Impacts of Solid Noise Barriers and Roadside Vegetation on Near-Road Air Quality

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U.S. Environmental Protection Agency

TRB Tools of the Trade Conference

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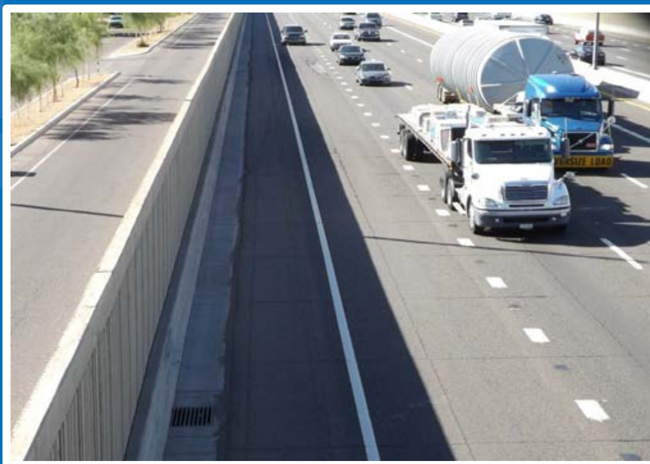

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Background on Health Concerns

- 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***

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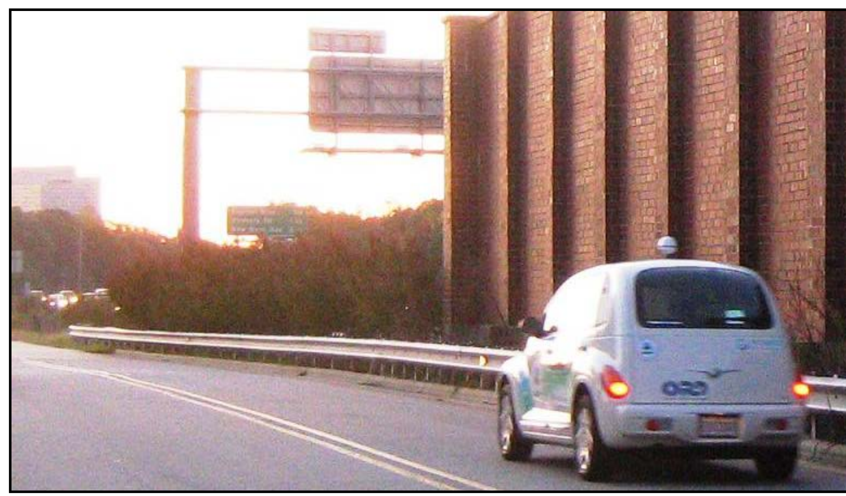
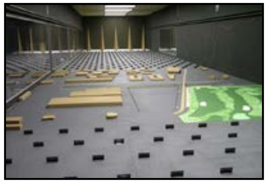
Why study roadside barriers?

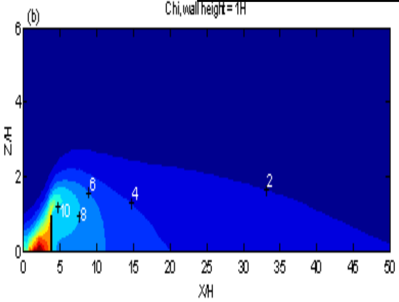
- Roadside barriers alter air pollution transport and dispersion
- Roadside barriers may already be present and affecting exposures
- Roadside barriers often have other positive benefits
- Few other “short-term” mitigation options
  - Emission reductions take long to implement (fleet turnover required)
  - Planning and zoning involved in rerouting/VMT reduction programs
  - Buffer/exclusion zones may not be feasible, especially in urban areas



Research Methodology

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





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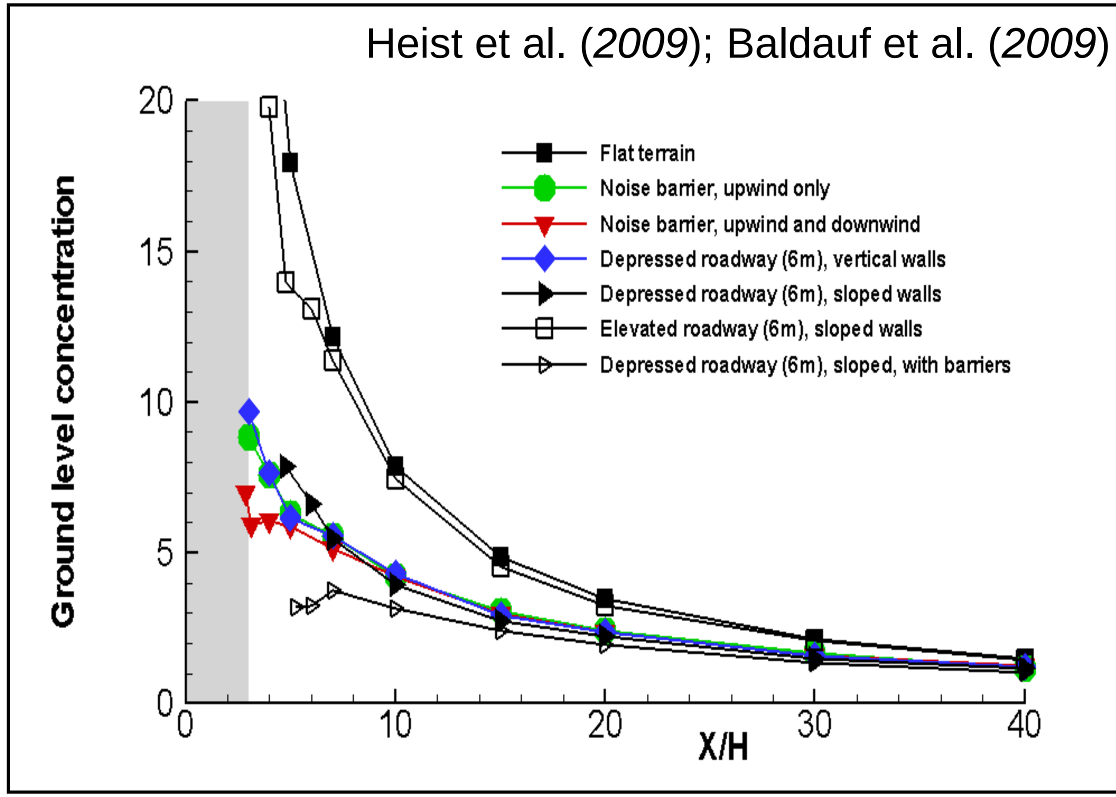
Roadway Configuration Effects

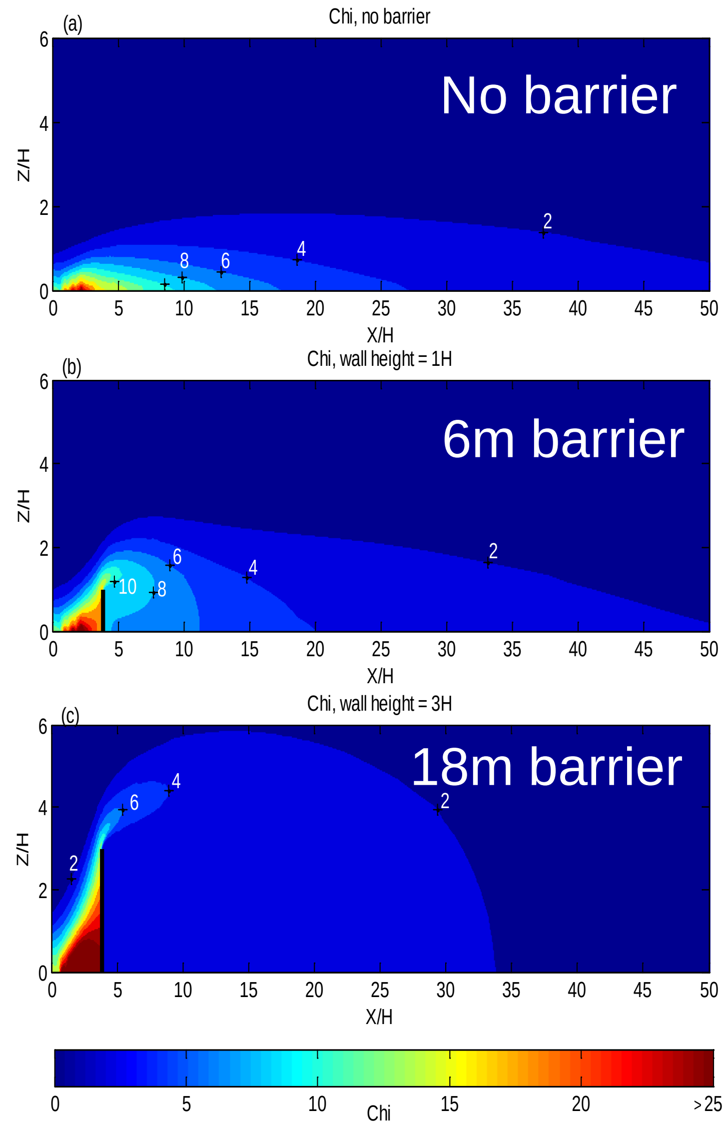


Wind tunnel simulations show roadway design impacts on pollutant transport and dispersion. Highest levels occur with at-grade and elevated fill roads; lowest levels occur with cut sections and noise barriers

