On-Road Motor Vehicle Emissions including NH_3, SO_2 and NO_2

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On-Road Emission Measurements of Reactive Nitrogen Compounds from Three California Cities

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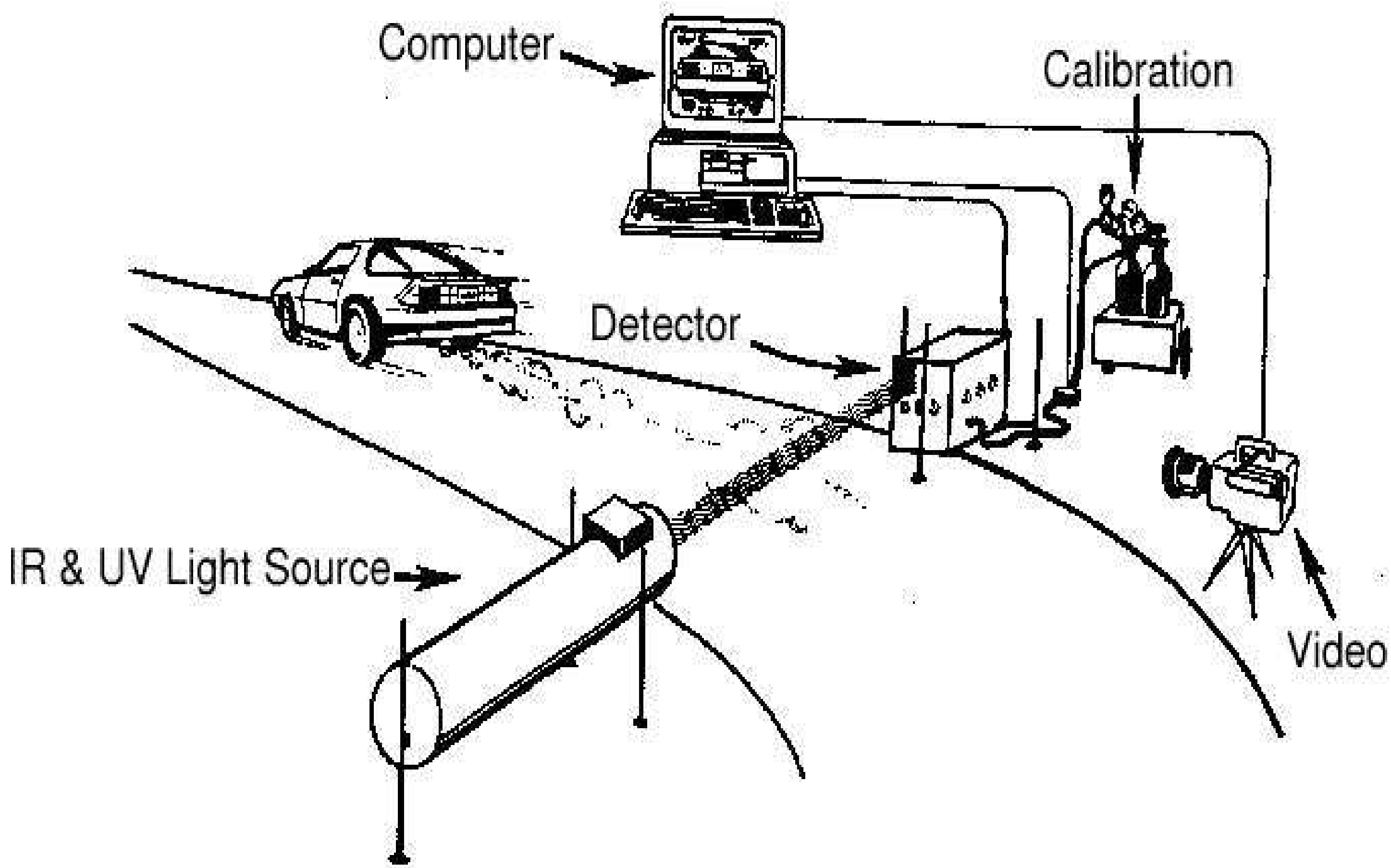
CO, HC and NO Remote Sensing



Now with NO_2, SO_2, NH_3, smoke

Brief History of Vehicle Remote Sensing

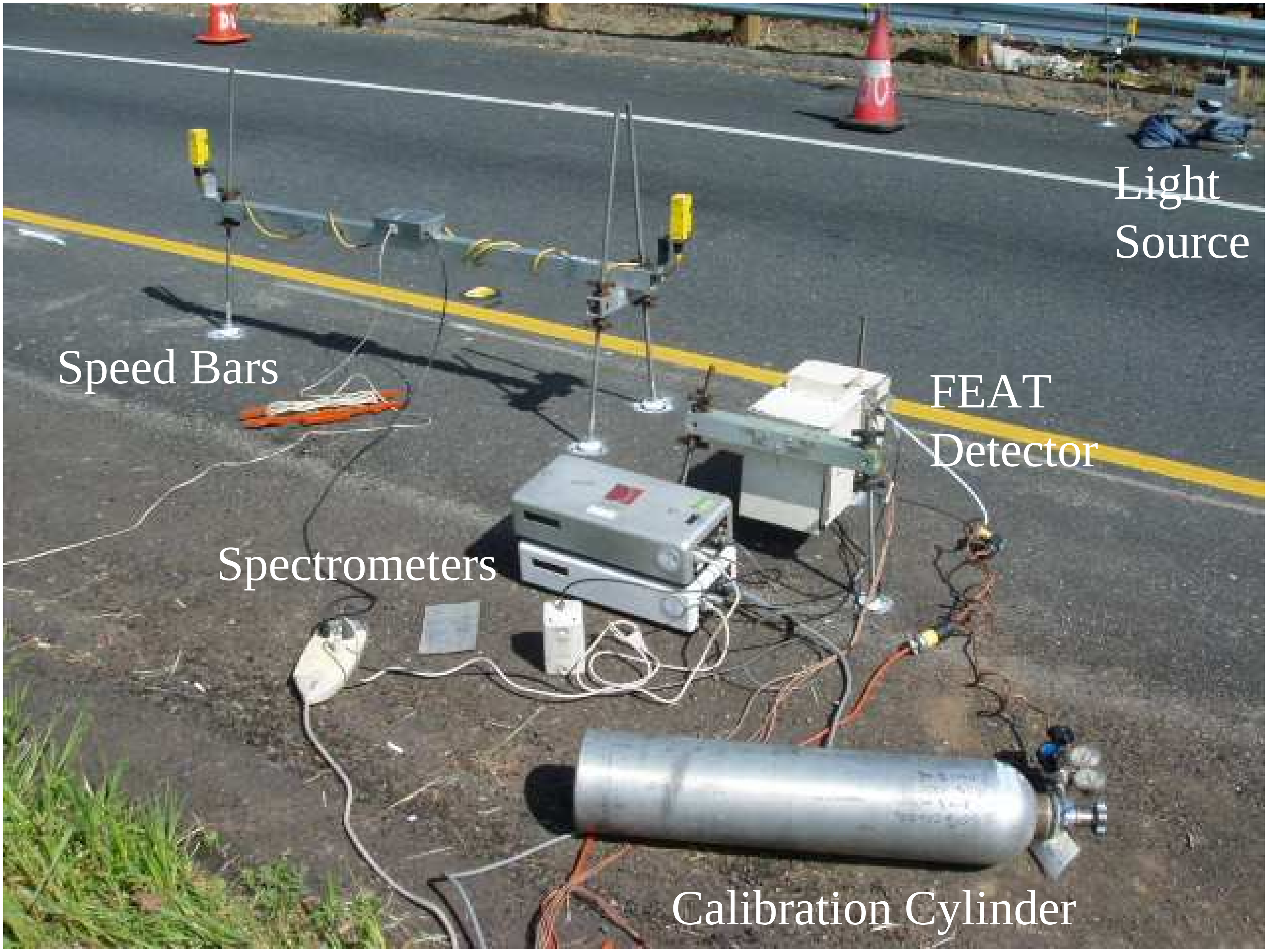
- 1973 *Vehicle Inspection Instrumentation*, Hoshizaki, Wood and Kemp, Report to CARB.
  - REMOVE reported CO, HC, and NO ratioed to [CO+CO_2] in the IR. Was battery powered and gave results on 3 analog meters. Worked sometimes for CO and HC up to 20mph. **Results were never published in the literature!**
- 1983 *The remote measurement of traffic generated CO*, Chaney, JAPCA.
  - Demonstrated the capabilities to measure individual vehicle CO plumes with a roadside detector.
- 1987 DU demonstrates the Fuel Efficiency Automobile Test 1000 instrument.
  - Liquid N_2 cooled InSb detectors for CO and CO_2.
  - Added video image capture and a detector for HC in 1989

Vehicle Remote Sensing History (cont.)

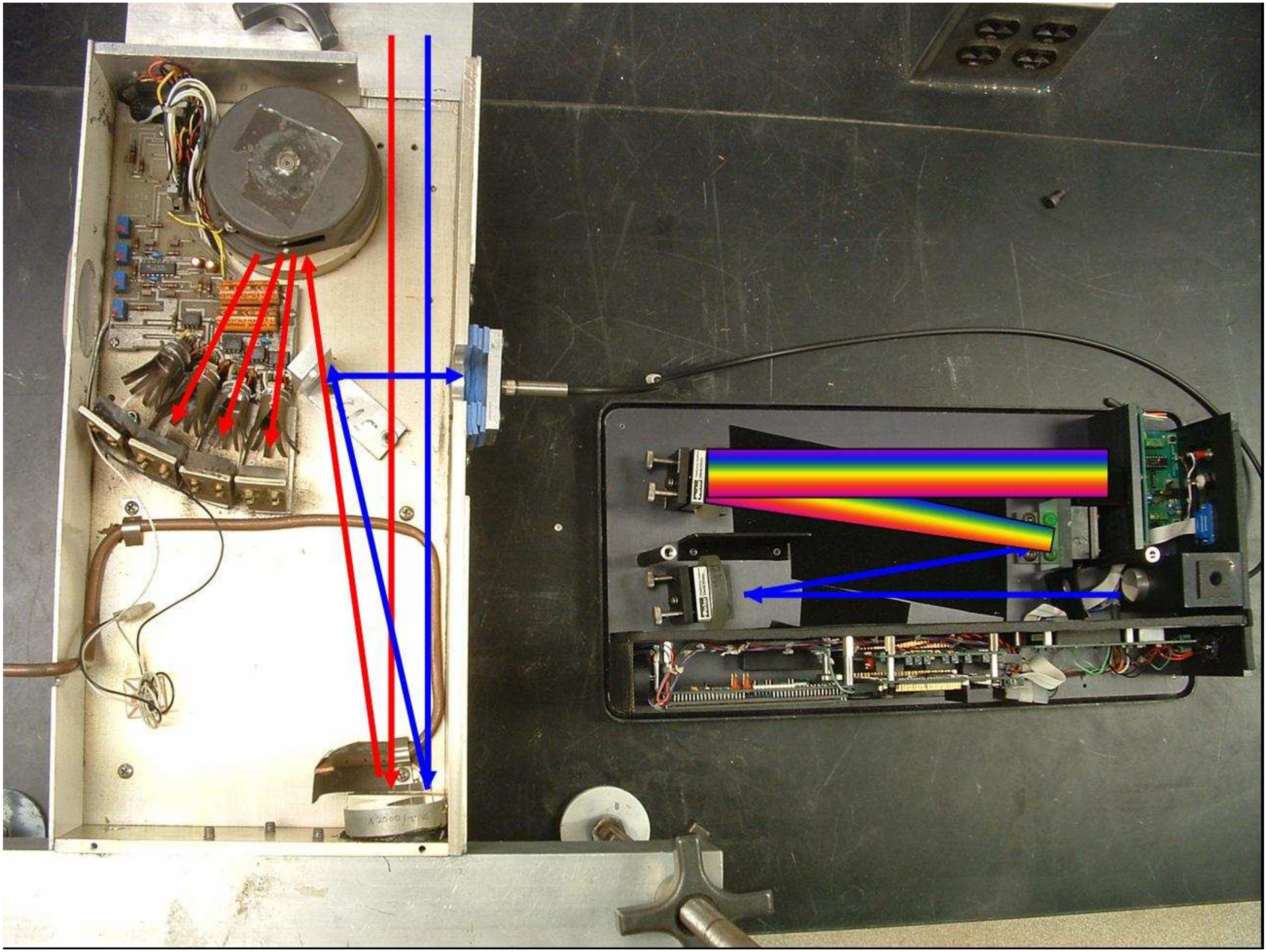
- 1989 General Motors (Stephens et al) develops an on-road sensor
- 1990 FEAT 3000 instrument developed
  - Four peltier cooled detectors CO, CO_2, HC and Ref
- 1991 Hughes Aircraft tests a sensor using an FTIR
- 1994 RSD1000 First commercial remote sensor
  - FEAT 3000 upgraded with NDUV NO
- 1997 FEAT 3000 upgraded with a dispersive UV spectrometer for NO
- 2005 FEAT 3000 upgraded to twin spectrometers to measure NO, SO_2, NH_3 and NO_2

