Implications of Measured In-Use Light Duty Gasoline Vehicle Emissions for Emission Inventory Development at High Spatial and Temporal Resolution

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Introduction

- Mobile source emissions contribute significantly to overall air pollution in the US
- Accurate assessment of motor-vehicle emissions is essential for effective air-quality improvement
- Real-world vehicle fuel use and emissions are episodic in nature
- Fleet-average emission factor models cannot capture the localized effect of episodic events such as high acceleration
- Multiple-scale emissions information are needed

Objectives

The objectives of this work are to:

– To evaluate the inter- and intra-vehicle variability in real-world light duty gasoline vehicle emissions

– To assess implications for emissions estimates at high spatial and temporal resolution

Overview of Methodology

The methodology used for this study includes:

- Experimental design for data collection
- Field data measurements using a portable emission measurement system (PEMS)
- Data processing
- Analysis of data, including
  - Empirical comparisons
  - Road grade effect assessment using Vehicle-Specific Power (VSP)-based modal models
  - Temporal and spatial analysis

Experimental Design for Data Collection

In order to cover a wide range of inter- and intra-vehicle variability in fuel use and emissions, a variety of factors influencing emissions are taken into account in experimental design, including:

- Vehicles
- Drivers
- Study area: Transportation network characteristics, such as roadway classes and road grade
- Traffic conditions (surrogate of time of day)

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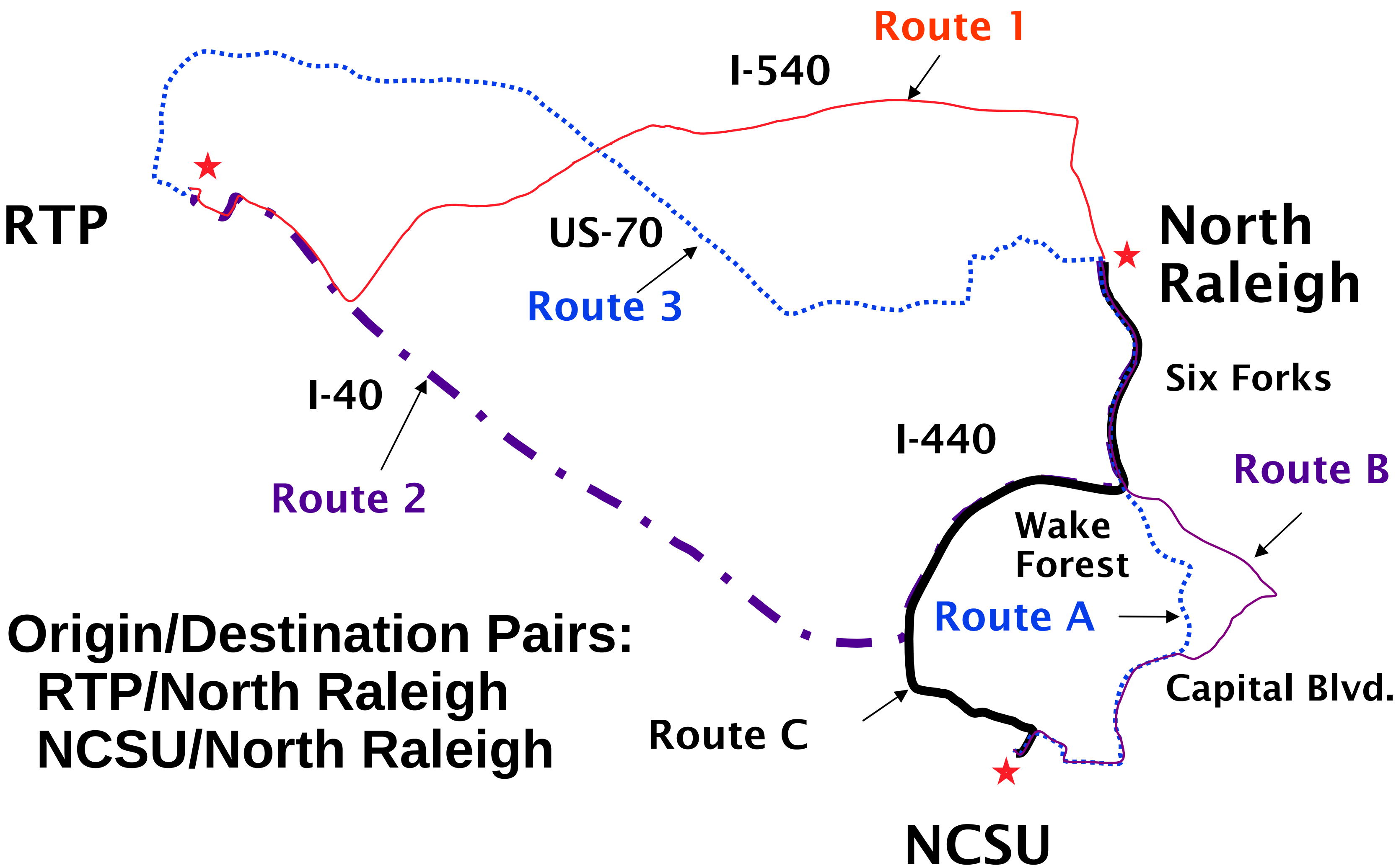
Study Area



Origin/Destination Pairs:
- RTP/North Raleigh
- NCSU/North Raleigh

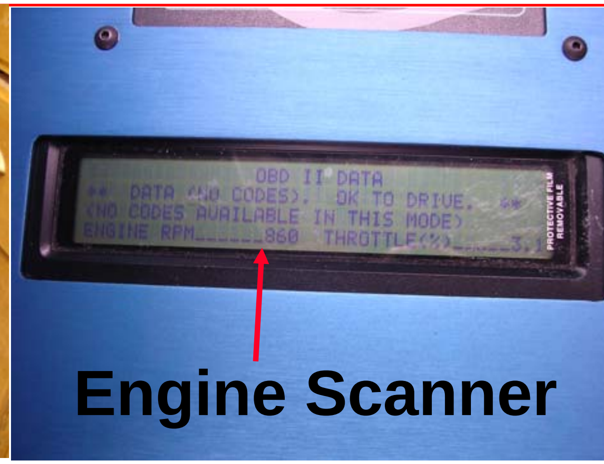
Portable Emissions Measurement System (PEMS)

Components of the PEMS include:

- Computer
- Engine Scanner
  - » Externally observable variables (EOVs) such as Speed, Acceleration
  - » Internally observable variables (IOVs) such as Engine speed (RPM), Coolant Temp, Intake Air Temp, Manifold Absolute Pressure (MAP), and Throttle Position Percentage
- Two parallel gas analyzers
  - » NO, O_2 (Electrochemical Sensor)
  - » HC, CO, and CO_2 (NDIR Optical Sensor)
- Global Positioning System (GPS)
- Exhaust gas sampling probe and hoses

Installation of the PEMS

System Interface



Engine Scanner

OBD-II Adapter

Installation

GPS

Sampling probe

Summary of Collected Data

Vehicle		Weight (Kg)	Hrs	Miles
2005 Chevrolet Cavalier 2.2 L	V1	1200	69	2519
2005 Dodge Caravan 3.3 L	V2	1760	64	2729
2005 Chevrolet Tahoe 5.3 L	V3	2250	62	2422
1997 Honda Accord 2.2 L	V4	1370	4	210
1998 Plymouth Breeze 2.4 L	V5	1330	9	458
2004 Dodge Stratus 2.7 L	V6	1390	2.5	119
1997 Dodge Caravan 3.3 L	V7	1610	2.5	87
2000 Dodge Caravan 3.3 L	V8	1610	11	532
2002 Dodge Caravan 3.3 L	V9	1740	2.5	119
2000 Ford Crown Victoria 4.6 L	V10	1800	3	127

Data Processing

- Identification of possible errors associated with field data collection, such as loss of engine or gas analyzer data, or invalid values of such data.
- Where possible, imputation of missing data, or correction or removal of invalid data (e.g., interpolation of engine or vehicle speed).
- Recalculation of mass rates
- Combination of road grade data with emission data
- Combination of multiple runs of data to develop a final database

Quantification of Intra- and Inter-Vehicle Variability in Emissions

- Intra-vehicle variability

  Emissions were compared on a route basis for a given time of day, and vehicle
- Inter-vehicle variability