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

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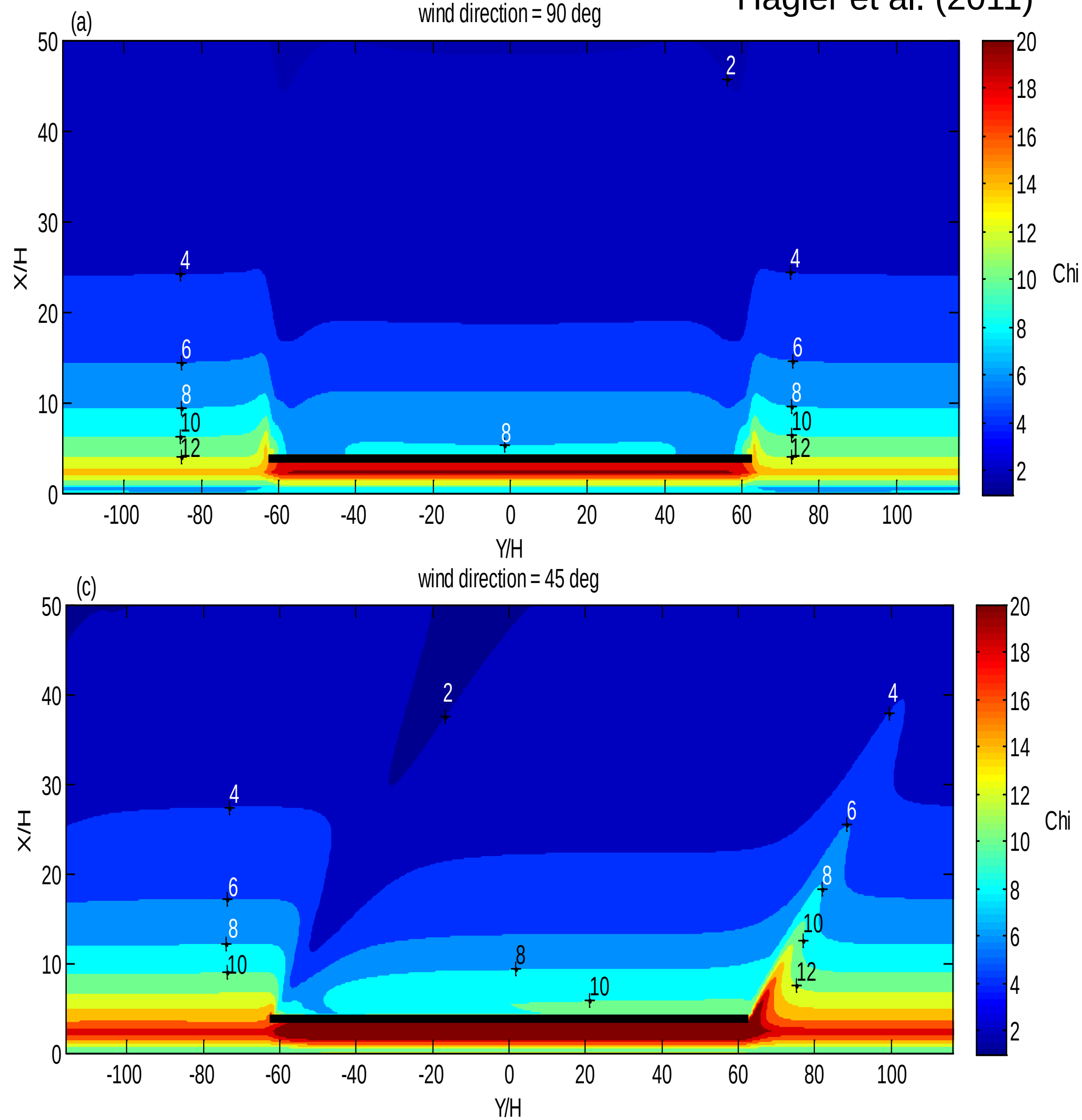
- Pollutant can wrap around barrier edges (top and sides)
- Modeling estimates effect <50m from side edges
- Higher open area concentrations can occur within ~20m

Hagler et al. (2011)



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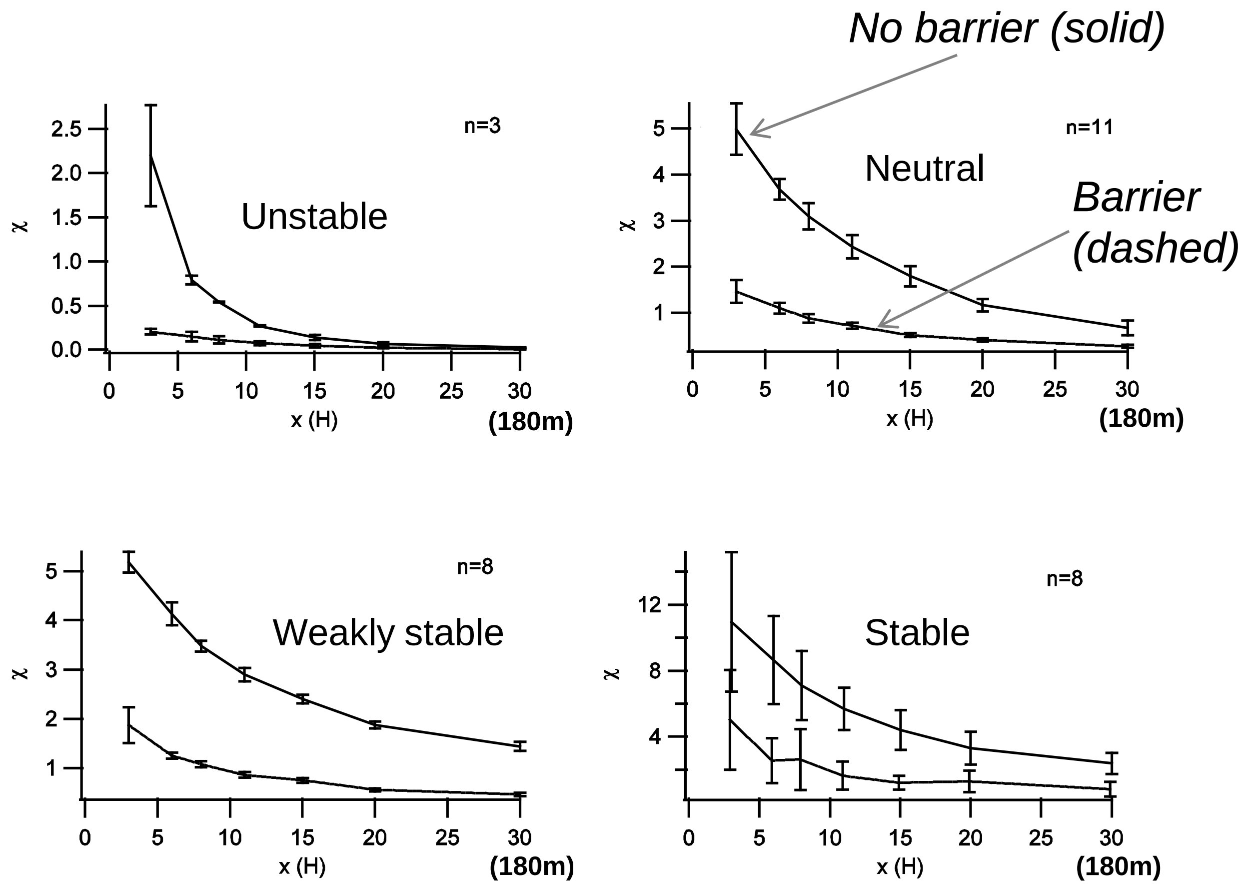
Noise Barriers & Air Quality

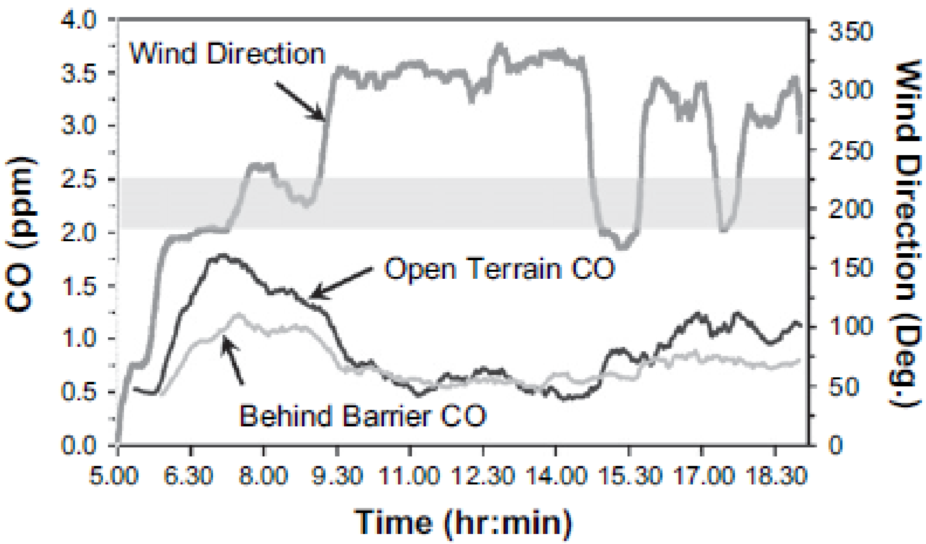
Finn et al., (2010)

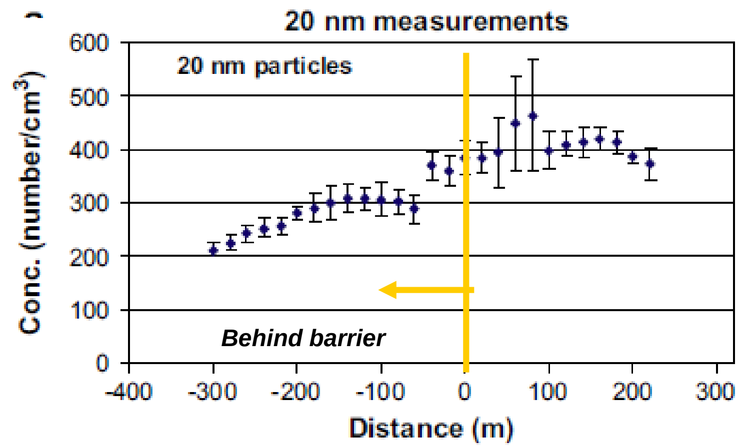


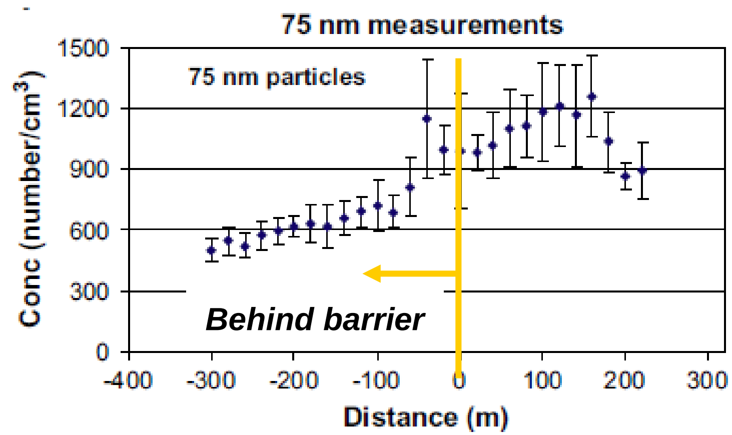
Tracer gas experiments show downwind pollutant reductions under all stability classes; more variability with stable, calm wind conditions