Roadside Instrument Setup

Roadside Instrument Setup

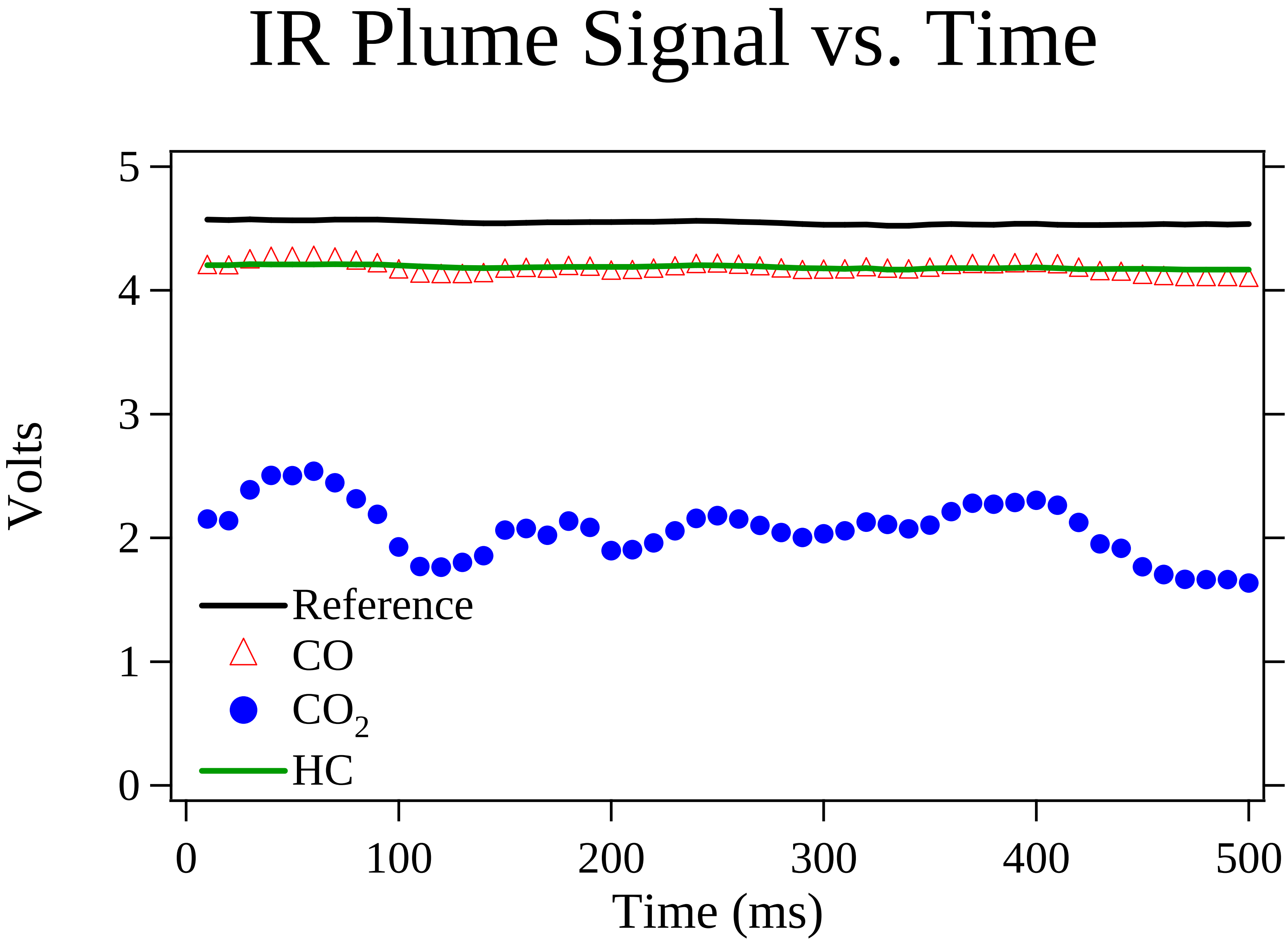


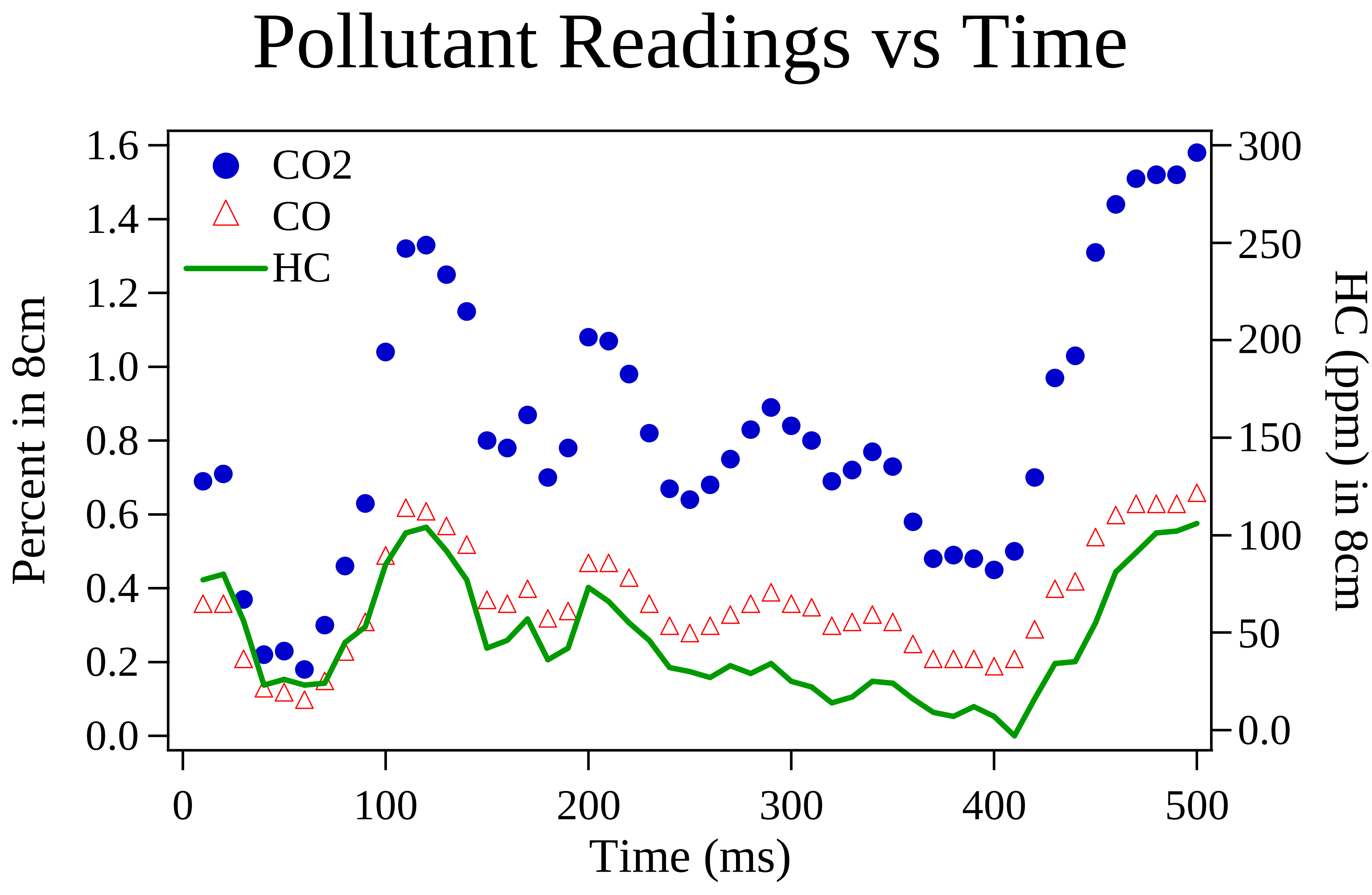
FEAT Detector and Mono IR/UV Light Paths



HOW FEAT WORKS

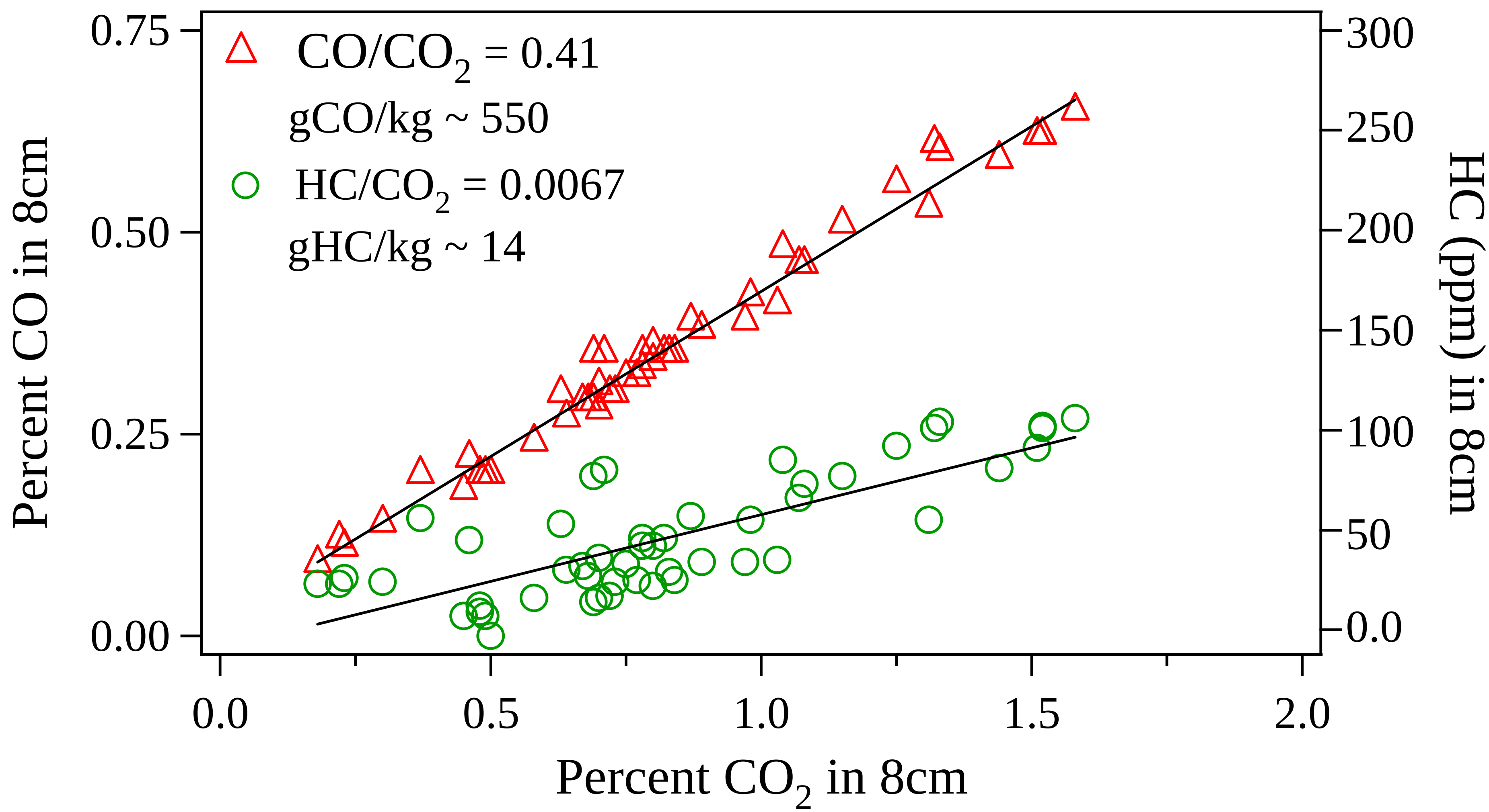
- FEAT does not MEASURE anything.
- It is a comparator.
- It compares the pollutant ratios (CO/CO_2, HC/CO_2, NO/CO_2 etc.) in the vehicle exhaust to the pollutant ratios in a certified cylinder.
- RATIOS are what we measure; all other results such as fuel specific emissions (grams/gallon or g/kg) are derived from the measured ratios.


