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Interpreting Remote Sensing NO_x Measurements

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Interpreting Remote Sensing NO_x Measurements

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Fall Fuels & Lubricants Meeting
San Antonio, TX, September 24-27, 2001

Presented May 9, 2002

Paper # 2001-01-3640



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Project sponsor: Coordinating Research Council

- Data collected by Prof. Donald Stedman's group at University of Denver
 - Reports available at <http://www.crcao.com>
 - Data at <http://www.feet.biochem.du.edu/>
- VINs decoded by Eastern Research Group



Paper # 2001-01-3640

Analyzing Vehicle Tailpipe Emissions

- Fleet emissions increase with age
- Possibility of sampling bias
- Emissions higher when catalyst cold
- Emissions depend on load
- Emissions may vary when vehicles measured under same conditions at different times
- Different model years & vehicle types have different standards & control technologies



Paper # 2001-01-3640

CRC E23 Project

Monitor how on-road vehicle tailpipe emissions (HC, CO, NO_x) are changing with time

- Use remote sensing
- Measurements in at least 4 cities
 - Chicago, Phoenix, Los Angeles, Denver
- Large number (20,000) of measurements at same time of the year at each location
- Uniform QC/QA and data reporting



Paper # 2001-01-3640

Remote Sensing

Measures concentrations of CO, HC, NO, CO₂ in automobile exhaust

- Accurate
- Measured over ~ 1/2 second
- Vehicle identified by video frame of license plate matched to registration records
- Related to grams/gallon, not grams/mile
- Limited numbers of suitable sites



Paper # 2001-01-3640

Calculate Vehicle Load

Vehicle Load estimated as Vehicle Specific Power (VSP) from

- Speed, Acceleration, and Road Grade
- Typical Values of VSP
 - No Load = 0 kW/tonne
 - Deceleration = <0 kW/tonne
 - ASM Test = 5 to 9 kW/tonne
 - Upper limit of FTP = 23 kW/tonne



Paper # 2001-01-3640

NO Vehicle Emissions

NOx emissions very sensitive to VSP (load)
under typical driving conditions

- NOx emissions vs VSP for individual vehicles
 - From low VSP ~ 0 kW/tonne, where NOx is low,
 - NOx increases until VSP = 15 to 20 kW/tonne
 - Then decreases if fuel enrichment employed
 - And increases again at higher VSP



Paper # 2001-01-3640

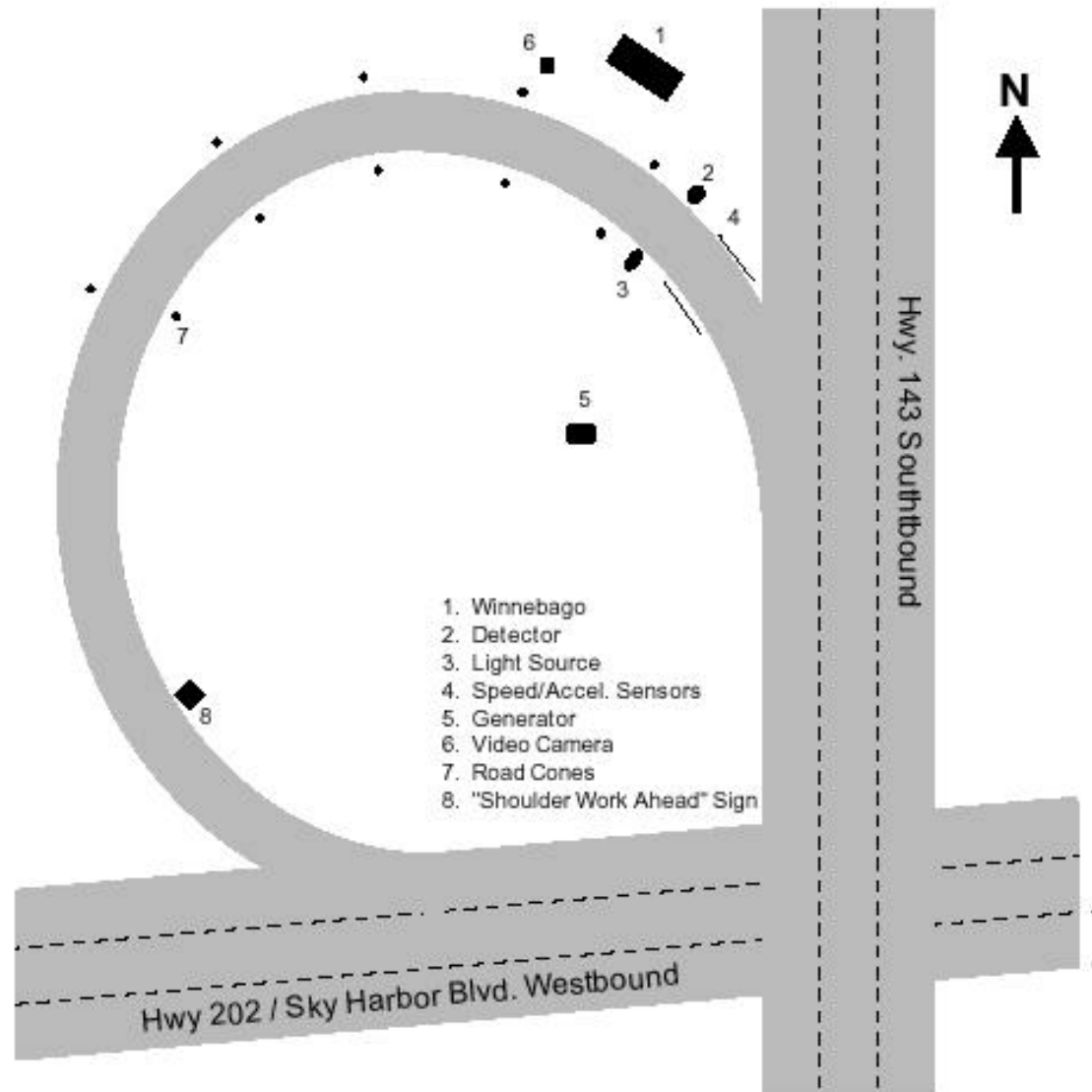
Three Phoenix Remote Sensing Sites

- In 1998, a high speed, low load site gave low percent valid readings due to small exhaust plumes.
- In 1999, two sites were used. These were at different positions on the same on-ramp.
 - **Site 1:** Free flowing traffic, no reason to rush; Trucks observed to dawdle, cars moved faster.
 - **Site 2:** Entry to highway, vehicles accelerate.
 - Two sites measured on different days.
 - Same model year distribution, similar fleet

