Ambient Air Mitigation Strategies for Reducing Exposures to Motor Vehicle Nanoparticle Emissions

Summary by: Richard Baldauf, U.S. Environmental Protection Agency (Baldauf.richard@epa.gov)

Introduction

As evidence increases that people living, working or going to school near large roadways experience increased risk for a number of adverse health effects (e.g. HEI, 2010), concerns have been raised that exposures to nanoparticles (NPs) emitted by traffic may be significantly contributing to these effects due to the highly elevated concentrations found near roads (e.g. Karner et al., 2010). Several strategies can be implemented to reduce population exposures to NPs emitted by traffic, which include emission and exposure reduction techniques that can be implemented through regulatory and voluntary programs. Common strategies that have been employed include:

- Regulatory emission standards or voluntary programs intended to reduce tailpipe emissions of air pollutants from the vehicle. Emission standards and retrofit programs have been extremely successful in reducing exhaust emissions of air pollutants from motor vehicles, including NPs. These programs have been applied to light-duty and heavy-duty vehicles. The main limitation of these programs is the time needed from initiating the control program to achieving air quality benefits. The time needed for manufacturers to develop the control technology, the vehicle fleet to turn over so the majority of vehicles on the road meet the emission standards, and/or the installation of a large number of retrofits can be extensive. Thus, emission standards and reduction programs often cannot address immediate exposure and health concerns.
- Techniques that reduce or restrict vehicle activity have also been used to decrease vehicle emissions. Strategies have included the development and promotion of public transit, congestion pricing, emission-free and pedestrian-only zones, and alternative commuting through walking or biking. The extent of emission reductions from implementing these programs can vary widely. In addition, some programs may just alter the location of emissions rather than providing reductions throughout an urban area. These programs also often take a relatively large amount of time to implement in order to achieve air quality benefits.
- Buffer and exclusion zones have been promoted as a means to reduce population exposures to the elevated air pollution concentrations found near roads, especially for susceptible populations. The state of California has legislation that attempts to restrict building new schools within 500 feet (~150 meters) of a major roadway (CARB, 2005). In addition, the U.S. Centers for Disease Control recommends restricting the development of any facilities serving children and the elderly from within 500 feet (~150 meters) of a major roadway (CDC, 2011). While buffer/exclusion zones do reduce exposures to motor vehicle emitted air pollutants, including NPs, these techniques do not improve overall air quality. In addition, concerns have been raised that restricting development near roads may force these facilities to be located far from the neighborhoods being served, requiring residents to commute longer distances to access these

services – increasing overall air pollution emissions, as well as potentially increasing their exposures during the longer commute time.

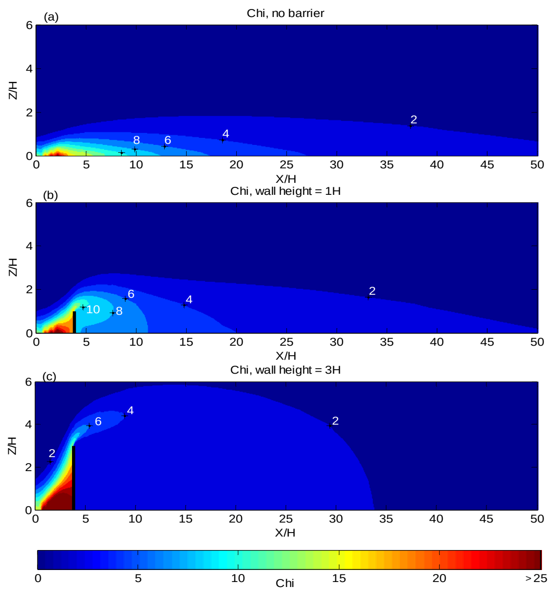
An area of recent research has been the use of roadside features, notably noise barriers and vegetation, along the roadway to alter the dispersion of NPs and other emitted pollutants, resulting in reduced exposures for near-road populations and potentially providing improved air quality through filtration of NPs by vegetation (Baldauf et al., 2008a; Baldauf et al., 2008b; Bowker et al., 2007; Hagler et al., 2011). Use of these features provides one of the only "short-term" options to reduce exposures to NPs and other pollutants for near-road populations.

Mitigating Near-Road Air Pollution by Roadside Features

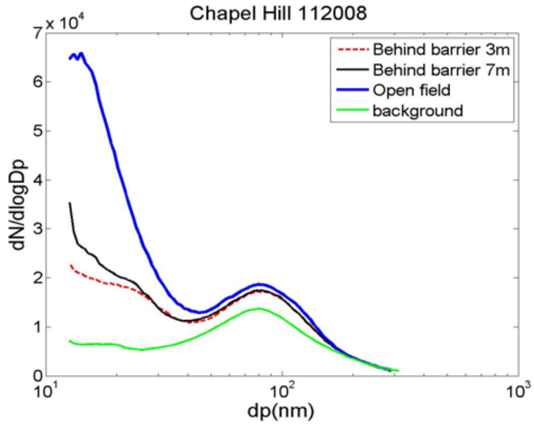
The presence of roadside features has been studied in three ways: field measurement studies, wind tunnel tests, and computational modeling. The following sections provide more detail on the effects of noise barriers and vegetation since these techniques can be implemented in the least amount of time.