IR Plume Signal vs. Time
Volts
Time (ms)
0
1
2
3
4
5
0
100
200
300
400
500
Reference
CO
CO2
HC

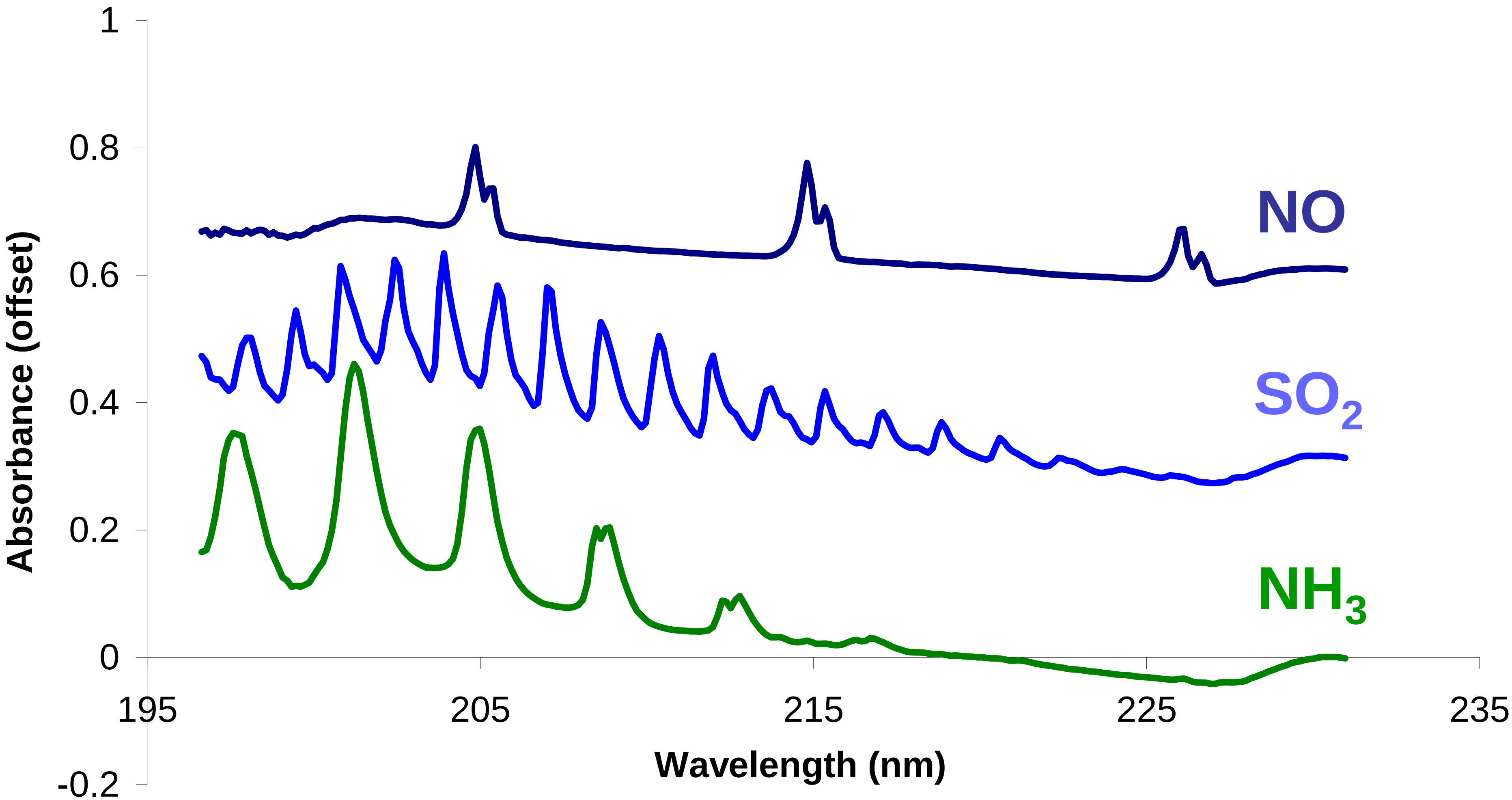


Pollutant Readings vs Time
CO2
CO
HC
Percent in 8cm
HC (ppm) in 8cm
Time (ms)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
300
250
200
150
100
50
0.0
0
100
200
300
400
500

