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EVALUATING THE EFFECTS OF NEAR-ROAD SOLID AND VEGETATION BARRIERS ON MSAT EXPOSURES

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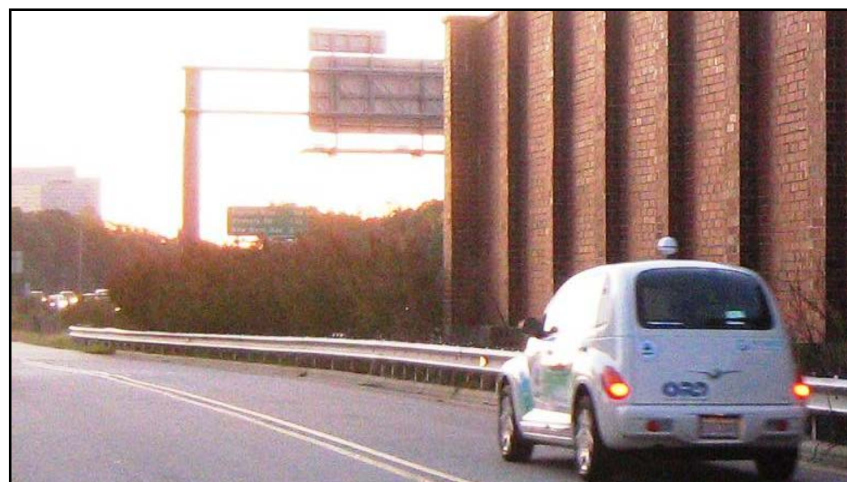
Background on Health Concerns

- Populations living, working and going to school near highways and large arterial roads have increased risks for many adverse health effects (e.g. asthma, cardiovascular disease, premature mortality)
- Elevated concentrations of air pollutants exist near large roads
- Significant portion of US population exposed, including residential and children at school
- Interest in methods to understand and mitigate these traffic emission exposures and adverse health effects
- Transportation and land use planning mitigation options include:
  - Reduce emissions through vehicle standards and voluntary programs
  - Reduce vehicle activity/Vehicle Miles Travelled (VMT)
  - Recommend or enforce buffer/exclusion zones
  - Use roadway design and urban planning
    - Road location and configuration
    - ***Roadside noise barriers and vegetation***

Why study roadside barriers?

- Roadside barriers alter air pollution transport and dispersion
- Roadside barriers may already be present and affecting exposures
- Roadside barriers often have other positive benefits
- 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, especially in urban areas



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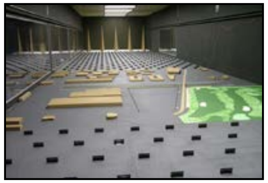
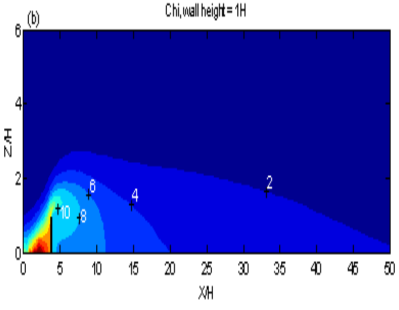
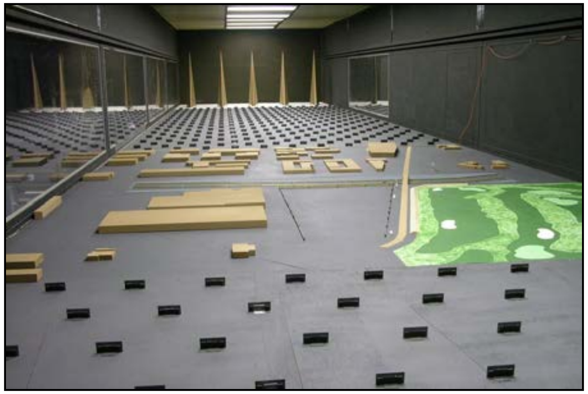
Research Methodology

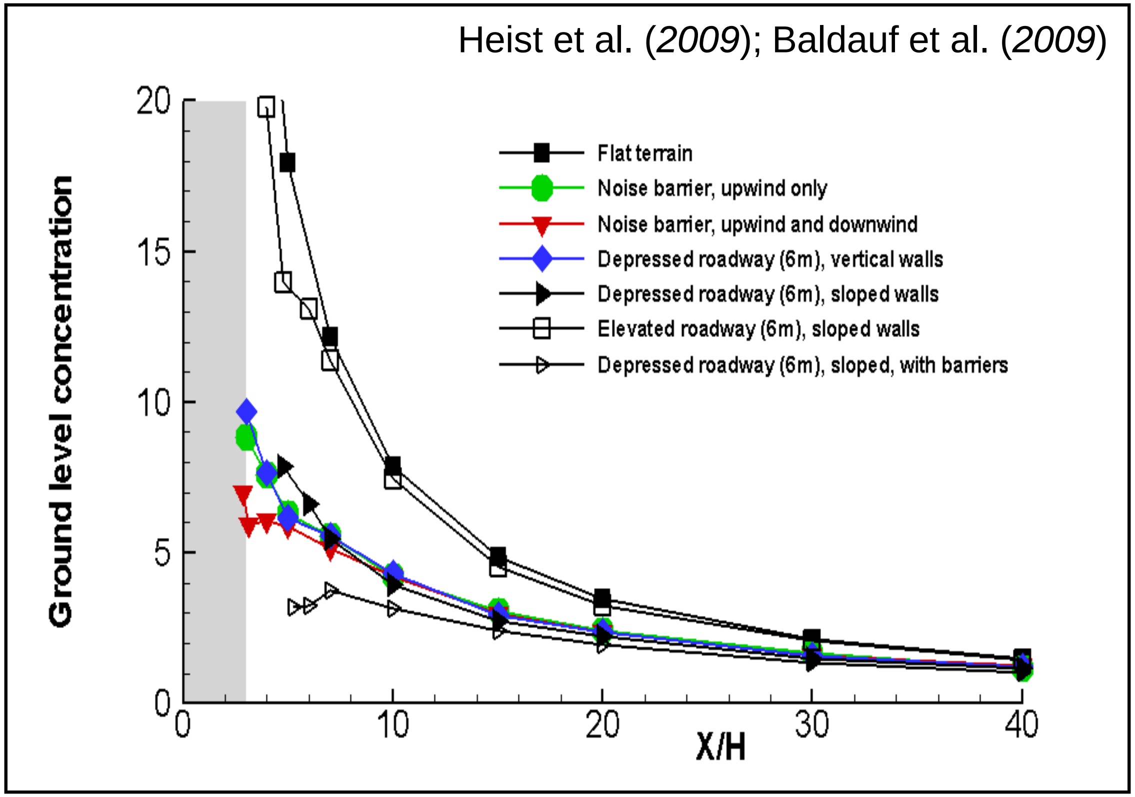
- EPA has initiated studies to examine how roadside features affect near-road air pollutant exposures
- Using modeling and measurements to characterize the impact of roadway features on near-road air quality
  - Wind tunnel assessments
  - CFD modeling
  - Field studies
- Developing new model algorithms to evaluate impacts of roadway features
  - Determine potential mitigation opportunities
  - Air quality characterization
  - Exposure assessment and characterization

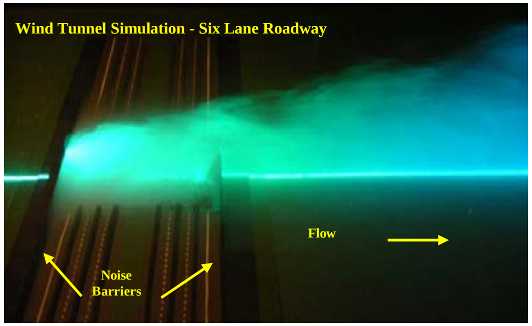




Roadway Configuration Effects







Wind tunnel simulations show roadway design impacts on pollutant transport and dispersion. Highest levels occur with at-grade and elevated fill roads; lowest levels occur with cut sections and solid noise barriers

Roadway Configuration Effects

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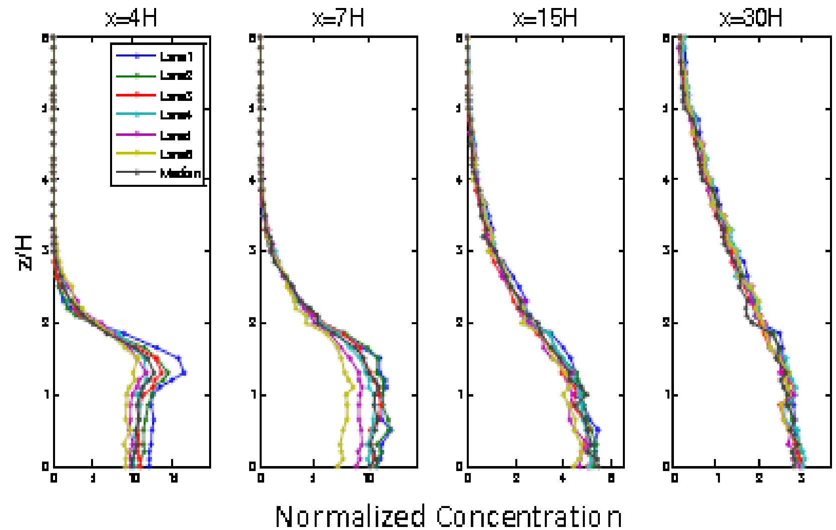
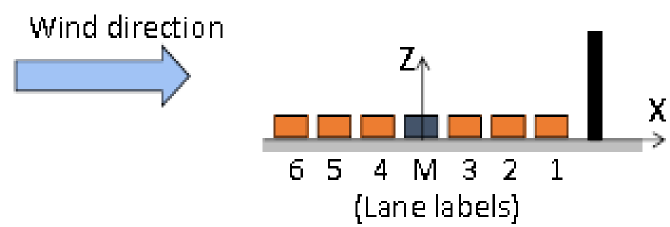
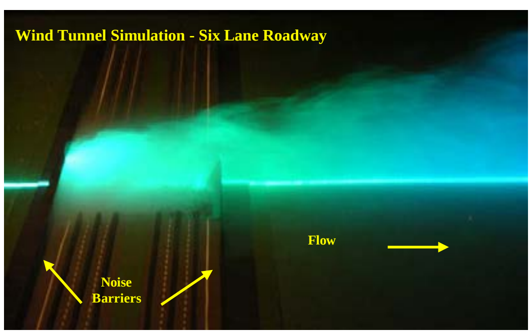


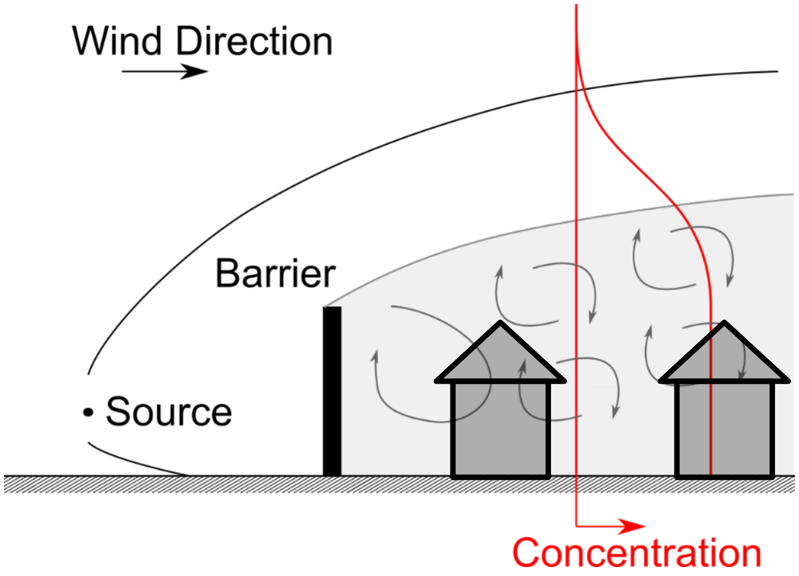
Vertical profiles with barrier





For solid noise barriers, vertical profiles show plume lofted up and over the barrier, increasing mixing and dilution. Pollutant concentrations higher at higher elevations, although still lower than would be at ground-level with no barrier

