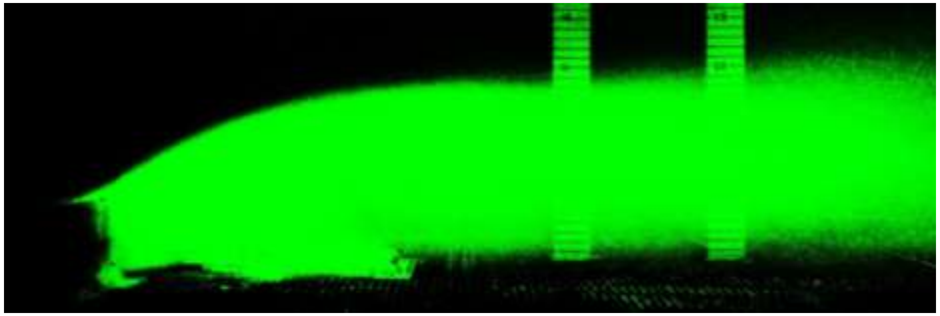






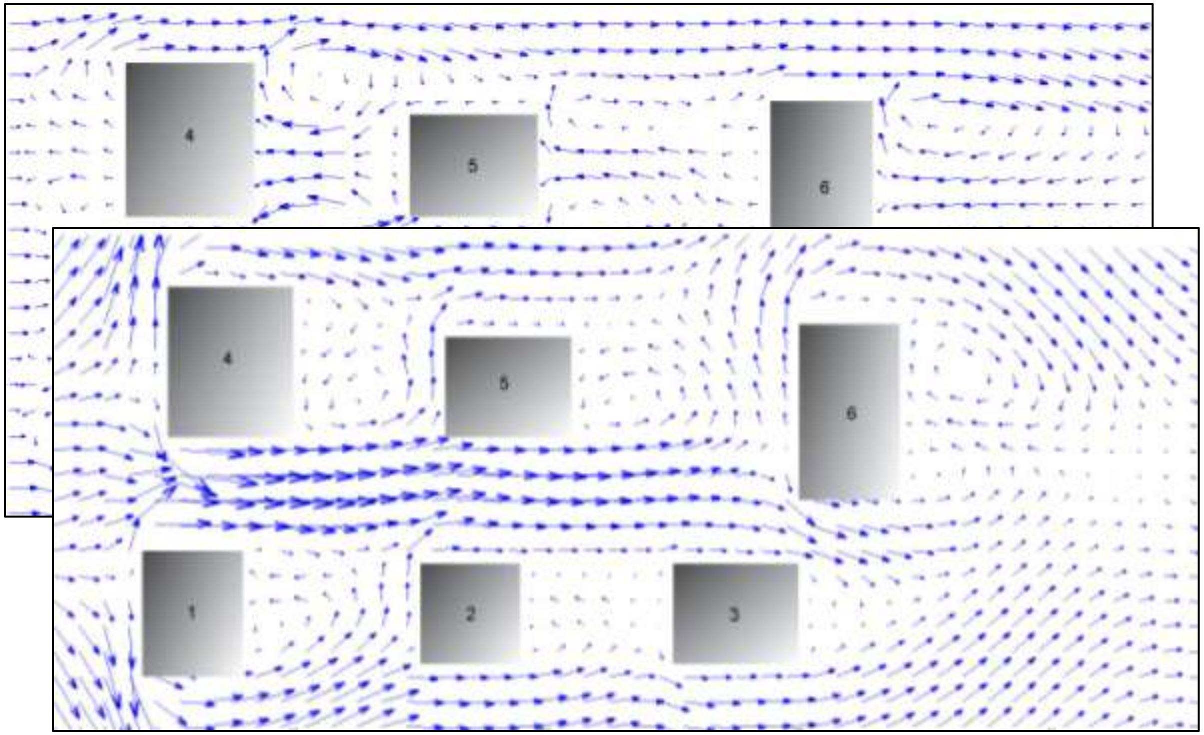
Visualizations





Numerical Modeling Efforts

- Quick Urban and Industrial Complex (QUIC)
  - QUIC URB
  - QUIC CFD

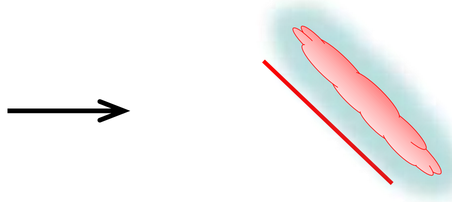


- Simple Gaussian (US EPA AERMOD type model – not part of the contract)

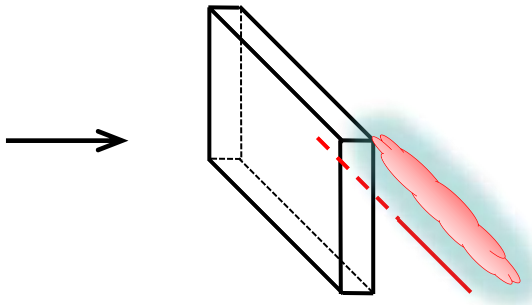
$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[exp\left(-\frac{(z-h_e)^2}{2\sigma_z^2}\right) + exp\left(-\frac{(z+h_e)^2}{2\sigma_z^2}\right)\right]$$

Roadway Configurations

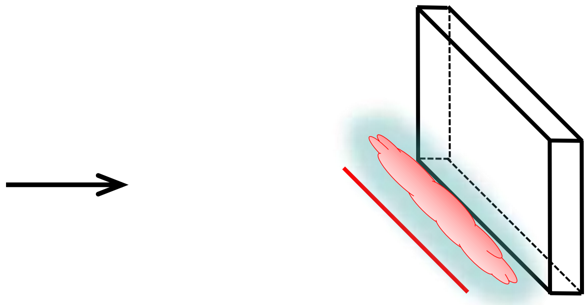
No Sound Barriers



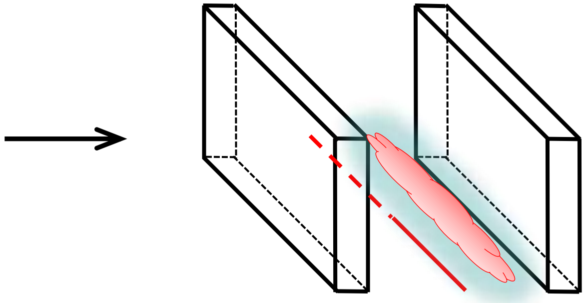
Upwind Only Sound Barrier



Downwind Only Sound Barrier

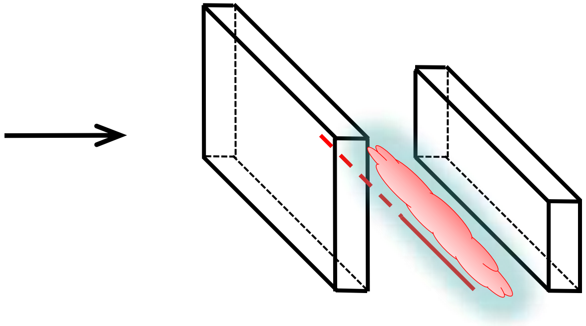


$H_{up} = H_{down}$

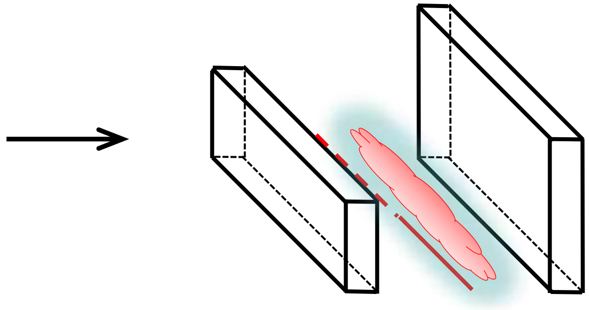


Roadway Configurations

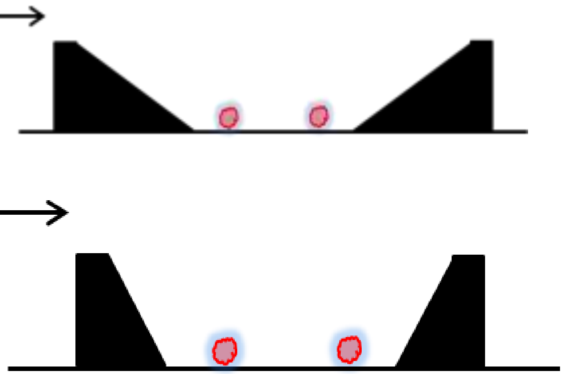
$H_{up} = 2\,H_{down}$



$H_{down} = 2\,H_{up}$



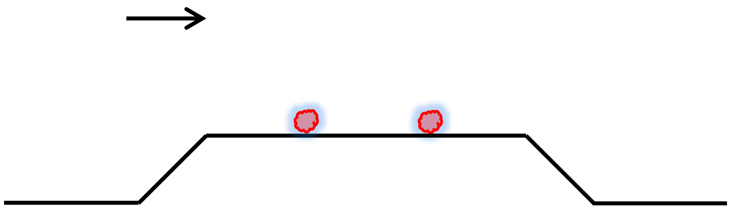
Inclined Barriers

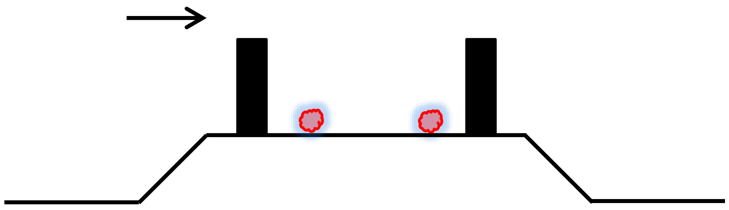


Roadway Configurations

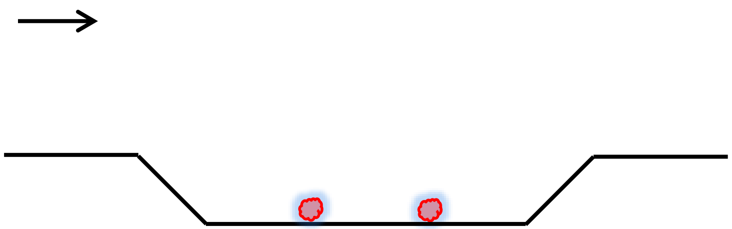
UCR

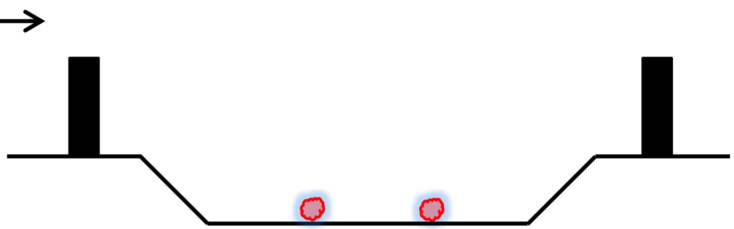
Raised Roadways



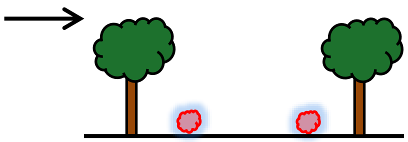


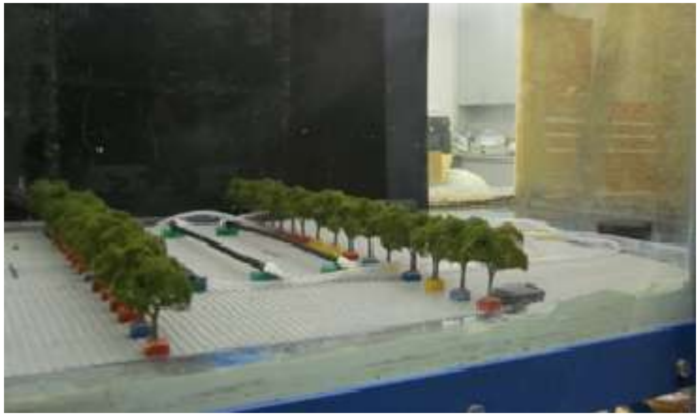
Sunken Roadways





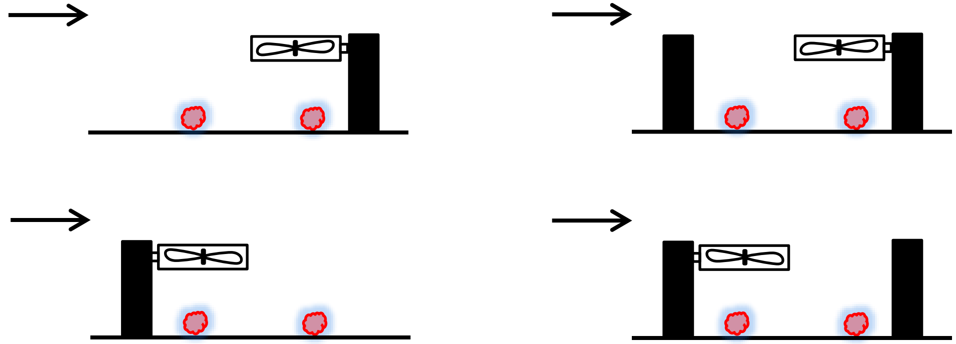
Roadways with Trees





Roadway Configurations

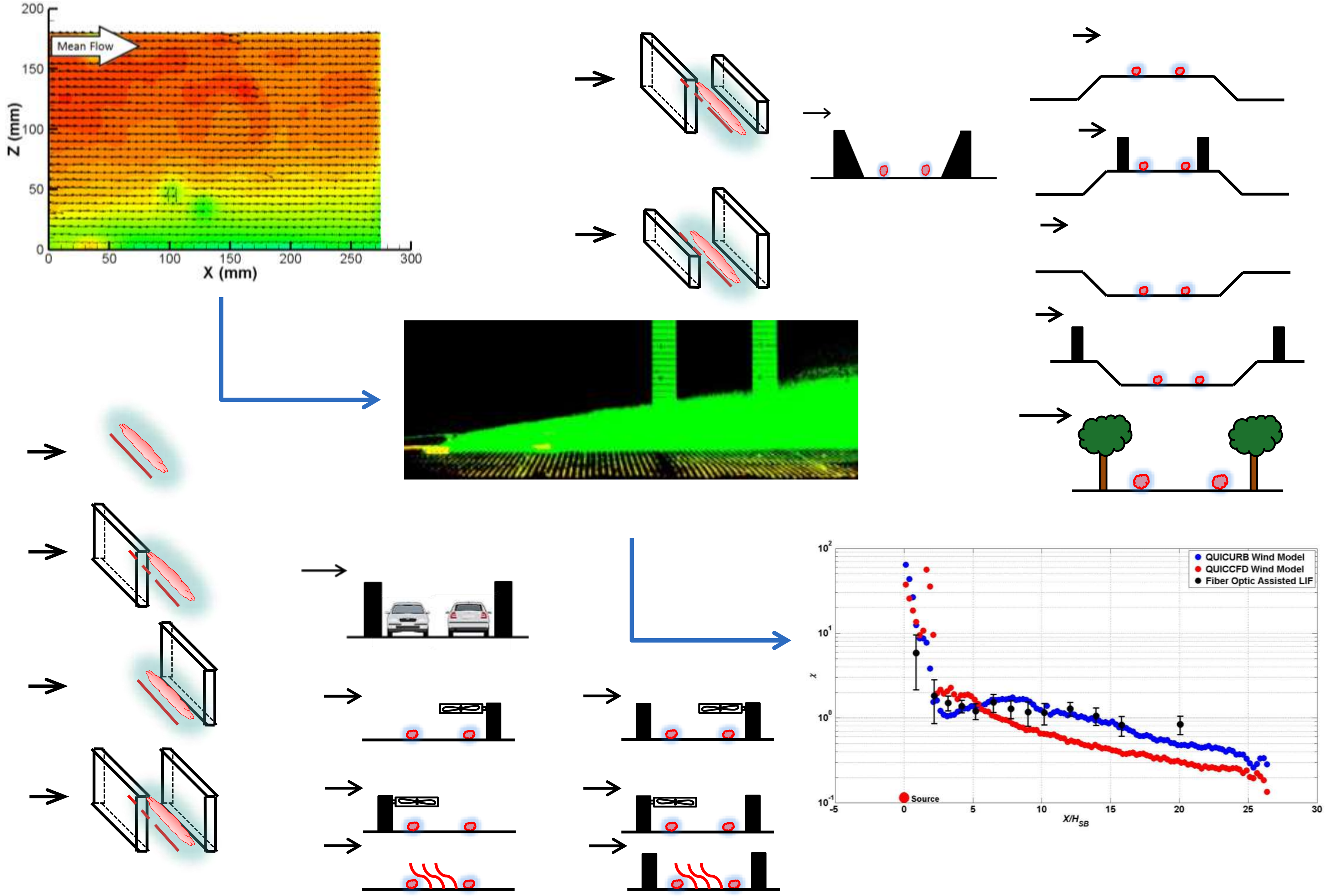
Roadways with Fans



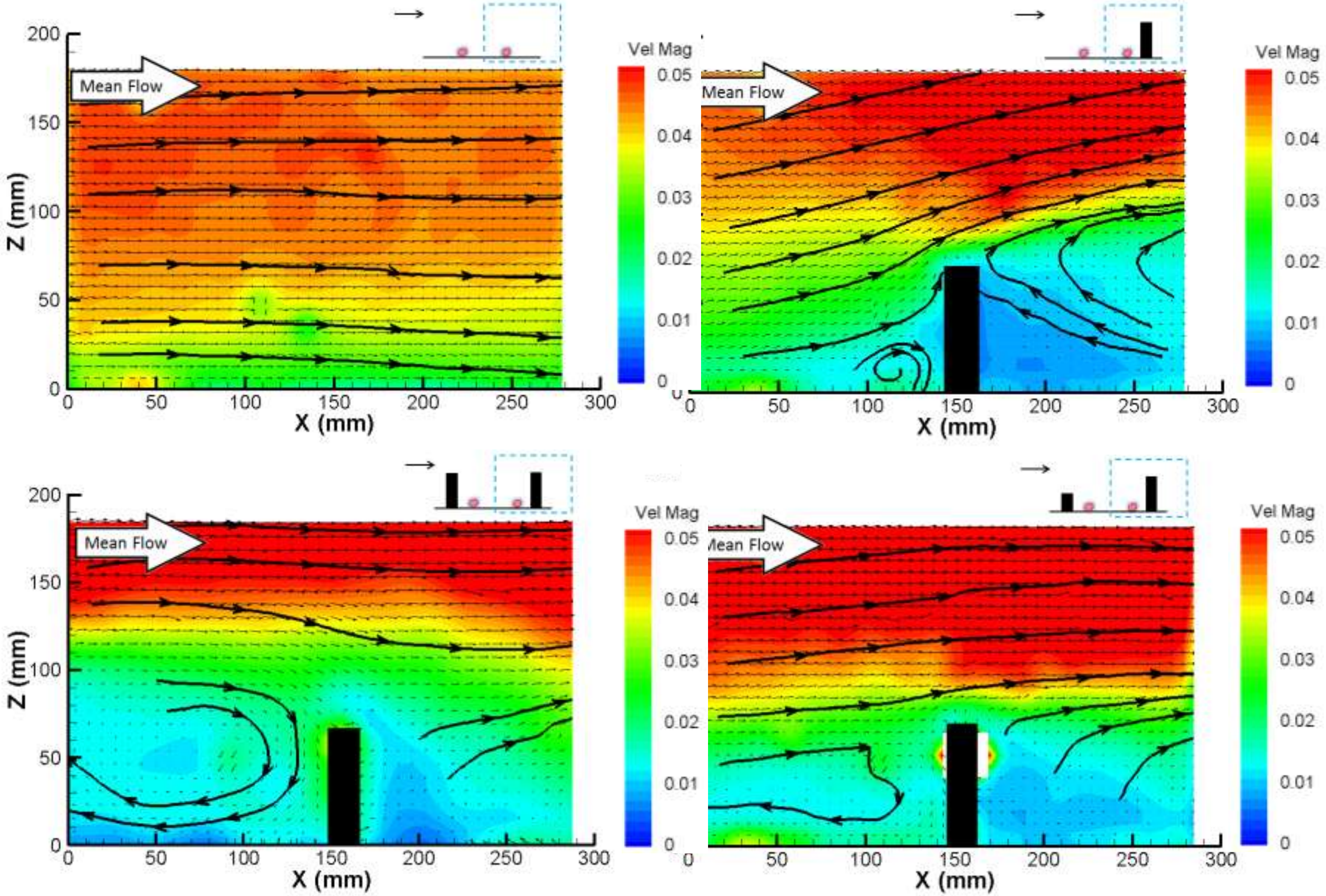
Ground Heating

Traffic Induced Turbulence

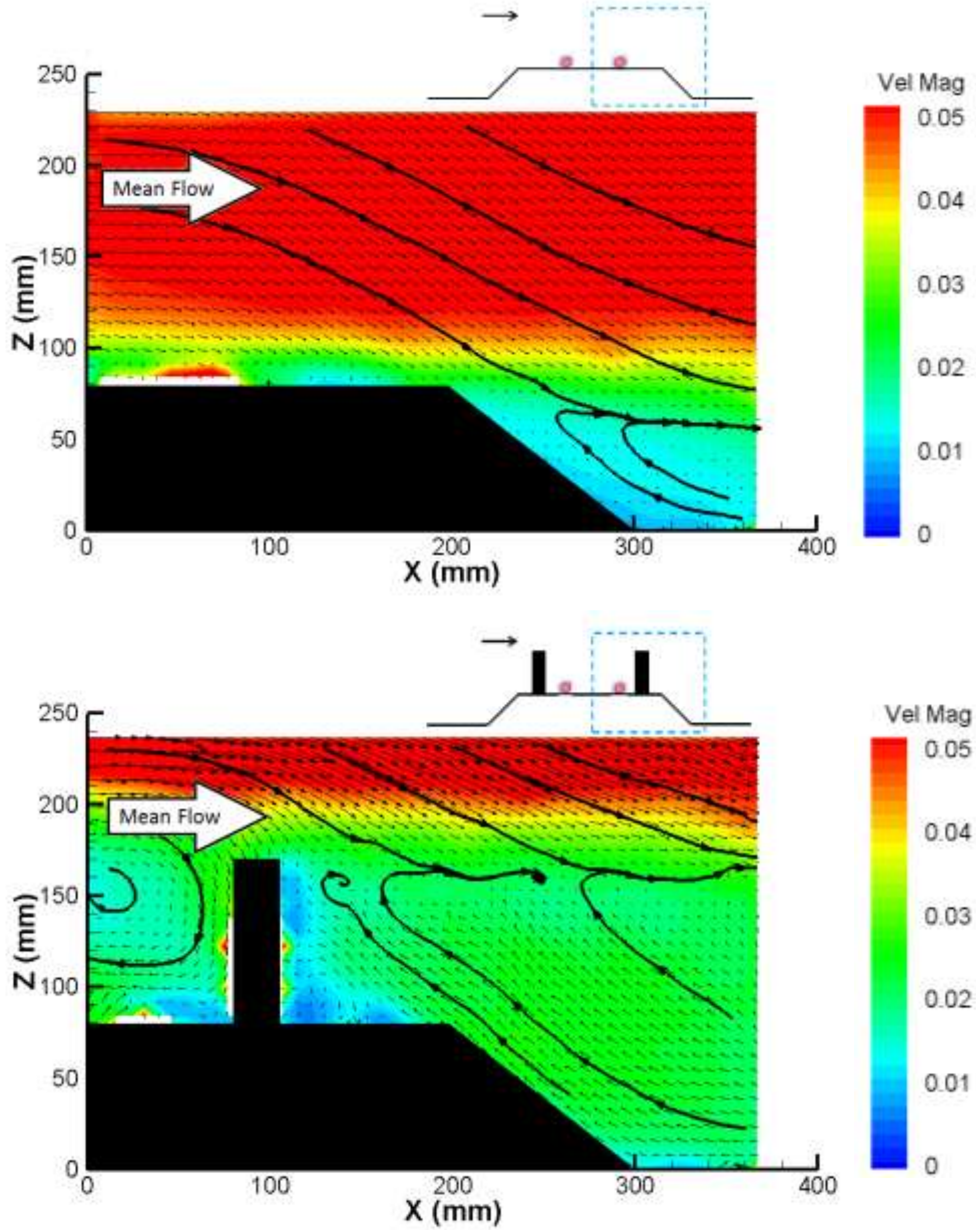
Experimental Procedure



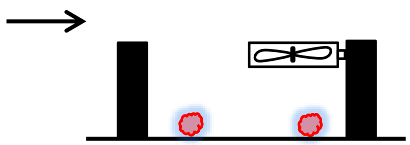
Velocity (PIV) Results

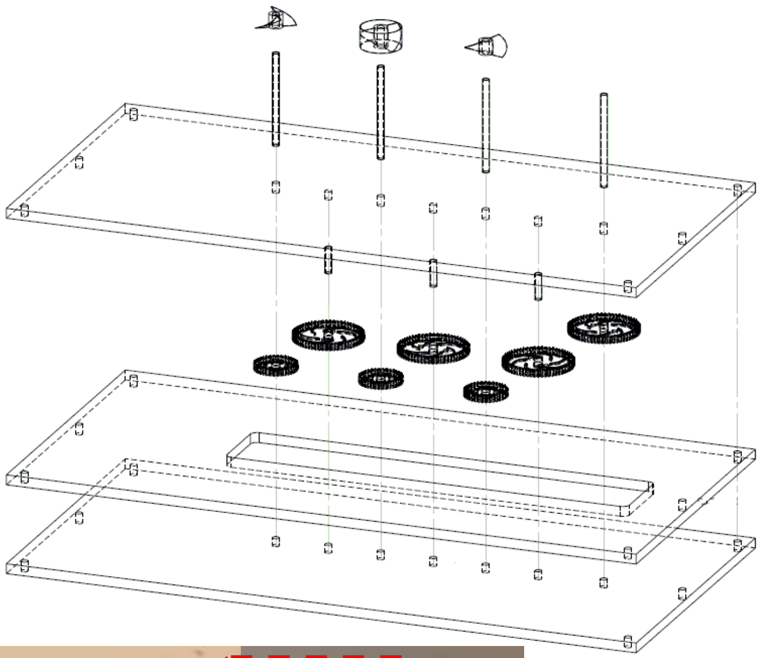


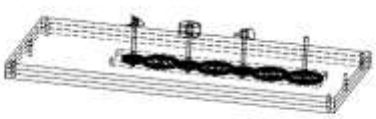
Velocity (PIV) Results

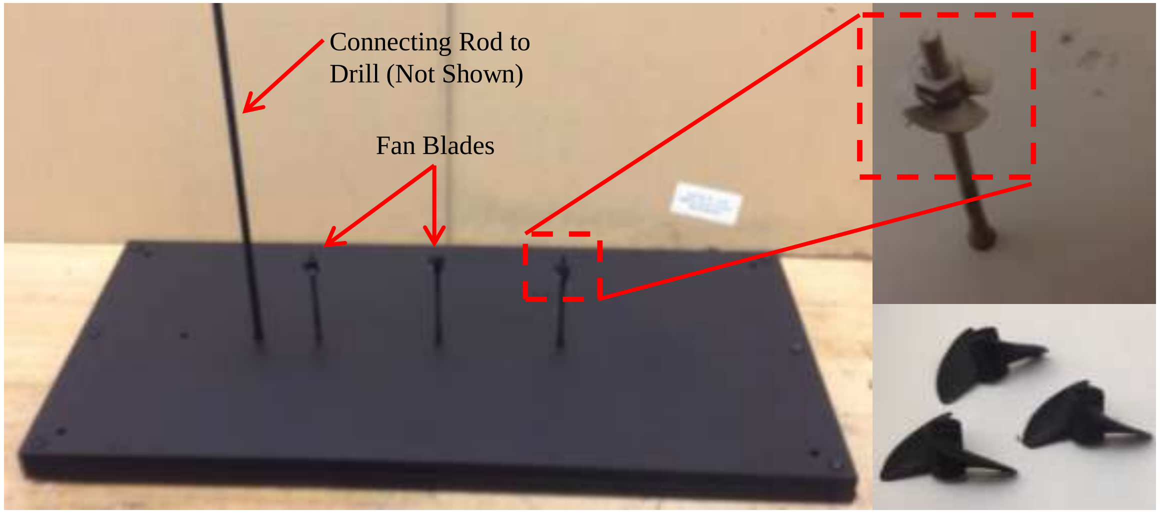


Active Ventilation Setup

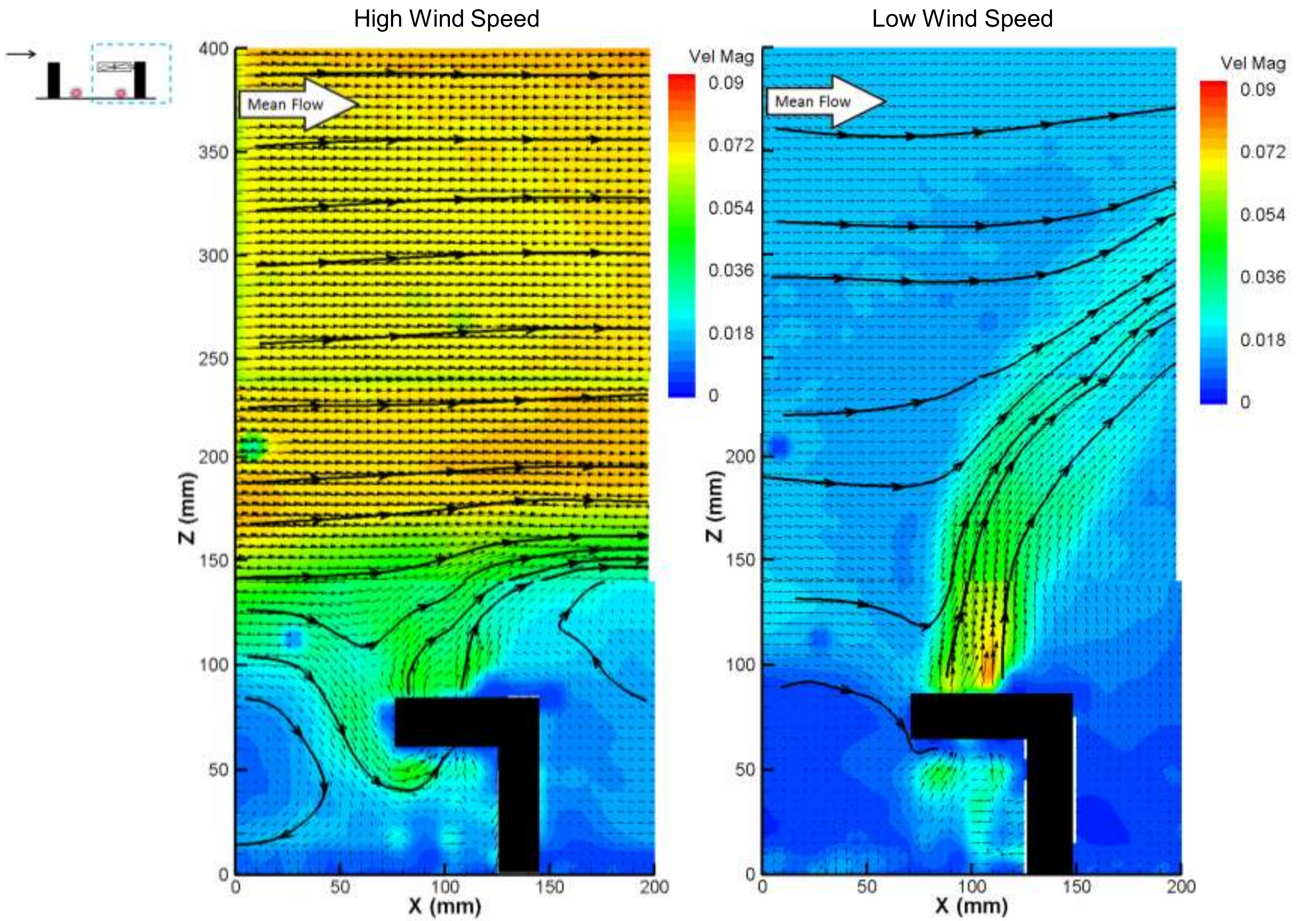




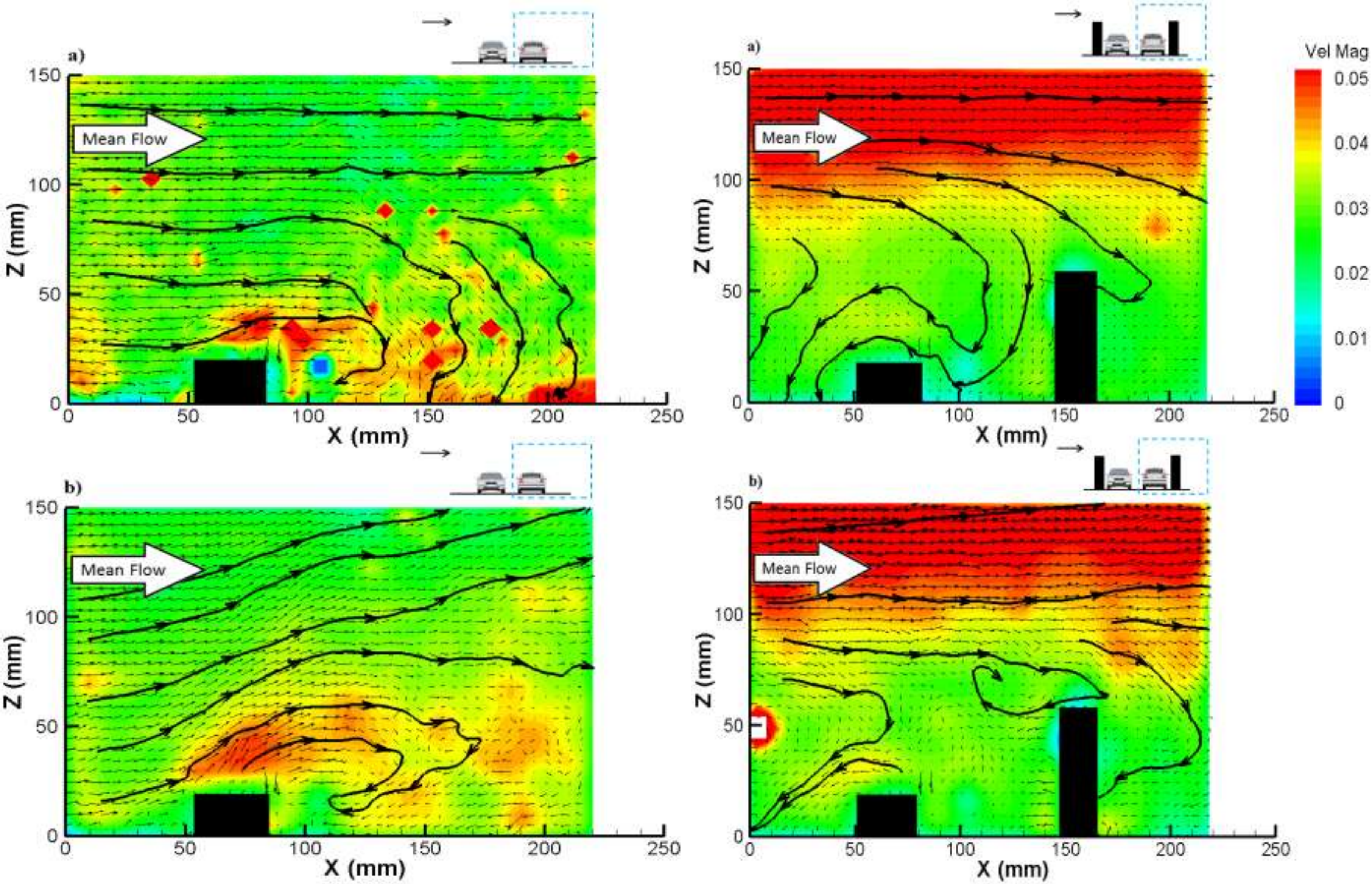




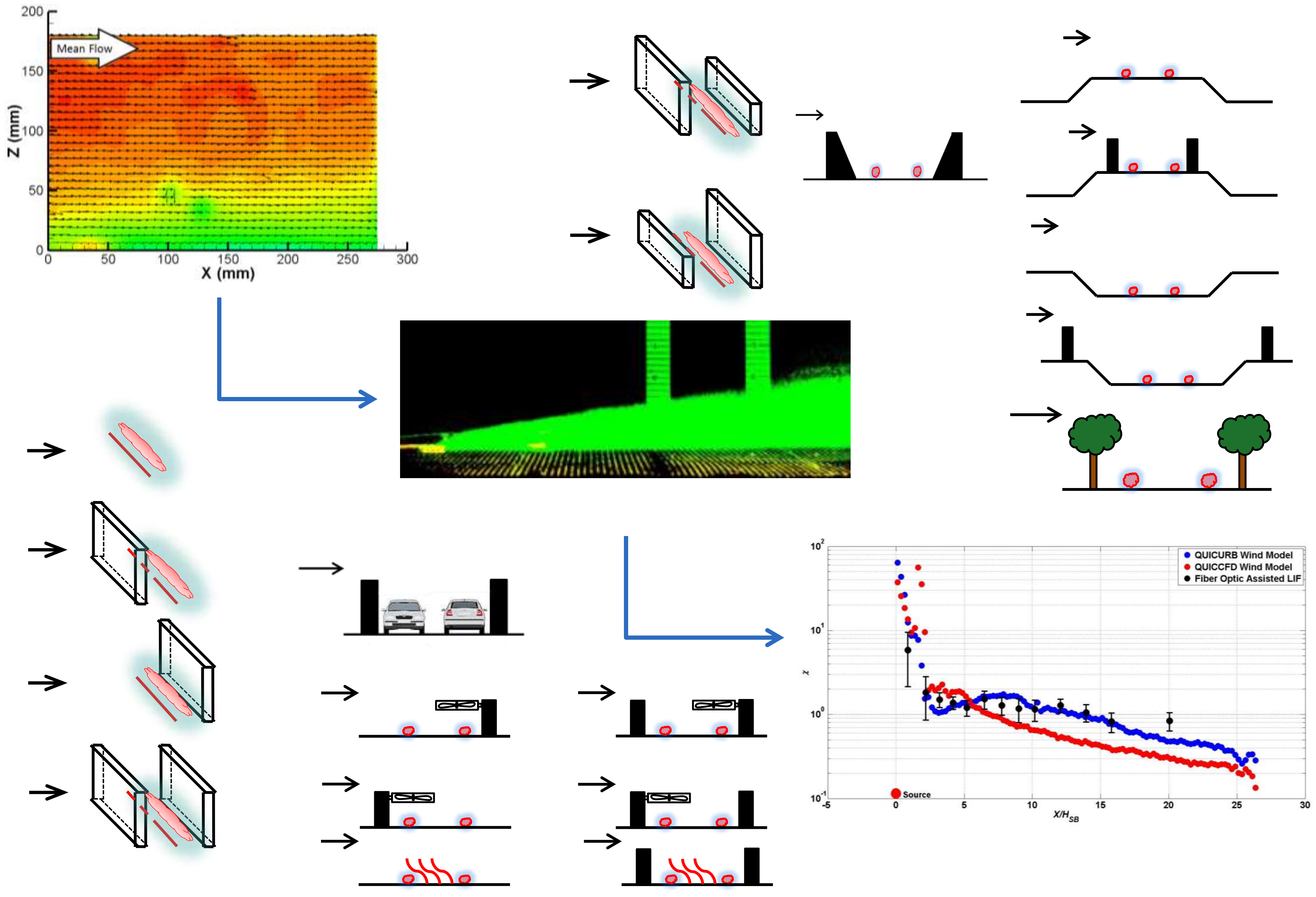
Velocity (PIV) Results



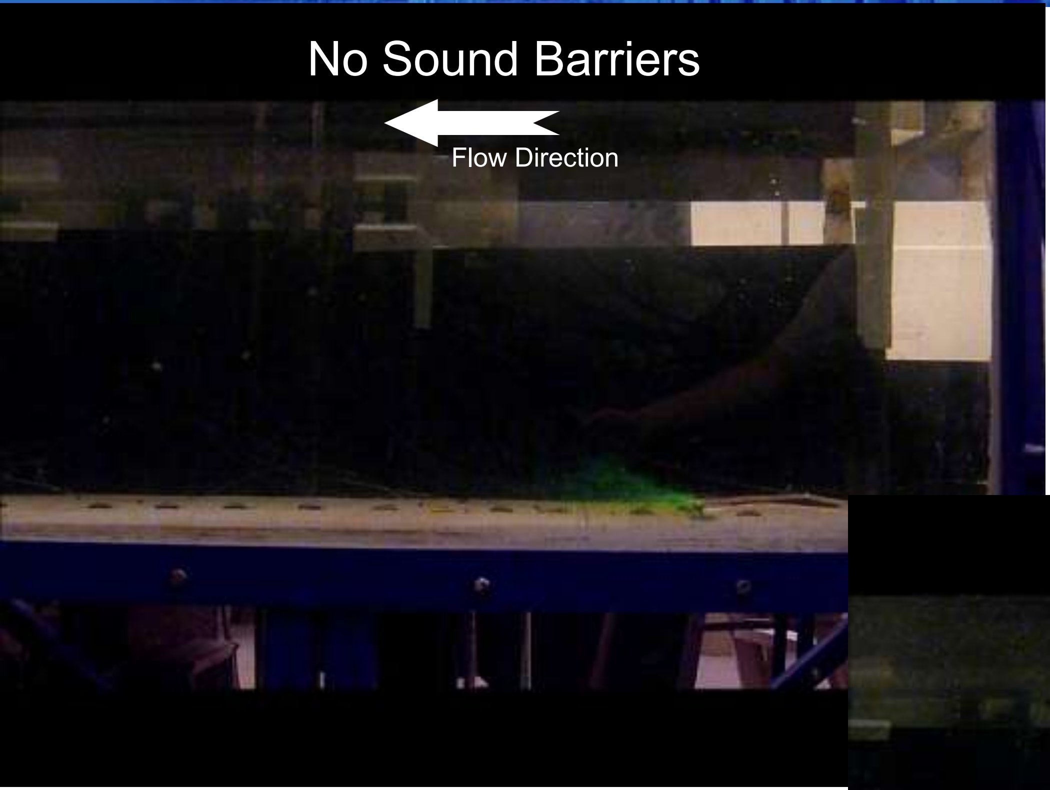
Traffic Induced Turbulence

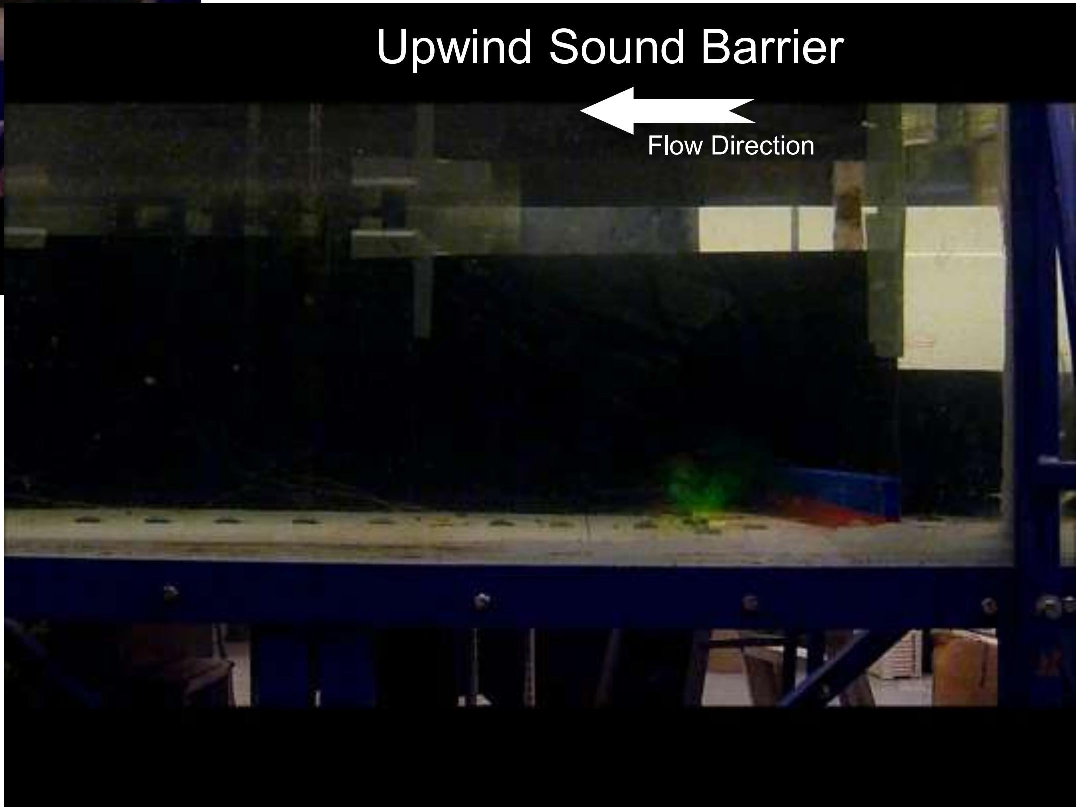


Experimental Procedure



Visualization Videos





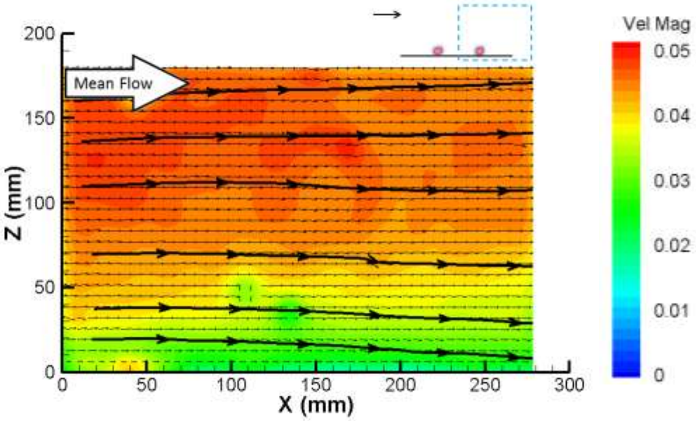
Visualization Videos

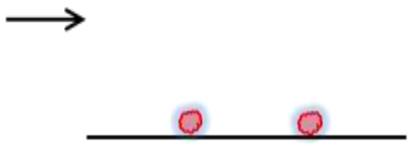
Downwind Sound Barrier

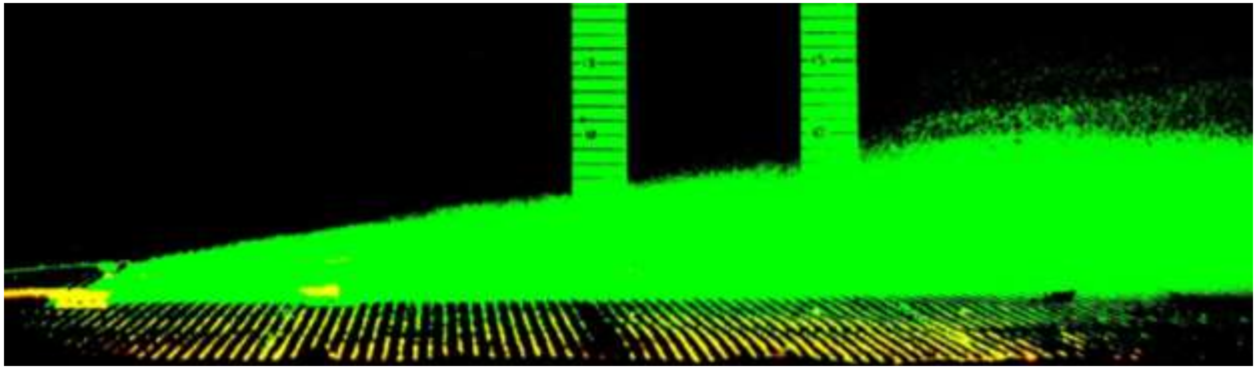
Upwind and Downwind Barriers

Visualization Videos

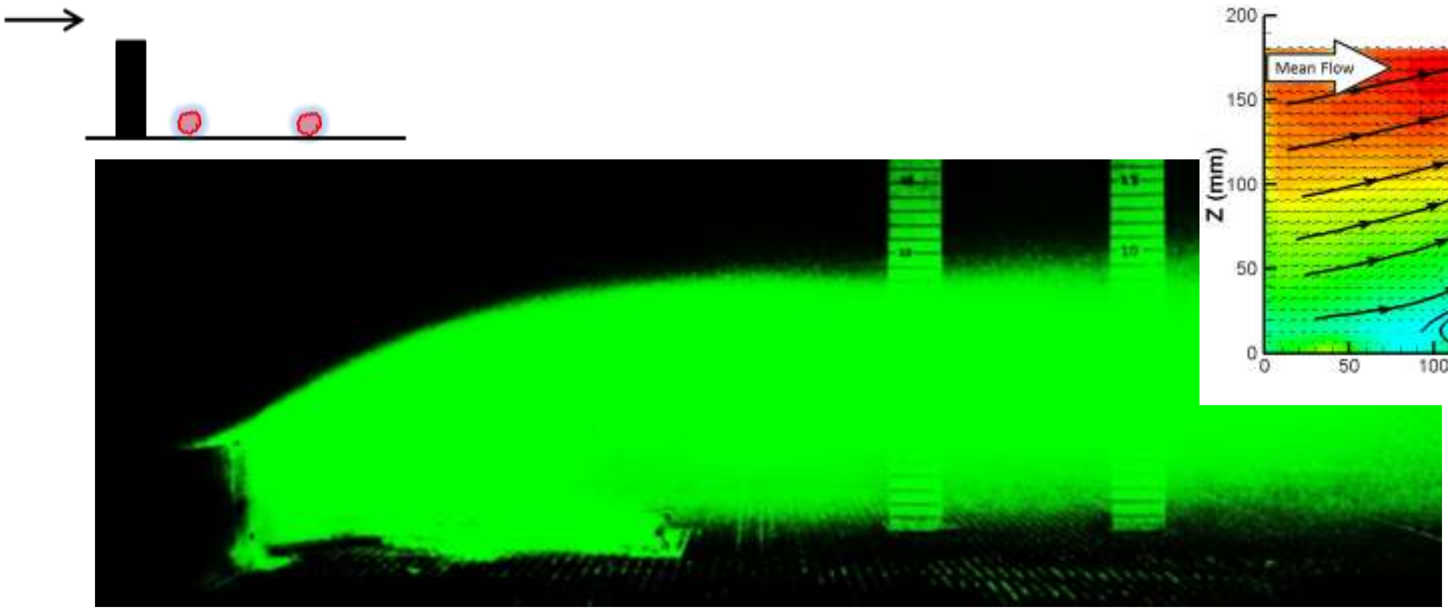
Qualitative Results (long exposure)