  VSP-modal emisison rates among vehicles were compared

Vehicle Specific Power-Based Modal Model

VSP accounts for power demand, rolling resistance, road grade, and aerodynamic drag

$$VSP = s[1.1a + 9.81(\sin(\arctan(r))) + 0.132] + 0.000302s^3$$

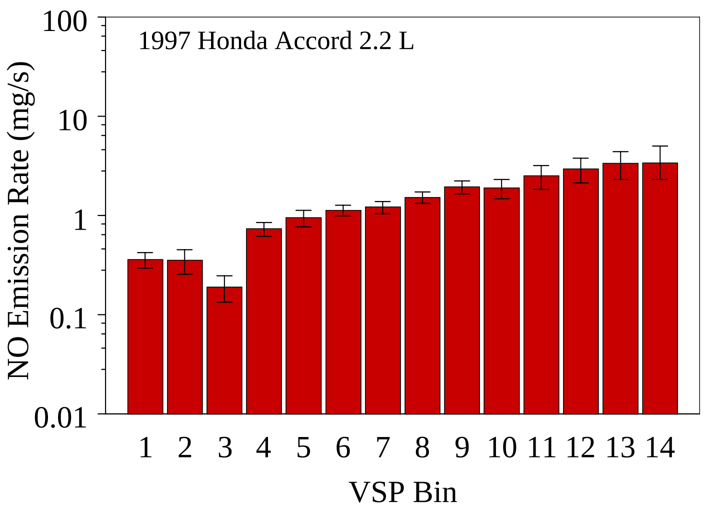
Where

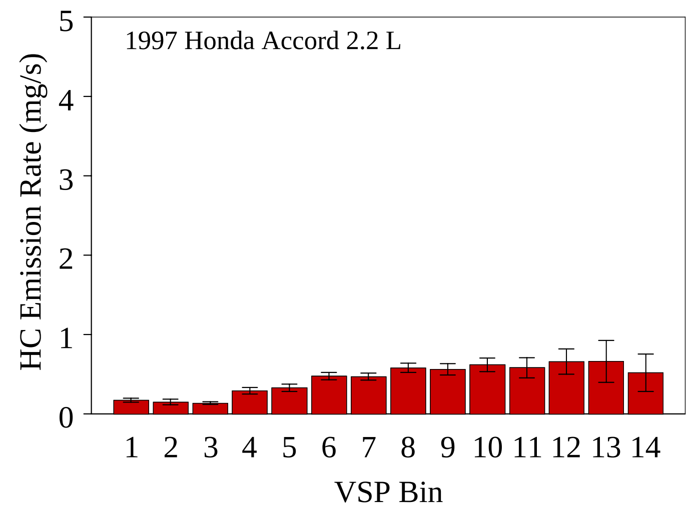
s	= speed (m/s)
r	= road grade
a	= acceleration (m/s^2)
VSP	= vehicle specific power (kw/ton)

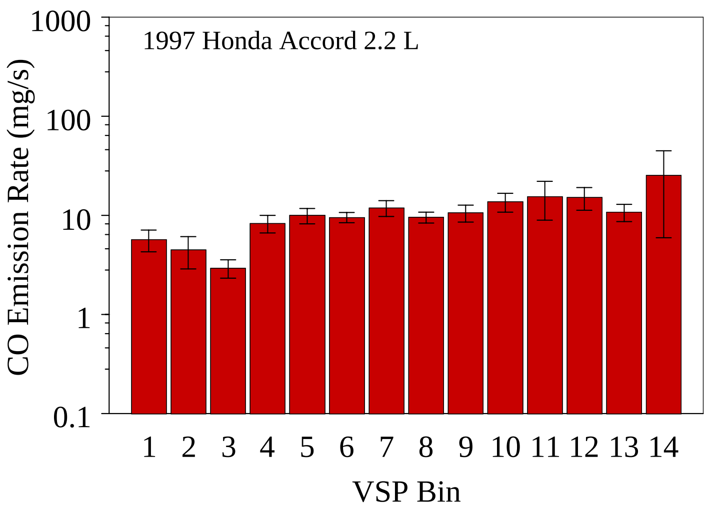
NCSU VSP Driving Modes

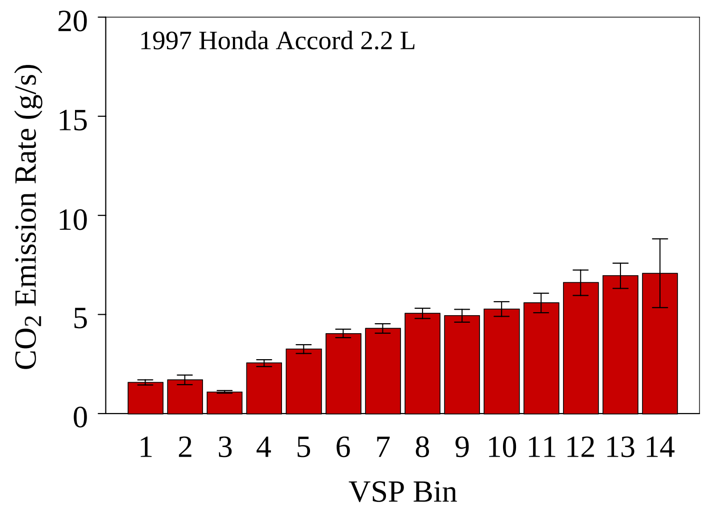
VSP Bin	Definition	VSP Bin	Definition
1	VSP < -2	2	-2 ≤ VSP < 0
3	0 ≤ VSP < 1	4	1 ≤ VSP < 4
5	4 ≤ VSP < 7	6	7 ≤ VSP < 10
7	10 ≤ VSP < 13	8	13 ≤ VSP < 16
9	16 ≤ VSP < 19	10	19 ≤ VSP < 23
11	23 ≤ VSP < 28	12	28 ≤ VSP < 33
13	33 ≤ VSP < 39	14	VSP ≥ 39

VSP Mode-Based Emission Rates for 1997 Honda Accord 2.2 L









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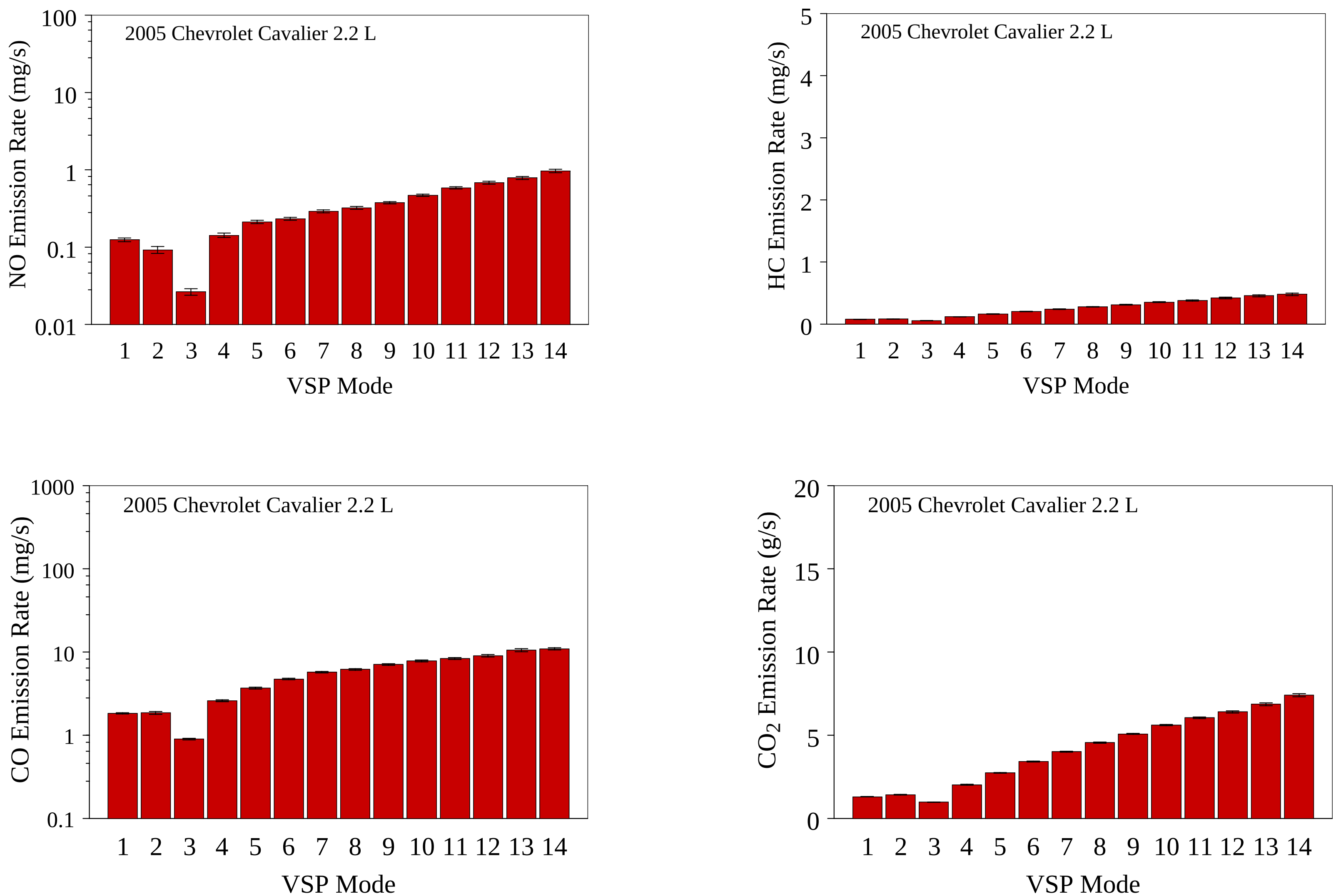
VSP Mode-Based Emission Rates for 2005 Chevrolet Cavalier 2.2 L