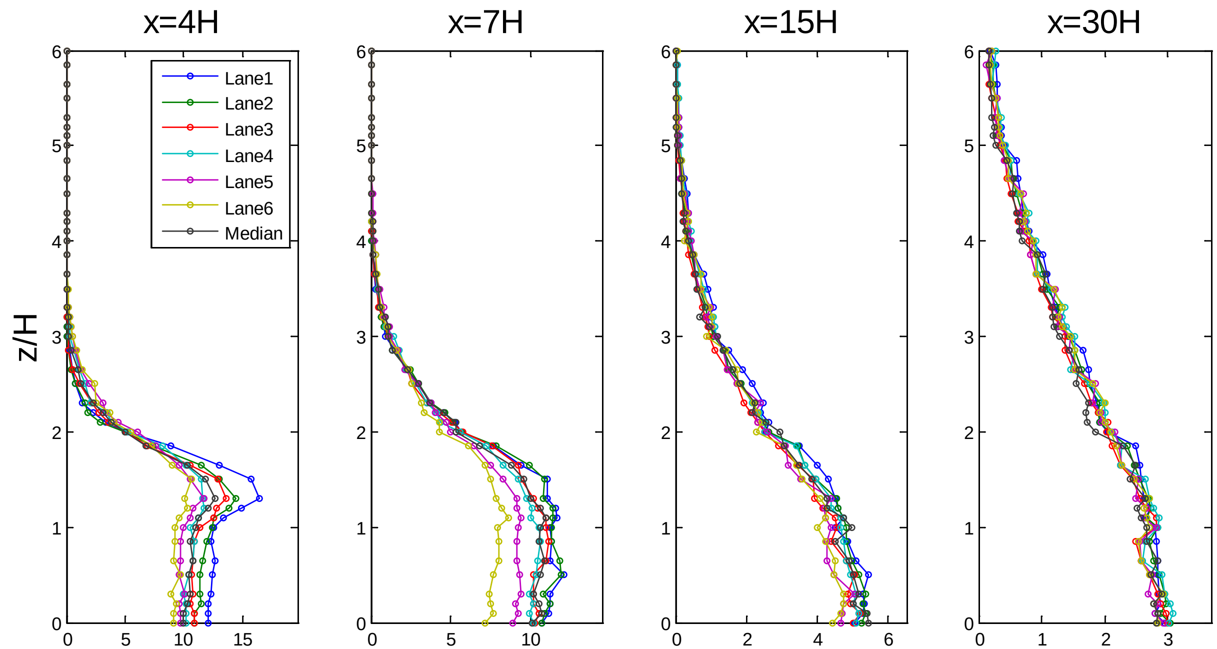
Roadside Noise Barriers



<u>2 studies:</u>
Wind Tunnel Study
Phoenix Field Study

<u>2 algorithms developed for:</u>
R-LINE
ADMS-Urban

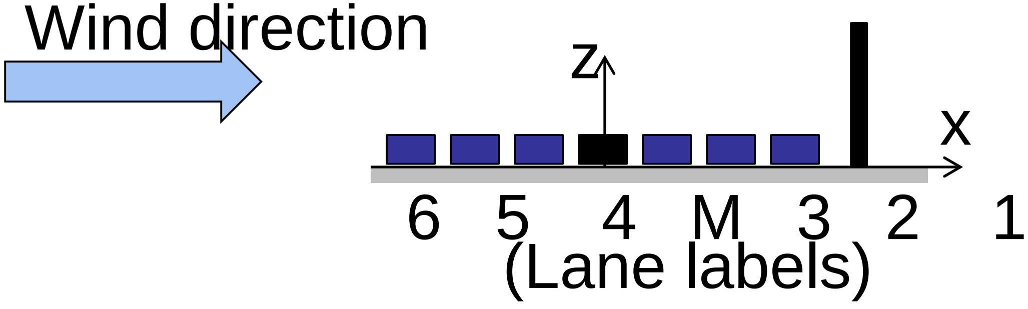
Wind tunnel measurements



Normalized Concentration

Vertical profiles with barrier

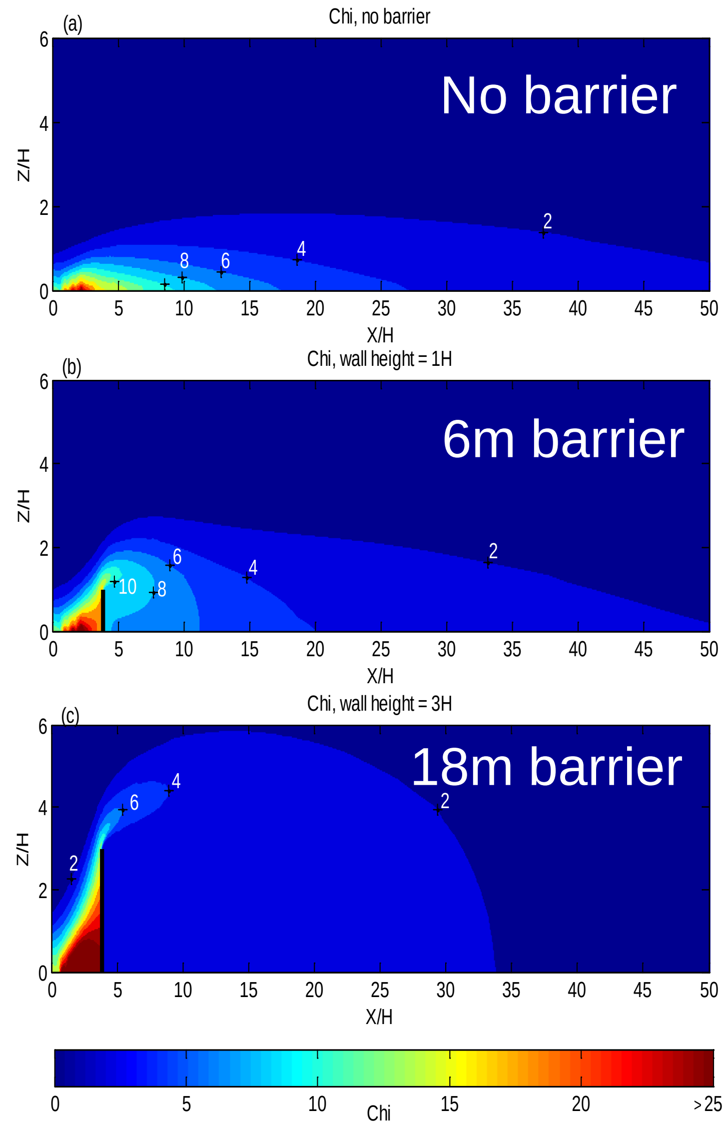
Wind direction



Noise Barriers & Air Quality

Computational Fluid Dynamics (CFD) modeling suggests:

- Decreased concentrations downwind of barrier
- Increased concentrations on-road due to upwind trapping
- The higher the barrier, the greater the downwind reduction and on-road increase

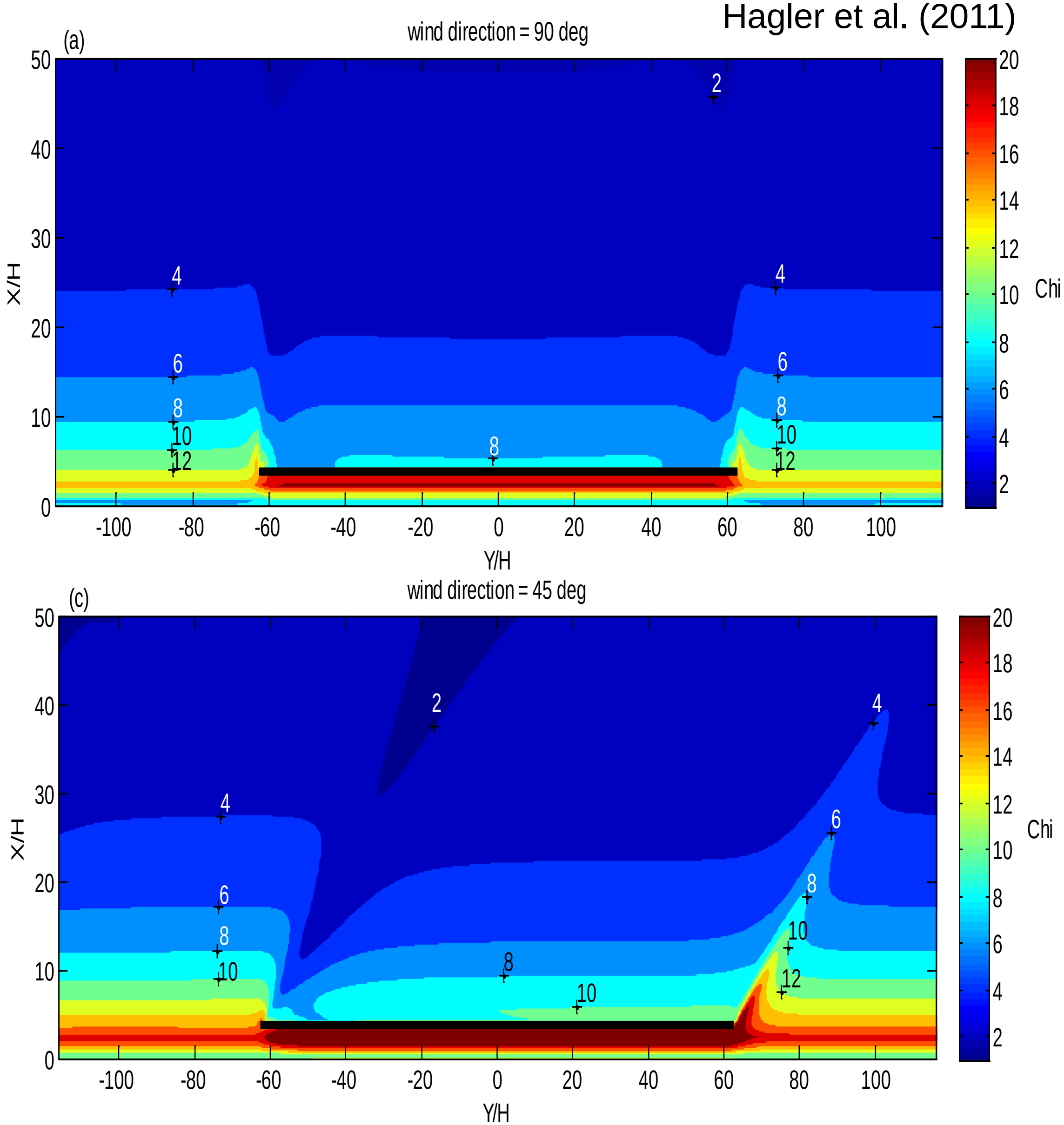


Hagler et al. (2011)

Noise Barriers & Air Quality

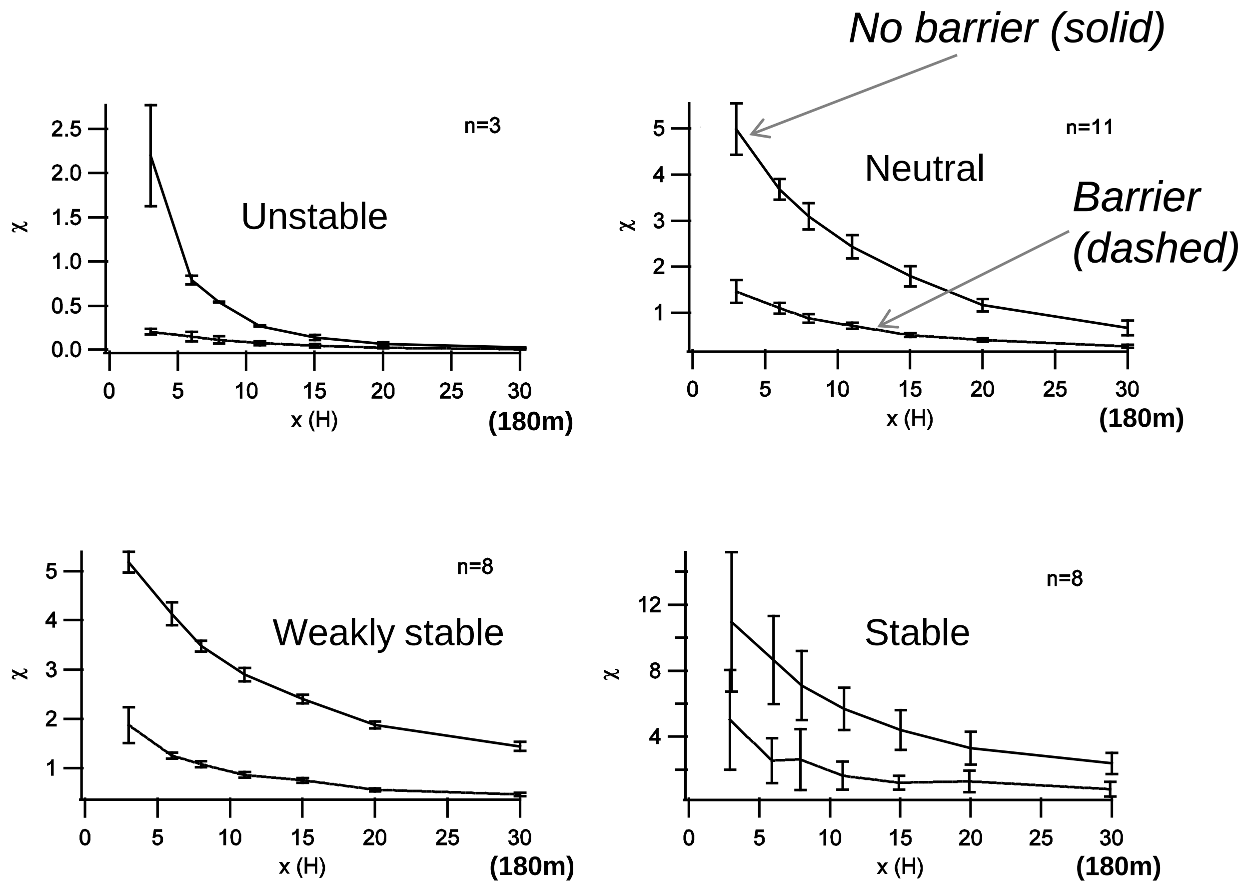
- Pollutant can wrap around barrier edges (top and sides)
- Modeling estimates effect <50m from side edges
- Higher open area concentrations can occur within ~20m

