UT-BATTELLE

The Watt Road Environmental Laboratory Initiative

John M. E. Storey

Oak Ridge National Laboratory
Fuels, Engines, Emissions Research Center

November meeting of the AWMA/AIChE
Oak Ridge, TN
November 16, 2006

The Initiative: Study the long-term emissions impact of heavy-duty trucks and other mobile sources

Researchers

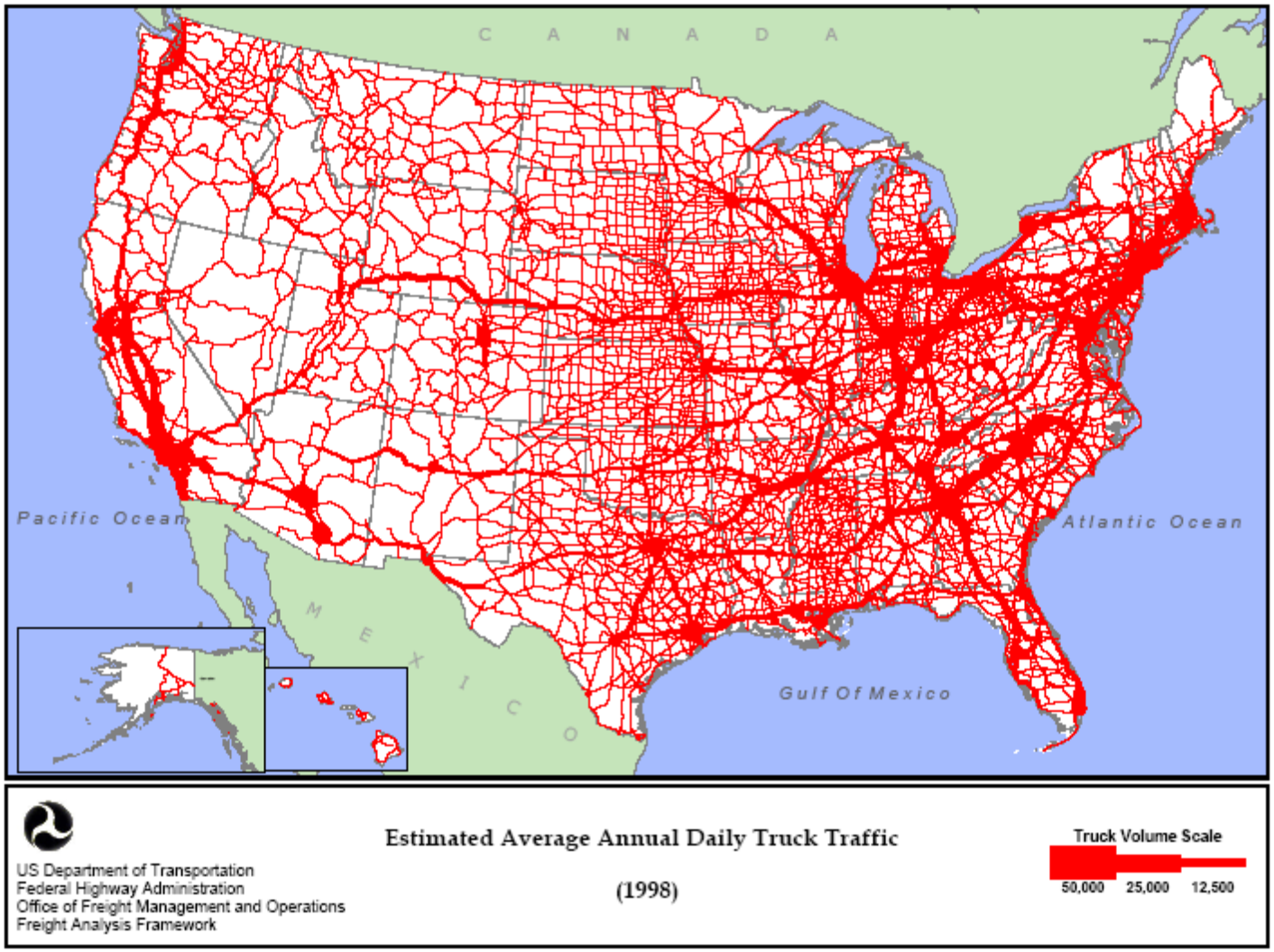
- **ORNL**
  - **Ralph McGill (ret), Keith Kahl, MD Cheng, Bob Miller, Jim Parks, Sam Lewis**
- **Univ. of Tennessee**
  - **Wayne Davis, Terry Miller, Josh Fu, Boris Hromis, Guenet Indale**
- **NOAA-ATDD**
  - **Jerry Herwehe**
- **University of Maryland**
  - **Joel Baker**
  - **Bernie Crimmins**

Sponsors

- **Knox Co. Municipal Planning Organization – NTRC**
- **Federal Highways Administration**
- **Department of Energy – Office of FreedomCAR and Vehicle Technologies**
- **U.S. EPA**

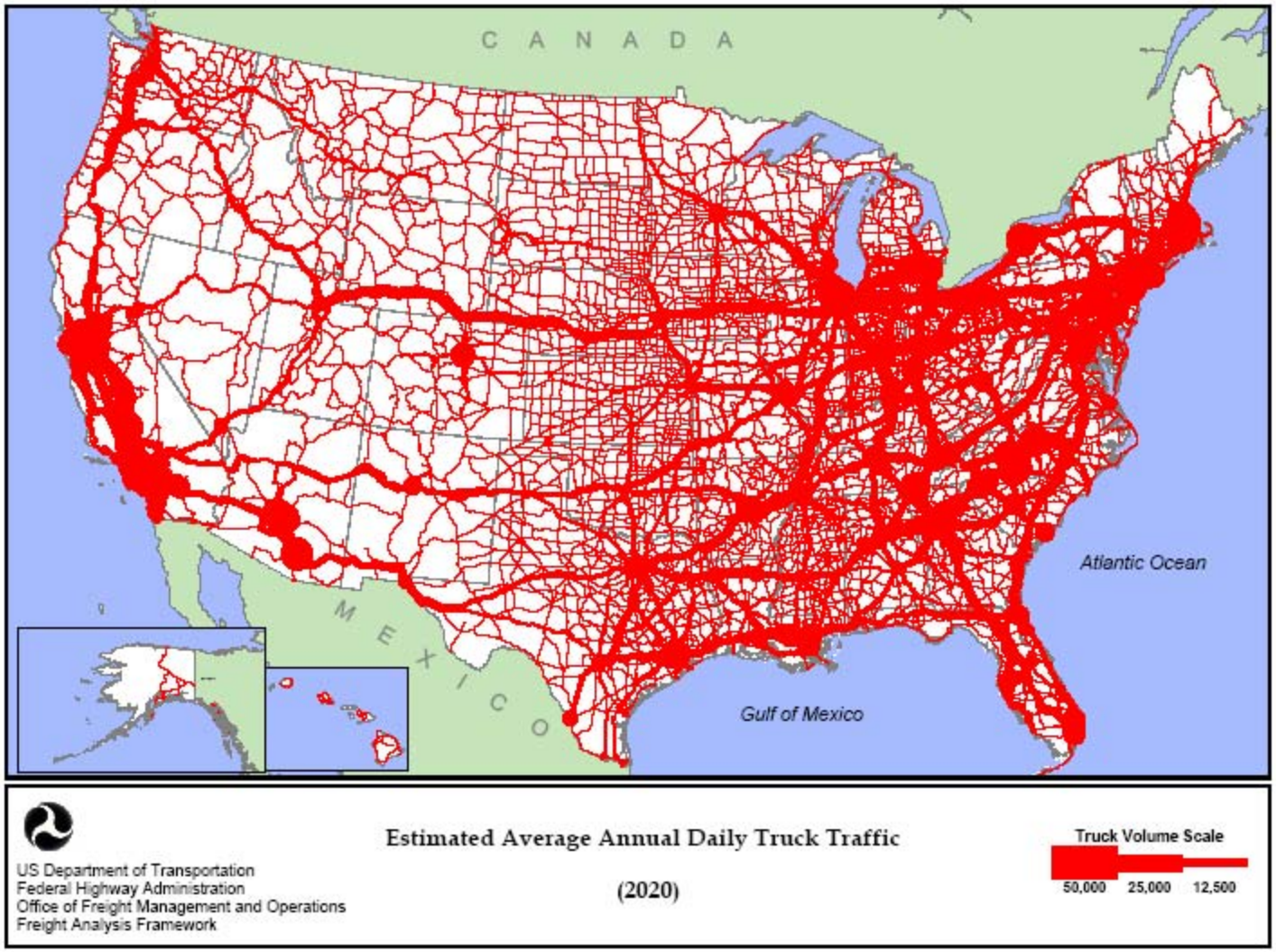
Average Annual Daily Truck Traffic

Source: Federal Highway Administration (DOT) [www.dot.gov/freight/]