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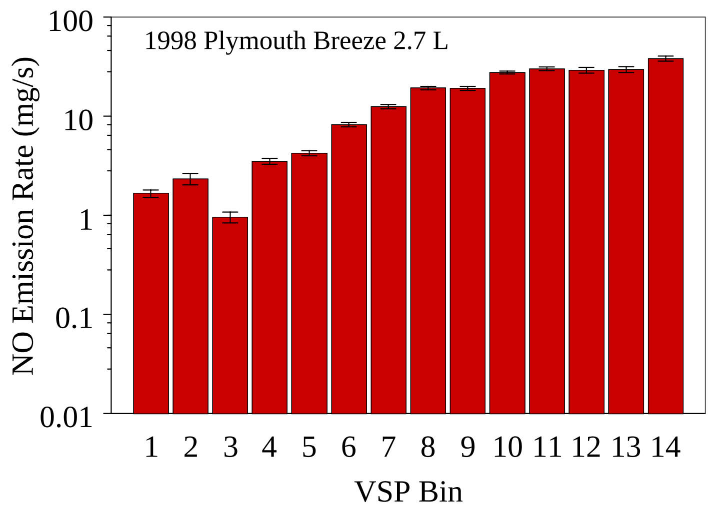
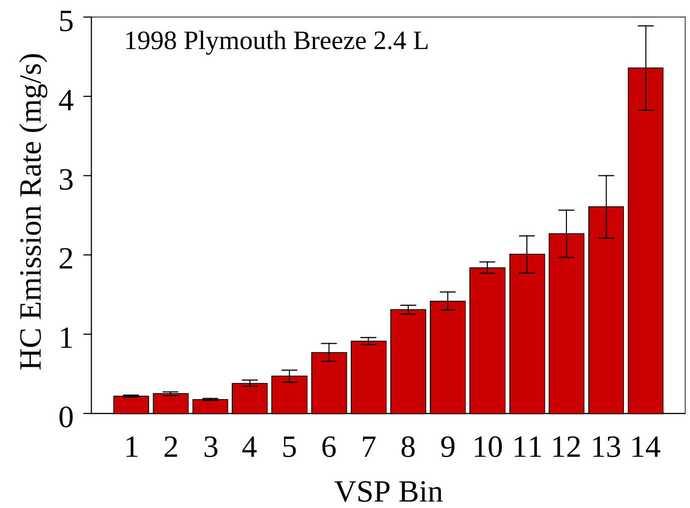
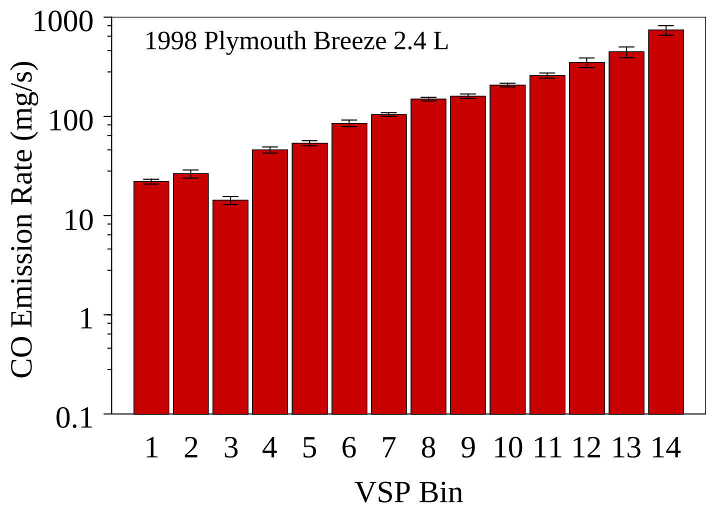
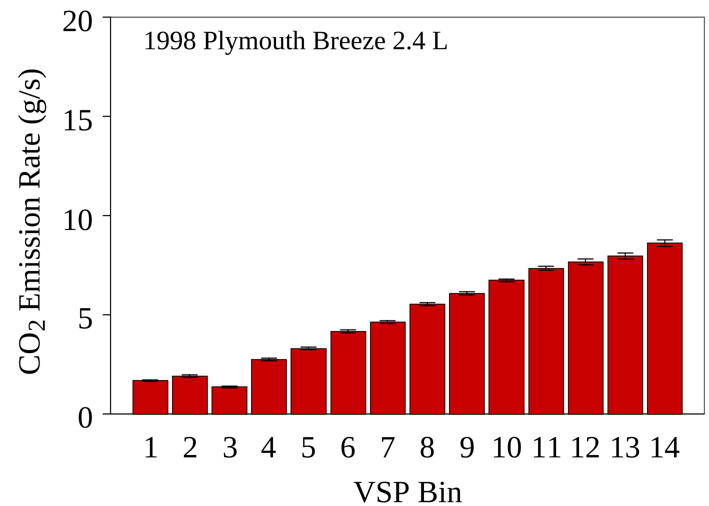
VSP Mode-Based Emission Rates for 1998 Plymouth Breeze 2.4 L