Hagler et al. (2011)



Noise Barriers & Air Quality

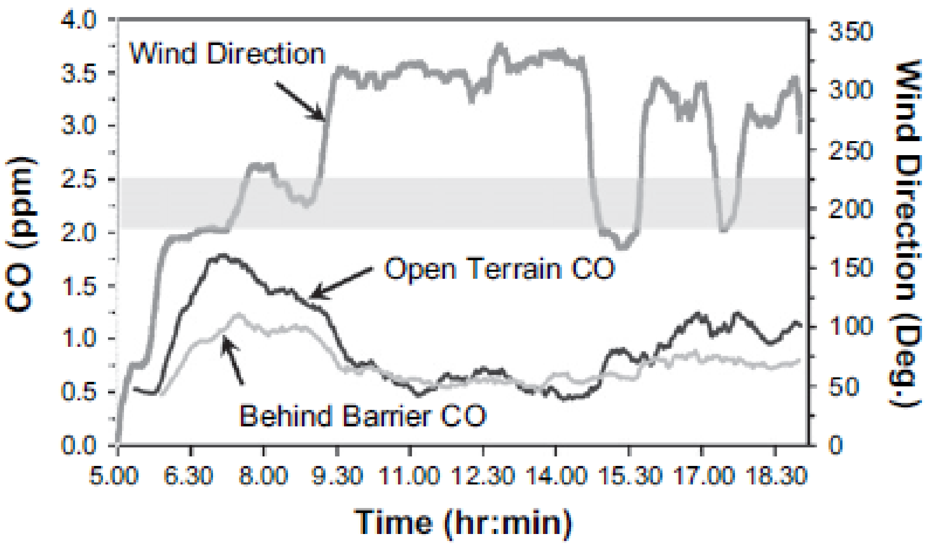
Finn et al., (2010)

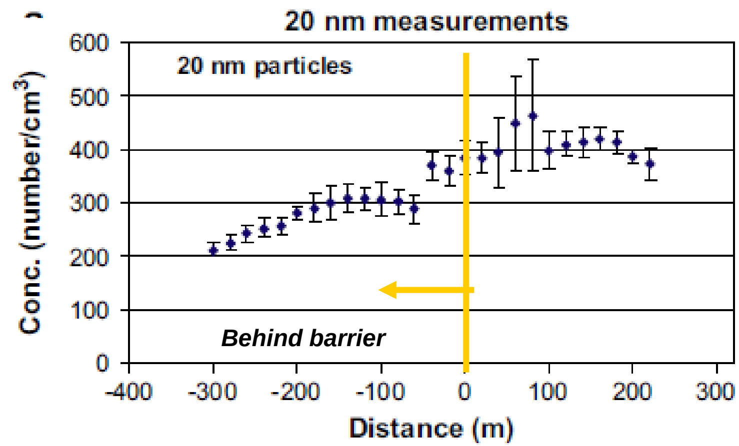


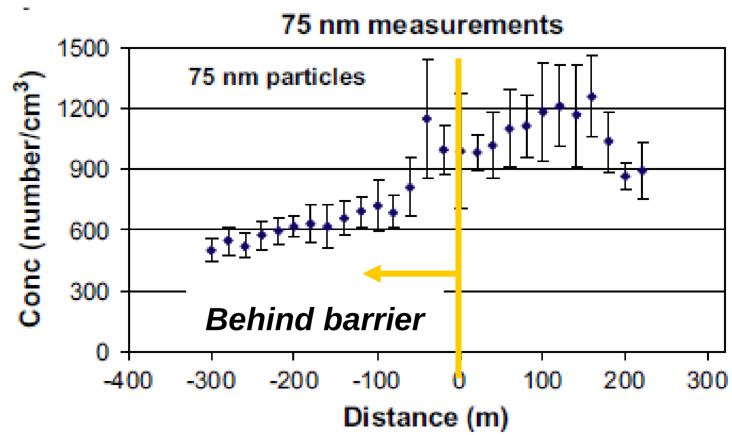
Tracer gas experiments show downwind pollutant reductions under all stability classes; more variability with stable, calm wind conditions

Noise Barriers & Air Quality

- Reductions of over 50% observed under downwind conditions
- Upwind pollutant trapping and wrapping around edges can occur



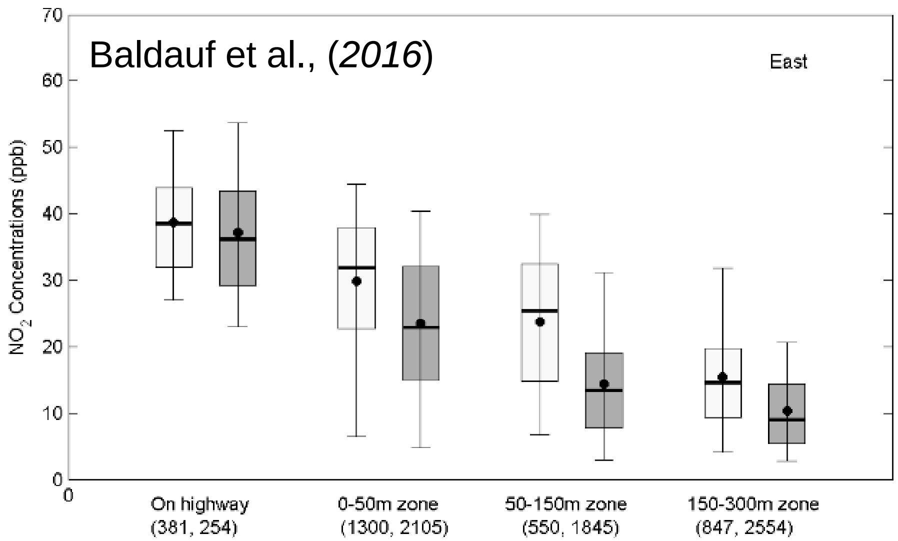


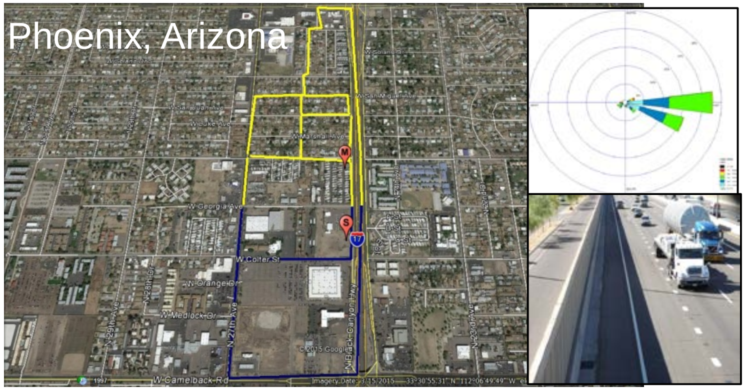


Baldauf et al. (2008)

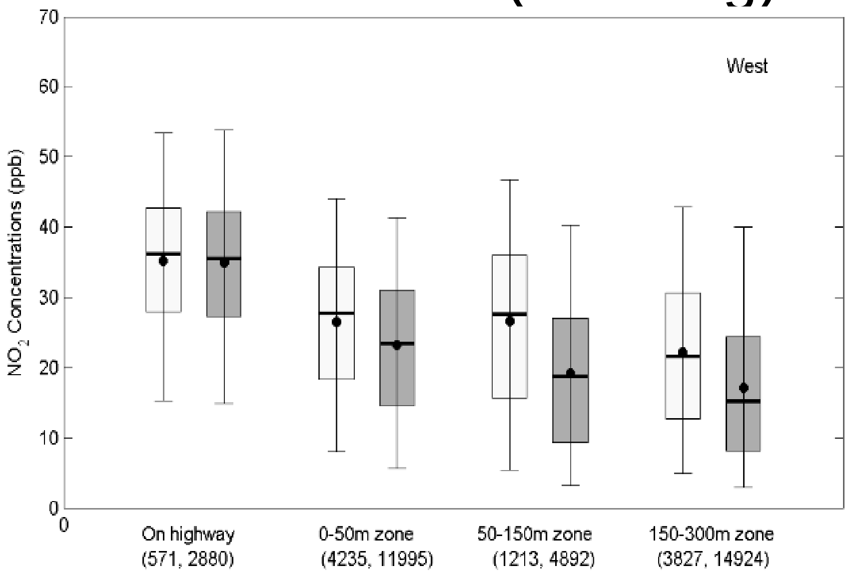
Noise Barriers & Air Quality

Impacts on NO_2 concentrations





West Section (Morning)



East Section (Afternoon)

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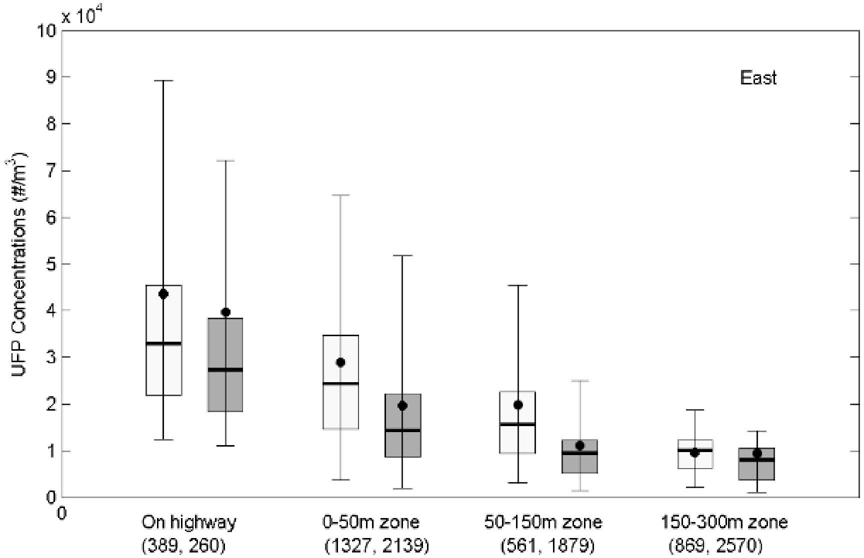
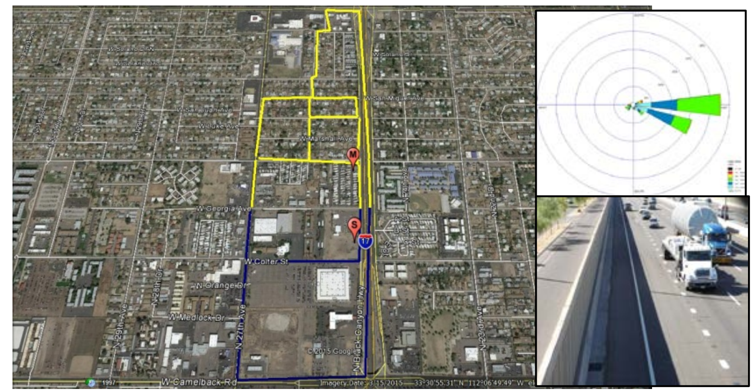
Noise Barriers & Air Quality

Reduced UFP concentrations





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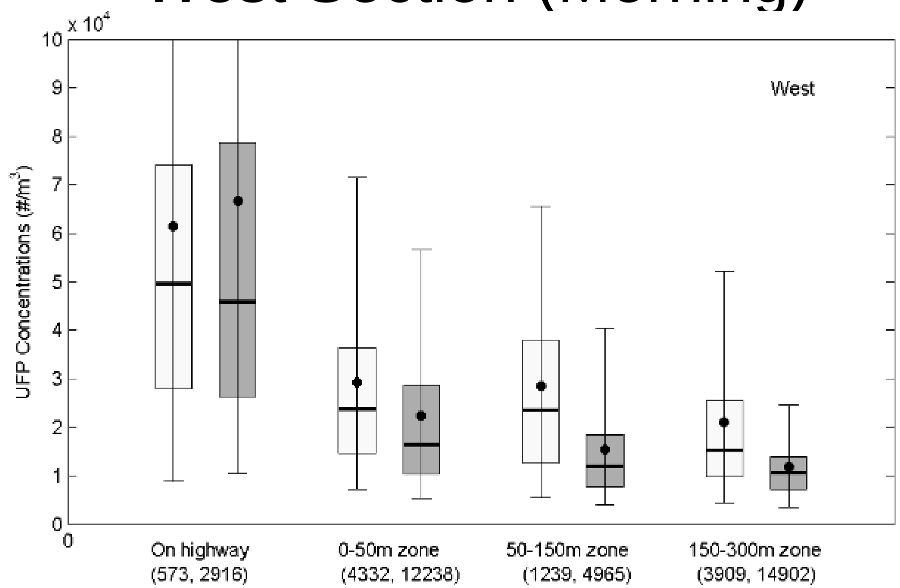
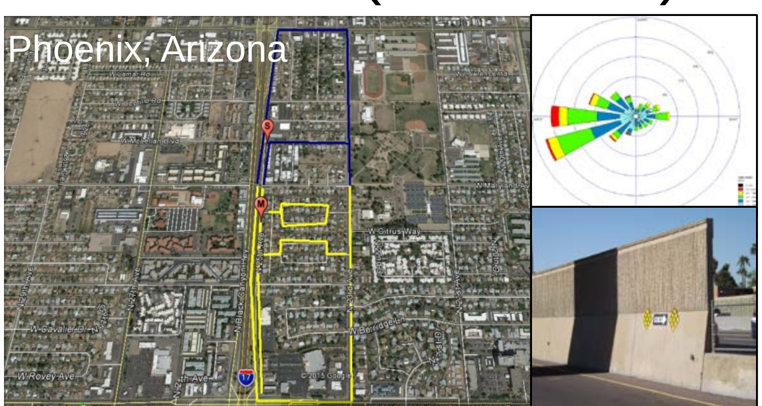