Average Annual Daily Truck Traffic ... Expected to Grow

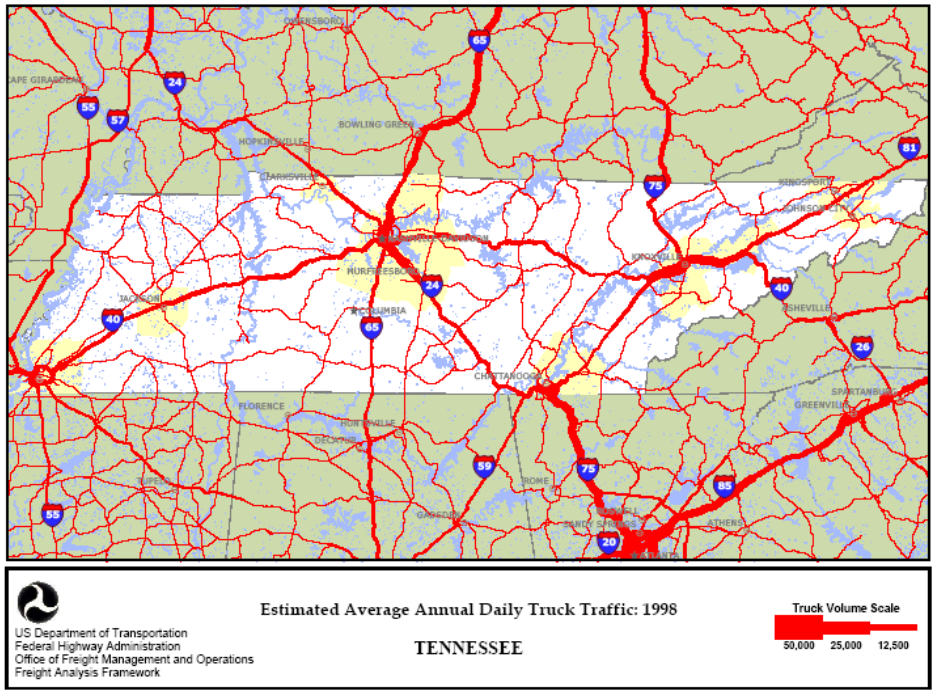
Source: Federal Highway Administration (DOT) [www.dot.gov/freight/]



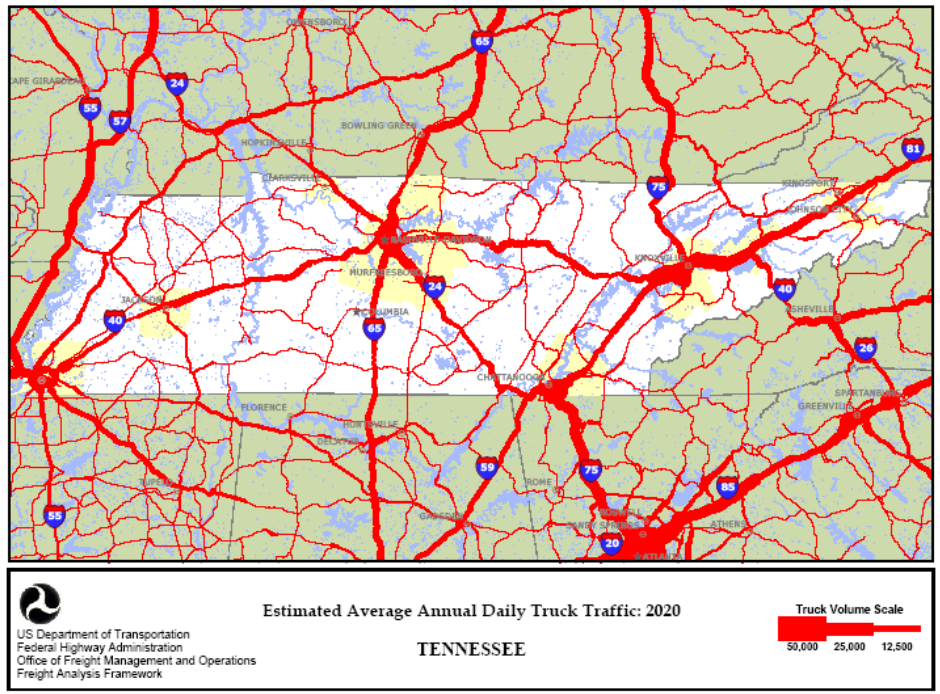
Tennessee Truck Traffic

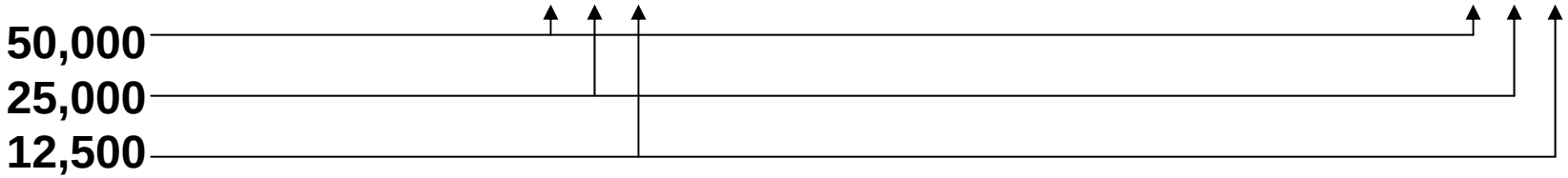
AADTT: Average Annual Daily Truck Traffic

1998

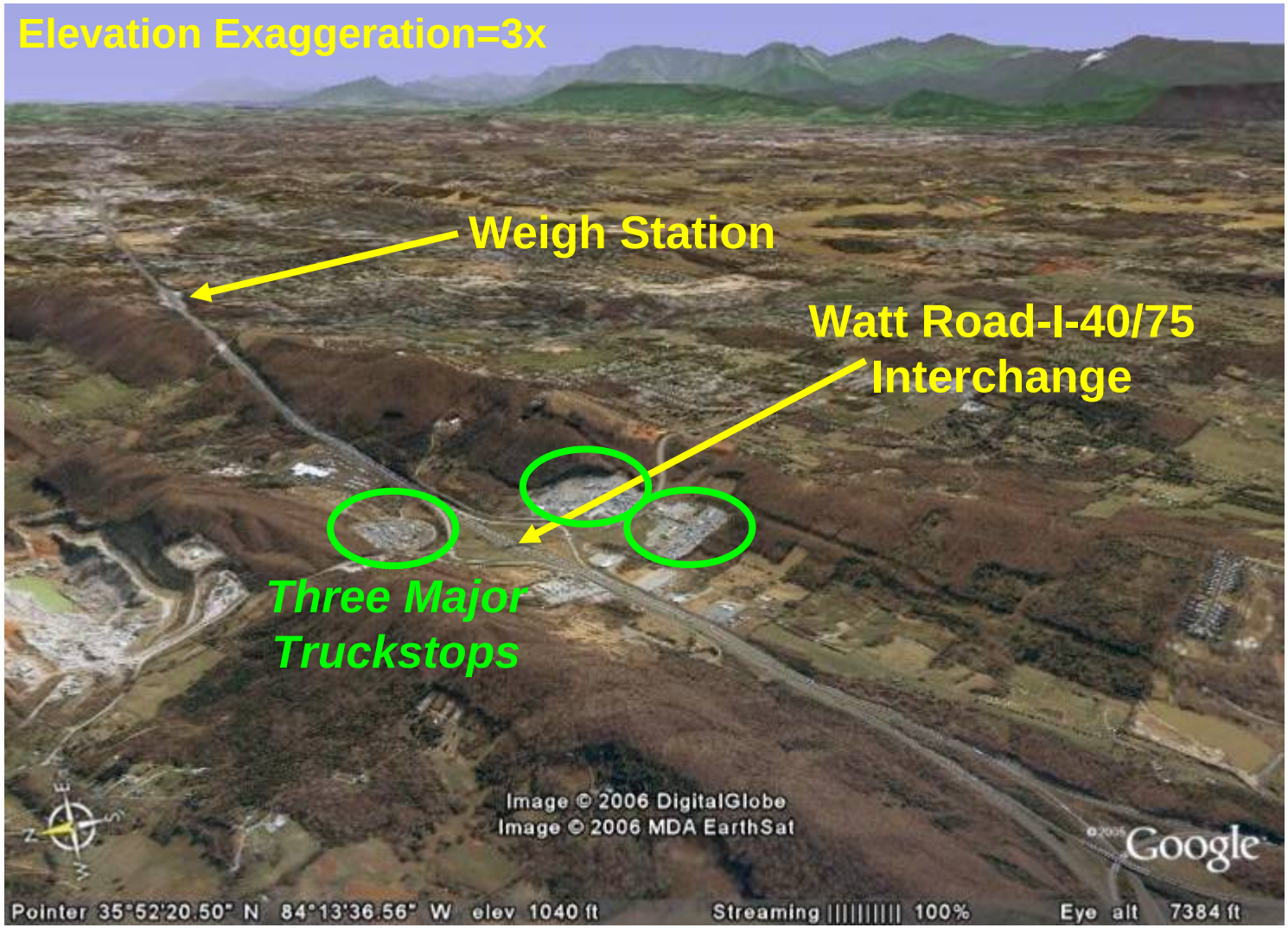


2020





Watt Road-Interstate 40/75 Interchange



Field Campaigns at Watt Rd.

- **Air Quality Campaigns at Watt Road-I/40/75 Interchange**
  - **2003-2004 Truck stop air quality**
  - **2005 In-cab air quality**
  - **2004-2005 Roadside and Ridge top comprehensive**
- **Remote Sensing Campaigns at Weigh Station**
  - **Determine NOx Mass Emissions from NOx Concentration and Engine Operation**
    - **UV Spectroscopy for NOx Measurement**
    - **Acoustic Analysis for Engine Parameters**

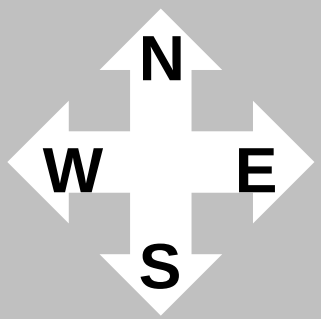
Air Quality Studies: Location of Roadside, Truckstop, and Ridgetop(Background) Sampling Points