Noise Barriers & Air Quality

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



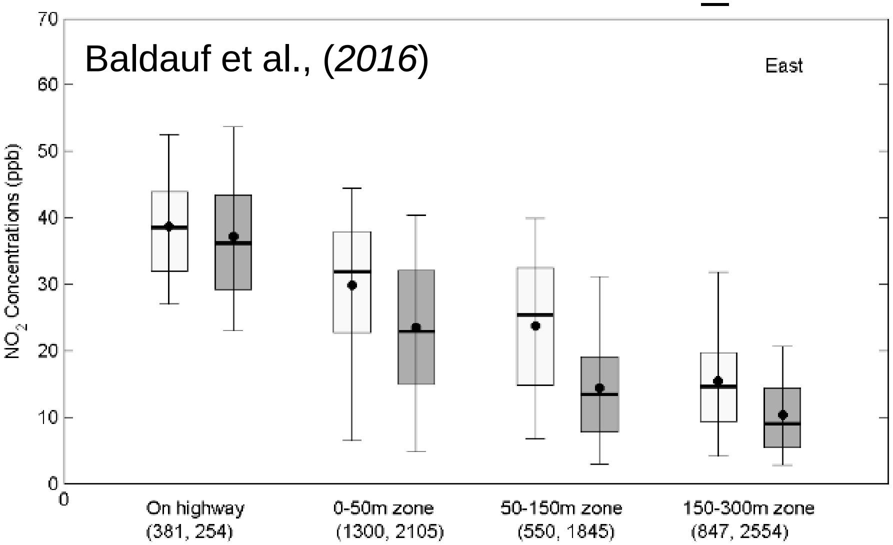


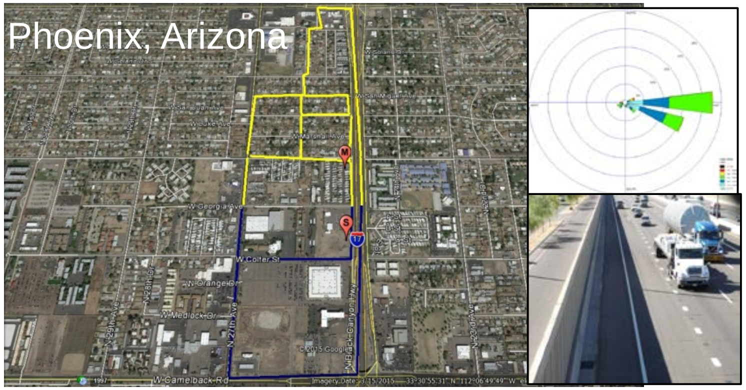


Baldauf et al. (2008)

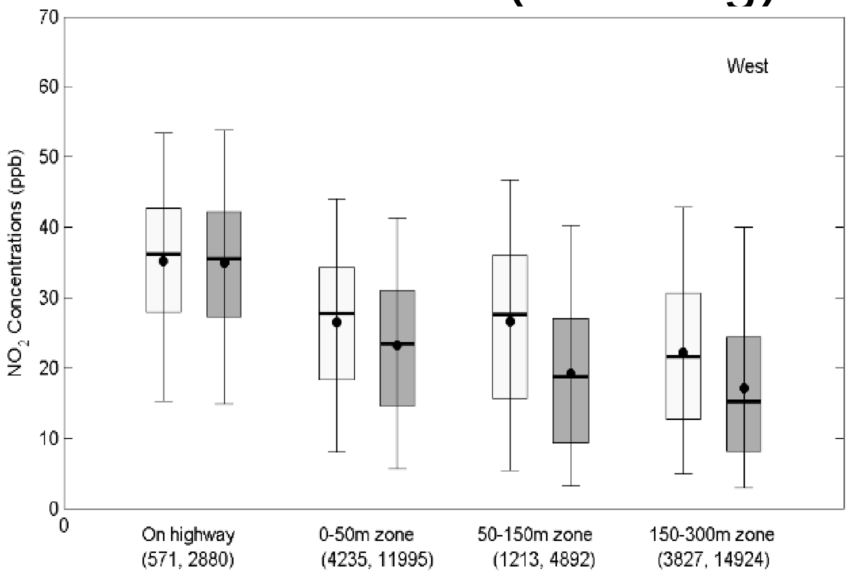
Noise Barriers & Air Quality

<u>NO_2 concentrations</u>





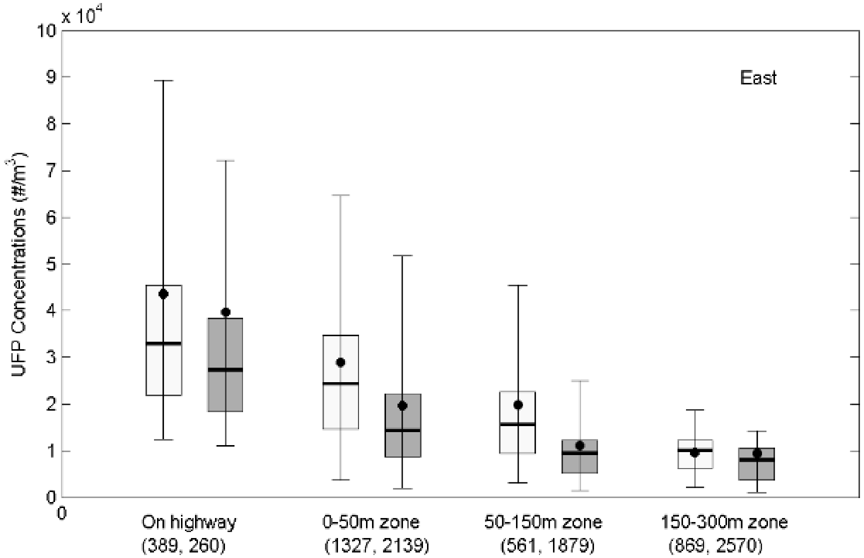
West Section (Morning)

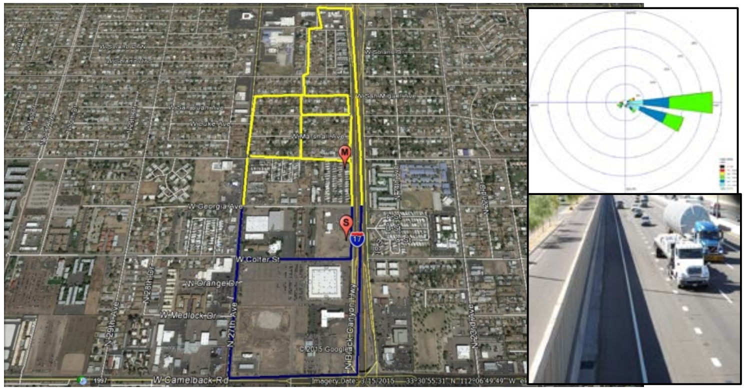


East Section (Afternoon)

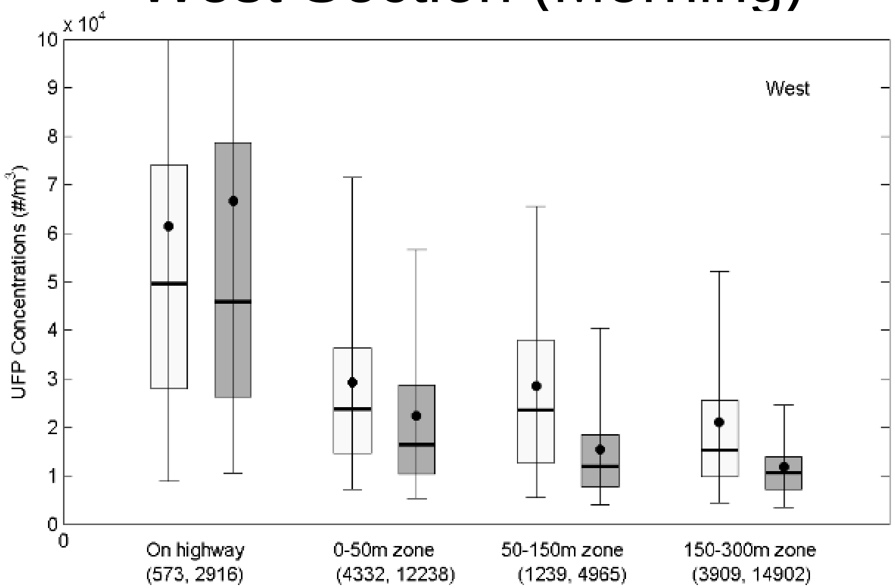
Noise Barriers & Air Quality

UFP concentrations

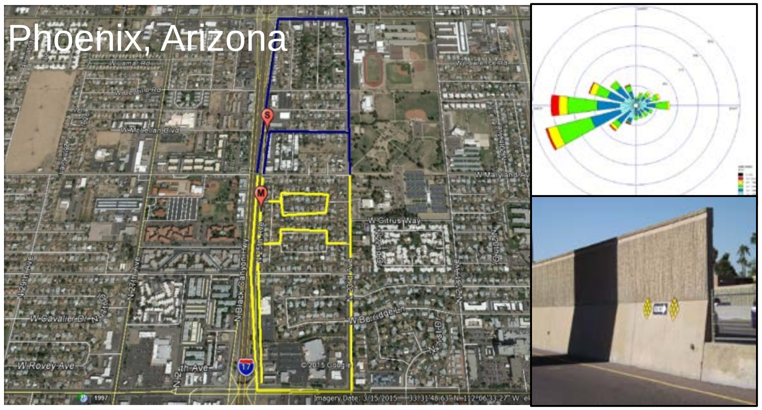




West Section (Morning)