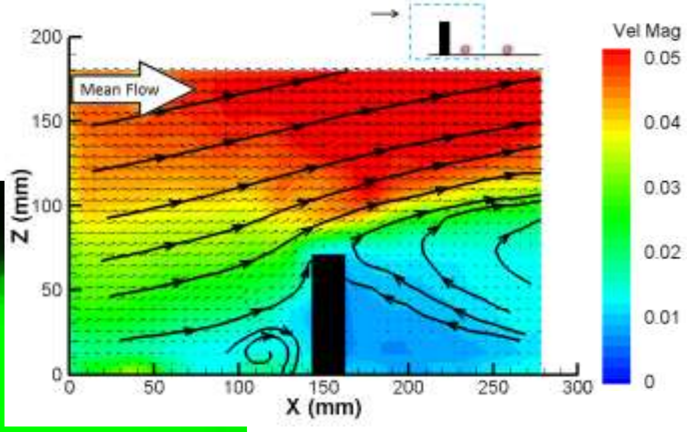


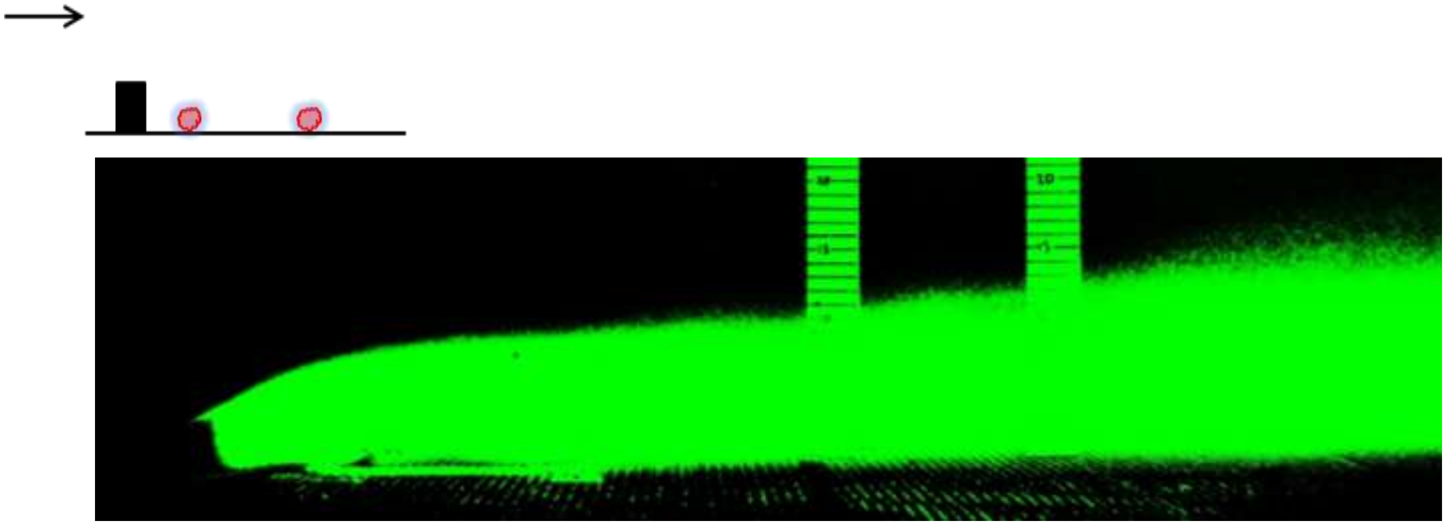




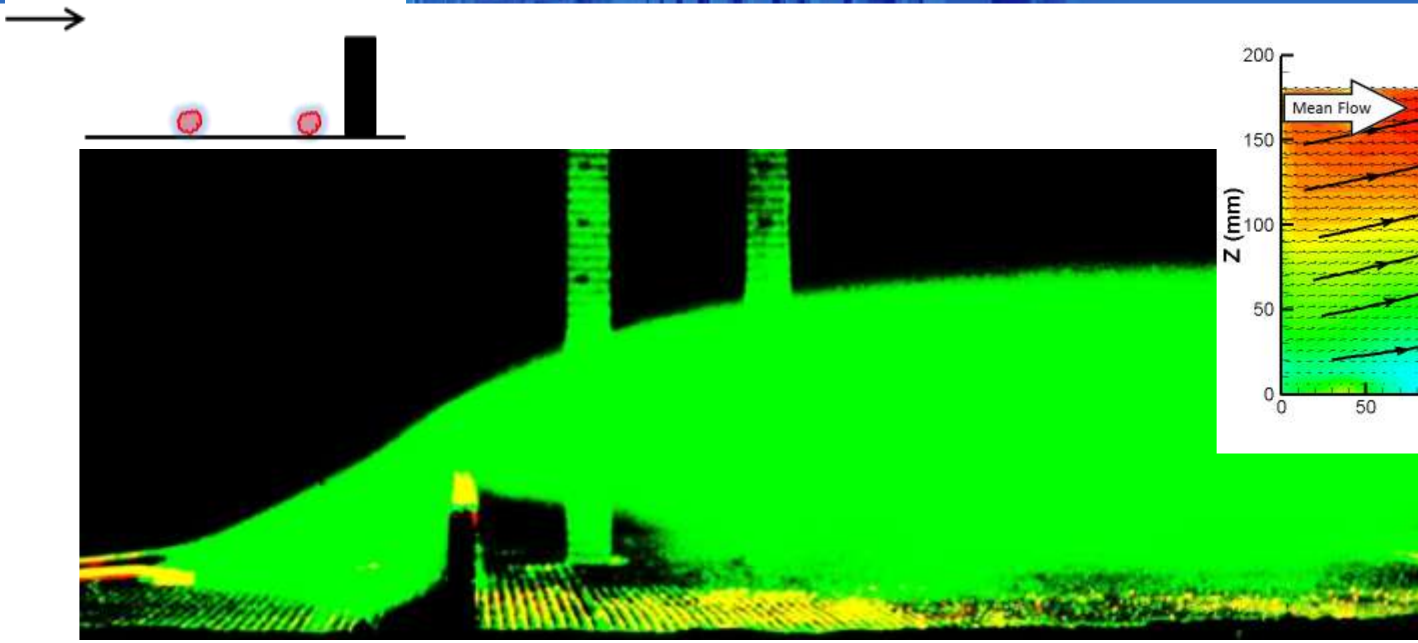
Qualitative Results (long exposure)

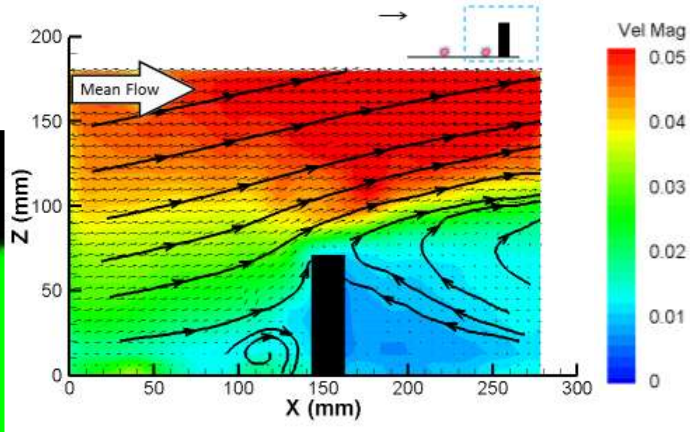


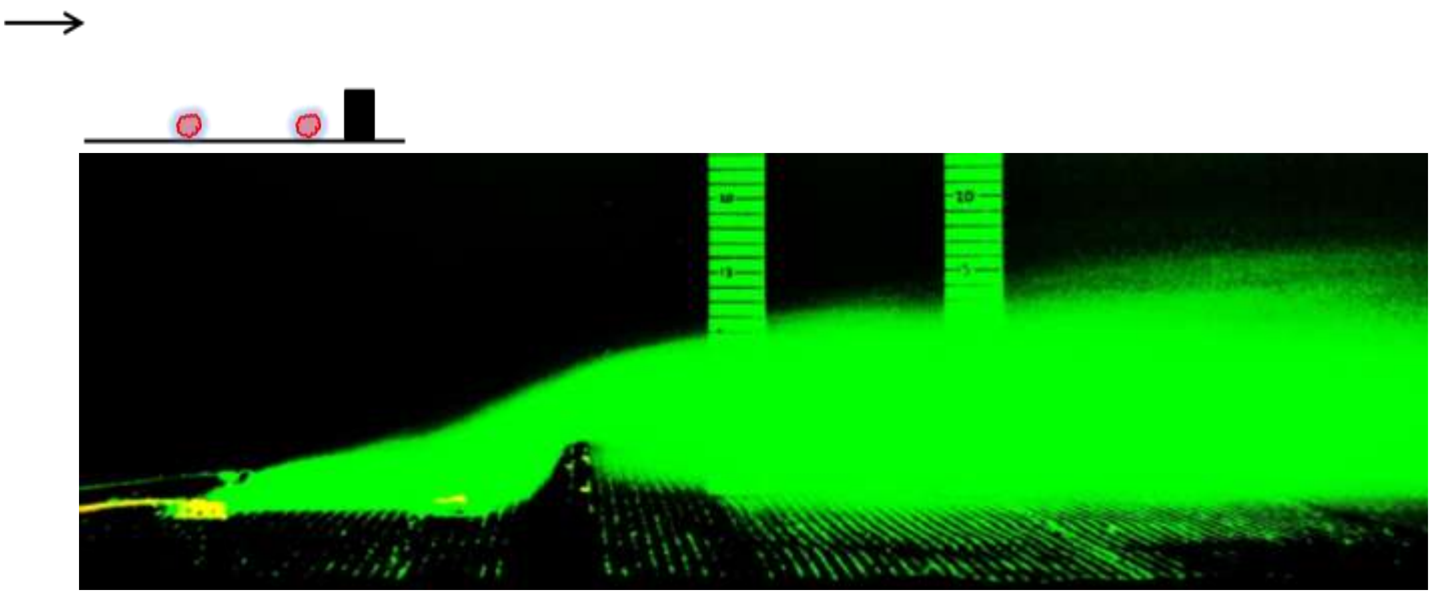




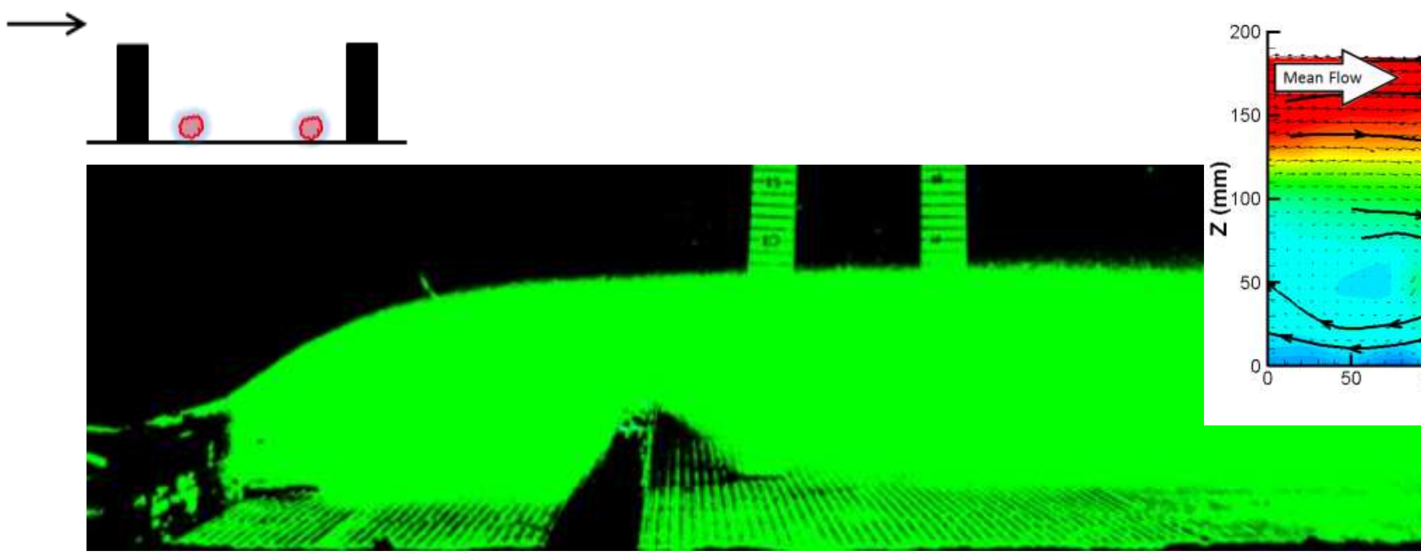
Qualitative Results (long exposure)

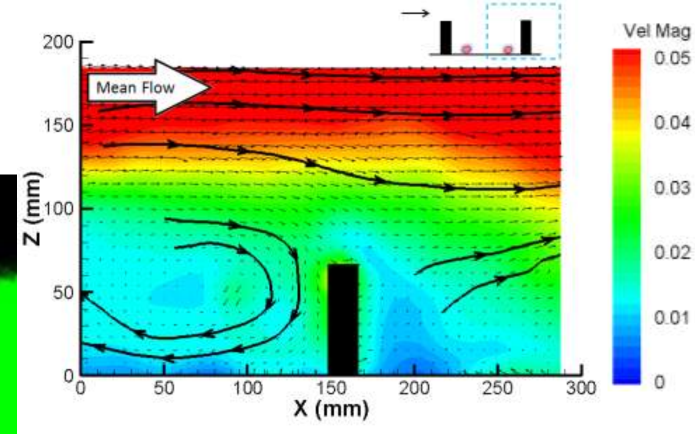


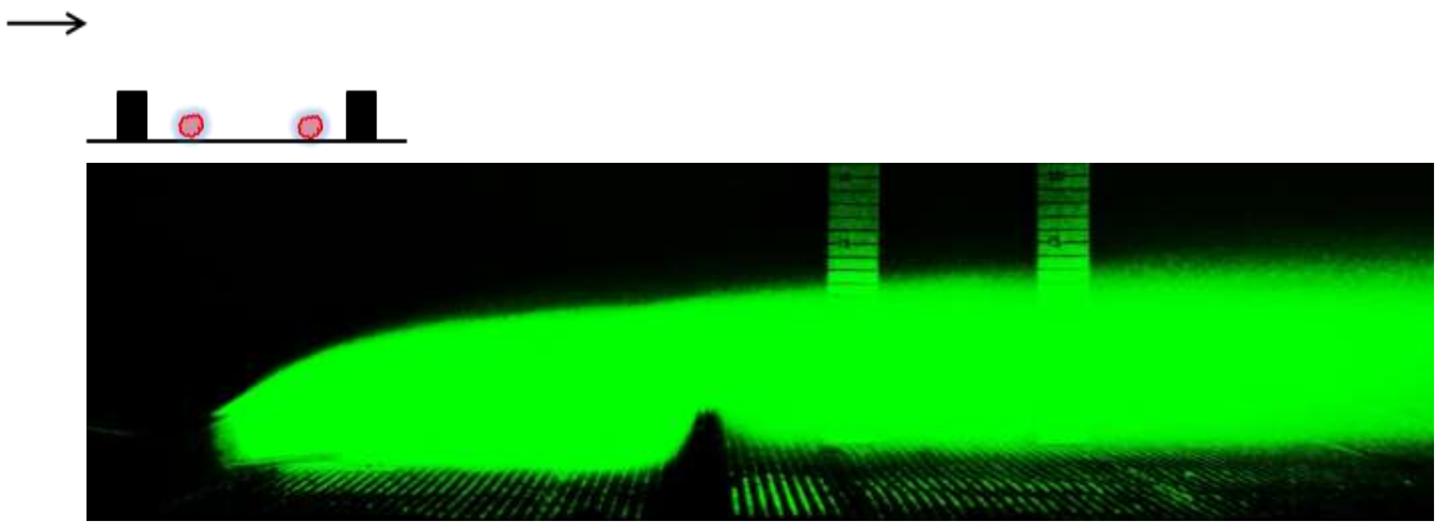




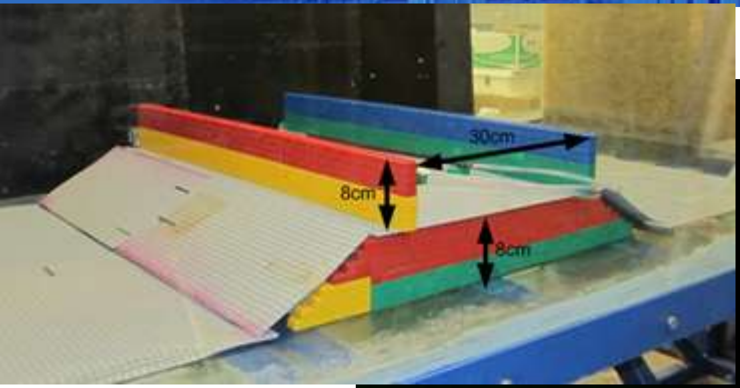
Qualitative Results (Visualizations)

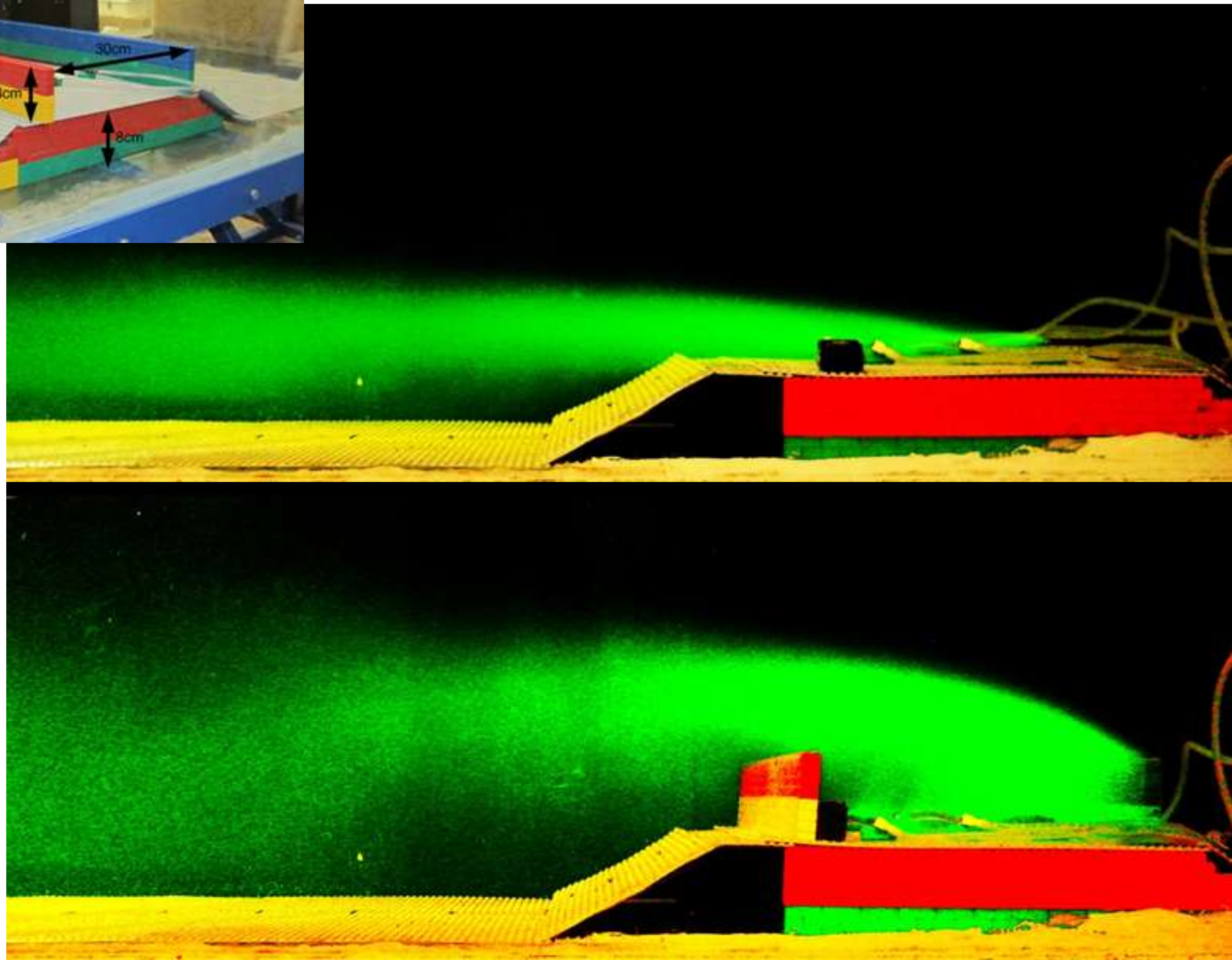




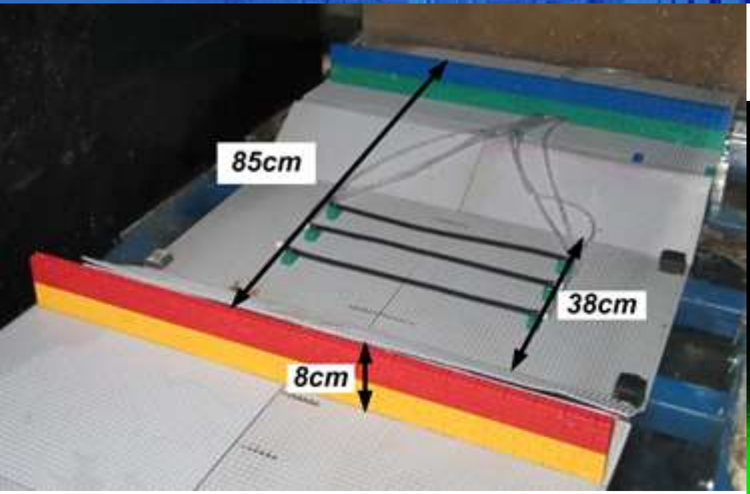


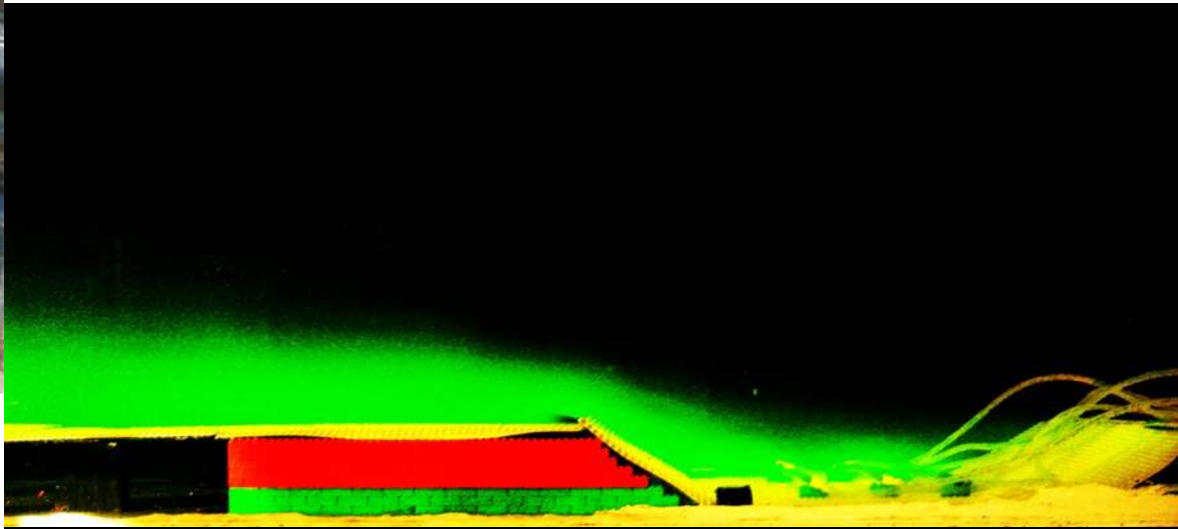
Qualitative Results (Visualizations)

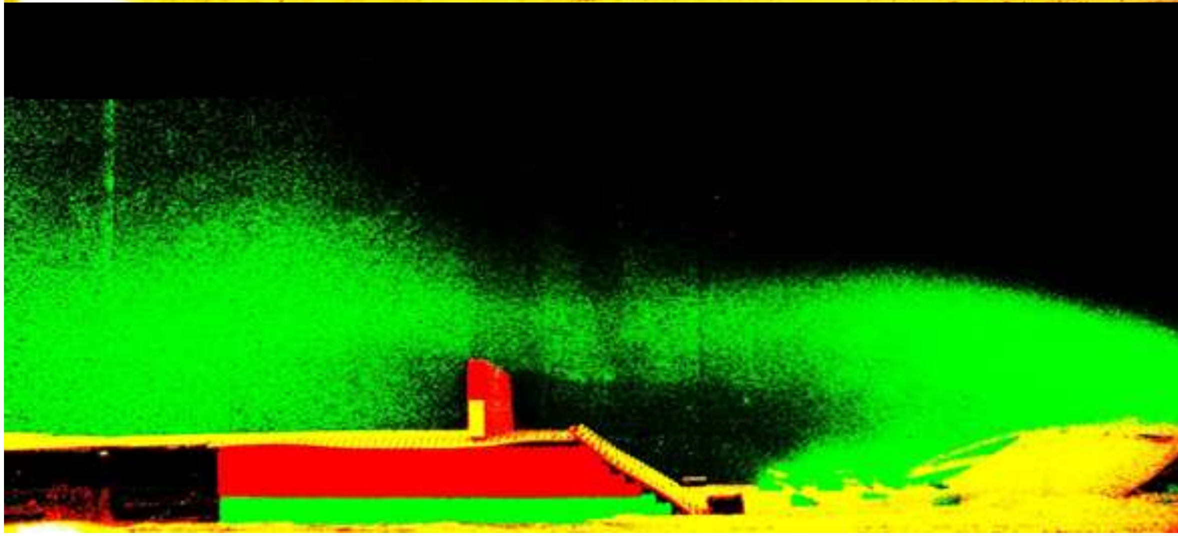




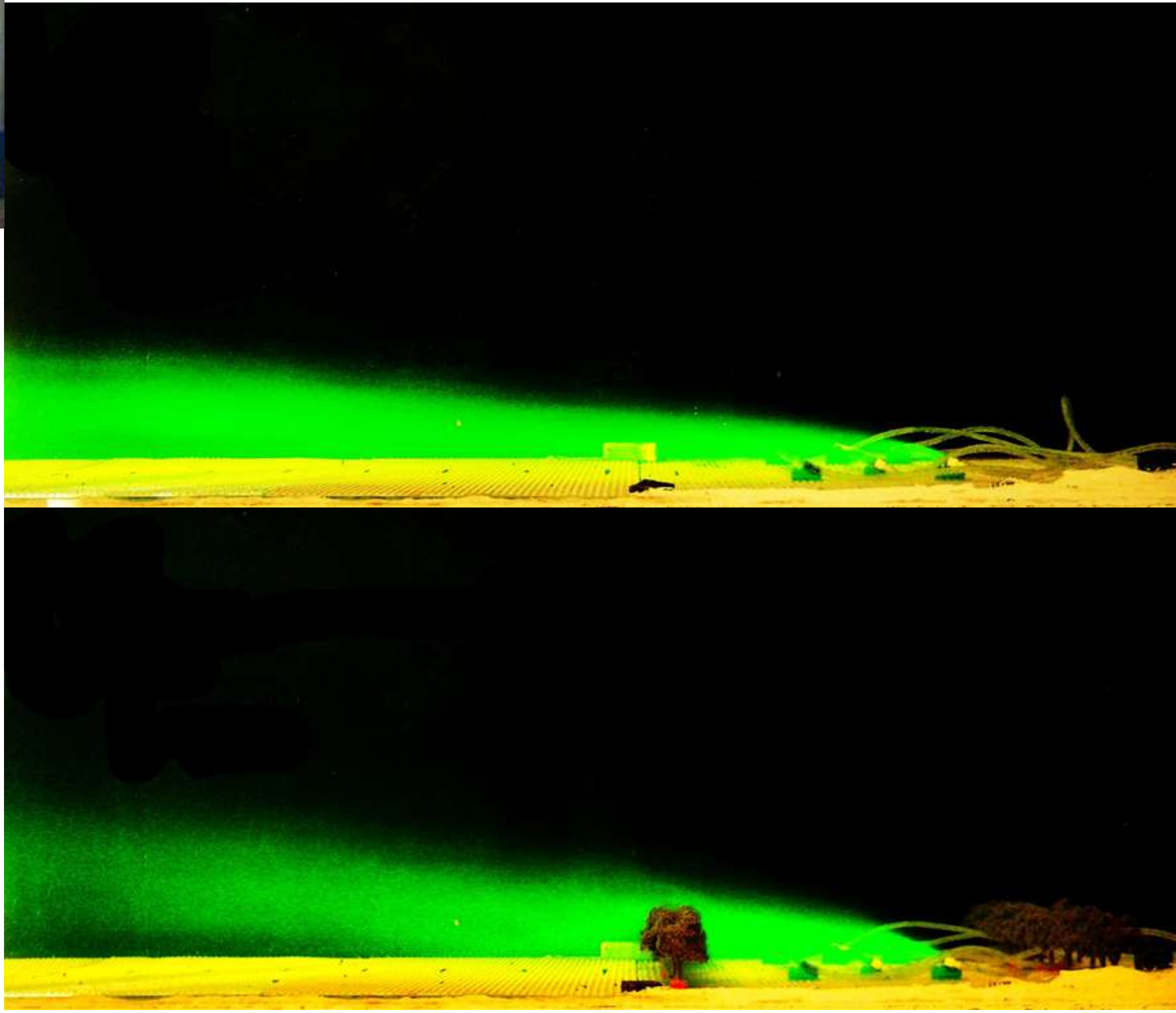
Qualitative Results (Visualizations)



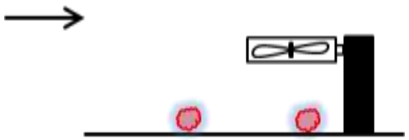




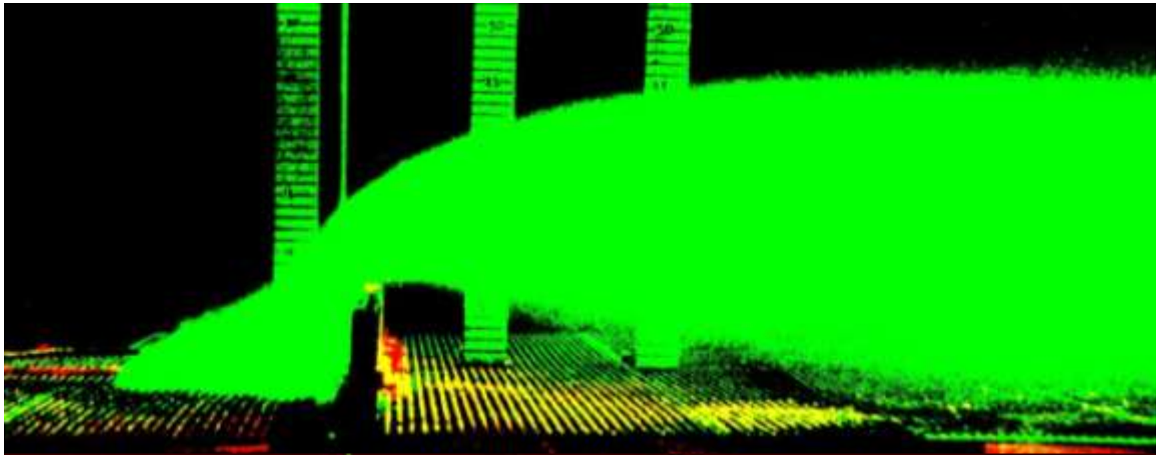
Qualitative Results (Visualizations)



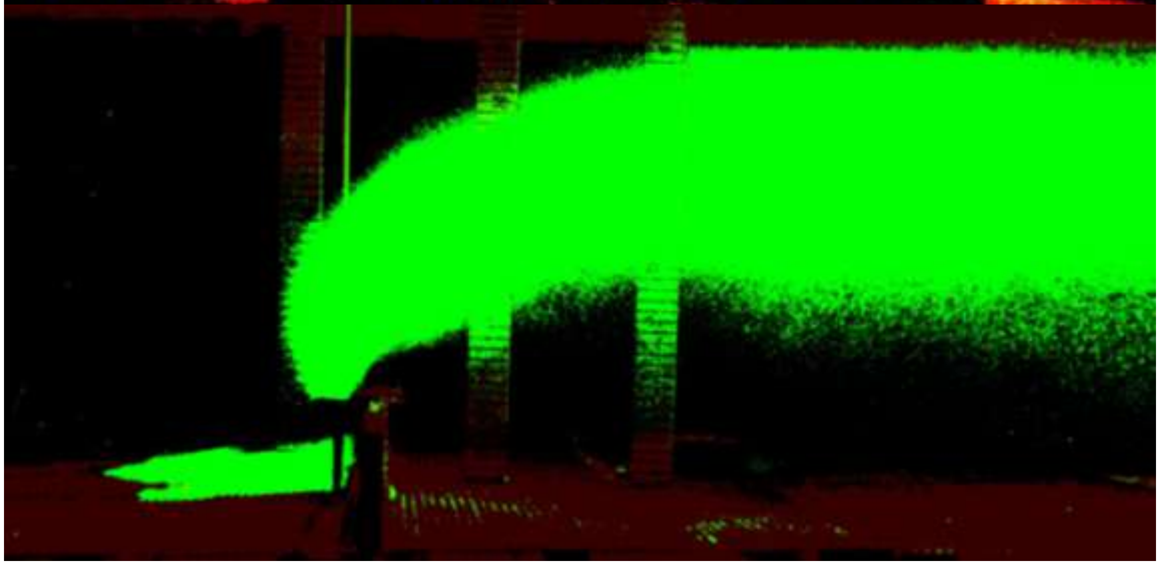
Qualitative Results (long exposure)



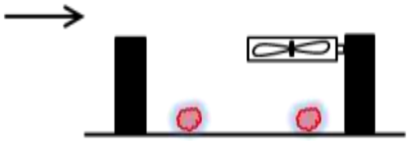
High Wind Speed



Low Wind Speed

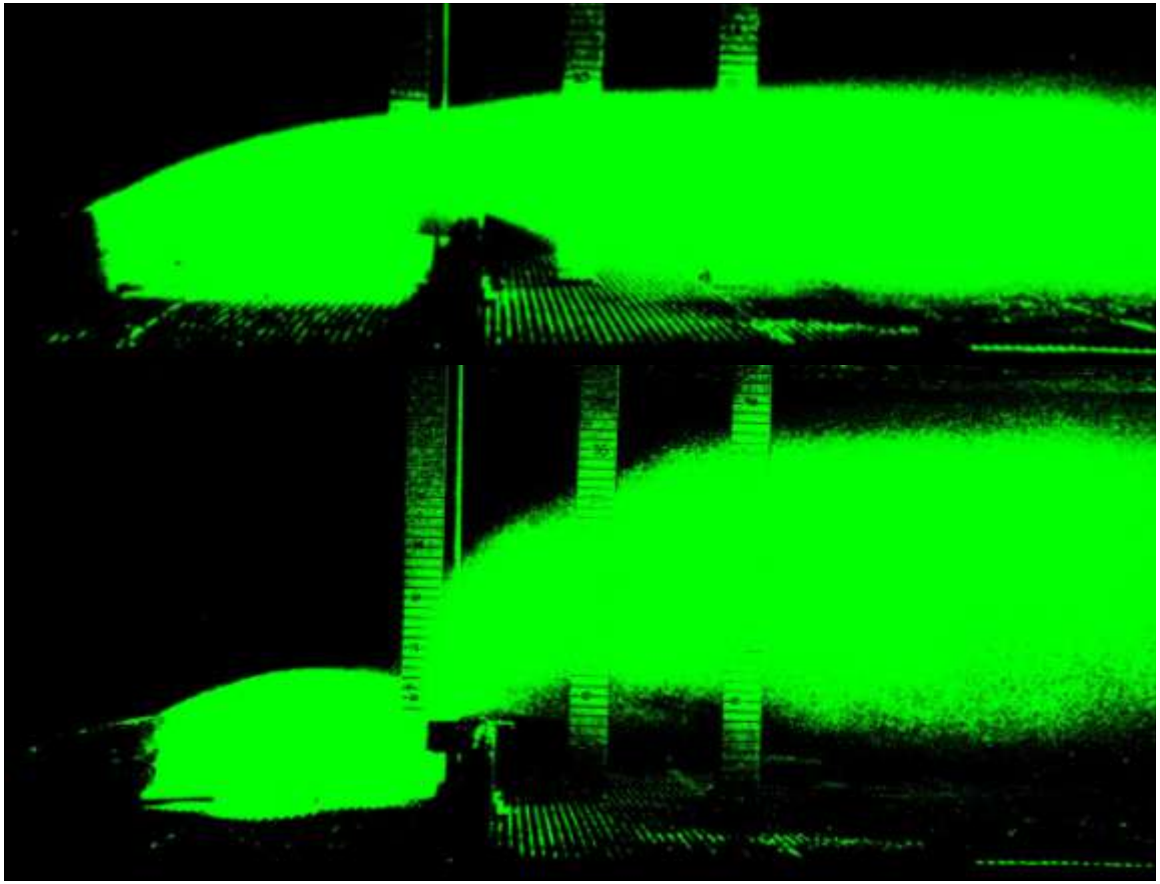


Qualitative Results (long exposure)

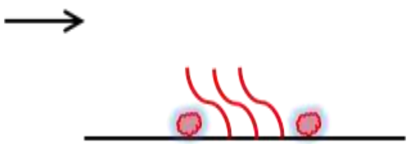


High Wind Speed

Low Wind Speed

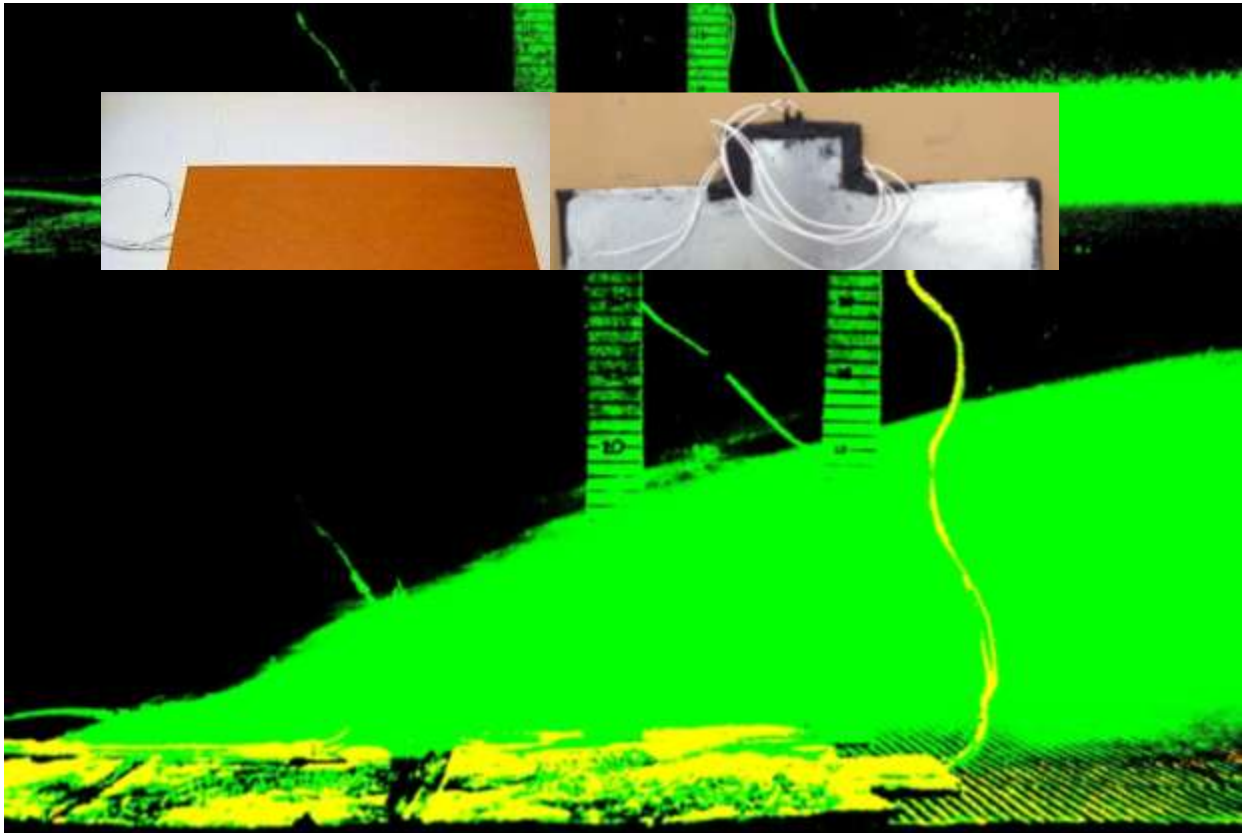


Qualitative Results (long exposure)

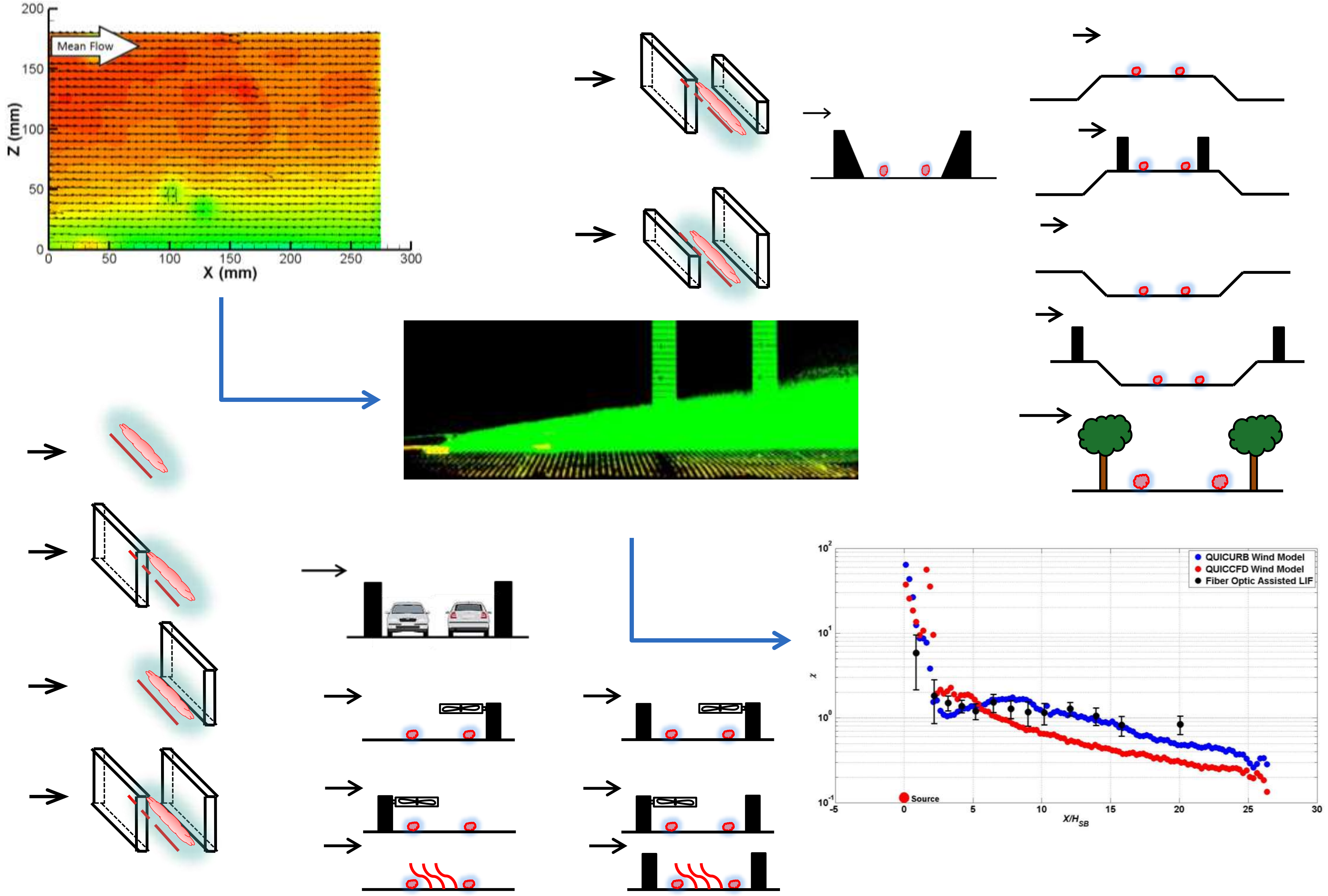


High Wind Speed

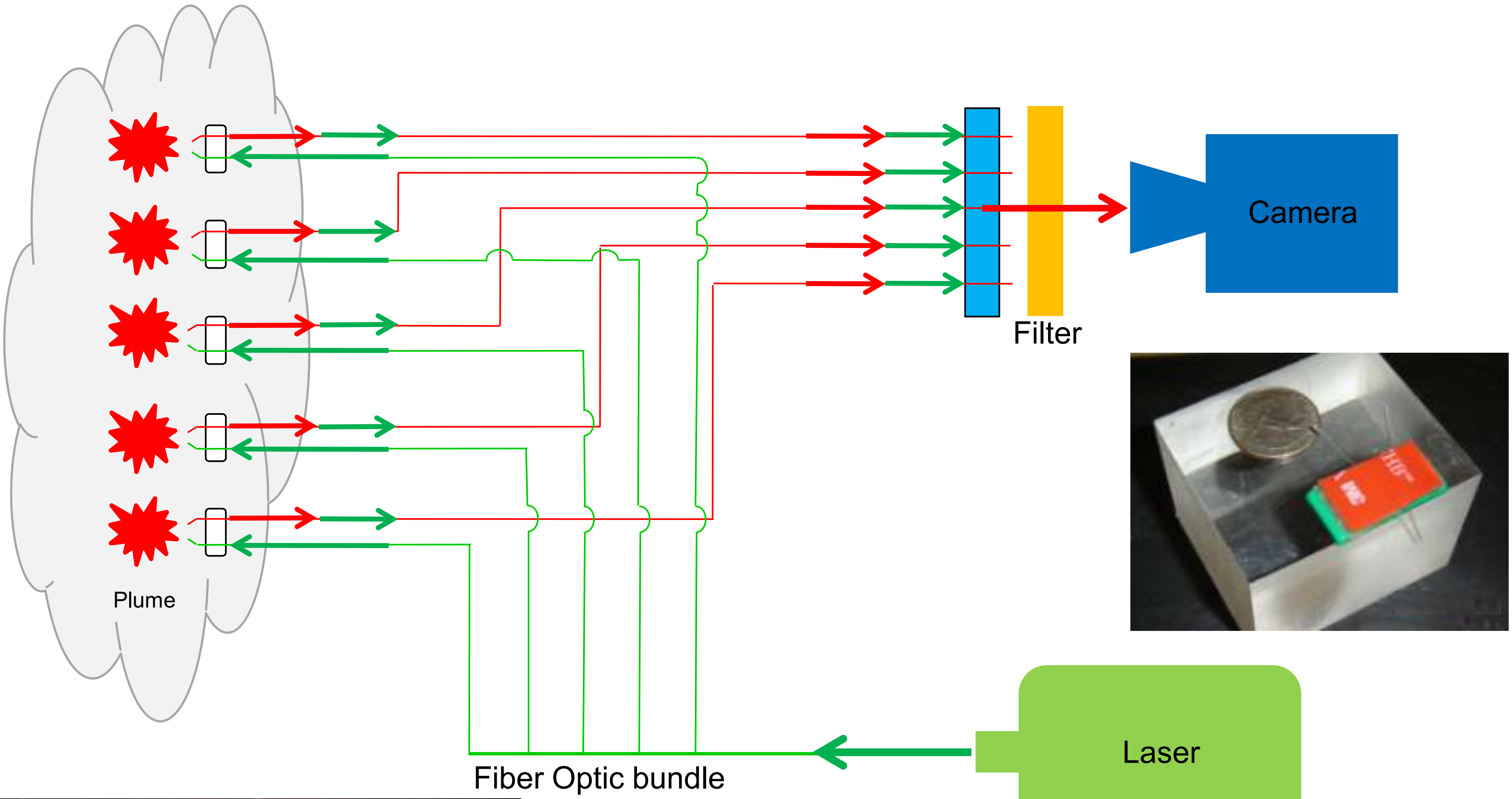
Low Wind Speed



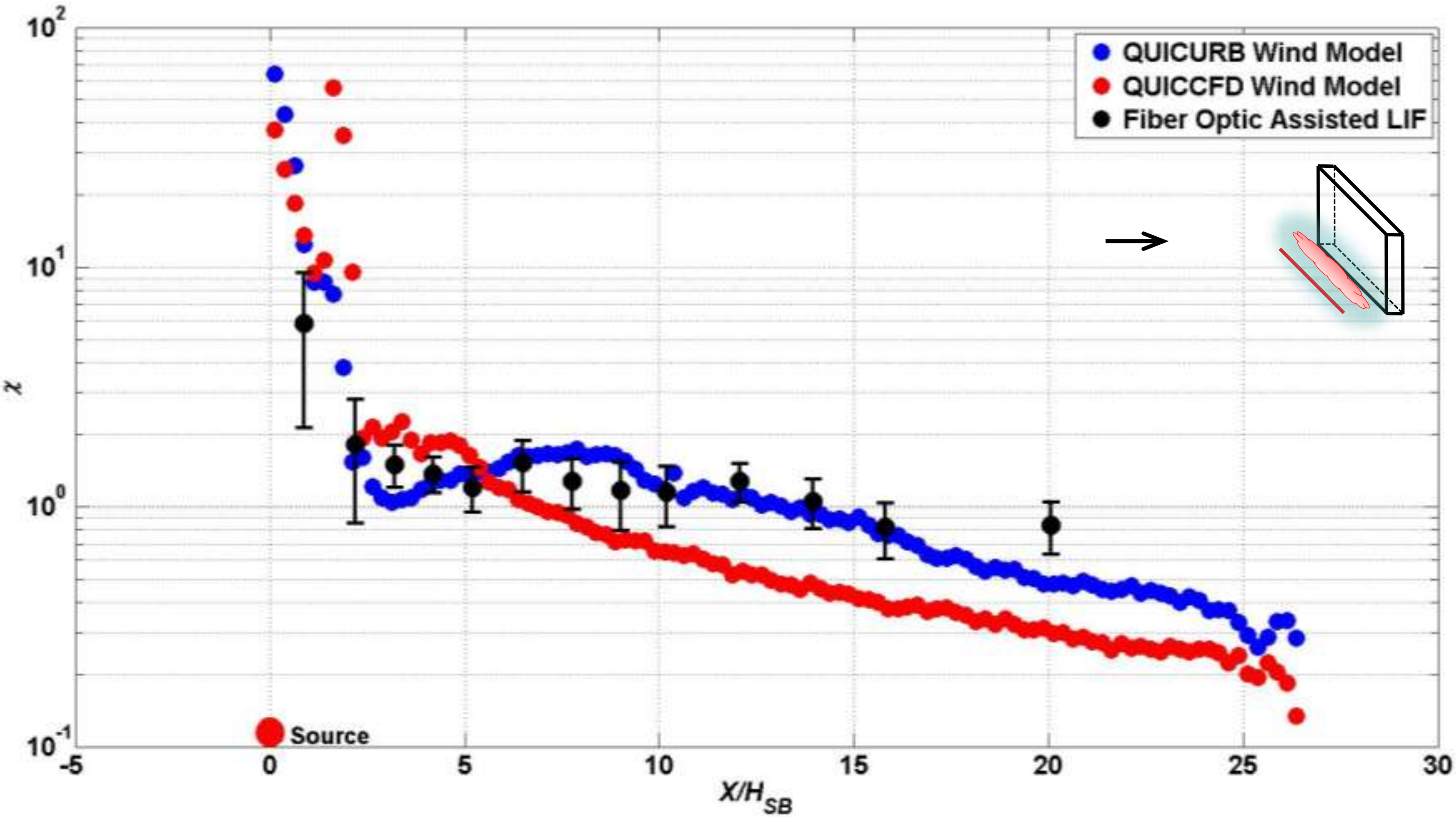
Experimental Procedure



Fiber Optic Assisted LIF

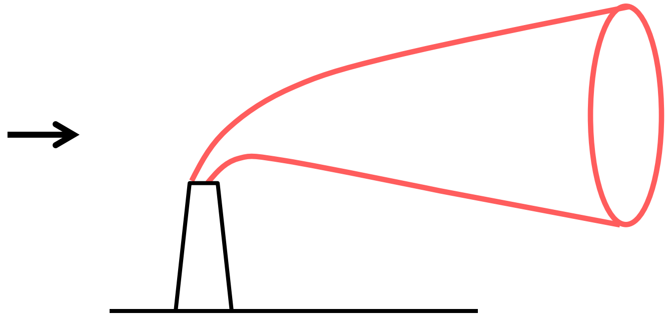


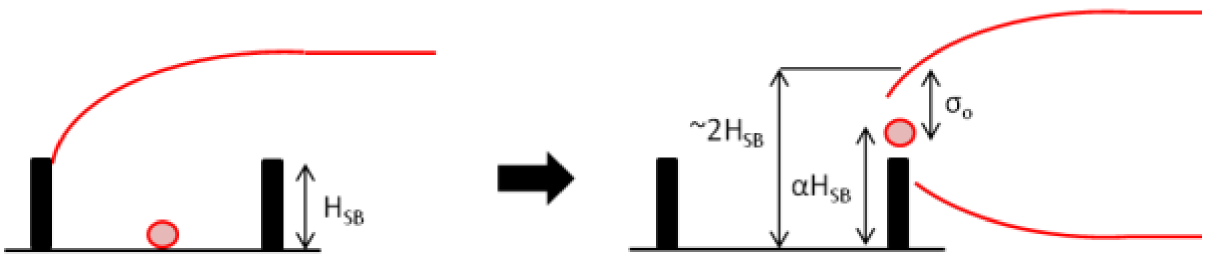
Quantitative Results



Gaussian Model

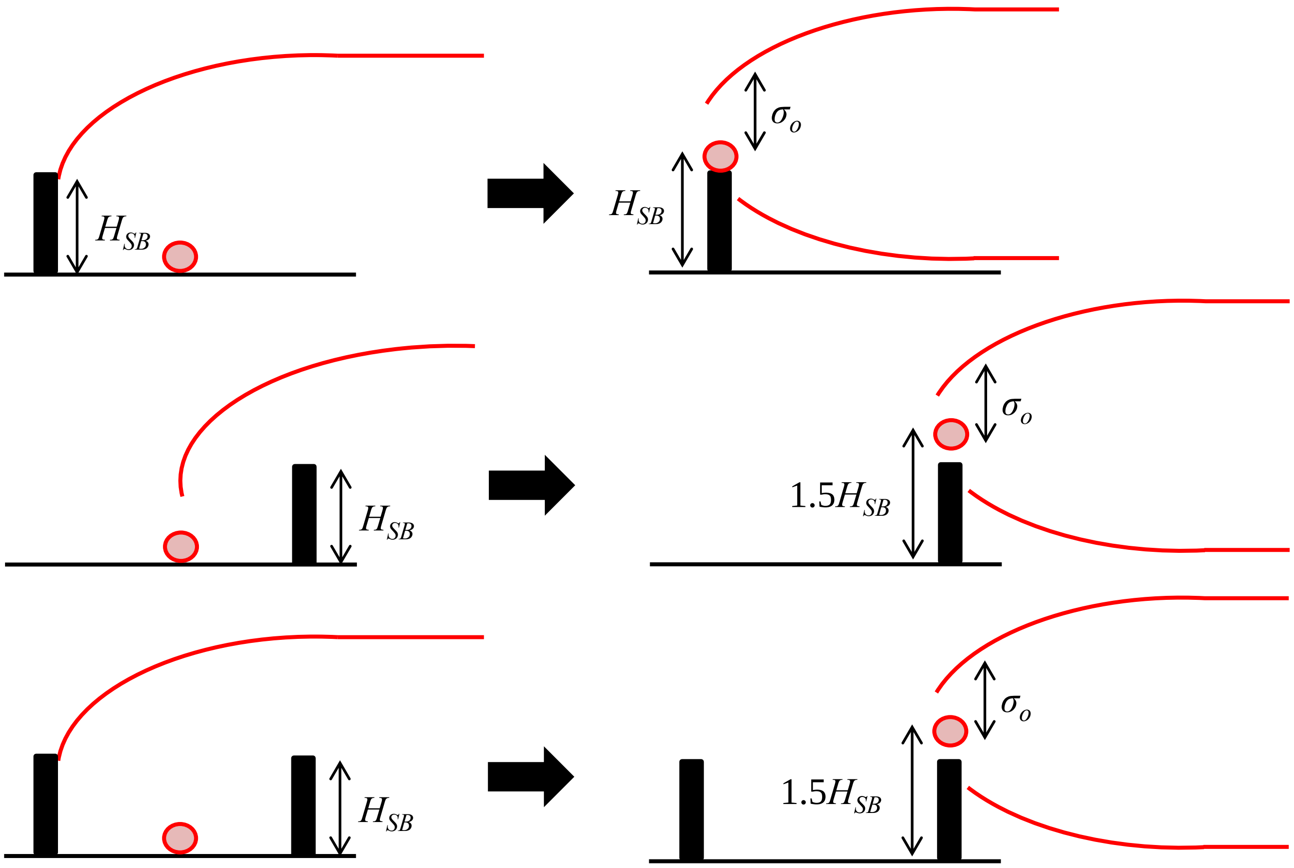
$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[exp\left(-\frac{(z-h_e)^2}{2\sigma_z^2}\right) + exp\left(-\frac{(z+h_e)^2}{2\sigma_z^2}\right)\right]$$