Roadside
Elevation: 877 ft

Truckstop
Elevation: 920 ft

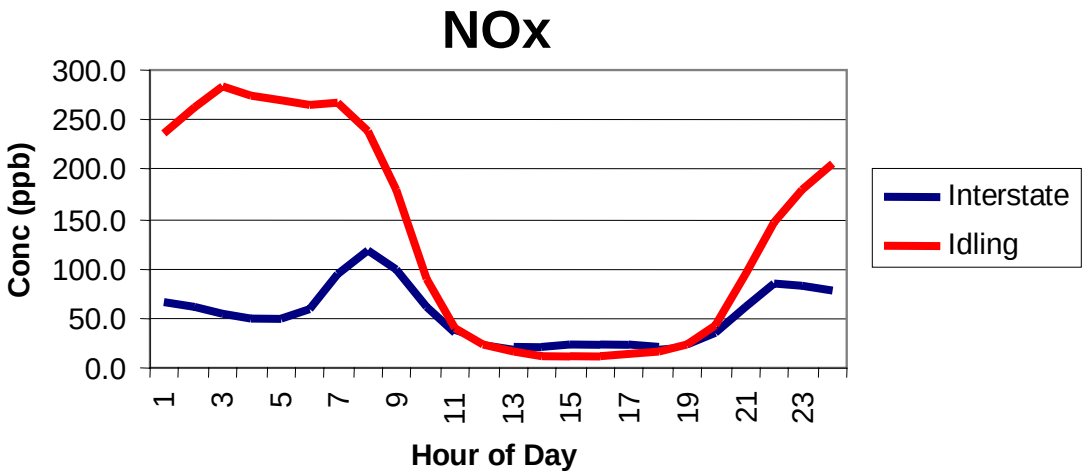
Ridgetop (Background)
Elevation: 1182 ft

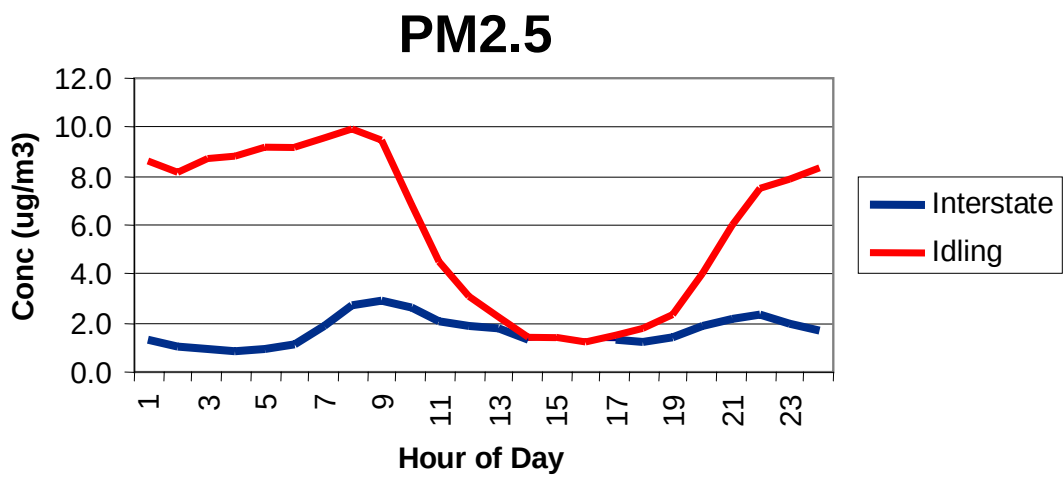
Idleaire Installation



Idling Trucks at Truckstops are Largest NOx and PM2.5 Contributor to Roadside Air Quality (Interstate Off Ramp)

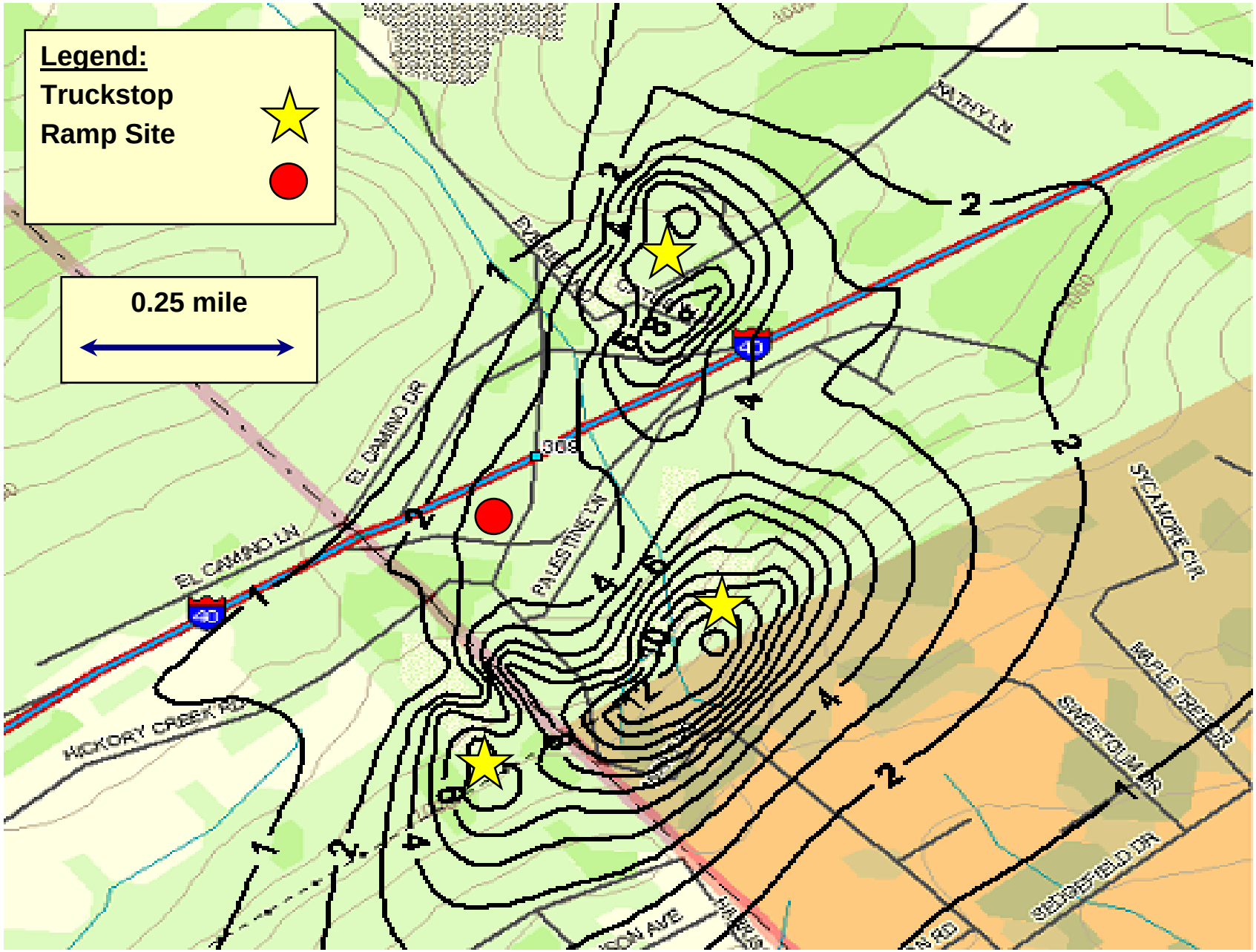
- **Combination of data used to determine contribution of idling trucks to air quality at ramp site near roadway**
  - **NOx, PM Monitoring**
  - **Meteorological Data**
  - **EPA's MOBILE 6.2 Emission Factors**
- **Despite >20,000 Trucks per day traveling interstate near interchange…**
  - **100s of Idling trucks dominate the NOx and PM2.5 right next to the interstate**
  - **Traffic on interstate free-flowing for this study**



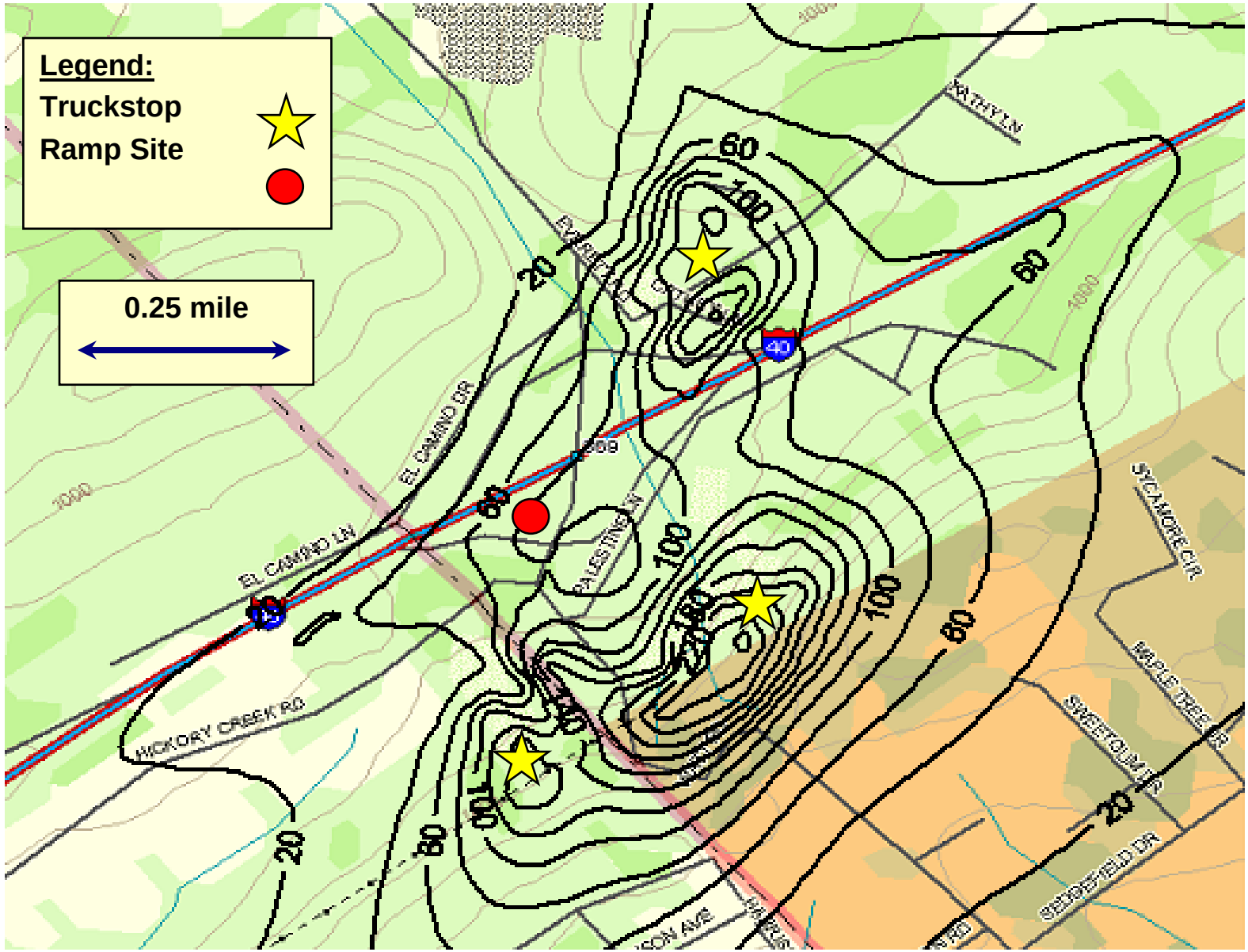


“Hot Spot” of High Pollutant Levels Formed by Idling Trucks at Truck Stops Near Roadway