East Section (Afternoon)



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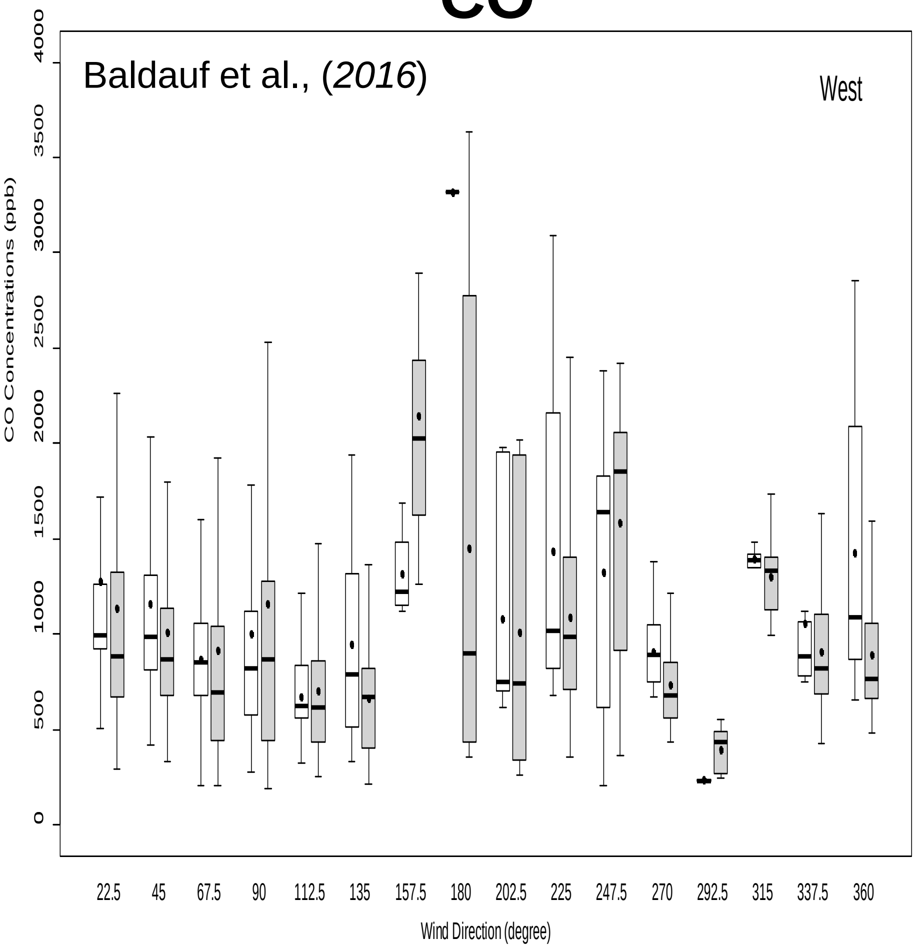
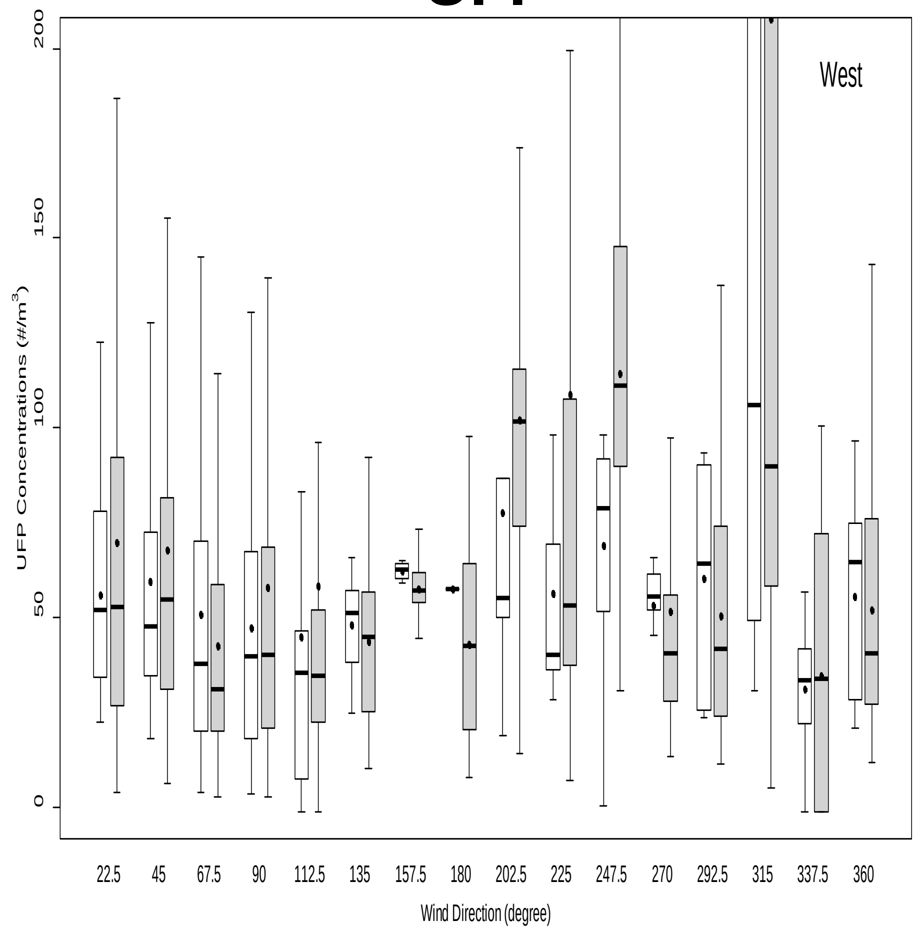
Noise Barriers & Air Quality

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

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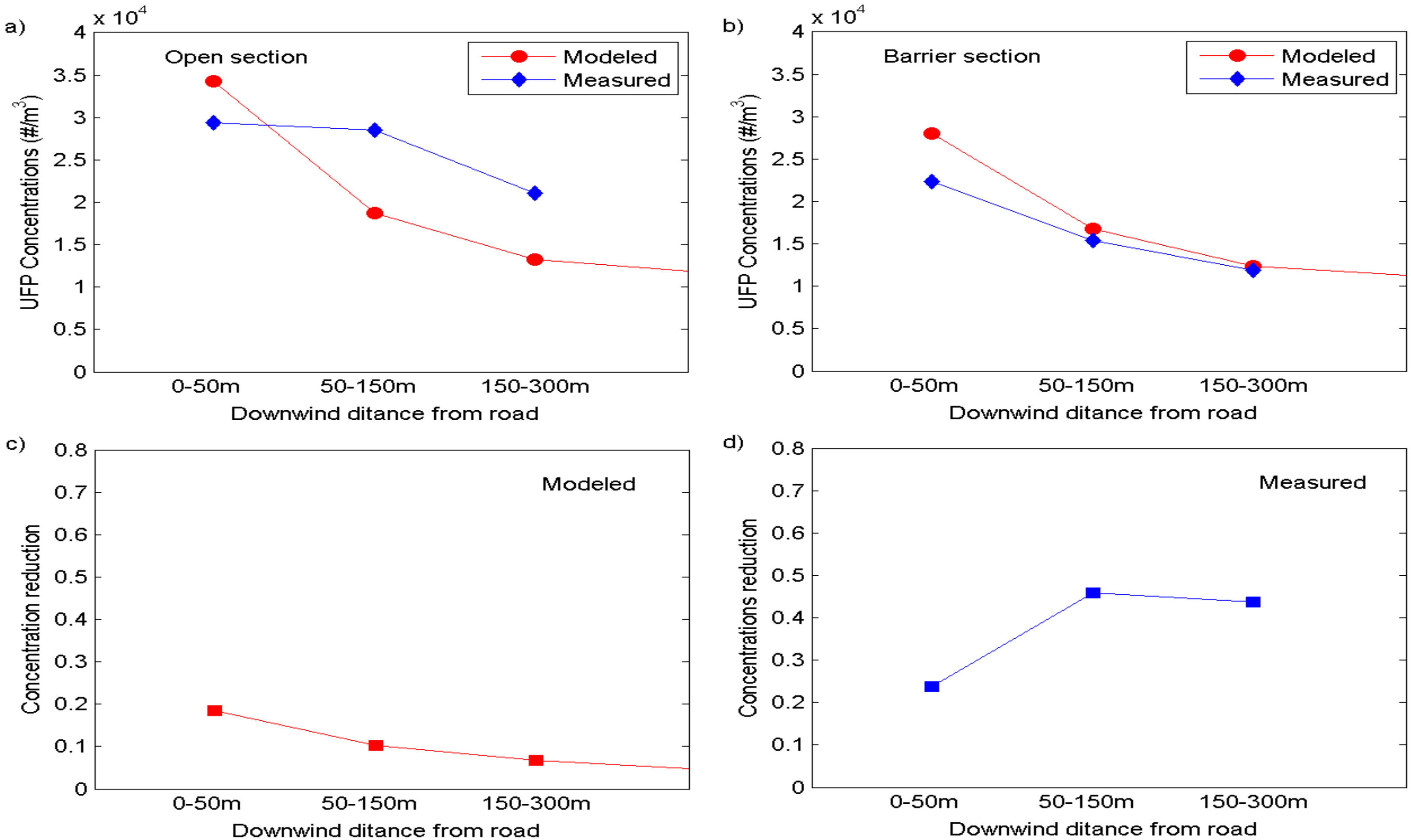
- Tracer study data (Finn et al., 2010) were used to develop an algorithm to simulate pollutant transport and dispersion from roads with noise barriers
- Phoenix study provided the first independent data set to evaluate this model
- This algorithm available in the R-LINE dispersion model