Noise Barriers

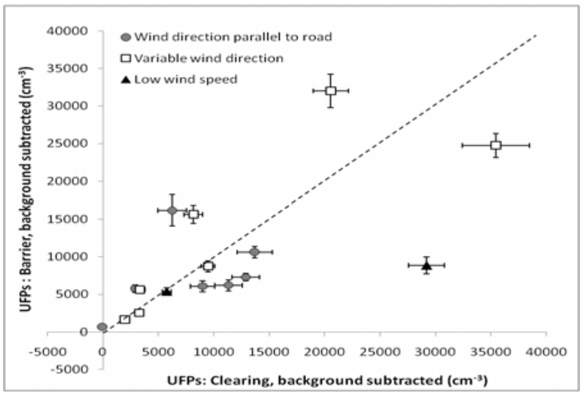
Research studies have highlighted the ability of noise barriers to affect pollutant transport and dispersion from traffic-generated emissions on nearby roadways. Reductions in air pollutant concentrations downwind of roadways have been shown to be as high as 50 percent. The solid barriers force the emissions plume up and over the barrier, resulting in a region of reduced concentrations behind the barrier. Generally, the barriers do not remove air pollution, although investigators have explored the use of surface coatings (e.g. TiO_2) that may remove certain pollutants. Studies also show that noise barriers can increase pollutant concentrations on the upwind side of the barrier, resulting in higher on-road pollutant levels. Concentrations may also be highly variable around the edges of these structures, limiting pollutant reductions. Figure 1 shwos results of computational fluid dynamic (CFD) modeling of noise barrier effects with changing barrier heights. For these figures, the roadway is at the origin, with the y-axis representing height above ground and the x-axis distance from the road. The x-axis distance is scaled by the barrier height of 6 meters; thus, the distances shown should be multiplied by a factor of "6" for actual distances (Hagler et al., 2011). This figure highlights the reduction in downwind concentrations, and increase in upwind concentrations, in the presence of a noise barrier. These effects are enhanced with increasing barrier heights. Wind tunnel and field studies have also shown pollutant concentration reductions under downwind conditions and changing wind directions (Baldauf et al., 2008b; Hagler et al., 2012).



Vegetation

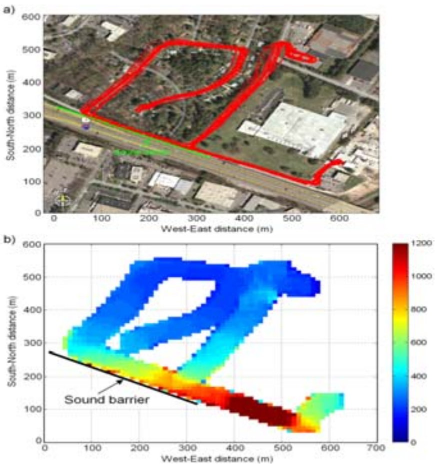


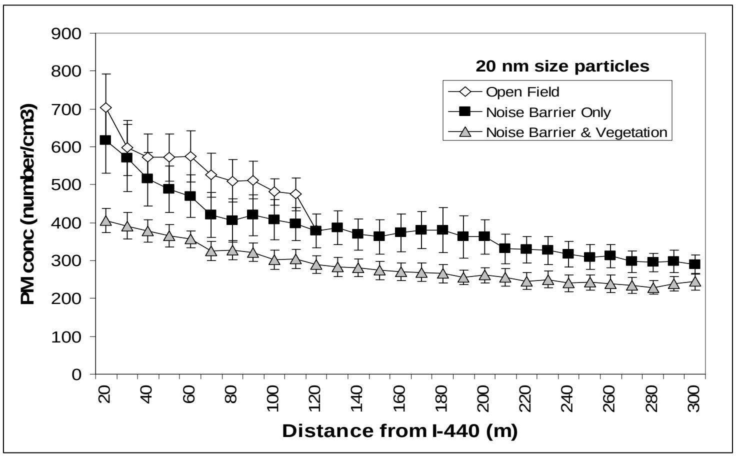
Barriers composed of vegetation can affect near-road pollutant concentrations through aerodynamic turbulence and physical removal. Some field studies suggest that ultrafine and coarse particles can be effectively removed by vegetative barriers. Figure 2 compares particle size distributions measured behind a vegetation barrier at two heights above ground (3m and 7m) compared with measurements at the same distance from the road without a barrier and regional background measurements (Khlystov et al., 2012). The results suggest that the vegetation preferentially removed particles less than approximately 30 nm in diameter. Physical characteristics of the vegetation barrier can have significant influence on the effectiveness of this technique for improved exposures and air quality near roads. The height, thickness, and coverage of the vegetation is important. Figure 3 provides a comparison of measurements behind a vegetation barrier at multiple locations and under multiple meteorological conditions (presented as wind direction in this figure) using mobile monitoring (Hagler et al., 2012). This figure suggests that under certain meteorological conditions, near-road concentrations may be higher behind a vegetative barrier compared with no barrier. These increased concentrations tended to occur at locations with gaps in the vegetation due to dead trees or lack of full vegetation coverage from the ground to the top of the tree canopy. Different types of vegetation have varying levels of effectiveness in absorbing or adsorbing particles and gases. In addition, seasonal vegetation may only provide benefits during summer months, with reduced, or even negative, benefits during the winter when leaves are lost.



Noise Barriers and Vegetation

One field study suggested that combining the attributes of noise barriers and vegetation may provide additional benefits over each individually. The combination provides the benefits of the solid barrier forcing the traffic emission plume from the roadway up and over the structure with the additional benefit of NP removal by diffusion on to the vegetation surface. Figure 4 shows mobile monitoring measurements of approximately 20 nm diameter particles along a highway with a clearing, behind noise barrier only, and behind noise barrier and vegetation section. The results indicated that the highest concentrations occurred in the clearing, while maximum concentration reductions occurred behind the noise barrier with vegetation (Baldauf et al., 2008a and 2008b).





Conclusions

Environmental and urban planners have multiple options available for reducing adverse health effects from exposures to air pollutants in urban areas, including methods to reduce emissions and techniques designed to reduce exposures. Each option has advantages and disadvantages, especially for situations where health concerns exist and short-term solutions are needed. While emission control and vehicle activity reductions are critical for long-term air quality improvement and sustainable community development, these programs typically cannot address short-term concerns. In addition, the creation of buffer/exclusion zones is often not feasible, and can lead to increased exposures from longer commutes if not carefully planned and implemented.

Recent research on the role roadside features such as noise barriers and vegetation can contribute in mitigating exposures and improving air quality for near-road populations shows promise. Studies suggest that noise barriers and vegetation can reduce exposures to traffic=generated pollutants, while vegetation may also provide a mechanism for removing NPs. However, the research also demonstrates potential limitations in this approach, and instances where concentrations can be higher both upwind and downwind of the barriers if not designed properly. In order to provide maximum benefit in improving air quality and reducing population exposures, especially from highly elevated NP concentrations often found near large roadways, multiple pollution control and exposure reduction techniques must be employed.