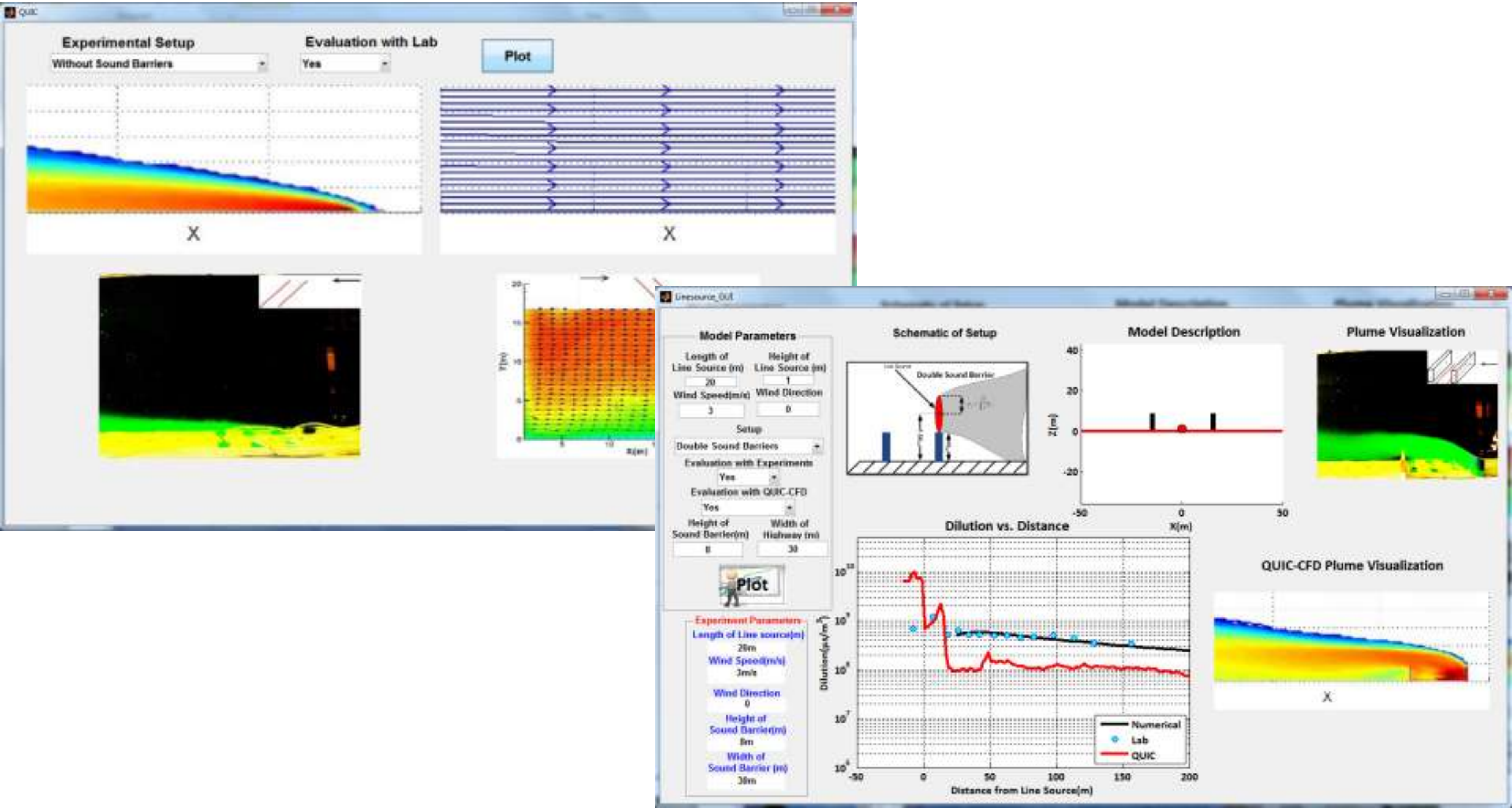
$$\frac{C(x,y,0)}{Q} = \int_{-L/2}^{L/2} \frac{dy}{\pi U \sigma_y \sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2}\right) exp\left(-\frac{(\alpha H_{SB})^2}{2\sigma_z^2}\right)$$

Gaussian Model

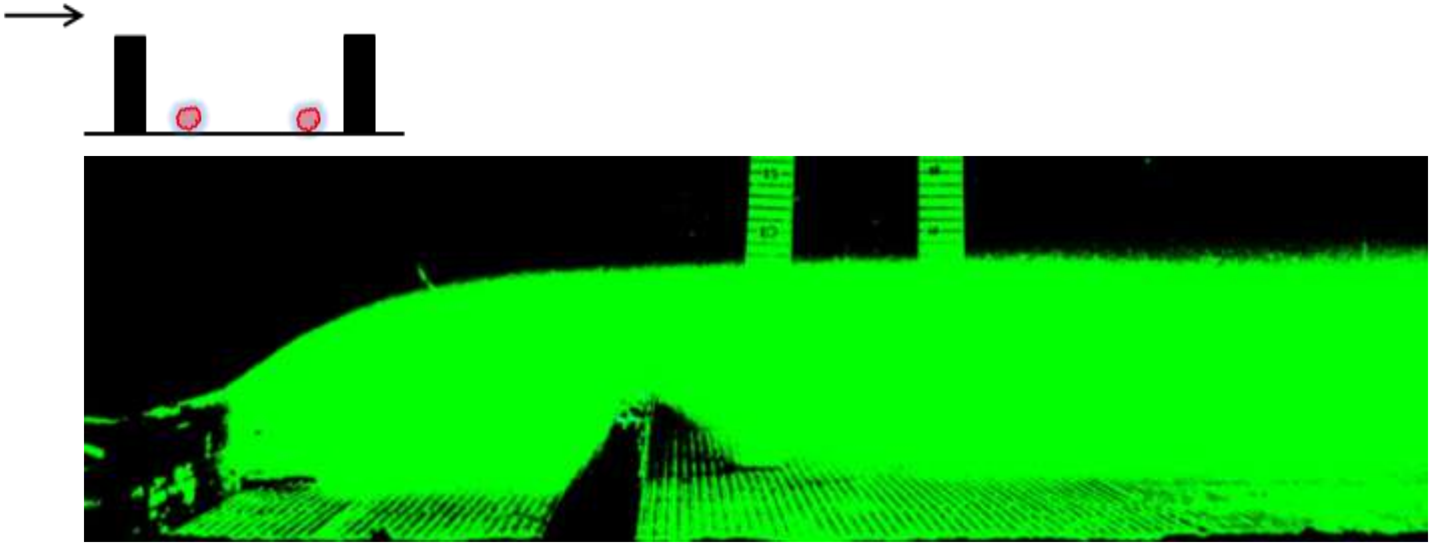


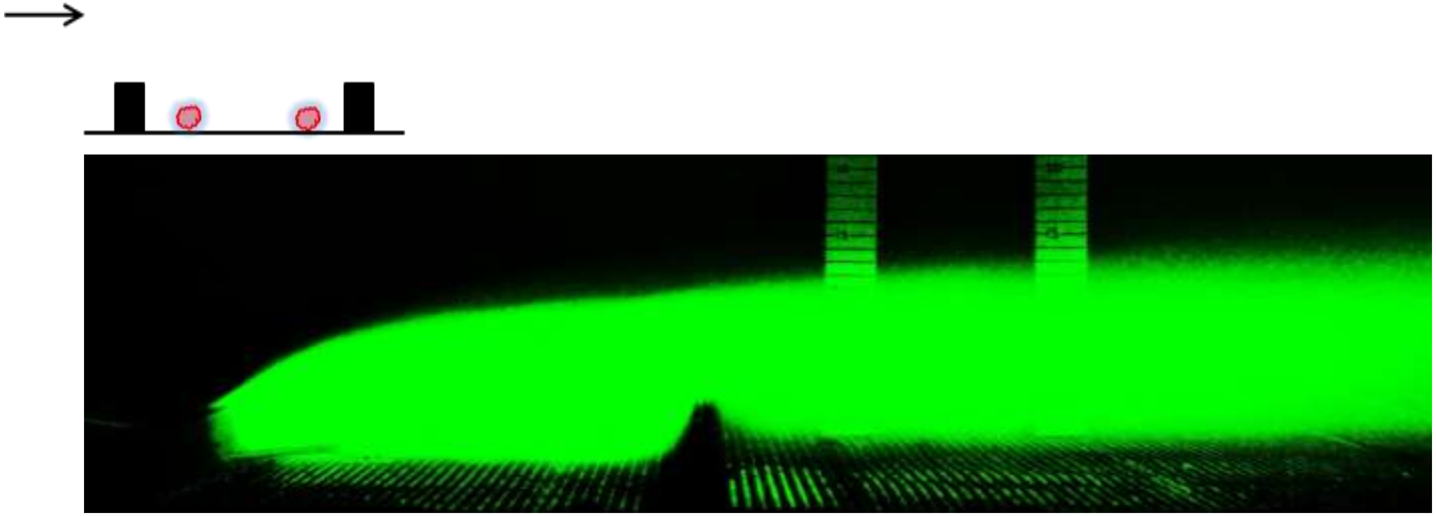
Digital Catalog

- Visualizations, velocity measurements, concentration measurements, QUIC results and a simple Gaussian model are all organized in the "Digital Catalog"

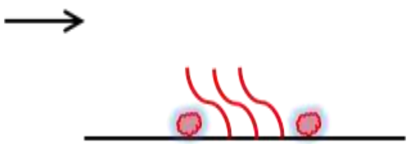


Conclusion



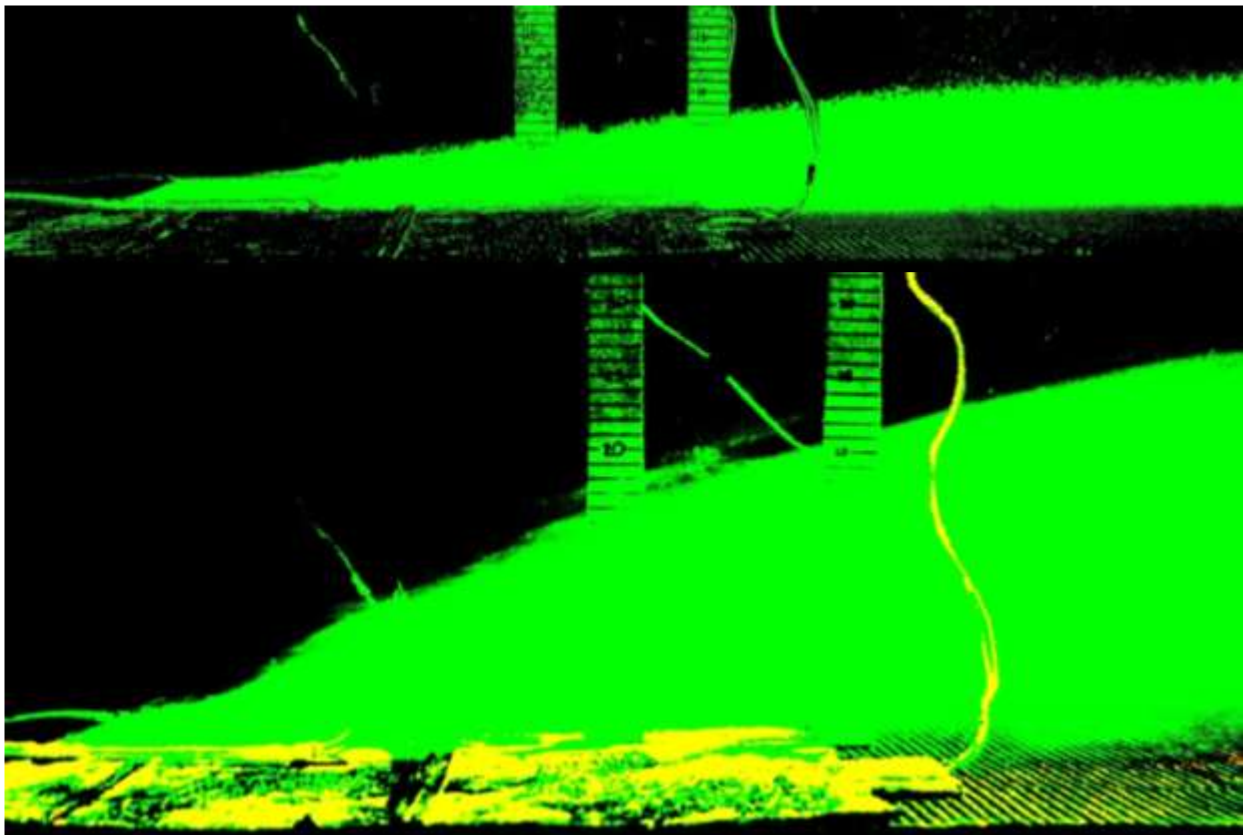


Conclusion

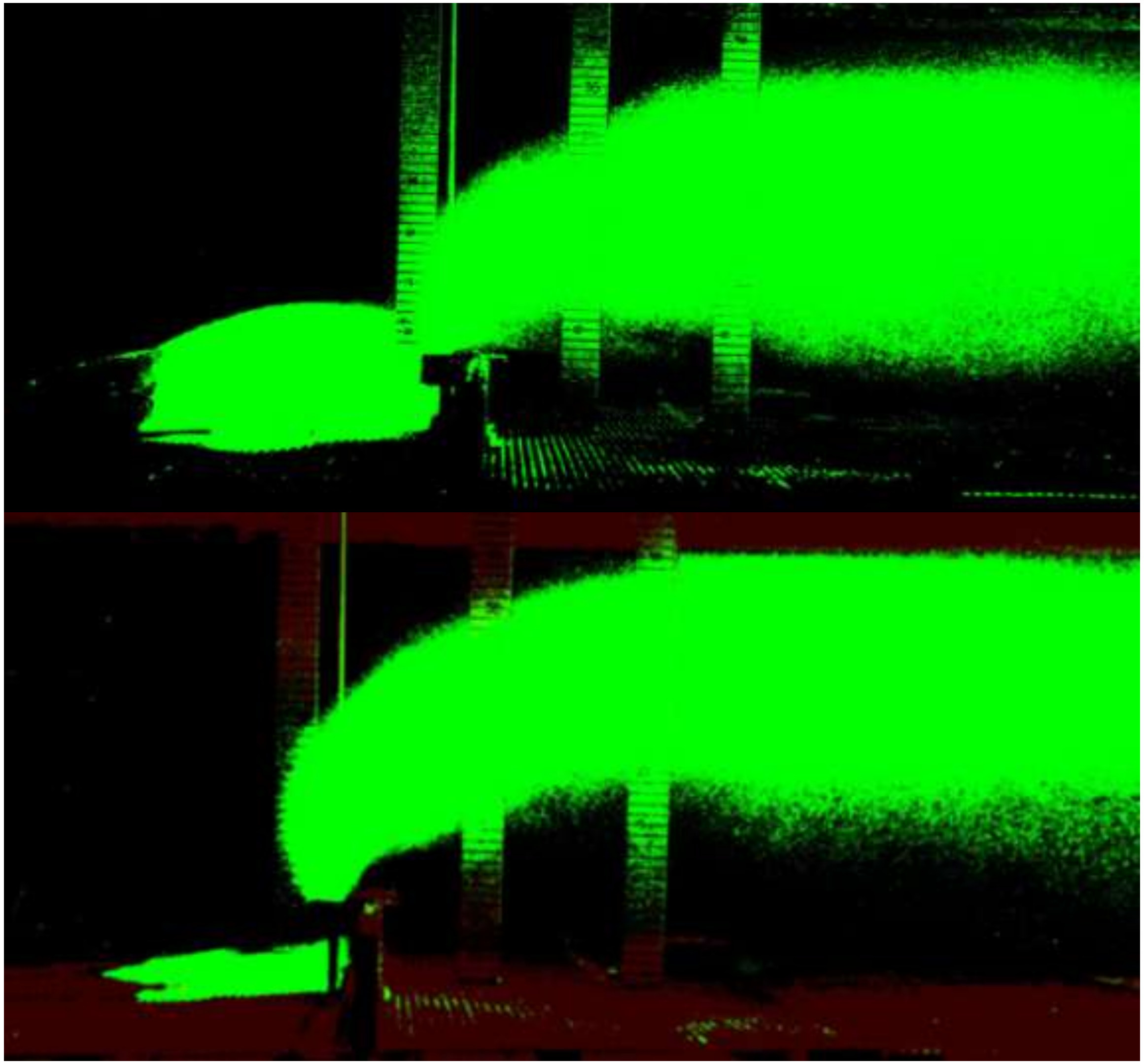


High Wind Speed

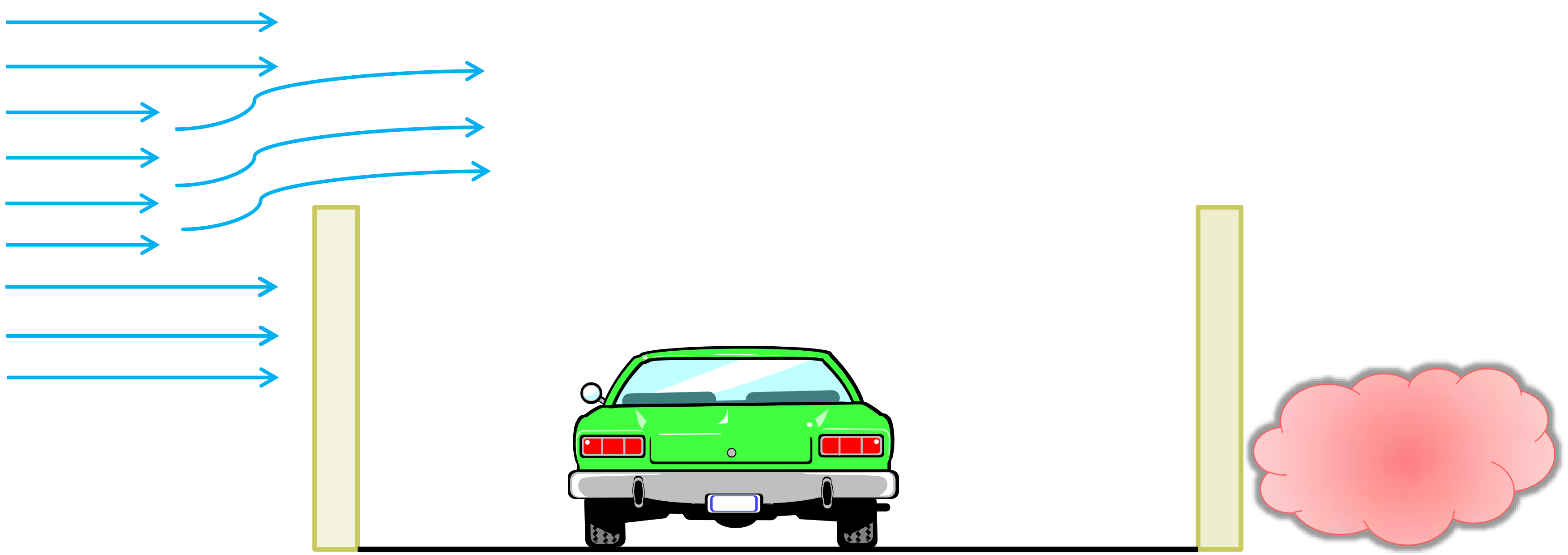
Low Wind Speed



Conclusion

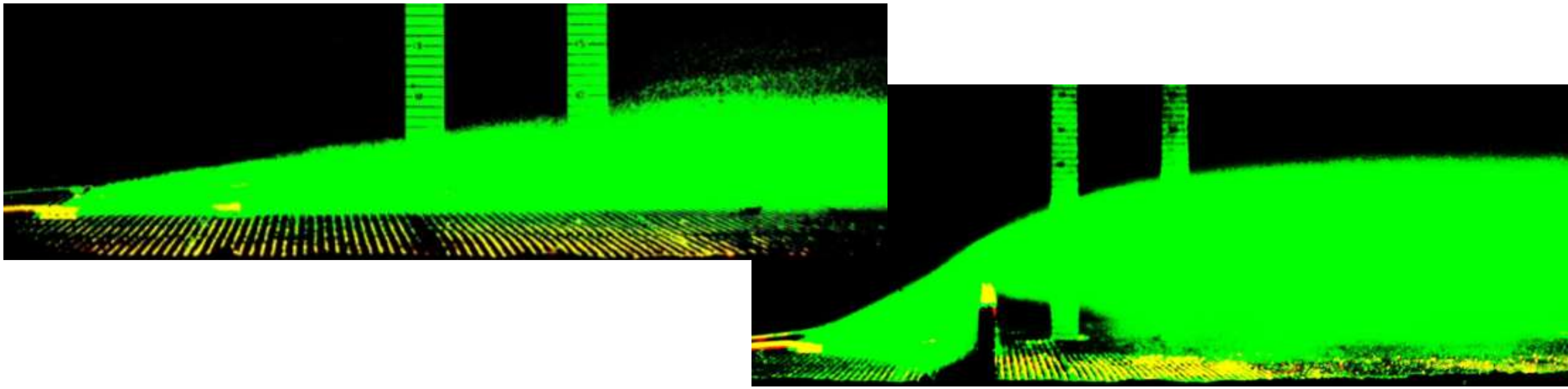


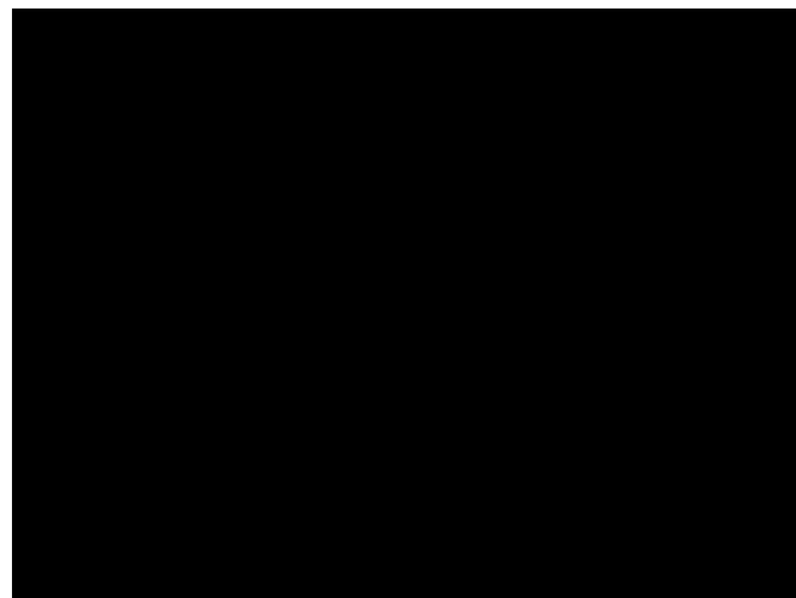
Conclusion



Note

Road without a sound barrier is like a point source without a tall chimney

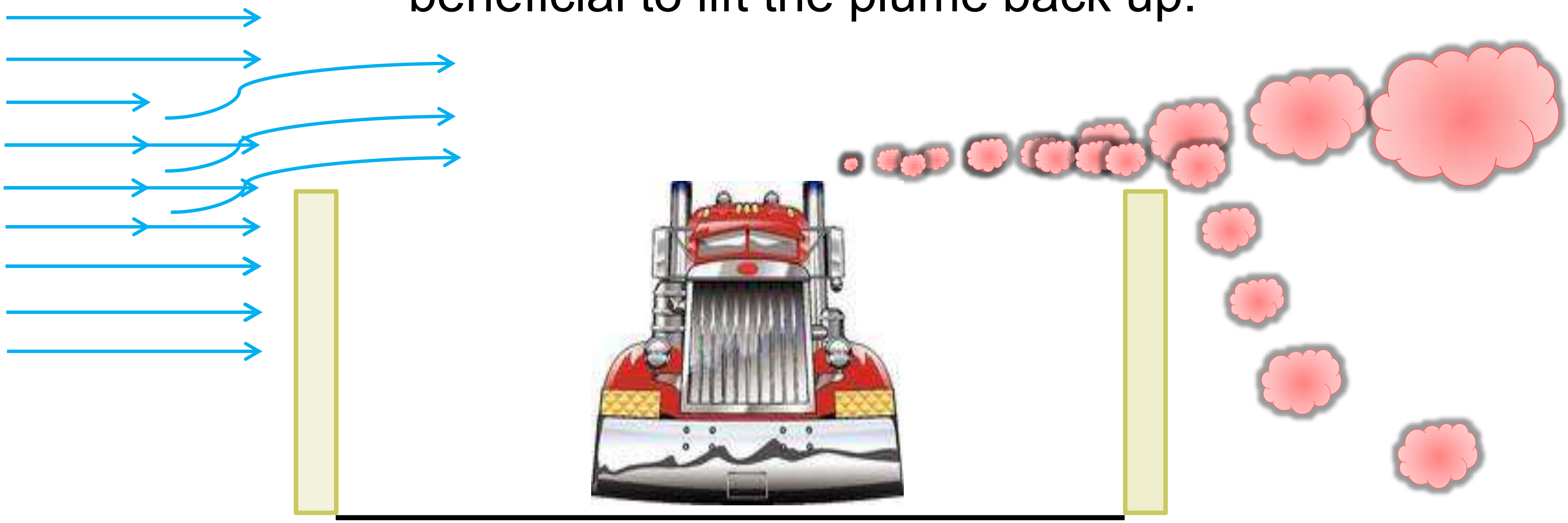




Note

However, barrier wake can bring down a plume released above the ground (e.g. non moving truck)

However, if truck is moving sufficiently fast, the plume would be mixed down in the truck's wake and the barrier would be beneficial to lift the plume back up.



Need lab work to confirm and to determine the critical truck velocity.

Recommendations

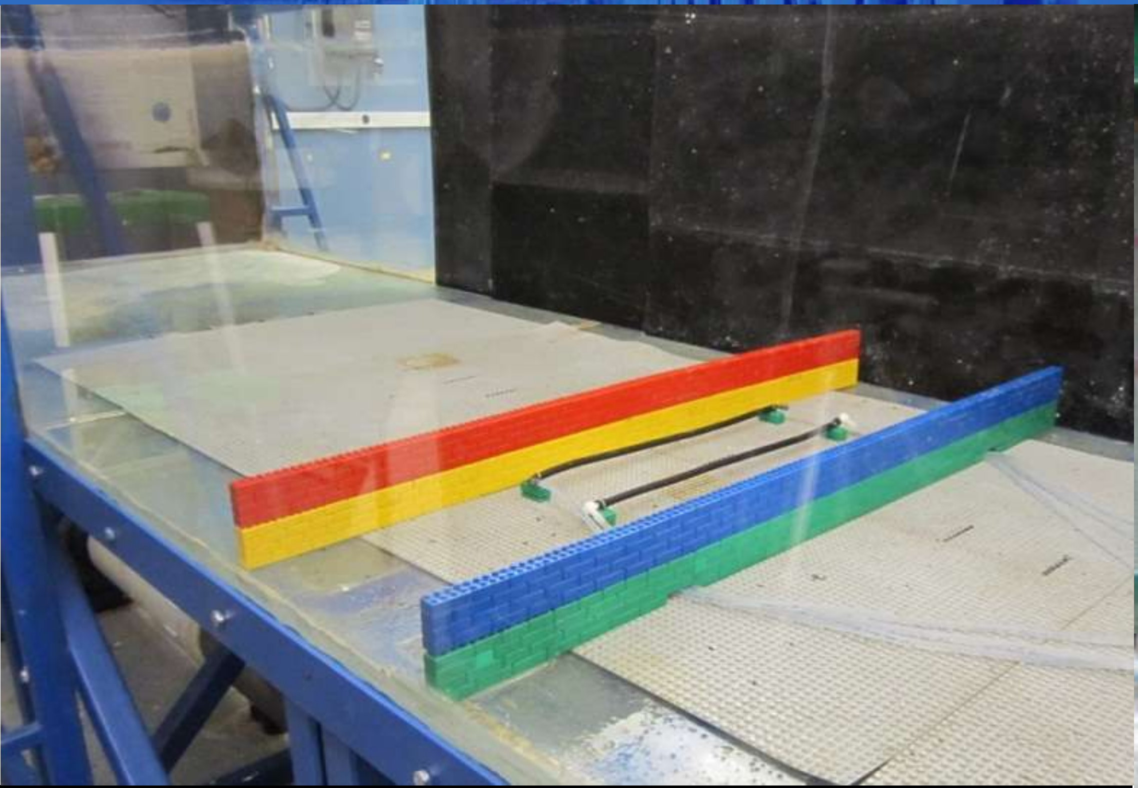
- Build sound barriers where feasible – any is better than none (analogy: tall chimney vs. no chimney)*

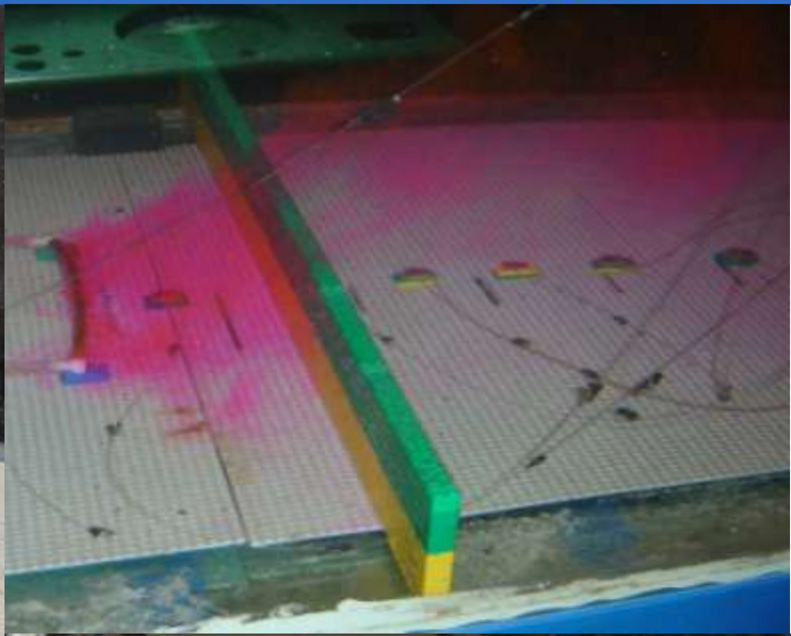
- Consider active flushing for critical areas (e.g. fans)**

- A future alternative can be automatically forcing hybrid vehicles to switch to electric drive in critical areas (e.g. downtown, vicinity of school…)***

*need lab/field verification for tall trucks and to be careful where the barrier ends
**this can be prohibitively expensive option
***most of vehicles already have GPS as standard

Questions

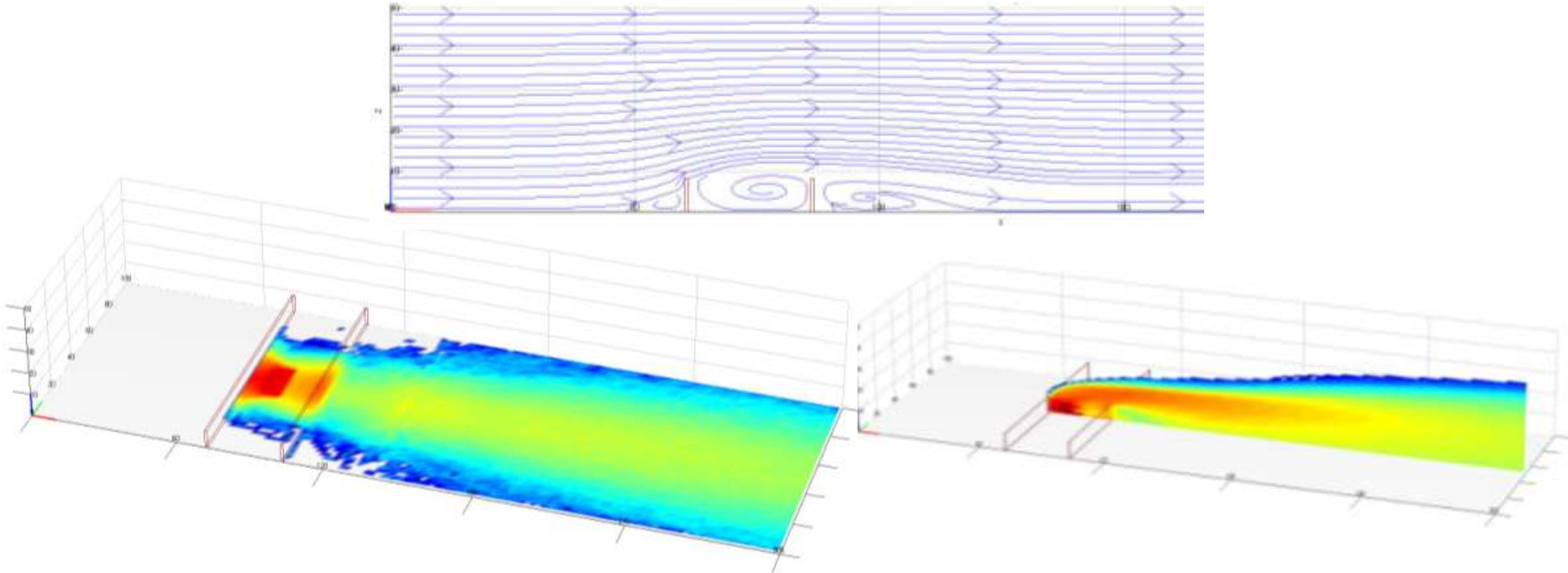




Backup

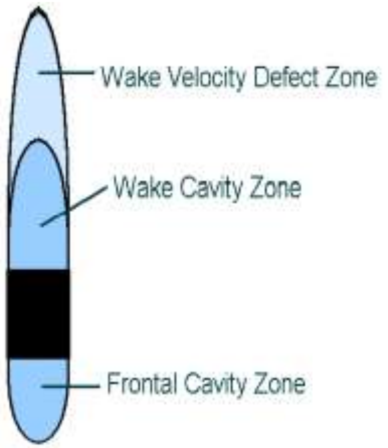
QUIC

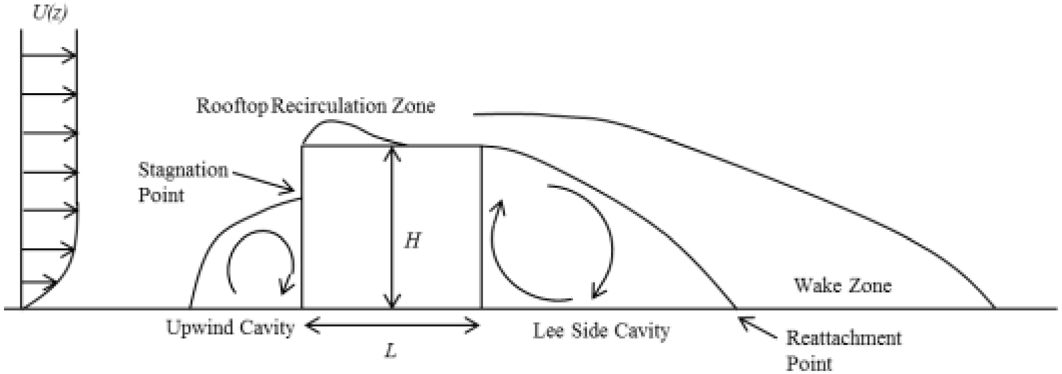
- Quick Urban and Industrial Complex
  - Fast response CFD model developed for Homeland Security
  - QUIC-URB – 3D Wind Model
  - QUIC-CFD – Computational Fluid Dynamics Model
  - QUIC-PLUME – Lagrangian Dispersion Model



QUIC-URB

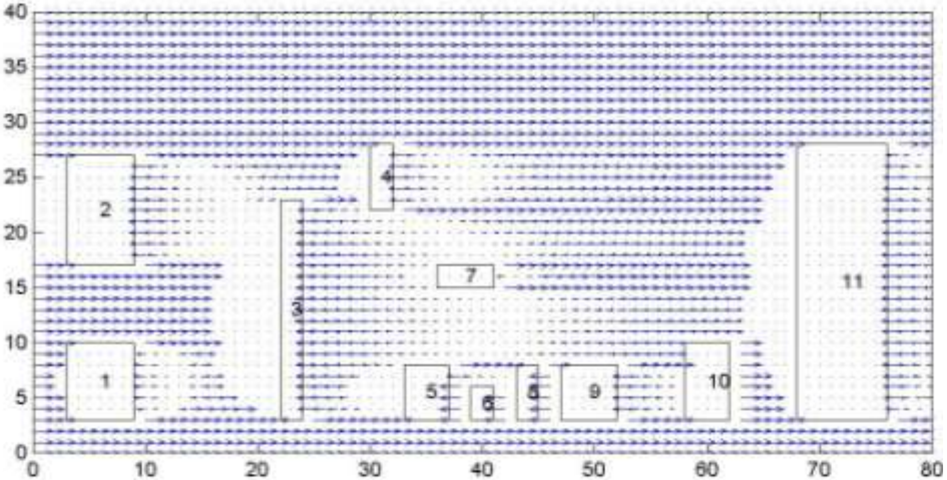
Fast response model

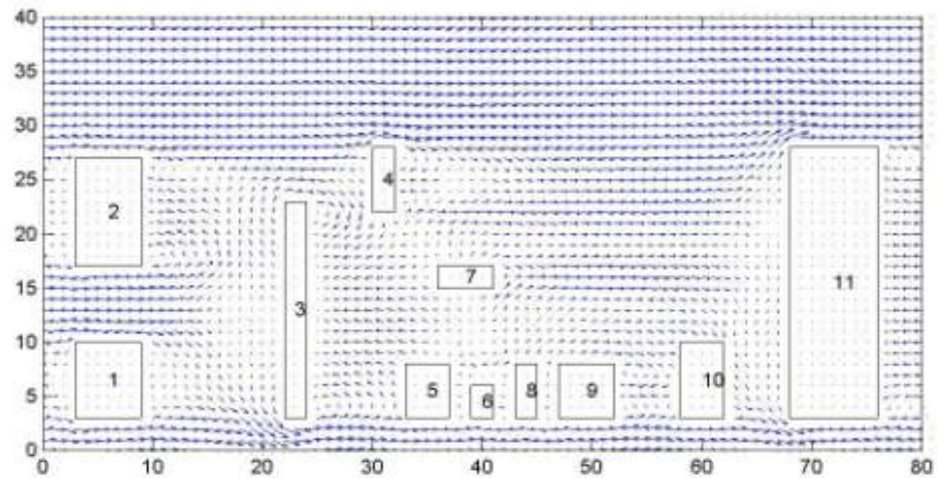




1) Use simple empirical equations to generate initial flow field

2) Satisfies Continuity Equation



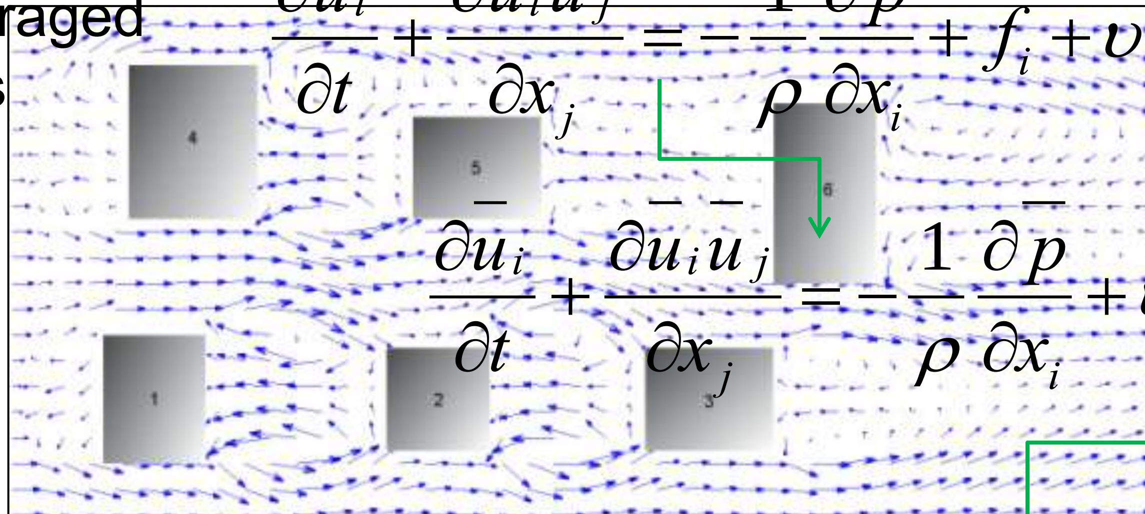


QUIC-CFD

UCR

Solves Simplified 3D Reynolds Averaged Navier-Stokes Equations

QUICURB

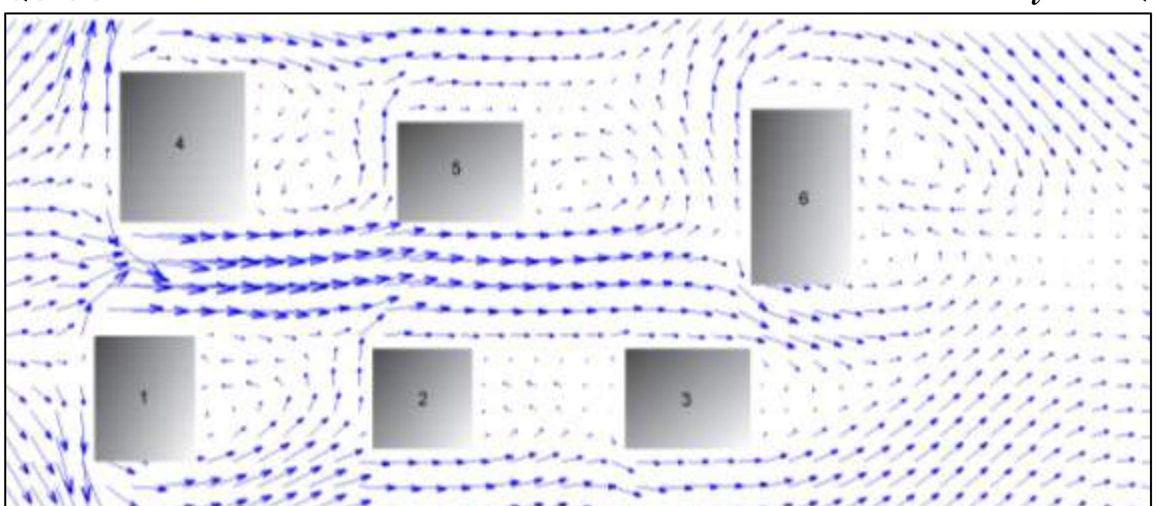


$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial \bar{u}_i \bar{u}_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + f_i + \upsilon \frac{\partial^2 \bar{u}_i}{\partial x_j^2} - \frac{\partial \overline{u_i' u_j'}}{\partial x_j}$$

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial \bar{u}_i \bar{u}_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + \upsilon_t \frac{\partial^2 \bar{u}_i}{\partial x_j^2}$$

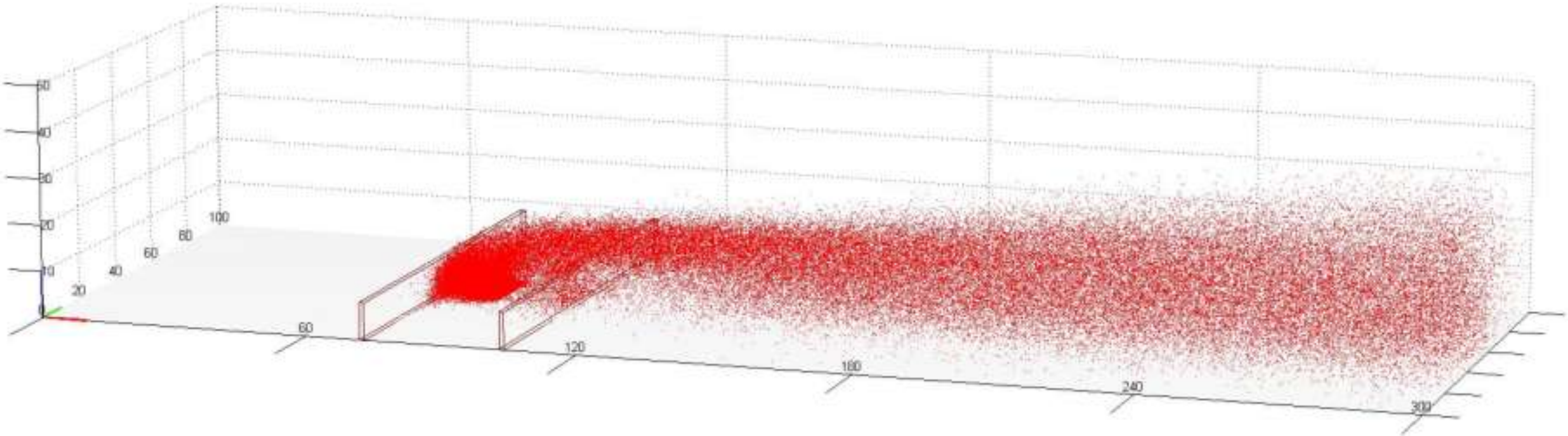
$$\upsilon_t = (l_{mix})^2 \sqrt{\bar{S}_{ij} \bar{S}_{ij}}$$