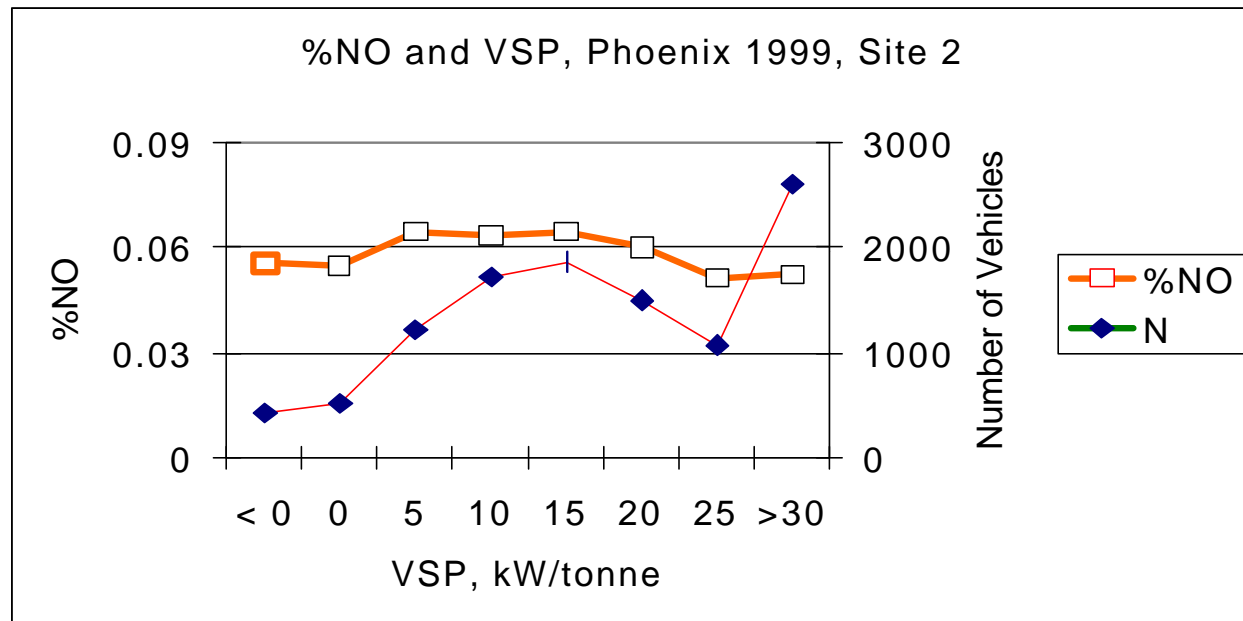
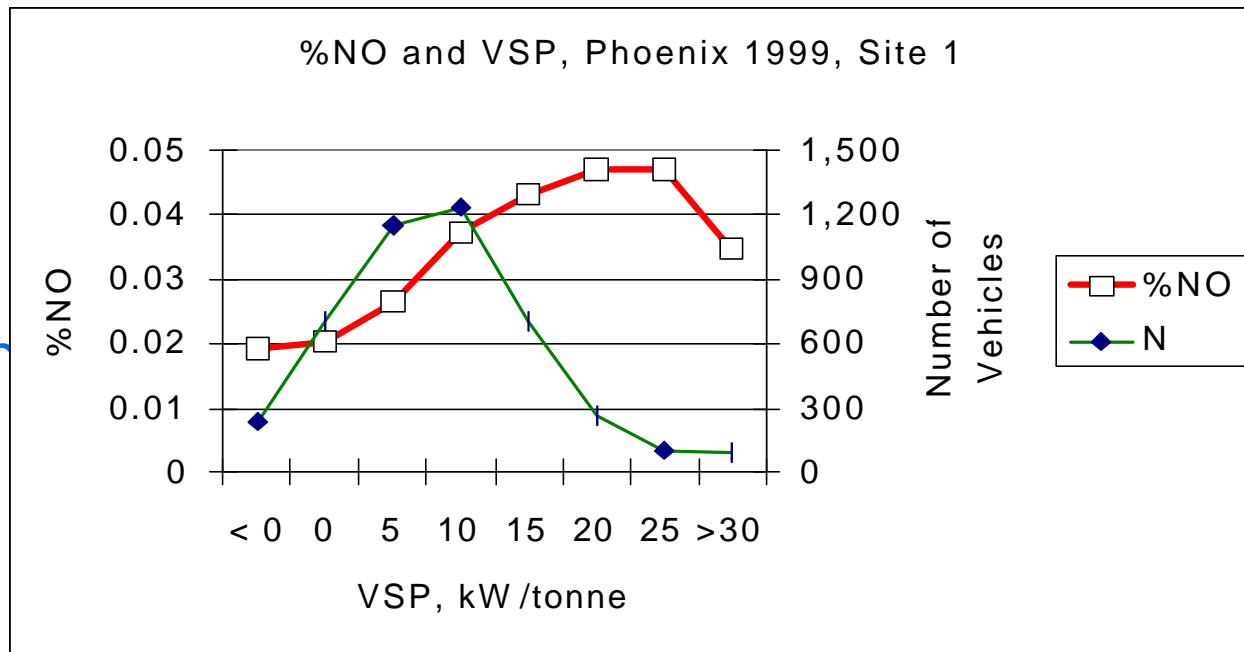


Paper # 2001-01-3640

Phoenix 1999
Sites at uphill
exit ramp from
Hwy 202 / Sky
Harbor Blvd.
Westbound to
Hwy 143
Southbound,
Site 2: at top of
ramp as shown,
Site 1: ¼ way
down the ramp.



%NO and VSP
 Phoenix 1999
 Site 1 on top
 Site 2 at bottom
 Average %NO
 & Number of
 vehicles
 measured
 on y-axis,
 VSP on x-axis.



NOx Emissions in Phoenix

- Phoenix 99 NOx measurements appear to be independent of VSP at Site 2 (high load site).
- %NO is a strong function of vehicle age and load interacted with vehicle age at Site 2.
- Fleet NO emissions analysis needs to take into account age, load, and vehicle type.
 - Data from three Phoenix Sites binned into
 - 5 kW/tonne bins (Bin 5 = VSP from 2.5 to 7.5)
 - 5 year age bins (Bin 3 years = 1 to 5 years)
 - analysis on CARS as defined in the VIN.