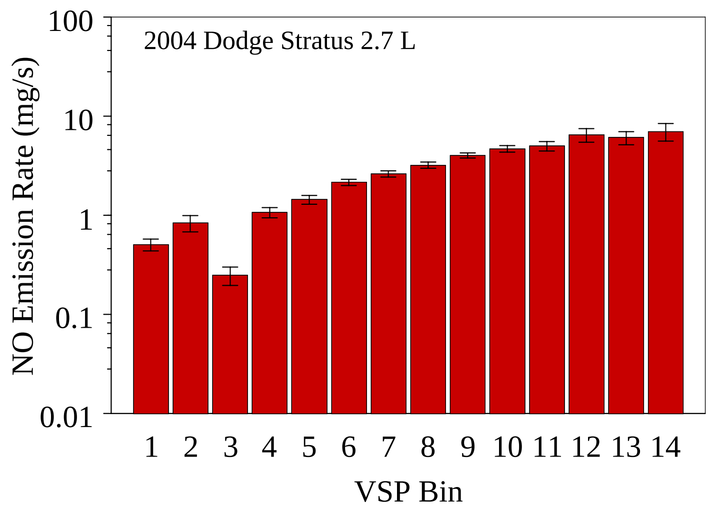


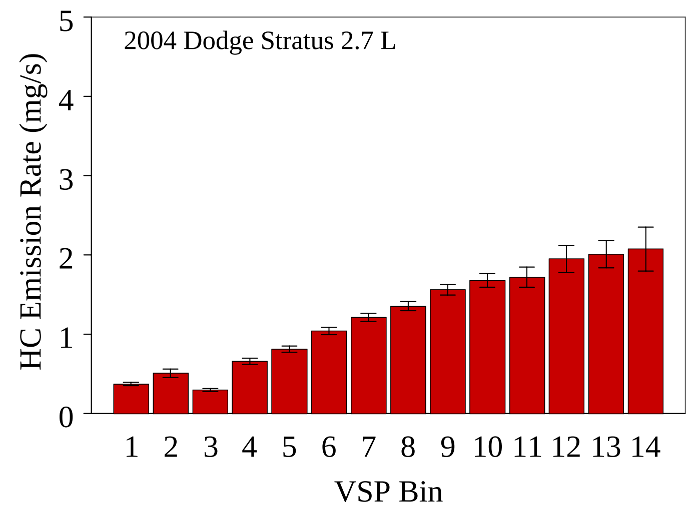


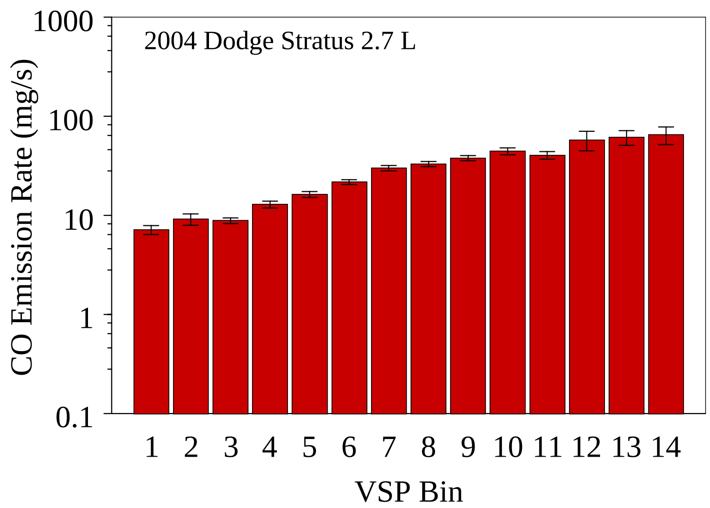


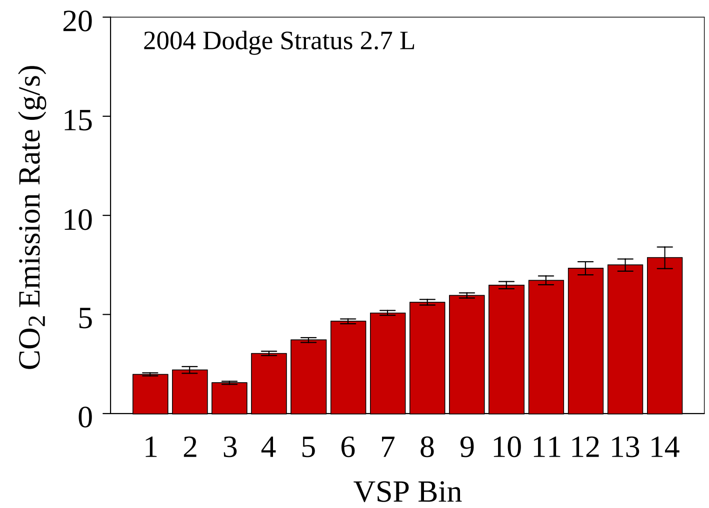


VSP Mode-Based Emission Rates for 2004 Dodge Stratus 2.7 L

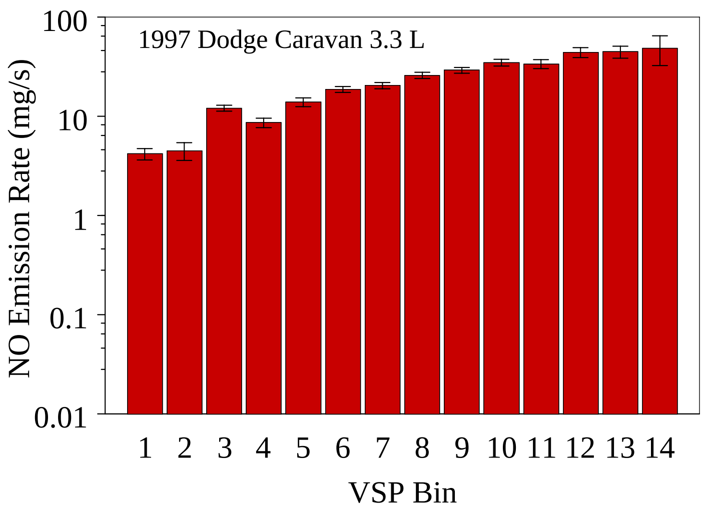


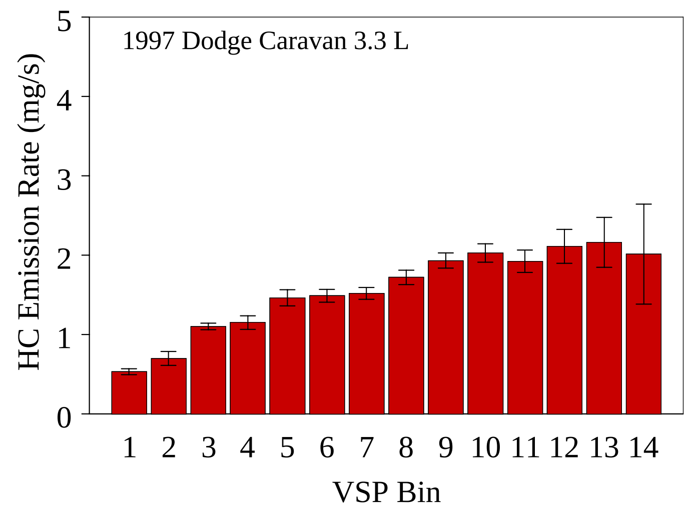


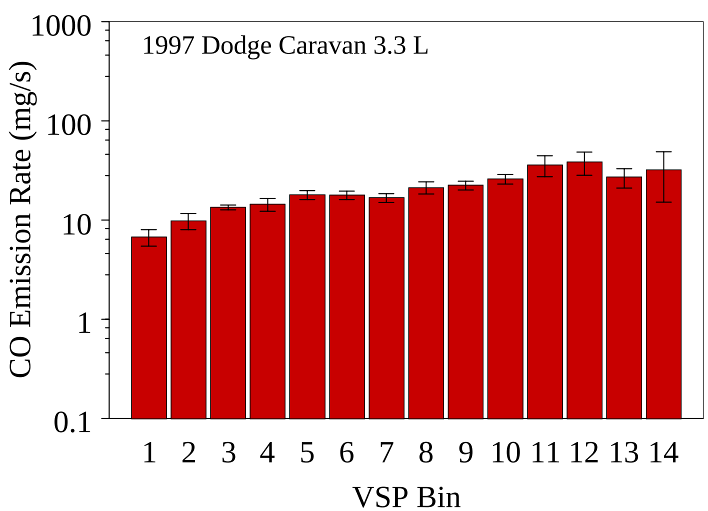


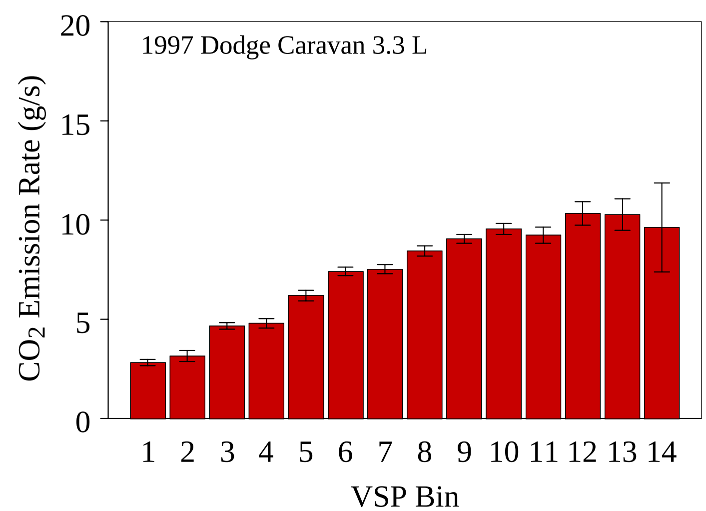


VSP Mode-Based Emission Rates for 1997 Dodge Caravan 3.3L









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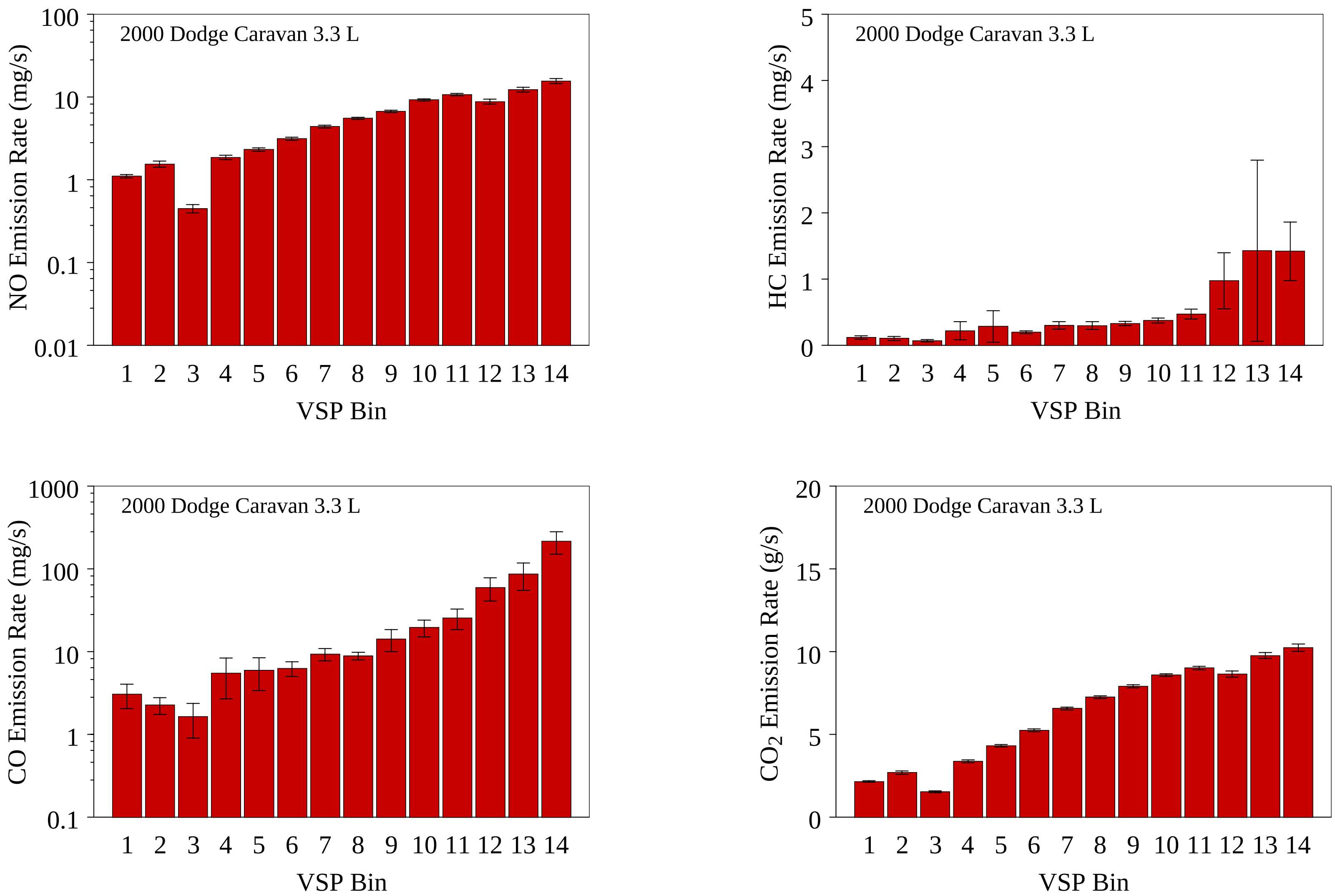
VSP Mode-Based Emission Rates for 2000 Dodge Caravan 3.3L