- **Truckstops form “Hot Spots” of poor air quality**
  - **NOx, PM, MSATs elevated**
- **Boundary of “Hot Spot” difficult to define**
  - **Dependent on number of factors**
- **Recent health risk studies link higher risk to residency near heavily traveled roadways**
- **Further studies of “Hot Spots” warranted**
  - **Health impacts of 2007/10 technology introduction**



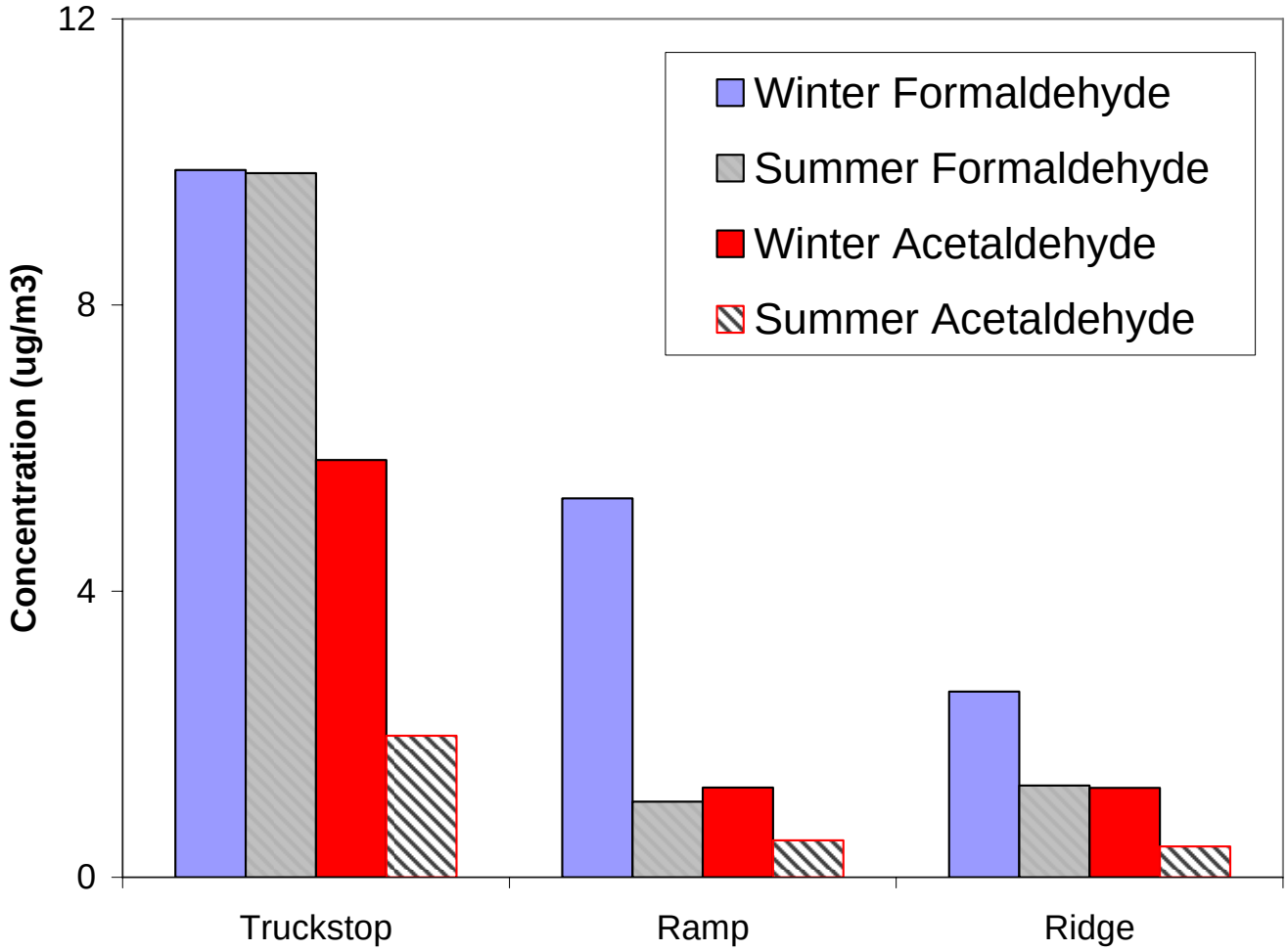
Isopleths of Predicted PM2.5 Annual Concentrations (µg/m3).



Isopleths of Predicted NOx Annual Concentrations (ppb) Ramp Site Location.

Mobile Source Air Toxics: Air Quality Near Truckstops

- **High Concentrations of Formaldehyde and Acetaldehyde observed at truckstop especially in winter**
- **Formaldehyde transports to roadway (Ramp site) in winter**



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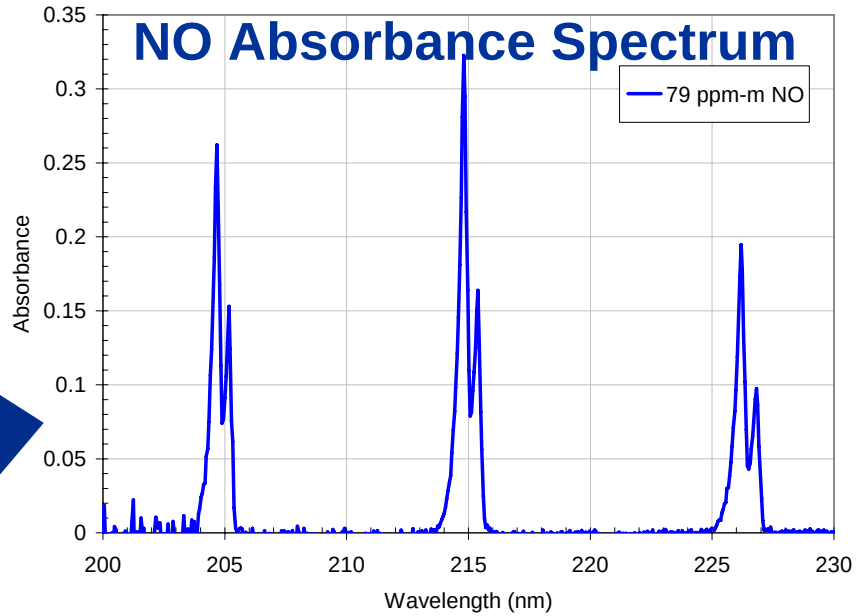
- **Remote Sensing Campaigns at Weigh Station**
  - **Determine NOx Mass Emissions from NOx Concentration and Engine Operation**
    - **UV Spectroscopy for NOx Measurement**
    - **Acoustic Analysis for Engine Parameters**
  - **LIDAR for PM Measurement**

UV Spectroscopy for Remote Sensing of NOx

UV light is absorbed by gas sample.
Absorption spectra unique to gas chemistry.