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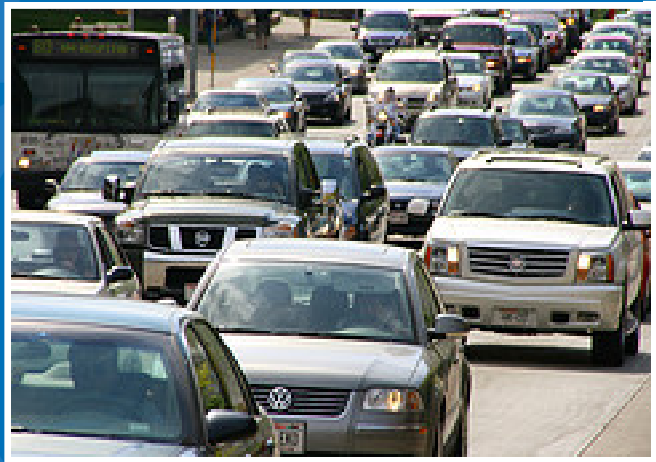

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Background

- International consensus on increased health risks for populations near large roadways
- Concentrations of many pollutants elevated near large roads, including nanoparticles
- Many studies suggest nanoparticles are a major contributor to these near-road health effects
- Public health concerns have raised interest in methods to mitigate these traffic emission impacts

Ambient Air Mitigation

- Transportation and land use planning options have been considered for reducing exposures to traffic-generated pollutants:
  - Vehicle emission reductions through 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

Vehicle Emission Reductions

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- Reducing emissions from on-road motor vehicles can significantly improve near-road air quality. Examples from the US include:
  - Light-duty emission standards (e.g. Tier 2, Mobile Source Air Toxics)
  - Heavy-duty emission standards (2010 HD Diesel Rule, National Clean Diesel Campaign)
- Emission programs often take time to implement
  - Requires fleet turnover or large-scale retrofits
  - May be offset by increased vehicle activity
  - Not necessarily an answer for existing concerns
- Emission standards focus on tailpipe exhaust
  - Brake and tire wear, re-entrained road dust still a concern

Vehicle Activity Reductions

- Reducing vehicle activity will lead to lower emissions, improving near-road air quality. Examples of programs to reduce VMT include:
  - Public transit
  - Congestion pricing
  - Pedestrian zones
  - Alternative commuting programs (telework, biking, walking)
- These programs can have local and regional impacts
  - The extent of emission reductions can vary widely by program, region, and time of day/year
- Some programs may shift the locations of emissions, decreasing in some areas but increasing in others

Buffer/Exclusion Zones

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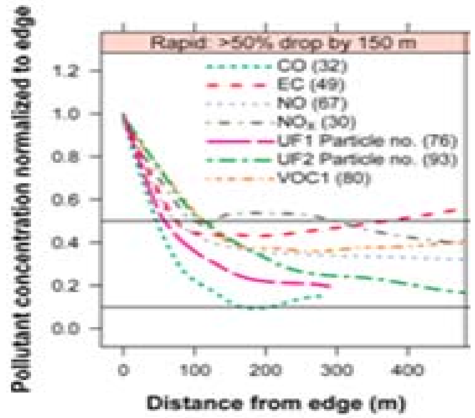
- Since near-road concentration gradients tend to be steep, some agencies have recommended limiting development near large roads
  - California "restricts" new schools being built within 500 ft (~150 meters) of a large roadway (>100,000 AADT highway; >50,000 AADT arterial)
  - US Centers for Disease Control (CDC) recommended that no facilities serving sensitive populations (schools, daycares, nursing homes, etc.) be developed within 500 ft of a major highway in their "Healthy People 2020" report
- Since pollutant concentrations drop rapidly, keeping development away from roads will reduce population exposures
- Limiting development near roads may have unintended consequences

  - If other land not available, may increase travel to access services

  - Schools may be located far from neighborhoods being served, increasing commute time and student exposures during commutes

Karner et al. (2010)