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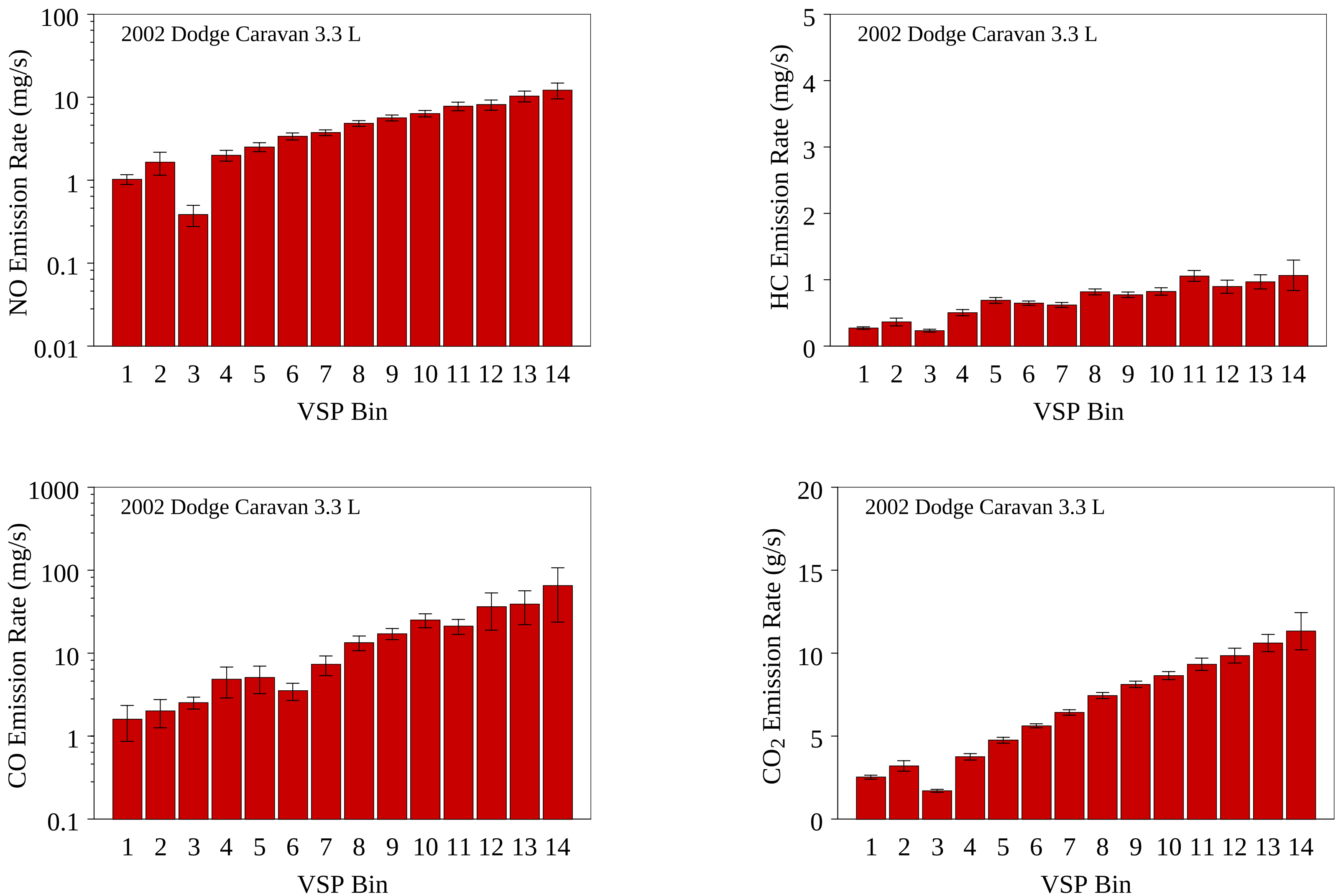
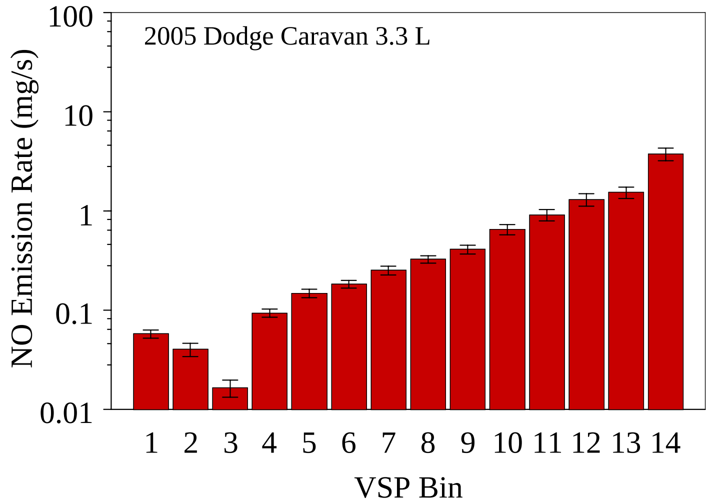
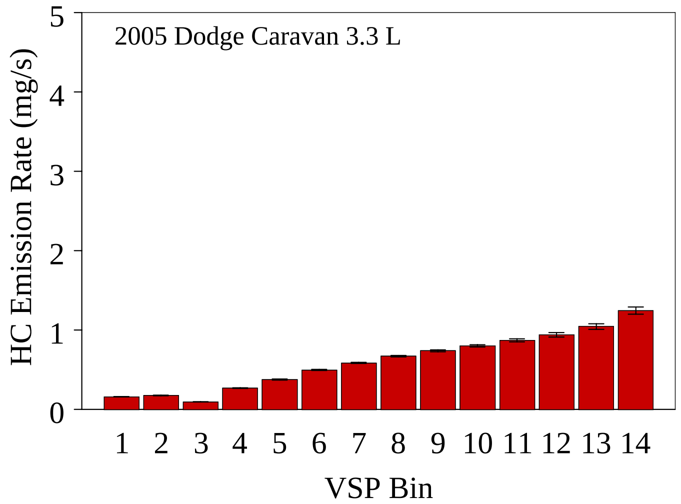
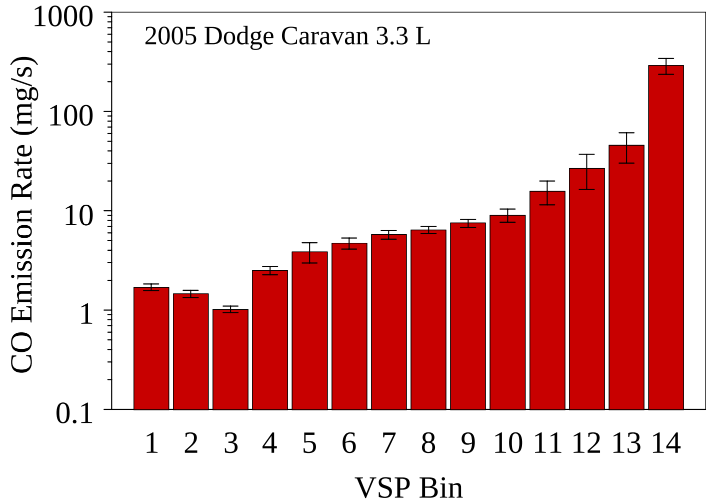
VSP Mode-Based Emission Rates for 2002 Dodge Caravan 3.3 L