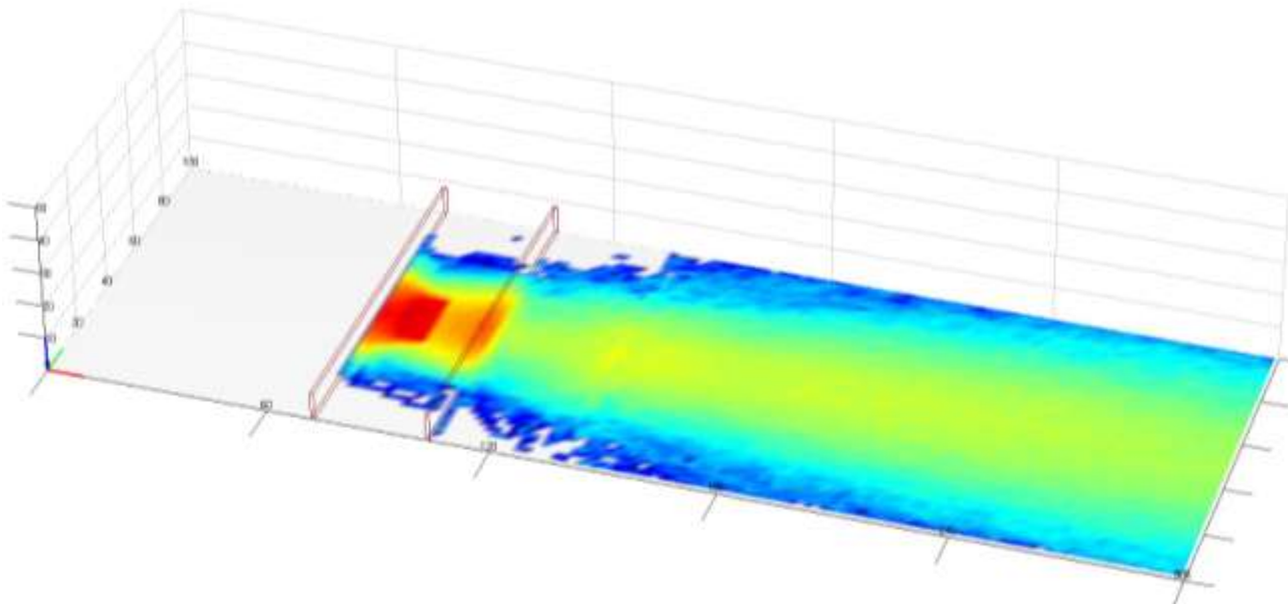
QUICCFD



QUIC-PLUME

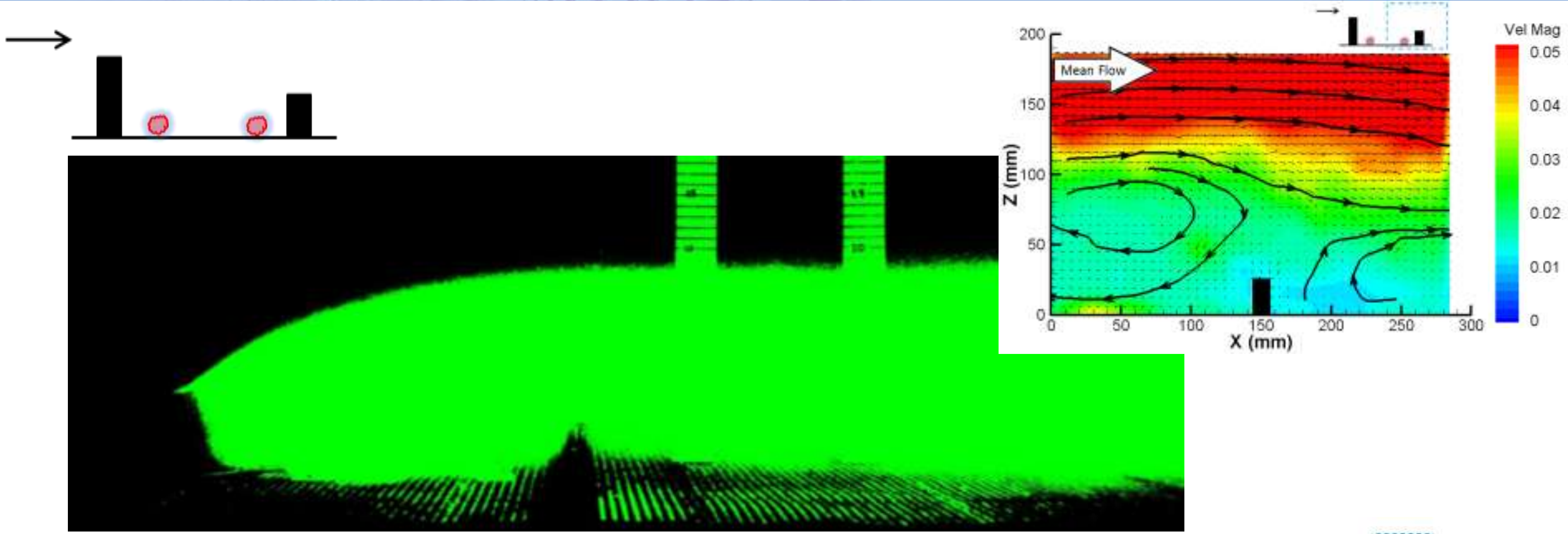
Langrangian Particle Dispersion Model

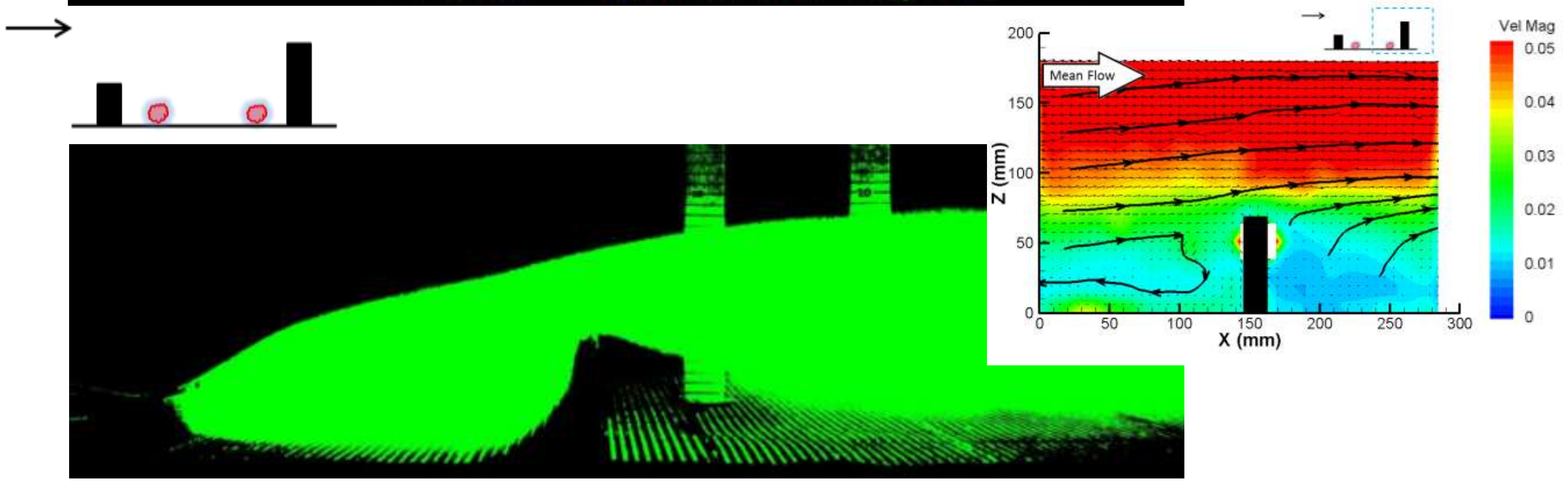




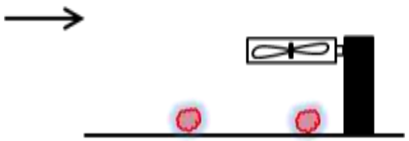
Traffic Influence

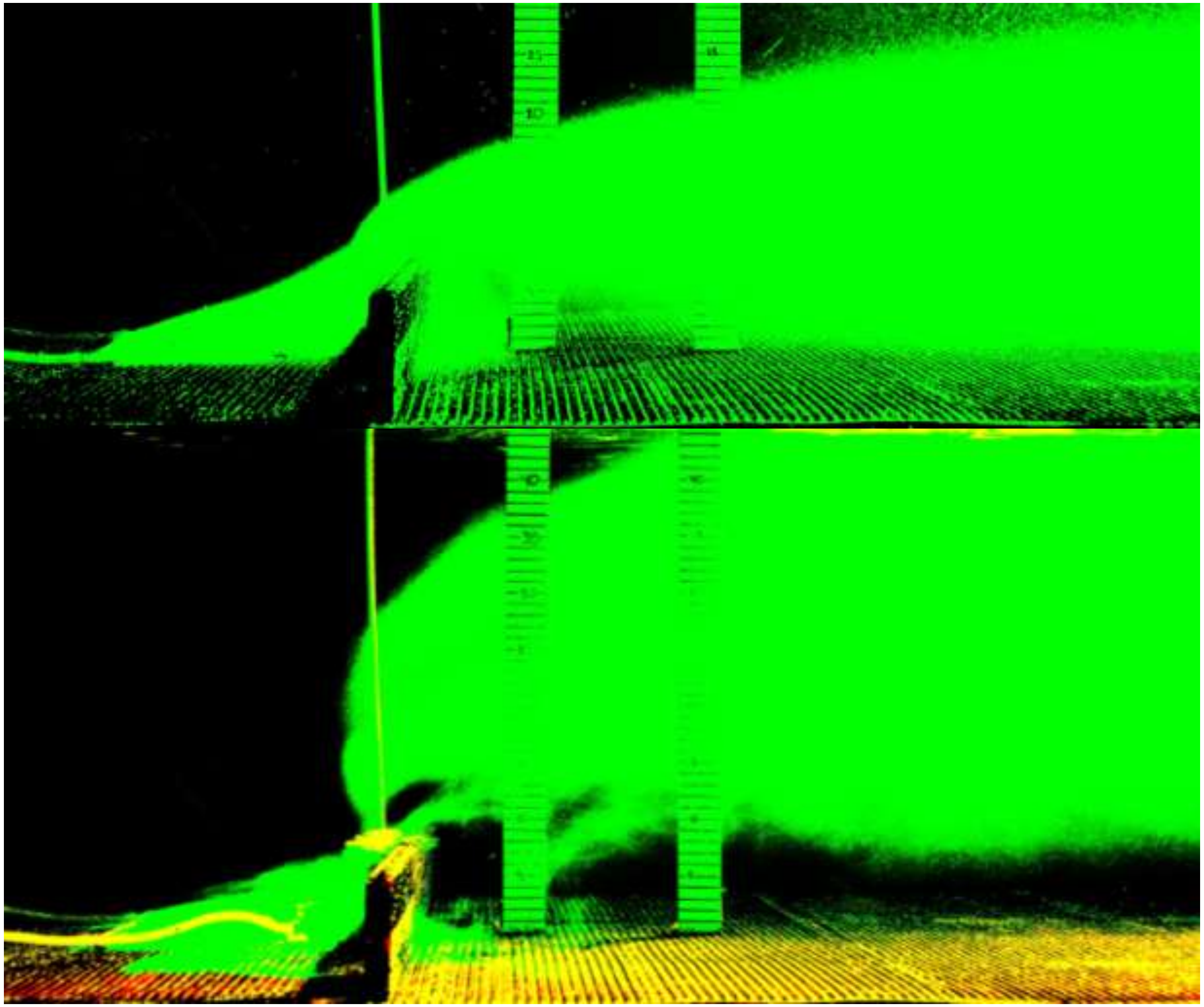
Qualitative Results





Qualitative Results

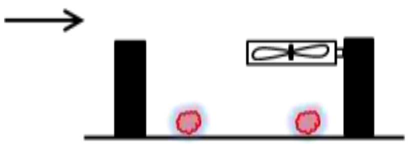




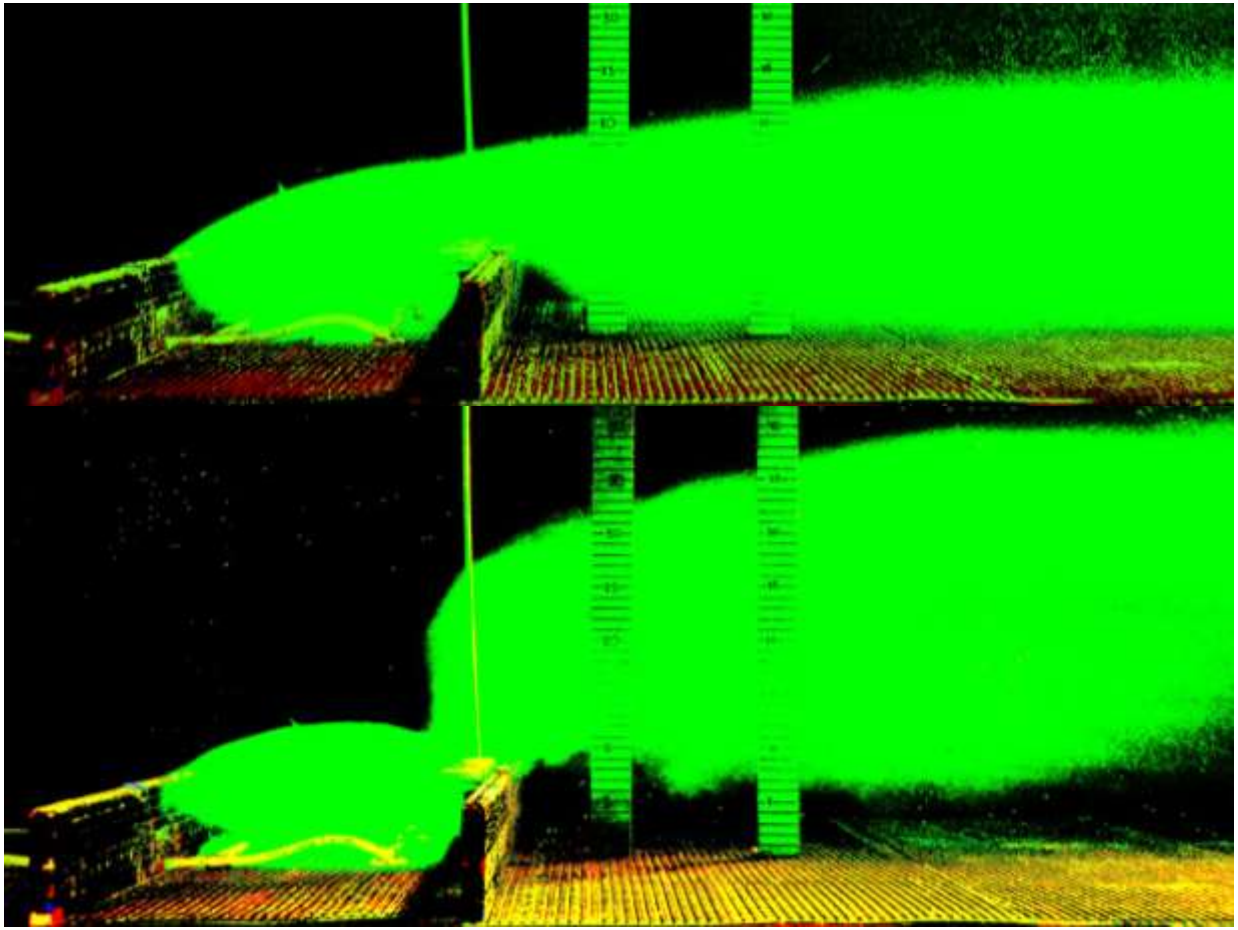
High Wind Speed
Small Fan Blades

Low Wind Speed
Small Fan Blades

Qualitative Results

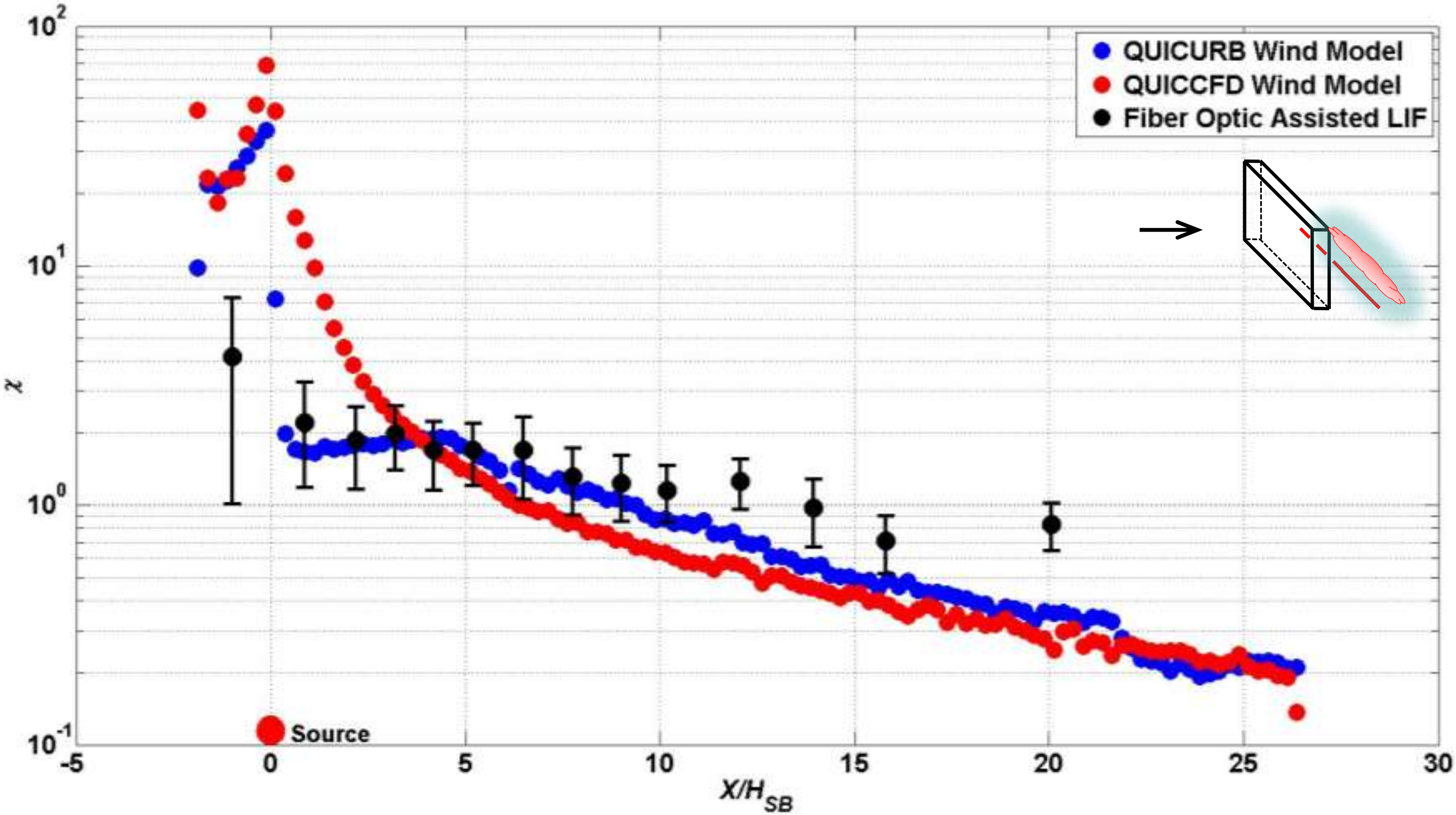


High Wind Speed
Small Fan Blades

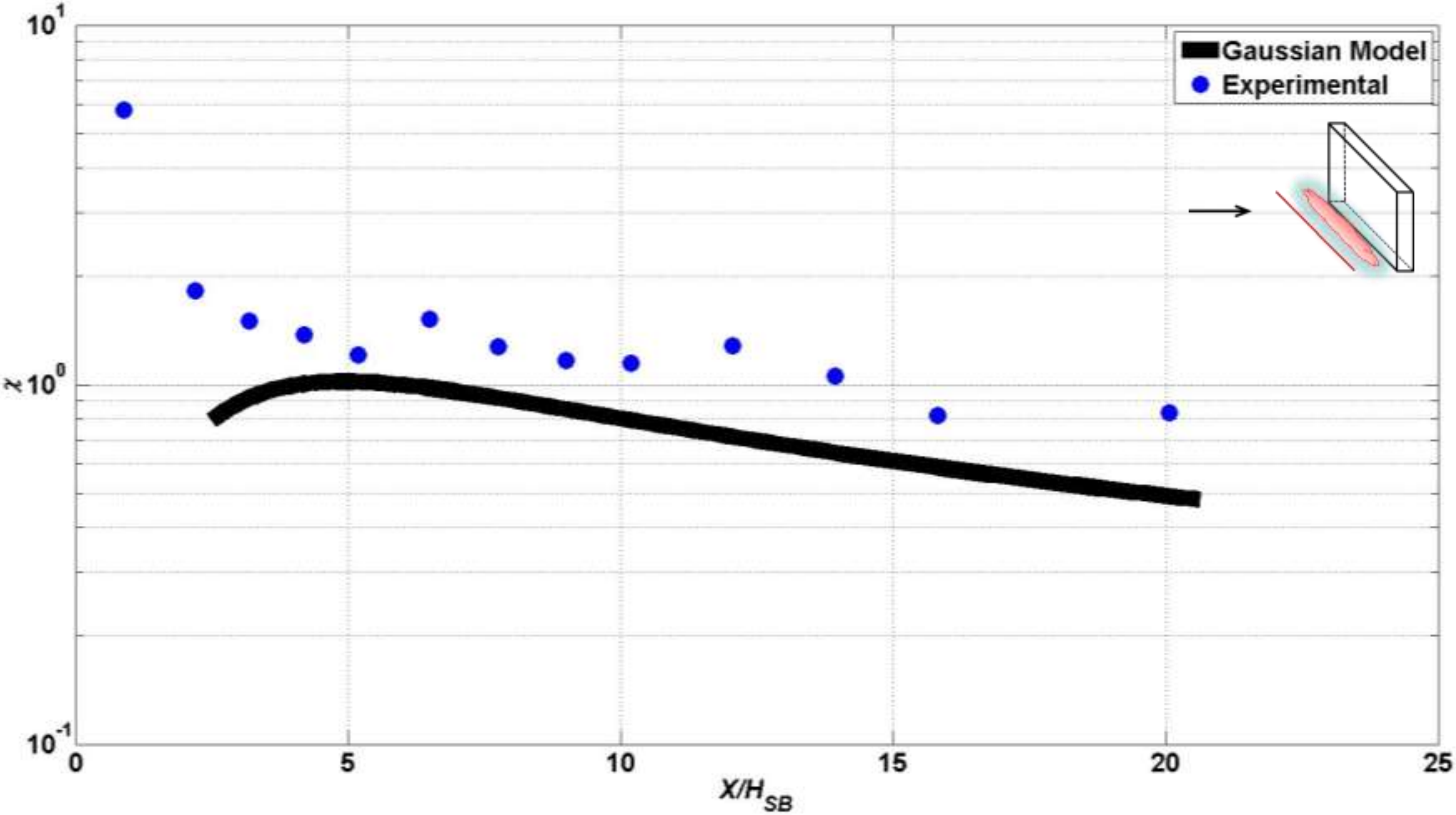


Low Wind Speed
Small Fan Blades

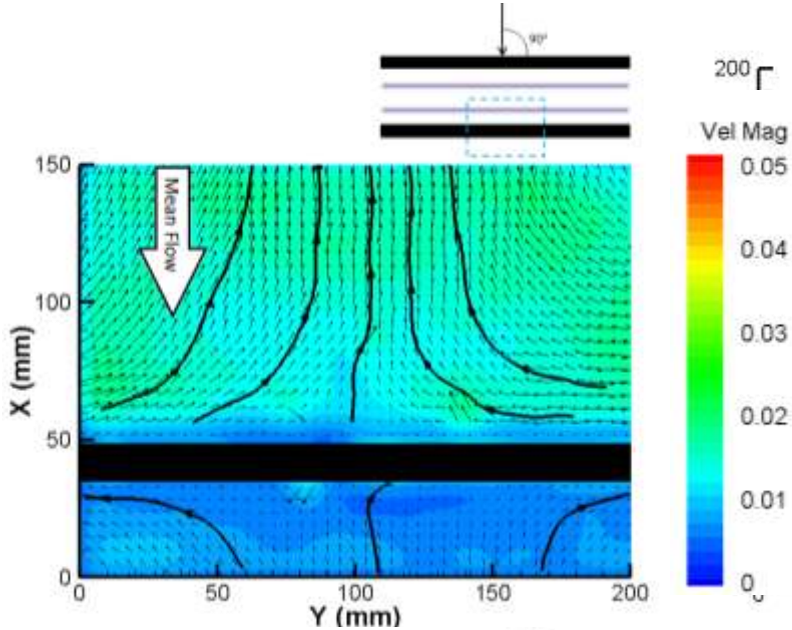
Quantitative Results



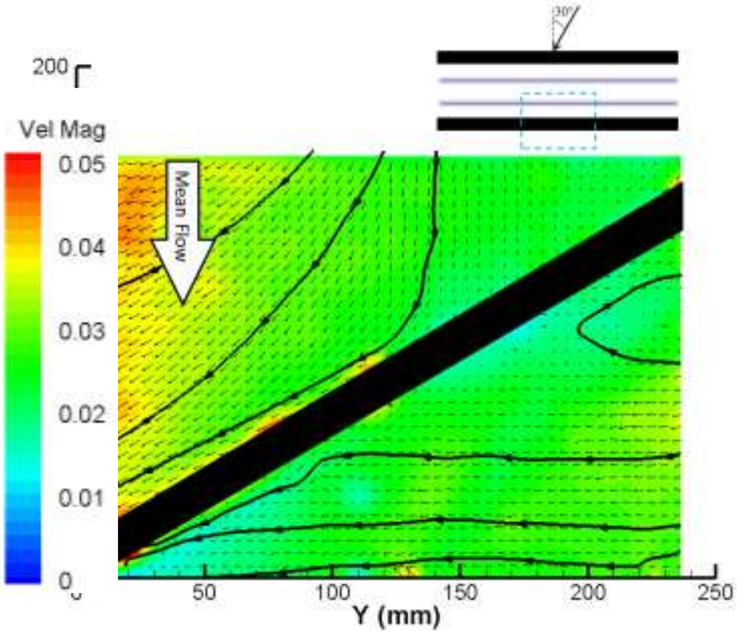
Gaussian Model



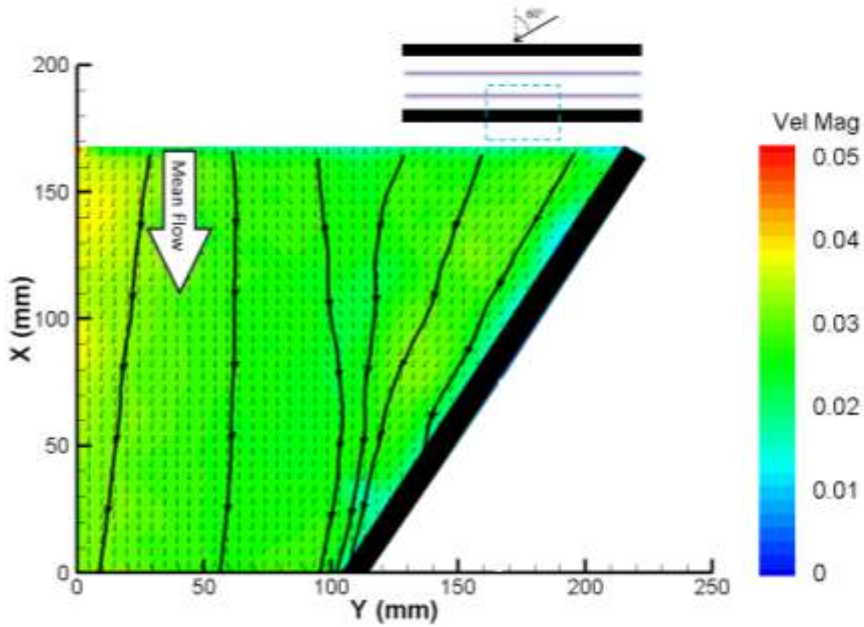
PIV Results



Mean Flow
X (mm)
Y (mm)
0
50
100
150
200
Vel Mag
0.05
0.04
0.03
0.02
0.01
0

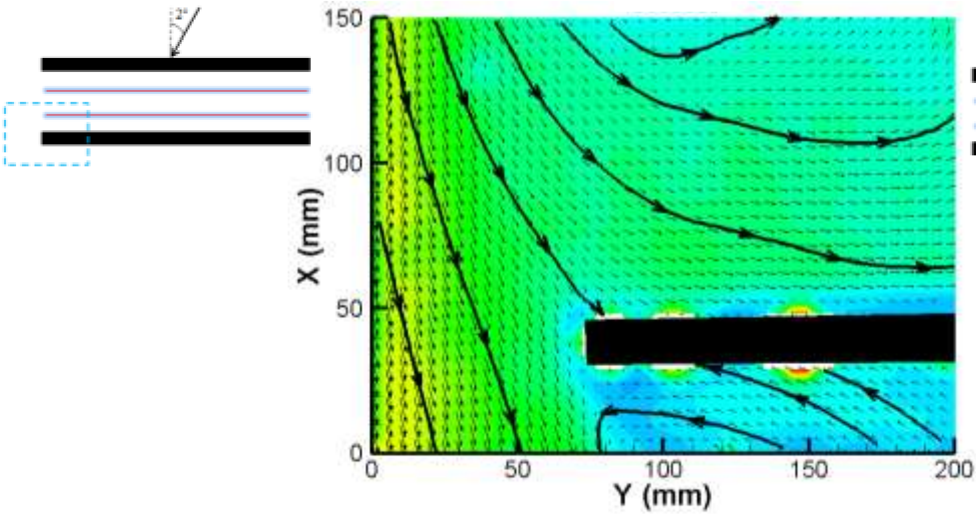


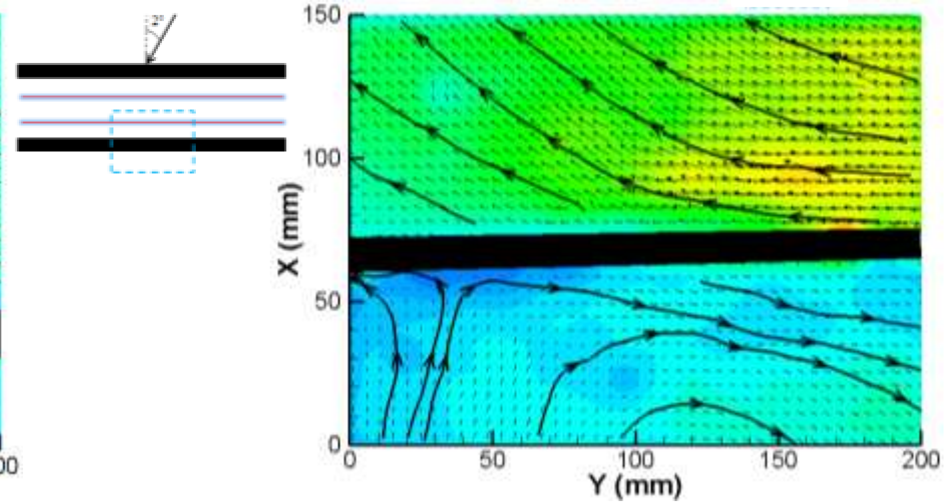
200
Mean Flow
Y (mm)
50
100
150
200
250
Vel Mag
0.05
0.04
0.03
0.02
0.01
0

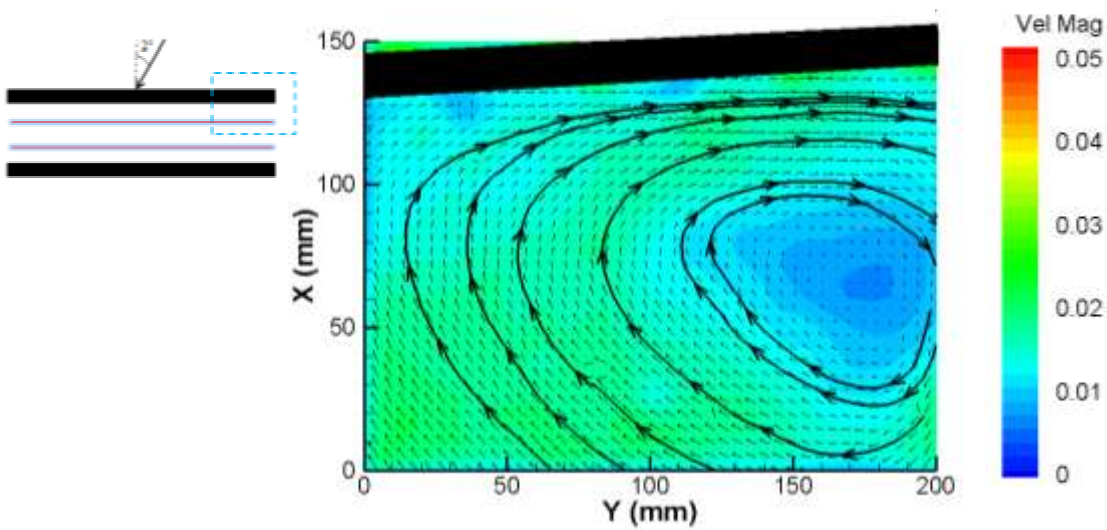


Mean Flow
X (mm)
Y (mm)
0
50
100
150
200
250
Vel Mag
0.05
0.04
0.03
0.02
0.01
0

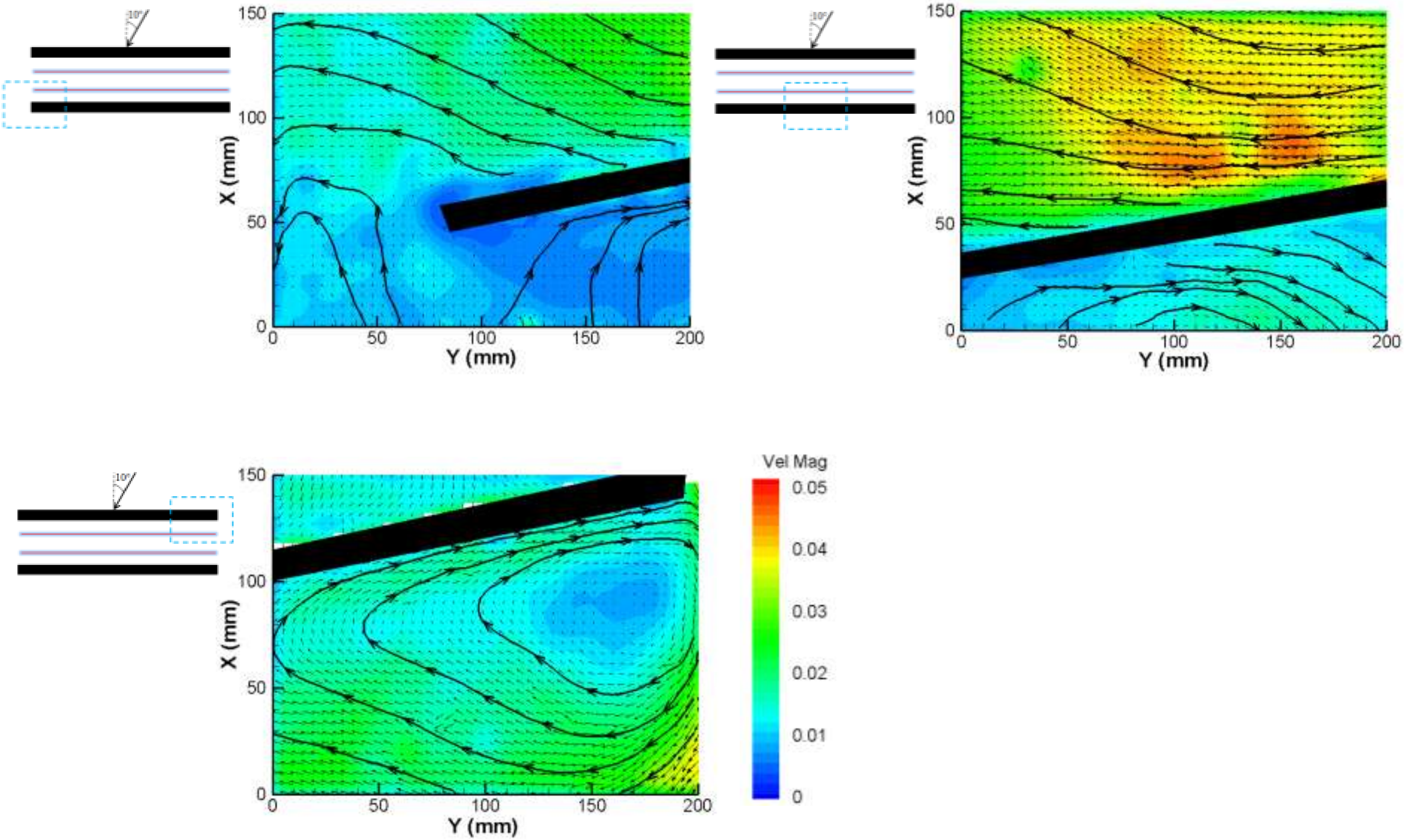
PIV Results


2°
150
100
50
0
X (mm)
0
50
100
150
200
Y (mm)

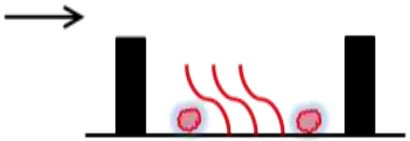

2°
150
100
50
0
X (mm)
0
50
100
150
200
Y (mm)


150
100
50
0
X (mm)
0
50
100
150
200
Y (mm)
Vel Mag
0.05
0.04
0.03
0.02
0.01
0

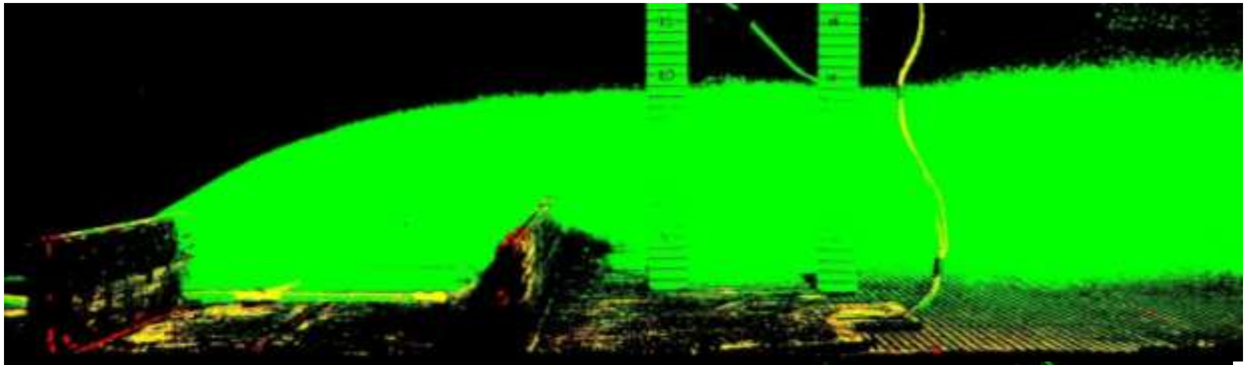
PIV Results



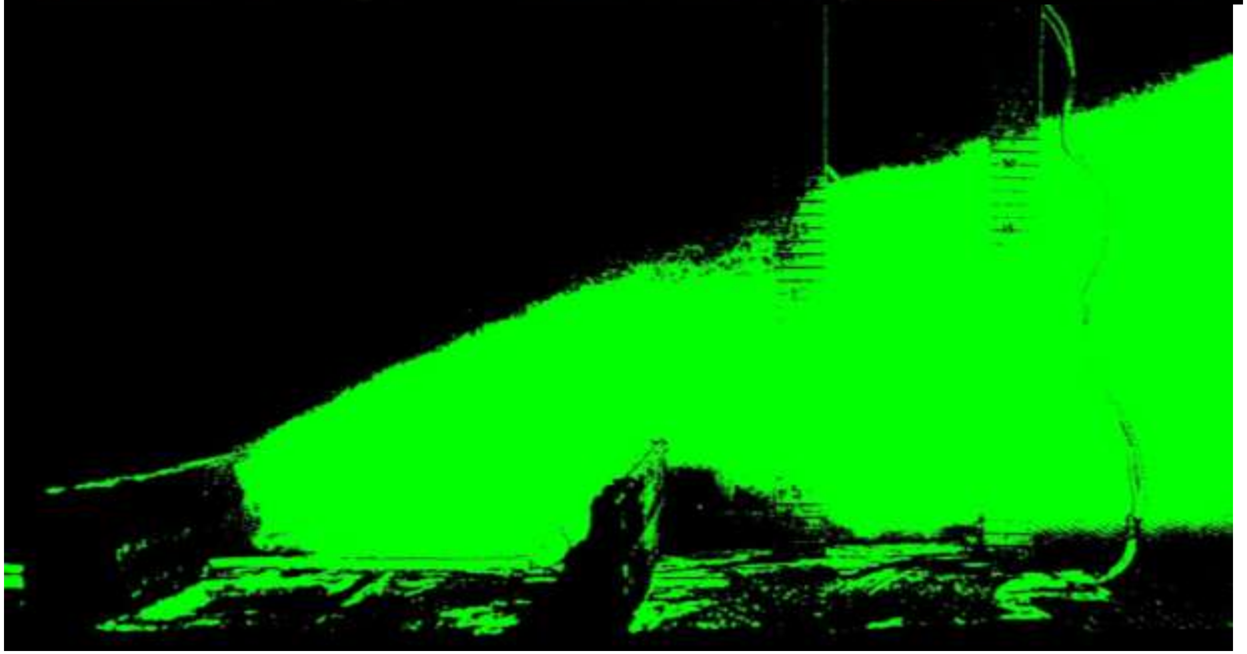
Qualitative Results



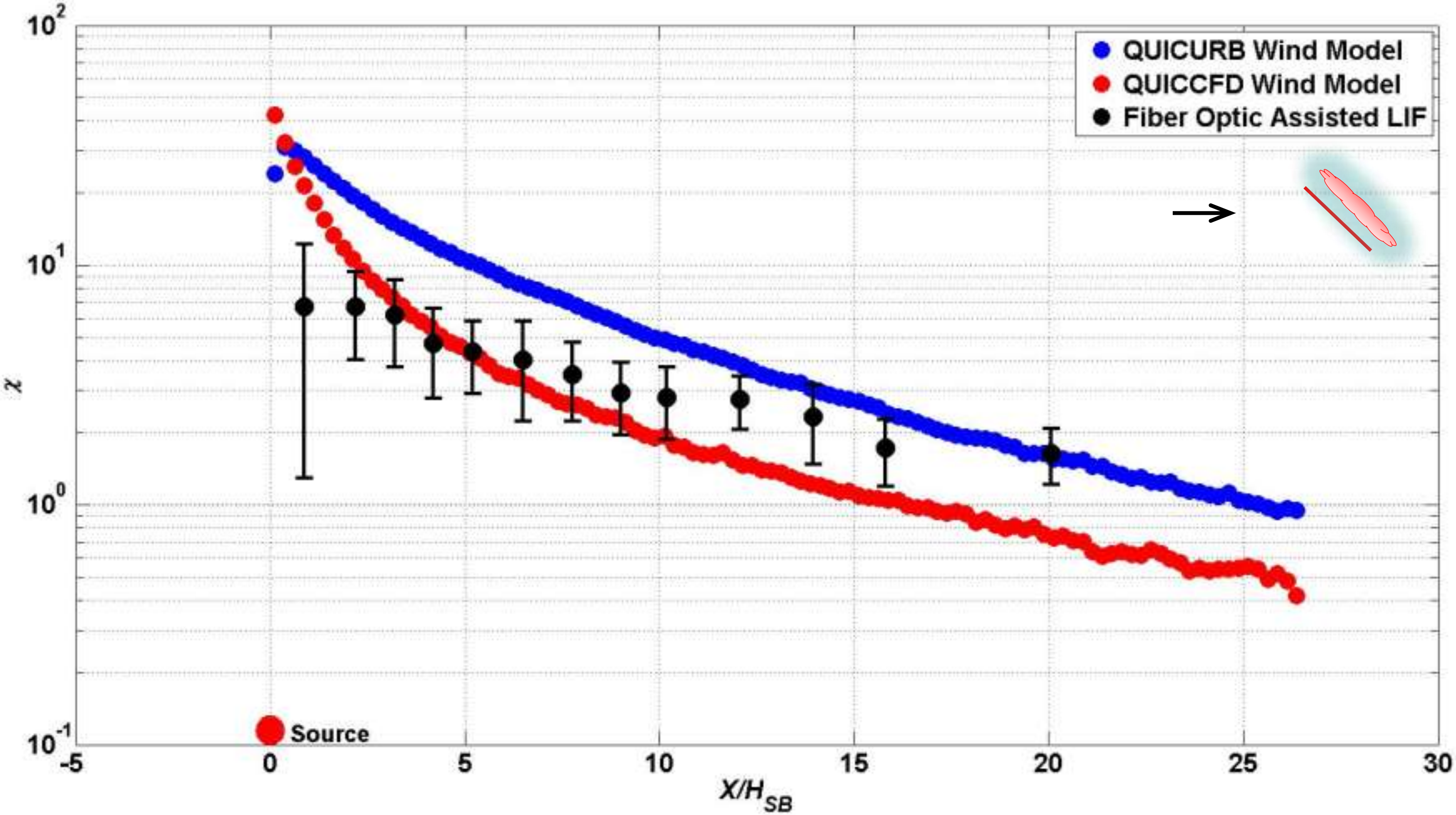
High Wind Speed



Low Wind Speed

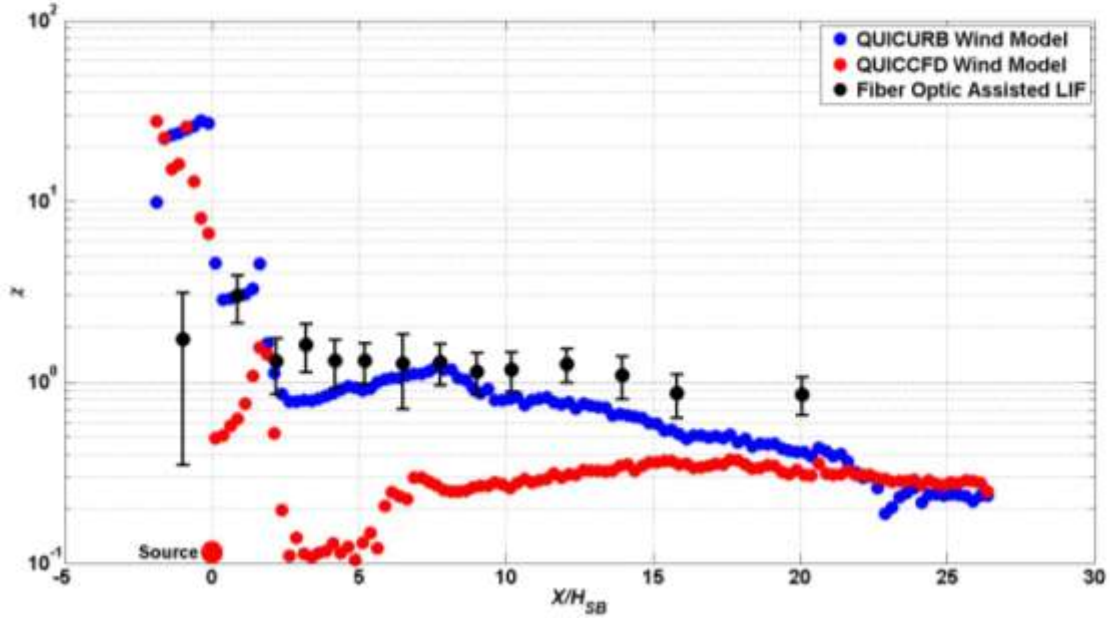


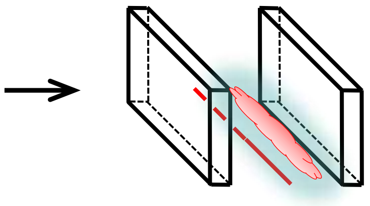
Quantitative Results



Quantitative Results

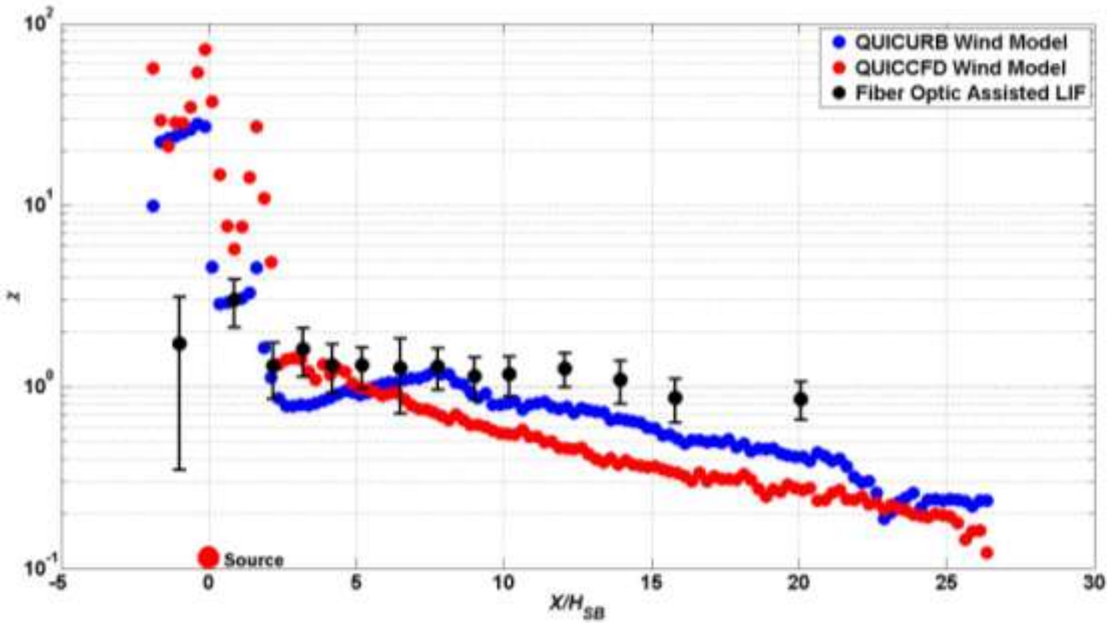
l_{mix} = Default



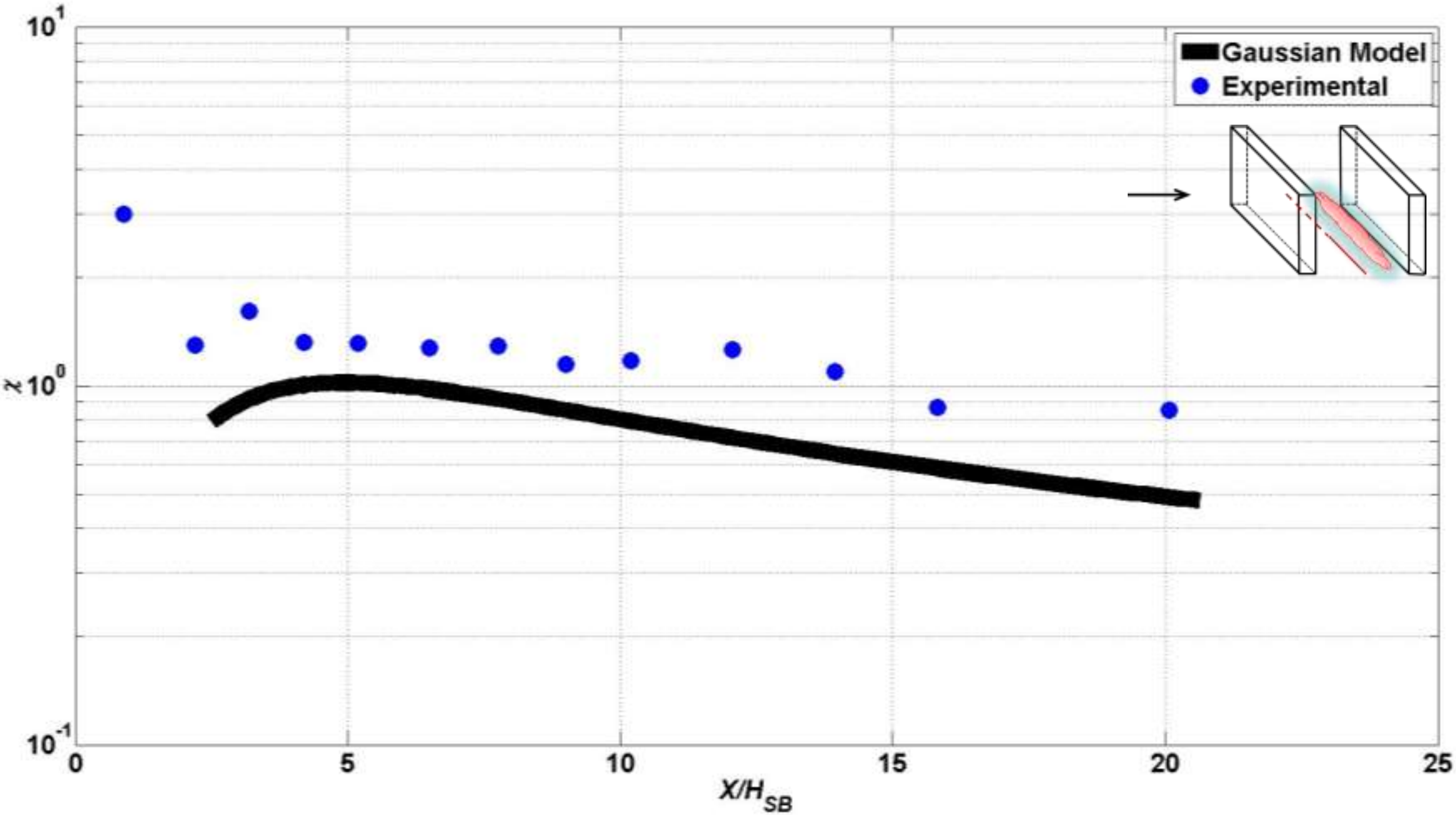


$$\upsilon_t = (l_{mix})^2 \sqrt{\overline{S}_{ij}\overline{S}_{ij}}$$

l_{mix} = 30



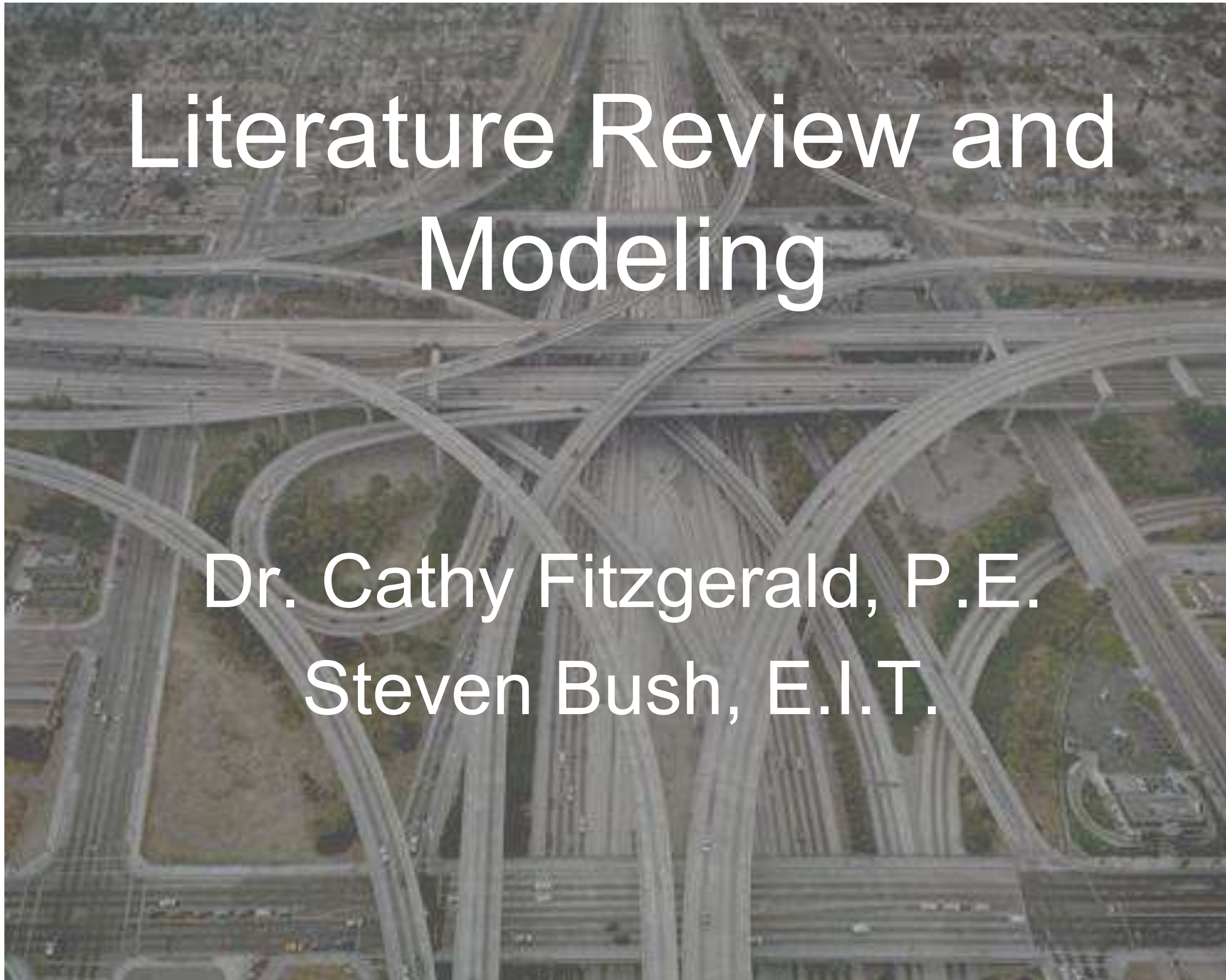
Gaussian Model



Back to Agenda

Literature Review and Modeling

Dr. Cathy Fitzgerald, P.E.
Steven Bush, E.I.T.