Data Acquisition

Data

UV Spectrometer

Grating

Lens

Detector Array

Lens

Beam Splitter

Gas Sample

Lens

UV D2 Lamp

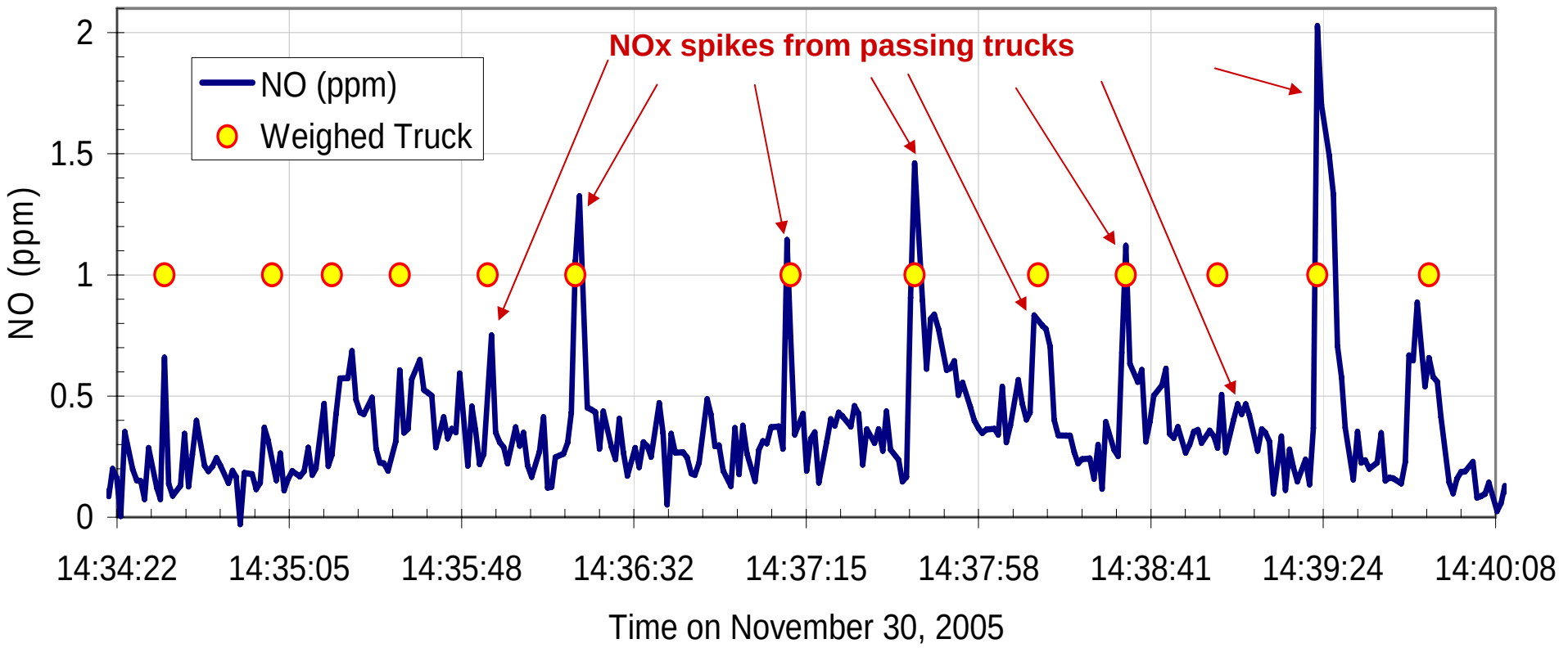
Retro Reflector

Deployment at Weigh Station on I-40/75

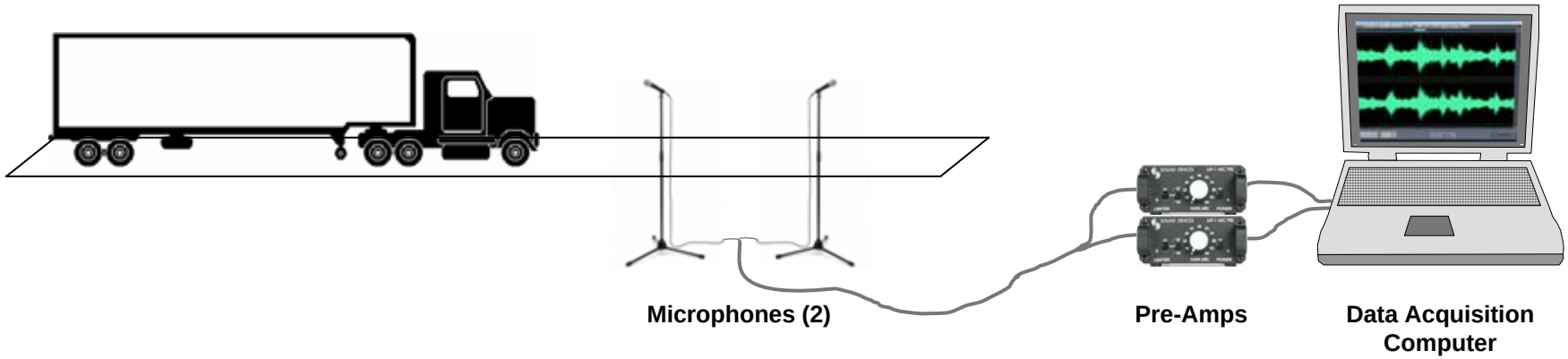
Special thanks to Lt. Lay and staff of Tennessee Department of Safety

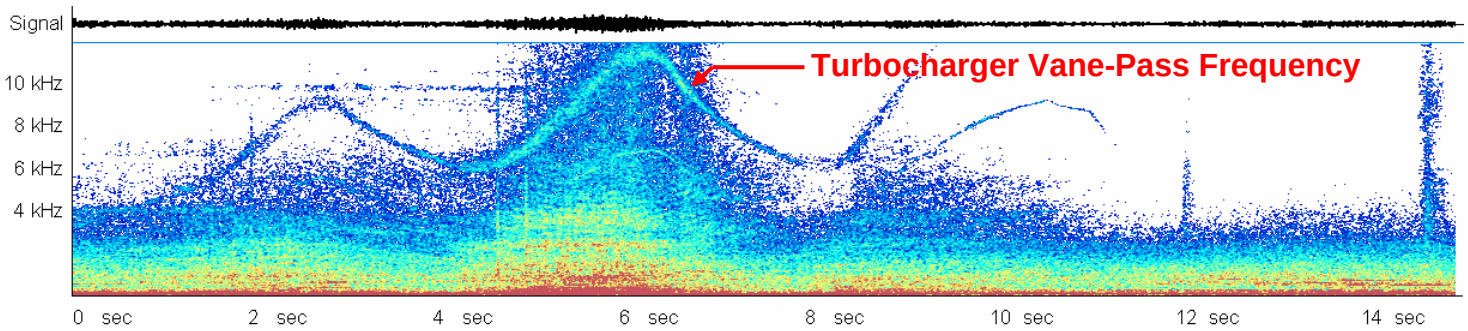
Truck Passing Under Light Beam Path

NOx measured as trucks left scales



Acoustic Analysis Enables Mass Emissions Measurement

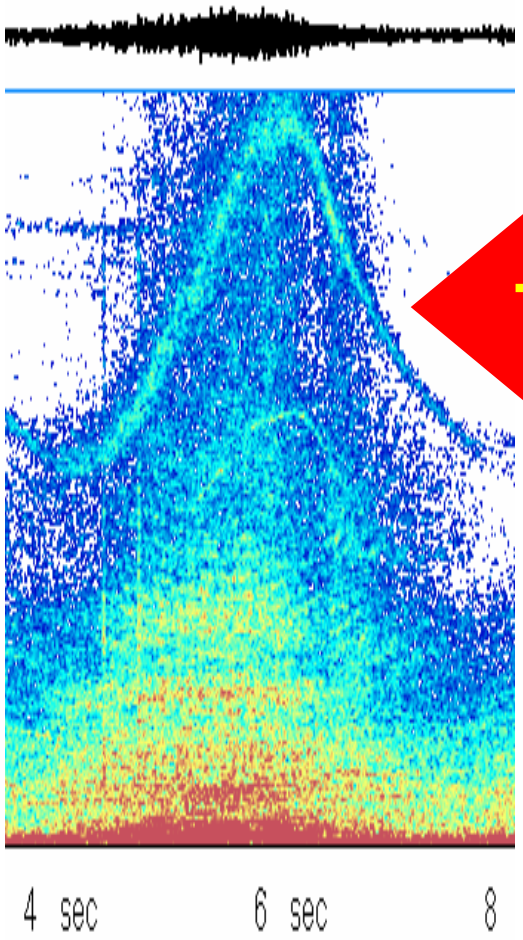




- **Acoustic spectrogram shows the frequency and magnitude variations of a truck accelerating out of the scale area of the weigh station**
- **Results enable determining mass emissions from concentration data**
- **Data also used to filter data sets by Vehicle Specific Power (VSP)**

Approach Linking Acoustic Analysis to Exhaust Flow Rate

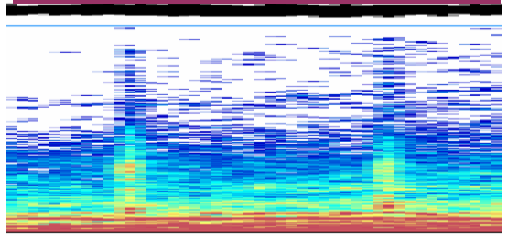
Truck 1.48
Turbo Vane Pass Frequency = 6560 Hz
Turbo Vane Pass Change is 3554 Hz/s