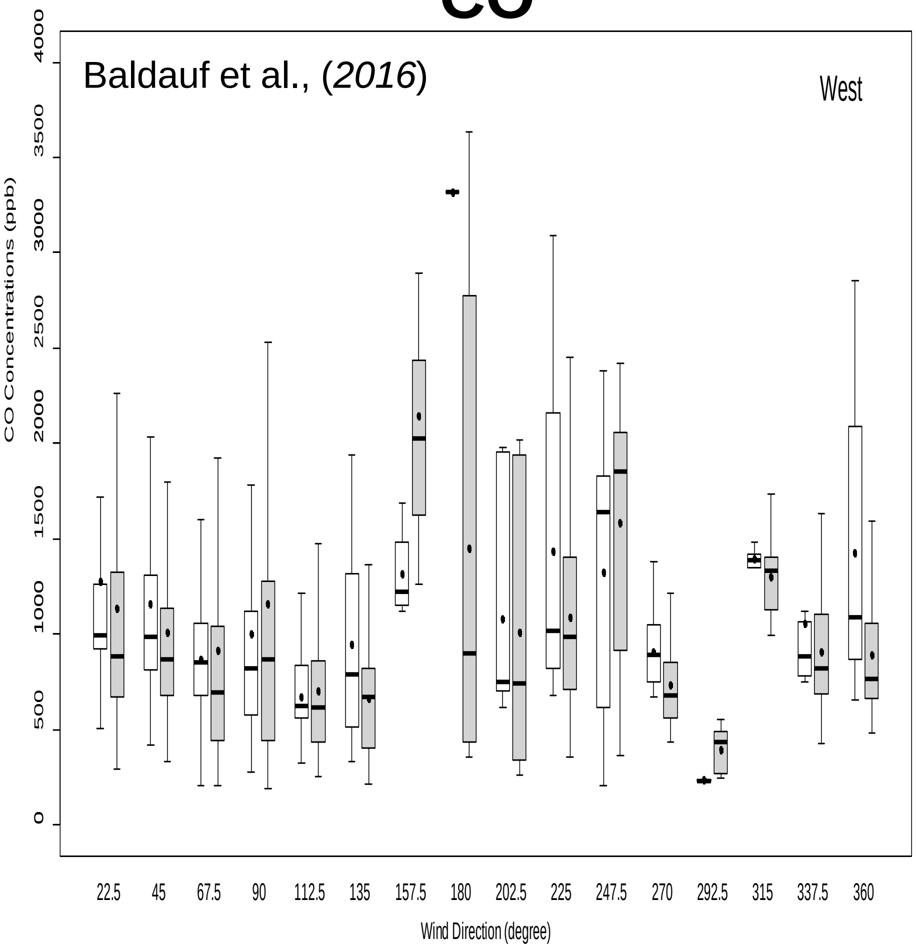
East Section (Afternoon)



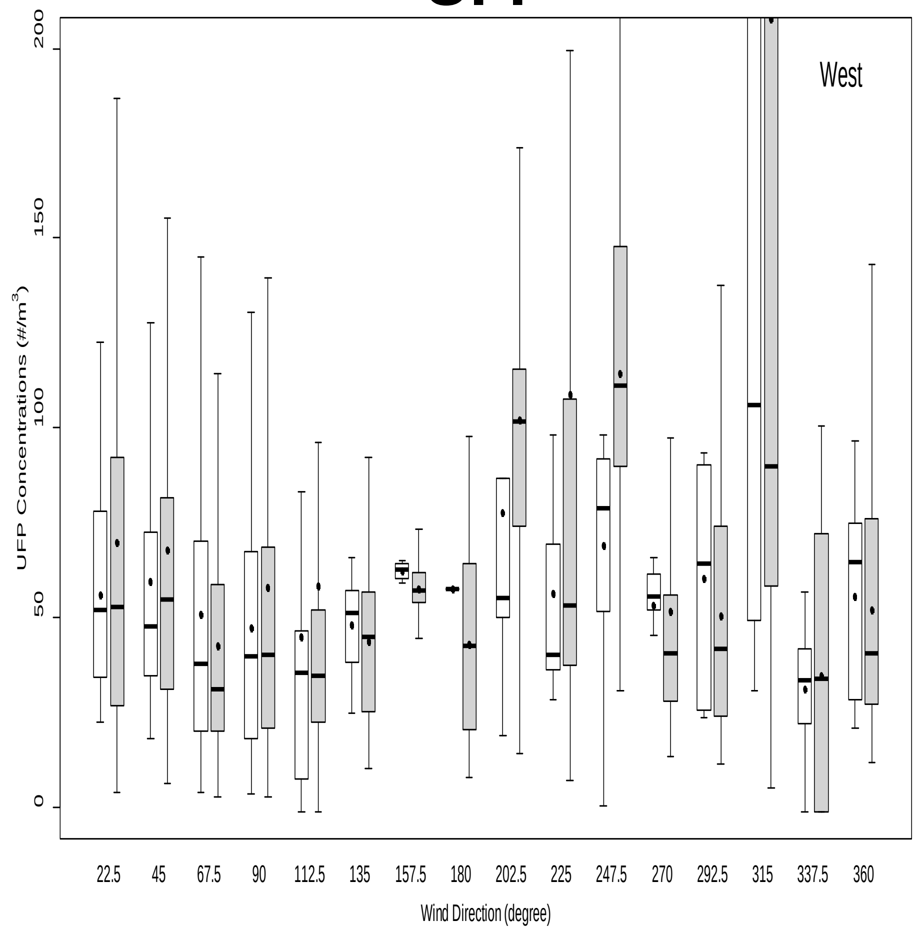
Noise Barriers & Air Quality

Phoenix, AZ Study Results

CO



UFP



On-road pollutant concentrations generally similar in front of the noise barrier (gray) and in front of the open section (white)

Noise Barrier Model Algorithm

- Tracer study data (Finn et al., 2010) were used to develop an algorithm to simulate pollutant transport and dispersion from roads with noise barriers
- Phoenix study provided the first independent data set to evaluate this model
- This algorithm available in the R-LINE dispersion model

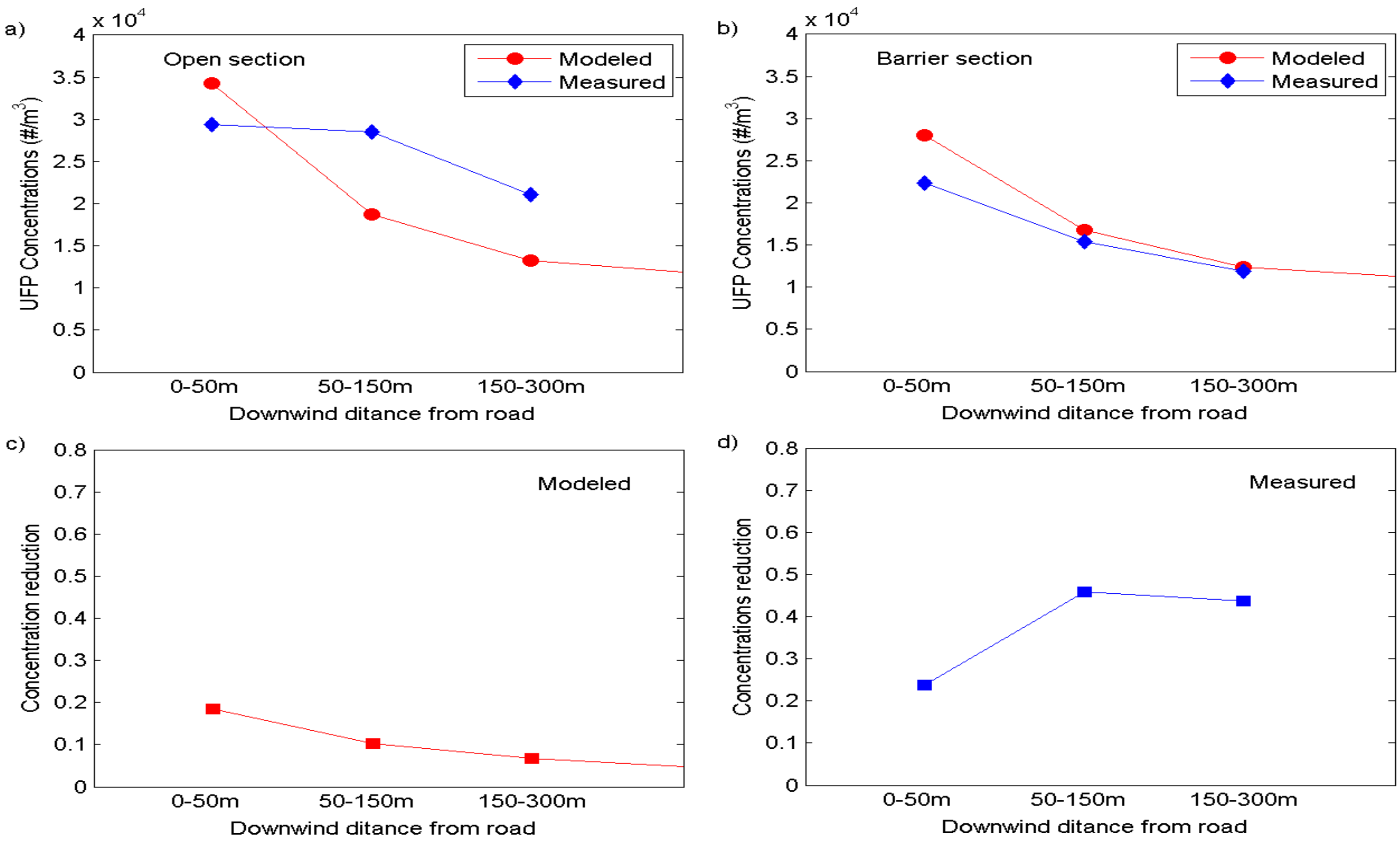
$$C_{\max} = q / \left(\cos\theta \left(h_w U_w f_m \left(\exp\left(-p_1^2\right) + \exp\left(-p_2^2\right) \right) \right) + U_e \sigma_z \left(2 - erf\left(p_1\right) - erf\left(p_2\right) \right) \right)$$

Venkatram et al., (*2016*)

UFP Model vs. Measurement Results

Open Section

Behind Barrier



Venkatram et al., (*in press*)