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

Venkatram et al., (*in press*)

UFP Model vs. Measurement Results

Open Section | Behind Barrier

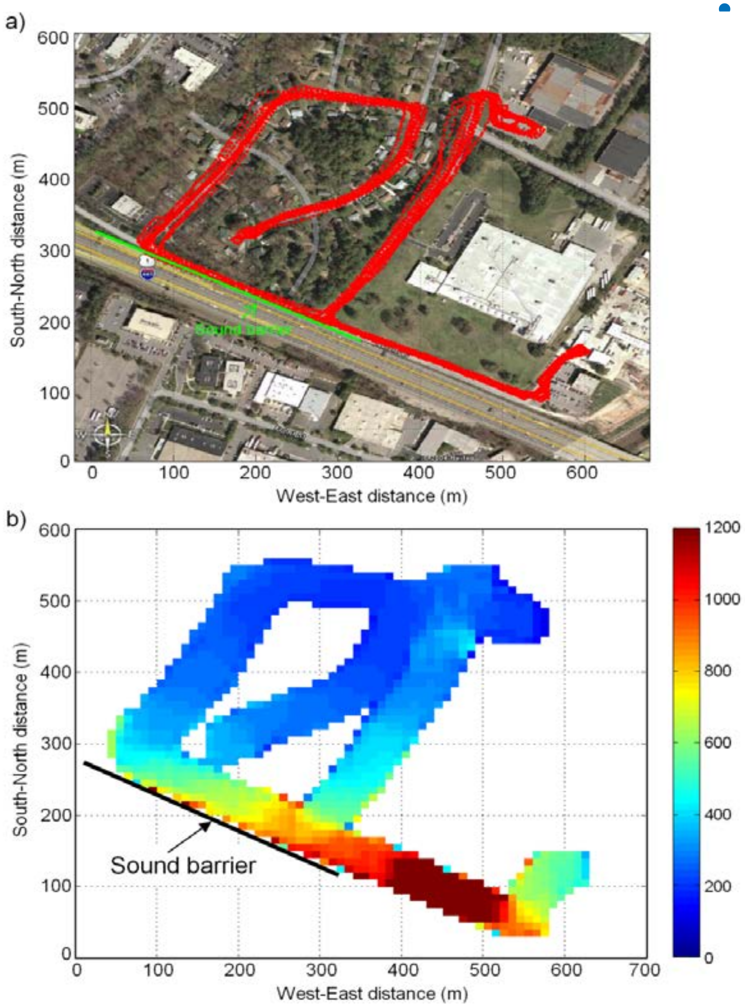


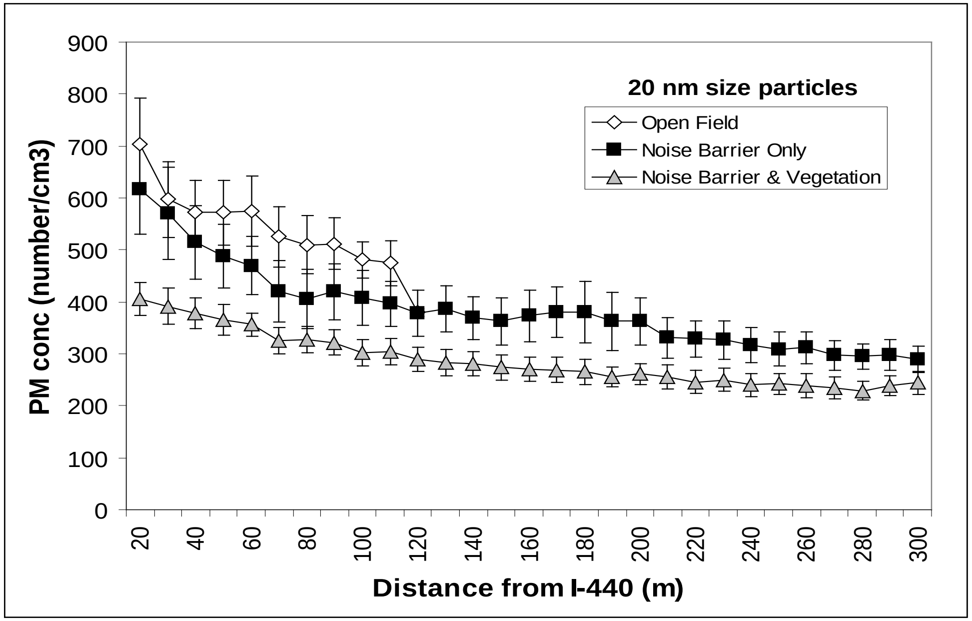
Venkatram et al., (*in press*)

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

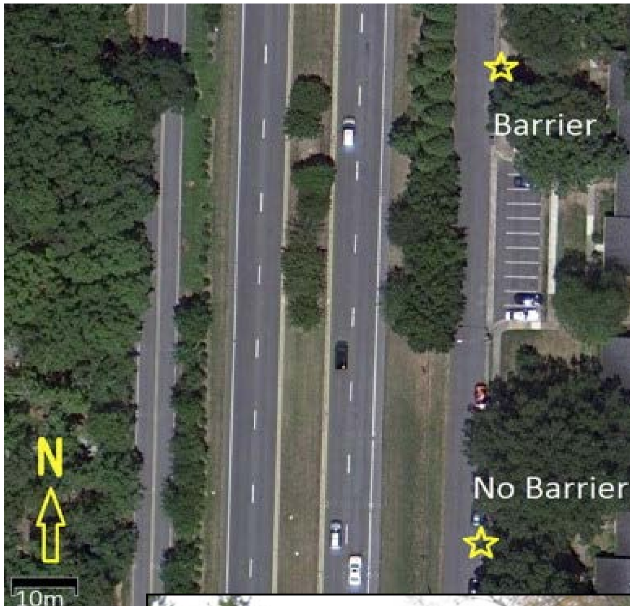


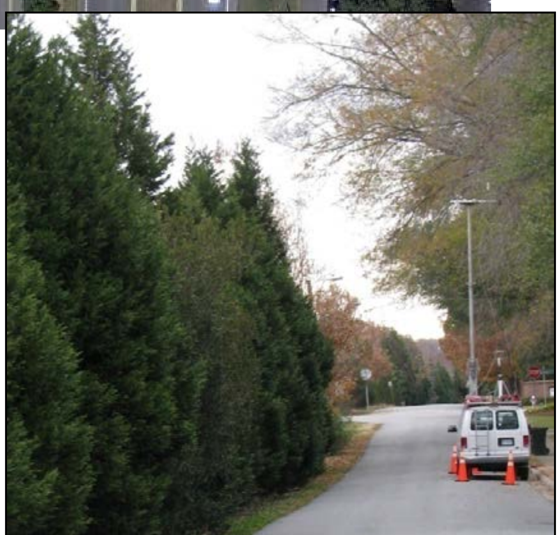


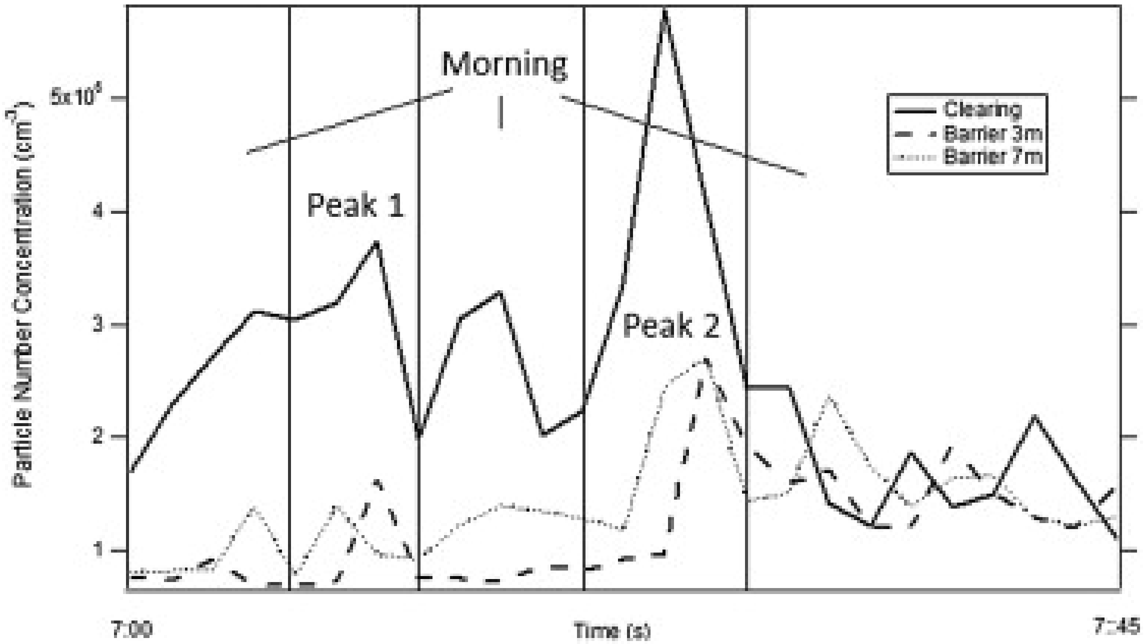
(Baldauf et al., 2008a; 2008b)

Vegetation Effects

Steffans et al. (2012)