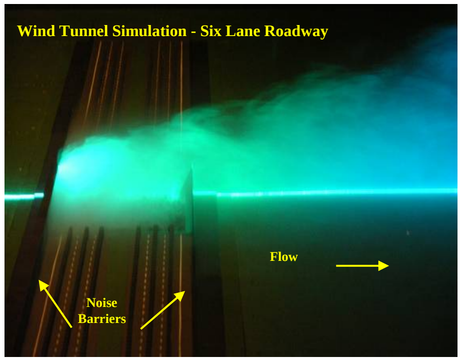


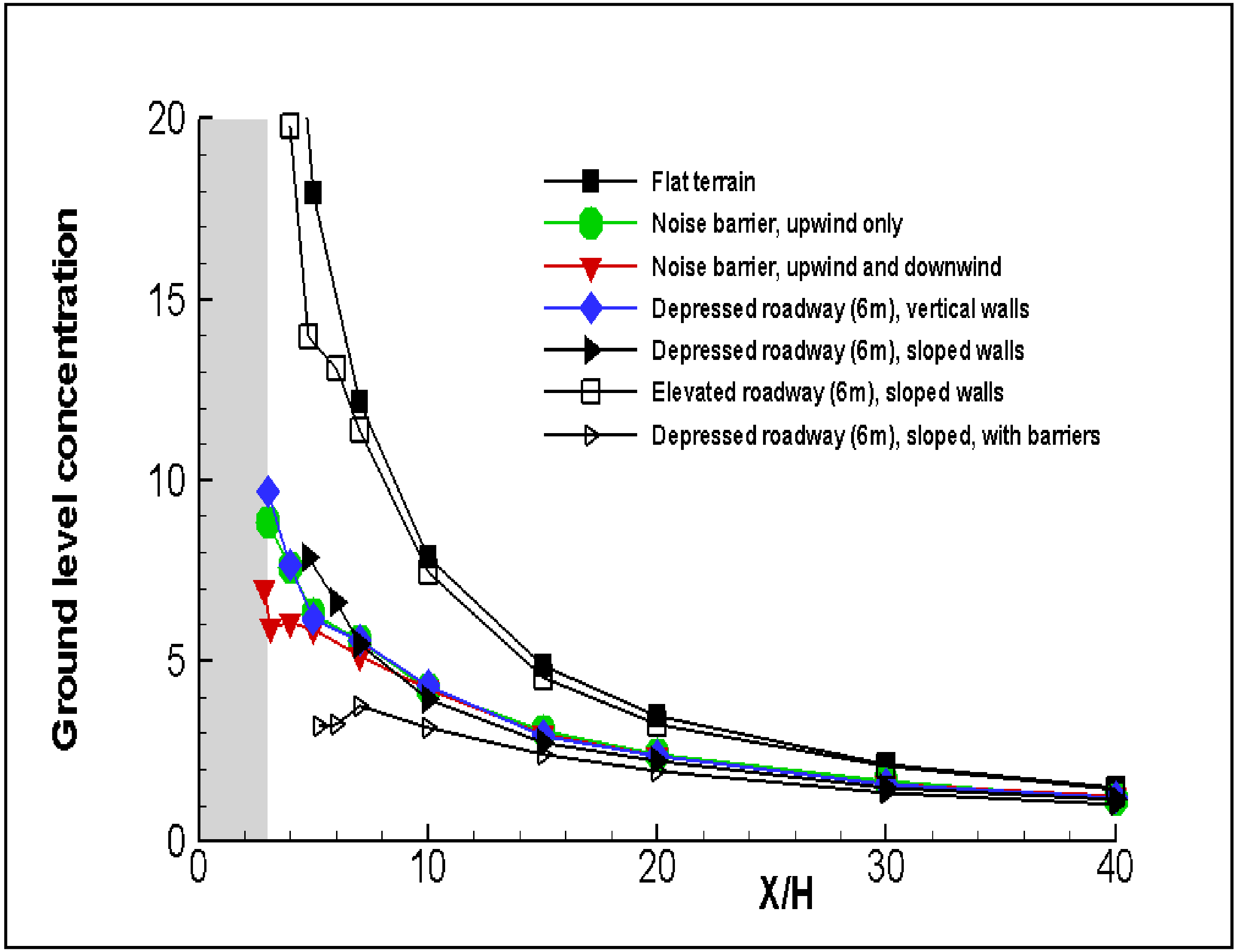
Roadway Design

- Roadway configuration and the presence of roadside features can affect pollutant transport and dispersion
  - Roadway configuration reflects design elements that affect the road surface elevation relative to the surrounding terrain
    - Cut/depressed road sections (road bed below surrounding terrain)
    - Elevated fill road sections (road bed above surrounding terrain)
    - Elevated bridge sections (road bed above surrounding terrain)
  - Roadside features are structures present near and along the side of the road
    - Noise Barriers/Sound Walls
    - Vegetation
    - Buildings and other infrastructure

Roadside features can provide a "short-term" mitigation option, may already be present, and often seen as a positive for other purposes (noise reduction, aesthetics, etc.)

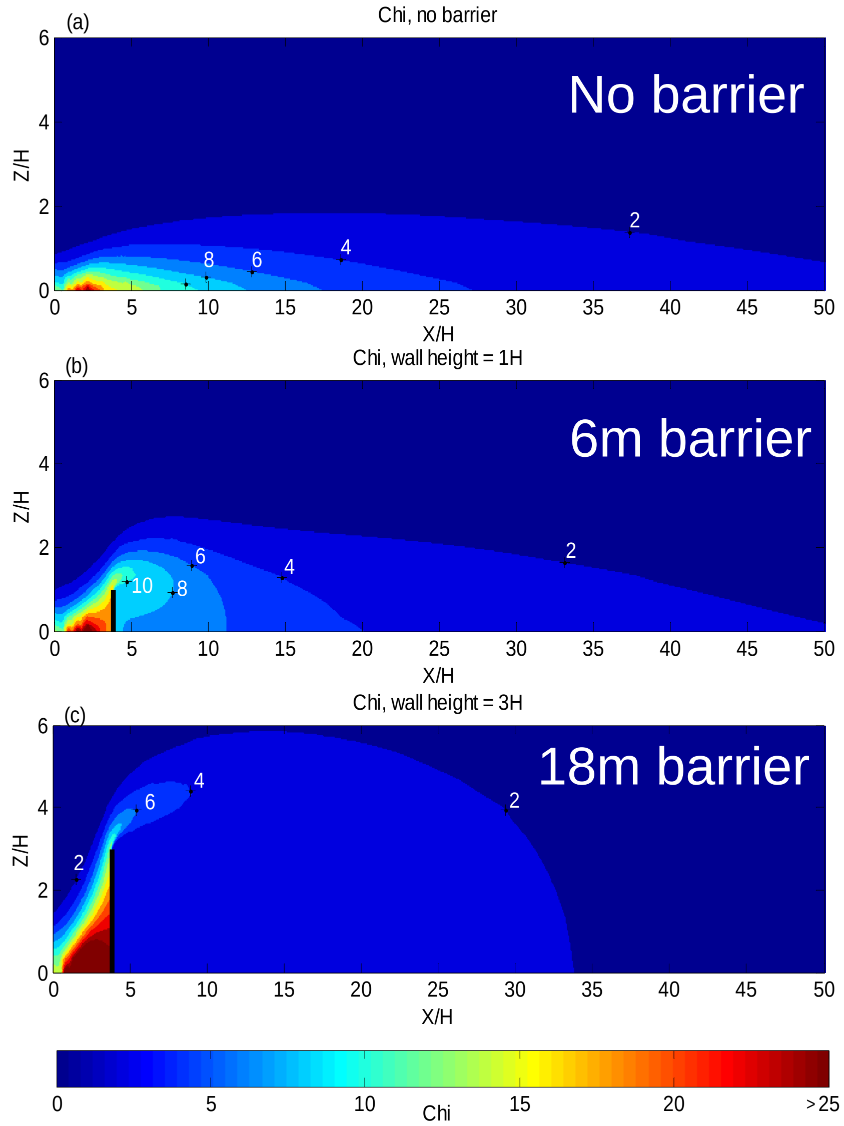
Roadway Configuration Effects





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)