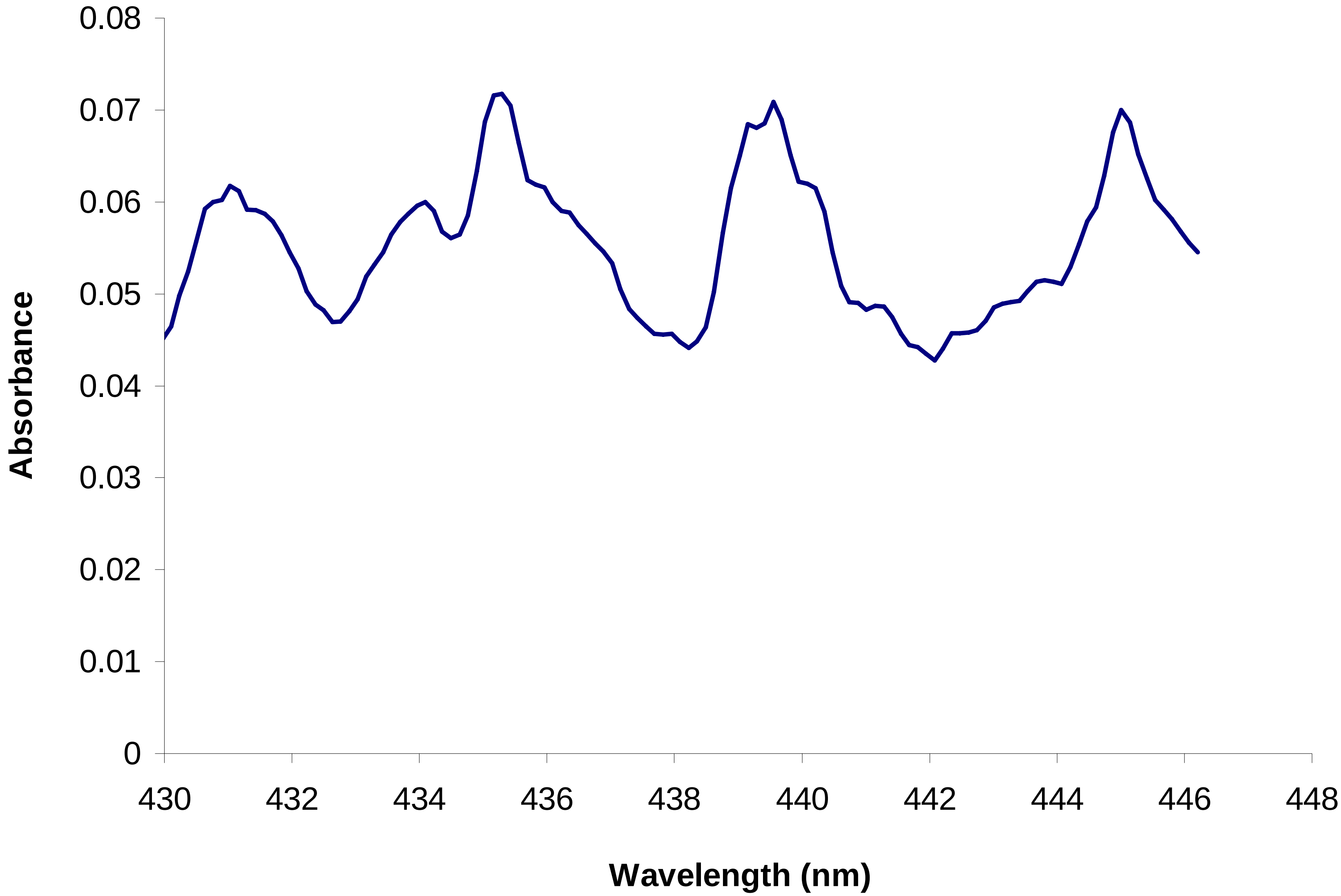
Pollutant Ratio Plots



UV Dispersive Spectroscopy

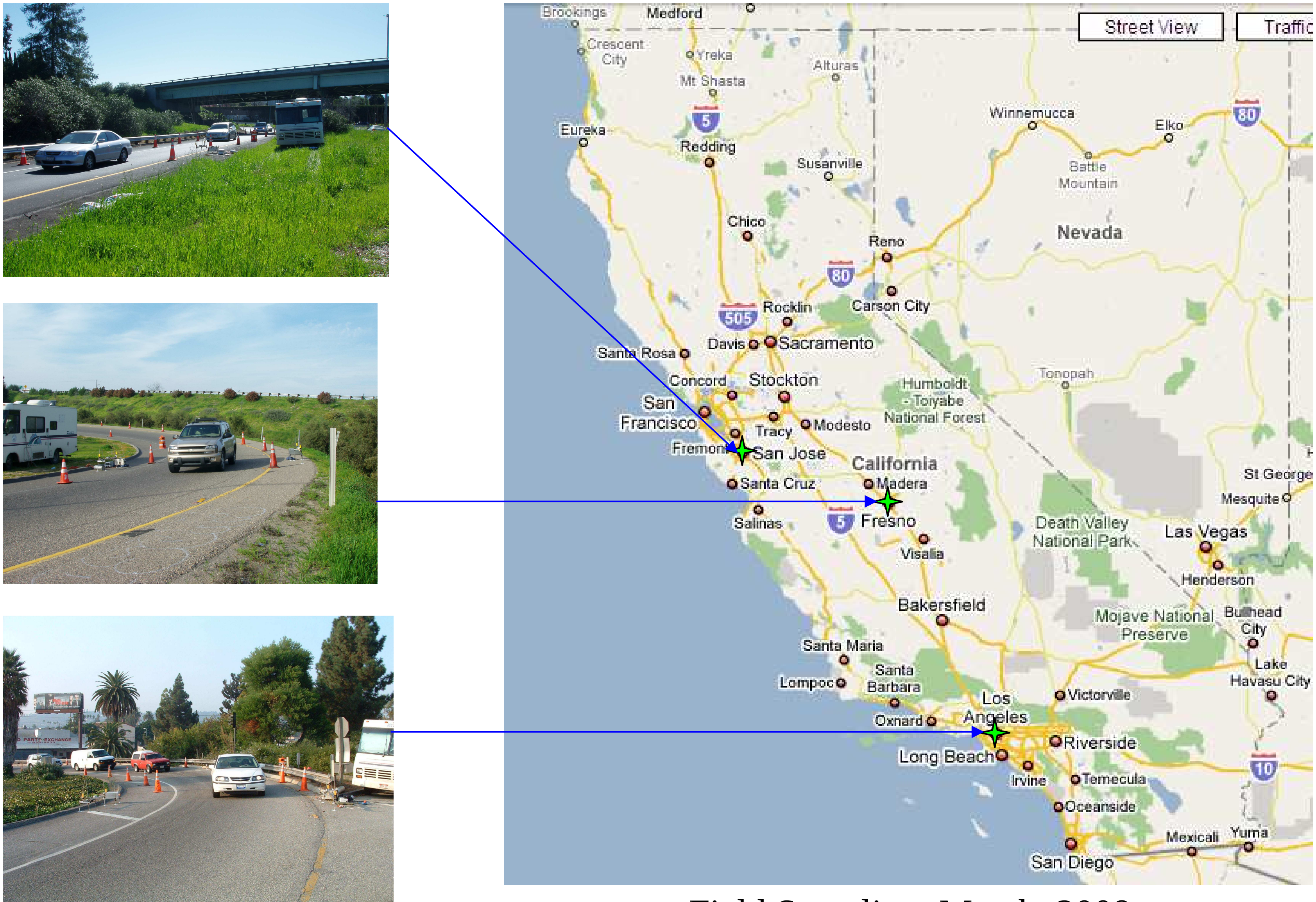


NO_2 Spectrum from FEAT Remote Sensor




14:21:12
0.01 0.004 0.0011 15.05

Three Field Sampling Sites



Field Sampling: March, 2008

San Jose Site / Nb I-280 to Nb I-880

March 4 – 7, 2008

Attempts / Valid Gas / Matched

31,116 / 25,371 / 24,978

Mean CO – 16.6 g/kg

Mean HC – 1.5 g/kg

Mean NO – 2.6 g/kg

Mean SO_2 – 0.06 g/kg

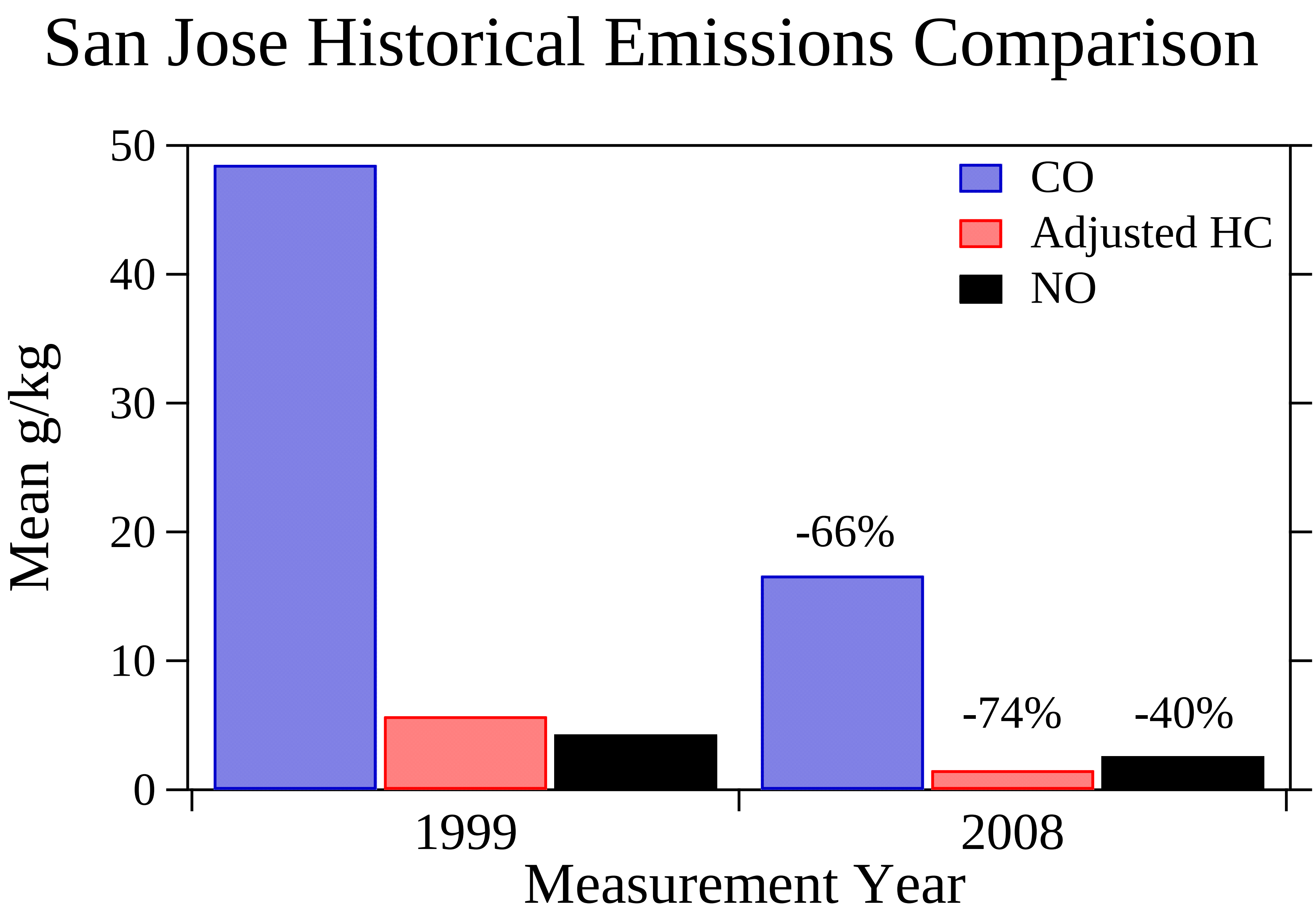
Mean NH_3 – 0.5 g/kg

Mean NO_2 – 0.05 g/kg

Mean MY – 2000.6

Mean Speed – 30.6 mph

Mean Accel – 1.0 mph/s


San Jose Historical Emissions Comparison
50
40
30
20
10
0
Mean g/kg
CO
Adjusted HC
NO
-66%
-74%
-40%
1999
2008
Measurement Year