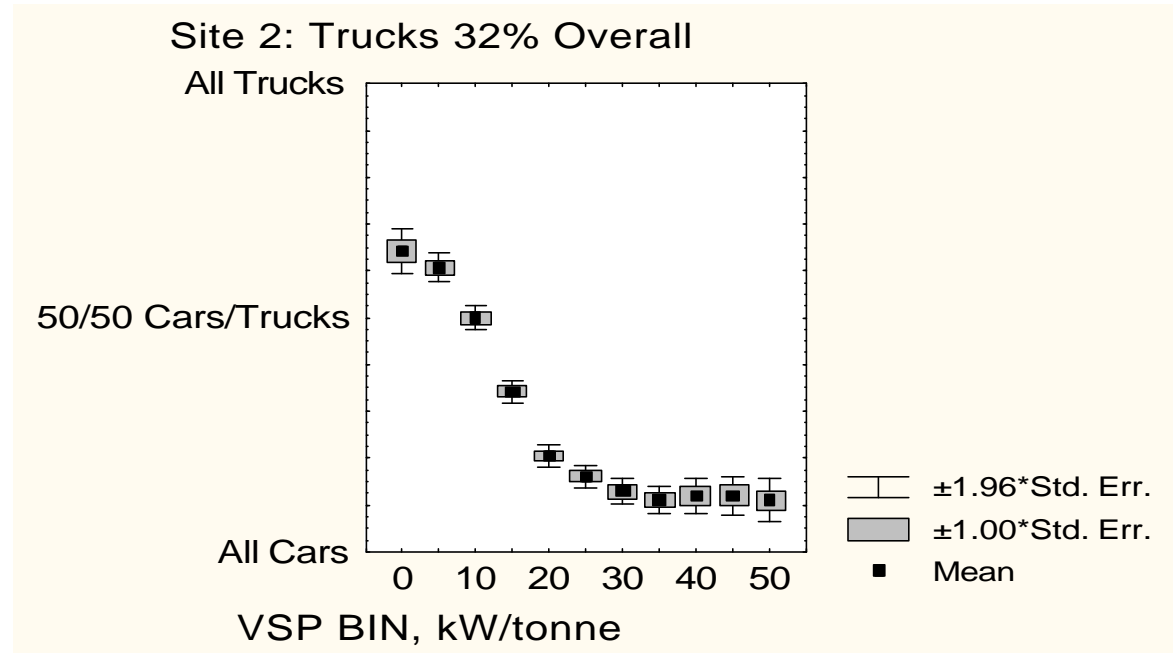
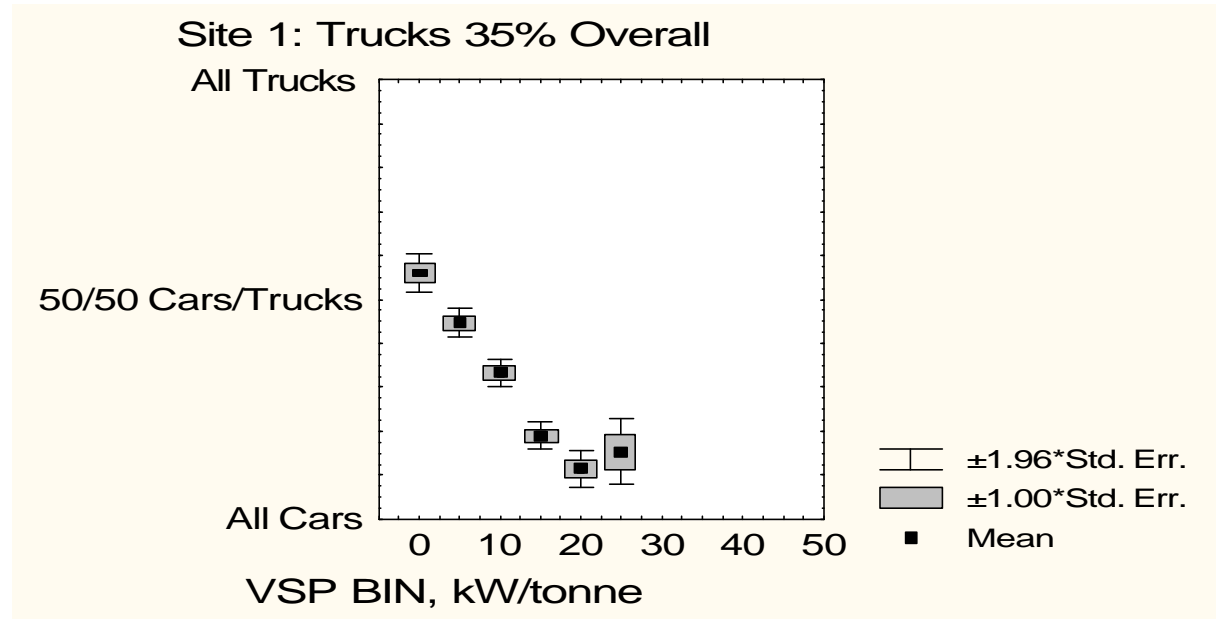