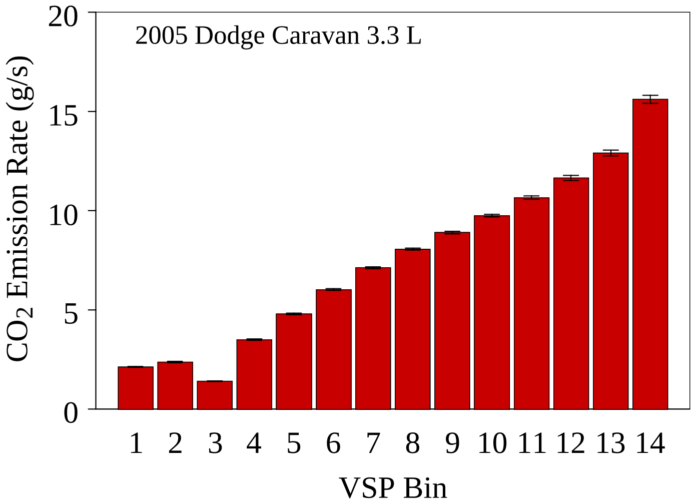


VSP Mode-Based Emission Rates for 2005 Dodge Caravan 3.3 L









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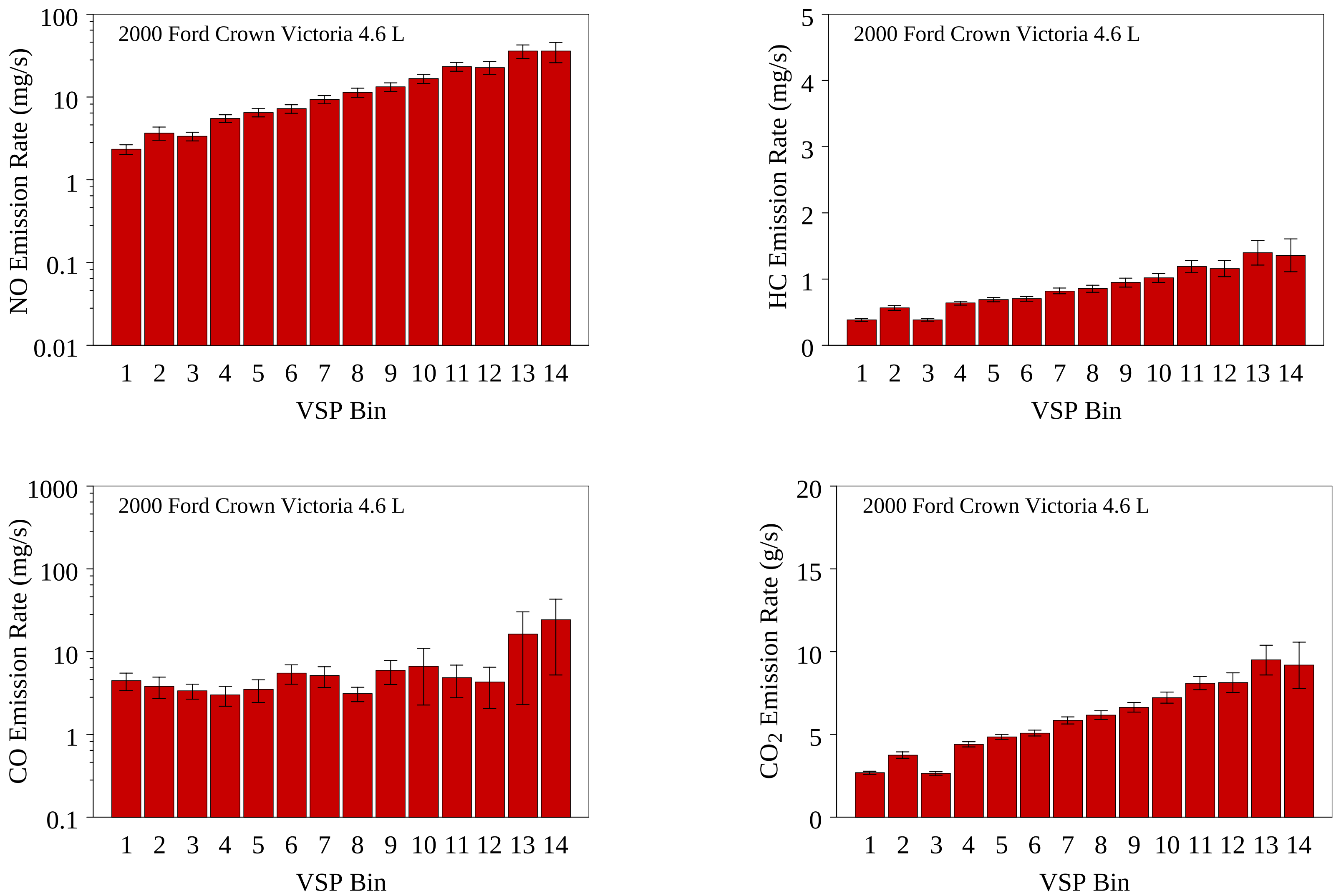
VSP Mode-Based Emission Rates for 2000 Ford Crown Victoria 4.6 L



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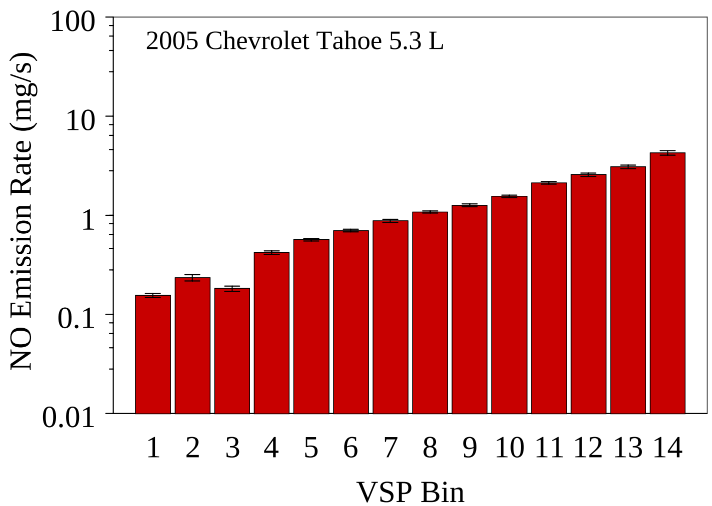
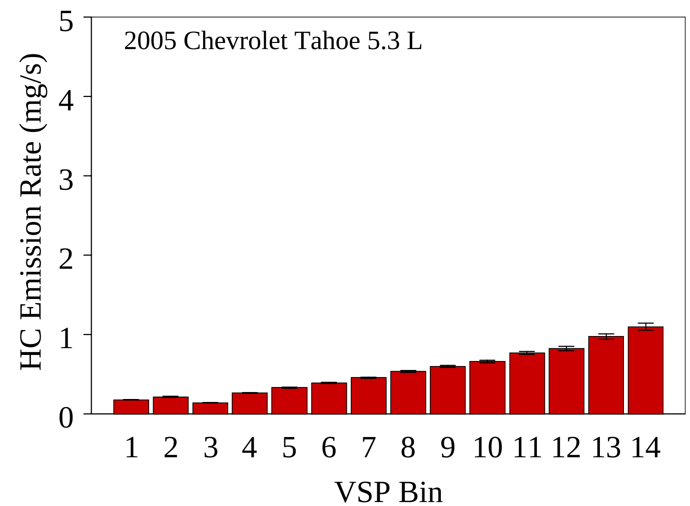
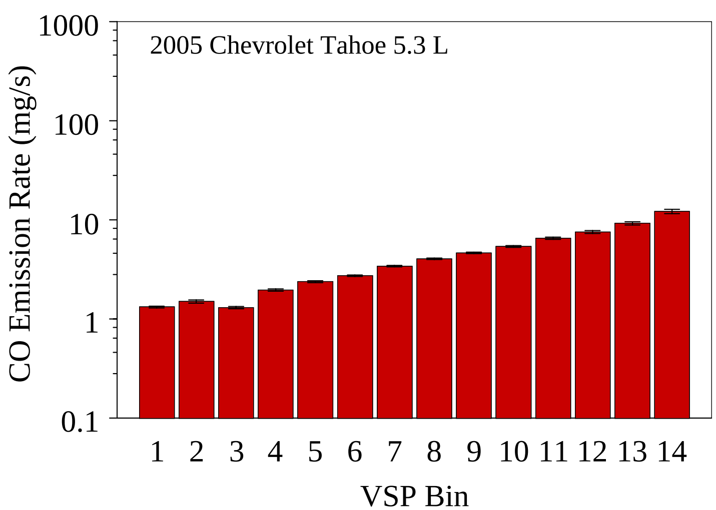
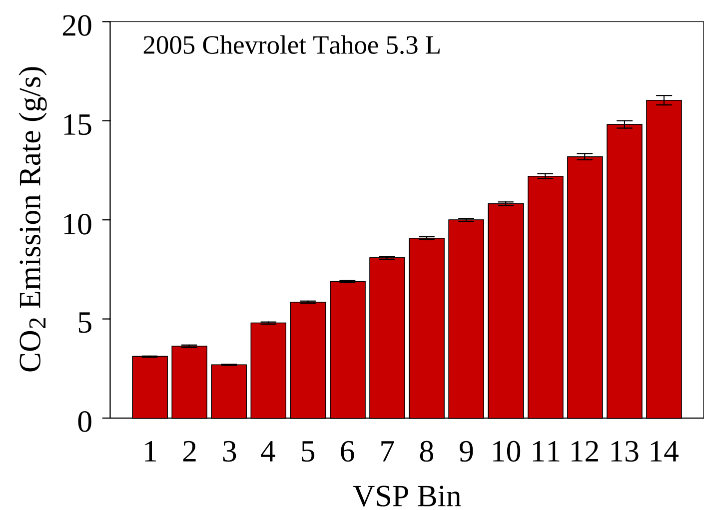
VSP Mode-Based Emission Rates for 2005 Chevrolet Tahoe 5.3 L









Empirical Comparisons of Emissions and Fuel Use on a Route-Basis

	Percent Difference When Comparing Highest Versus Lowest Values[a]							
	NO		HC		CO		Fuel	
	Rate	Total	Rate	Total	Rate	Total	Rate	Total
Route	18	24	18	15	46	41	14	14
Time of day	18	19	16	23	32	33	7	9

[a] For the "route" comparison, differences are based upon the route with the highest value to that with the lowest value for the O/D pair and time of day with the largest such difference

[a] For the "time of day", difference in average values for peak versus off-peak travel times for the O/D pair with the largest such difference

Effect of Road Grade on Fuel Use and Emission Rates

- Three cases were studied to assess the effect of road on fuel use and emissions
  - Case A: only negative road grades
  - Case B: only positive road grades
  - Case C: both negative and positive road grades
- For each case
  - Fuel use and emissions were estimated using VSP-based modal model
  - Fuel use and emissions were compared with and without consideration of road grade when calculating VSP
- Three alternative routes between RTP and NR were selected for this study, i.e., Route 1, 2 and 3
- For each primary vehicle, all runs on each of the selected routes were used for analysis