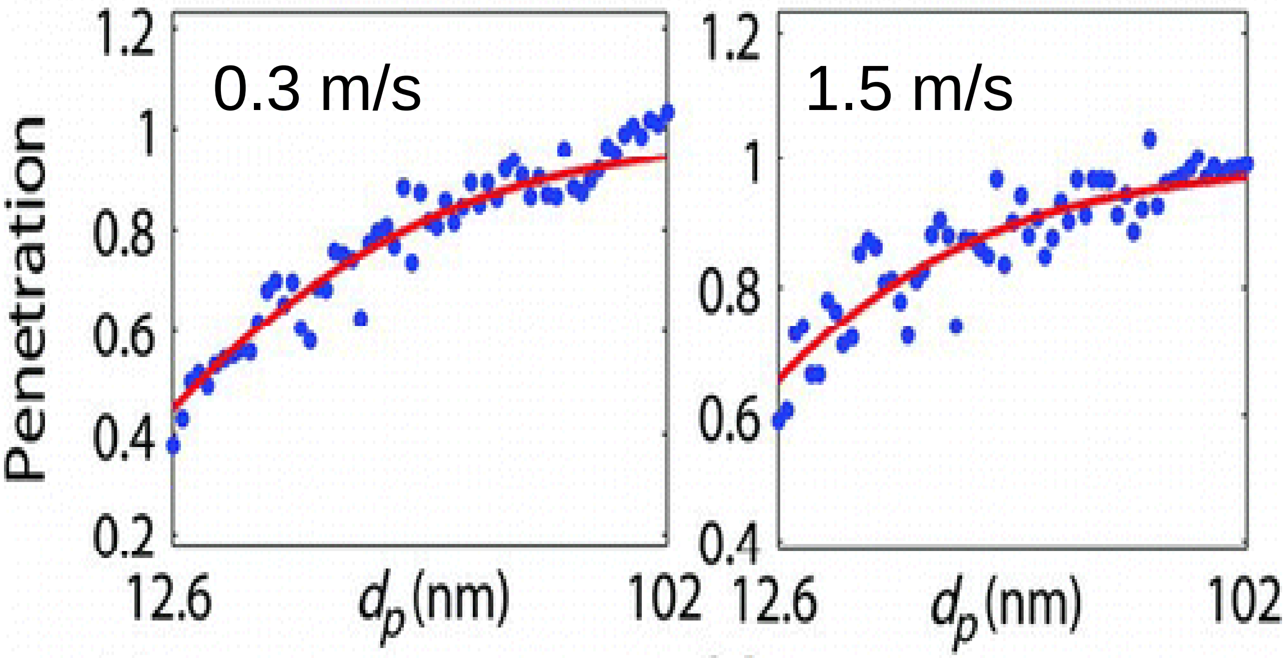


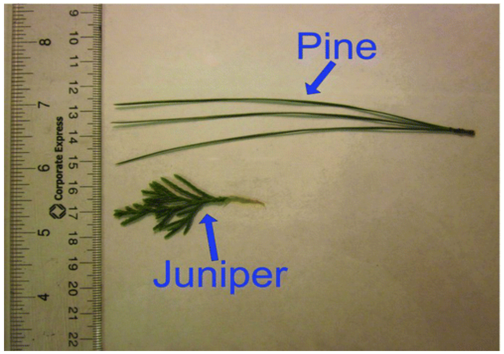


- Ultrafine PM number count generally reduced downwind of a vegetation stand
- Higher reductions most often occurred closer to ground-level
- Variable winds caused variable effects

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

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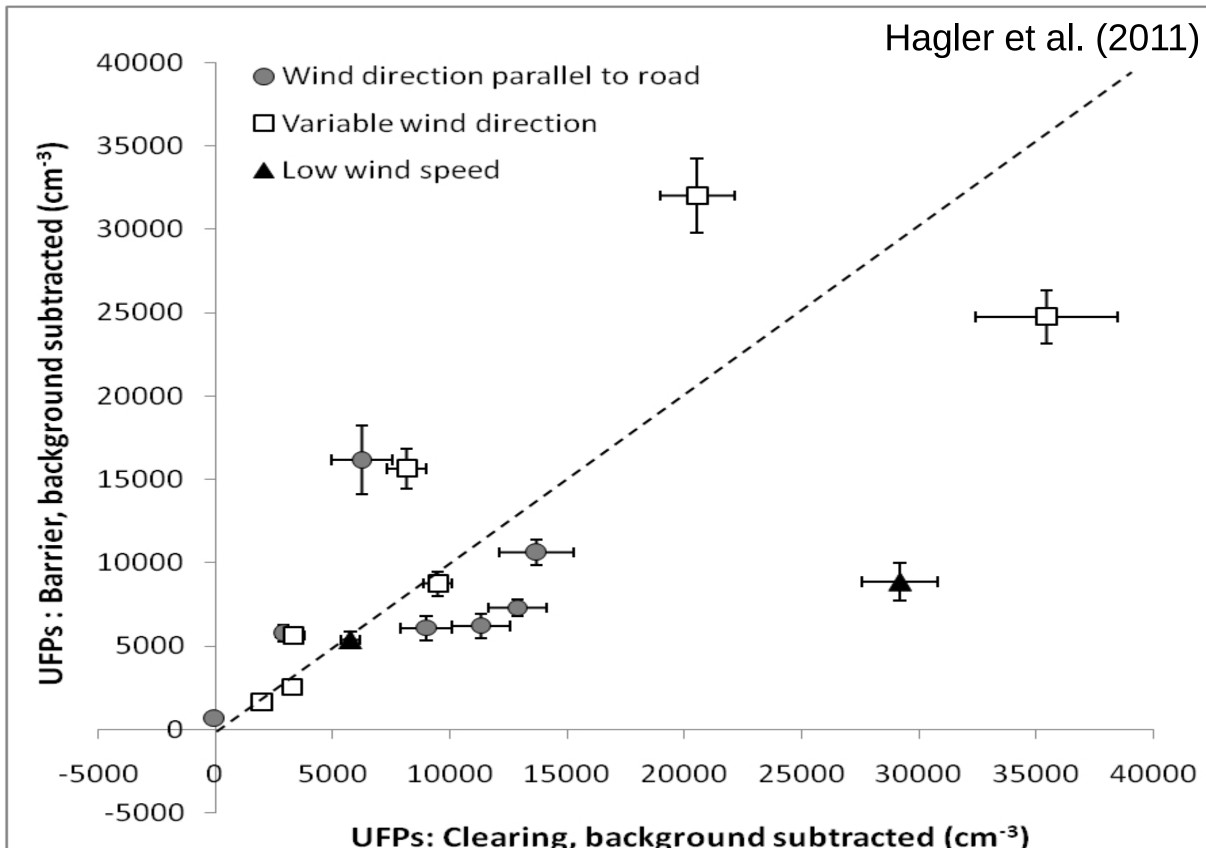
- For thin tree stands, variable results seen under changing wind conditions (e.g. parallel to road, low winds)
- Gaps/dead trees can lead to higher downwind concentrations



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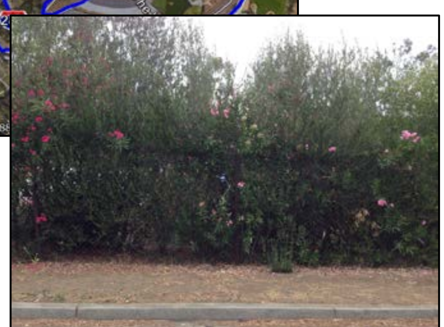
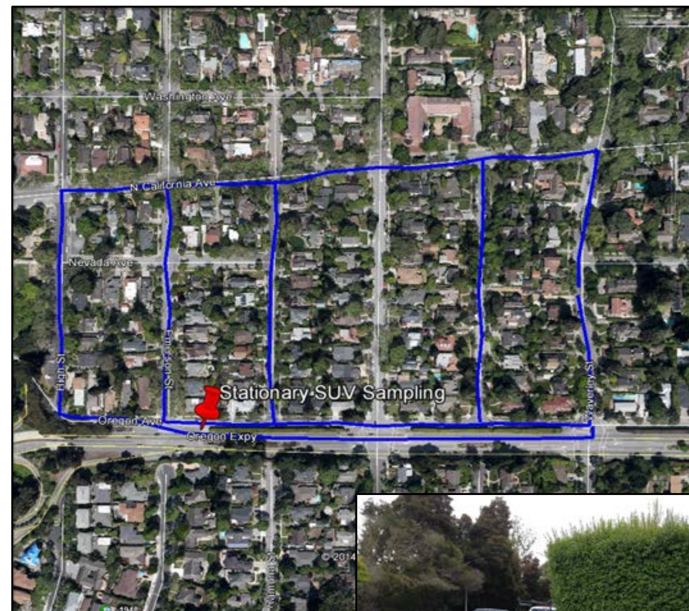
San Francisco Area Vegetation Study