Fresno Site / Nb US-41 to Nb US-180

March 8 – 14, 2008

Attempts / Valid Gas / Matched

15,656 / 15,048 / 13,365

Mean CO – 20 g/kg

Mean HC – 2.9 g/kg

Mean NO – 2.9 g/kg

Mean SO_2 – 0.09 g/kg

Mean NH_3 – 0.5 g/kg

Mean NO_2 – 0.14 g/kg

Mean MY – 1999.8

Mean Speed – 25.4 mph

Mean Accel – 0 mph/s

West LA Site / Sb Labrea Blvd. to Eb I-10

March 17 – 21, 2008

Attempts / Valid Gas / Matched

23,579 / 22,072 / 17,953

Mean CO – 21.4 g/kg

Mean HC – 1.8 g/kg

Mean NO – 3.75 g/kg

Mean SO_2 – 0.07 g/kg

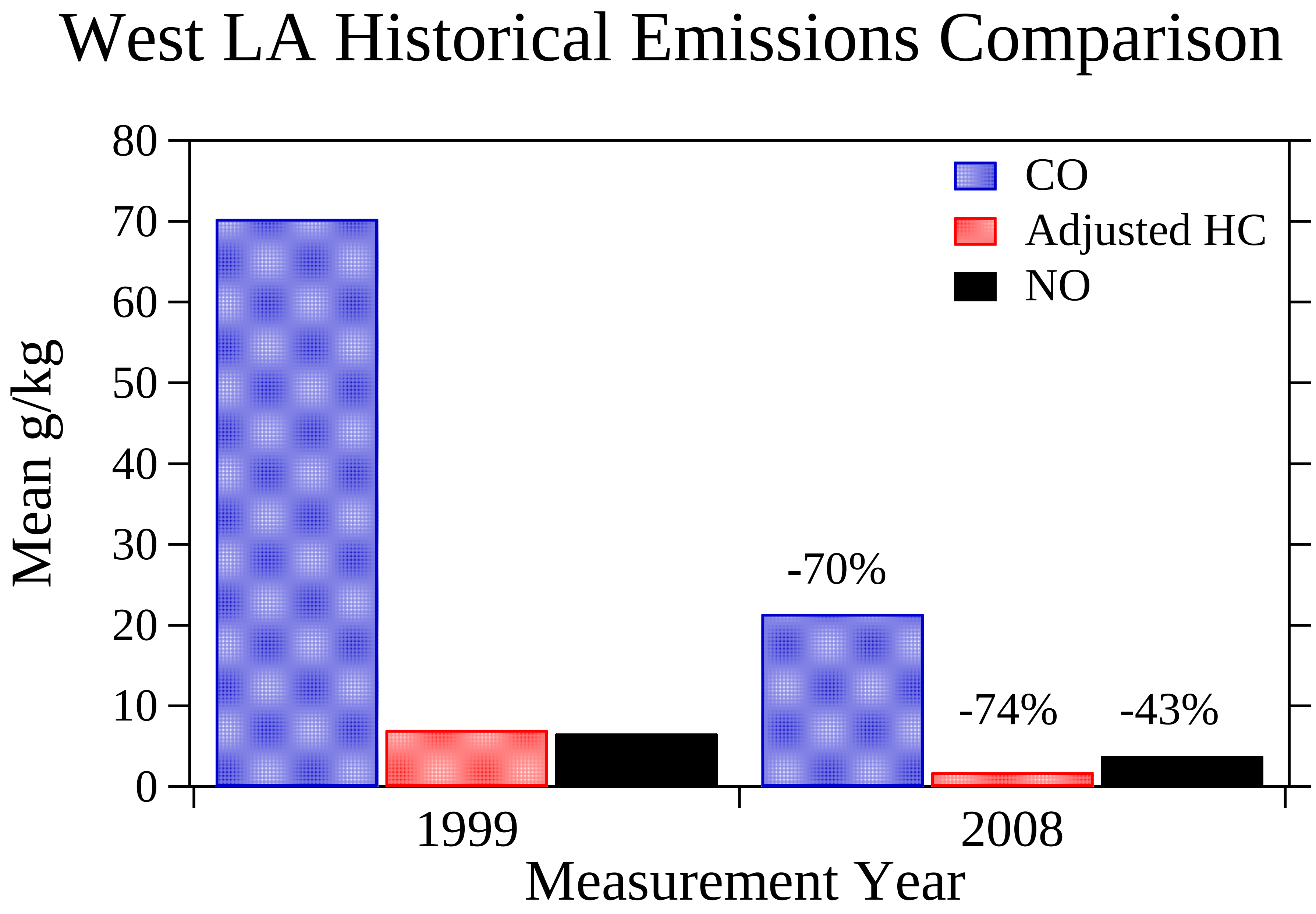
Mean NH_3 – 0.8 g/kg

Mean NO_2 – 0.08 g/kg

Mean MY – 2001.2

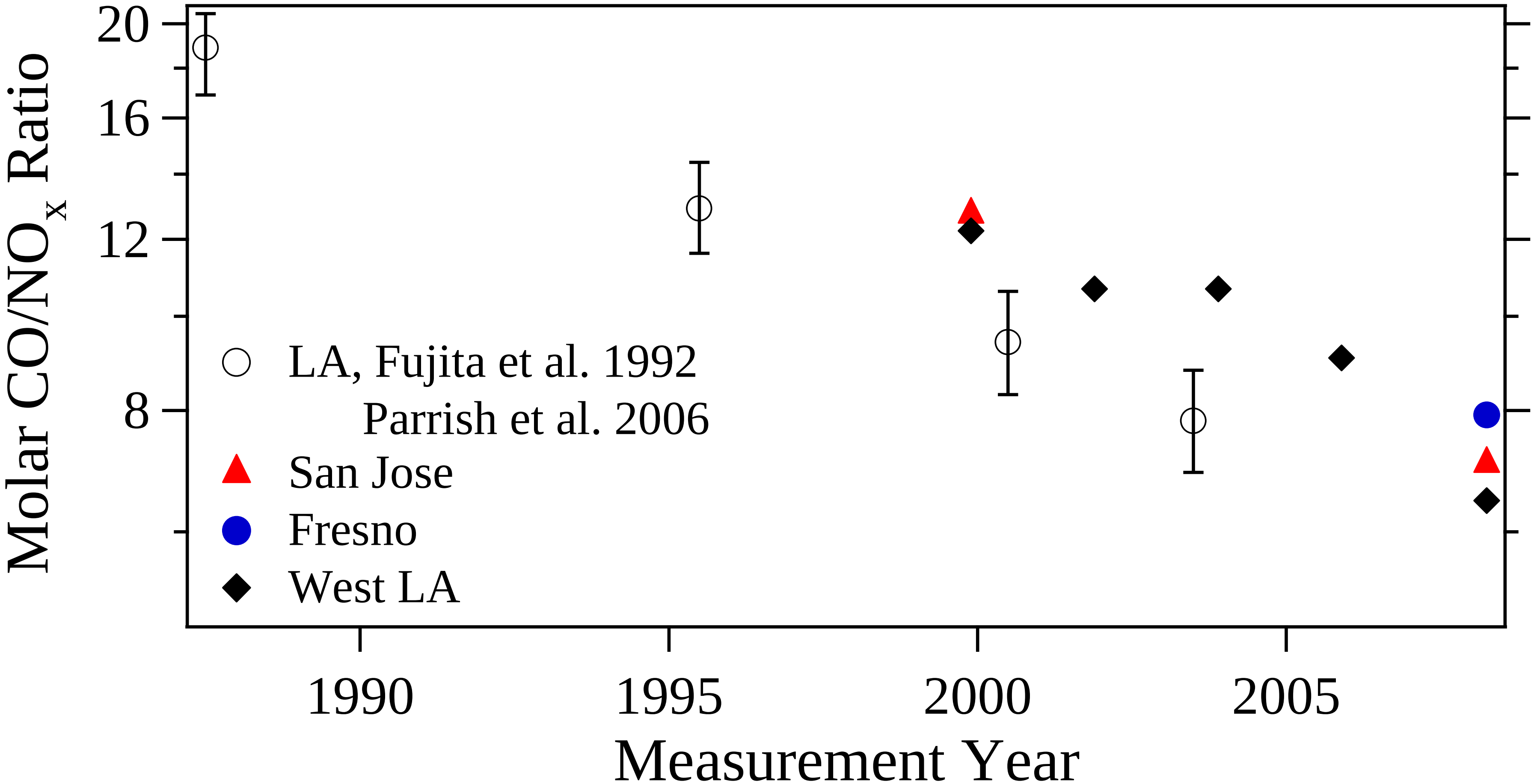
Mean Speed – 17.6 mph

Mean Accel – 1.9 mph/s



West LA Historical Emissions Comparison
CO
Adjusted HC
NO
-70%
-74%
-43%
0
10
20
30
40
50
60
70
80
Mean g/kg
1999
2008
Measurement Year

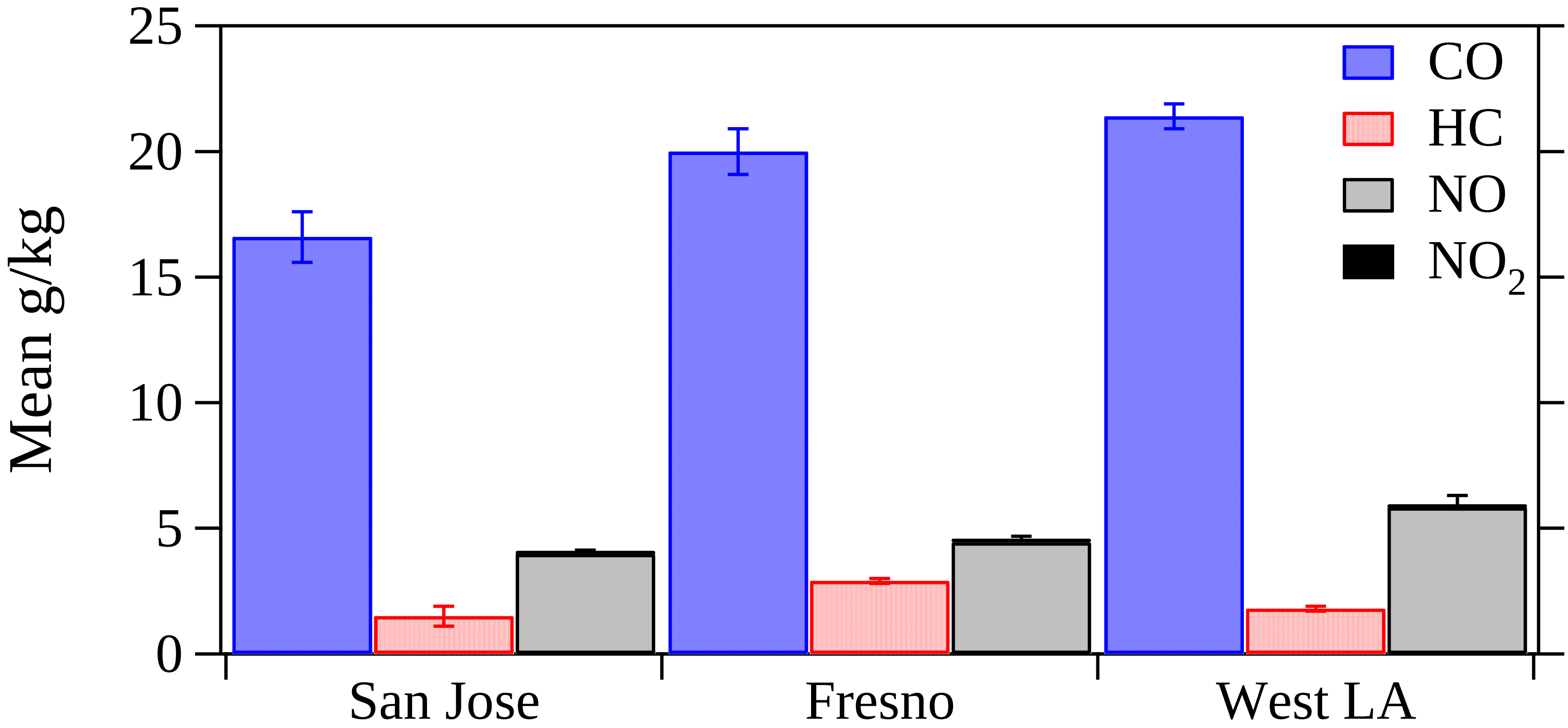
CO/NO_x Emissions Trend Comparison



Parrish LA -5.5 ± 0.4%   San Jose -7.1%   WLA -7.0 ± 0.2%

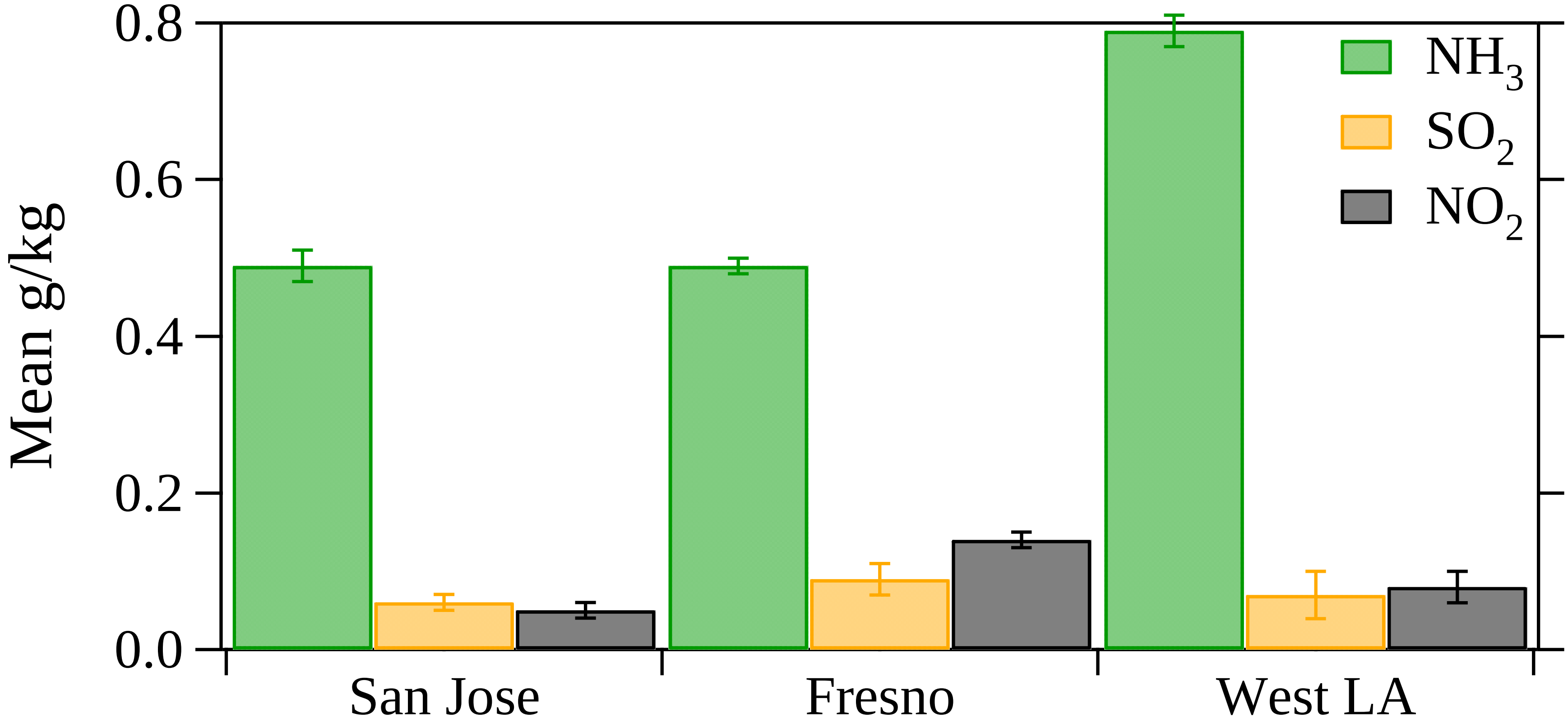
Parrish Nashville -8.8 ± 1.0%

Summary of Regulated Emissions



Grams of NO reported as grams of NO_2 so bar height equals total NO_x.
Error bars are standard errors of the means calculated from the daily means.