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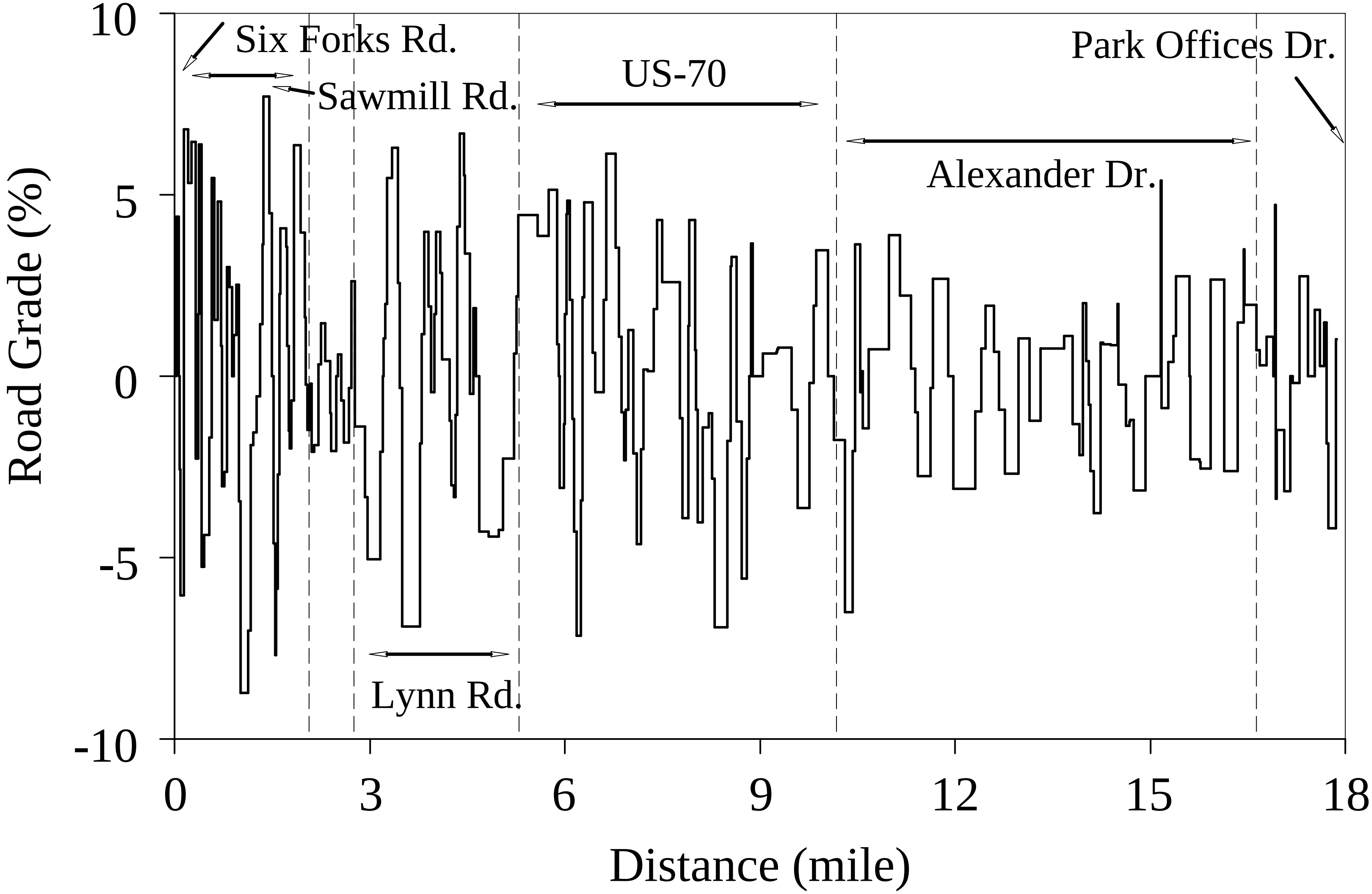
Road Grade Profile for A Route in the Study Area



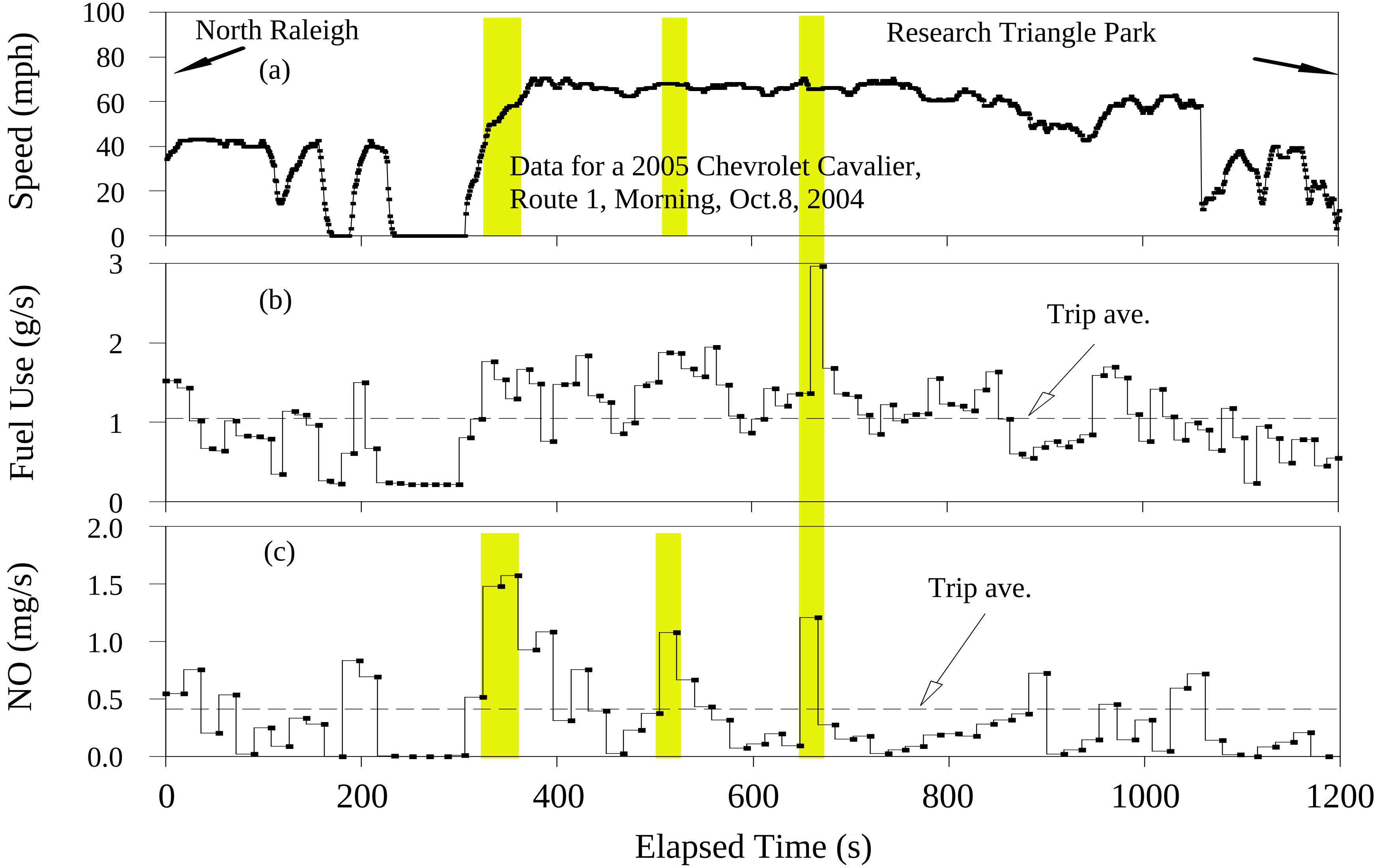
Effect of Road Grade on Fuel Use and Emissions

Route	Case	Segments	% Difference of Total Fuel Use & Emissions For Actual vs. Zero Grade			
			NO	HC	CO	Fuel
1	*A*	"-" road grade	17	15	15	14
	B	"+" road grade	-16	-12	-12	-11
	C	entire route	-0.6	0.4	0.6	0.7
2	*A*	"-" road grade	21	19	19	17
	B	"+" road grade	-15	-14	-13	-12
	C	entire route	-0.5	-0.5	-0.7	-0.9
3	*A*	"-" road grade	24	24	23	22
	B	"+" road grade	-20	-17	-16	-16
	C	entire route	-3	0.6	0.7	0.2

Temporal and Spatial Analysis

- Time-based analysis (e.g., time series data over a single trip)
- Distance-based analysis (e.g., Hot-spots in fuel use and emissions)
- “Hot-spots”:
  - Fuel use: peak fuel use rate greater than a standard deviation than average fuel use rate over the entire trip, either in mass per time or mass per distance
  - Emissions: peak emissions greater than a factor of two than average emissions over the entire trip, either in mass per time or mass per distance
- These analysis were done using empirical data