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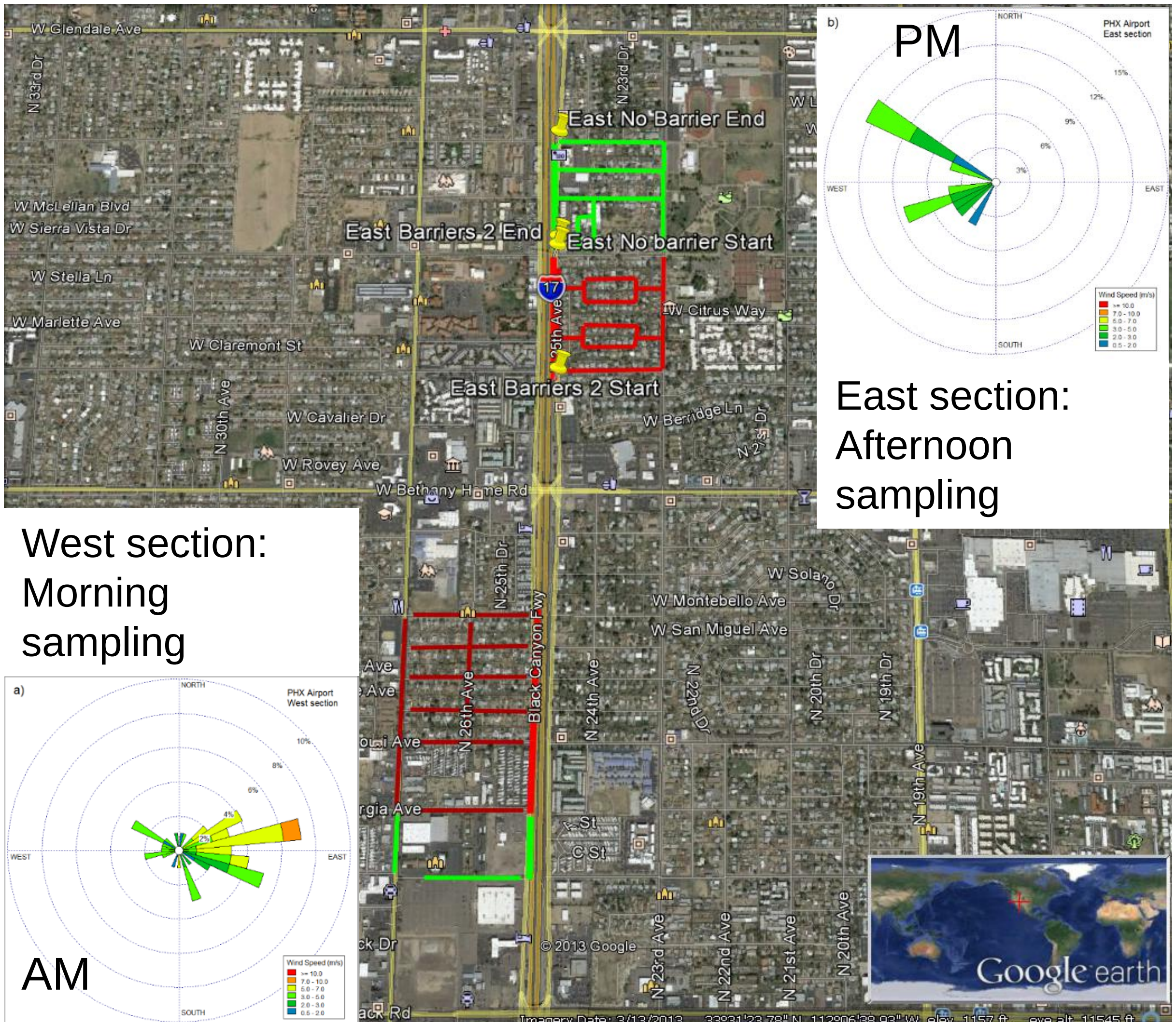
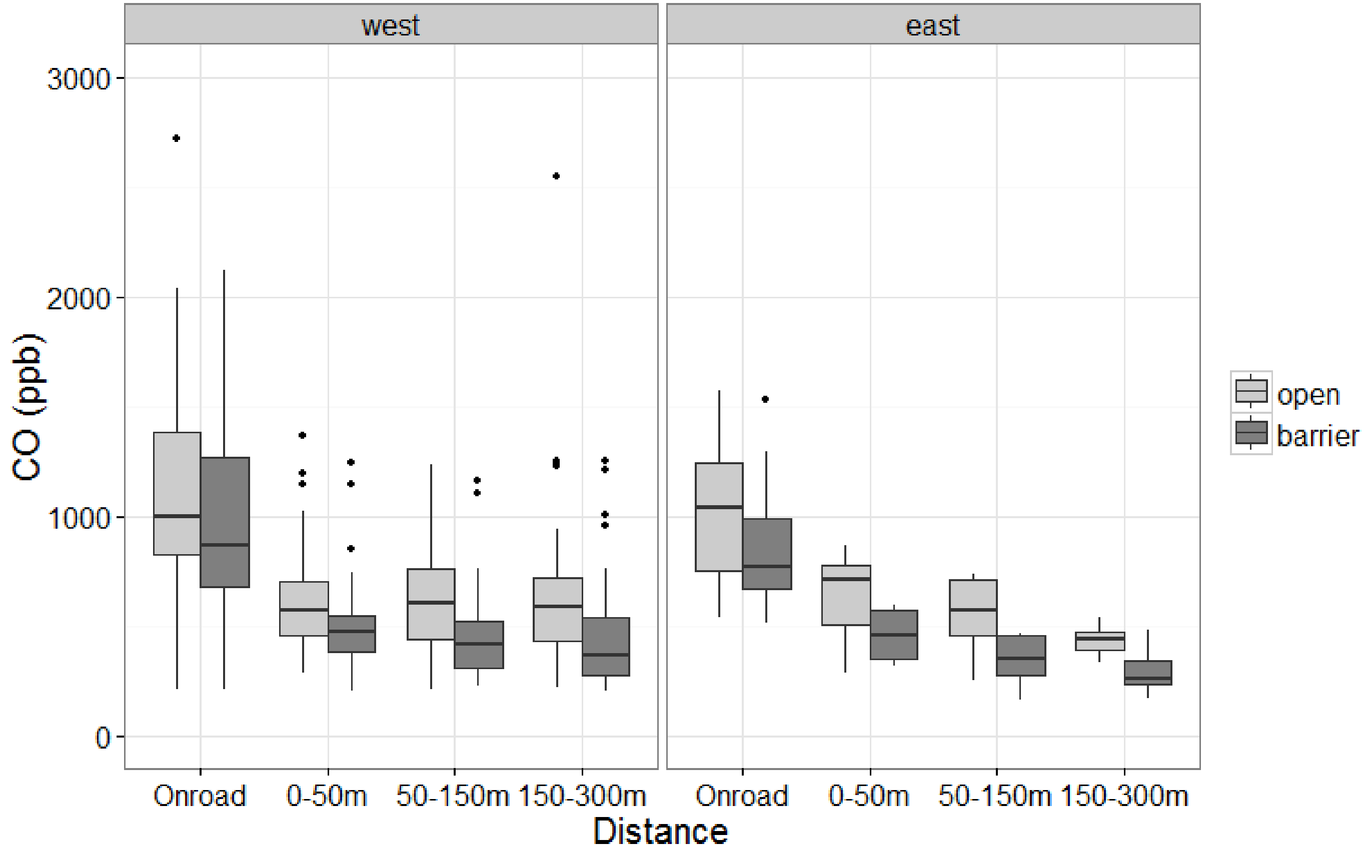
Phoenix Field Study

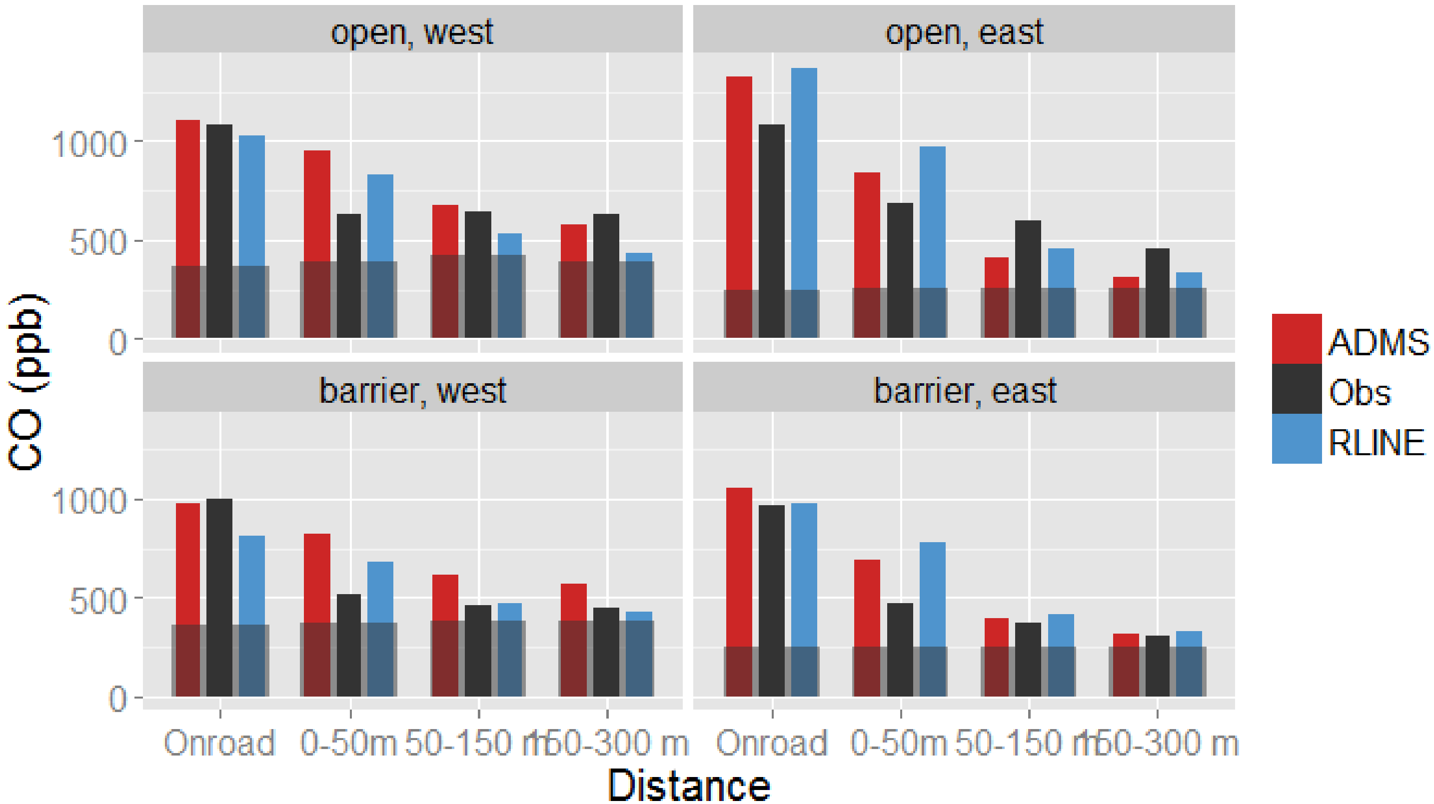


Phoenix – Effect of Barriers



Richard Baldauf, Vlad Isakov, Parikshit Deshmukh, Akula Venkatram, Bo Yang, and K. Max Zhang. 2016. Influence of Solid Noise Barriers on Near-Road and On-Road Air Quality, *Atmospheric Environment,* **129:** 265-276.