Engine Speed

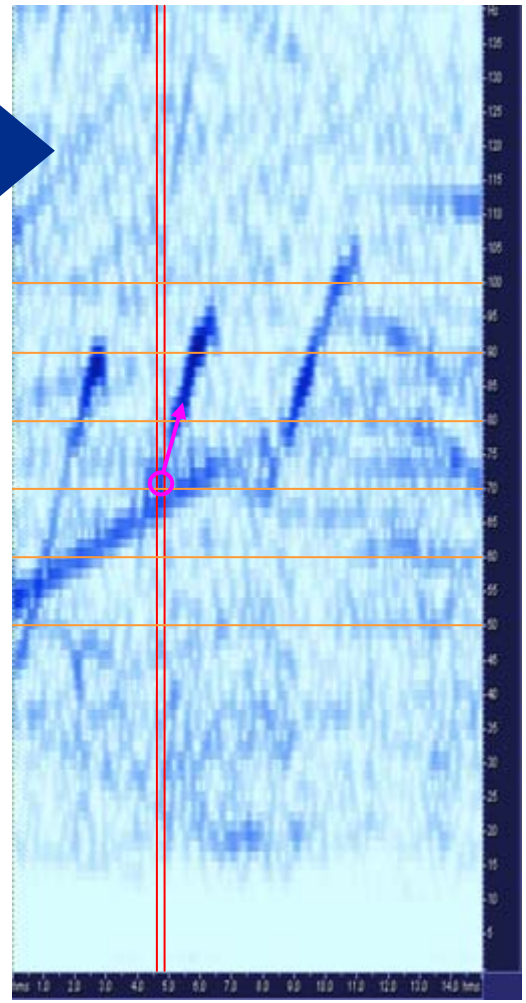
Turbo Speed

Truck Speed



Truck Speed is ~ 8.8 mph

Truck 1.48
Engine Speed ~ 1446 RPM
Acceleration ~ 330 RPM/s

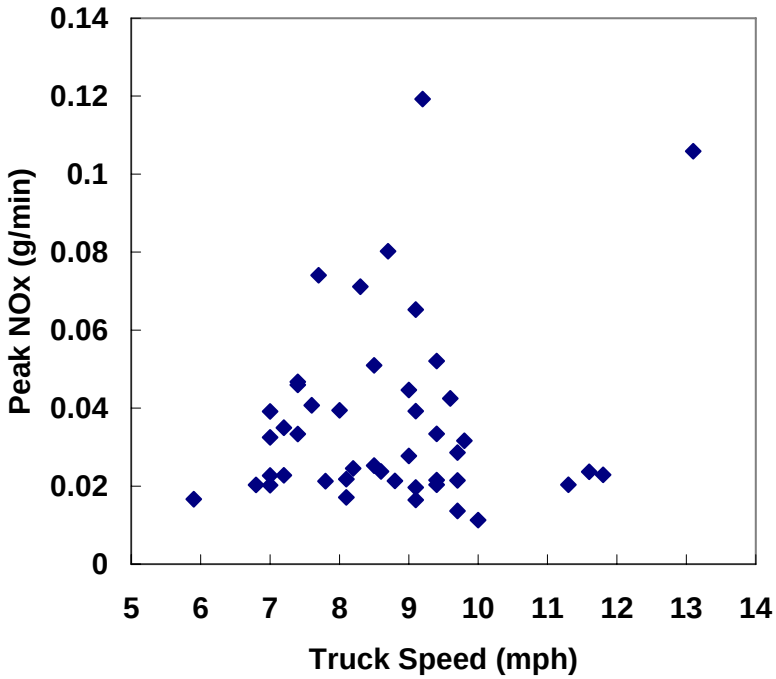


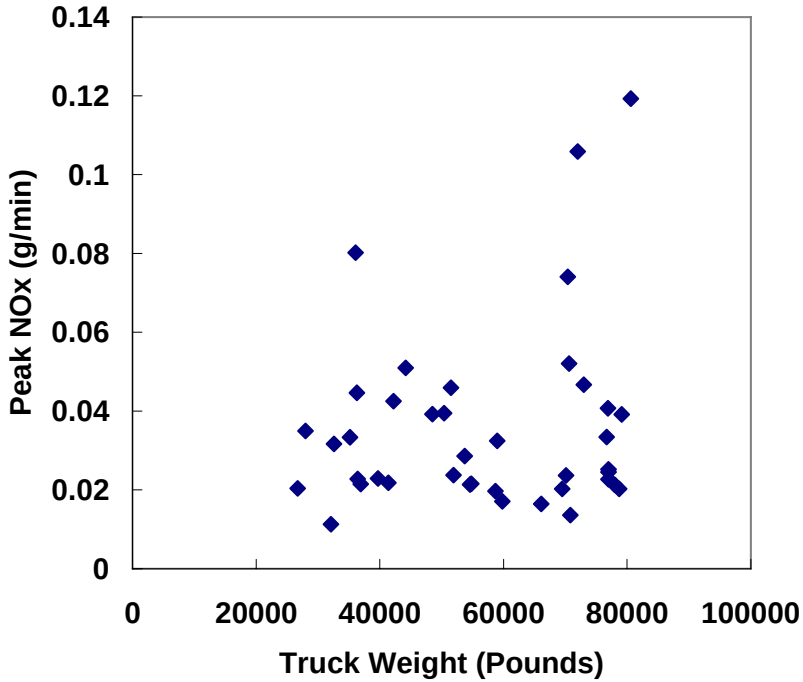
"click-click"

* Experience has shown that for 6 cylinder engines, the dominant low-frequency spectral component is 3X the engine speed. For example: if the dominant frequency is 60 Hz, the engine speed is 60/3 = 20 Hz, or 1200 RPM.

Remote Sensing Results: Weigh Station Dec 2005

- Emission Trends
  - NOx Increases with Increasing Truck Weight
  - NOx Increases with Increasing Truck Speed

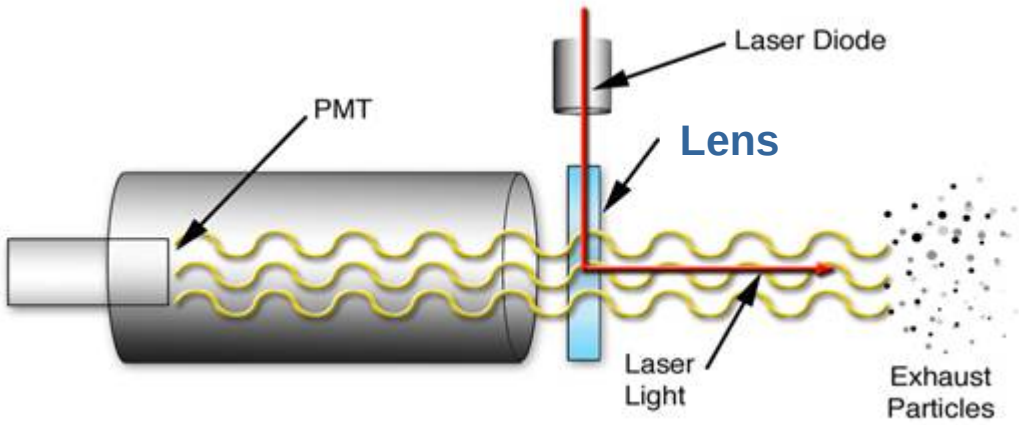


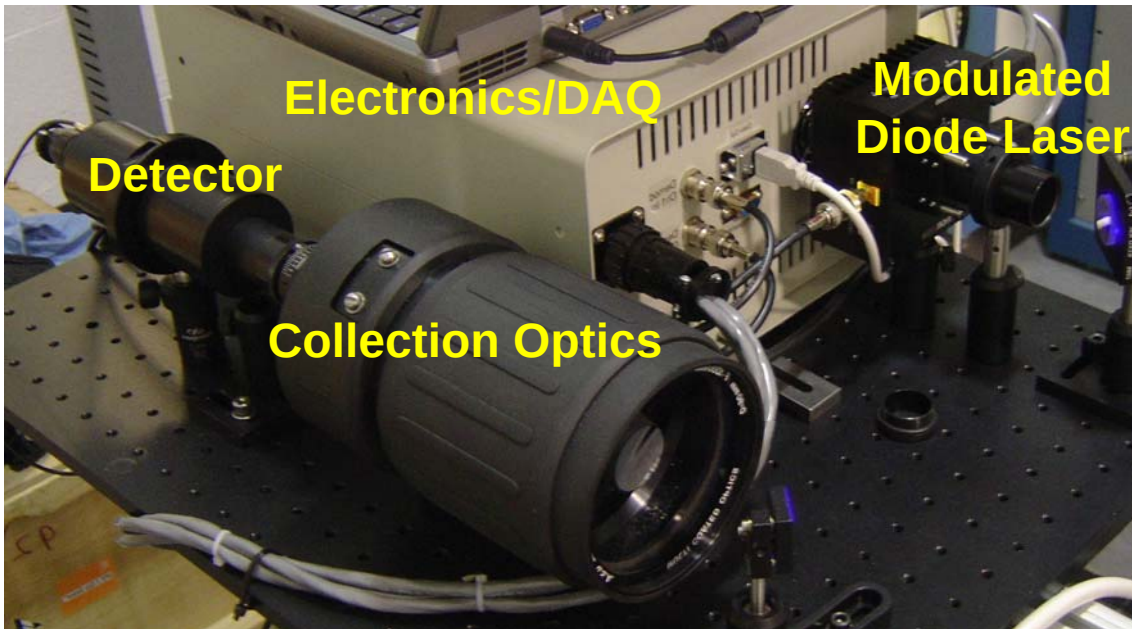


- Most Significant Trends Observed Show Higher NOx Associated with Vehicle Operation (Load and Speed)

LIDAR Technique for Remote PM Density Measurement

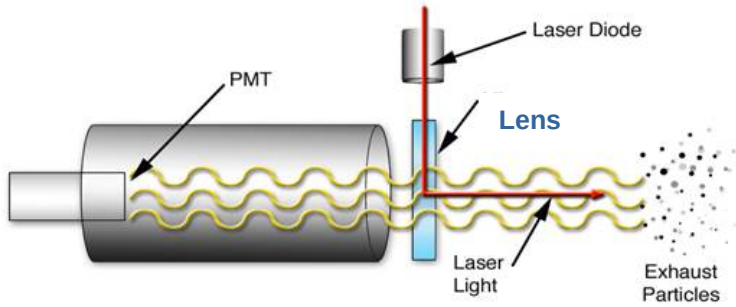
- **Novel methodology developed**
  - **Uses sequenced set of frequencies (10-200 MHz)**
  - **Can measure slices of a plume that is <1 m wide at 10 m away**
  - **Measures range and concentration of PM**

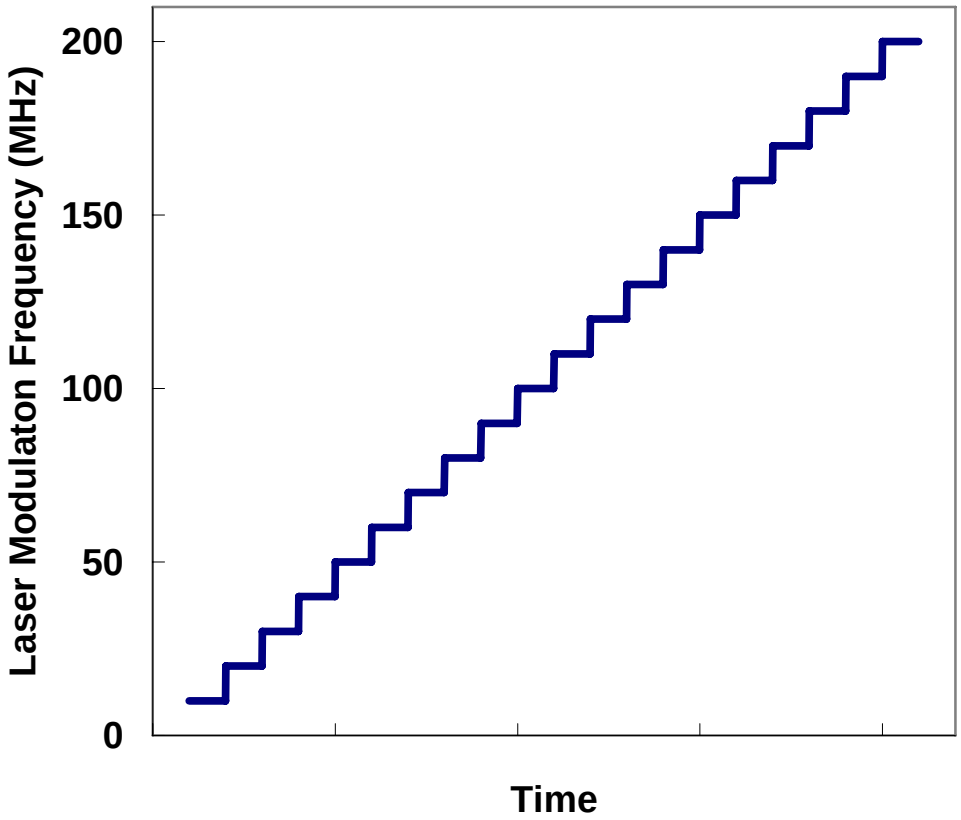




- **Recently upgraded LIDAR system; newest prototype has lower wavelength (λ) laser diode for improved sensitivity**
  - **Scattering coefficient is inversely proportional to λ^4**