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





Woodside Vegetation Study

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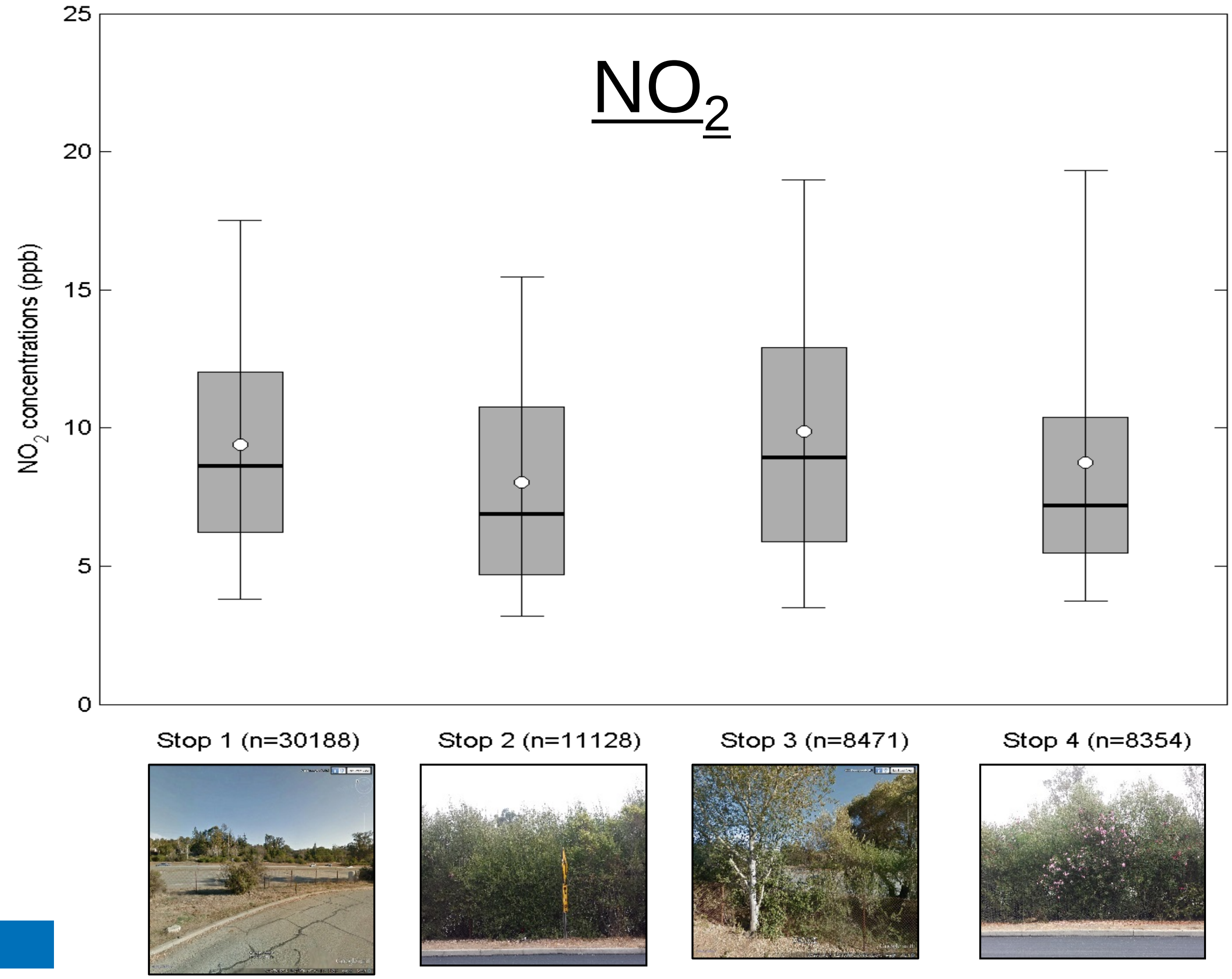
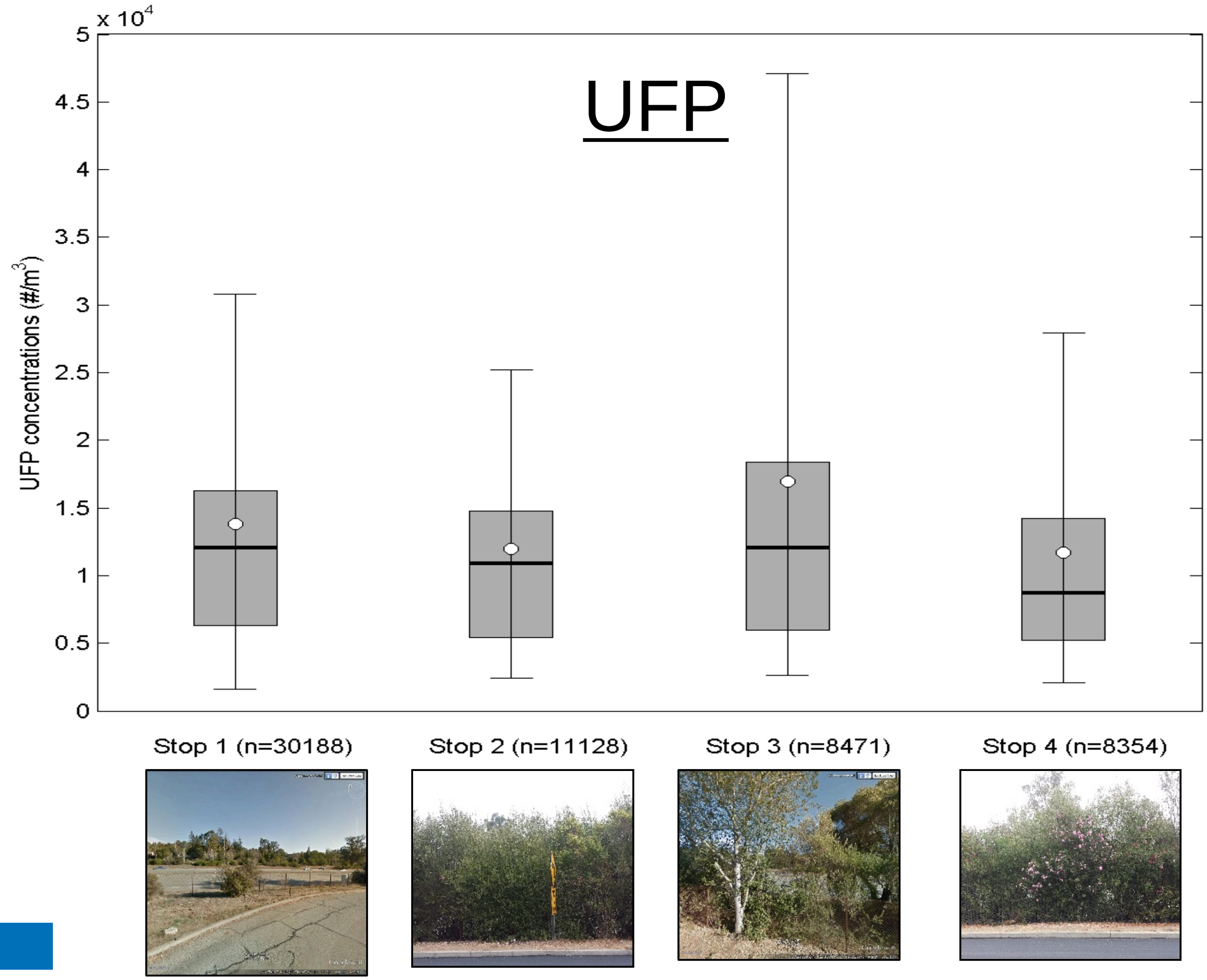
- Initial results suggest the importance of thickness, porosity and full coverage



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

Woodside Vegetation Study

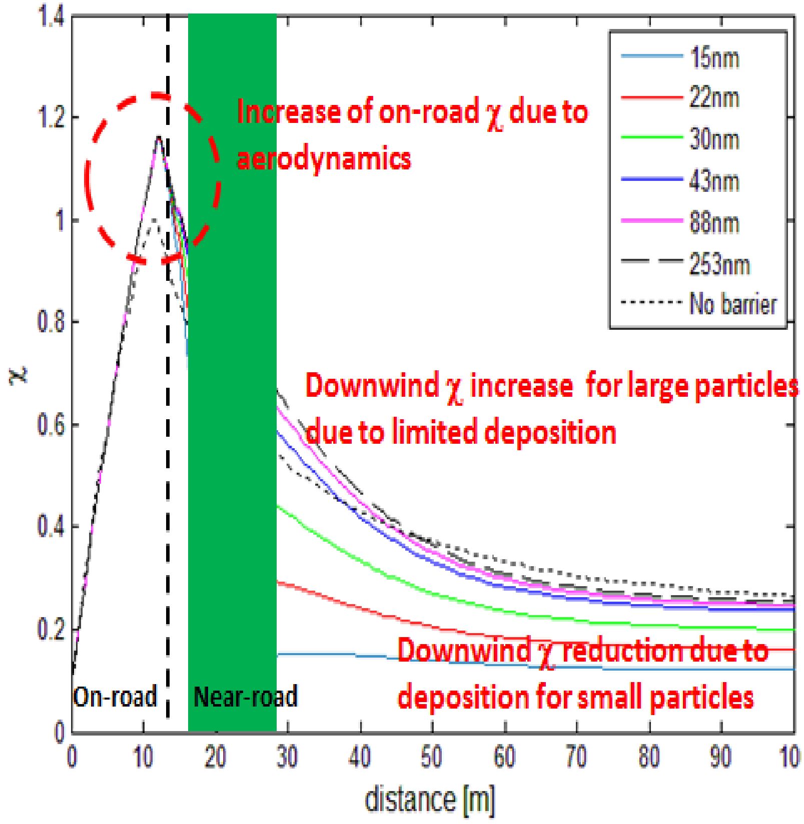
- Initial results suggest the importance of thickness, porosity and full coverage

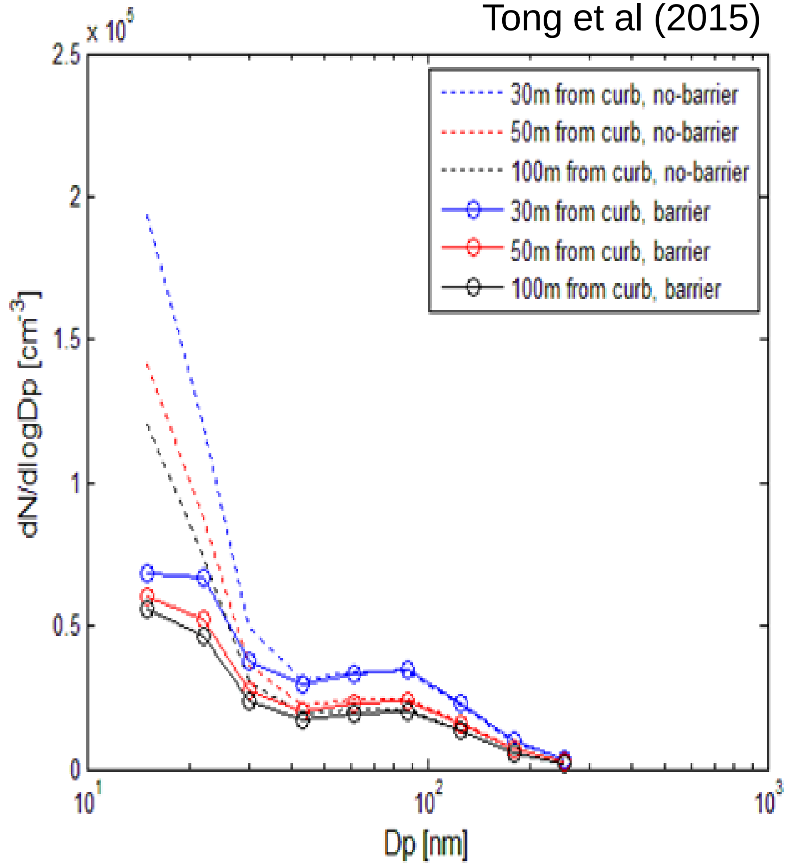


- All wind directions
- ~10k data pts/stop
- ~10min/stop/day

Vegetation Model Algorithm

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





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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 ≥ 4m
  - Pollutants can meander around edges
    - Sensitive areas should be ≥ 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 ≤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