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Noise Barrier Effects

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

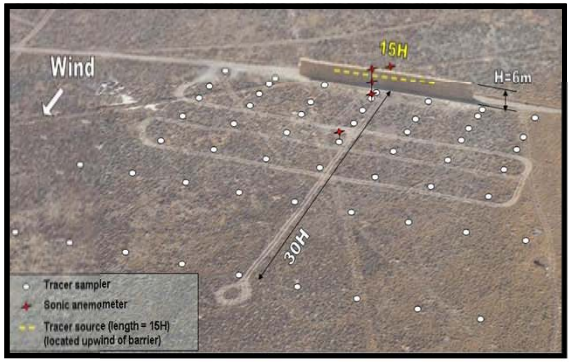
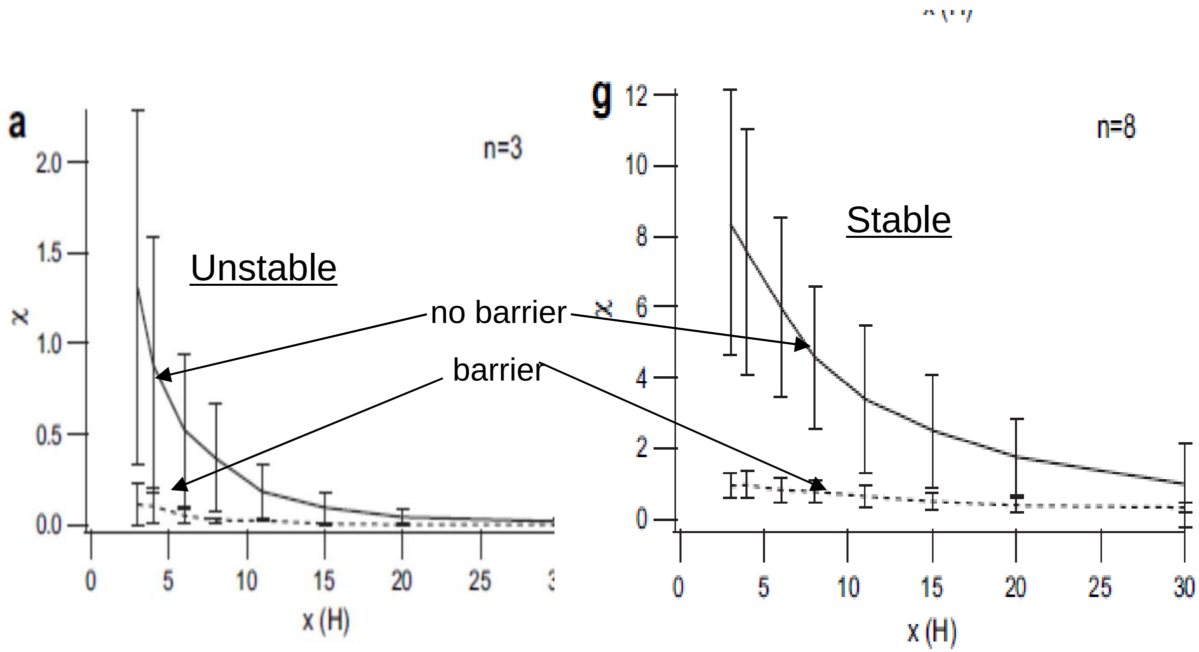


Fig. 1. Mock straw bale sound barrier, 6 m high and 90 m long.

Finn et al., (2010)



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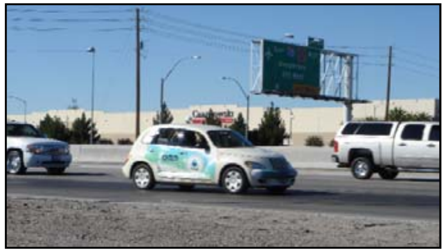
Monitoring Methods

Mobile Electric Vehicle

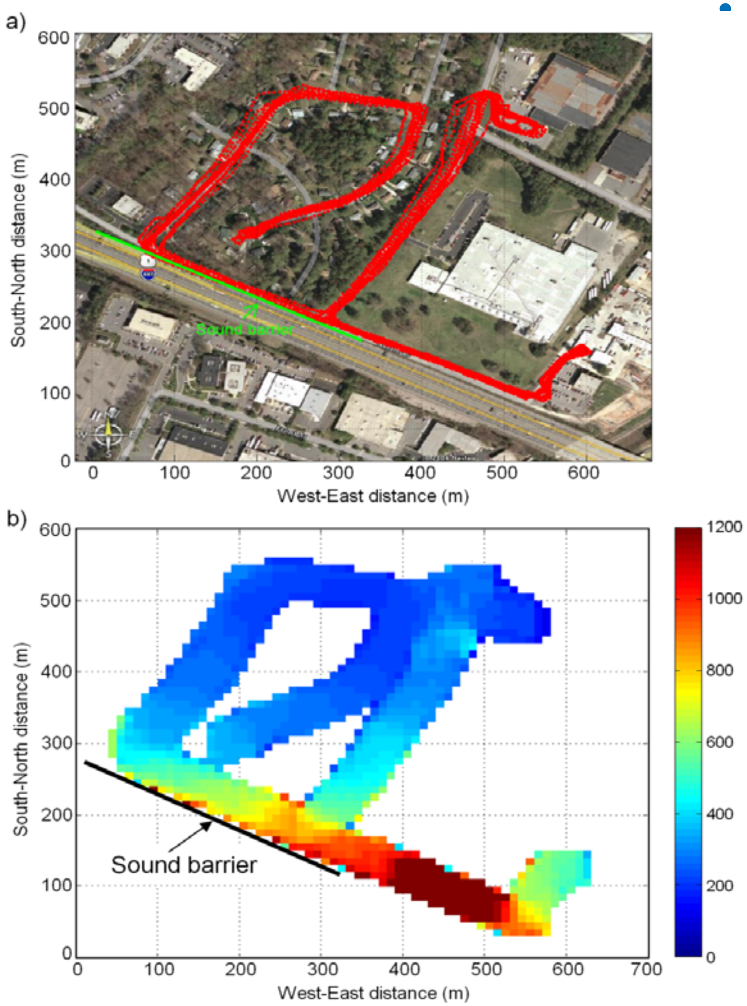
- →Particulate Matter
  - →UFP count and size distributions (EEPS/SMPS)
  - →Coarse and fine size distributions (APS)
  - →Black carbon (AE51)
- →Gases
  - →CO (Single Quantum Cascade Laser, QCL)
  - →NO2 (Cavity Attenuated Phase Shift, CAPS)