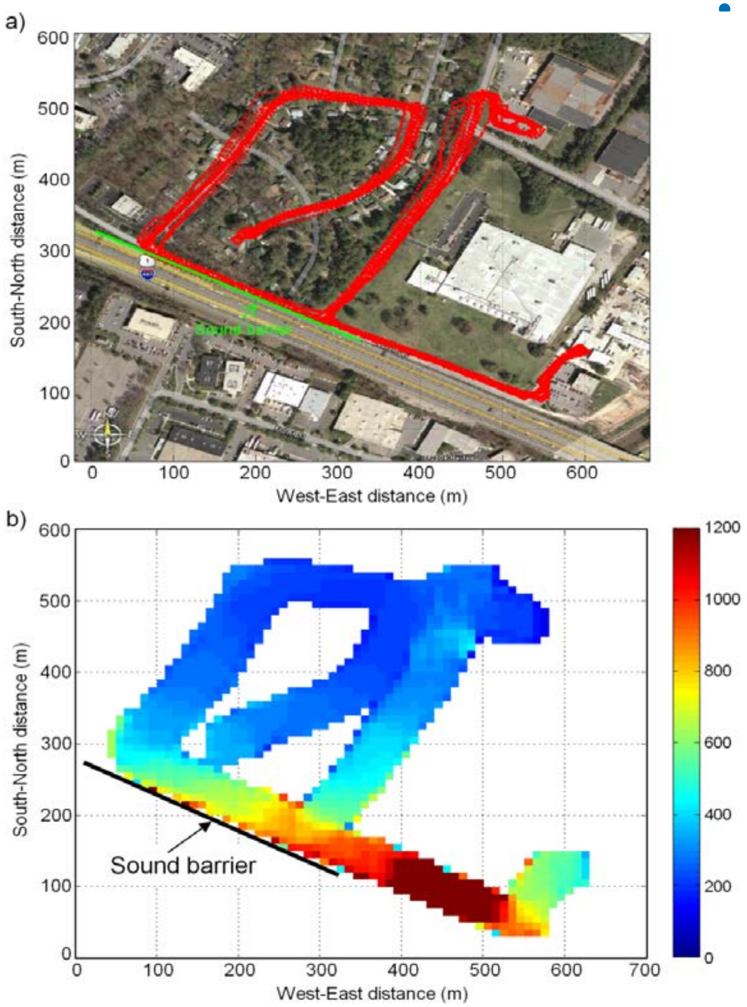
Phoenix results - CO

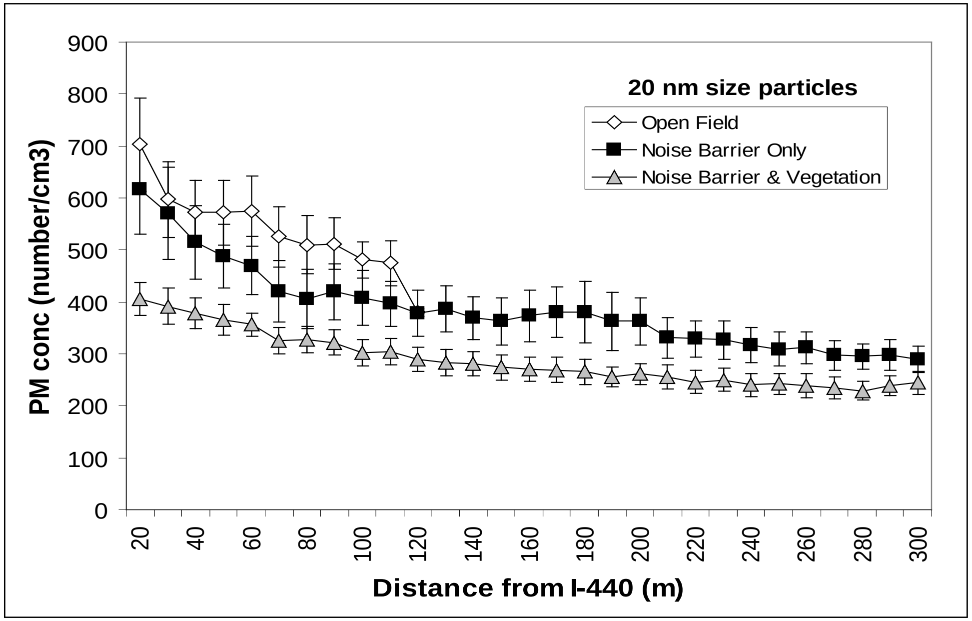


Noise Barrier & Vegetation Effects

- Noise barriers reduced PM levels compared with a clearing

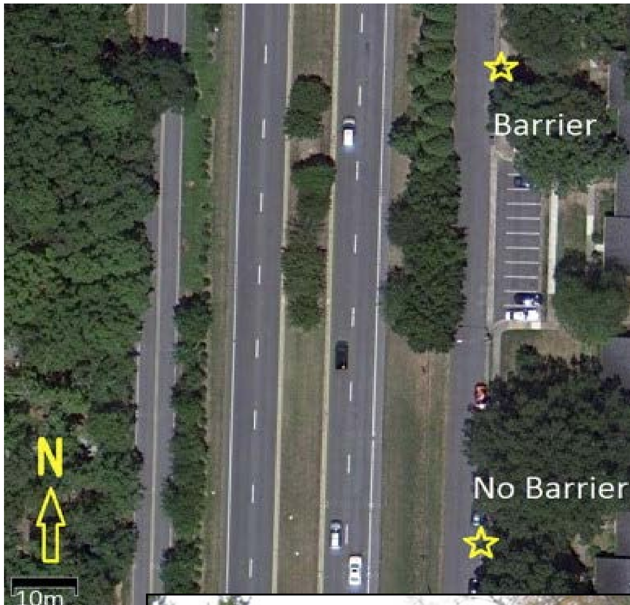
  Vegetation with noise barriers provided a further reduction of PM concentrations and gradients

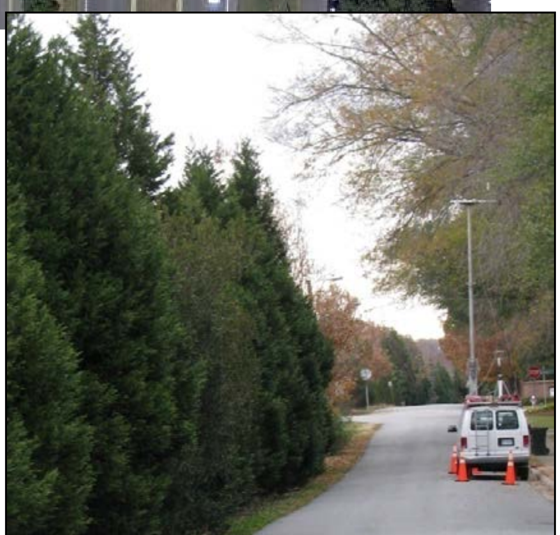




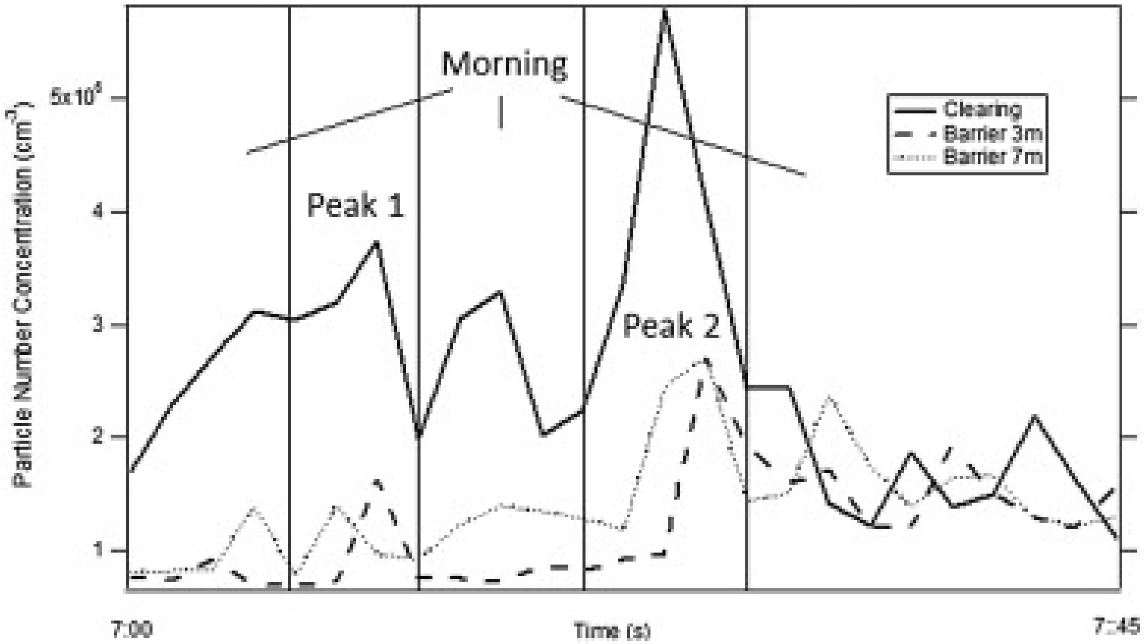
(Baldauf et al., 2008a; 2008b)

Vegetation Effects





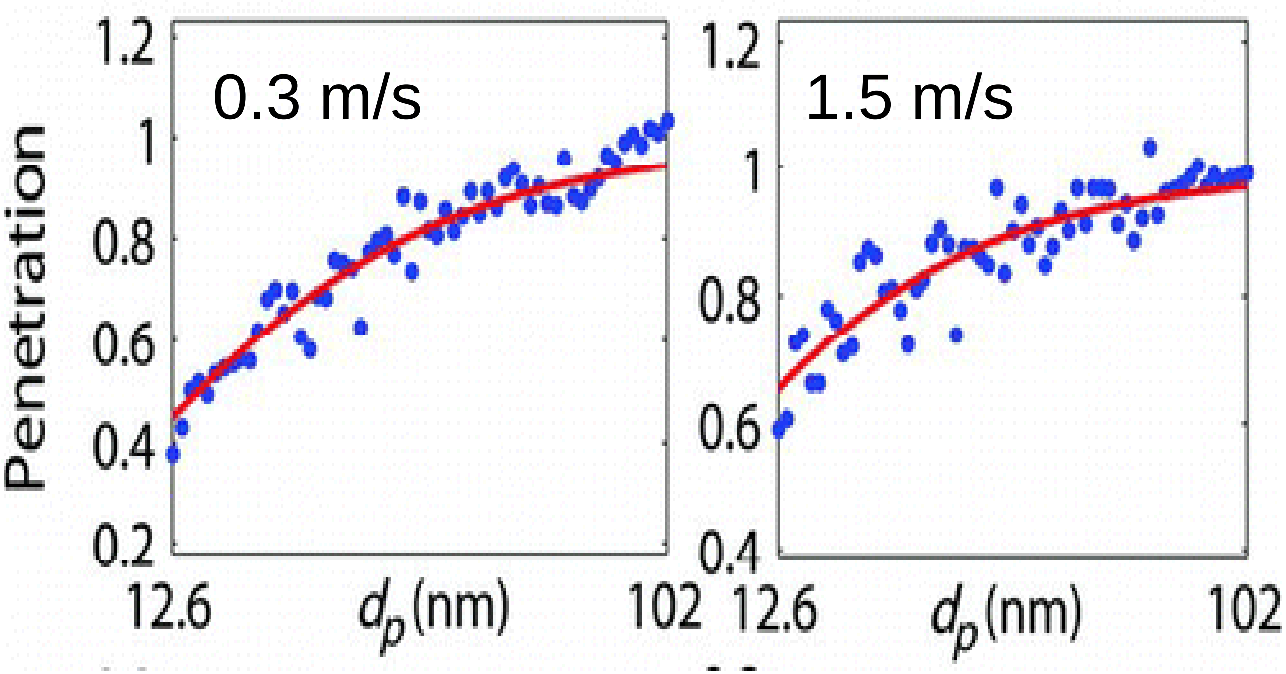
Steffans et al. (2012)

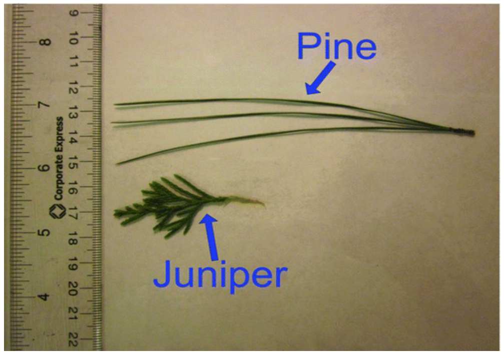


- Ultrafine PM number count generally reduced downwind of a vegetation stand
- Higher reductions most often occurred closer to ground-level
- Variable winds caused variable effects

Vegetation Effects

- Smaller size PM have higher removal rate
- Removal increases at lower wind velocities
- Branch/leaf shape and size affects removal

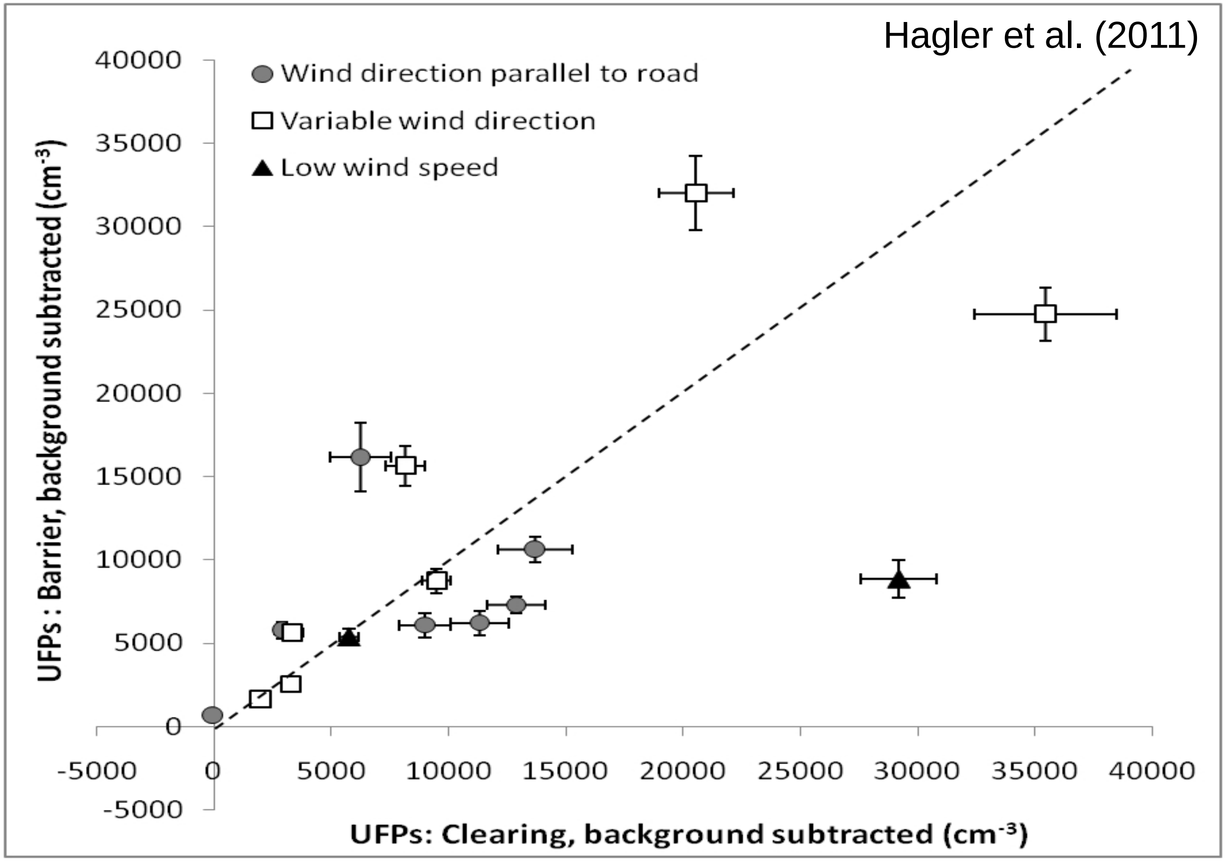




Cahill et al., (2010)