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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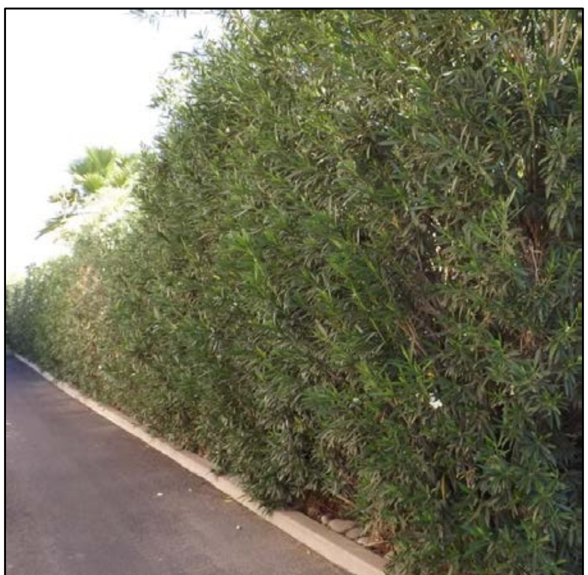
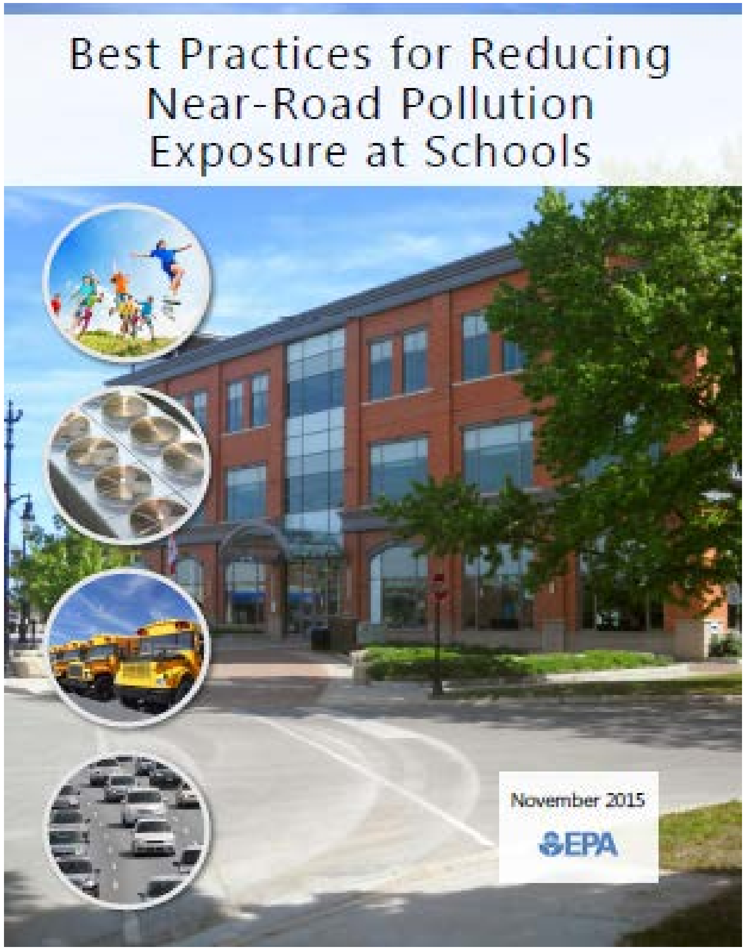


- Combination of noise and vegetative barriers may provide the most benefit
  - Provides opportunity for pollutant dispersion and removal
  - May be solid barrier with vegetation behind and/or in front (research had vegetation behind barrier)
  - Use of climbing vegetation and hedges with solid barrier 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

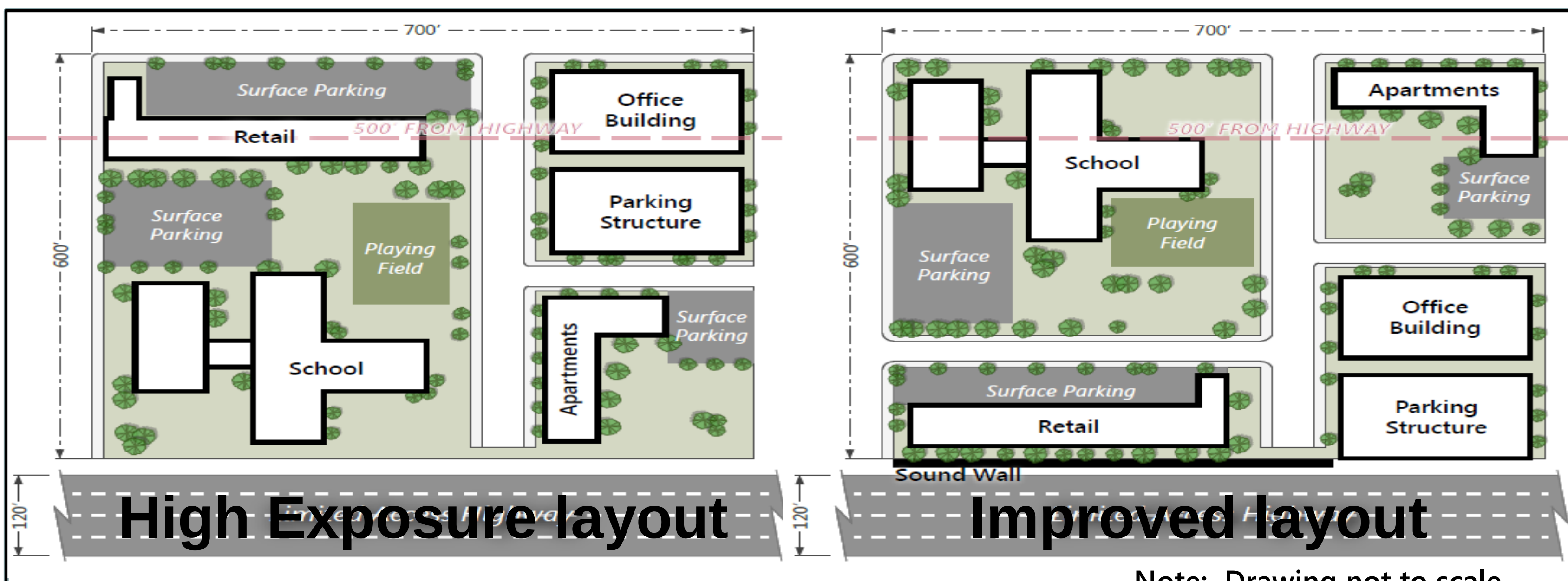
- Developed to provide practical solutions to mitigate traffic-related pollution based on issues in the School Siting Guidance
- Document for schools and parents
- Types of solutions provided:
  - Building Design and Operation Strategies
    - Ventilation, Filtration, and Indoor Air
    - Building Occupant 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

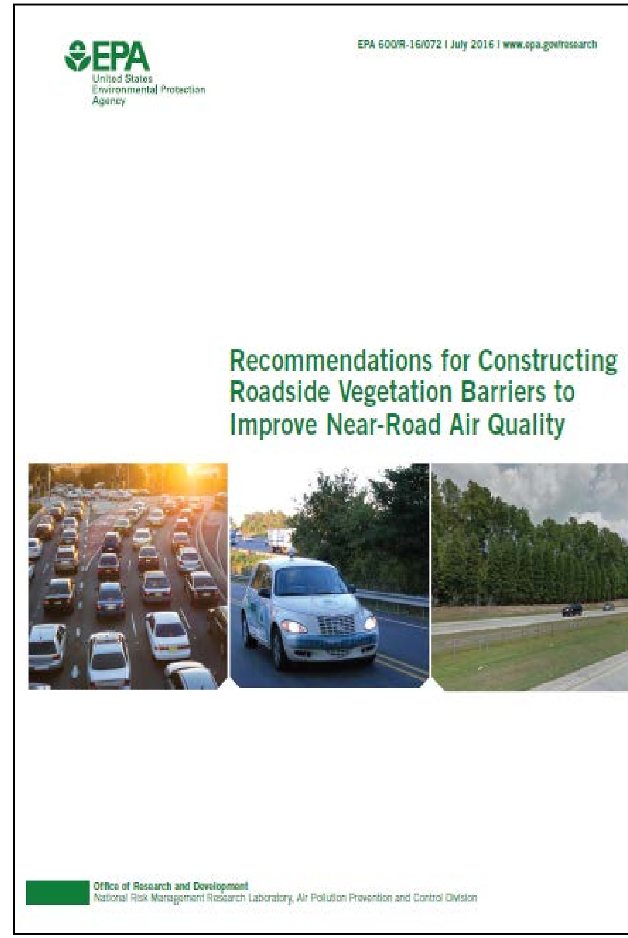
Best Practices for Planners

- 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



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 conditions 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
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