THE PLANNING CENTER DC&E

Literature Review

Passive

- Sound walls
- Vegetation
- Roadway configuration
- Harder wearing vehicle tires
- More durable brake pads/ partial enclosure
- Regenerative braking
- Porous asphalt

Active

- Photocatalytic cement
- Dust suppressants
- Roadway sweeping
- Ventilation – Plexiglass canopy; street canyons
- Filtration
- Electrostatic precipitation
- Axial fans on sound walls
- Biofiltration – soil beds

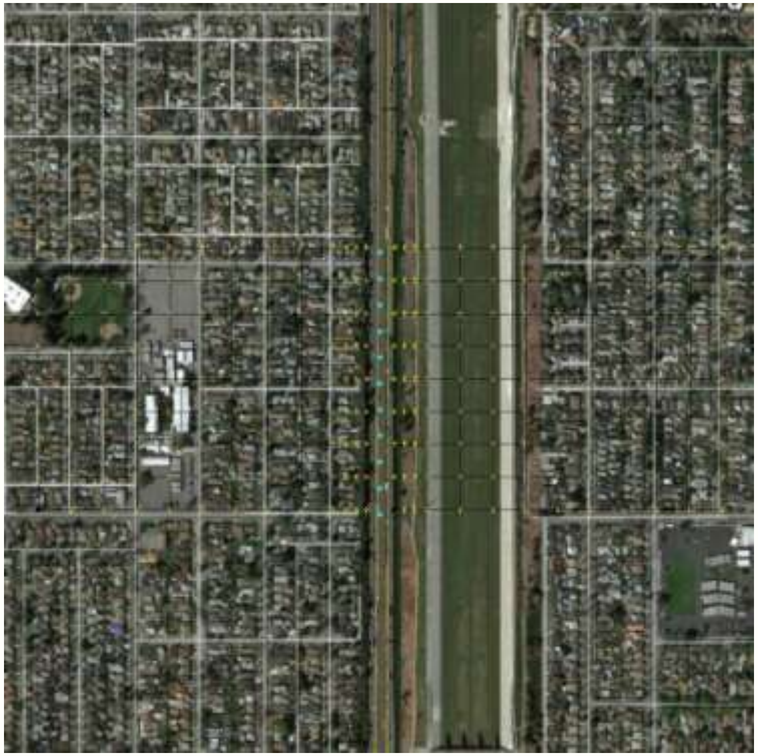
The Great Wall of Mulch – Terminal Island Freeway

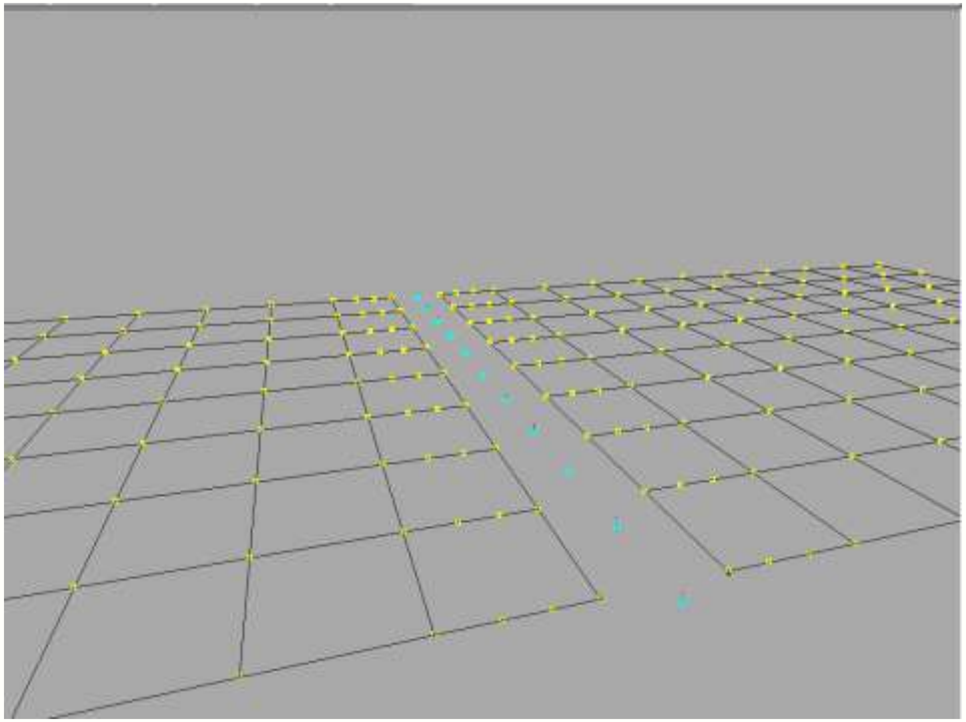
- 12-feet high, 3 feet thick, 600 feet long
- Tree clippings – City of Long Beach
- Sound attenuation; pollution mitigation; graffiti free

AERMOD Modeling

- Sound walls – straight and cloverleaf
- Vegetation
- Axial fans on sounds walls
- Multi-story buildings
- Biofiltration in cloverleaf

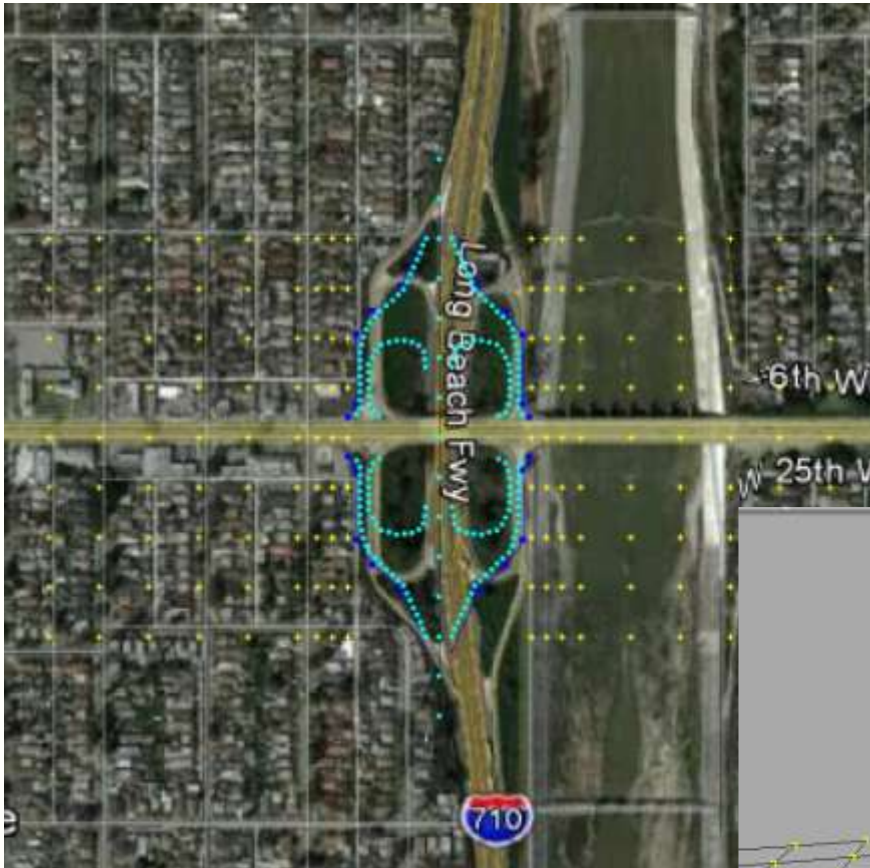
LONG BEACH FREEWAY



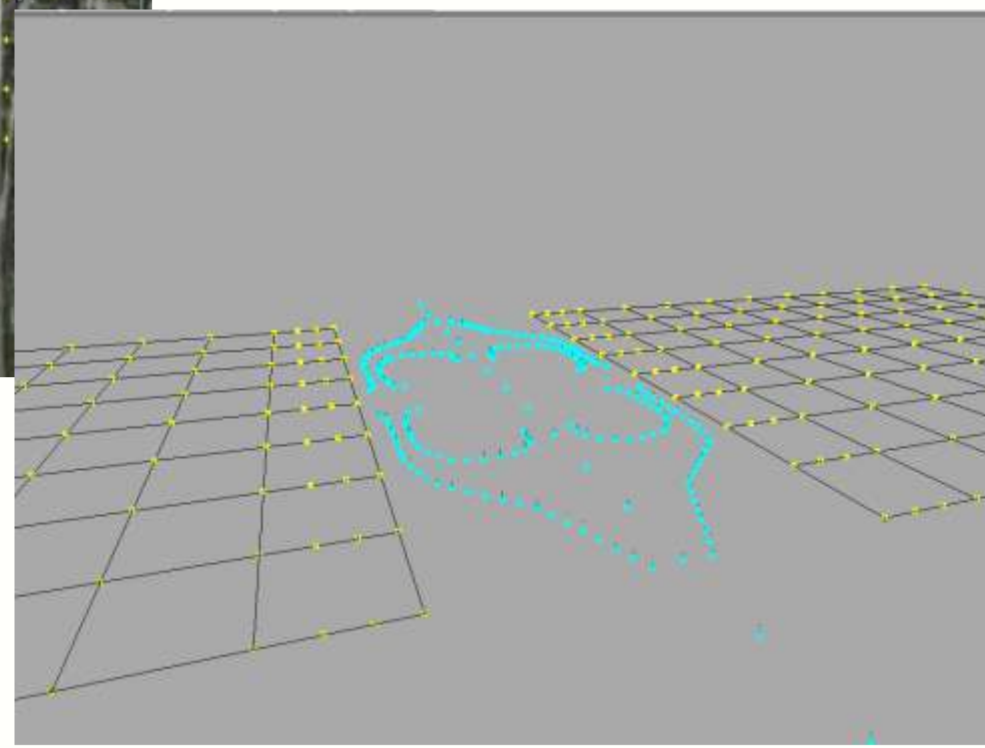


- Traffic volume from CalTrans
- Emission rate – 1 lb/hr
- 1,000 foot segment
- Point source

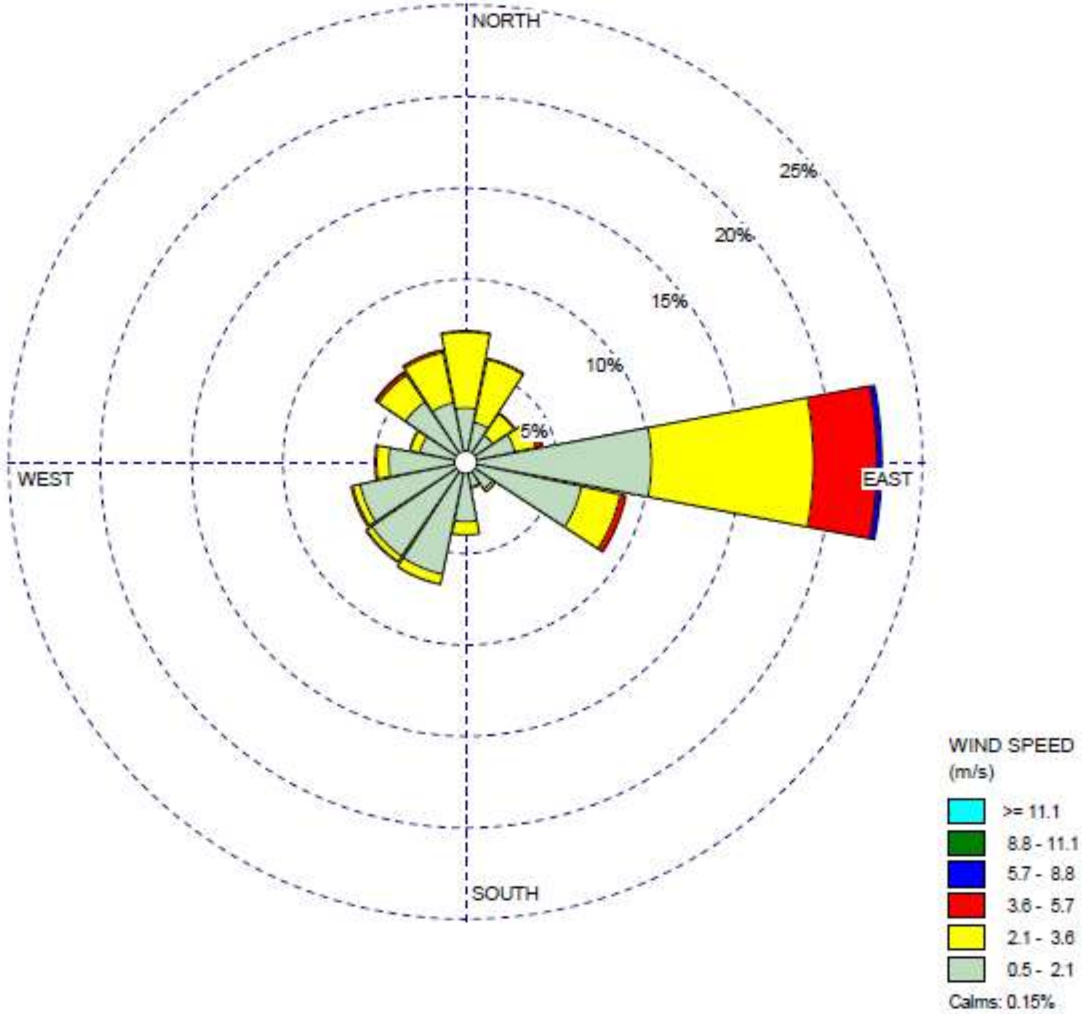
- Downwash
- Release height – 4.15 m
- Release diameter – 6 inches
- Ambient temperature



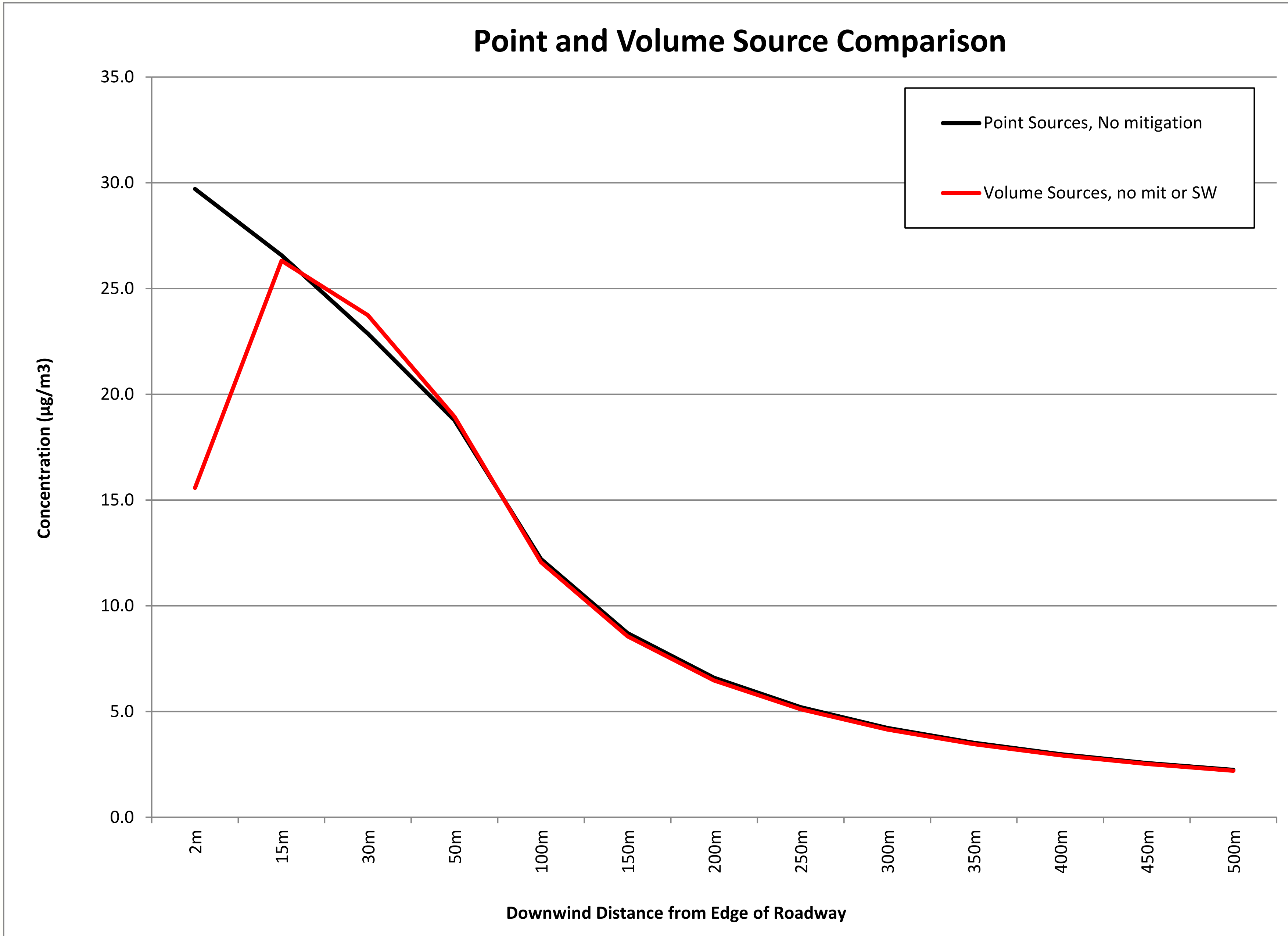
CLOVERLEAF - FREEWAY

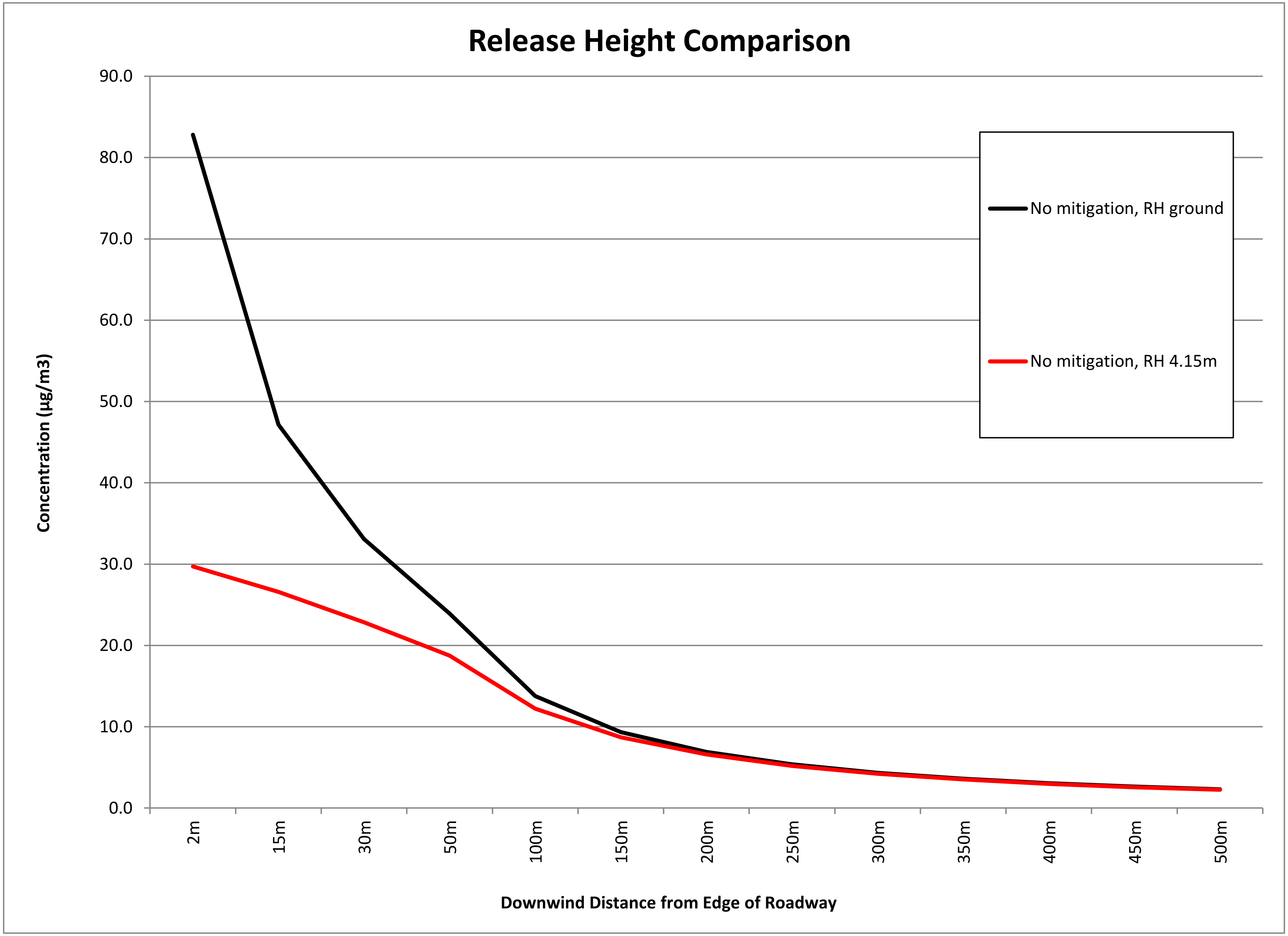


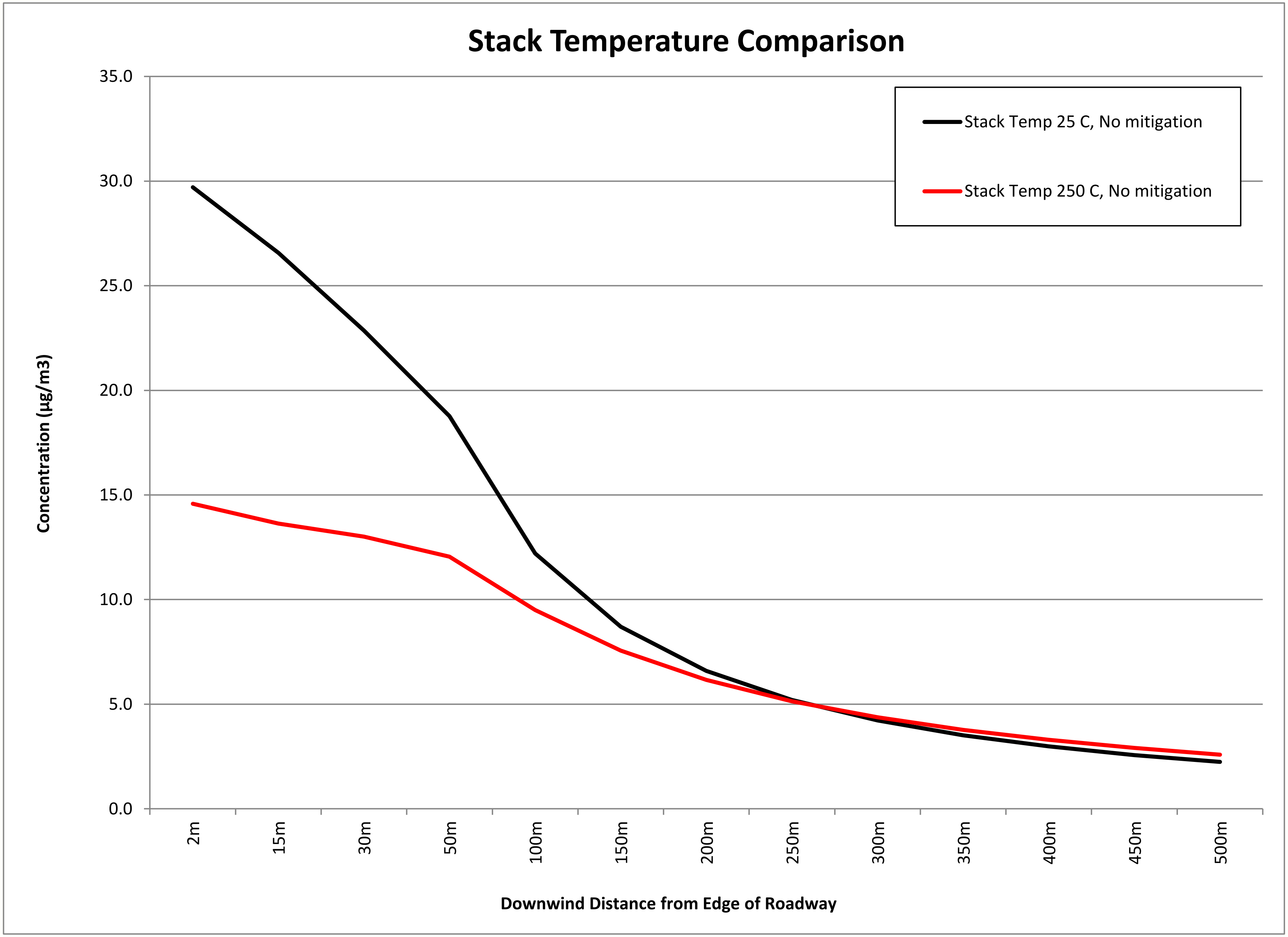
WIND ROSE – LONG BEACH



AERMOD Output

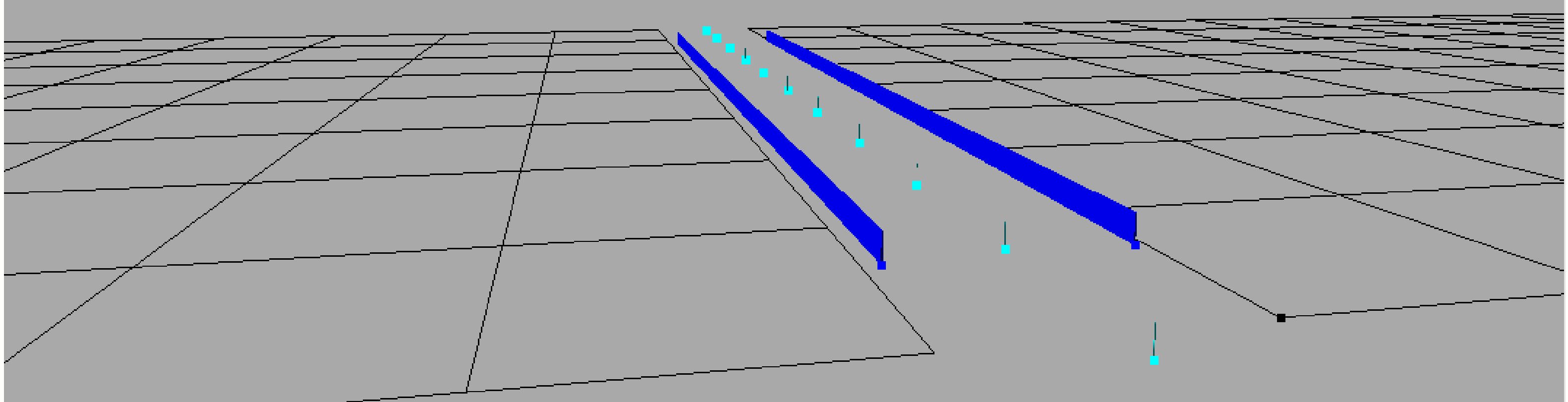

Point and Volume Source Comparison
Point Sources, No mitigation
Volume Sources, no mit or SW
Concentration (µg/m3)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway

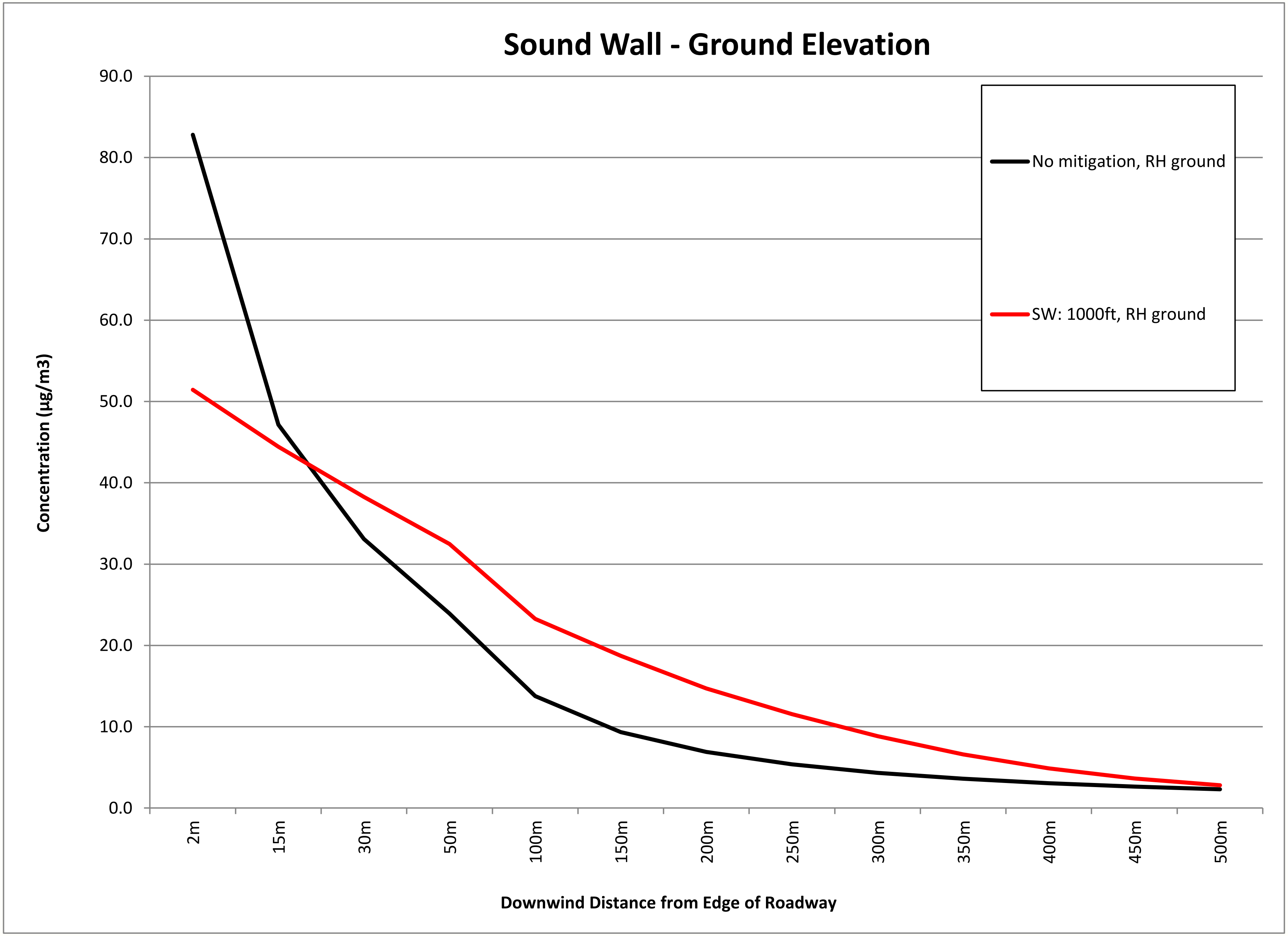

Release Height Comparison
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Concentration (µg/m3)
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
No mitigation, RH ground
No mitigation, RH 4.15m

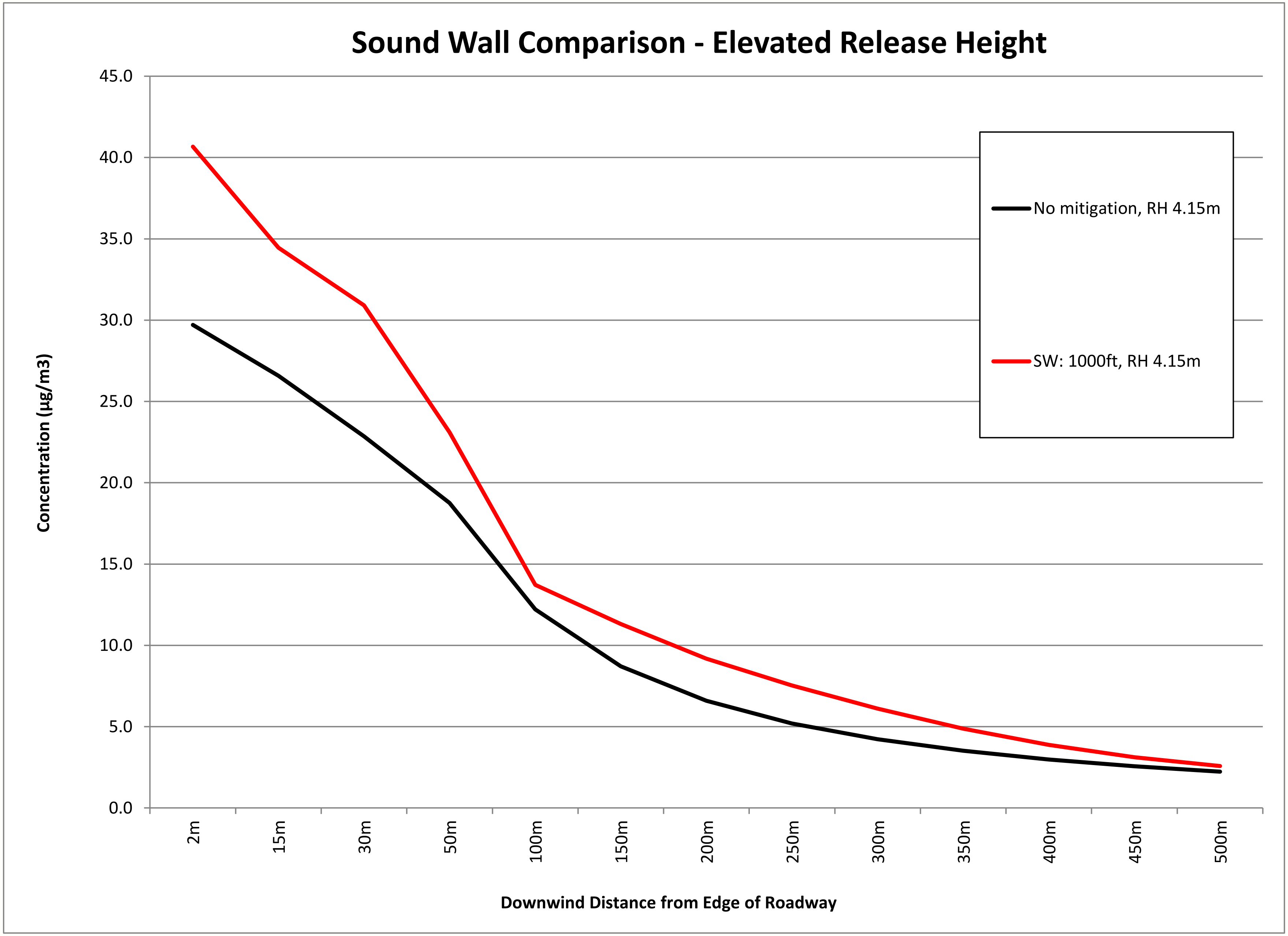

Stack Temperature Comparison
Concentration (µg/m3)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
Stack Temp 25 C, No mitigation
Stack Temp 250 C, No mitigation

SOUND WALL

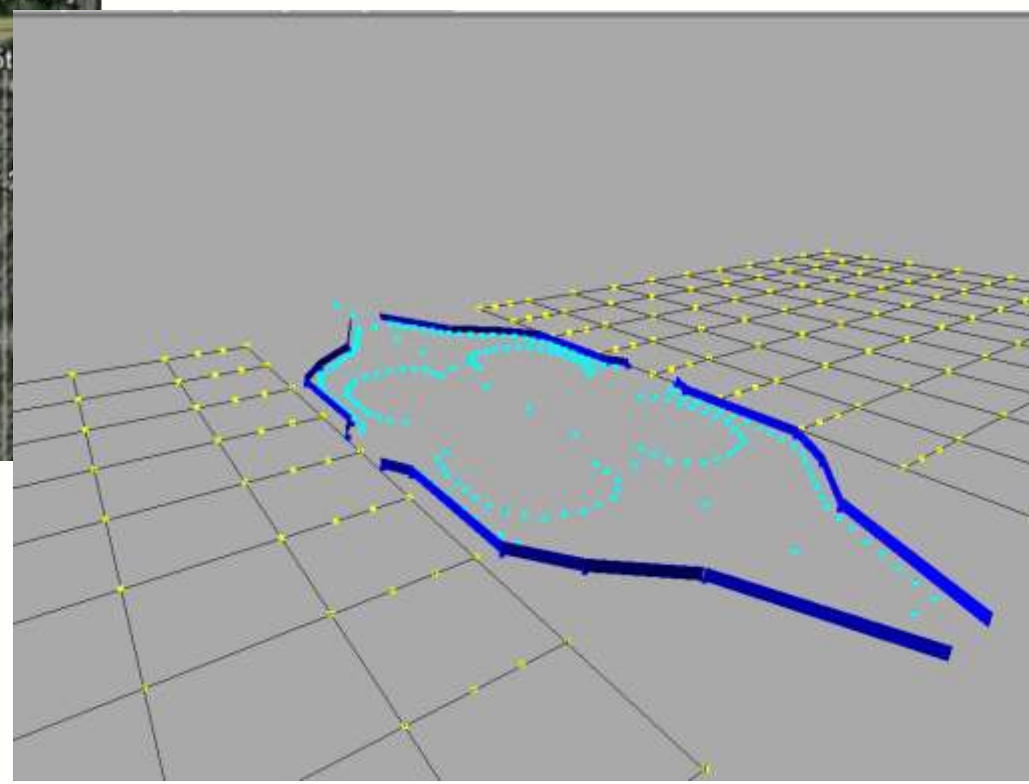
- 5 m high
- 1 foot wide
- 1,000 feet long
- Point sources
- Downwash



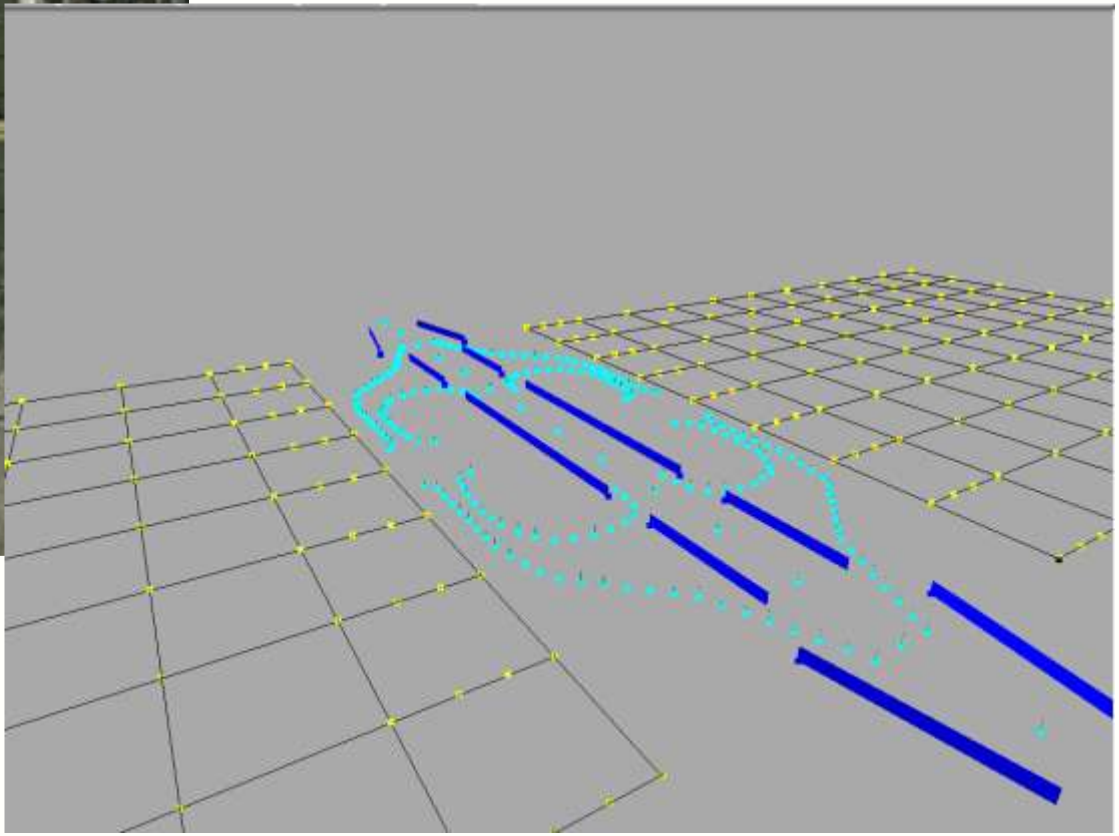


Sound Wall - Ground Elevation
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Concentration (µg/m3)
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
No mitigation, RH ground
SW: 1000ft, RH ground

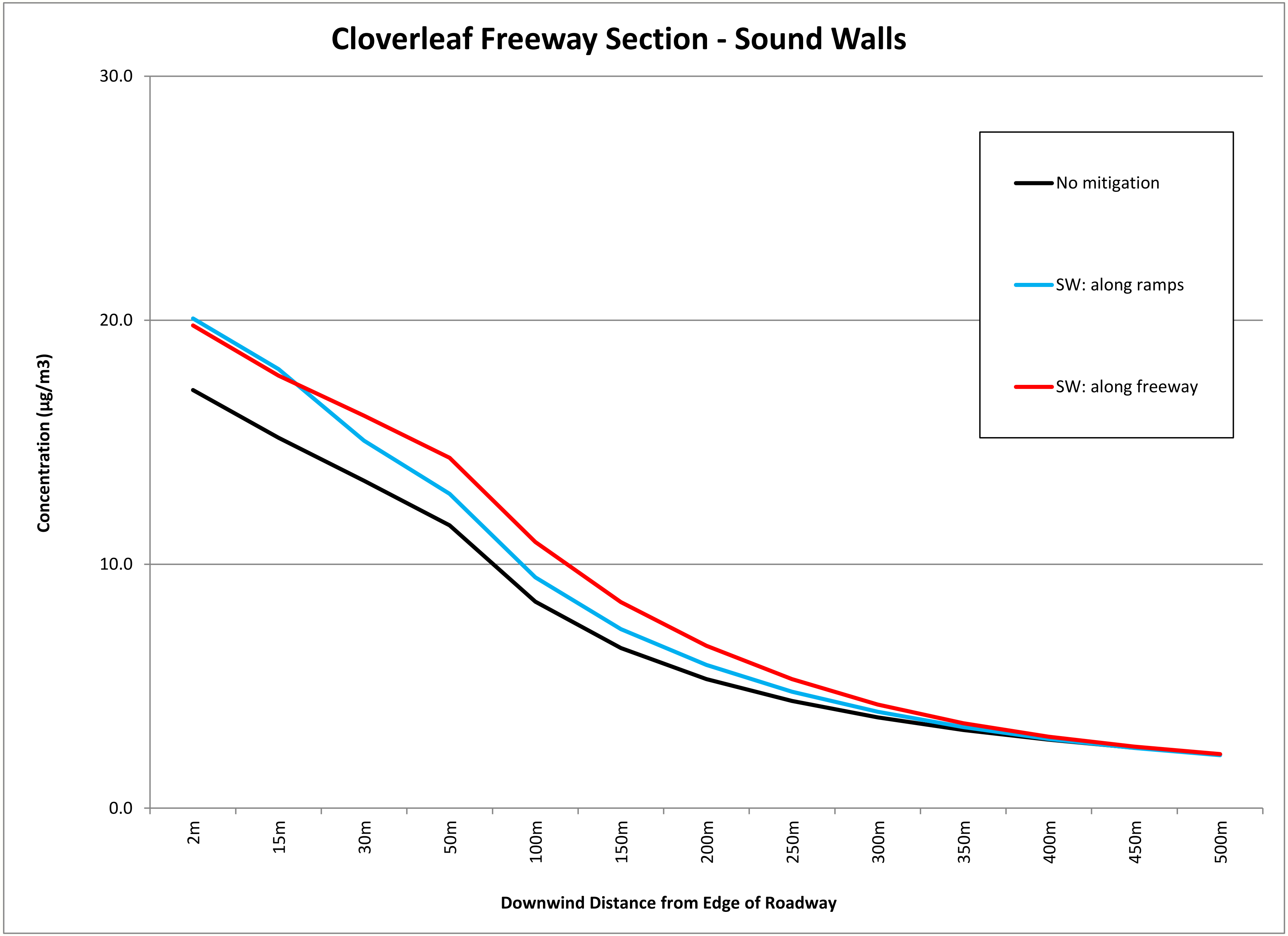

Sound Wall Comparison - Elevated Release Height
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Concentration (µg/m3)
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
No mitigation, RH 4.15m
SW: 1000ft, RH 4.15m

Cloverleaf Configuration 1



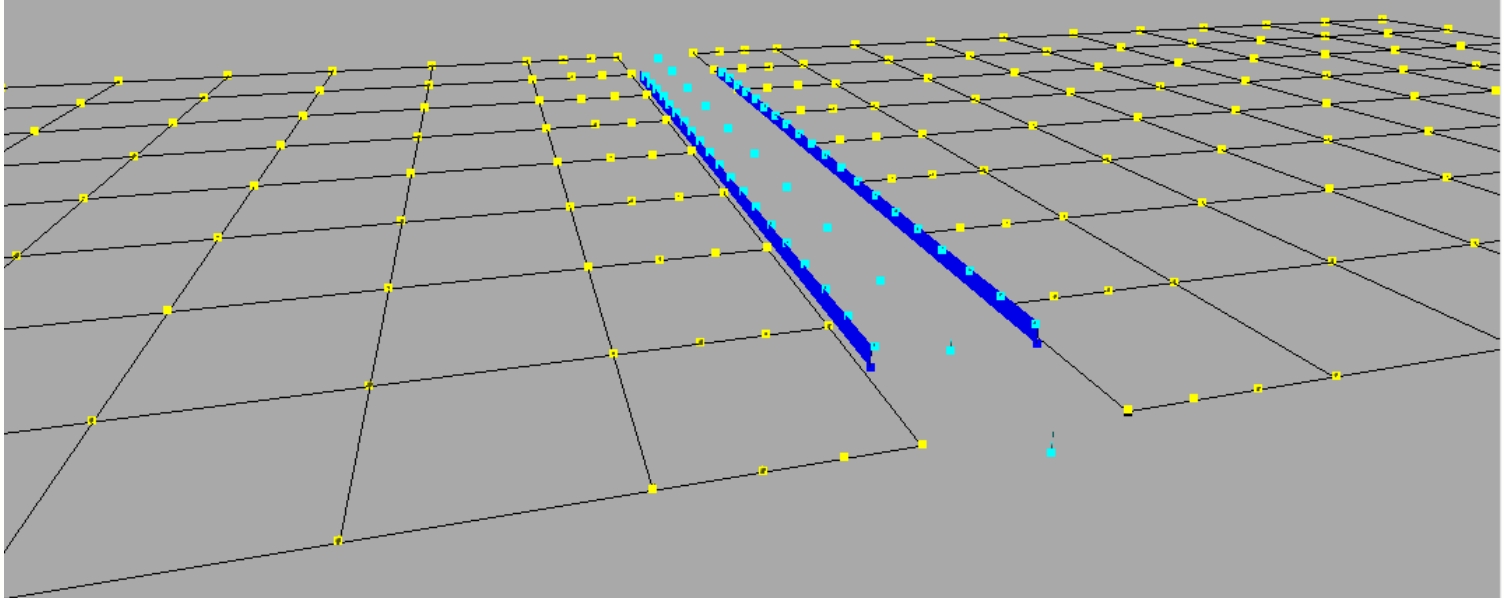
Cloverleaf Configuration 2

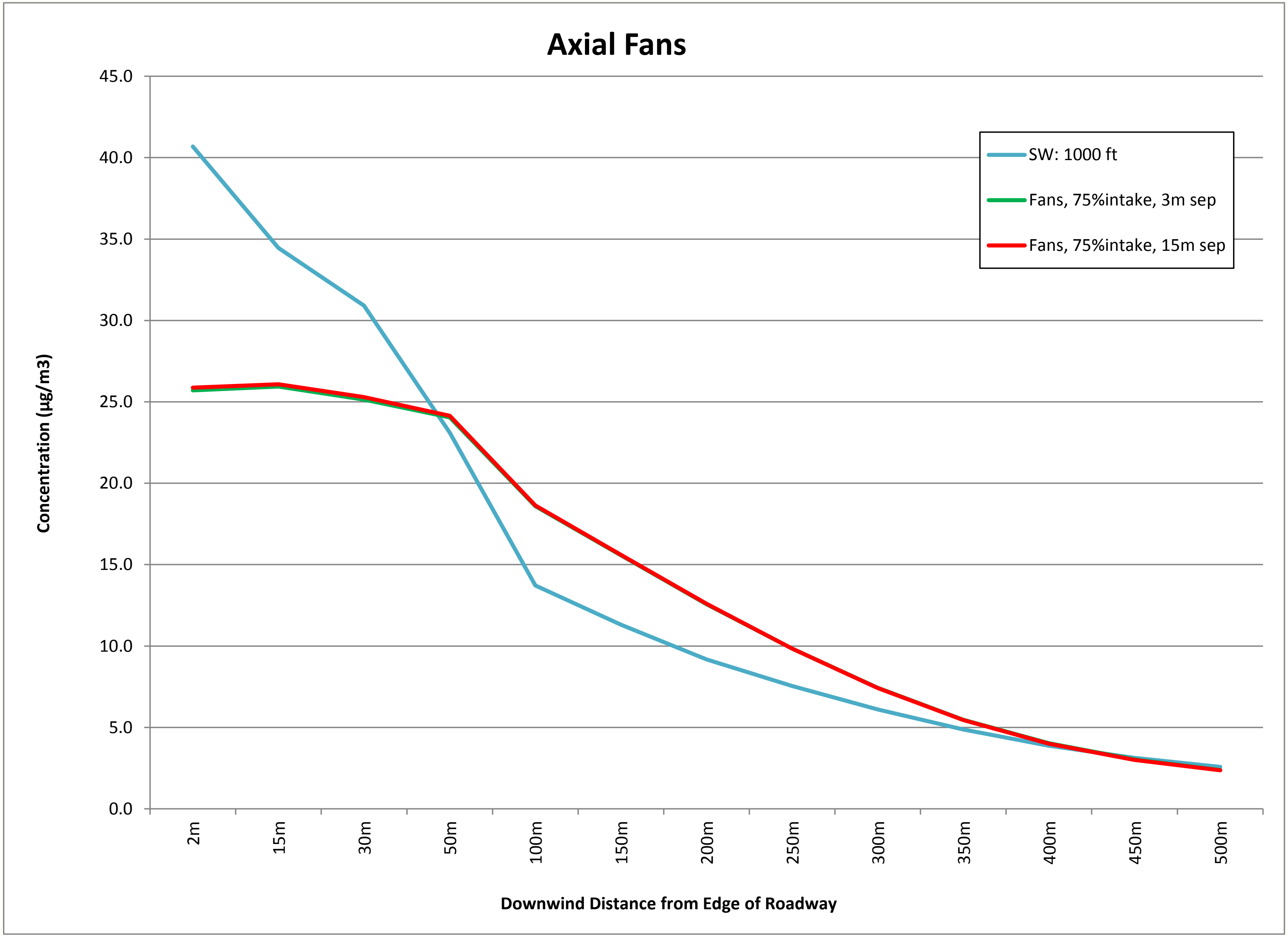



Cloverleaf Freeway Section - Sound Walls
30.0
20.0
10.0
0.0
Concentration (µg/m3)
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
No mitigation
SW: along ramps
SW: along freeway