Summary of Specialty Species



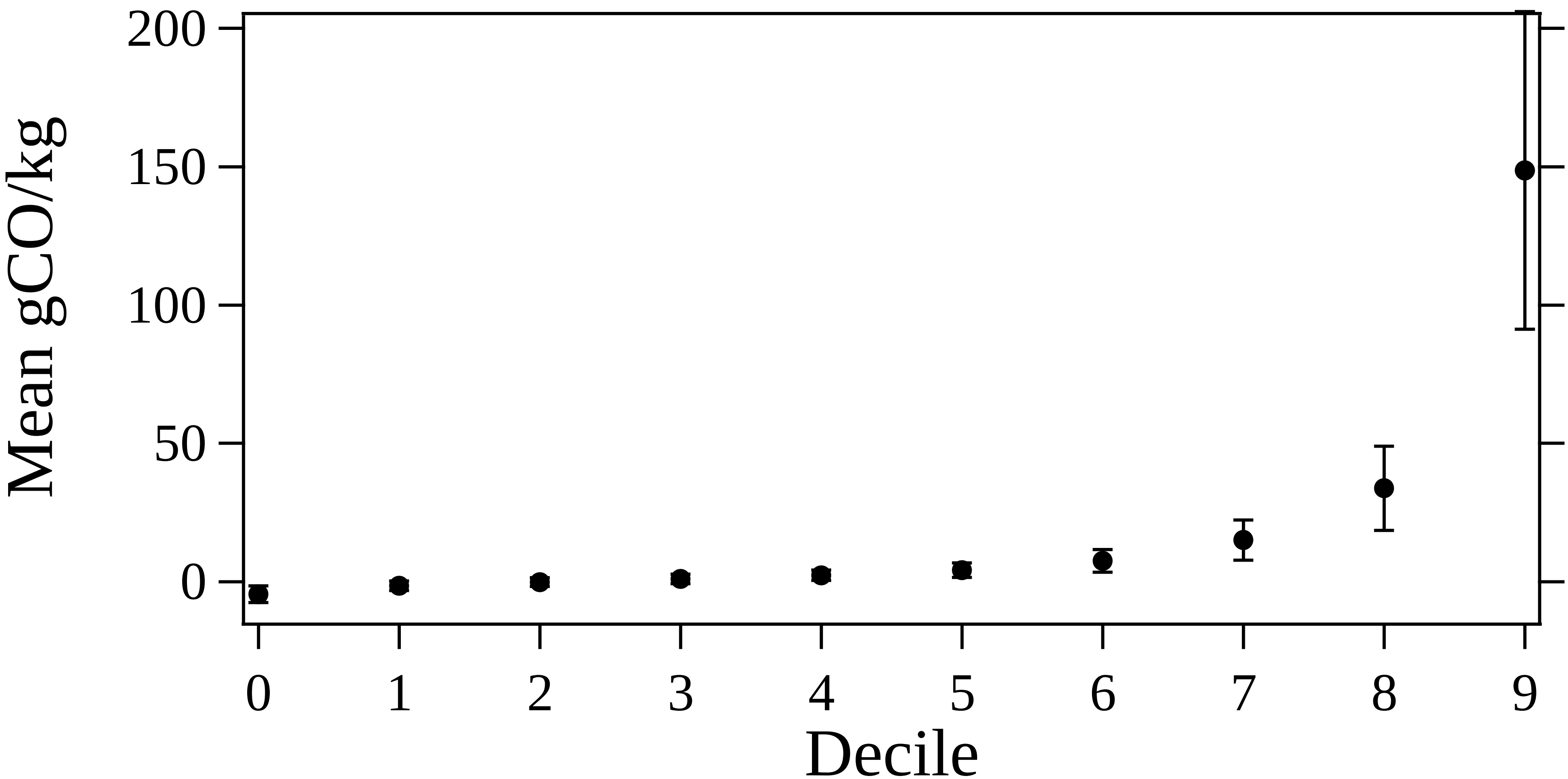
Baum et al. (1999) 0.35 g/kg   Burgard et al. (2005) 0.47 ± 0.02 and 0.51 ± 0.01
Kean et al (2000 and 2006) 0.64 ± 0.04 and 0.4 ± 0.02
Error bars are standard errors of the means calculated from the daily means.

There are still low hanging emissions…

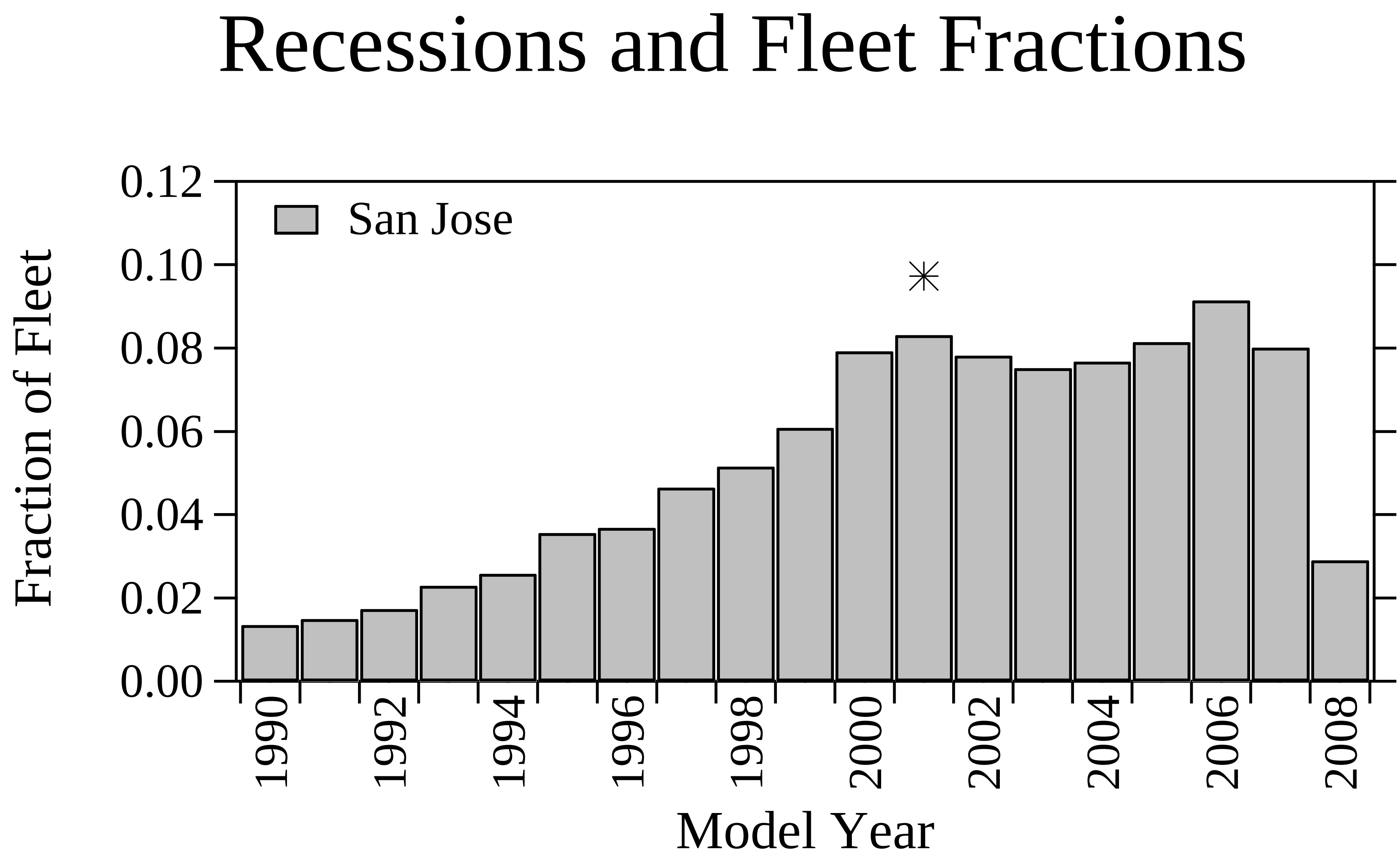
Top 1% Contribute	CO	HC	NO
San Jose	34%	17%	16%
Fresno	33%	15%	15%
West LA	31%	38%	14%
Denver 2007	27%	34%	12%

If a study misses one vehicle out of 100, these are the potential errors in the resulting inventory