Temporal Variation in Fuel Use and Emissions



Interpretation of Temporal Variation in Fuel Use and Emissions

For NO,
- 17% of the trip time contributes to 52% of the total emissions
- 22% of the total fuel use is associated with NO hotspots

- For Fuel Use,
  - Not as sensitive as NO to episodic events such as high accelerations
  - 16% of the trip time contributes to 31% of the total fuel use based upon current definition

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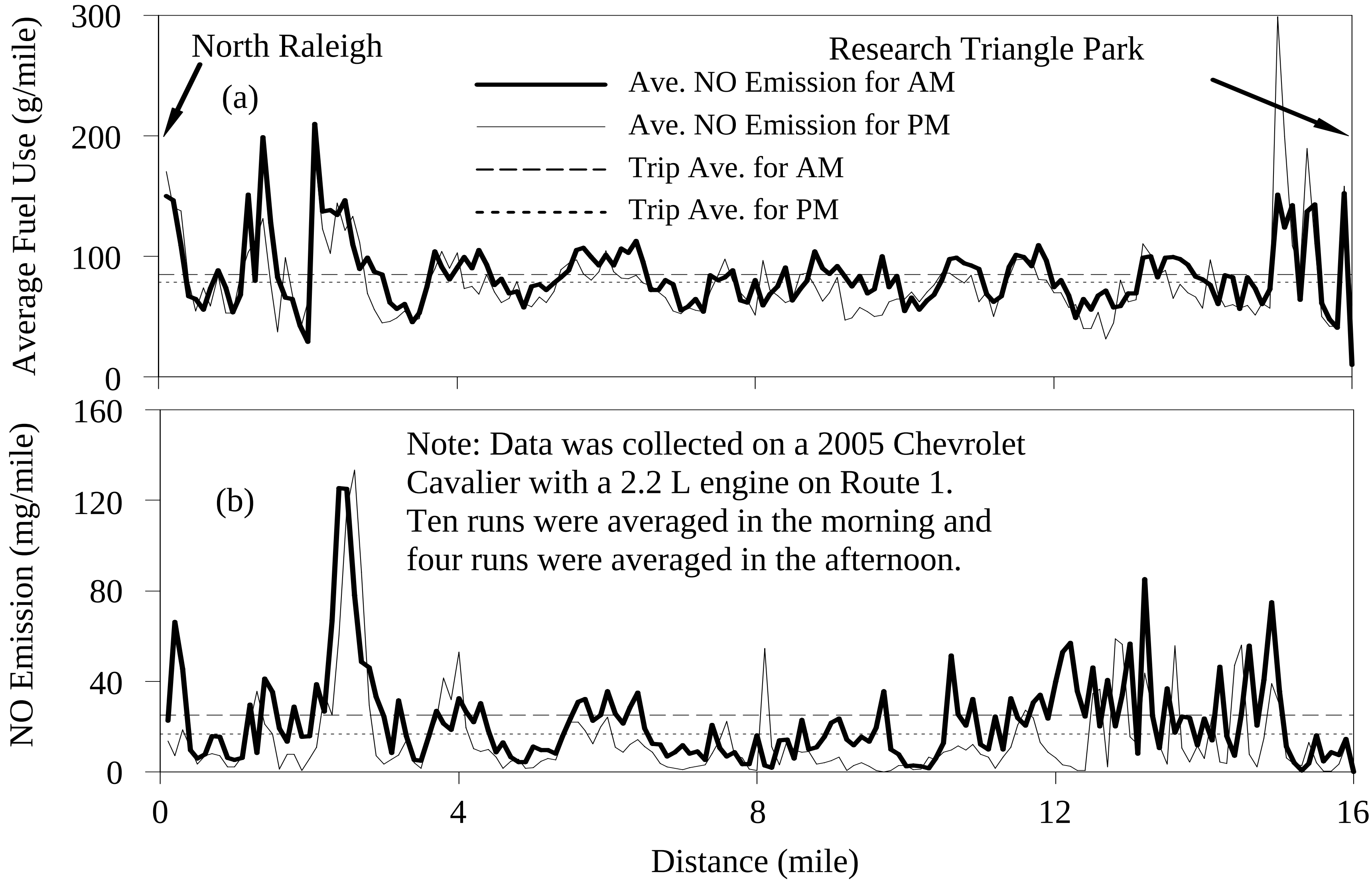
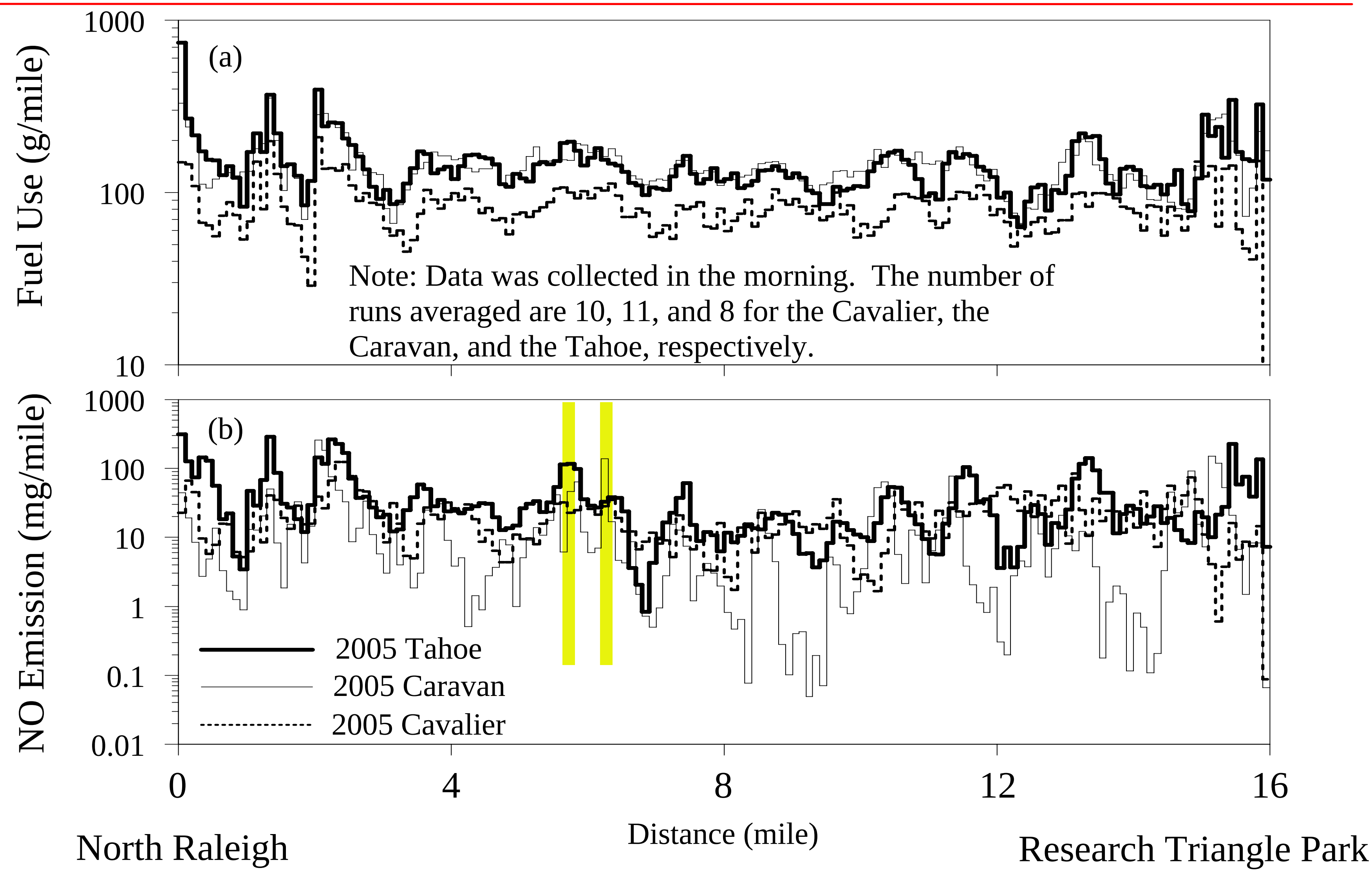
Spatial Variation in Fuel Use and Emissions



Inter-Vehicle Variability in Spatially-Based Fuel Use and Emissions



Interpretation of Inter-Vehicle Variability in Spatially-Based Fuel Use and Emissions

- Average emissions vary among vehicles due to differences in vehicle weight, engine size, and other design factors
- For a given vehicle, emissions varied by location
- Location and importance of hotspots varied by vehicle
- Vehicle-specific hotspots have average emissions a factor of 3.5 greater than the trip average
- 7% of the route contributed to 10-30% of emissions, depending on the vehicle.

Conclusions

- “Micro-scale” emissions are affected by route choice, time of day, road grade, and vehicle characteristics
- Characterization of spatial and temporal variations in emissions will improve the accuracy of near roadside exposure and risk assessments
- Transportation improvement measures, such as signal timing and coordination, should be prioritized to reduce or eliminate hotspots in fuel use and emissions

Recommendations

- The assessment of real-world microscale effects of fuel use and emissions hotspots should be extended to more vehicles and locations in order to support more robust and generalizable conclusions and models
- Data regarding the effect of route choices and microscale conditions should be used to inform real-time traffic control and advisories

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