Axial Fans

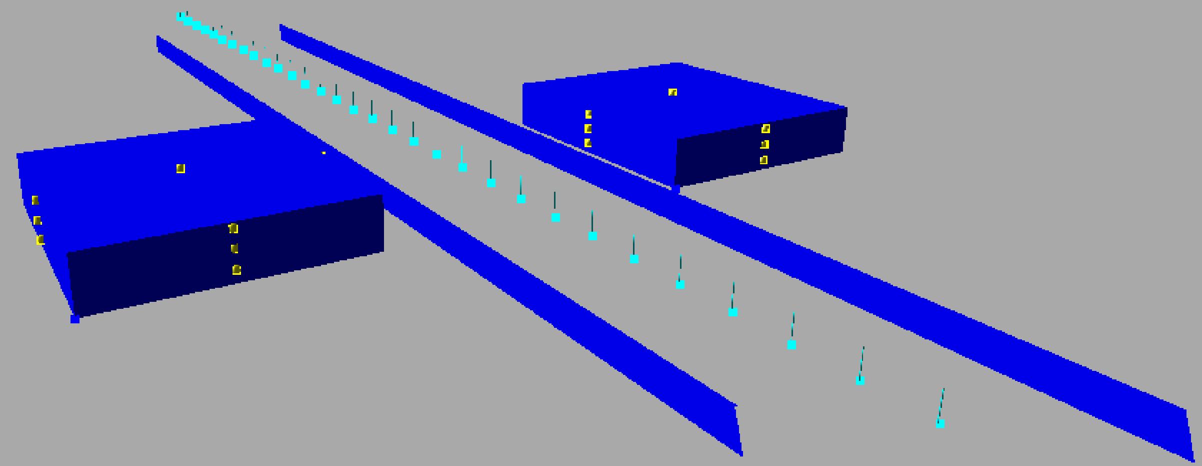
- 5 m elevation
- 2.6 feet inside each sound wall
- Height – 2 feet
- Velocity – 7 m/sec
- Diameter – 2 feet
- 75% capture, 25% bypass

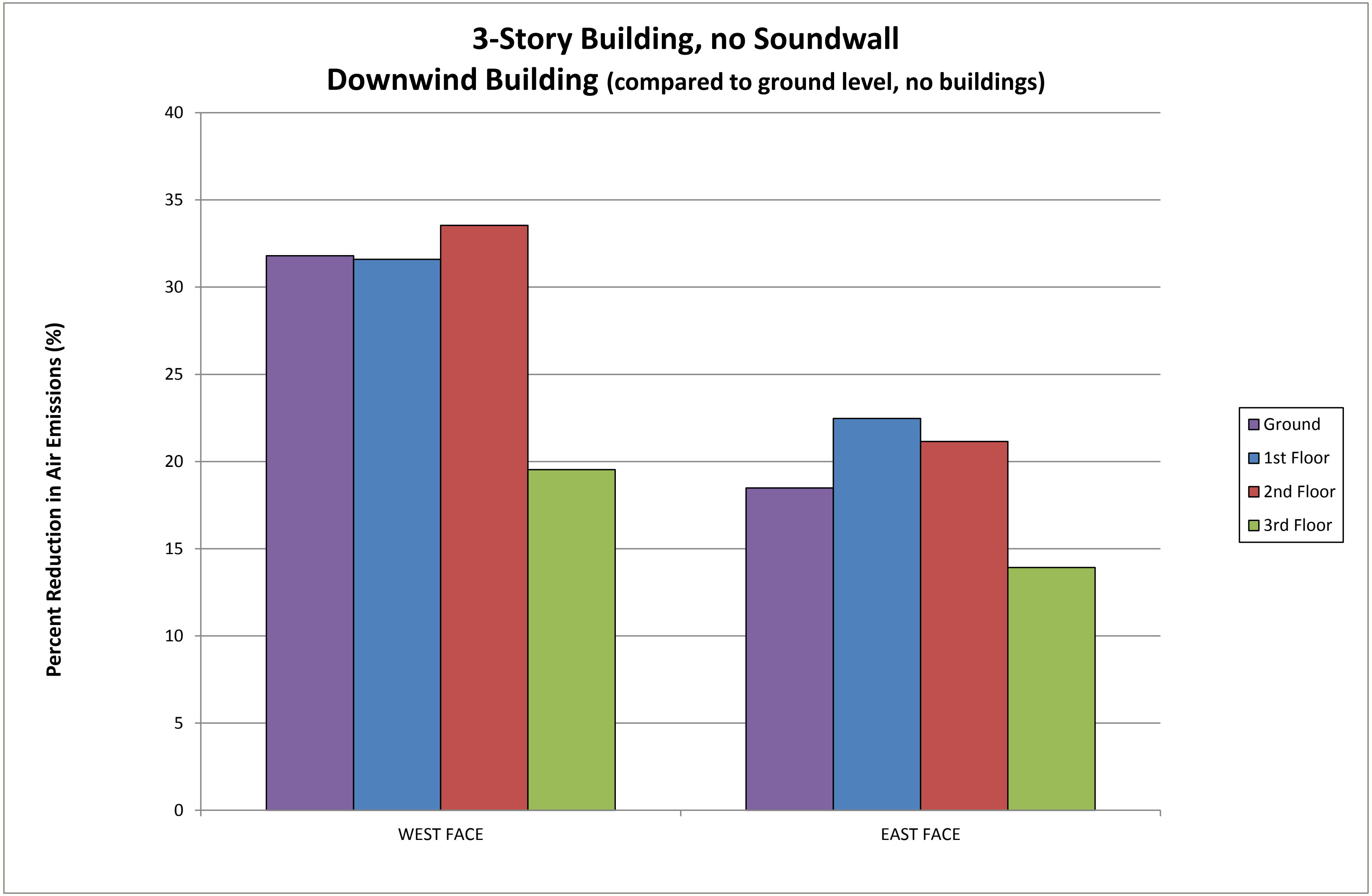


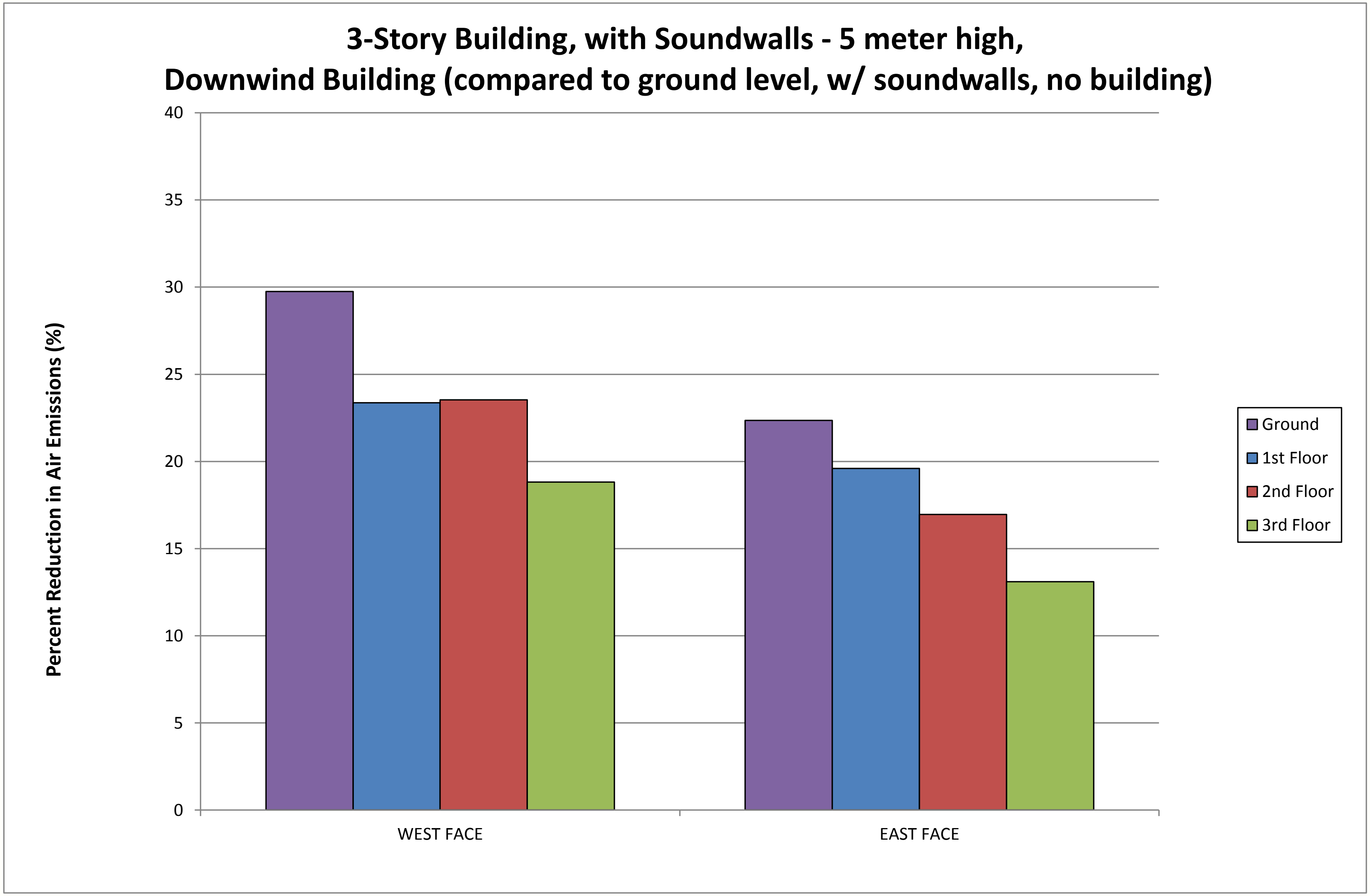

Axial Fans
Concentration (µg/m3)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
SW: 1000 ft
Fans, 75%intake, 3m sep
Fans, 75%intake, 15m sep
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway

3-Story Building

- Each story – 10 feet high
- Building dimensions – 50m x 50 m
- Distance from roadway edge – 5 m

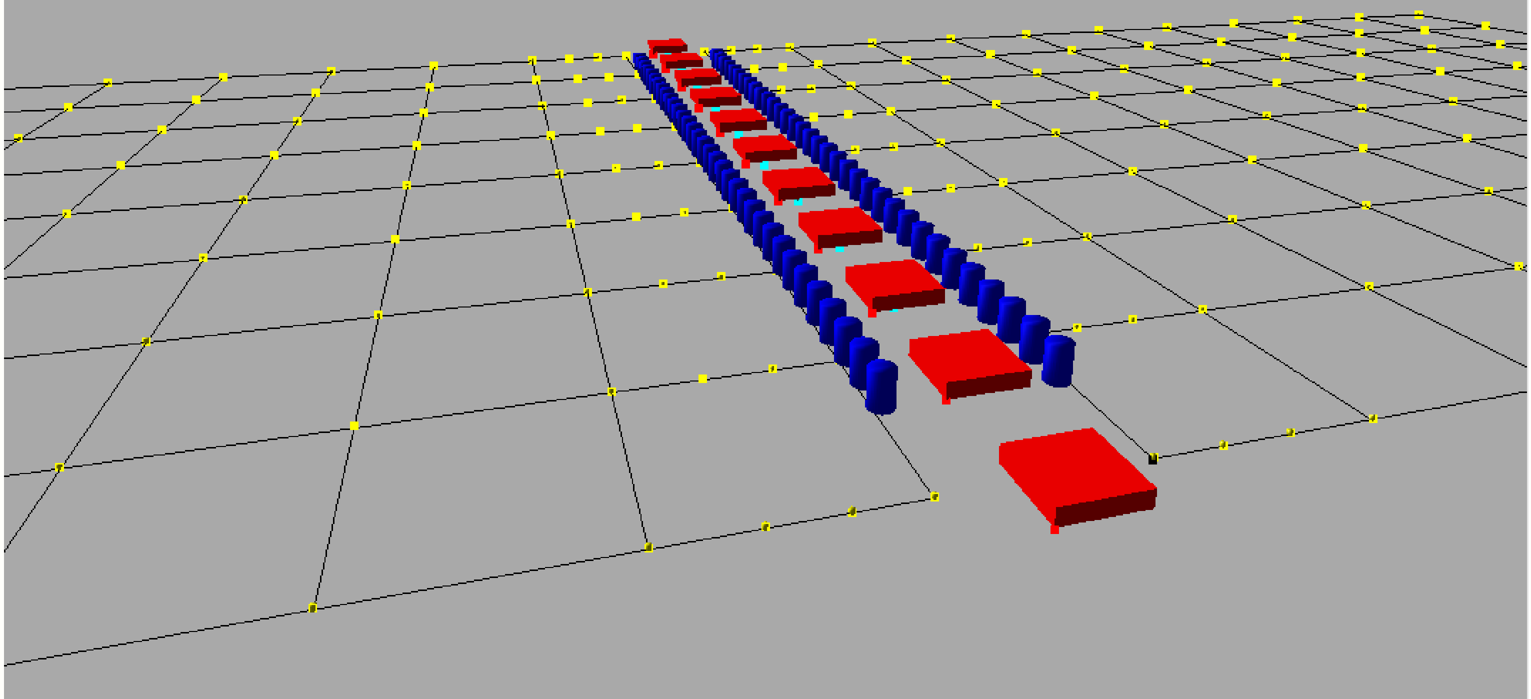


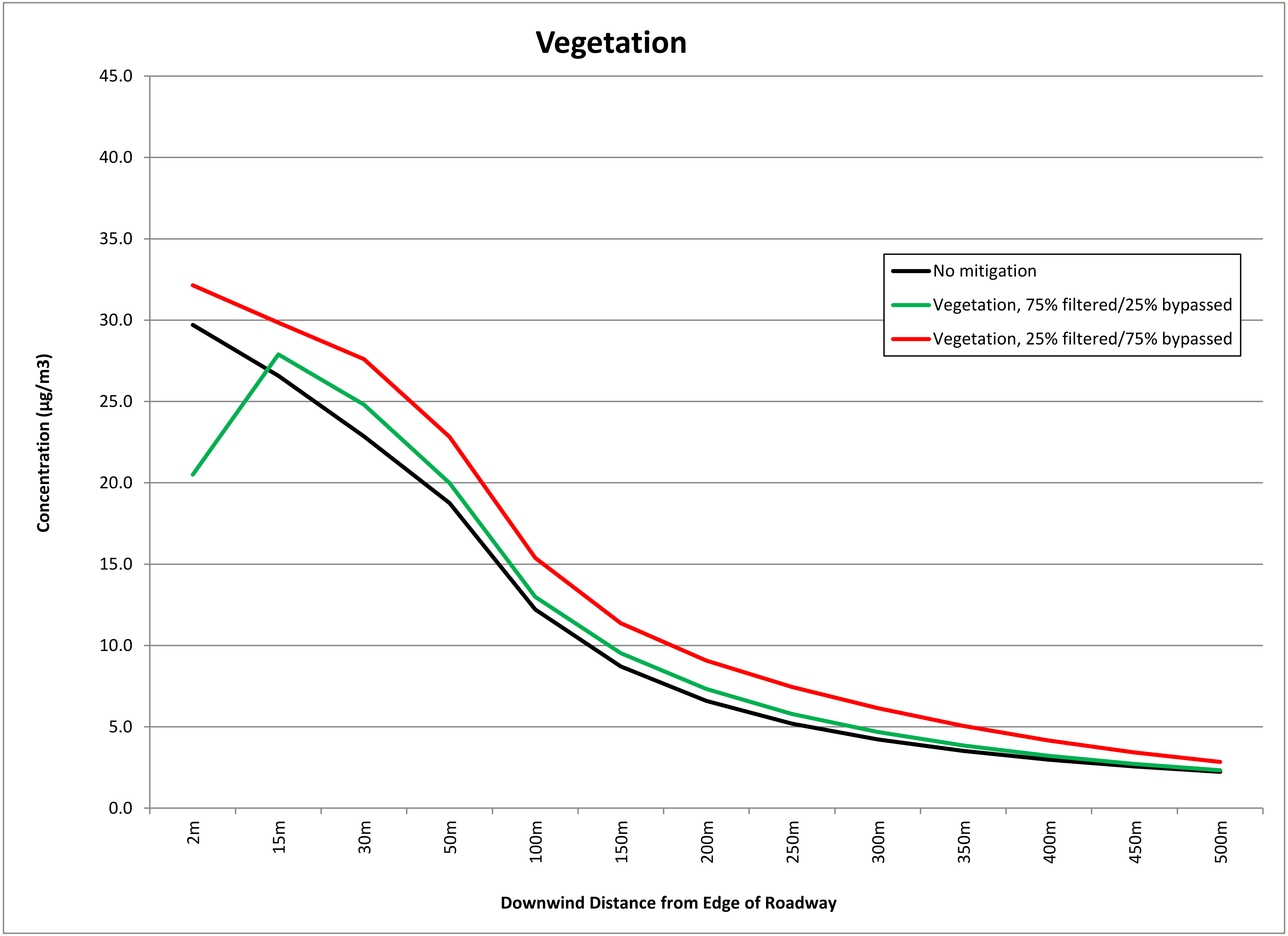

3-Story Building, no Soundwall
Downwind Building (compared to ground level, no buildings)
Percent Reduction in Air Emissions (%)
40
35
30
25
20
15
10
5
0
WEST FACE
EAST FACE
Ground
1st Floor
2nd Floor
3rd Floor


3-Story Building, with Soundwalls - 5 meter high,
Downwind Building (compared to ground level, w/ soundwalls, no building)
Percent Reduction in Air Emissions (%)
40
35
30
25
20
15
10
5
0
WEST FACE
EAST FACE
Ground
1st Floor
2nd Floor
3rd Floor

Vegetation

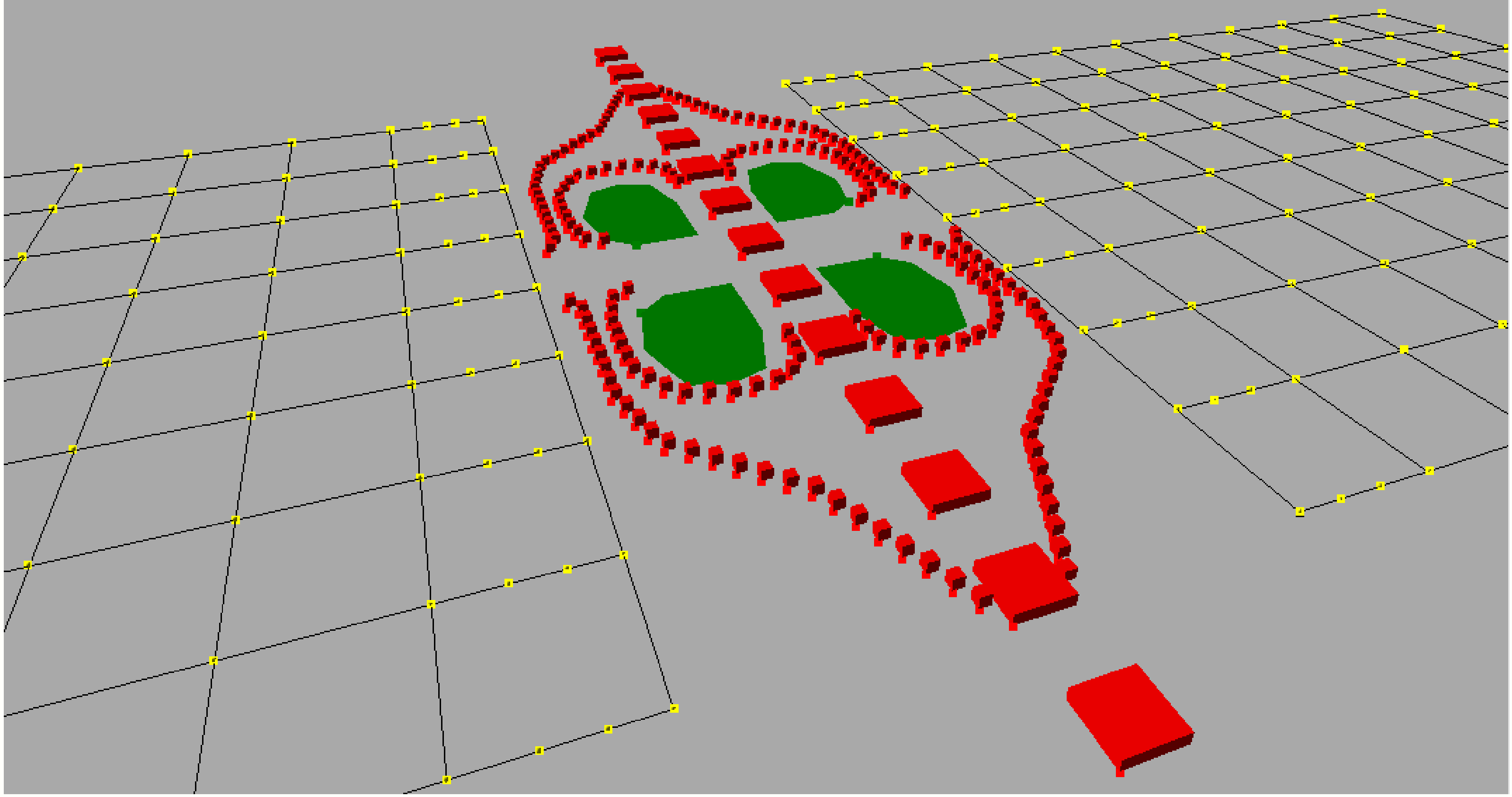
- Trees – 30 feet high
- Spacing – 10 m apart
- Radius – 10 feet
- 75% filtered, 25% bypass



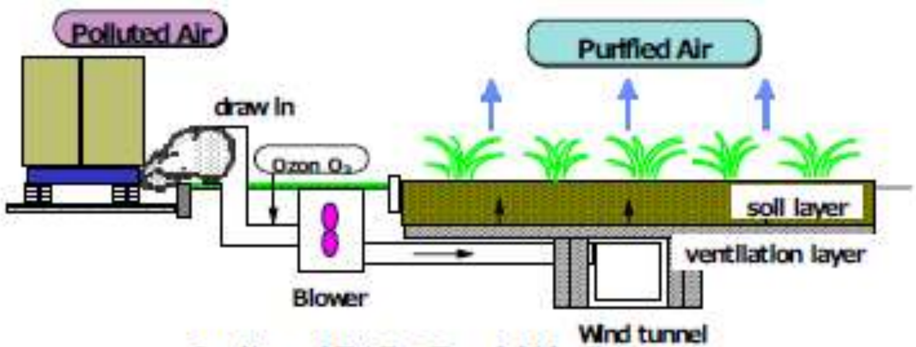

Vegetation
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Concentration (µg/m3)
2m
15m
30m
50m
100m
150m
200m
250m
300m
350m
400m
450m
500m
Downwind Distance from Edge of Roadway
No mitigation
Vegetation, 75% filtered/25% bypassed
Vegetation, 25% filtered/75% bypassed

Biofiltration - Cloverleaf

Area of biolfiltration – 2,400 m^2
Filtered air – 25%, 75%
Removal rate of filtered area – 90%
Roadway – no sound walls, no downwash



Fujita Earth Air Purifier (EAP)

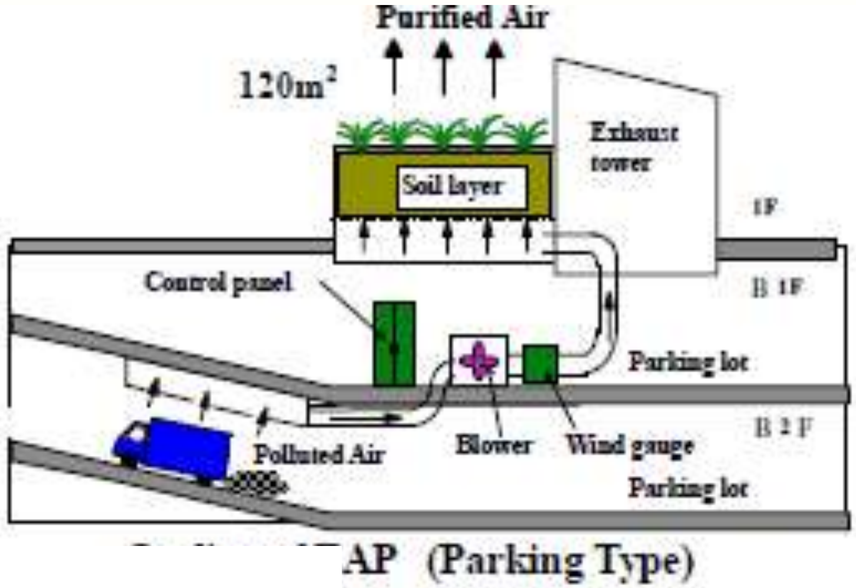


Outline of EAP (Road Side Type)

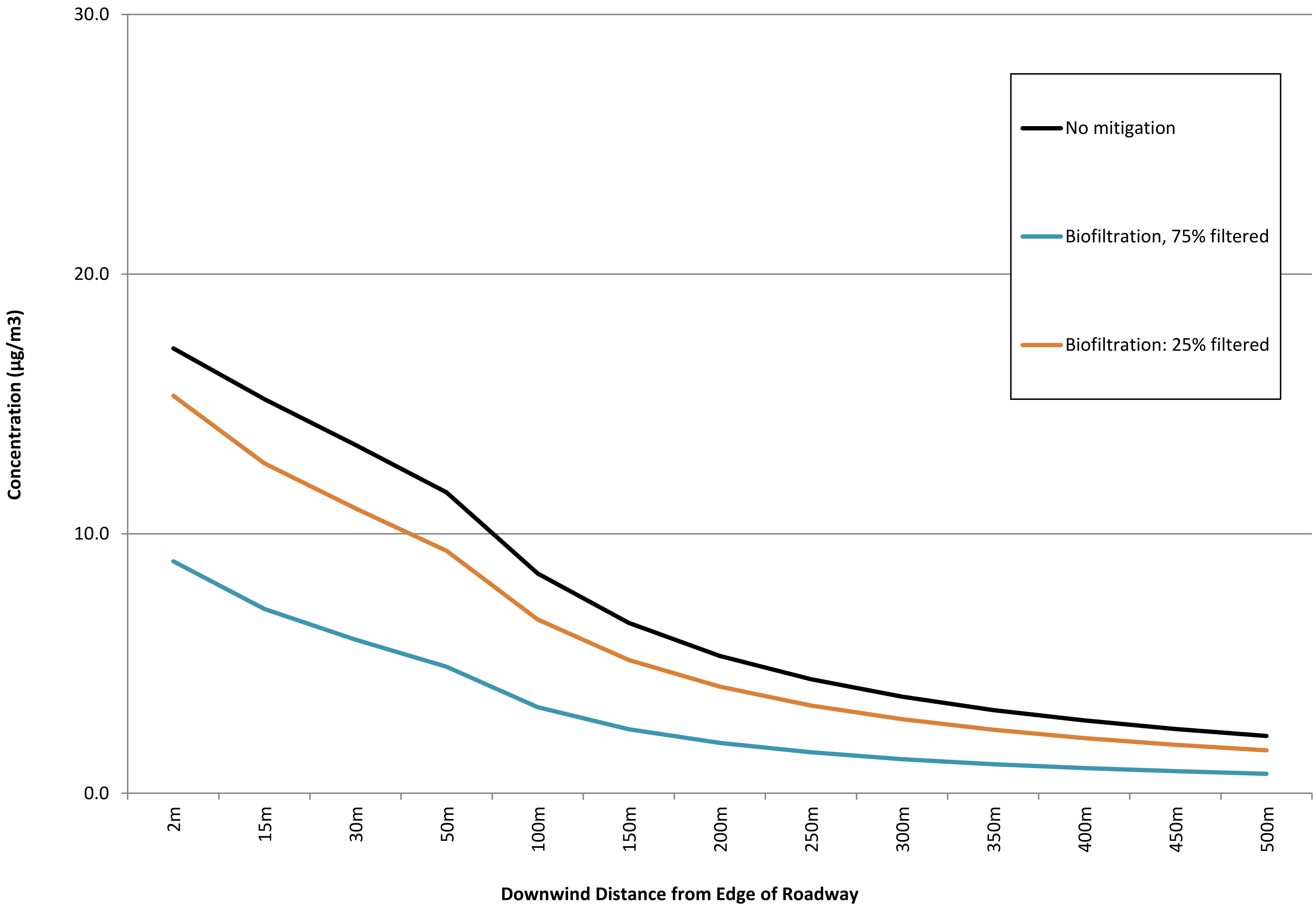
Roadside - Freeway

Fujita – Earth Air Purifier

Tunnels
Parking Garage



Mitigation Comparison for Cloverleaf Freeway Section



Summary
AERMOD Modeling

Increase Downwind

- Sound Walls
- Vegetation

Decrease Downwind

- Multi-story buildings
- Biofiltration - cloverleafs

Recommendations

- Cut, at-grade, elevated freeway model runs
- Sound walls – elevated vs ground level
- Vegetation – model with deposition
- Sound wall + vegetation model run
- Obtain additional information on Fujita biofiltration system
- Investigate noise attenuation and pollution filtration – Great Wall of Mulch

Back to Agenda

Conceptual Research Studies to Assess the Feasibility of Near-Roadway Pollution Mitigation Technologies: Vegetative Barriers

presented
at
South Coast Air Quality Management District
Technology Forum on Near-Road Mitigation Measures and Technologies
by
Frank Di Genova QEP
co-authors Dr. Marc Valdez and Bob Dulla PI
Sierra Research
November 21, 2013

Purpose

To investigate…

- Conceptual feasibility
- Design
- Benefits and
- Effectiveness

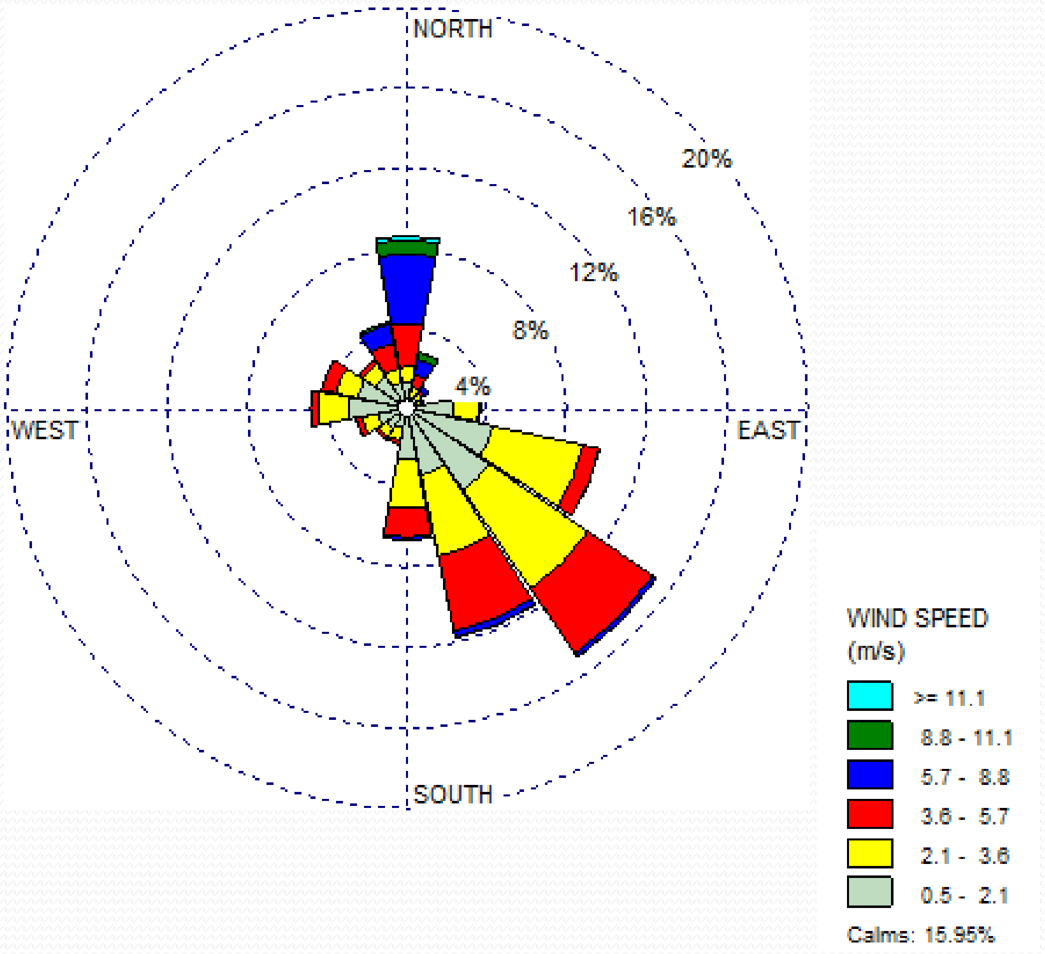
of roadside vegetative barriers in reducing roadway air quality impacts on nearby receptors

Approach

- Literature Review
- Field Study (to help select &‘calibrate’ AQ model)
  - Site Selection (w. District staff)
  - Sampling
  - Model Selection (EPA-approved AERMOD)
- Conceptual Modeling
  - parts of study site with & w/o veg barriers
  - hypothetical barriers
- Findings/Recommendations

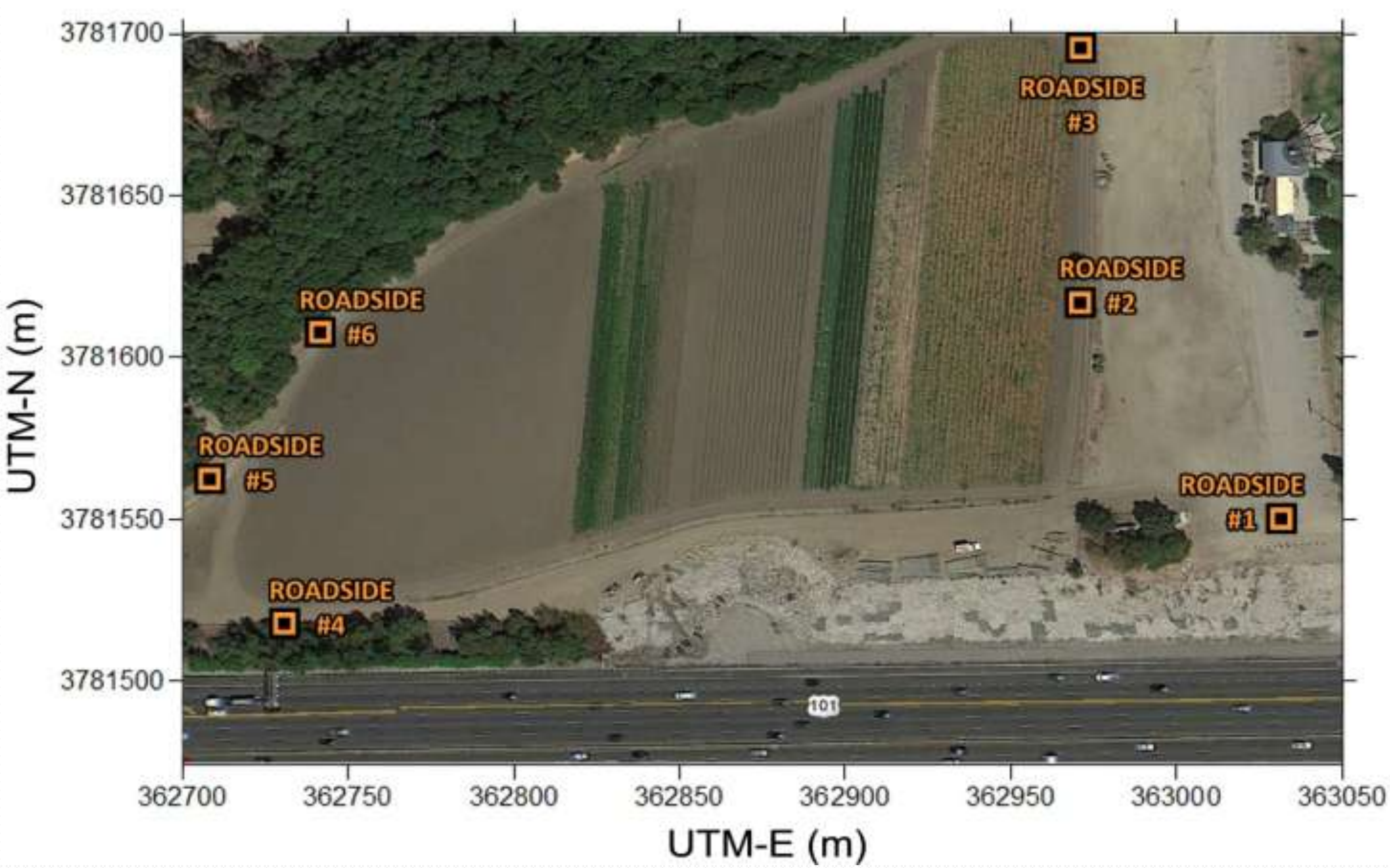
Site – Ventura Freeway near Lake Balboa, LA County

Van Nuys Airport 10-year Wind Rose
(source: Iowa Environmental Mesonet, ISU)

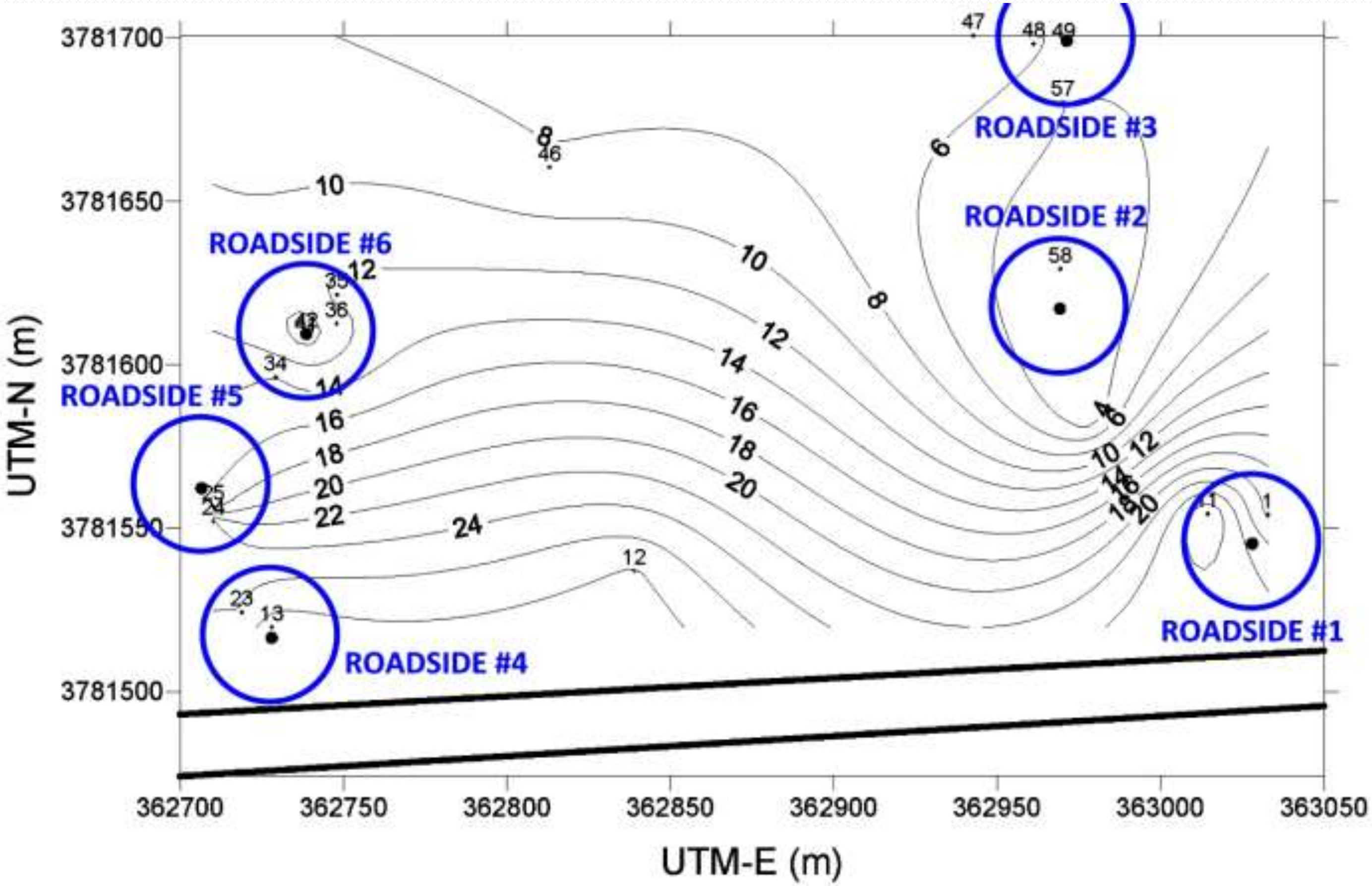


Met Tower, Sampling Vehicle & Part of Veg. Barrier

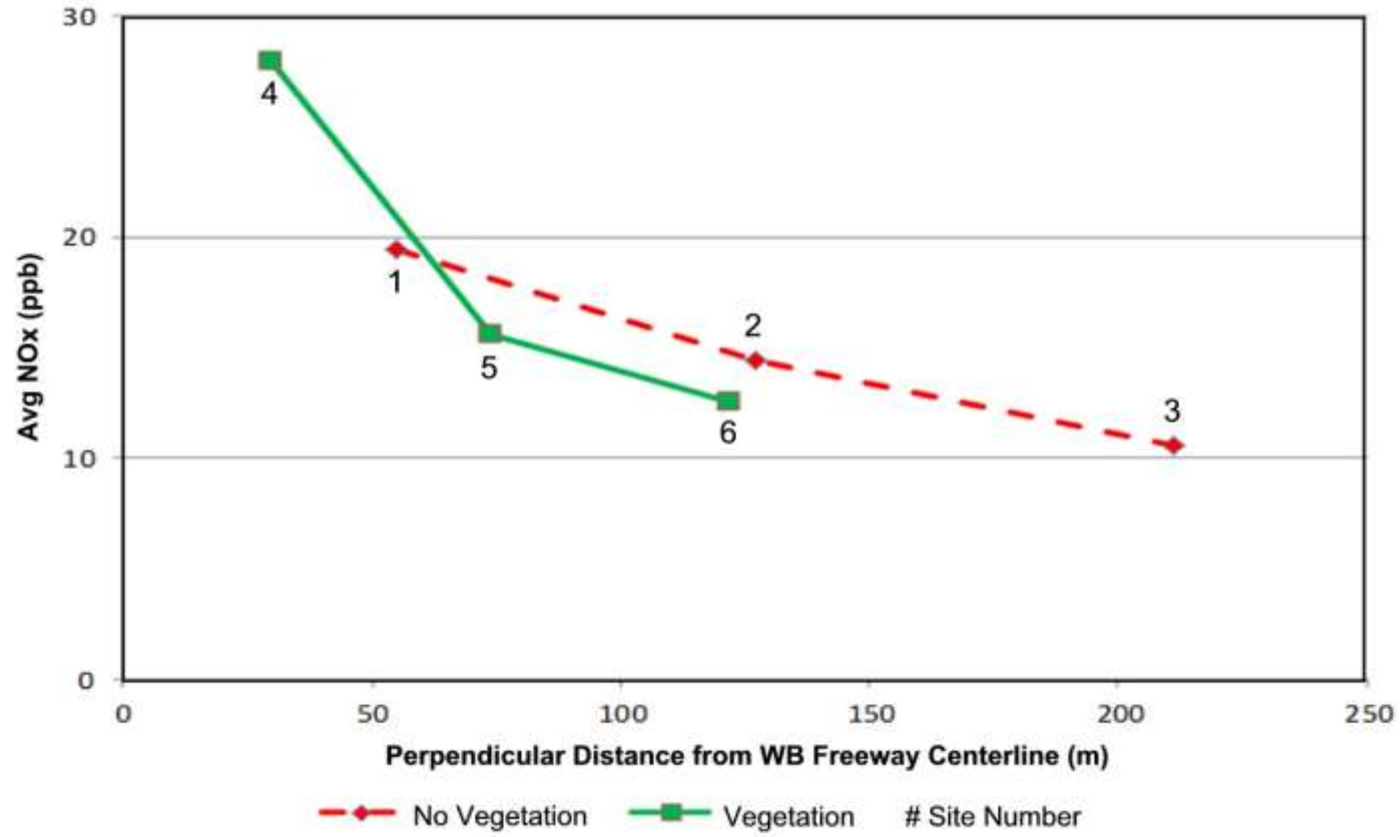
Study Site showing Veg. Barrier (4,5,6) and Non veg. barrier (1,2,3) sites



NOx isopleth ‘snapshot’ for predictable, steady sea breeze 6/4/12, wind 179^o@1.98 m/s



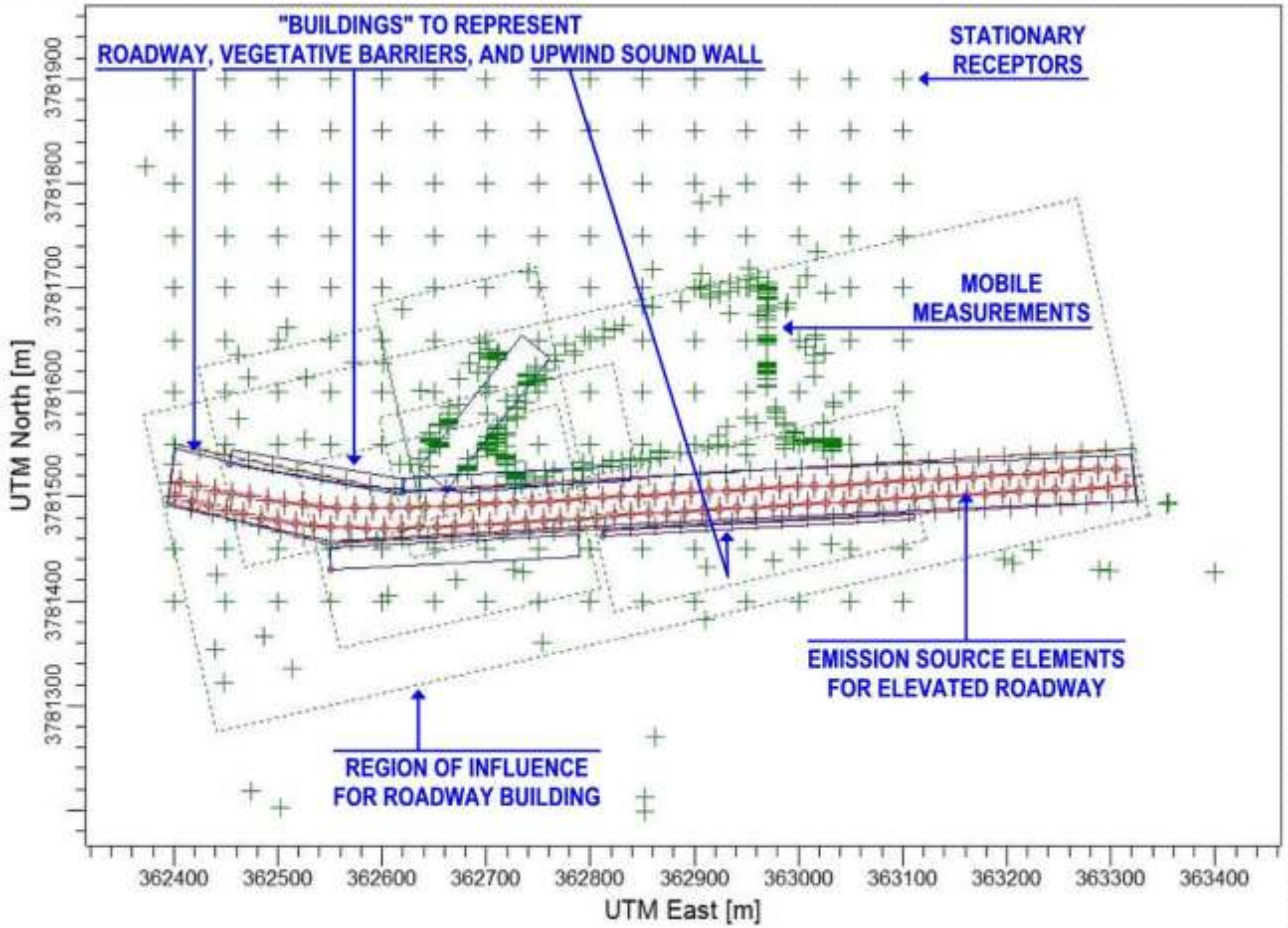
Avg. NOx Concentration vs Distance for sites with (4-6) and Without (1-3) Veg. Barrier



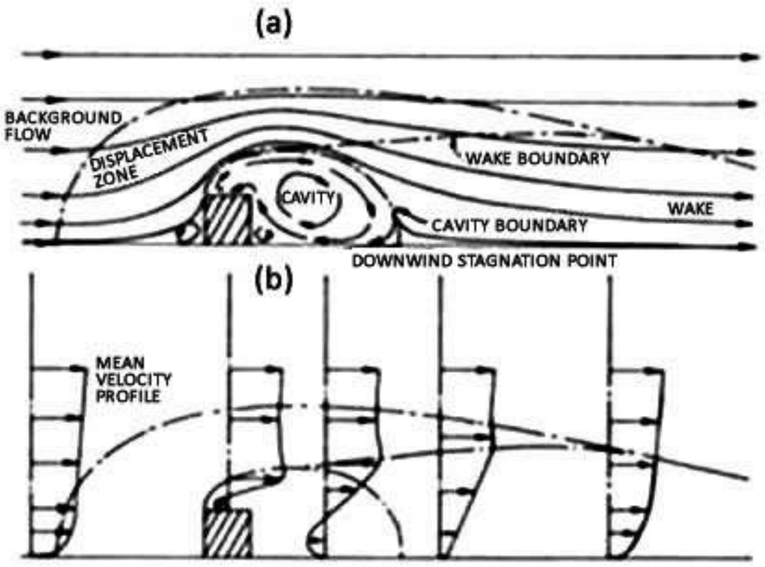
Field Measurements Showed Complex Patterns

- Concentrations declined with distance from freeway
- Average concentrations higher on W (barrier) side but it's closer to freeway
- Can't say which side higher peak concentration (fewer readings E side)
- E concentrations sometimes high, but fleeting (varied more w. wind direction)
  - Winds <130^{o} no E hot spot activity
  - Winds >130 (from S) showed E hot spot
- Likely source is sound wall S (upwind) side of freeway