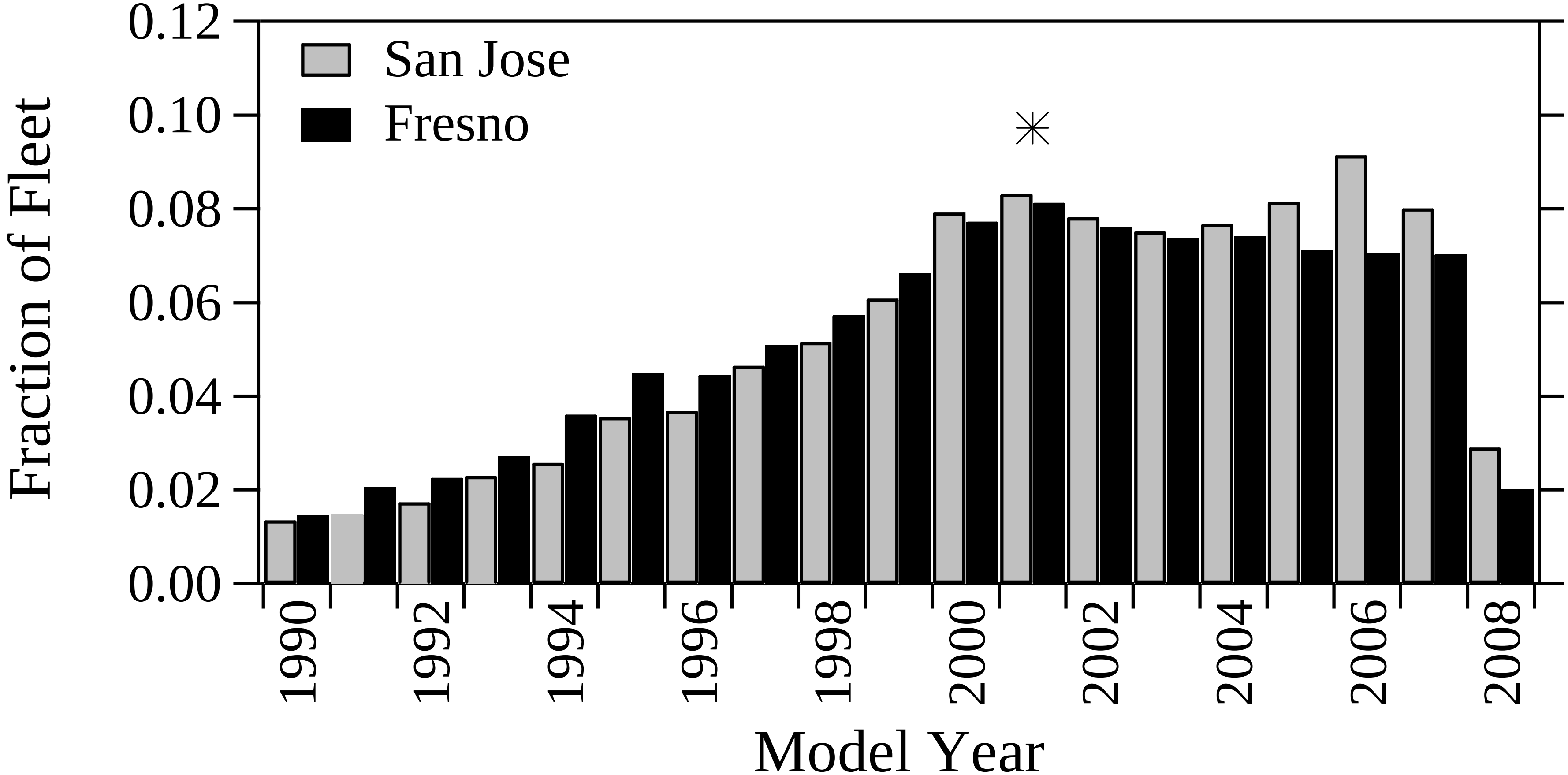
High Emitter Variability



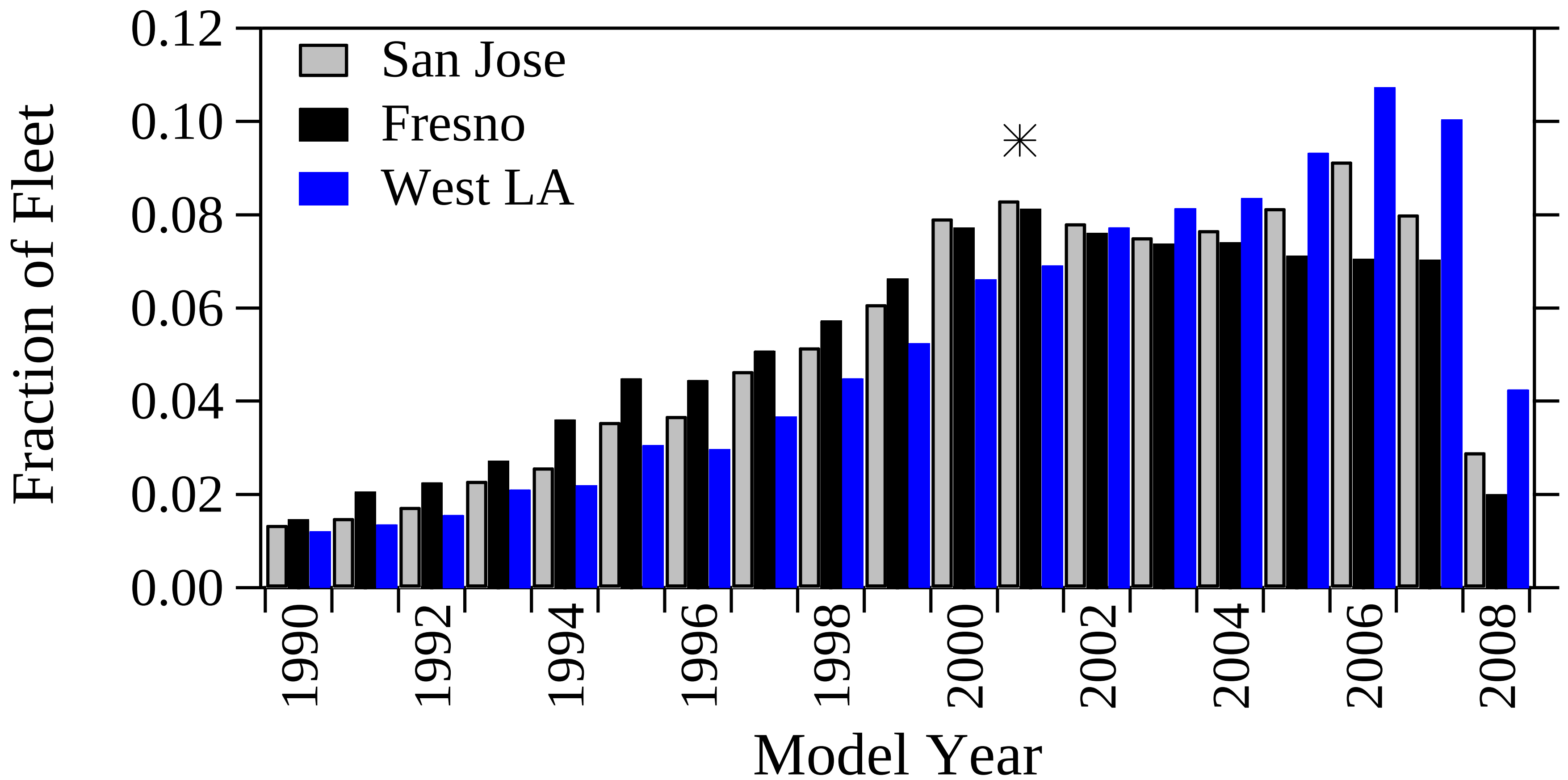
All cities combined and 960 vehicles selected that have at least 3 repeat measurements.

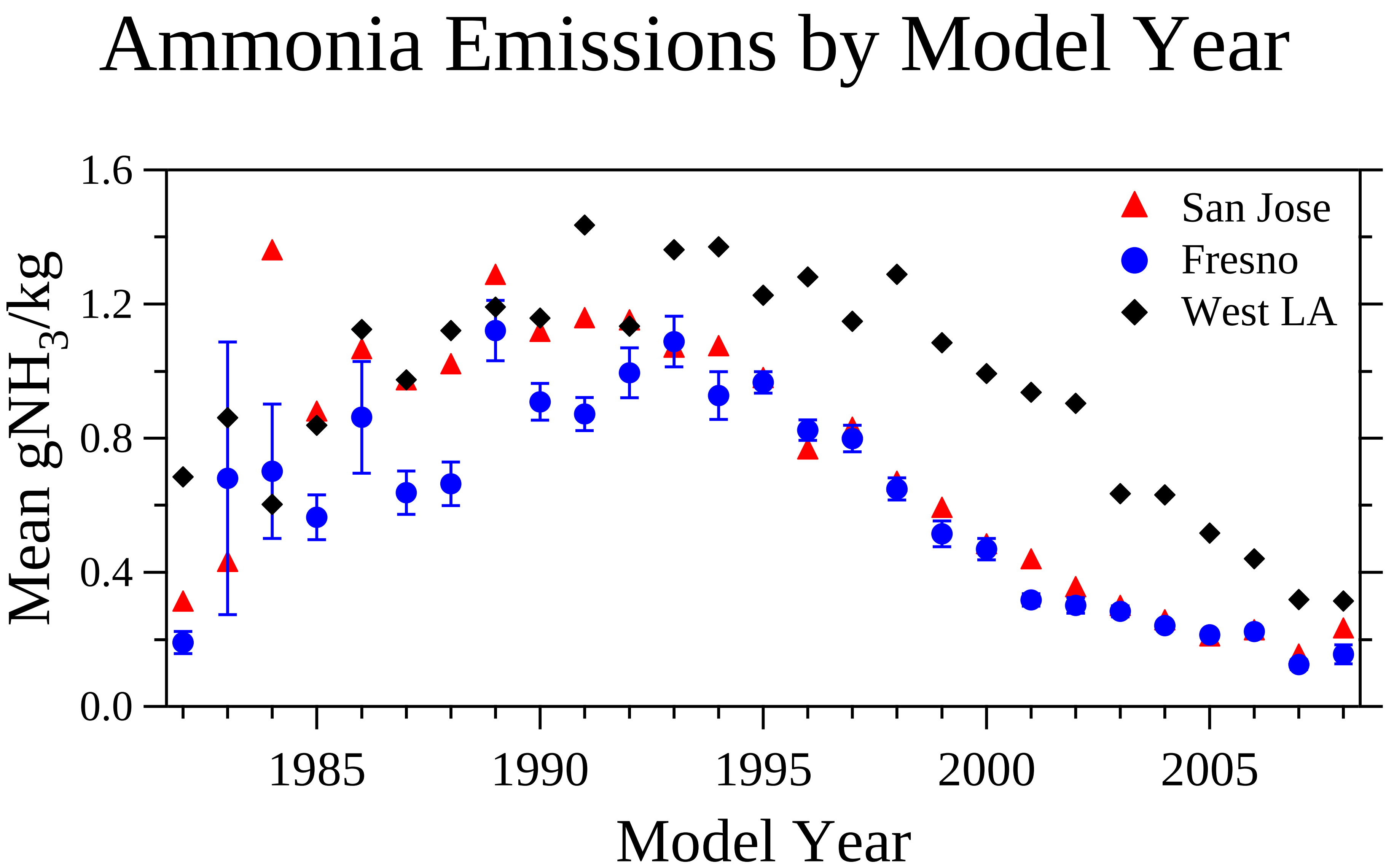

Recessions and Fleet Fractions
San Jose
Fraction of Fleet
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Model Year