Stationary Fixed and Portable

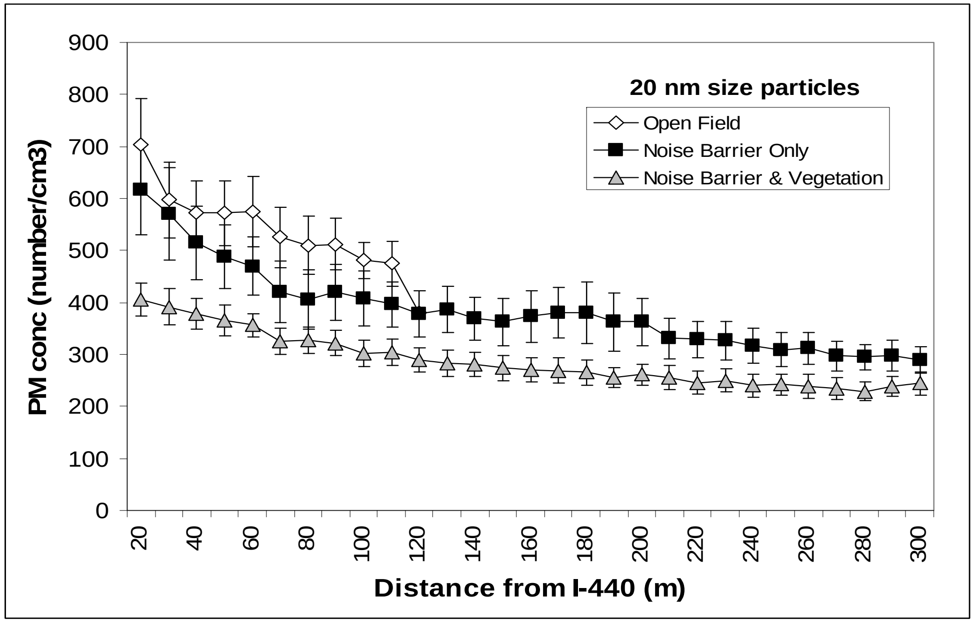
- →Stations meeting US NAAQS requirements
  - →PM, CO and NO_x Federal Reference Methods
  - →Particle count in select size bins (UFP 3031)
  - →Black carbon AE51)
- →SUV equipped with NAAQS instrumentation
  - →Particle count in select size bins (EEPS/SMPS)
  - →Black carbon (AE51)
- →Backpack systems for mobile and stationary sampling
  - →Particle count in select size bins (HHPC)
  - →Black carbon (AE51)

Noise Barriers and Vegetation



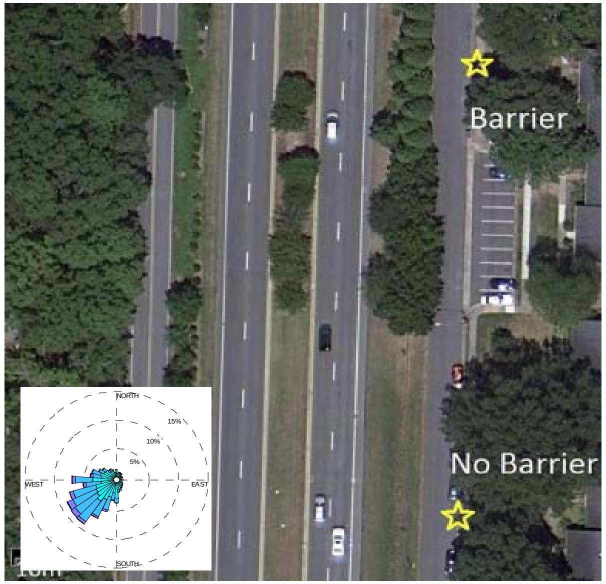
- Noise barriers reduced PM levels compared with a clearing

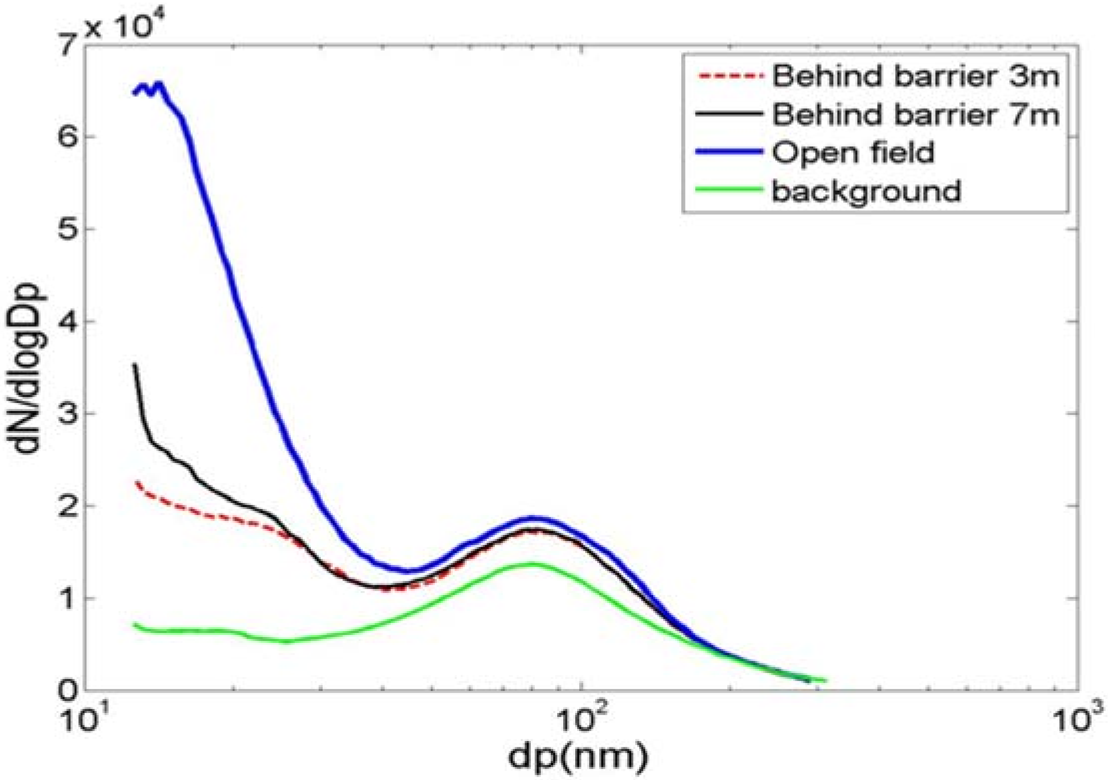
  Vegetation with noise barriers provided a further reduction of PM concentrations and gradients