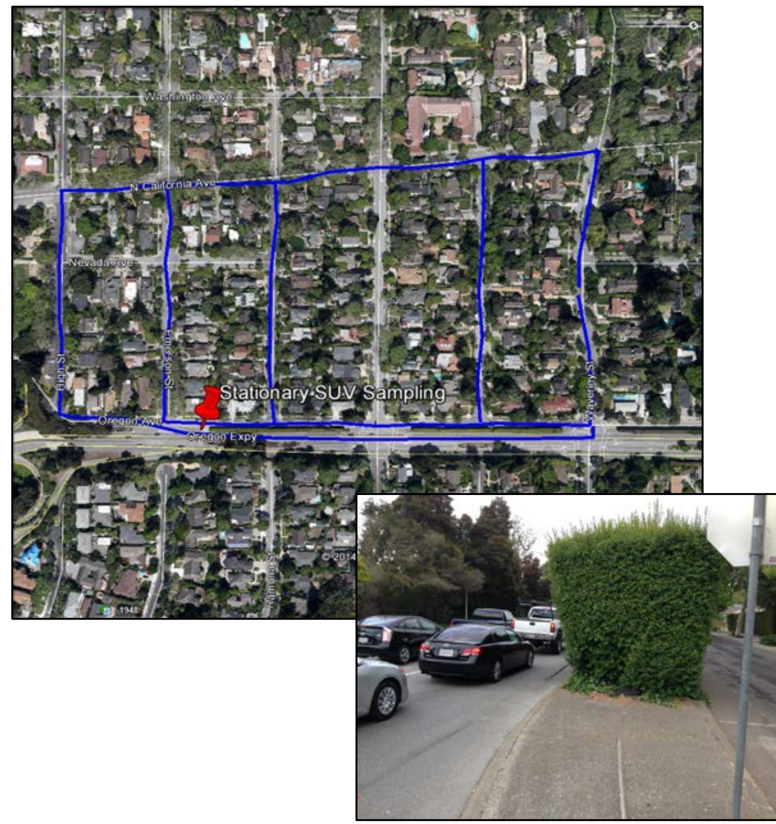
Vegetation Effects

- For thin tree stands, variable results seen under changing wind conditions (e.g. parallel to road, low winds)
- Gaps/dead trees can lead to higher downwind concentrations



San Francisco Area Vegetation Study

- On-road and near-road mobile and fixed measurements to evaluate varying vegetation types
  - Bush/tree combinations with varying porosity (Woodside, CA)
  - Manicured hedges (Palo Alto, CA)



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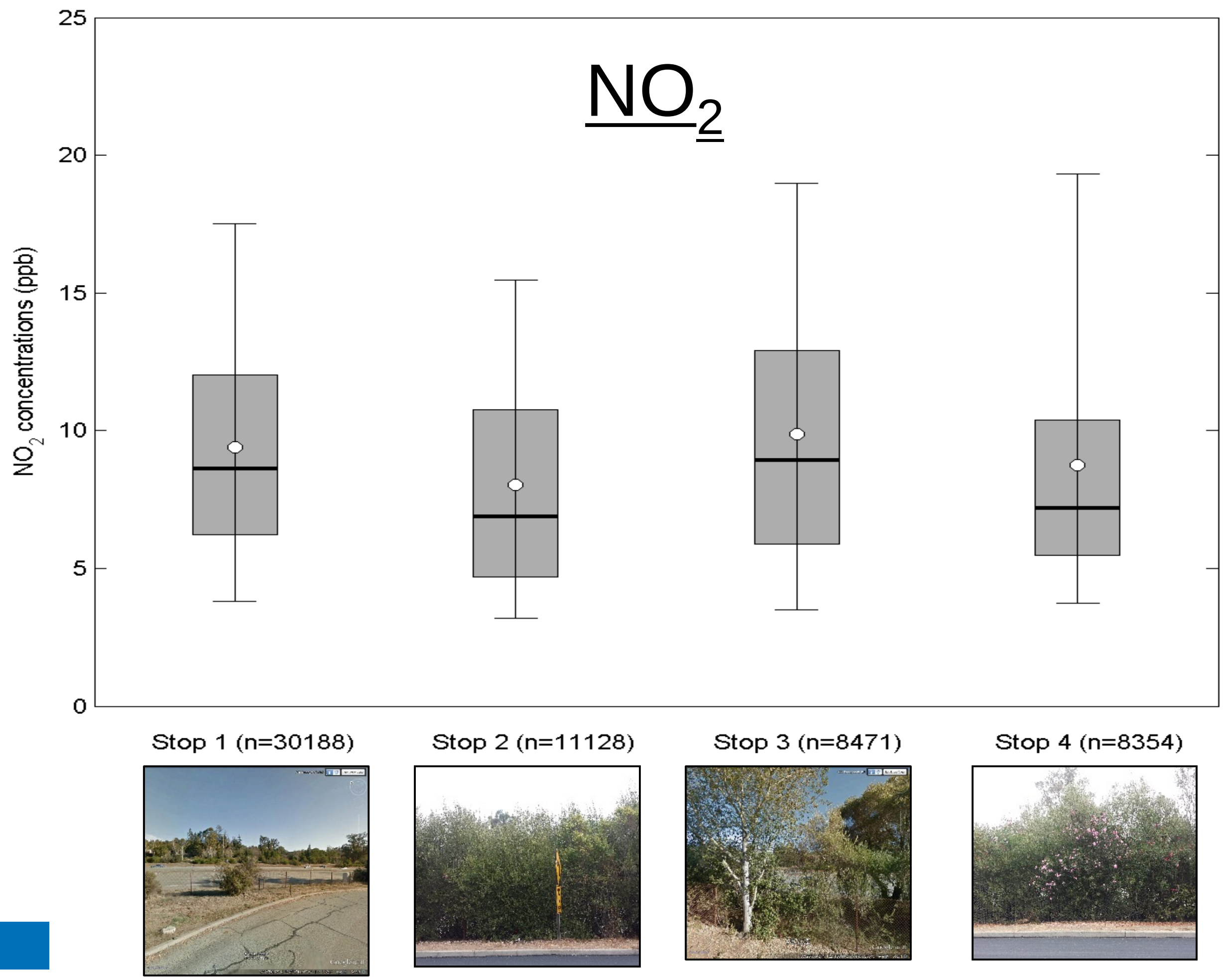
Woodside Vegetation Study

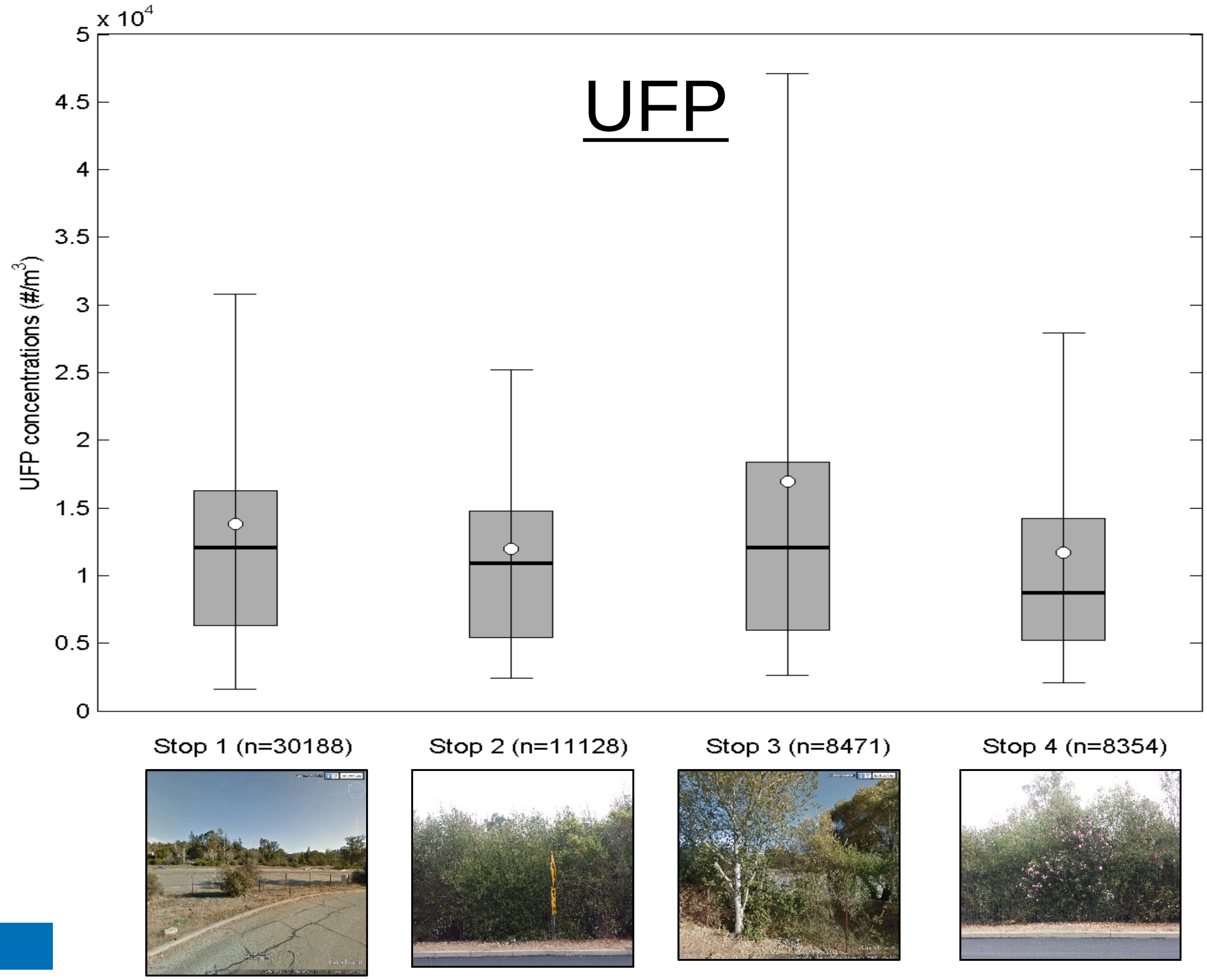
- Initial results suggest the importance of thickness, porosity and full coverage



- All wind directions
- ~10k data pts/stop
- ~10min/stop/day

Woodside Vegetation Study

- Initial results suggest the importance of thickness, porosity and full coverage



- All wind directions
- ~10k data pts/stop
- ~10min/stop/day

Vegetation Model Algorithm

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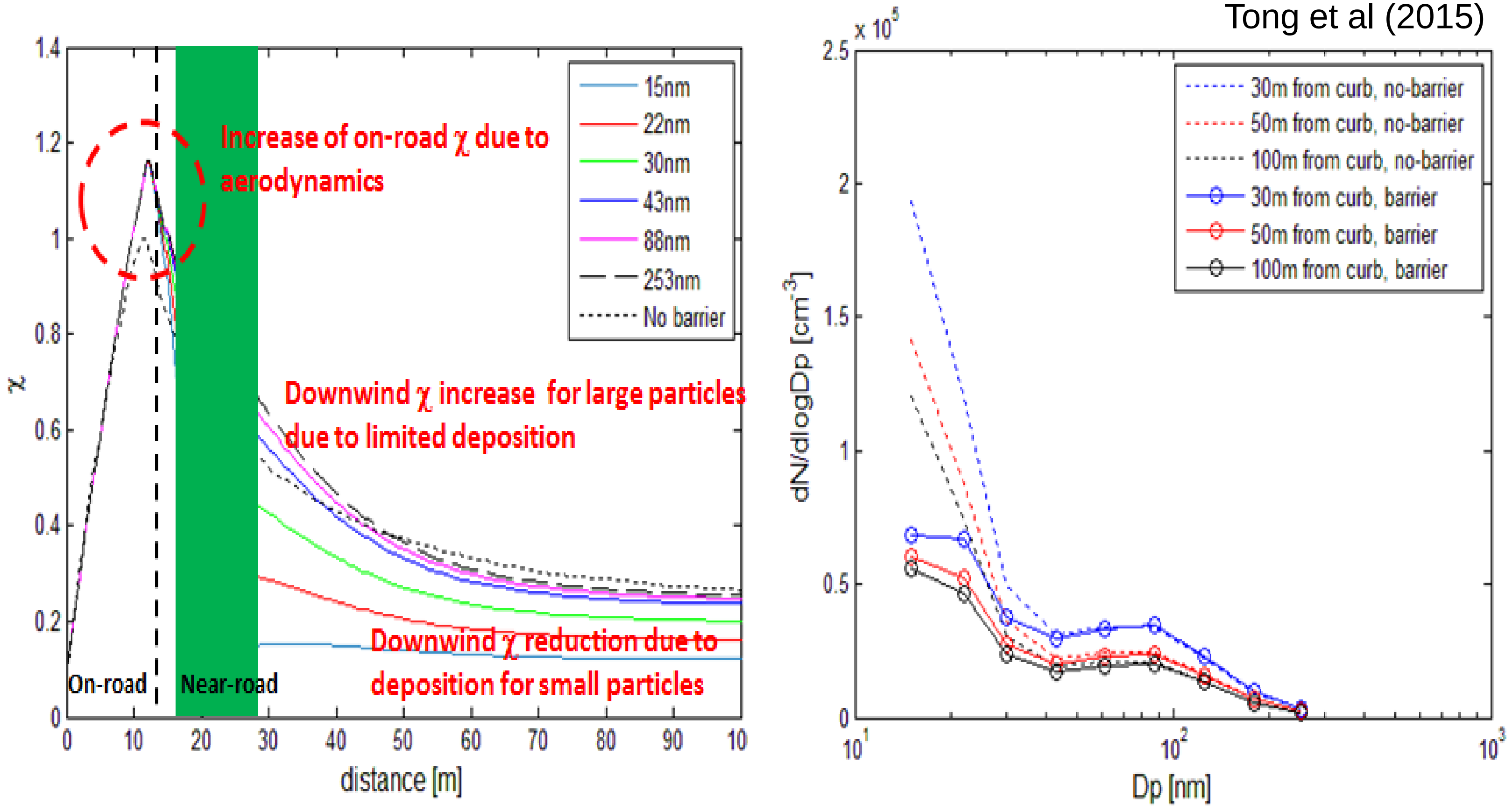
- CFD modeling highlights PM removal from vegetation, especially for smaller, ultrafine particles