Paper # 2001-01-3640

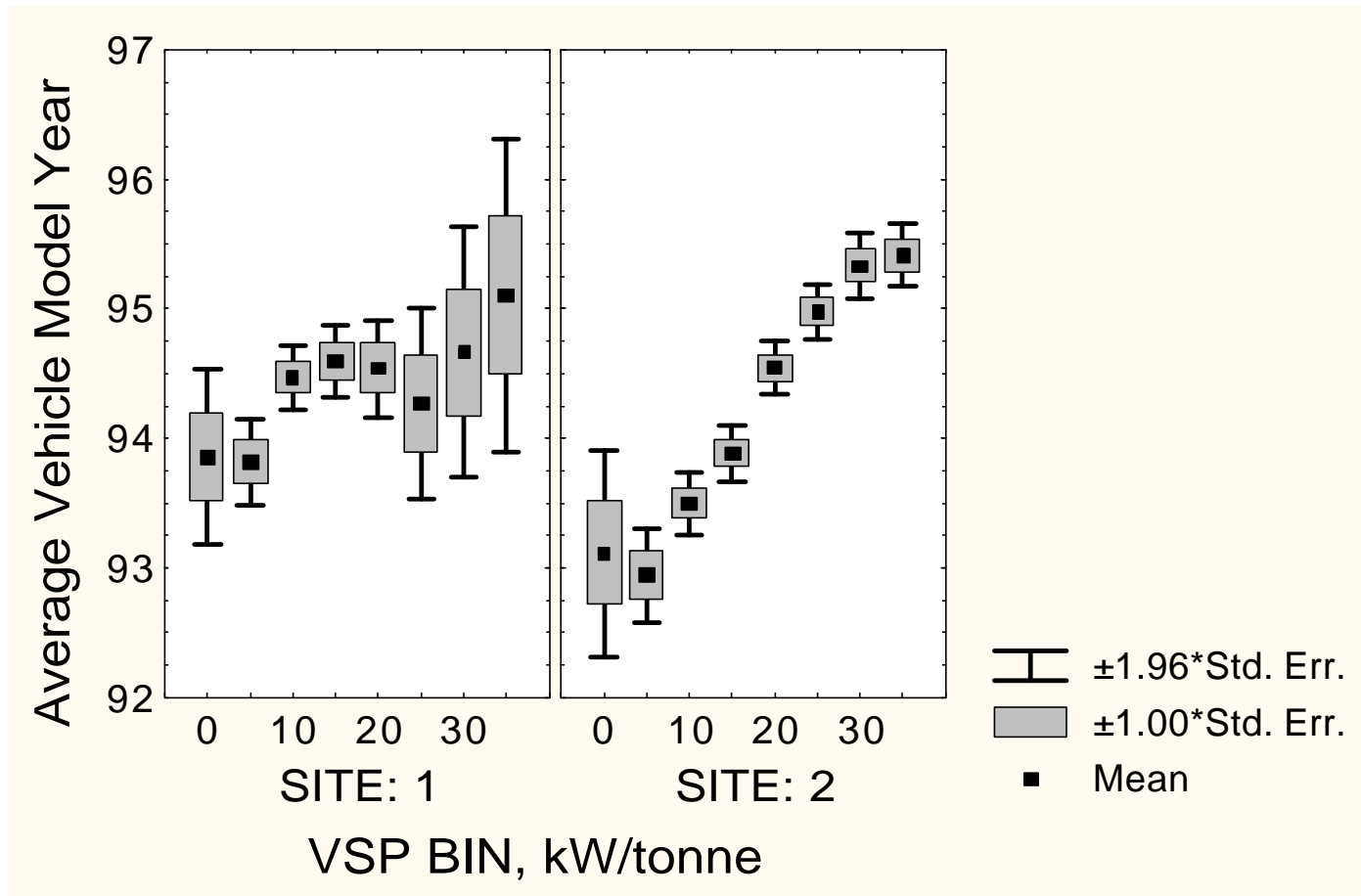
% Trucks
 Phoenix 1999
 Site 1 on top
 Site 2 bottom
 In both sites
 vehicle type
 interacts with
 VSP.

%Trucks on the
 y-axis

VSP on x-axis.



Model year vs VSP, Phoenix 99 Sites



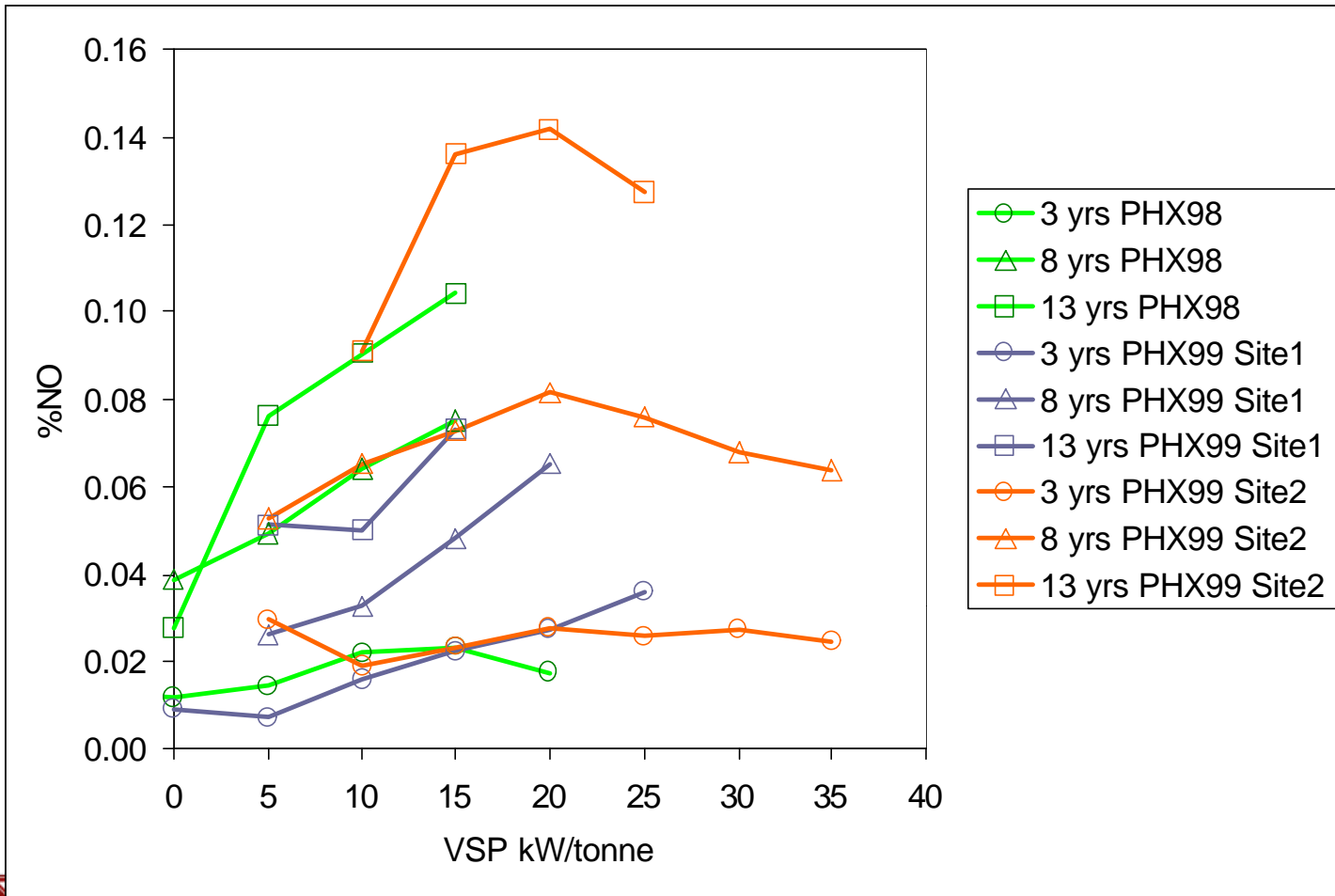
Vehicle age is much more dependent on load at Site 2.