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

Vegetation Effects

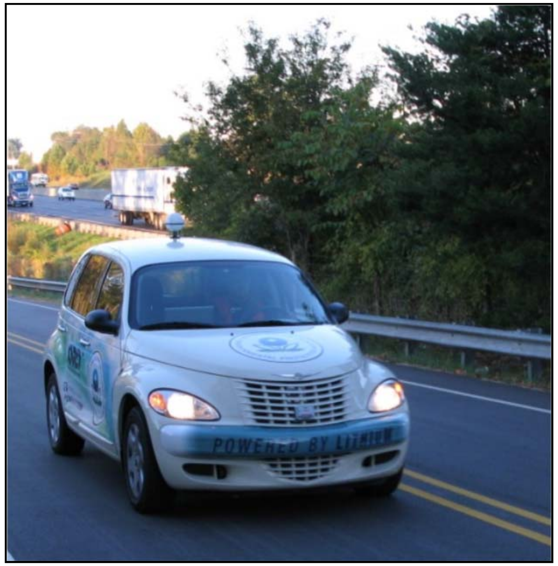


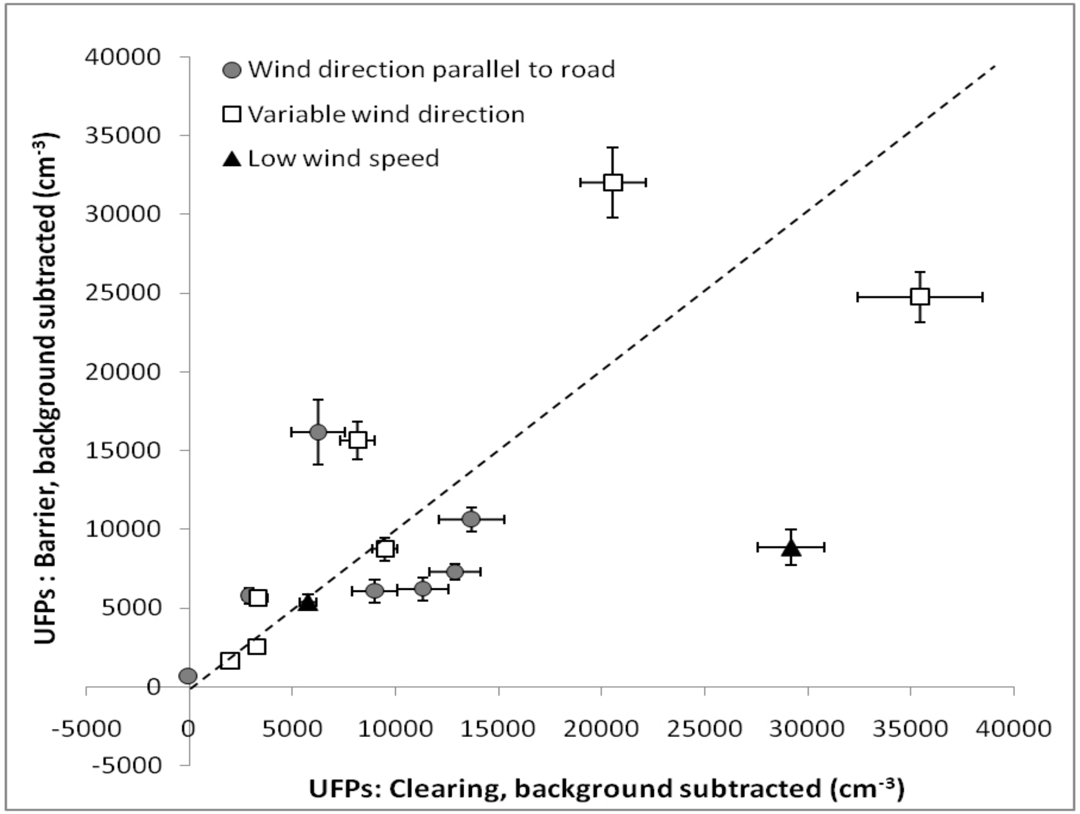


- Lower size fractions of PM most reduced downwind of the vegetation stand
- Effect most evident closer to ground-level

Vegetation Effects

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





Hagler et al. (2012)