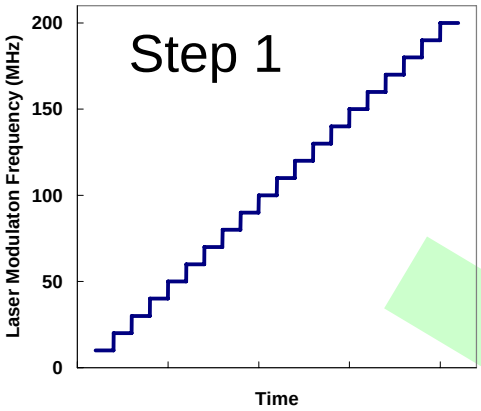
How LIDAR Works

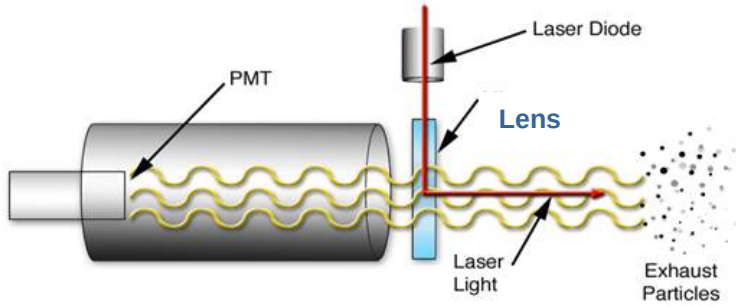




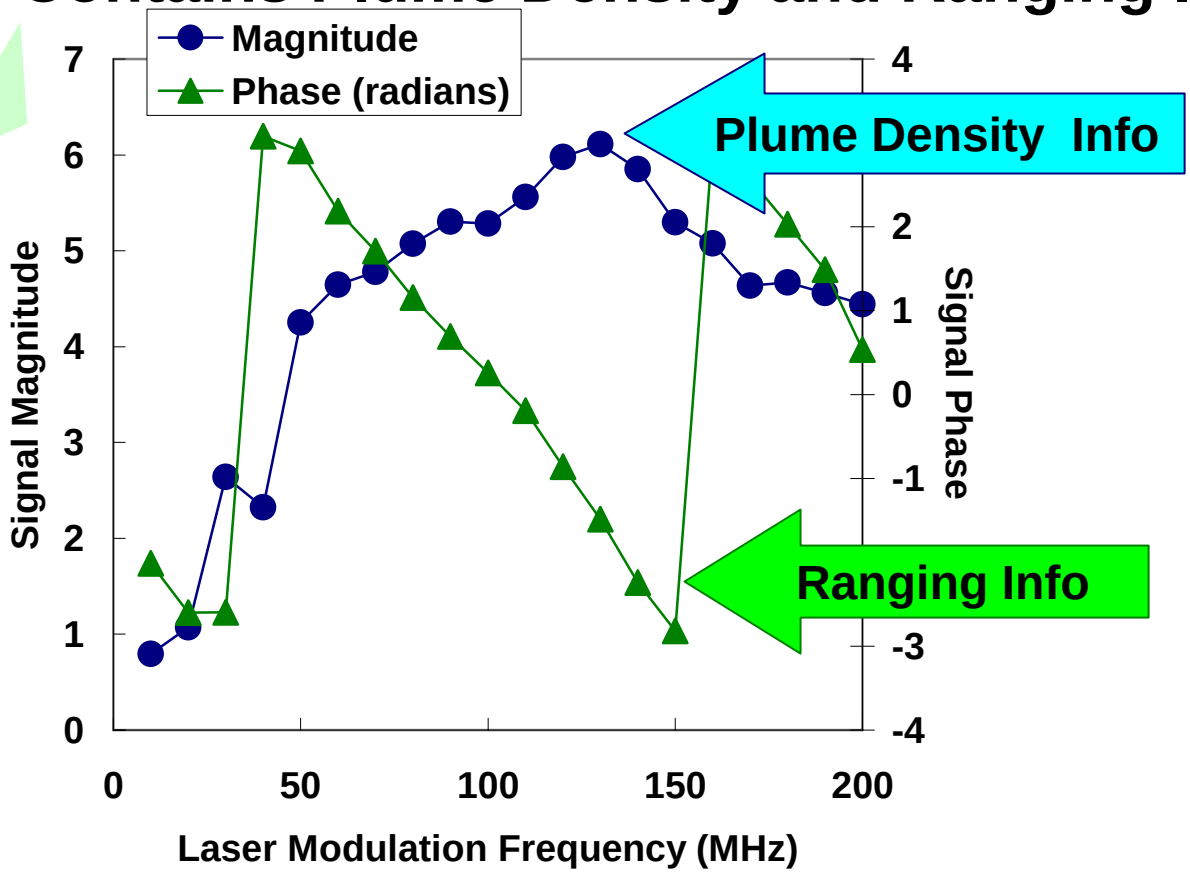
- **Step 1: Stepped Modulation of CW Laser**

How LIDAR Works





- **Step 2: Collected Scattered Light Signal Contains Plume Density and Ranging Info**



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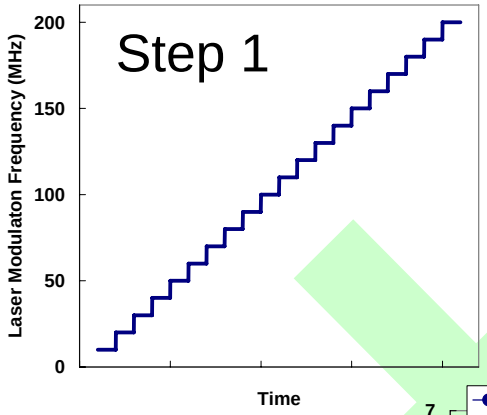
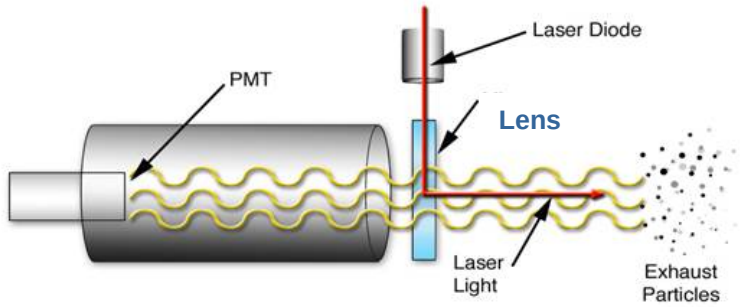
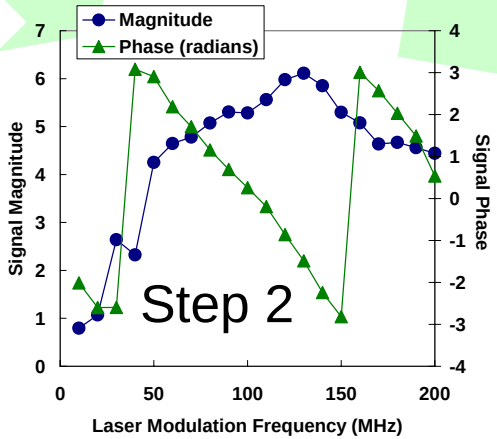
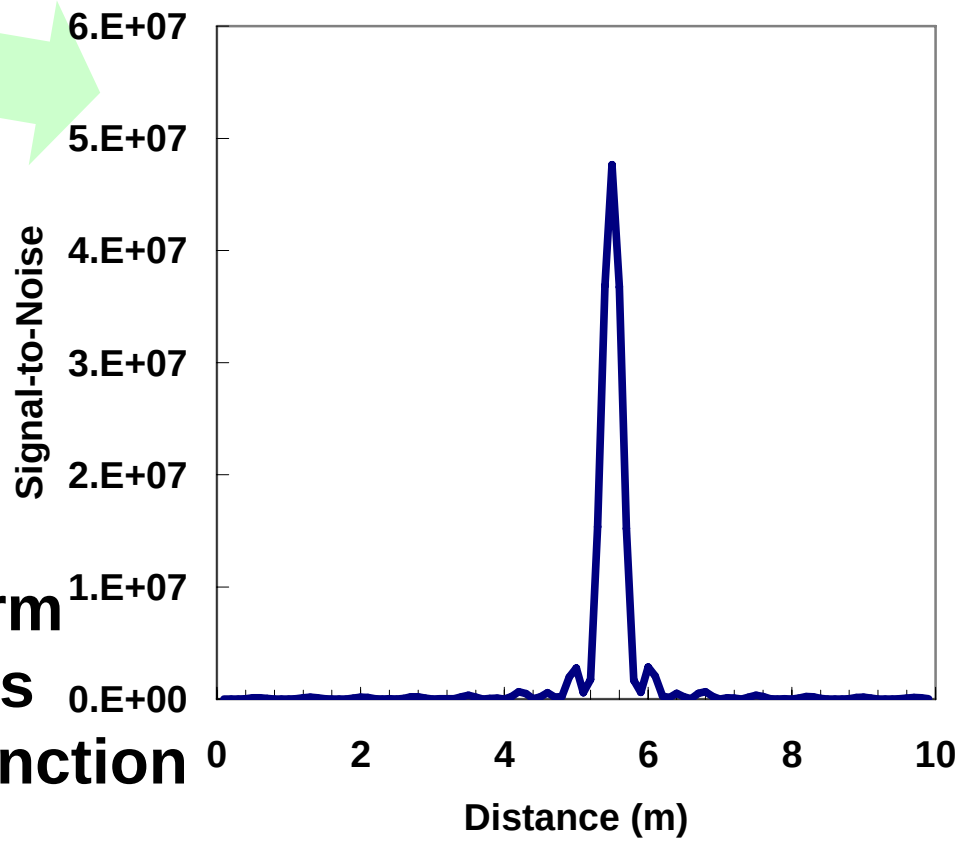