Configuration of AERMOD



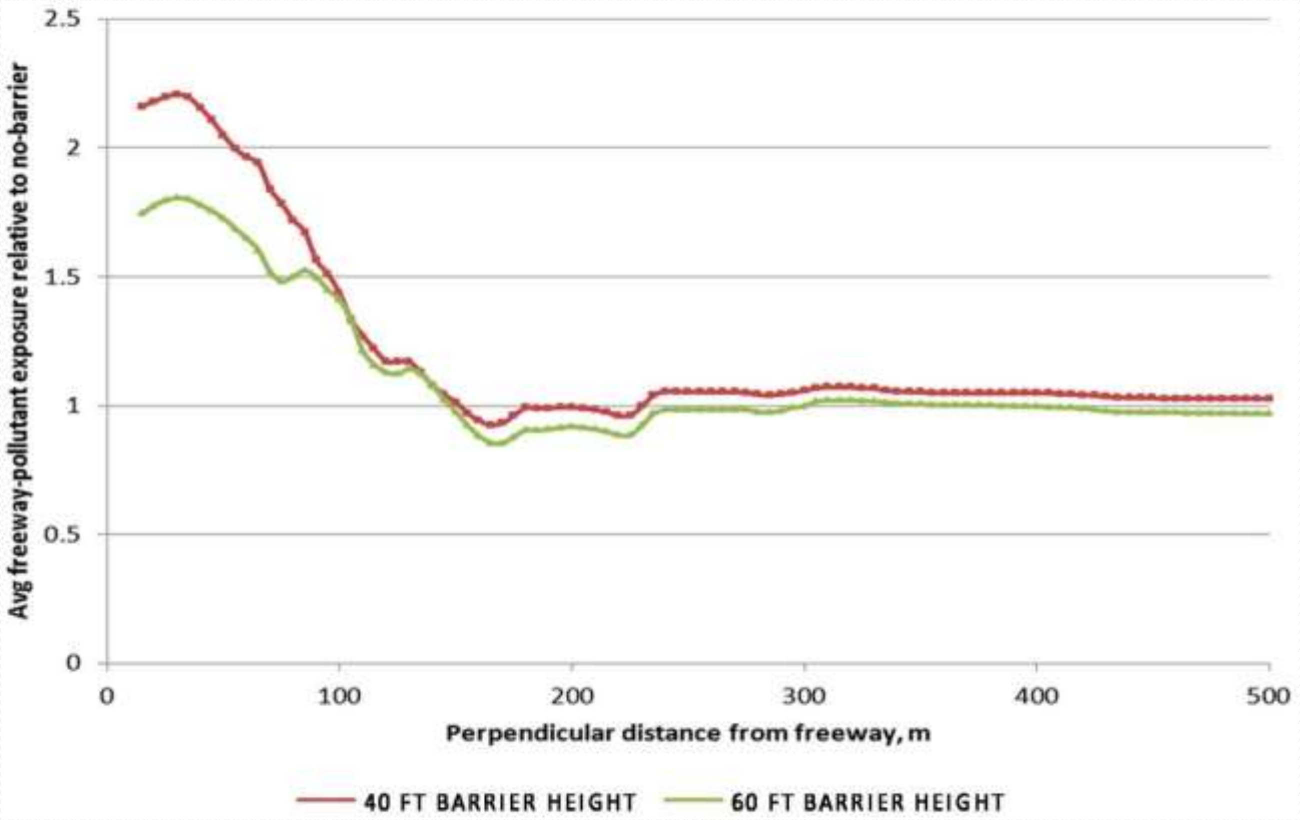
Building Downwash Helped Explain Effects of Upwind Soundwall



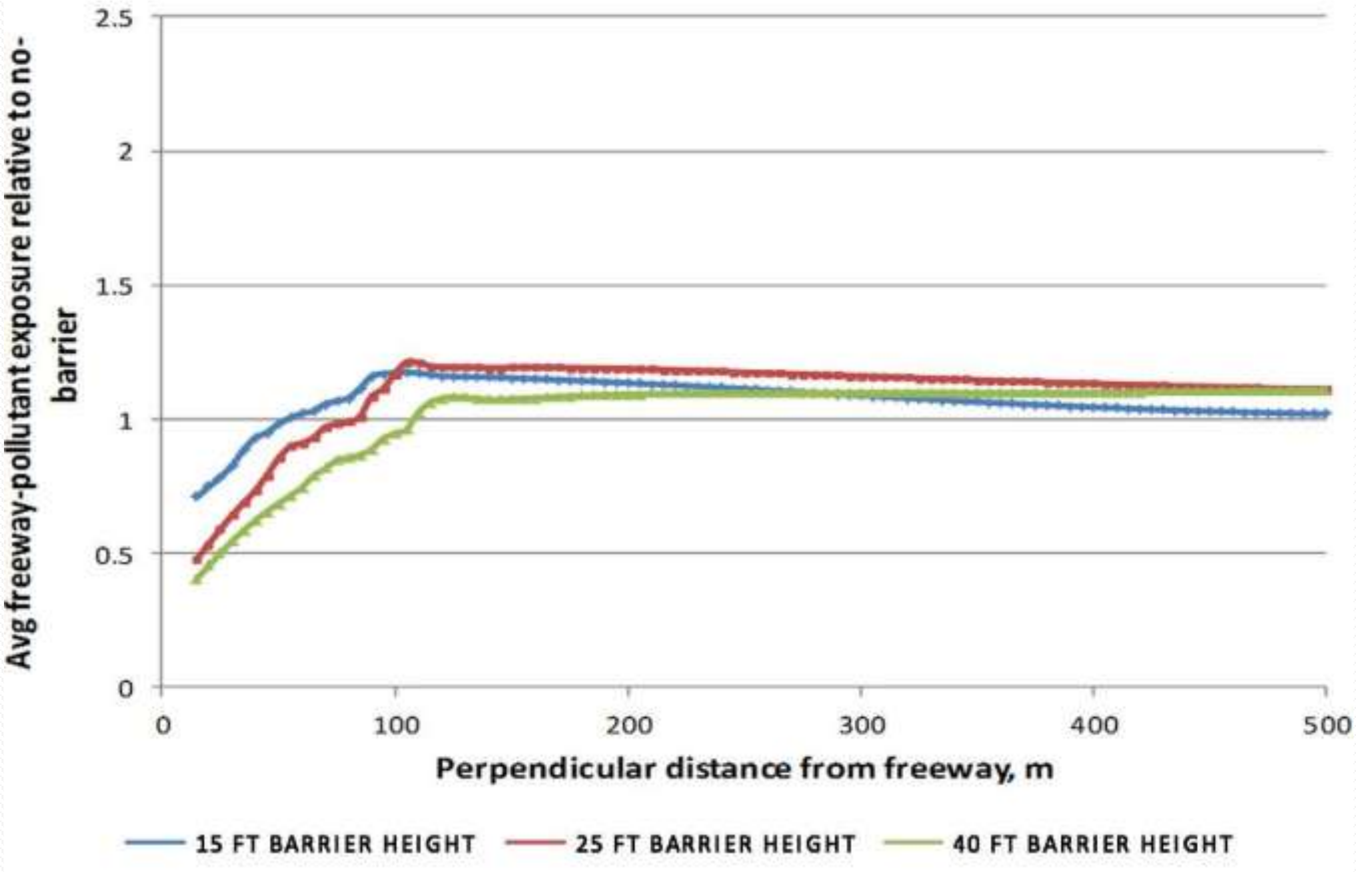
(Adapted from http://www.rag.org.au/tunnel/plumes.htm)

Source: *http//blog.nus.edu.sg/yiuyan/2009/10/08/Gaussian-plume-modeling/*

Modeled Relative Annual Average Exposure vs. Downwind Distance: 25'Elevated Freeway, Point Source Modeling, Varying Barrier Height

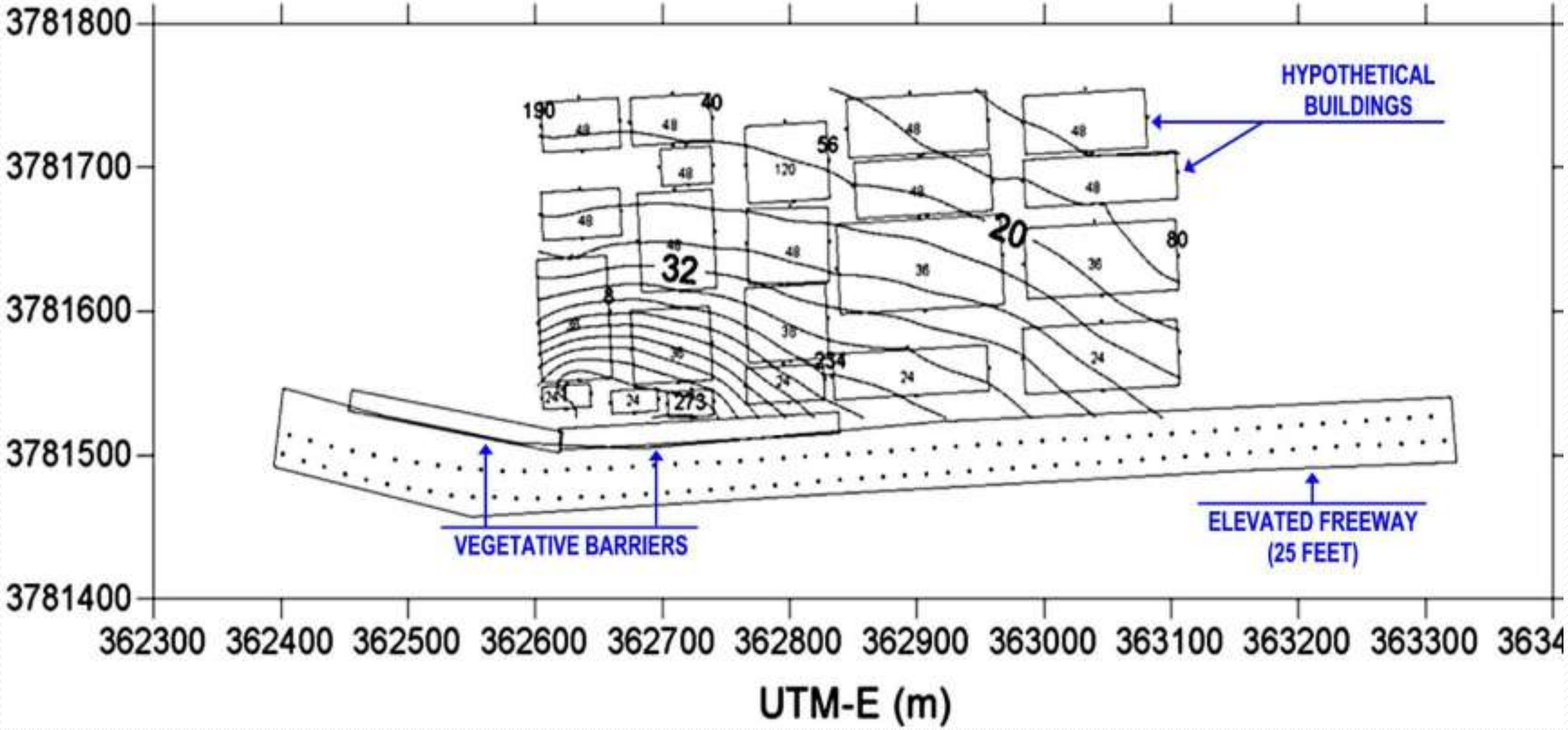


Modeled Relative Annual Average Exposure vs. Downwind Distance: Hypothetical At-Grade Freeway and Varying Barrier Heights



Modeling of Hypothetical Complex Building Structures

small fonts are building height(ft), larger fonts are receptor number labels;
bold isopleth labels are modeled ground-level unit concentrations;
inside-building contours shown for continuity only, they do not represent indoor concentrations



Summary of Findings
(see full report for important caveats)

1. Barriers can increase or decrease near-roadway concentrations.
2. Measured data (5 days) were used to validate AERMOD for these cases.
3. Complex measured & modeled concentrations; highest concentration (but closest sample point) was behind the veg. barrier
4. Barrier-induced bldg. downwash more important than roughness element.
5. Taller barriers made lower cavity concentrations (dilution effect).

(cont'd)

(Summary, cont'd)

6. Point modeling best at higher wind speed (can model downwash), volume modeling at lower ws; both poor at lowest wind speeds.
7. Lower barriers -> higher concentrations closer to freeway and vice versa.
8. Model results sensitive to small wind speed change; need care in modeling.
9. Hypothetical at-grade freeway has near-field AQ benefit , mid-disbenefit, no effect beyond.
10. Exploratory multi-building model with veg. barrier showed downwash.
11. Results consistent with prior studies where sufficient detail to compare.

Recommendations

- Considering downwash effects of roadside barriers provides a new perspective.
- Key elements new from this work:
  - documenting the importance of roadway grade in understanding barrier effects and
  - identification of at-grade roadways as possible sites where benefits of barriers may be maximized.
  - Therefore, when a project includes such barriers:
  - Data should be collected on the key parameters including freeway height, barrier height relative to freeway, etc, and
  - These need to be accounted for in assessing potential benefits of near-roadway barriers, vegetative or otherwise.

For more information

- Full report:

  Valdez, Marc, PhD, et al.,"Conceptual Research Studies to Assess the Feasibility of Near-Roadway Pollution Mitigation Technologies: Vegetative Barriers", Sierra Research Report No. SR2013-07-01, prepared for the South Coast Air Quality Management District, July 31, 2013.
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- Sierra Research: www.SierraResearch.com

Black Carbon Particle Removal in School Classrooms Near Busy Roadways in Las Vegas, Nevada

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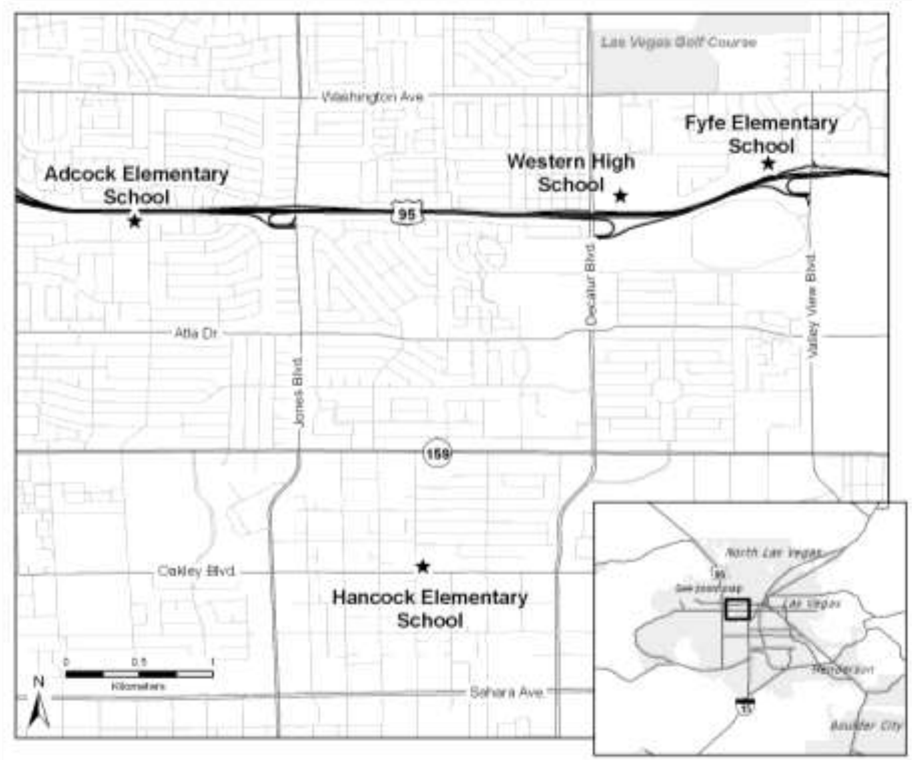
Needham, Massachusetts



Presented at the
SCAQMD Forum on Near-Road
Mitigation Measures and Technologies
Diamond Bar, California
November 21, 2013

Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Back to Agenda

BC Removal in Classrooms: Outline

- Study objectives
- Ambient diurnal pattern
- Filtration systems
- Efficiency results
- Characteristics of classrooms
- Implications and mitigation strategies

BC	Black carbon

Study Objectives

Objective: To determine the efficiency of existing and improved filtration systems installed at three schools near US Highway 95 in Las Vegas, Nevada, for removal of black carbon particles. To re-determine the efficiency after five years of operations.

Black carbon is used as a surrogate for Diesel Particulate Matter (DPM), identified by the U.S. Environmental Protection Agency (EPA) as a priority Mobile Source Air Toxic.

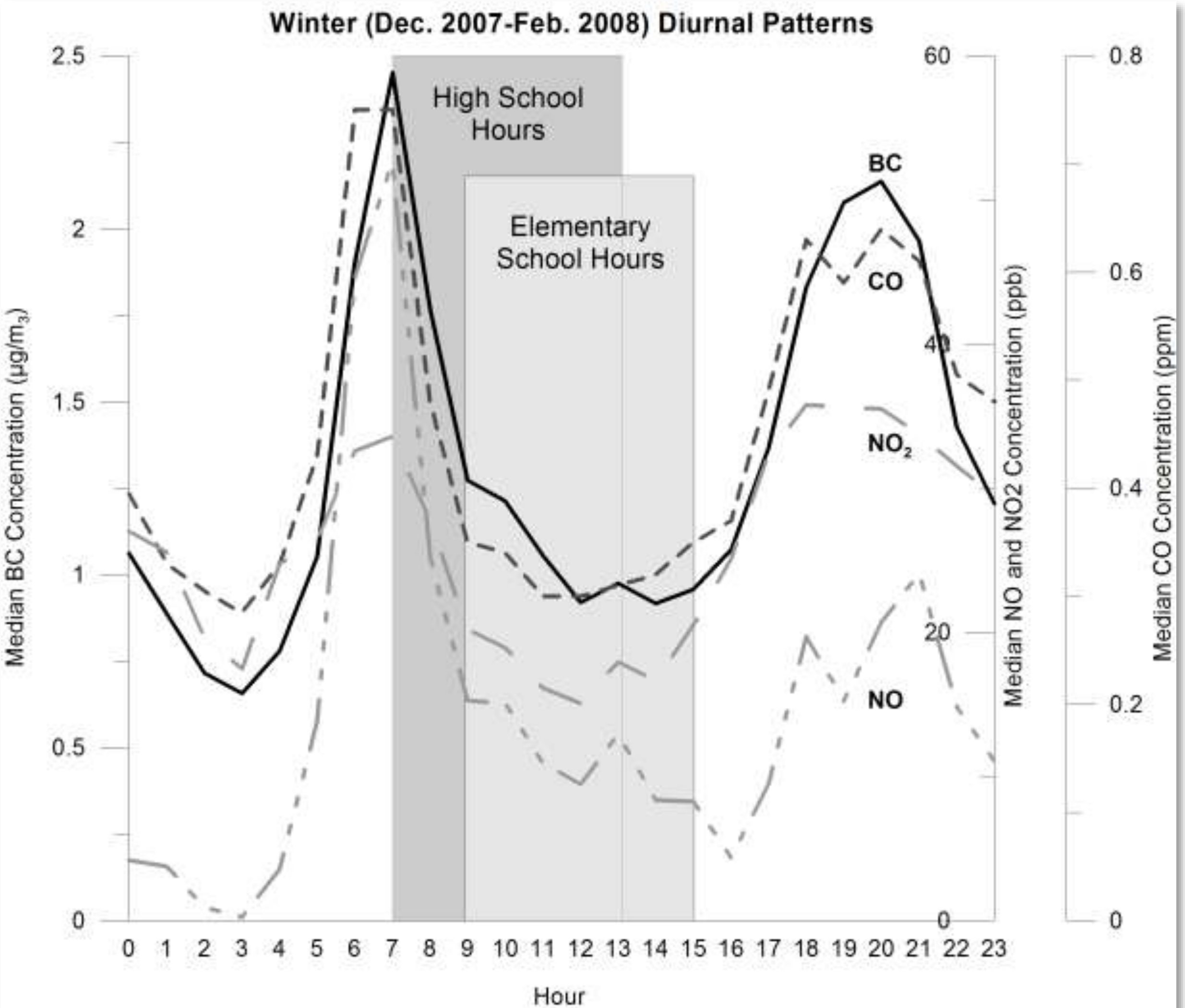
STI Sonoma Technology, Inc.

US 95 Highway Widening Project – Before

US 95 Highway Widening Project – After

Western High School　　　　Fyfe Elementary School

Diurnal Pattern of Pollution Is an Important Consideration for Exposure and Mitigation



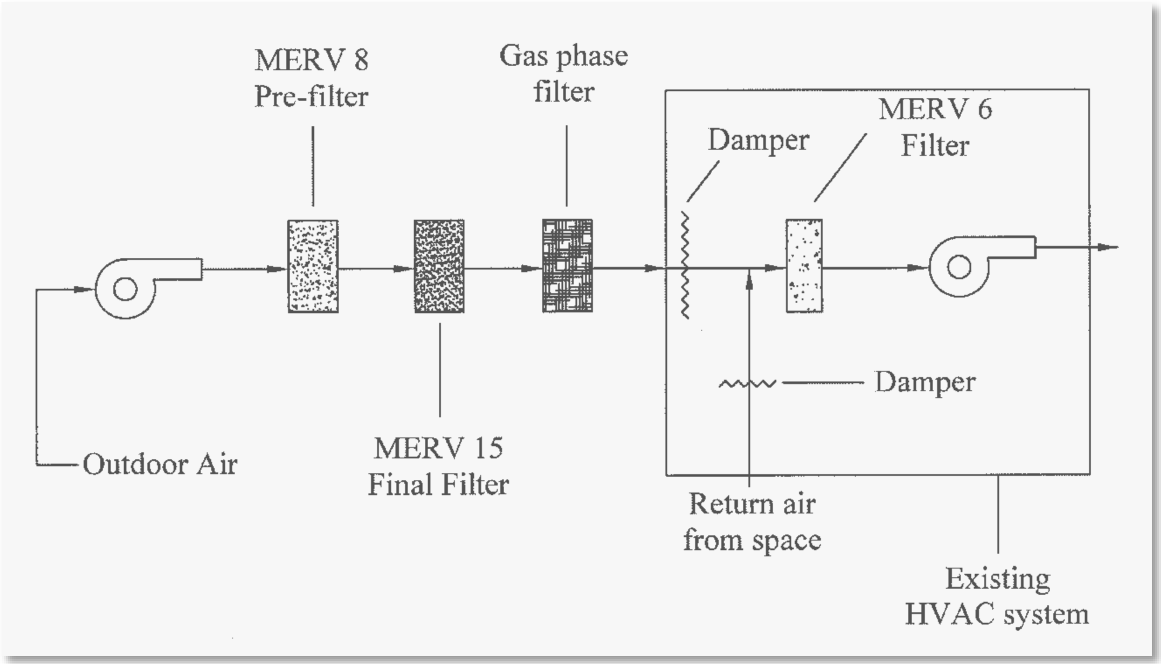
Median concentrations by hour of

- BC ($\mu g/m^3$)
- CO (ppm)
- NO (ppb)
- NO_2 (ppb)

at Fyfe Elementary school ambient site on weekdays in winter.

CO	Carbon monoxide
NO	Nitric oxide
NO_2	Nitrogen dioxide

Filtration Systems for Fyfe and Adcock



Note:

- Systems with original filters were tested in May and June 2007.
- Filtration systems were modified in August–October 2007.
- Western High School had only PM filters; no gas-phase filter was installed.
- Modified filtration systems were tested in November 2007–June 2008.
- Systems were retested in March–June 2013.

Typical Classroom & Sampling Location

Note carpet on floor and fabric on walls; potential absorption surfaces.

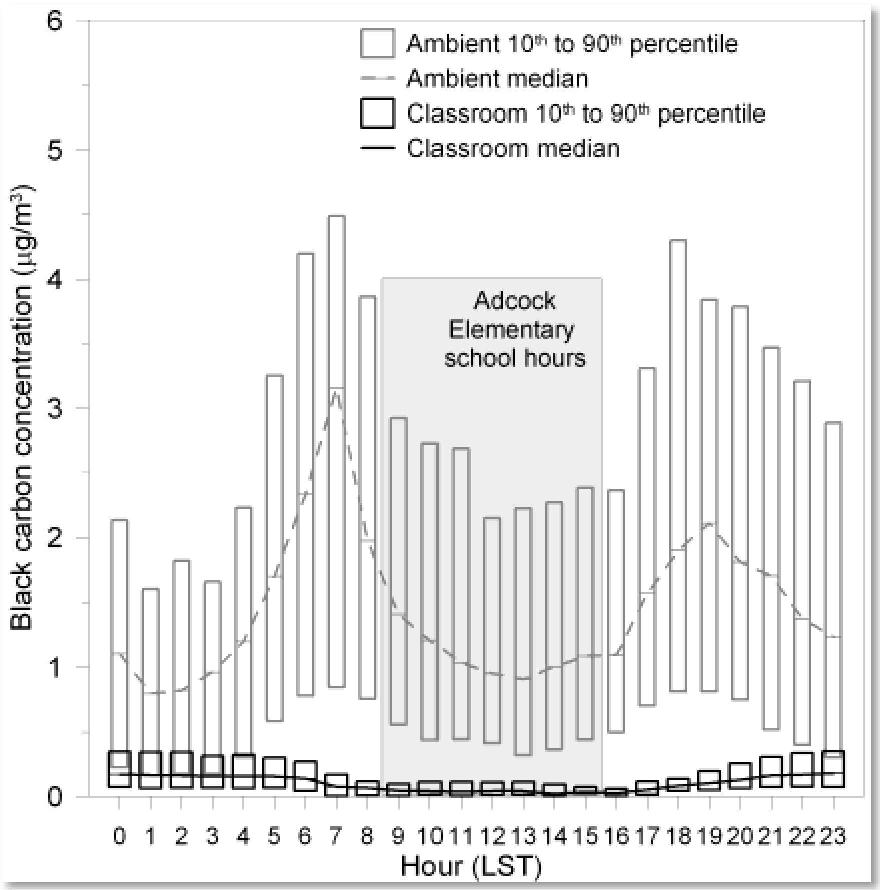
Filtration System Characteristics and BC Filtration Efficiency Results

School	Original Filter Rating	% Outdoor Air	Upgraded Prefilter Rating	Upgraded Filter Rating
Adcock Elementary	MERV 6	30	MERV 8	MERV 15
Fyfe Elementary	MERV 6	22	MERV 8	MERV 15
Western High School	MERV 6	30	None	MERV 11

MERV = Minimum Efficiency Reporting Value, per the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). This is the typical efficiency of particle removal in the size range of 0.3 to 10 microns in diameter.

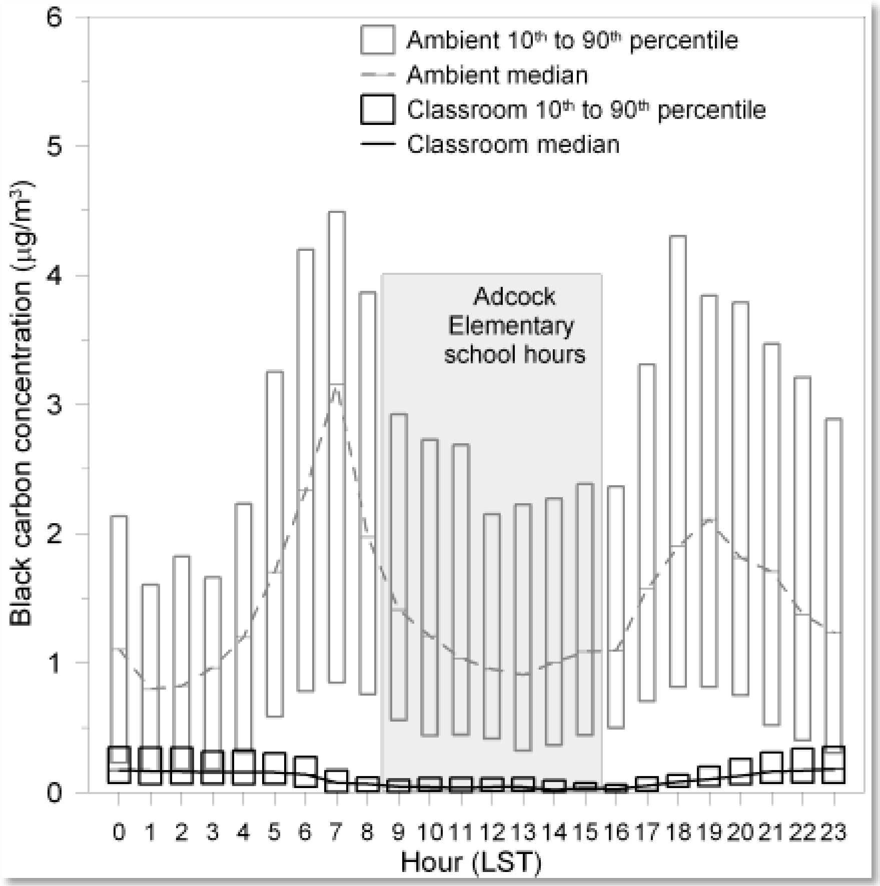
School	Original Filtration Efficiency	Upgraded Filtration Efficiency (2008)	5-Years-Later Filtration Efficiency (2013)
Adcock Elementary	66%	97%	91%
Fyfe Elementary	50%	72%	50%
Western High School	31%	71%	93%

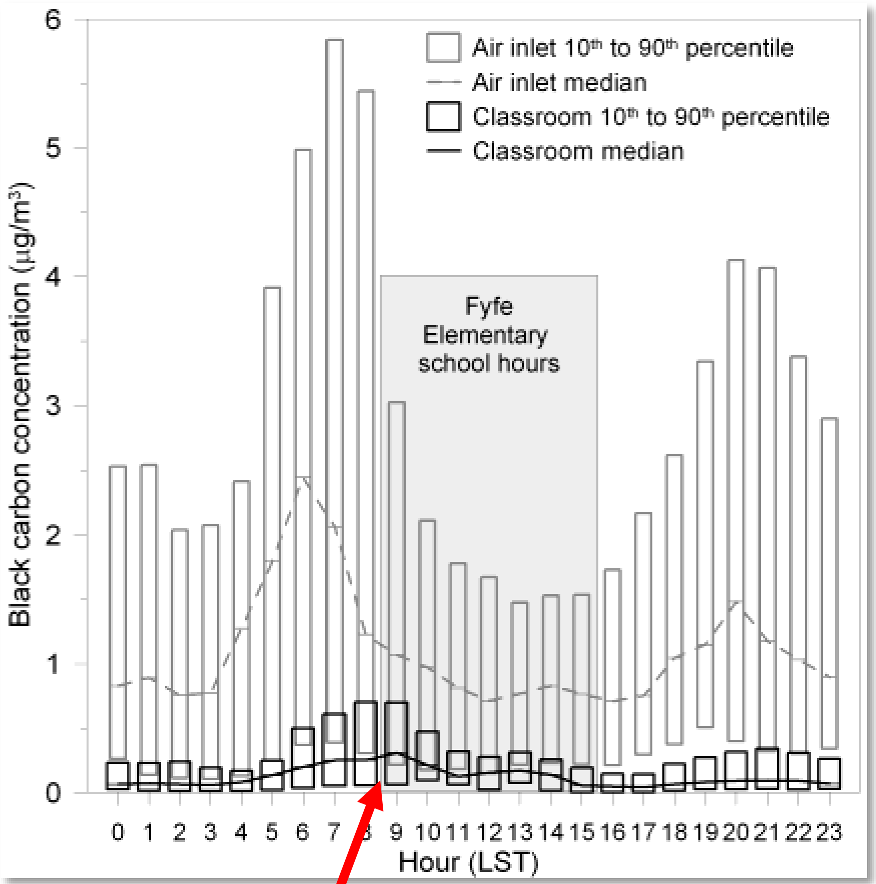
BC Distributions Outdoors and in a Classroom: Significant BC Removal at Adcock and Fyfe



Effective filter efficiency: original system about 66%; improved system about 97%; re-tested efficiency about 91%.

BC Distributions Outdoors and in a Classroom: Significant BC Removal at Adcock and Fyfe





Effective filter efficiency: original system about 66%; improved system about 97%; re-tested efficiency about 91%.

Effective filter efficiency: original system about 50%; improved system about 72%.

Teacher often left door open to outside.

Important Classroom and Ventilation System Characteristics

- Open hallways or closed/pod design?
- HVAC system capacity (e.g.controls, fan, motor, wiring, space to modify)
- HVAC system or unit ventilator?

Horizontal Classroom Unit Ventilator

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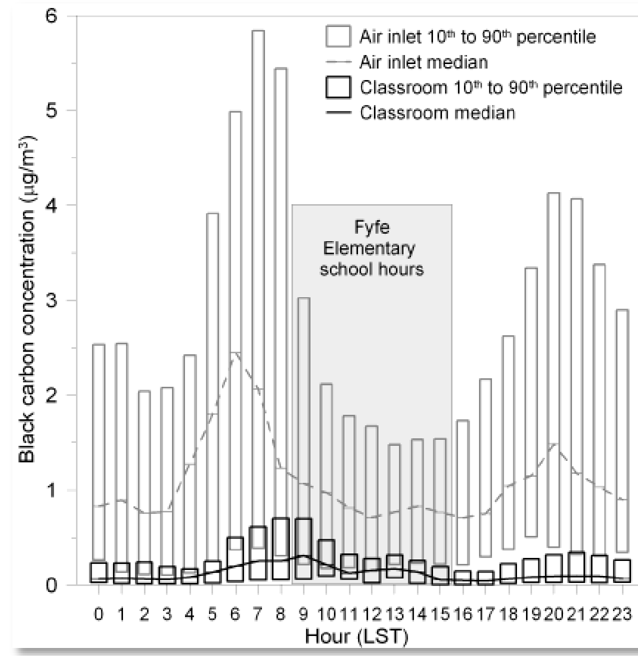
Implications for Exposure: BC

- Temporal variability in concentrations matters for exposure.
- Filtration of outdoor air was effective for reducing near-road particles.
- HVAC operations can influence indoor concentrations (start time was during morning rush hour).
  - fills classroom with the dirtiest air
  - places large burden on system
- Opening doors and windows to outdoor air will bypass filtration system.



Implications for Exposure: VOC

- Indoor sources likely dominate exposure for VOCs.
- Filtration of outdoor air was not effective for VOCs.
- If indoor sources are present, filtration needs to occur on recirculated air.
- A better understanding is needed for VOCs.

Study results summarized by Roberts, et al., at 2011 SCAQMD forum on indoor VOC removal in schools.
http://www.aqmd.gov/tao/ConferencesWorkshops/VOCRemovalForum/VOC_Removal_Agenda.htm

Mitigation Strategies (1 of 2)

- Improve filtration systems; these can significantly reduce particle exposure from outdoor air.
- Change HVAC start times so they do not coincide with rush hour.
- Avoid physical education classes and recess during rush hour.

Mitigation Strategies (2 of 2)

- Implement bus anti-idling measures; these can significantly reduce exposures.
- Run recirculated air through filtration system, rather than just outdoor air, in order to reduce concentrations of pollutants with indoor sources. Note that this has higher energy and pressure drop costs for the HVAC system and is not a near-road mitigation measure.

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BC	Black carbon

Acknowledgments

- This work was funded by the Nevada Department of Transportation (NDOT).
- John Terry was the NDOT Project Manager.
- Pat Mohn (now at Nevada Department of Environmental Protection) was the NDOT technical staff for this project.
- Joanne Spaulding and Jane Feldman (Sierra Club), Kevin Black (Federal Highway Administration), and Rich Baldauf (EPA) also contributed to the study design.
- Clark County School District (Paul Gerber and Steve Dellosritto) provided access and support at the schools.
- Joey Landreneau and David Vaughn (STI) performed monitoring and sampling. Alison Ray, Jennifer DeWinter, Theresa O'Brien, and Steve Brown (STI) performed data validation and data analyses.

Filter Details for Adcock and Fyfe

Filter	Name	Description
MERV 8 pre-filter	Camfil Aeropleat 2"	
MERV 15 PM filter	Camfil Farr Durafil 4V	DU4V-1511-11-MV15
Gas-phase filter	Camfil Farr Camsorb Riga-Carb	CSRC-205-242412-PH carbon impregnated with oxidation coating

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Back to Agenda

HIGH PERFORMANCE AIR FILTRATION FOR CLASSROOM APPLICATIONS

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SCAQMD Science and Technology Advancement

AQMD

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PILOT STUDY: Introduction

- School-aged children spend ~30% of their day in classrooms. Minimizing the concentration of PM and other air toxics inside classrooms is important

- <u>Common approach</u>: installation of panel filters inside the HVAC system

- Filters in most classrooms and commercial buildings (e.g. MERV 7) not effective for PM < 0.3 µm (e.g. diesel PM and UFP)

- <u>In-classroom filtration challenges</u>
    - Older HVAC systems
    - Noise regulations
    - Doors and windows are frequently open
    - Indoor generation of PM and other pollutants

PILOT STUDY: Objectives

- Investigate the effectiveness of different air purification systems/solutions in reducing the exposure of children to indoor air contaminants

    - *SCAQMD*
    - *IQAir (air filtration manufacturer)*
    - *Thermal Comfort Systems (an HVAC contractor)*

- Pollutants for which the performance of the installed systems were tested:

    - *UFPs: < 0.1 µm; combustion of fossil fuels*
    - *$PM_{2.5}$: < 2.5 µm; primary and secondary origin*
    - *PM_{10}: < 10 µm); mechanical processes*
    - *BC: incomplete combustion; good indicator of diesel PM*
    - *VOCs: evaporative processes and combustion sources*

PILOT STUDY: Schools & Classrooms Characteristics

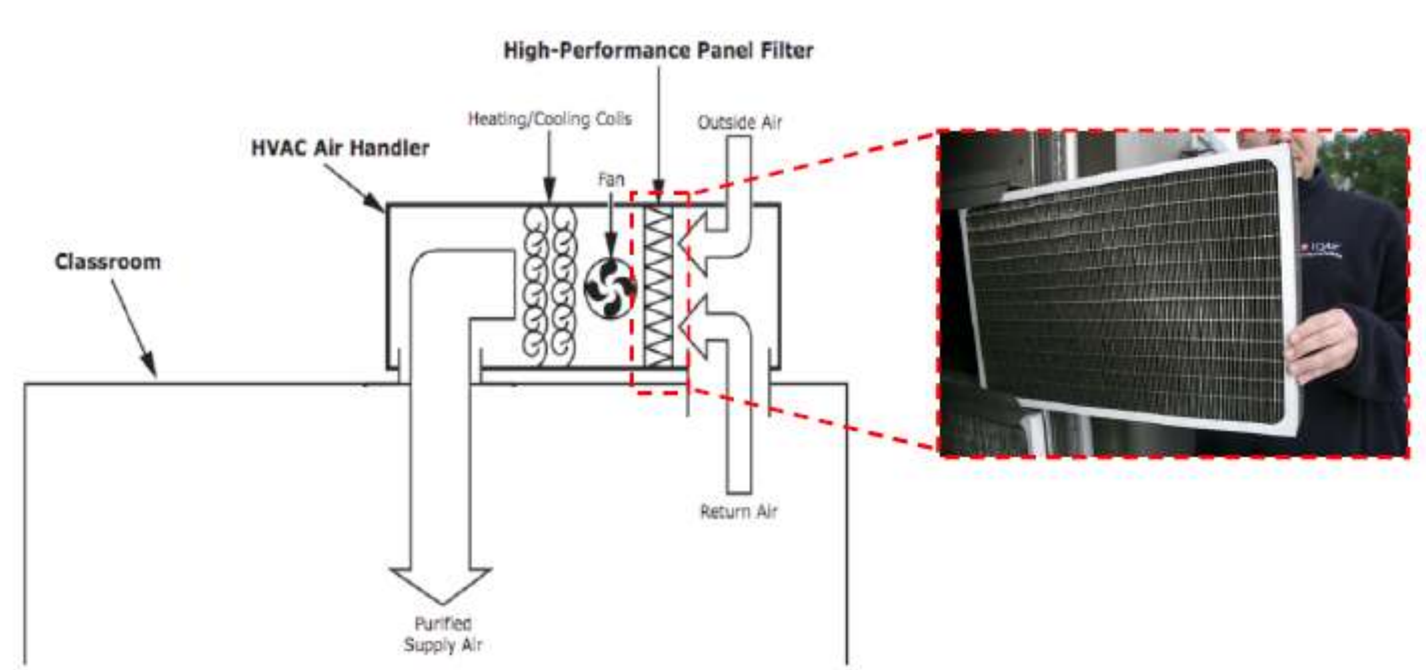
Union Pacific Railroad Intermodal Container Transfer Facility

- Del Amo Elmentary (LAUSD)
- Dominguez Elementary (LAUSD)
- Hudson (LBUSD)

- <u>Pilot Study</u>
  - April - December 2008
  - 3 schools / 9 classrooms
    - *Similar size (7500 to 9200 ft^3)*
    - *Similar ventilation conditions (HVAC)*
    - *MERV 7 (replaced every 3 mo)*

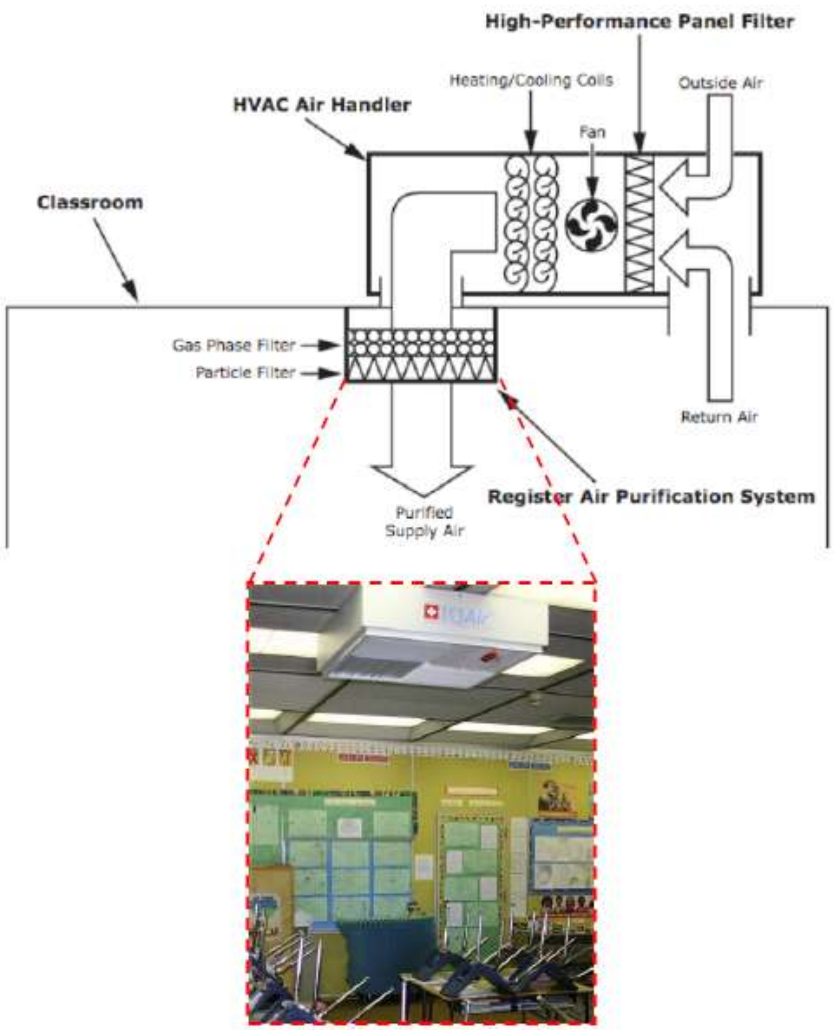
- <u>Major emission sources</u>:
  - *Refineries*
  - *Roadways*
  - *Los Angeles / Long Beach Port*
  - *UPRR ICTF*

PILOT STUDY: Air Filtration Solutions
High-Performance Panel Filter (HP-PF)



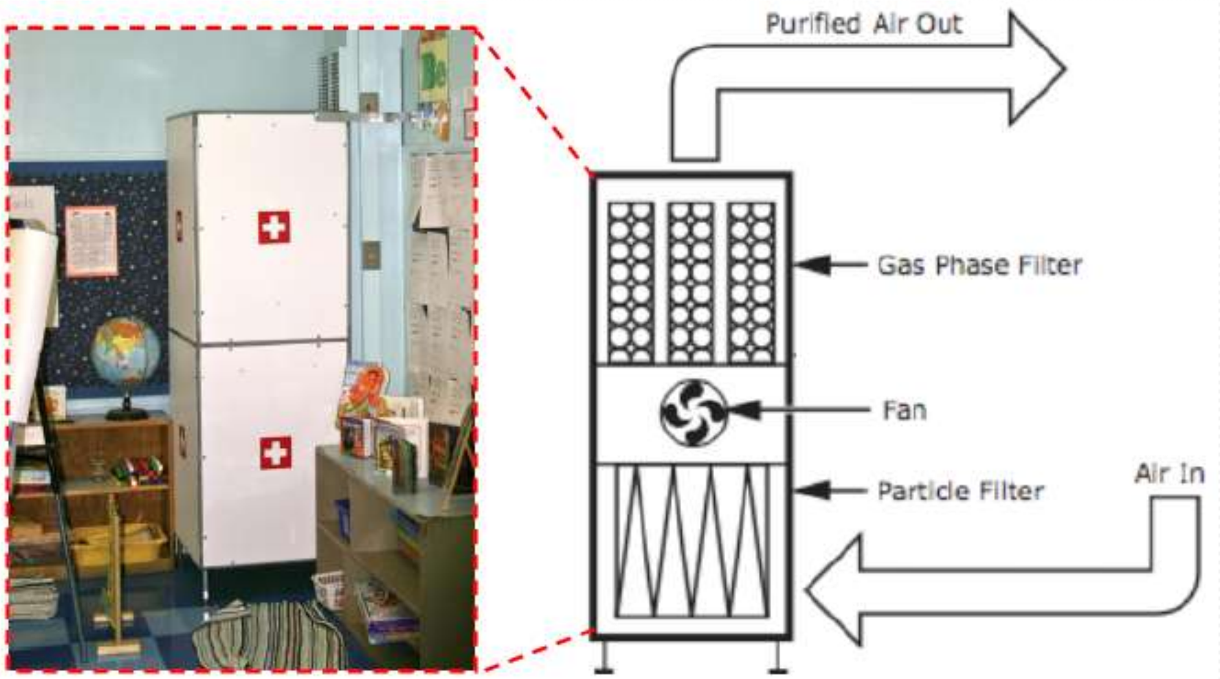
- Compared to standard / conventional filters
    - *Proprietary technology (remove UFPs and BC)*
    - *Twice as thick (2" in depth); larger surface area (5-9 times larger)*
    - *Similar air resistance properties (do not reduce HVAC air flow)*
    - *Longer lifetime (>1 year)*

PILOT STUDY: Air Filtration Solutions
Register System (RS)



- Installed directly on the HVAC register
- Equipped with:
  - *HP-PF*
  - *High-capacity gas phase filter cartridges for VOC removal*
- RS does not reduce the overall HVAC system airflow

PILOT STUDY: Air Filtration Solutions
Stand-alone System (SA)



- Operates independently of a classroom's HVAC
- Height: 6' feet; Footprint: 4 ft^2
- Runs on a standard power circuit
- Ultra quiet operation (<45 db(A) at high airflow)
- Equipped with: HP-PF + 12 high-capacity gas phase filter cartridges

PILOT STUDY: *In-classroom Configurations*

HP-PF

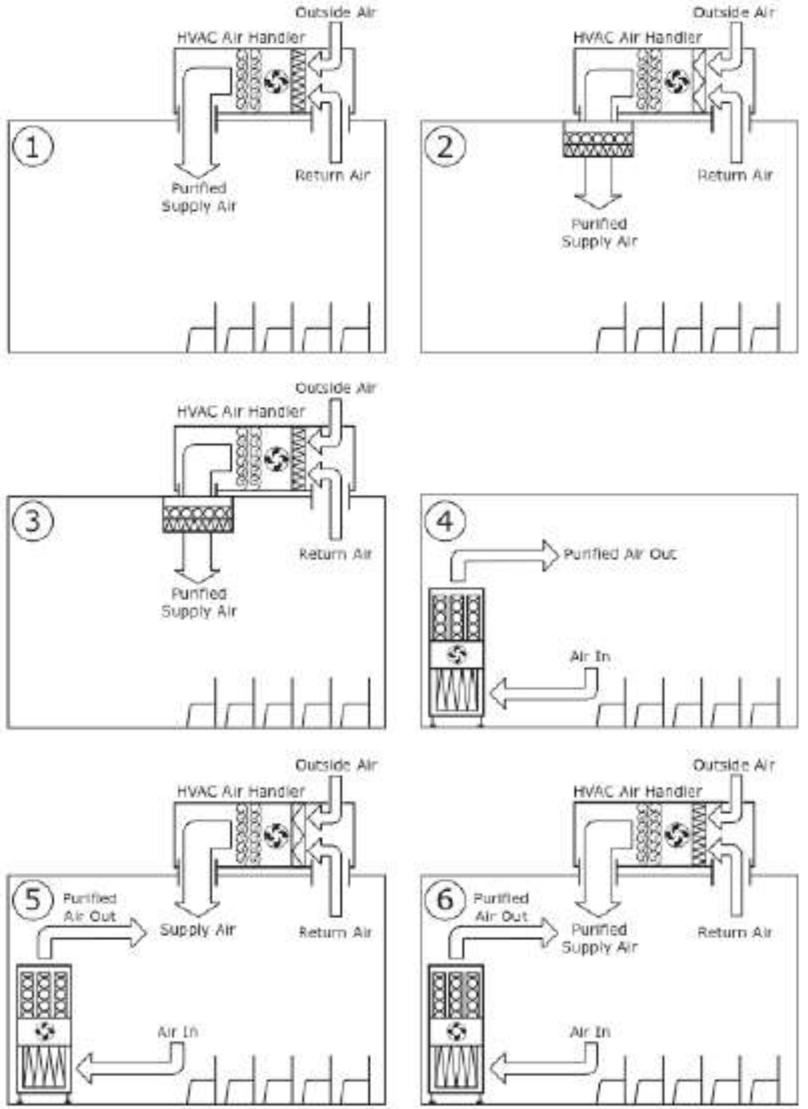
RS + PF

RS + HP-PF

SA
(no HVAC running)

SA + PF
(HVAC running)

SA + HP-PF



PILOT STUDY: *Indoor and Outdoor Measurements*

- Continuous Instruments
  - *UFP; #/cm^3*
  - *BC (µg/m^3)*
  - *$PM_{2.5}$ (#/cm^3)*
  - *$PM_{2.5}$ and PM_{10} (µg/m^3)*