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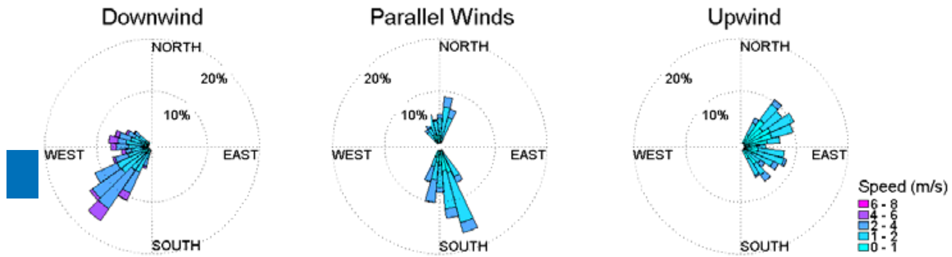
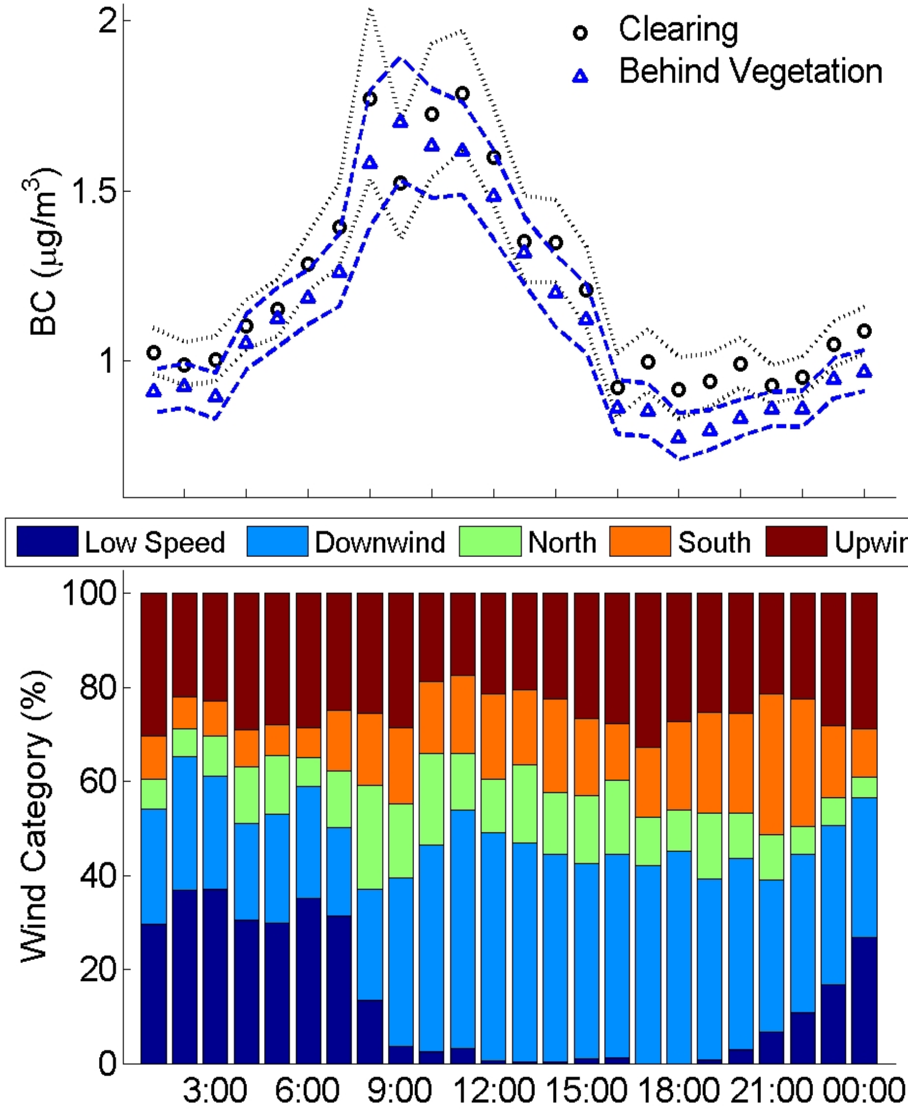
Vegetation Effects

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





Brantley et al. (in prep)

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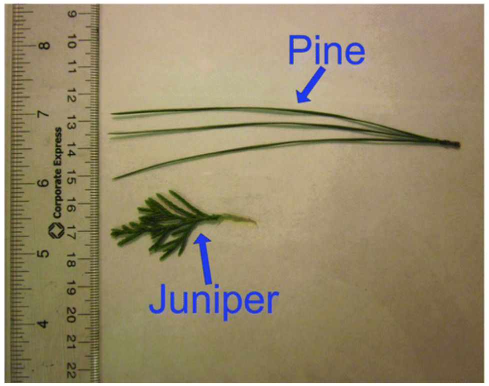
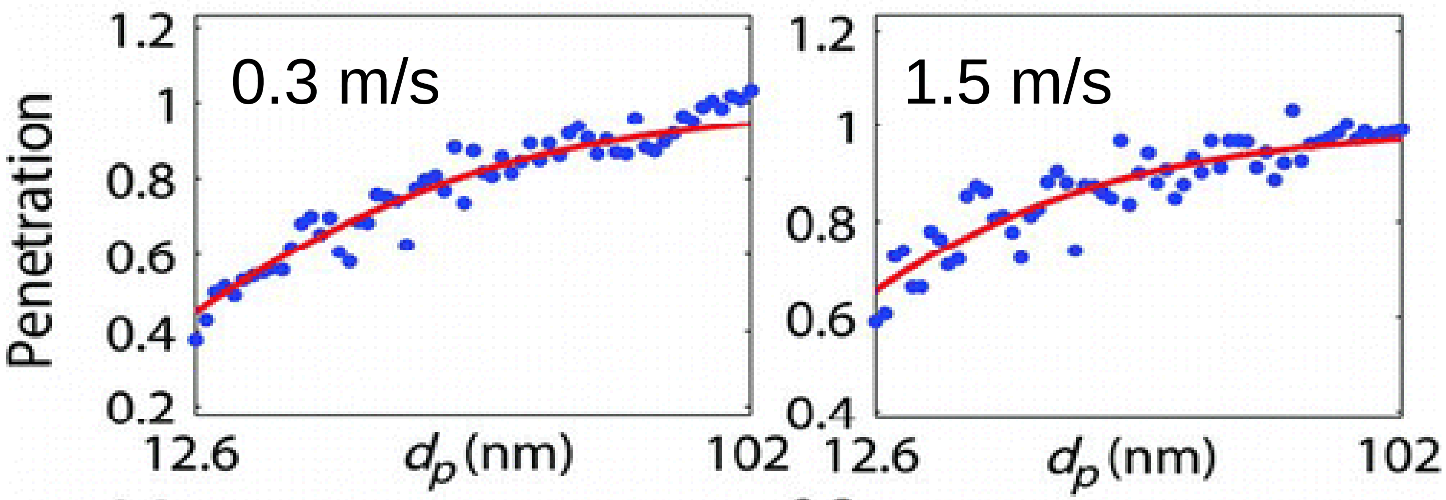
Vegetation Effects

Courtesy: Cahill, UC-Davis

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





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Summary

- Multiple options exist to mitigate traffic emission impacts on near-road air quality and population exposures
  - Reducing emissions
  - Reducing exposures
- Each mitigation option has advantages and disadvantages in 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

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Acknowledgements

Academia

K. Max Zhang
Tom Whitlow
Andrey Khlystov
Tom Cahill
Ye Wu
Doug Eisinger

EPA

Sue Kimbrough
Gayle Hagler
Vlad Isakov
David Heist
Chad Bailey
Rich Cook
Richard Shores
Laura Jackson
Nealson Watkins

FHWA

Victoria Martinez
Kevin Black

USFS

David Nowak
Greg McPherson

NOAA/DOE

Dennis Finn

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Questions?