Tong et al (2015)



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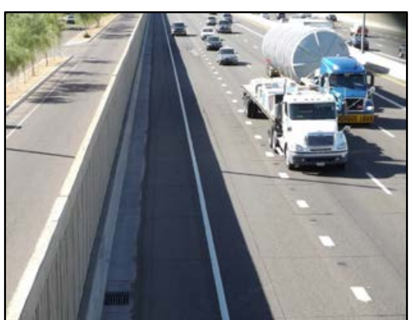
Summary – Noise Barriers



- Research shows noise barrier design characteristics that can reduce downwind pollutant levels
  - The higher the barrier, the higher the downwind pollution reduction
    - Most studies conducted with barriers $\geq$ 4m
  - Pollutants can meander around edges
    - Sensitive areas should be $\geq$ 50m from edges
    - Sensitive areas should be below barrier top
  - Pollutants can be trapped on the upwind side of the barrier
    - "Upwind" sources need to be considered
    - May lead to increased levels on the road
  - Barrier should be close to the road
    - Most studies had barriers $\leq$5m of travel lane

Summary - Vegetation

- Research shows roadside vegetation can reduce downwind pollutant concentrations near roads
- What the research shows related to design:
  - The higher and thicker the vegetation, the higher the downwind pollution reduction
  - Vegetation affects pollutant transport and dispersion as well as removes particulates and select gases (e.g. NO2)
  - Pollutants can meander around edges or through gaps
    - Existing vegetation with gaps may lead to increased concentrations/exposures
    - Areas targeted for reductions should avoid edge effects
    - Vegetation must be well maintained to avoid gaps and insure pollutant reductions

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Summary - Vegetation

- Areas desired for reduced pollutant concentrations should avoid gaps and edge effects
  - Vegetation barrier needs to provide coverage from the ground to the top of canopy
  - Barrier thickness should be adequate for complete coverage to avoid gaps
- Pine/coniferous trees and thick bushes may be good choices
  - No seasonal effects
  - Complex, rough, waxy surfaces
  - Mix of species may increase coverage

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 - Vegetation

- Vegetation more complex than noise barriers
  - Non-uniform in height, width, thickness
  - Must be appropriate for the location of use
  - Effectiveness dependent on species type and maintenance
  - Vegetation grows and changes over time
- Vegetation also has many other benefits that make this technique worth pursuing, including:
  - Storm-water runoff and water quality improvement
  - Carbon sequestration
  - Heat relief
  - Aesthetic value
  - Health benefits

Summary – Combination Barriers

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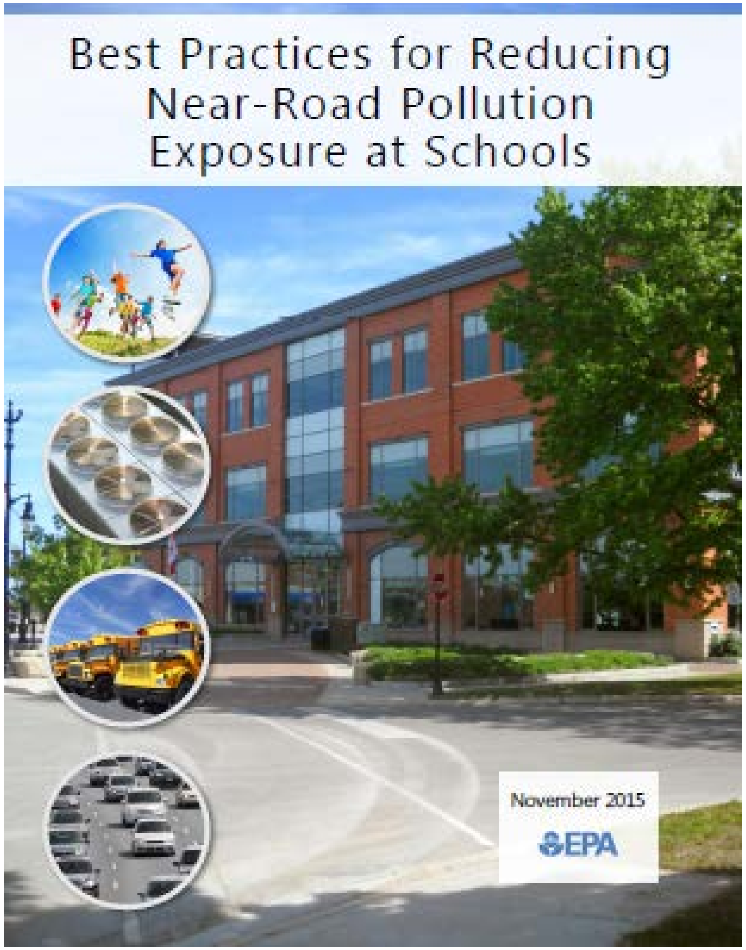
- Combination of noise and vegetative barriers may provide the most benefit
  - Provides opportunity for pollutant dispersion and removal
  - May be solid barrier with vegetation behind and/or in front (research had vegetation behind barrier)
  - Use of climbing vegetation and hedges with solid barrier may also provide benefits (studies with CFD only)
    - Field study results mixed
    - Vegetation on solid wall should extend enough to allow air to flow through

Examples of solid/vegetation barriers

Best Practices for Reducing Near-Road Pollution Exposure at Schools

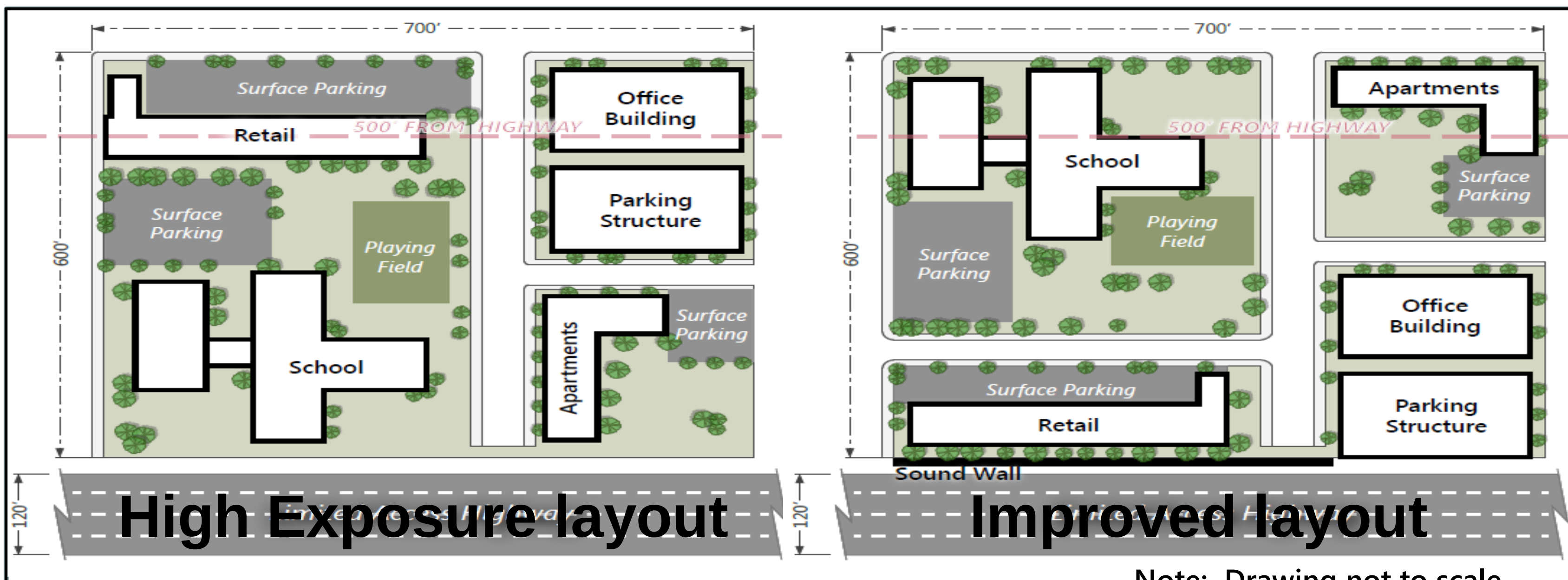
- Developed to provide practical solutions to mitigate traffic-related pollution based on issues in the School Siting Guidance
- Document for schools and parents
- Types of solutions provided:
  - Building Design and Operation Strategies
    - Ventilation, Filtration, and Indoor Air
    - Building Occupant Behavior
  - Site-Related Strategies
    - Transportation Policies
      - Anti-Idling and Idle Reduction Policies
      - Upgrade Bus Fleets
      - Encourage Active Transport
    - Site Location and Design
    - **Roadside Barriers**
      - **Noise Barriers**
      - **Vegetation**



https://www.epa.gov/schools/best-practices-reducing-near-road-air-pollution-exposure-schools

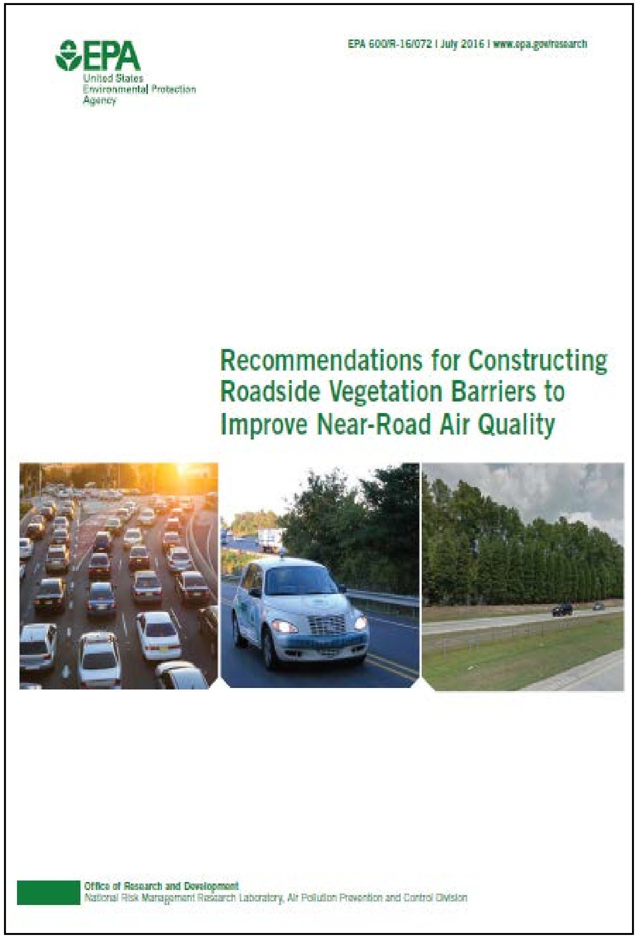
Best Practices for Planners

- EPA's Office of Sustainable Communities developing draft recommendations for Near-Road development
  - Encompasses Corridor Management, Building Design and Operations, Site Design and Layout, and Barrier Use
  - Site Layout: Development can be implemented so that sensitive land uses are farthest from the road
  - Barriers can provide added benefits



Recommendations for the Design of Roadside Features

- EPA has developed recommendations for designing and planting roadside vegetation
  - Developed for implementing the Oakland and Detroit pilot studies
  - Includes vegetation alone and vegetation in combination with solid barriers
  - Maximize the potential for near-road air pollution reduction
  - Avoid unintended consequences such as increased downwind pollution concentrations due to gaps in the vegetation
- EPA planning to develop similar set of recommendations for solid barriers in cooperation with FHWA


EPA 600/R-16/072 | July 2016 | www.epa.gov/research

Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality

Office of Research and Development
National Risk Management Research Laboratory, Air Pollution Prevention and Control Division

Conclusions

- With the increase in near-road public health concerns, comprehensive mitigation strategies are needed
- Solid noise barriers and roadside vegetation can affect local pollutant transport and dispersion, providing an opportunity for air pollution mitigation
  - Design characteristics have been identified that lead to downwind pollutant reductions and potential pollutant increases
  - Model algorithms have been developed to quantify barrier impacts under certain design conditions
- Research still needed to understand the range of options and reductions available from roadside barriers
- Models still need to be developed and/or evaluated to quantify reduction benefits and identify potential unintended consequences under range of designs

For More Information

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

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