Phoenix Site Comparisons, Cars Only

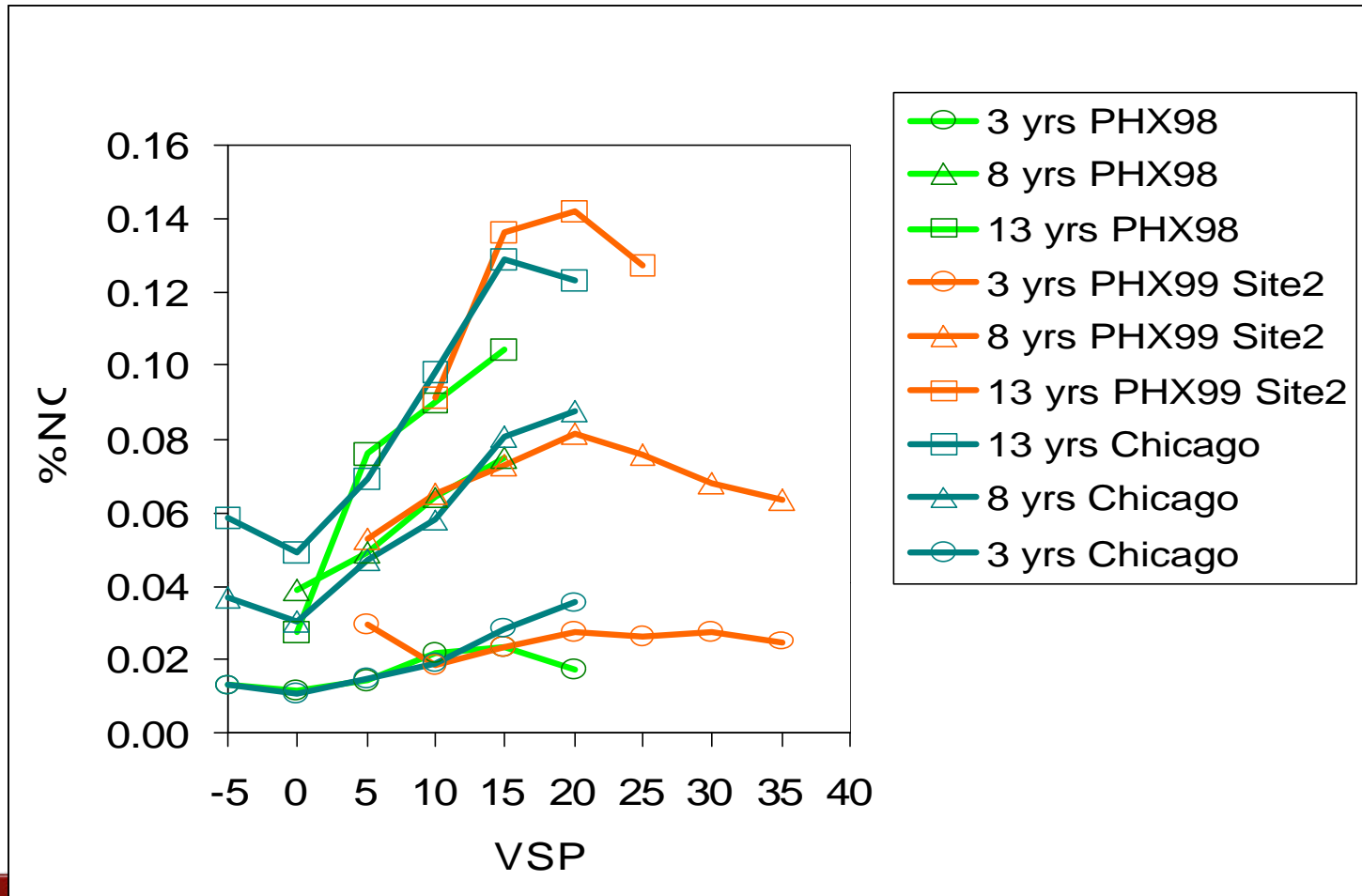
- Which Phoenix site in 1999 was giving a typical NO vs VSP relationship when binned for age as well as VSP?
 - Comparing the two Phoenix 99 Sites with the Phoenix 98 Site, **Site 2 in Phoenix 99 was more similar to Phoenix 98 Site than Site 1.**
 - [Phoenix 98 Site] and [Phoenix 99 Site 2] are similar in their NO vs VSP relationship to Chicago 99 remote sensing measurements.