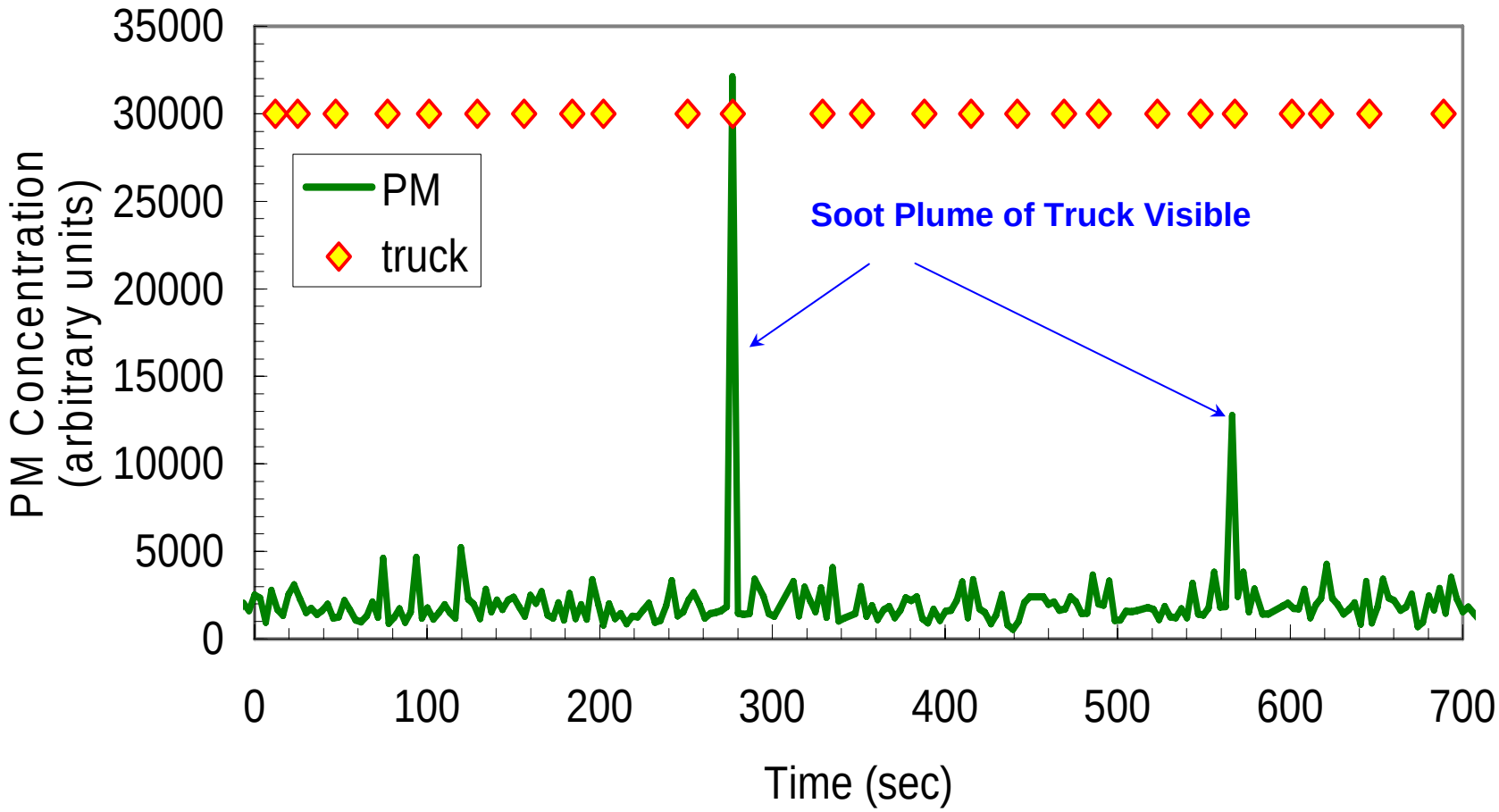




- **Step 3: Fourier Transform Analysis of Signal Yields Particle Density as a Function of Range (Distance)**

LIDAR Results: Weigh Station April 2006

- Preliminary data shows LIDAR detection of PM from passing trucks
- Sensitivity and speed are issues



Related Studies – ORNL Fuels, Engines, and Emissions Research Center (FEERC) *located* at the NTRC

- **Cold start emissions and fuel economy**
- **Truck APU emissions**
- **Influence of Mexican trucks on Border air quality**

Future Plans: Focus on Impact of Introduction of New Emission Control Technologies

- **Introduction of MY2007 Trucks**
  - Continued deployment of remote sensing for NOx, PM, and MSATs
- **Truck Electrification for Idling Reduction**
  - As technology use grows, determine impact on local “Hot Spots” of poor air quality
  - Develop and deploy remote sensing capability for Mobile Source Air Toxics
    - Initial focus on formaldehyde (high concentration observed in AQ studies)
  - Develop large-eddy scale simulation of Watt Road-I-40/75 Interchange
- **Continue interactions and share database with stakeholders**

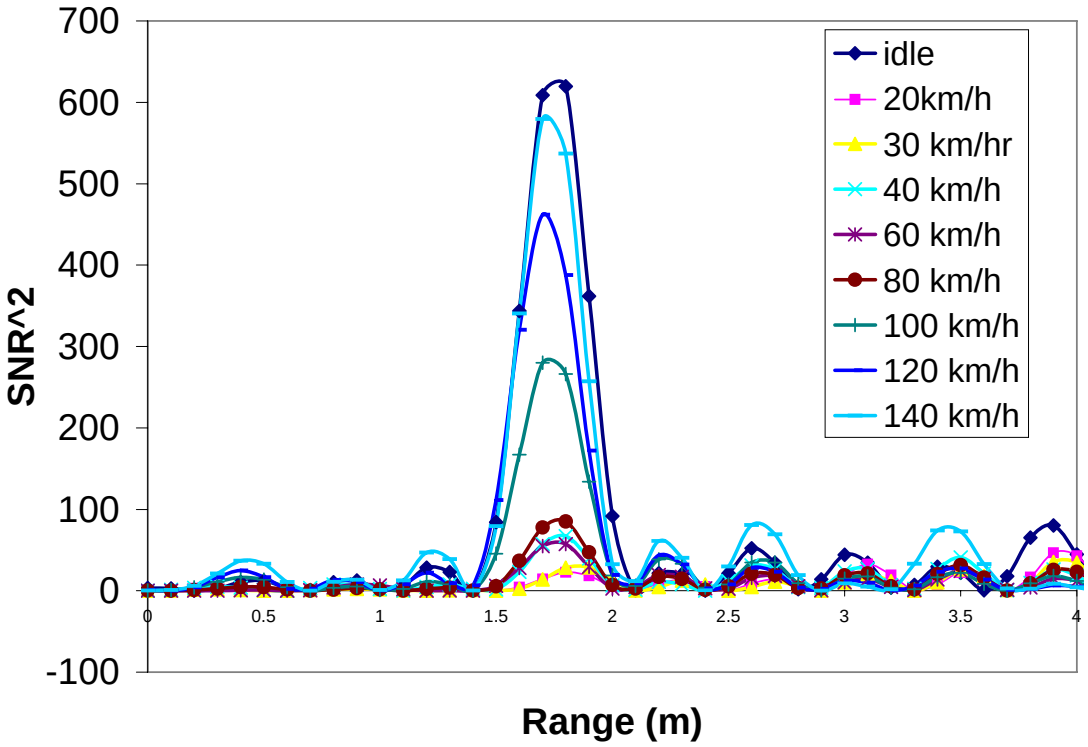
Truck Electrification Installation at Watt Road

Supplementary Material

Interactions in FY06

- **Publications:**
  - **Simpson, M. L. *et al.,* "Intensity-modulated, stepped frequency CW lidar for distributed aerosol and hard target measurements," *Applied Optics*, 44, pp.7210-7217. 2005**
  - **Paper submitted to the Air and Waste Management (AWMA) conference (scheduled for June 2006 in New Orleans)**
- **(2) Posters presented at 16th CRC On-Road Vehicle Emissions Workshop on March 28-30, 2006 in San Diego, CA**
- **(1) Patent pending on acoustic technique for remote sensing of engine parameters (US Application No. 10/922,023, "Truck Acoustic Data Analyzer System")**
- **Meetings:**
  - **EPA at Research Triangle Park (Raleigh-Durham, NC) in Jan. 2006**
  - **Transportation Research Board (Washington, DC) in Feb. 2006**

LIDAR Technique for Remote PM Density Measurement



LIDAR Instrument

- **Chassis dynamometer LIDAR demonstration on Mercedes diesel passenger car (A170)**
  - **PM signal magnitude varies with vehicle speed (load)**
  - **Range information constant (as expected)**
  - **SMPS and LIDAR results compare well**