- Integrated measurements
  - *PM_{10} (µg/m^3)*
  - *VOCs (ppbv)*

- Four carts: 1 outdoors + 3 indoors

- Removal efficiency (%) = [(OUT – IN) / OUT] × 100

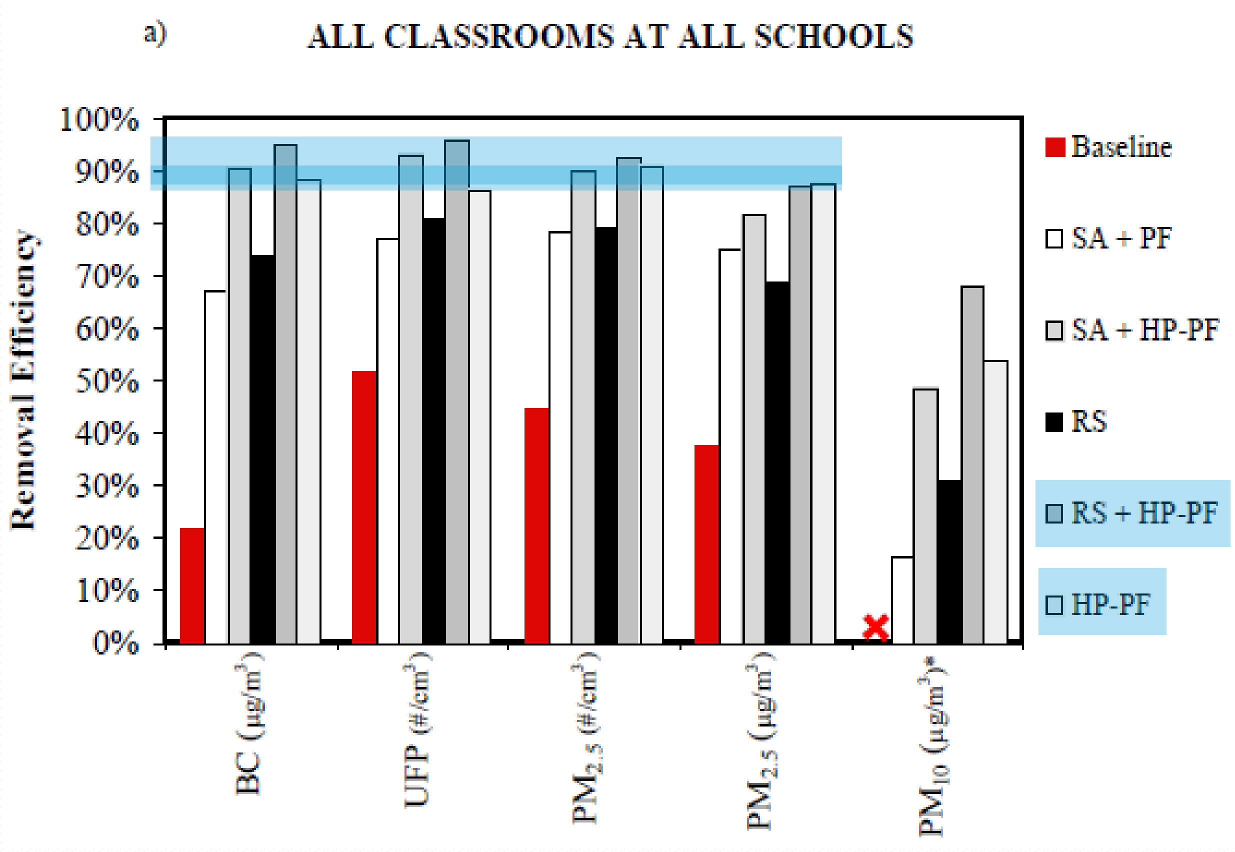
- Baseline measurements (pre-existing removal efficiencies)

- Collocated measurements (QA; precision, potential problems)

- Testing period: during school hours; >150 measurement days

PILOT STUDY: *Results*

Removal of PM and Other Particle Species

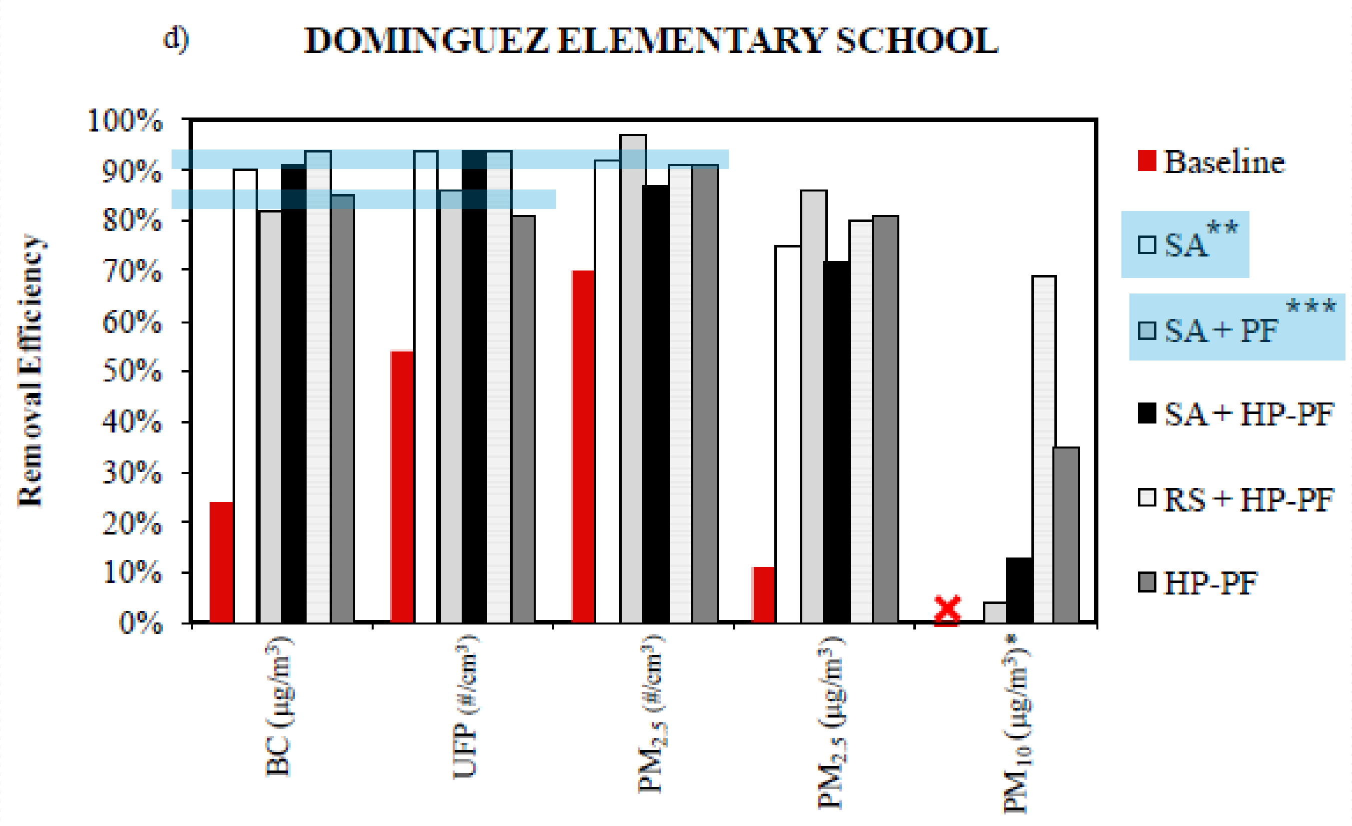


- RS + HP-PF: most effective solution (study average removal efficiency = 87-96%)

- HP-PF: also an effective solution (study average removal efficiencies = 86-91%)

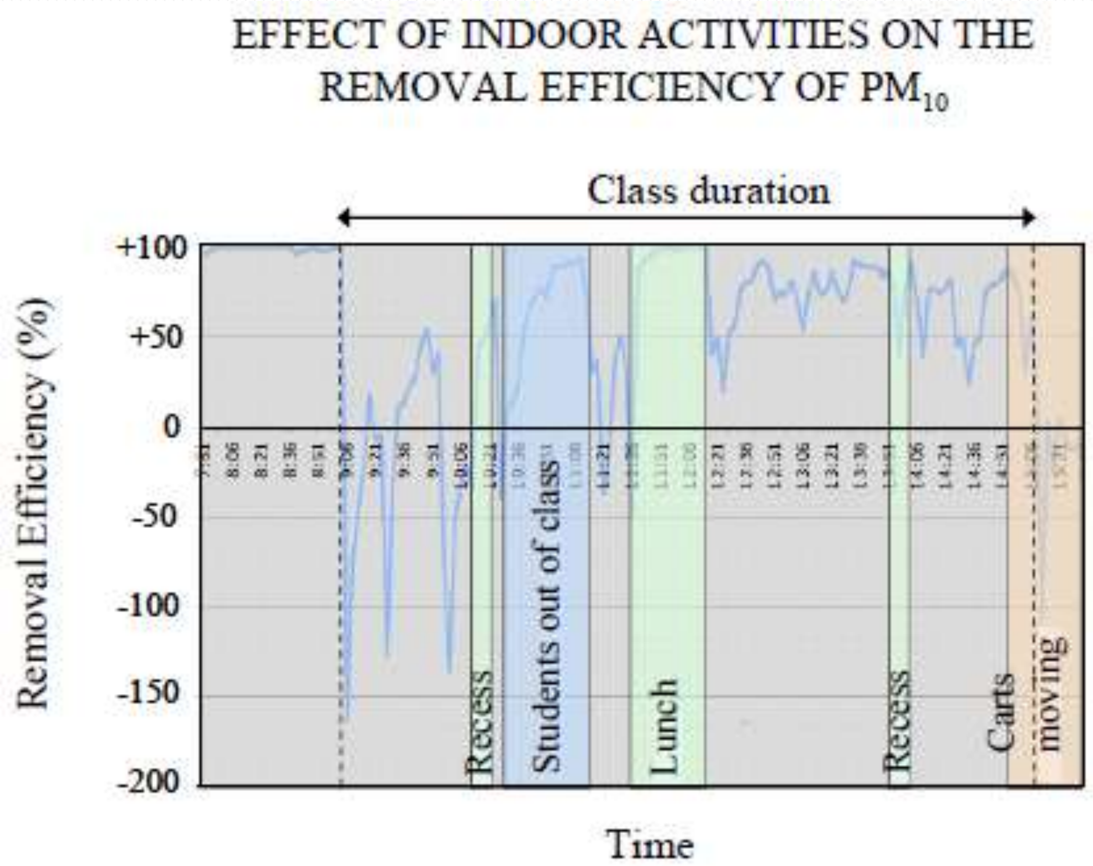
PILOT STUDY: *Results*

Removal of PM and Other Particle Species



- SA (HVAC off): removal efficiencies ~90% for BC, UFP and $PM_{2.5}$ (count)
- SA + PF (HVAC on): removal efficiencies < 90% for BC and UFP

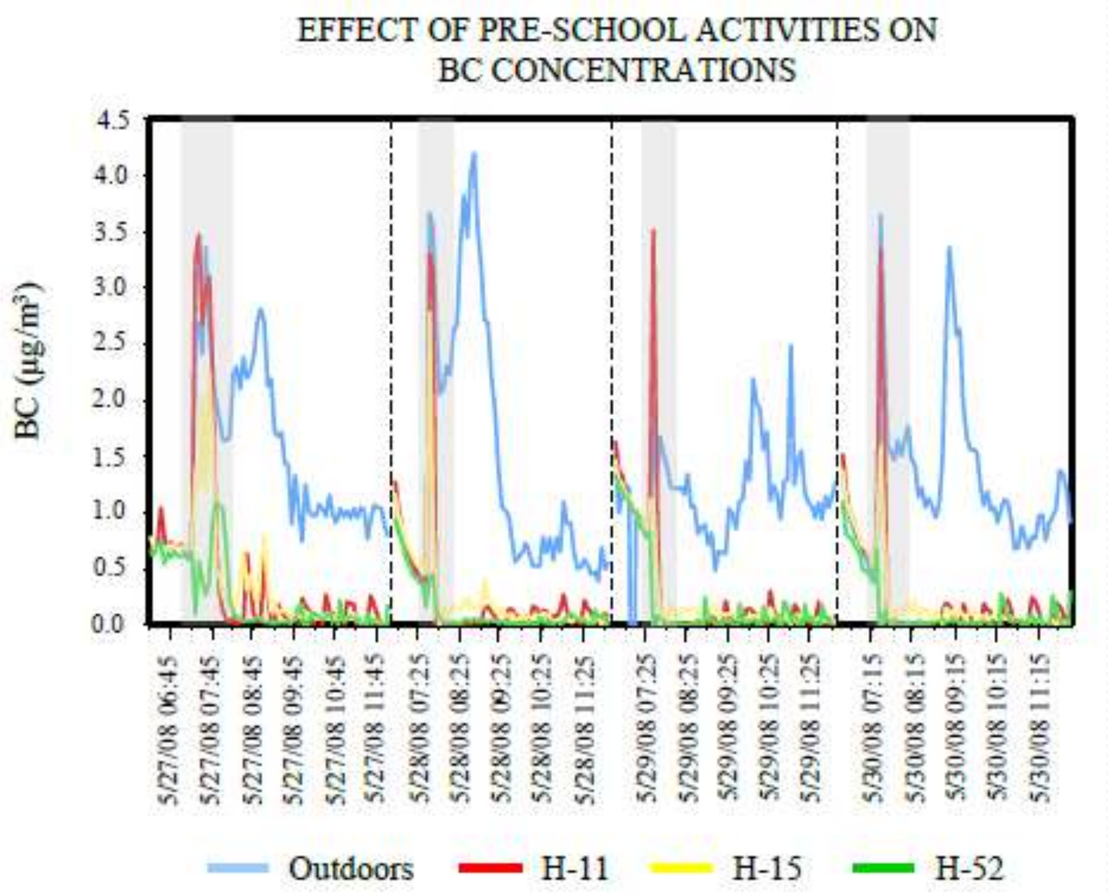
PILOT STUDY: *Results*
Effect of Indoor Activities



Hudson; room H-15
(May 21, 2008)

- Removal efficiency for PM_{10}
    - *High: before the school day started and during lunchtime*
    - *Low: when classes were in session*

PILOT STUDY: *Results*
Effect of Outdoor Activities



- Effect of morning drop-off (doors were open)
    - *BC increase; temporary decrease in removal efficiency*
    - *Relatively small decrease in average removal performance*

PILOT STUDY: *Results*
VOC Removal

	DOMINGUEZ ELEMENTARY SCHOOL			
	Study Days (#)	Total VOCs (%)[1]	Ethanol (%)	Benzene (%)
Baseline	18	-114 ± 731	-1230 ± 982	-11 ± 22
SA (HVAC off)*	3	15 ± 132	-349 ± 276	52 ± 35
SA + PF (HVAC on)**	4	19 ± 198	-587 ± 903	58 ± 33
SA + HP-PF	6	-6 ± 280	-929 ± 853	73 ± 11
RS	N/A	N/A ± N/A	N/A ± N/A	N/A ± N/A
RS + HP-PF	8	-3 ± 345	-534 ± 502	58 ± 49
HP-PF	18	-64 ± 404	-1111 ± 1164	1 ± 38

[1]Sum of 61 known VOCs and 53 unspeciated organic compounds
*Operated with the HVAC system turned off
**Operated with the HVAC system turned on

- Ethanol: from both indoor and outdoor sources
- Benzene: indicator of VOCs of outdoor origin

- Large standard deviations: wide concentration ranges for the different chemicals
- SA: 52-73% removal performance for benzene
- Several measured indoor VOCs are mostly of indoor origin

PILOT STUDY: *Summary and Conclusions*

• RS + HP-PF: most effective solution for BC, UFP, and $PM_{2.5}$ (study average removal efficiencies = 87-96%)

• HP-PF: reductions close to 90%

• Removal performance of PM_{10} was lower due to re-suspension of dust and other indoor activities (e.g. walking and cleaning)

• In all cases, air quality conditions were improved substantially with respect to baseline (pre-existing) conditions

• The effectiveness, lifetime, costs, benefits, and maintenance of the gas removal systems tested in this pilot study must be further assessed before conclusions and recommendations can be made

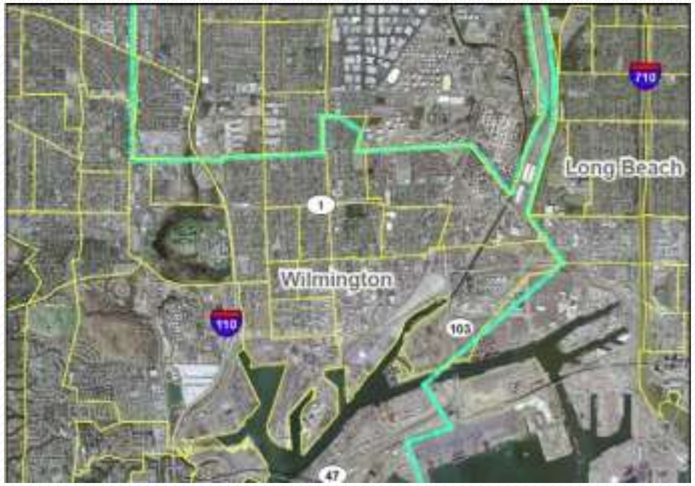
SCAQMD AIR FILTRATION IMPLEMENTATION

- SCAQMD started $1.125M implementation program in Los Angeles-Long Beach Port area schools (2009)
- Air filtration installation at seven Los Angeles and Long Beach schools within 10 mile of Valero Refinery (penalty settlement) (2010-2012)

First installation of air filtration systems completed at Del Amo Elementary (LAUSD) in Jan 2010

TRAPAC AIR FILTRATION PROGRAM

- In Jan 2011 SCAQMD Governing Board approved execution of a $5.4M contract with IQAir North America for installation of air filtration systems in 47 schools
- Selection of contractor involved RFP for air filtration installers and testing of air filtration technologies
- Steering and technical advisory committees
- Installation completed at 27 Phase I schools in 2012-2013; starting Phase II schools



Geographical area of schools in TraPac program

RFG AIR FILTRATION PROJECTS

- MELA and CCAEJ installed air filtration at schools in Boyle Heights and San Bernardino using RFG funds ($950,000 and $1M respectively) (2012-2013)
- Combined with EPA Region 9 CATI, Targeted Air Shed grants, SCAQMD Priority Reserve funding
  - 7 Boyle Heights schools - LAUSD and Archdiocese
  - 6 San Bernardino schools - SBCUSD and JUSD

CVUSD AIR FILTRATION

- CVUSD and IQAir received grants for $337,200 and $921,000 to install air filtration in at least 10 schools
  - PM filtration to assist with dust and agricultural burning issues
  - Saul Martinez and Mecca ES will demonstrate VOC removal technologies to mitigate odor issues at schools

ACKNOWLEDGEMENTS

SCAQMD air filtration pilot study was funded through the use of mitigation fees collected by the South Coast Air Quality Management District (SCAQMD) under Rule 1172 for VOC releases by local refineries. SCAQMD is the air pollution control agency for all of Orange County and urban portions of Los Angeles, Riverside and San Bernardino counties, the smoggiest region of the United States. UnoCal Reformulated Gasoline Settlement fund provided grants to Mothers of East Los Angeles and Center for Community Action and Environmental Justice. EPA Region 9 provided a Clean Air Technology Initiative and a Targeted Air Shed grant. SCAQMD's Priority Reserve mitigation fee fund and AB1318 mitigation fee fund provided funding for Boyle Heights, San Bernardino, and Coachella Valley schools.

IQAir North America, Inc., a leading specialist in air filtration solutions for homes, hospitals and schools, and Thermal Comfort Systems, specialist in HVAC system design, were selected by SCAQMD through a competitive bid process to provide for the design, engineering and installation of the air filtration devices used for this work.

NEXT

02:30 pm - Planning and Policy Discussion

Moderator: Philip Fine (Assistant Deputy Executive Officer; Science & Technology Advancement; SCAQMD)

Panelists:
- Connie Chung (Supervising Regional Planner; LADRP)
- David Vintze (Manager; Planning and Research Division; BAAQMD)
- Huasha Liu (Director; Dept. of Land Use and Environmental Planning; SCAG)
- Mike McCarthy (Manager; Advanced Engineering Section; CARB)
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Application of High Efficiency Cabin Air (HECA) Filter for Simultaneous Mitigation of Ultrafine Particle and Carbon Dioxide Exposures in Passenger Vehicles

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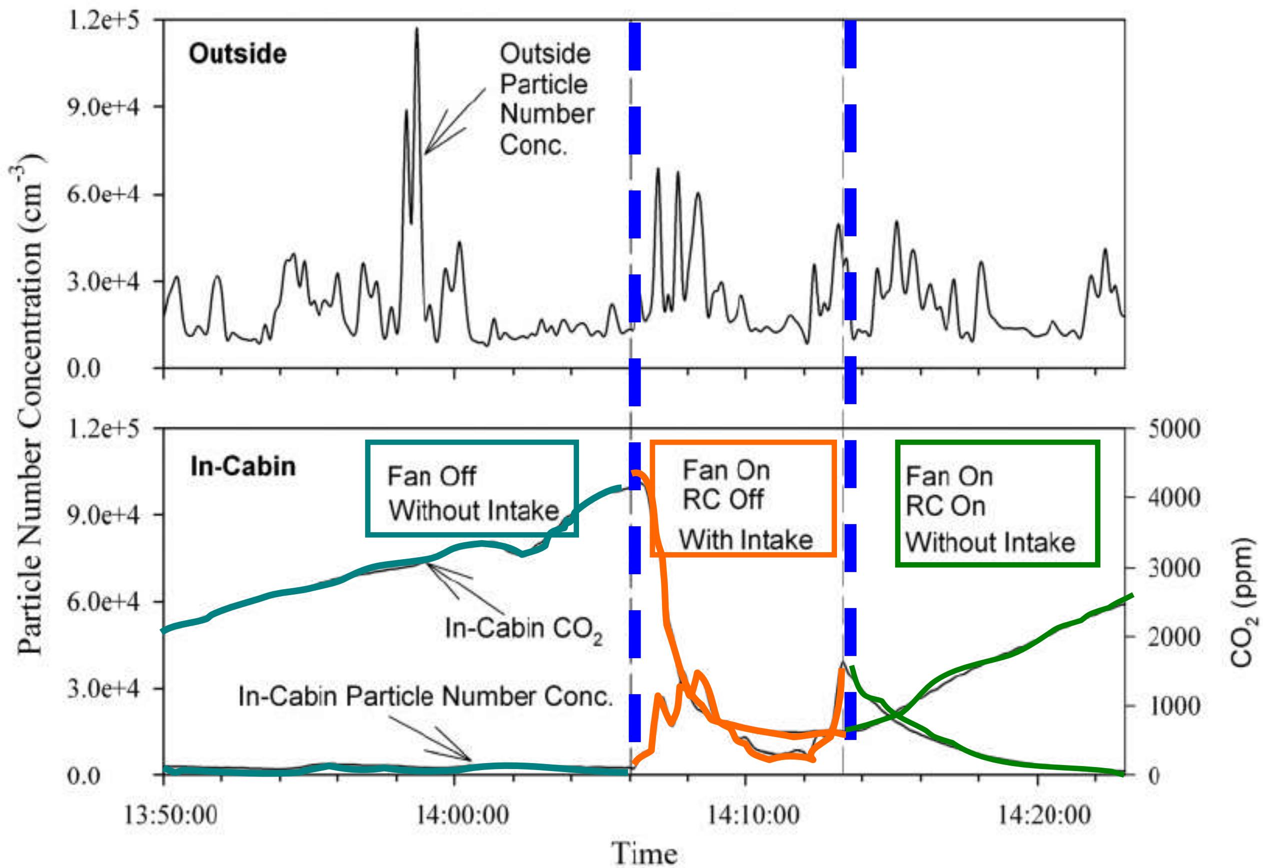
Back to Agenda

Background & Motivation

- Ultrafine particles (UFPs)
  - Health effects
    - Pulmonary and cardiovascular diseases (Peters et al., 1997; Penttinen et al., 2001; von Klot et al., 2002; Stolzel et al., 2007; Andersen et al., 2010)
    - Inter-organ translocations (Kreyling et al., 2002; Hamoir et al., 2003; Gilmour et al., 2004; Nemmar et al., 2002; Nemmar et al., 2004; Oberdorster et al., 2004)
    - Cell penetration (Li et al., 2003)
    - Systemic inflammation (Sioutas et al., 2005; Elder et al., 2007)
  - Origin from combustion processes
    - Traffic emissions (Shi et al., 1999; Hitchins et al., 2000)
    - Urban background: $5 \times 10^3 \sim 5 \times 10^4$ #/cm^3
    - On-road: > 10^5 #/cm^3
    - In-cabin: > 5×10^4 #/cm^3

- In-cabin exposure
  - 5.5% of time spent in commuting (Klepeis et al., 2001)
  - In-cabin UFP exposure occurs up to 50% of daily total (Zhu et al., 2007; Fruin et al., 2008)
    - Close proximity to the high emission sources and self-pollution (Behrentz et al., 2004)
    - Low cabin air filter efficiency (Qi et al., 2008; Xu et al., 2011)
    - High leakiness of automotive envelope (Chan et al., 2002; Esber et al., 2007)

Background & Motivation



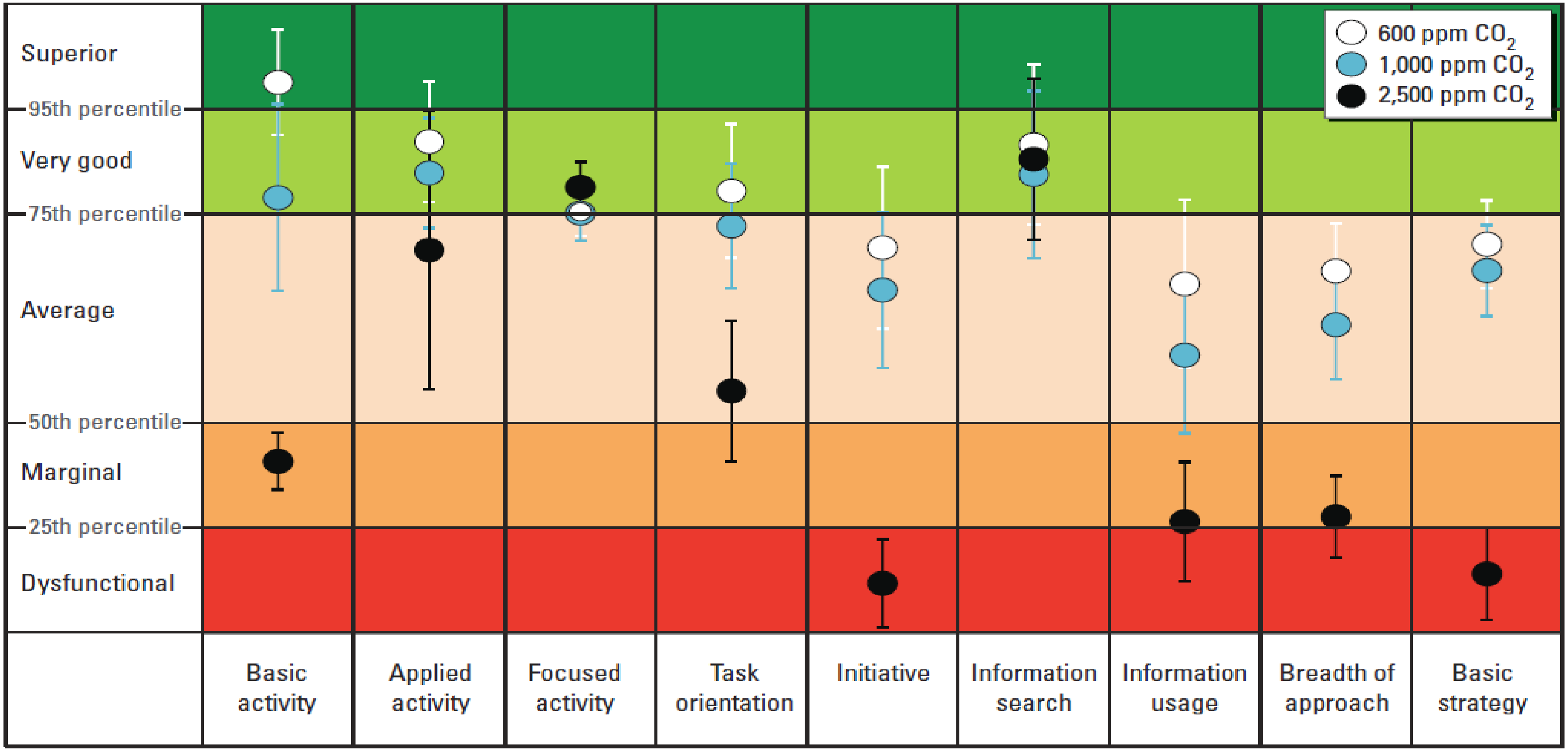
Key Point Turn on recirculation (RC) provides the best protection for UFP exposures, but lead to high CO_2 levels.

Zhu et al., 2007 , "In-cabin commuter exposure to ultrafine particles on Los Angeles freeways". *Environmental Science and Technology*. 41: 2138-2145.

Carbon Dioxide Accumulation

- On-freeway level: 500 ~ 600 ppm
- In-cabin level: above 2500 ppm with 2 passengers only in 15 minutes

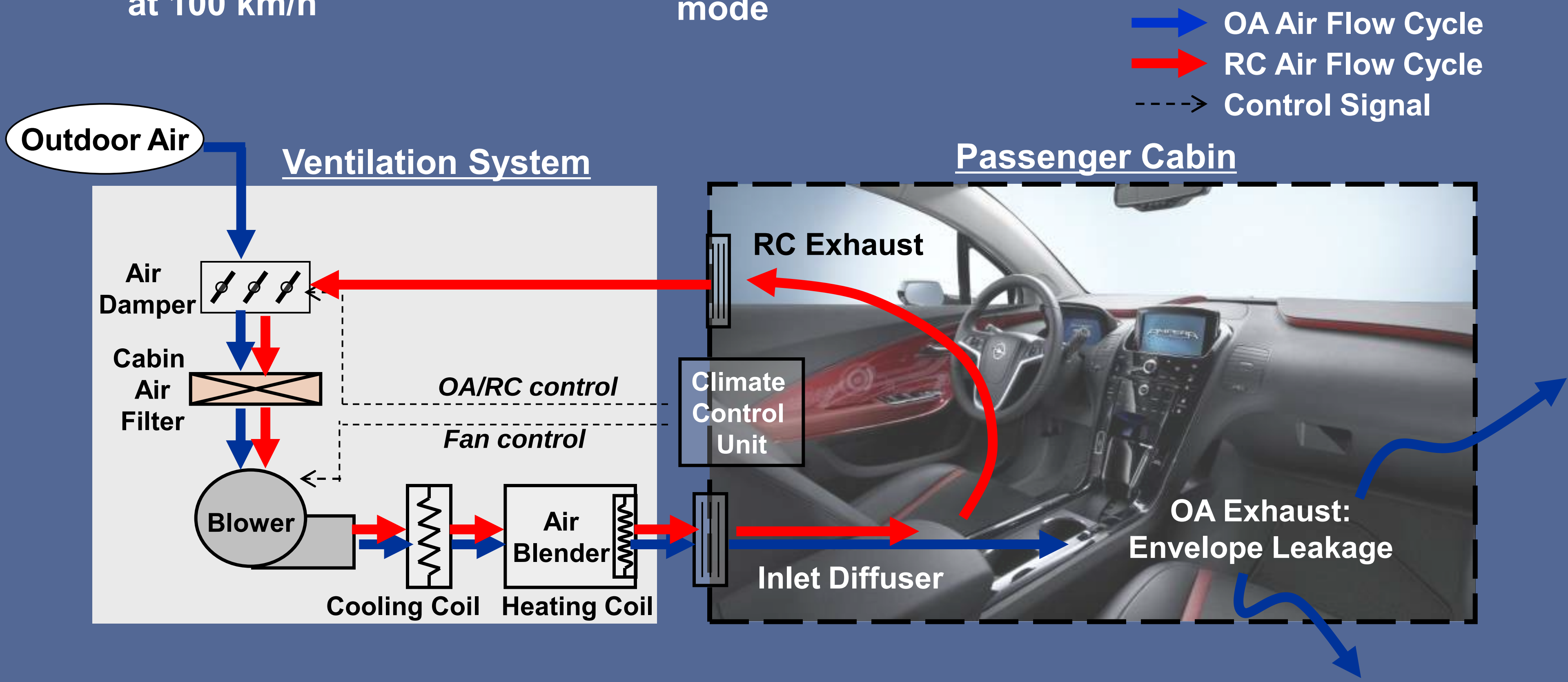
Decision Making Performance Changes (Satish et al., 2012)



Automotive Ventilation System

Air Exchange Rate (AER):
- OA AER: 100~200 h^{-1} at max. fan setting
- RC AER: 5~30 h^{-1} at 100 km/h

In-cabin UFP Removal (1 - I/O):
~40% in OA mode
~85% in RC mode
But, CO_2 accumulates in RC mode



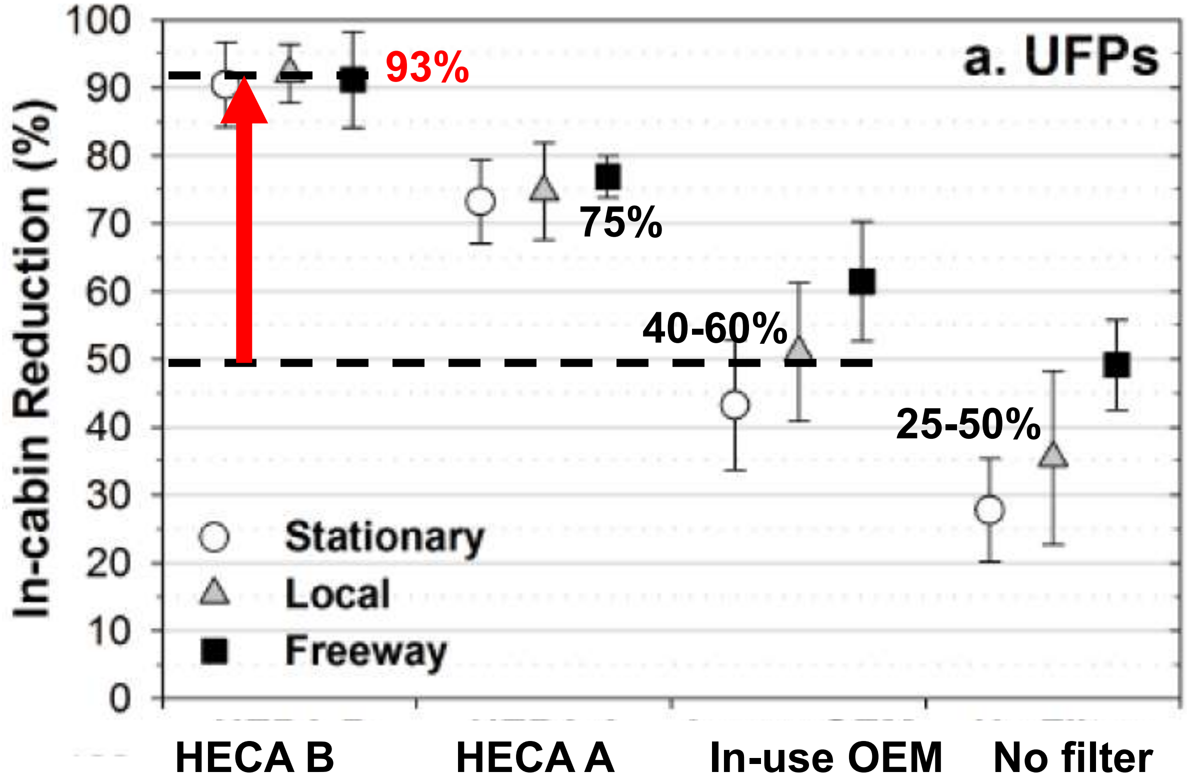
Experimental Set-up

- 4 filter types: HECA B, HECA A, In-use OEM, No filter
- 3 driving conditions: Stationary, Local, Freeway
- OA-mode & median fan setting
- < 3 years, California Vehicle Fleet

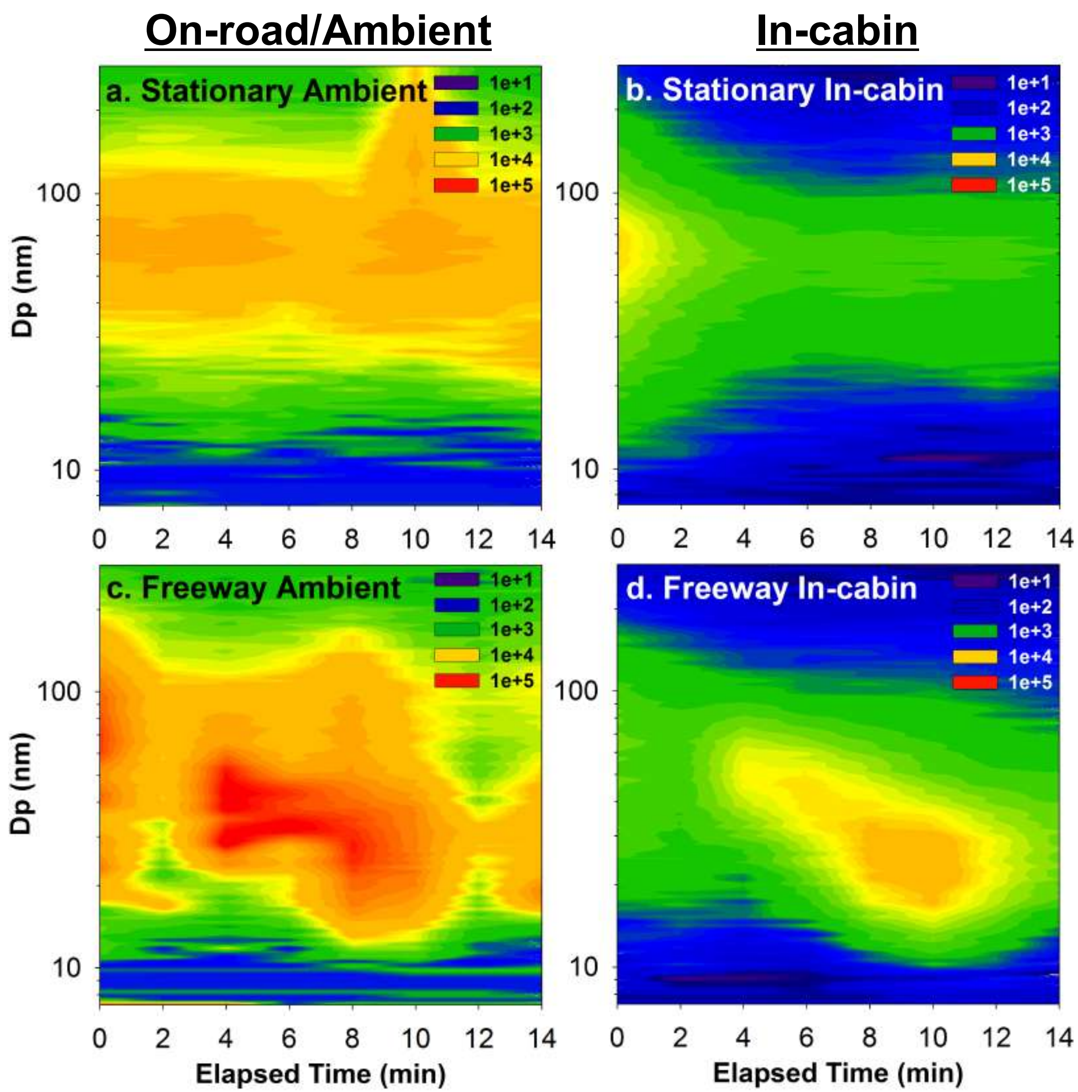
Vehicle Type	Maker	Model	Year	Mileage (km)	Cabin Filter Locations	Cabin Volume (m^3)
Hatchback	Ford	Focus	2012	51,347	Glove Box	2.94
	Toyota	Prius	2012	9,102	Glove Box	3.88
Sedan	Chevrolet	Impala	2012	1,339	Glove Box	4.01
	Honda	Accord	2011	51,194	Glove Box	3.83
	Hyundai	Sonata	2013	21,712	Glove Box	3.41
	Nissan	Sentra	2012	30,398	Under Dash	3.50
	Toyota	Camry	2012	1,931	Glove Box	3.78
	Volkswagen	Jetta	2012	14,917	Under Hood	3.55
SUV	Ford	Explorer	2013	16,510	Glove Box	4.89
	Toyota	Highlander	2012	10,611	Glove Box	4.43
Minivan	Honda	Odyssey	2010	38,622	Glove Box	7.03
	Toyota	Sienna	2011	74,174	Glove Box	5.76

In-cabin UFP Reduction

Higher Efficiency!
Less Variability!



Temporal Changes of In-cabin UFPs



In Stationary Condition

Substantially Decreased
UFP number concentration

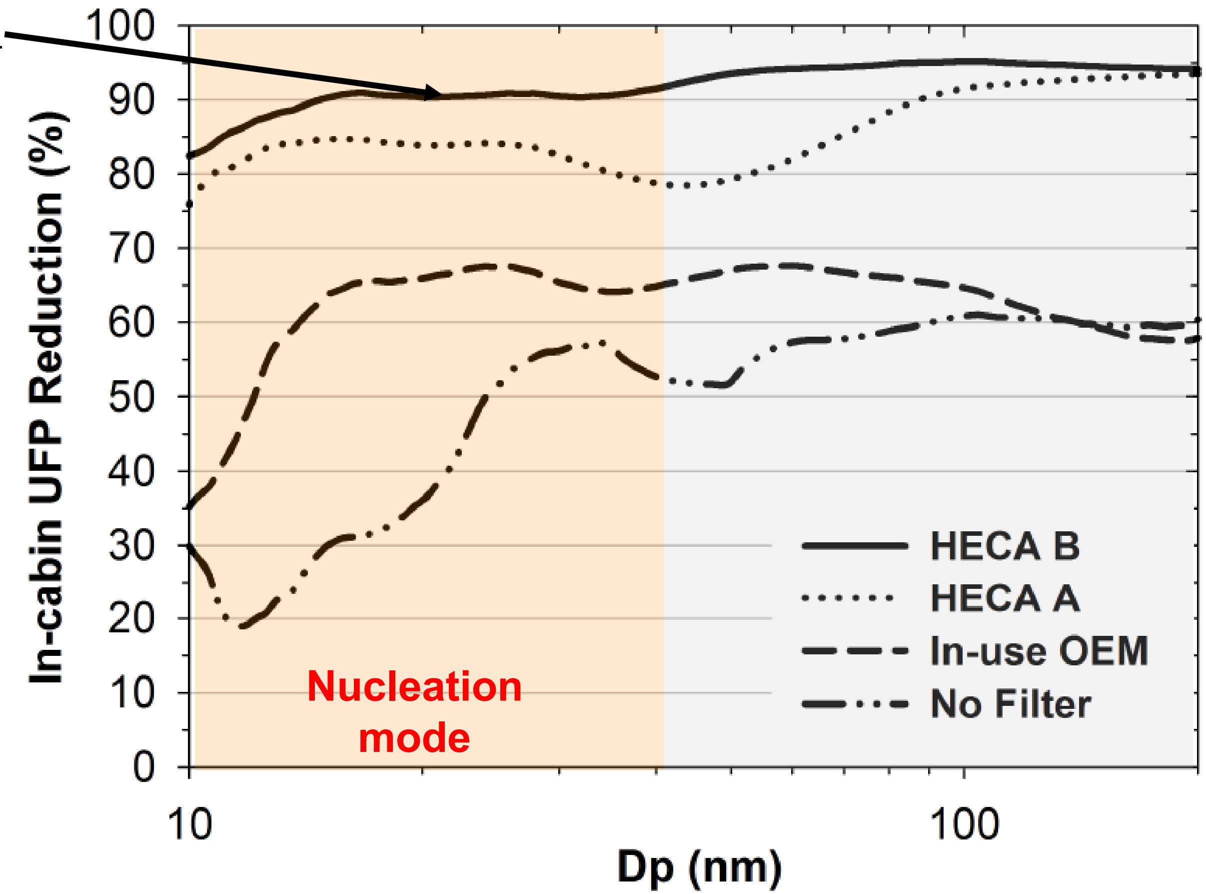
In Freeway Condition

UFP Mitigation on Freeway by an order of magnitude

Size-resolved Particle Removal Efficiency

HECA B

More effective removal of UFPs in nucleation mode!

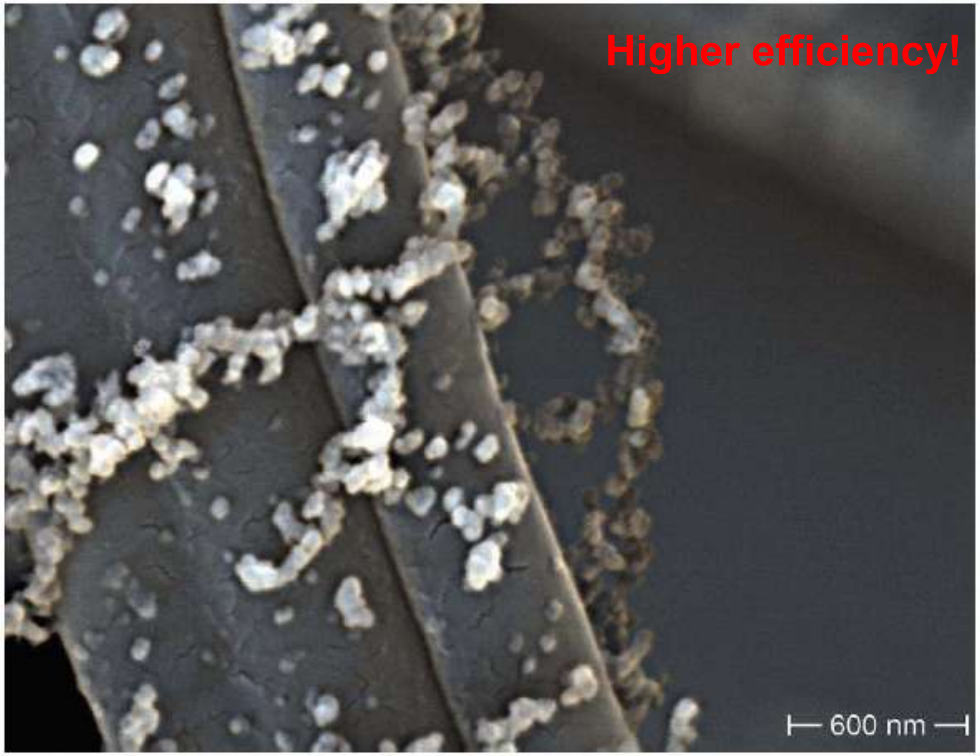


In-cabin HECA filter

HECA A Filter

~ 1 µm

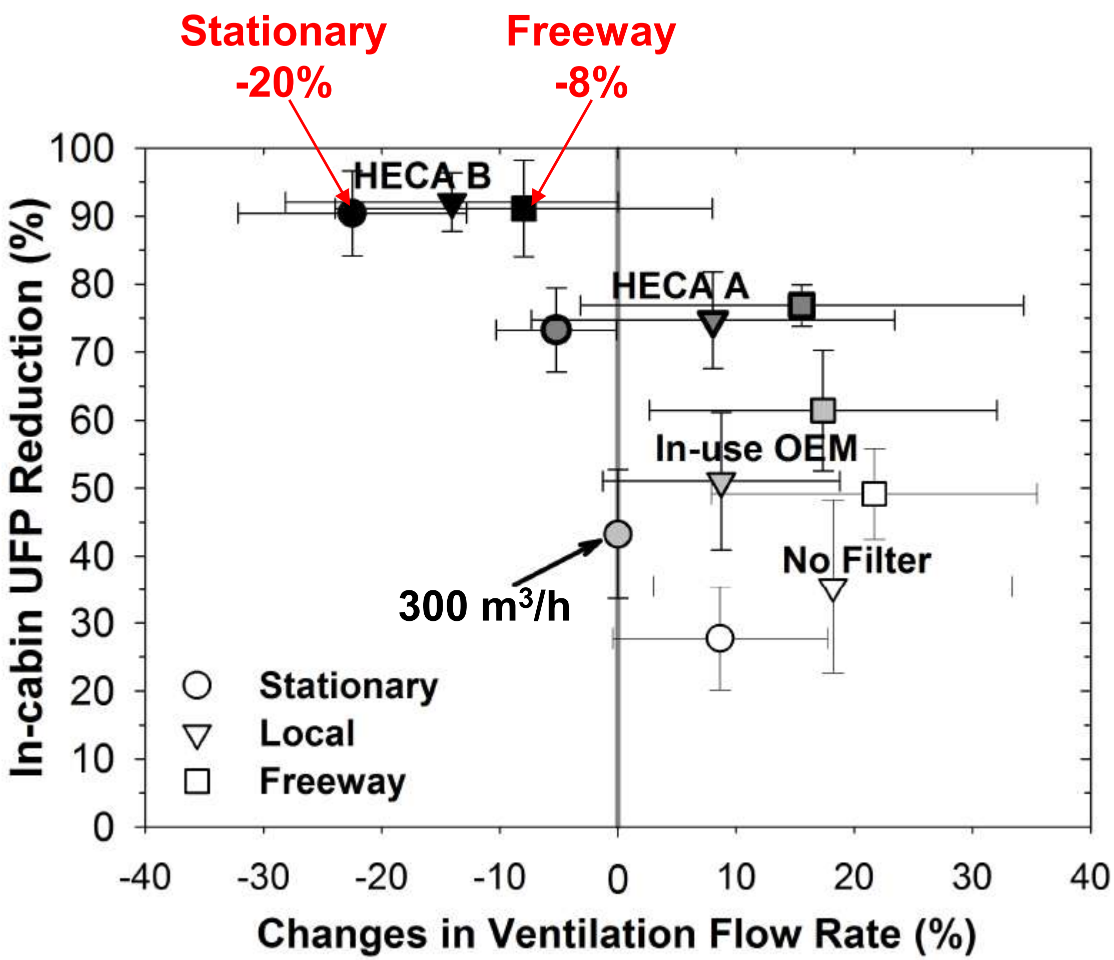
HECA B Filter



~ 0.6 µm

The difference is in the filter fiber diameter.

Changes in Ventilation Air Flow Rate

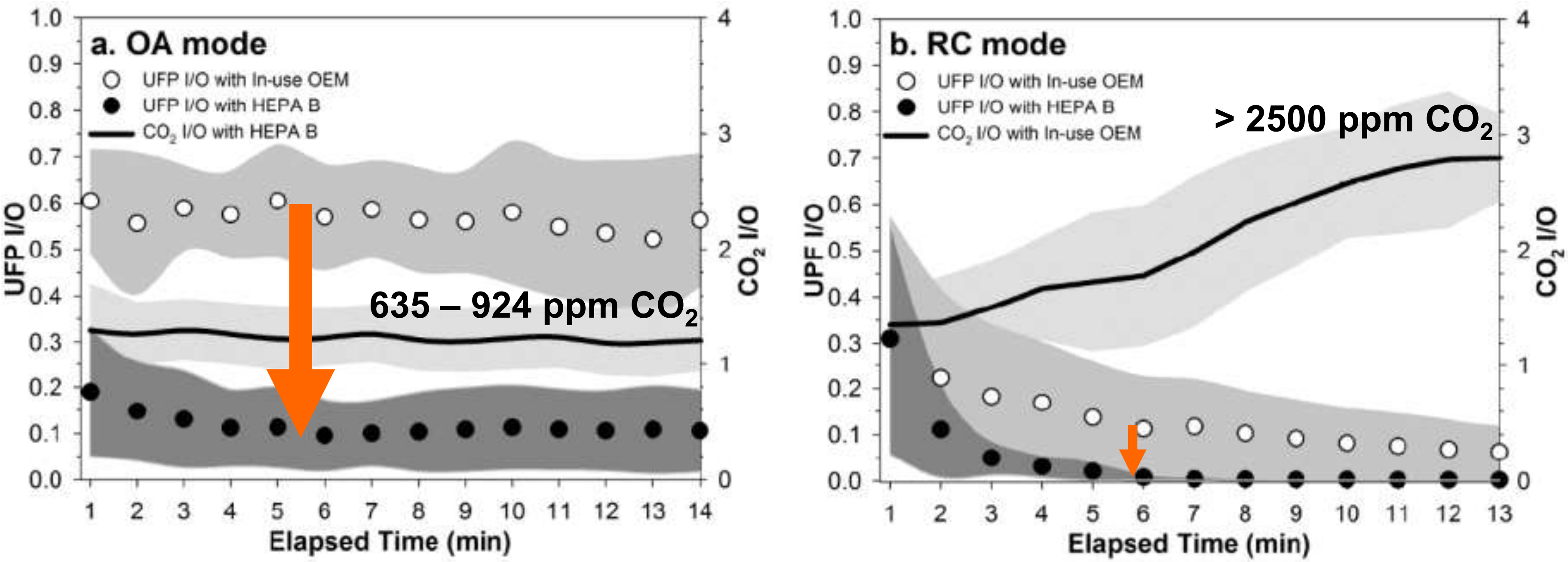


Pressure drop is present but would unlikely become a problem.

On Freeway,
Air-flow reduction is Less than 10%!

Simultaneous Control for UFPs & CO_2

Means & Standard Deviations of measurement data in 12 vehicles



Conclusions

- Proposed a simultaneous control of UFPs and CO_2 using in-cabin HEPA filters.
- 93% reduction of in-cabin UFPs on average in field conditions.
- Thermal comfort issue would unlikely be a problem from ventilation air-flow reduction ~ 20 % in stationary conditions, < 10 % on freeway.
- More effective UFP reduction in freeway environments due to nucleation mode particle diffusion.
- This control method holds in-cabin CO_2 build-up at 635-924 ppm (vs. 2500 – 4000 ppm in RC mode) with 2 passengers.

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Thank you!

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