Phoenix 1998 & 1999, Cars Only

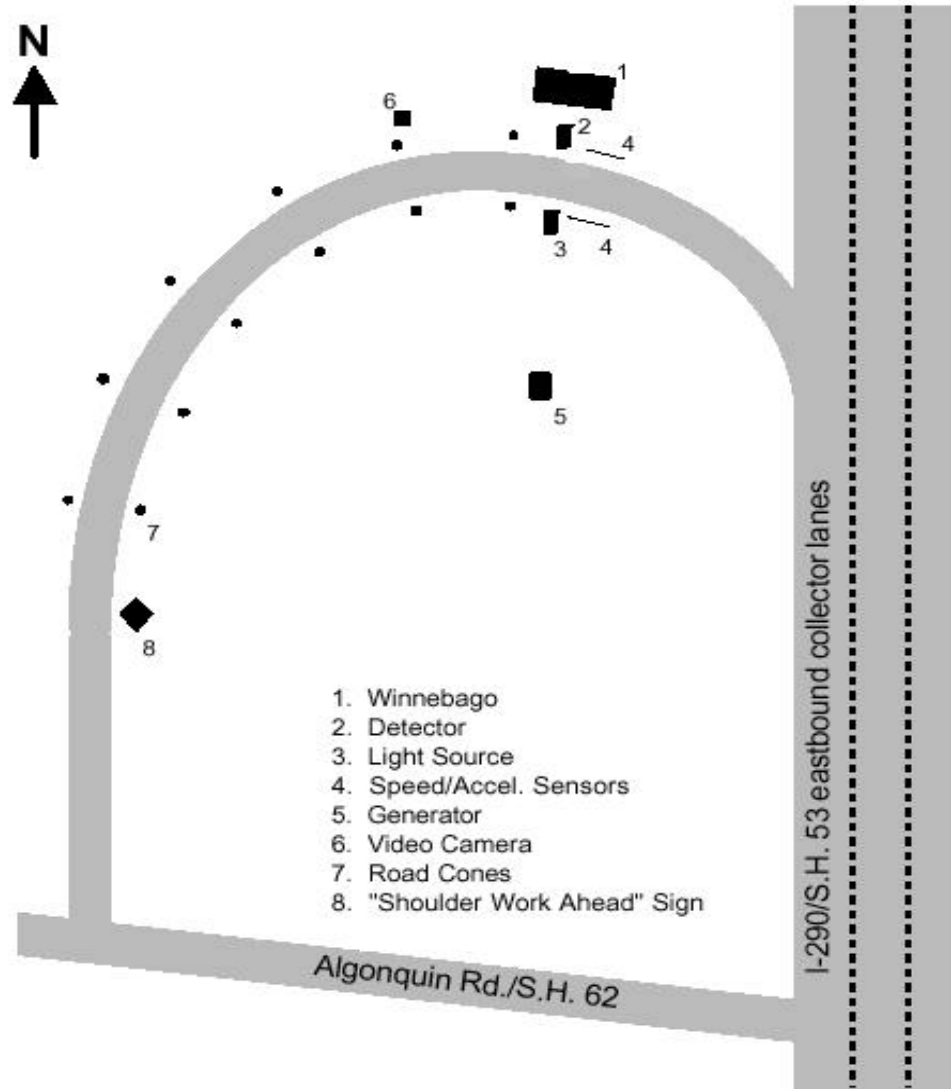


Phoenix 98-99 & Chicago 99, Cars

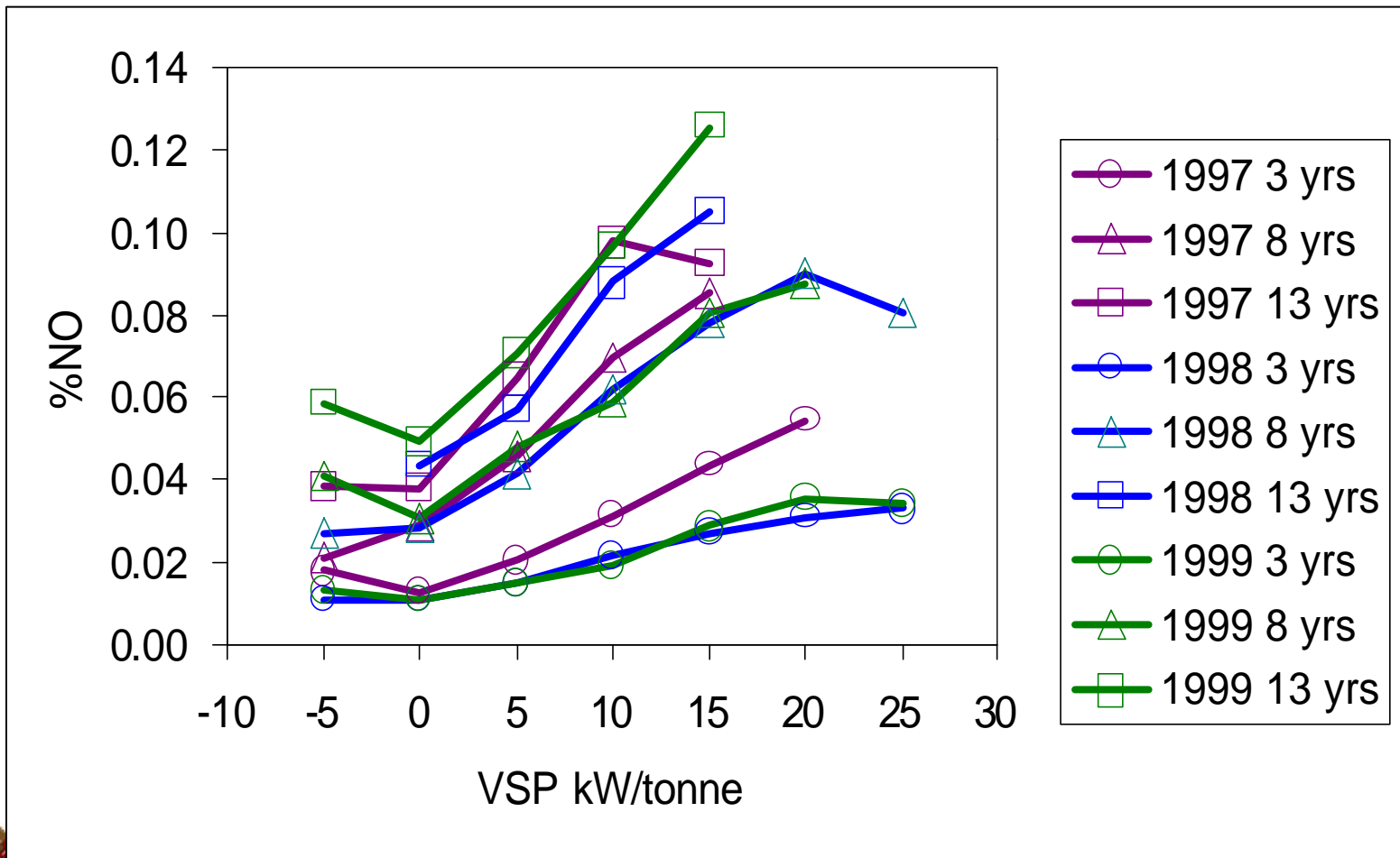


Chicago Remote Sensing Site

On-ramp from
Algonquin Rd.
to eastbound
I-290
(S.H. 53)
in northwest
Chicago



Chicago 1997-1999, Cars

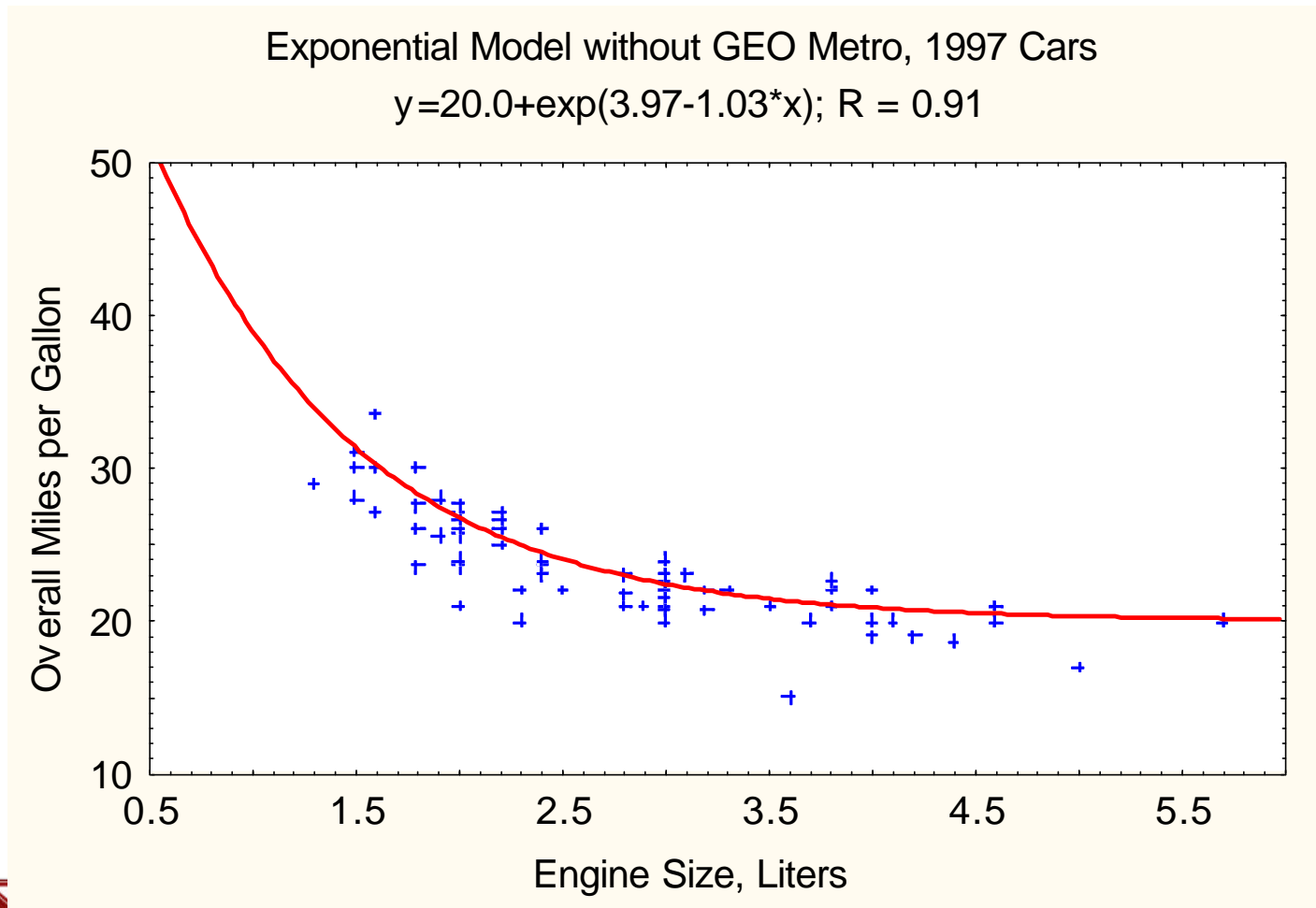


Adjusting %NO to gpm NO

- In Chicago, the change of %NO vs VSP by measurement year from 1997 to 1999 was small compared to the change of %NO seen in any of these years due to vehicle age.
- Combined %NO data by vehicle age (from 1997, 1998, and 1999 measurements) was converted to grams/gallon, and then, using a correlation based on engine size and 1997 vehicles' fuel economy, to grams/mile (gpm).

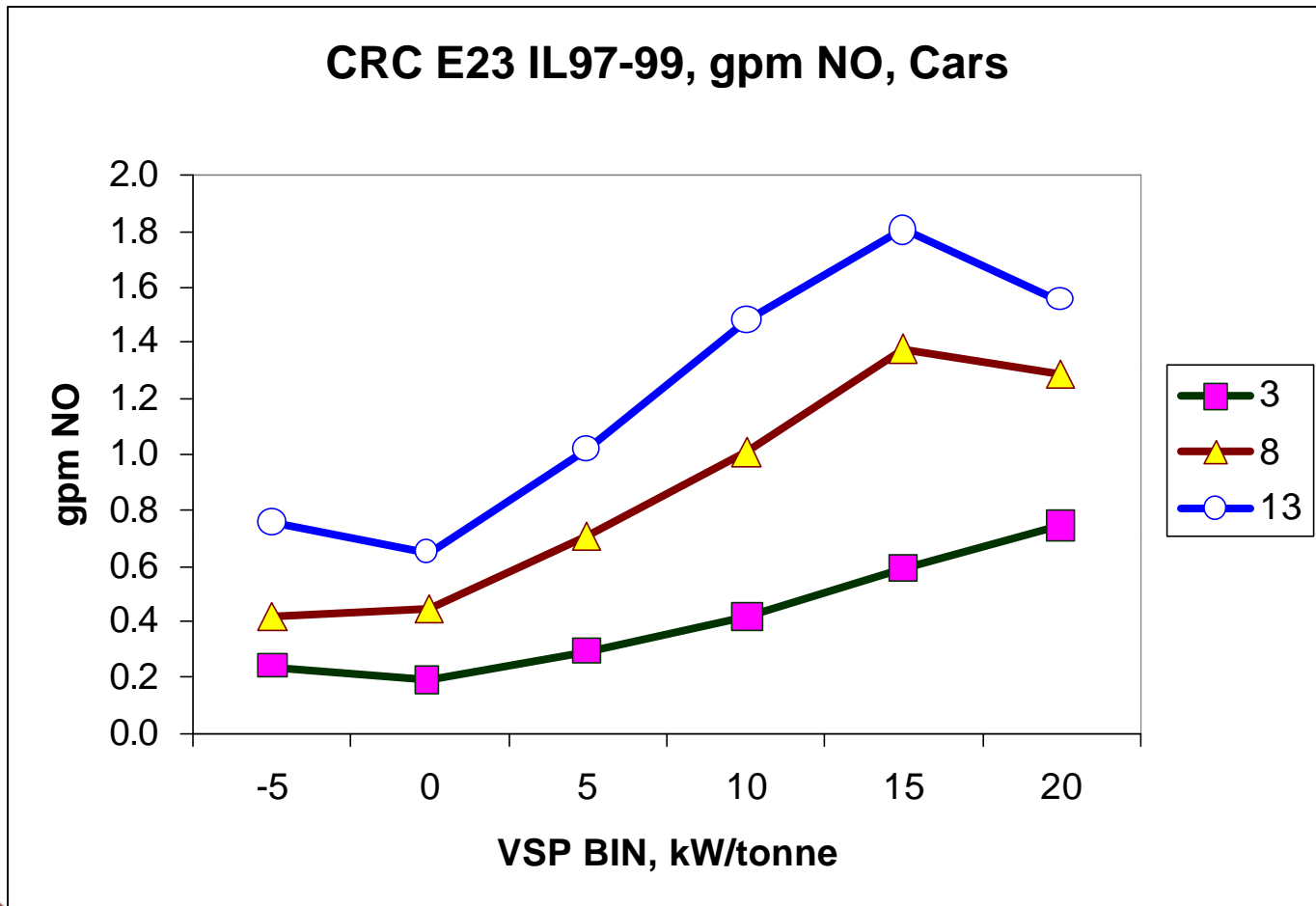


Gram/mile (gpm) for CARS 1997

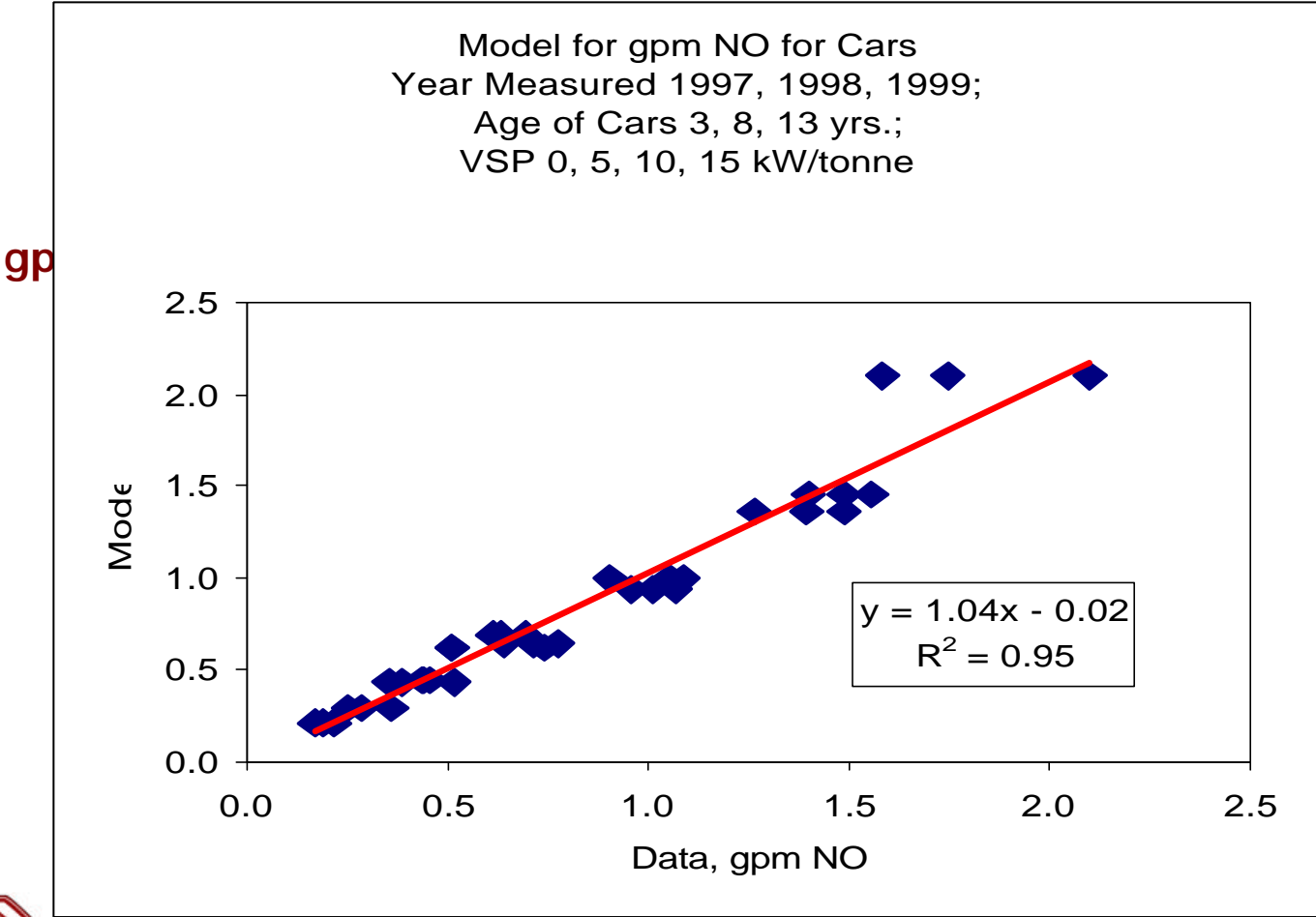


Correlation between engine size and mpg weighted vehicles based on frequency they were seen in 1997 remote sensing measurements.

NO gpm for 3, 8, 13 year Age Bins



Model vs Data in gpm NOx



Modeled gpm NOx in Chicago

- Chicago 97-99 remote sensing NO emissions, binned by load and vehicle age, and converted to gpm using average fuel economy, can be modeled from $VSP = 0$ to 15 kW/tonne , and age = 1 to 15 years, by a equation based on age and VSP.
- Two points off the line are due to older vehicles (measured in 97 & 98) at 15 kW/tonne . This could be explained if some of these older vehicles have gone into fuel enrichment at 15 kW/tonne , suppressing NO formation.



Status of E23 Measurements

| CRC E-23 | 5-Mar-02 | | | | | | | | | | |
|-----------------------------|----------|------|------|------|------|------|------|------|------|------|------|
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| Chicago (September) | | 1 | 2 | 3 | 4 | | 5 | | 6 | | 7 |
| Report | | X | X | X | X | | | | | | |
| Denver (January) | # | # | | 1 | 2 | 3 | # | 4 | | 5 | |
| Report | | | | X | X | X | | | | | |
| LA Riverside (July) | | | | 1 | 2 | 3 | | | | | |
| Report | | | | X | X | | | | | | |
| LA la Brea (October) | | | | # | | 4 | | 5 | | 6 | |
| Report | | | | | | | | | | | |
| Phoenix* (November) | | | 1 | 2 | 3 | # | 4 | | 5 | | 6 |
| Report | | | X | X | | | | | | | |



Not E23 Project but measurements conducted under E23 protocol and available for analysis