Recessions and Fleet Fractions

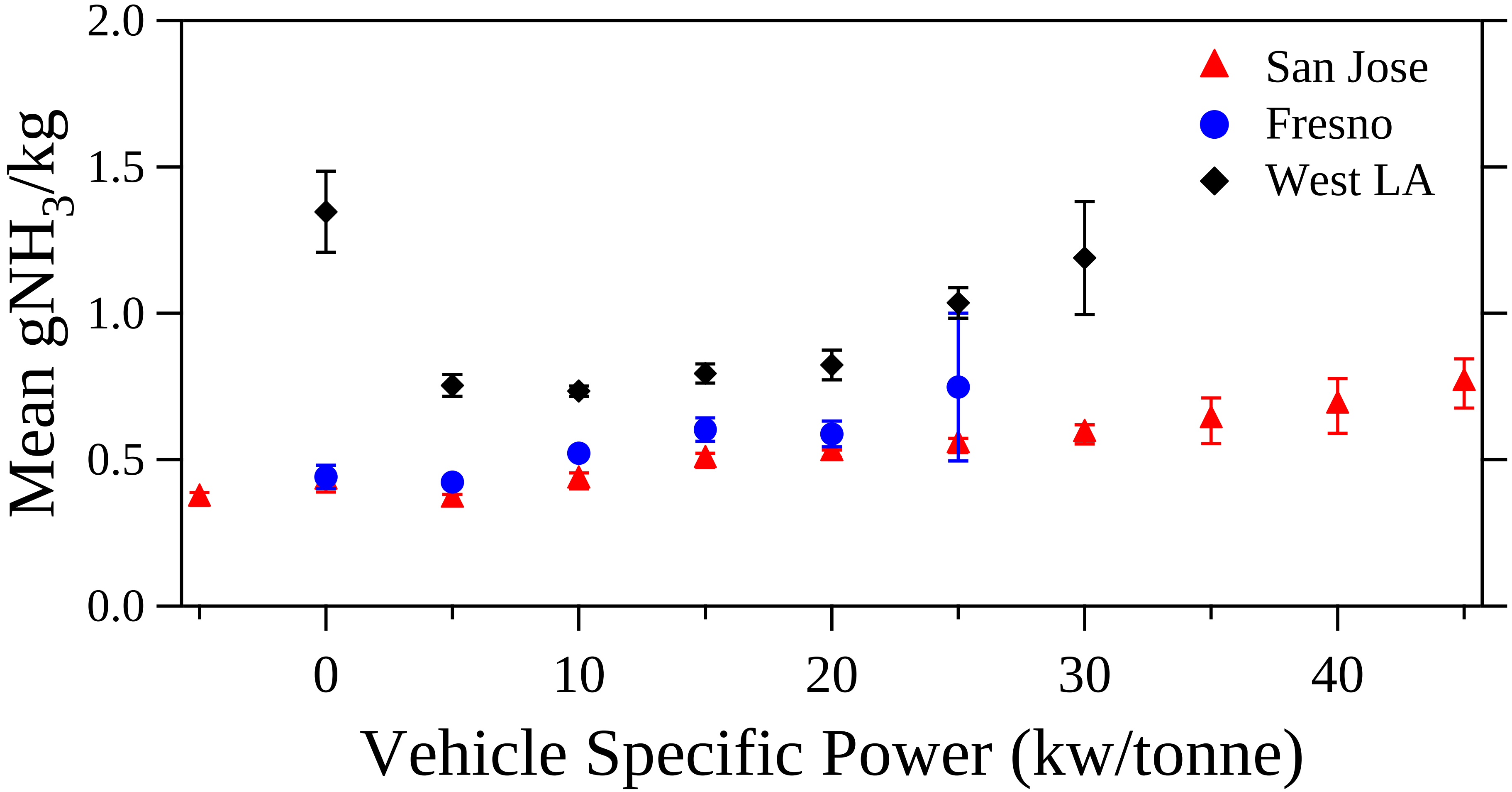


Recessions and Fleet Fractions

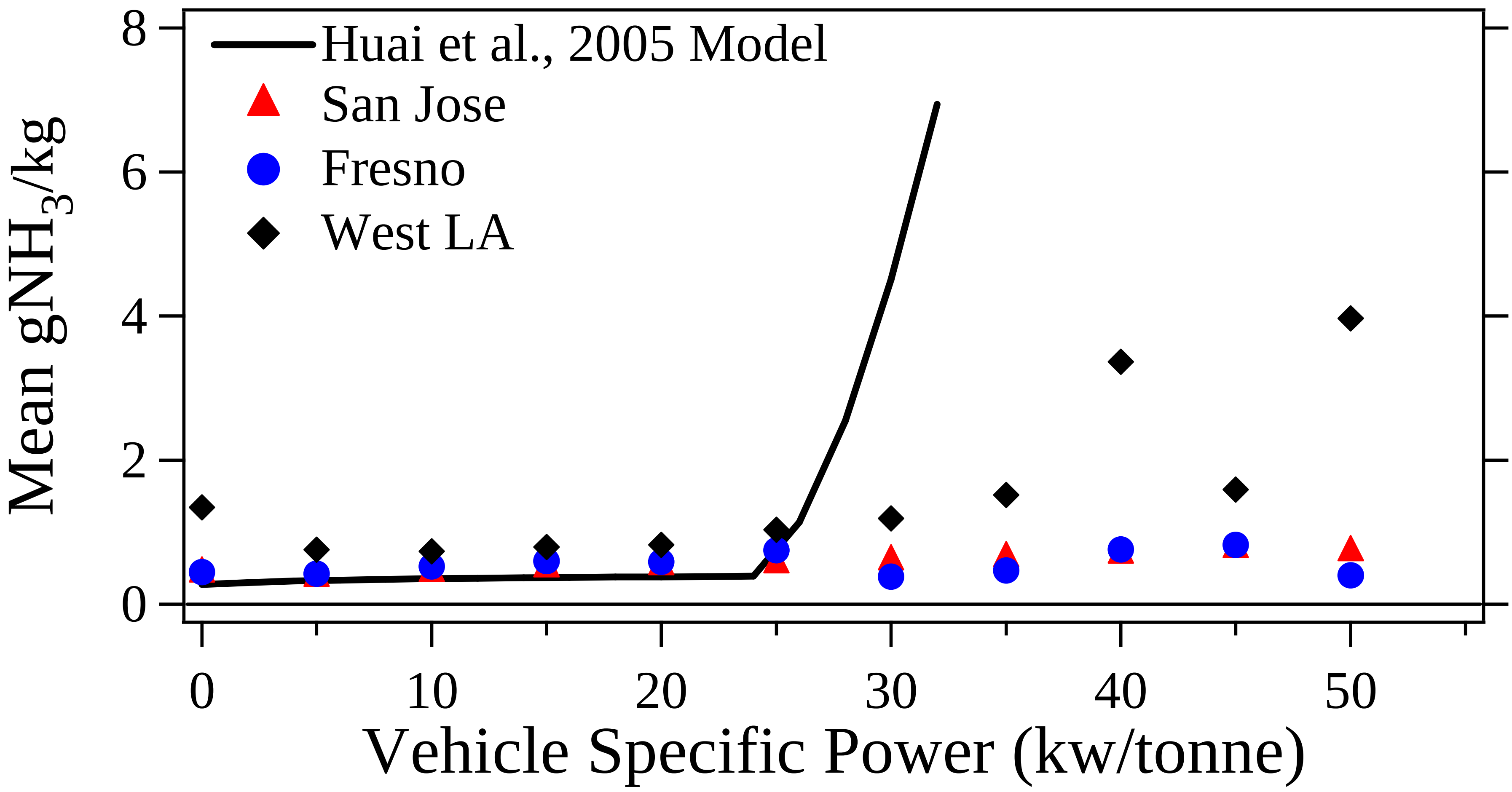



Ammonia Emissions by Model Year
Mean gNH_3/kg
Model Year
San Jose
Fresno
West LA
0.0
0.4
0.8
1.2
1.6
1985
1990
1995
2000
2005

VSP Dependence of Ammonia Emissions

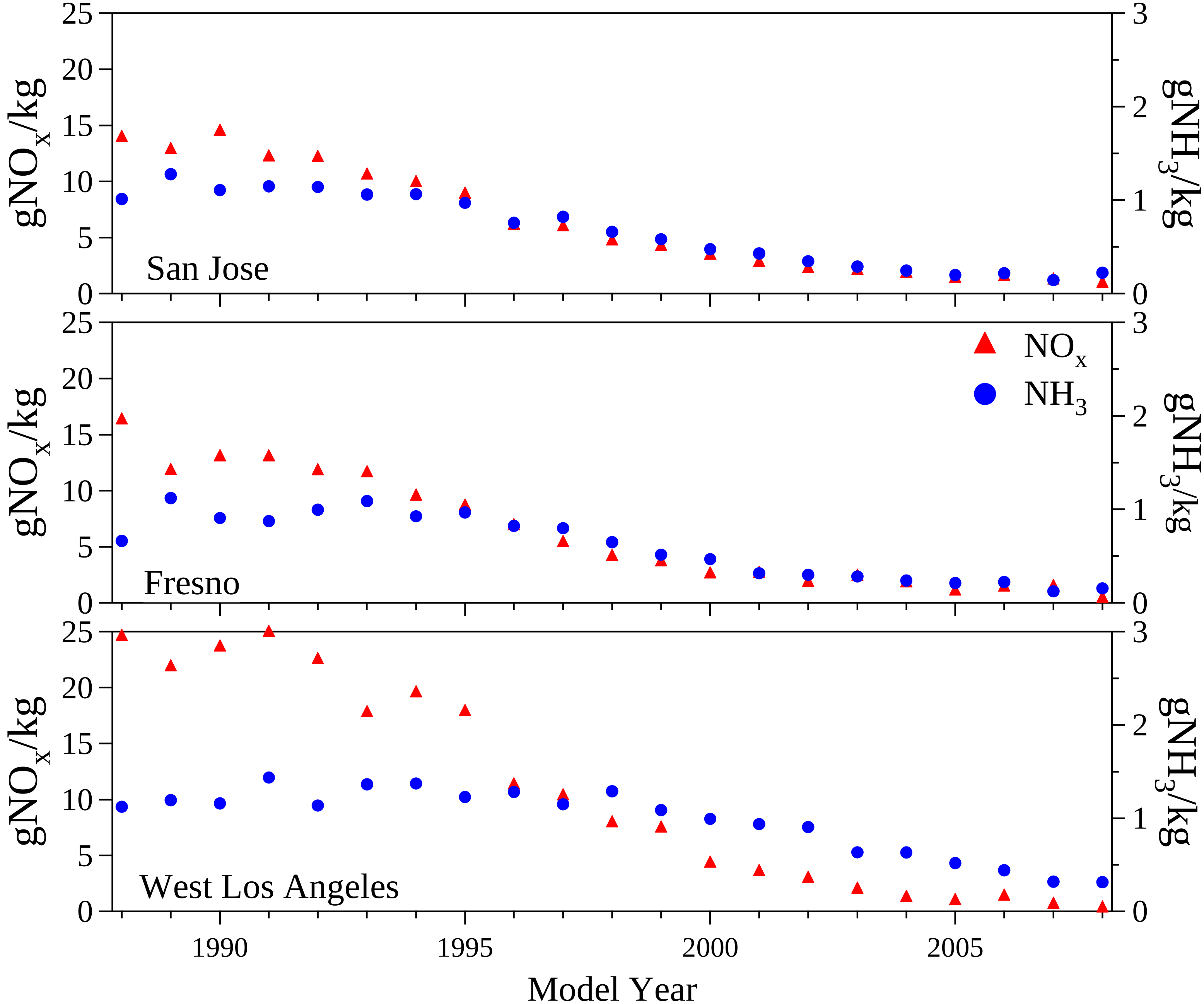


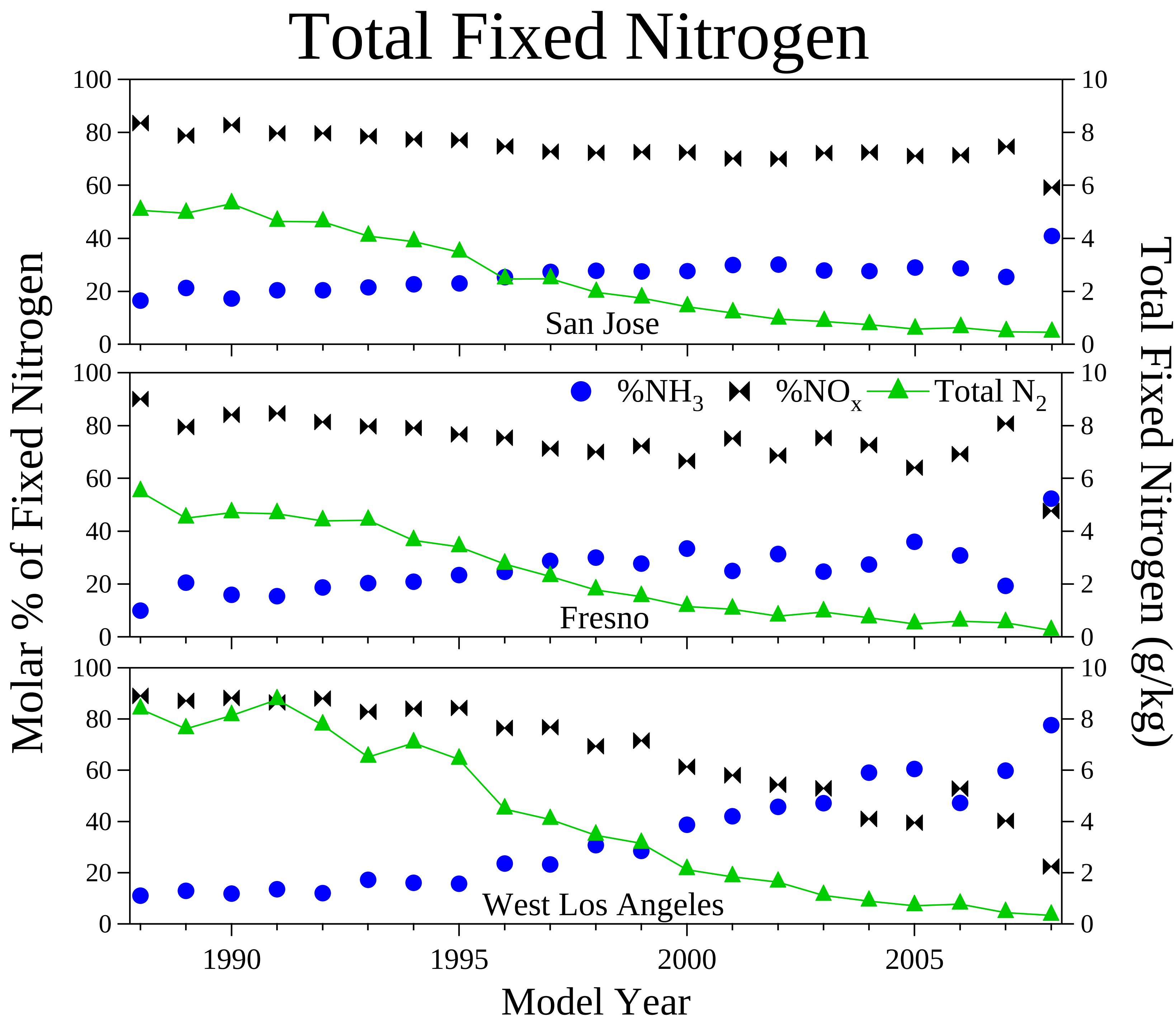
Huai’s Ammonia Model Comparison



Note: West LA points at vsp’s of 40, 45 and 50 have only 9, 9 and 3 vehicles.

NO_x and NH_3 Emission Trends





Total Fixed Nitrogen
Molar % of Fixed Nitrogen
Total Fixed Nitrogen (g/kg)
San Jose
Fresno
West Los Angeles
%NH3
%NOx
Total N2
Model Year
0
20
40
60
80
100
0
2
4
6
8
10
1990
1995
2000
2005

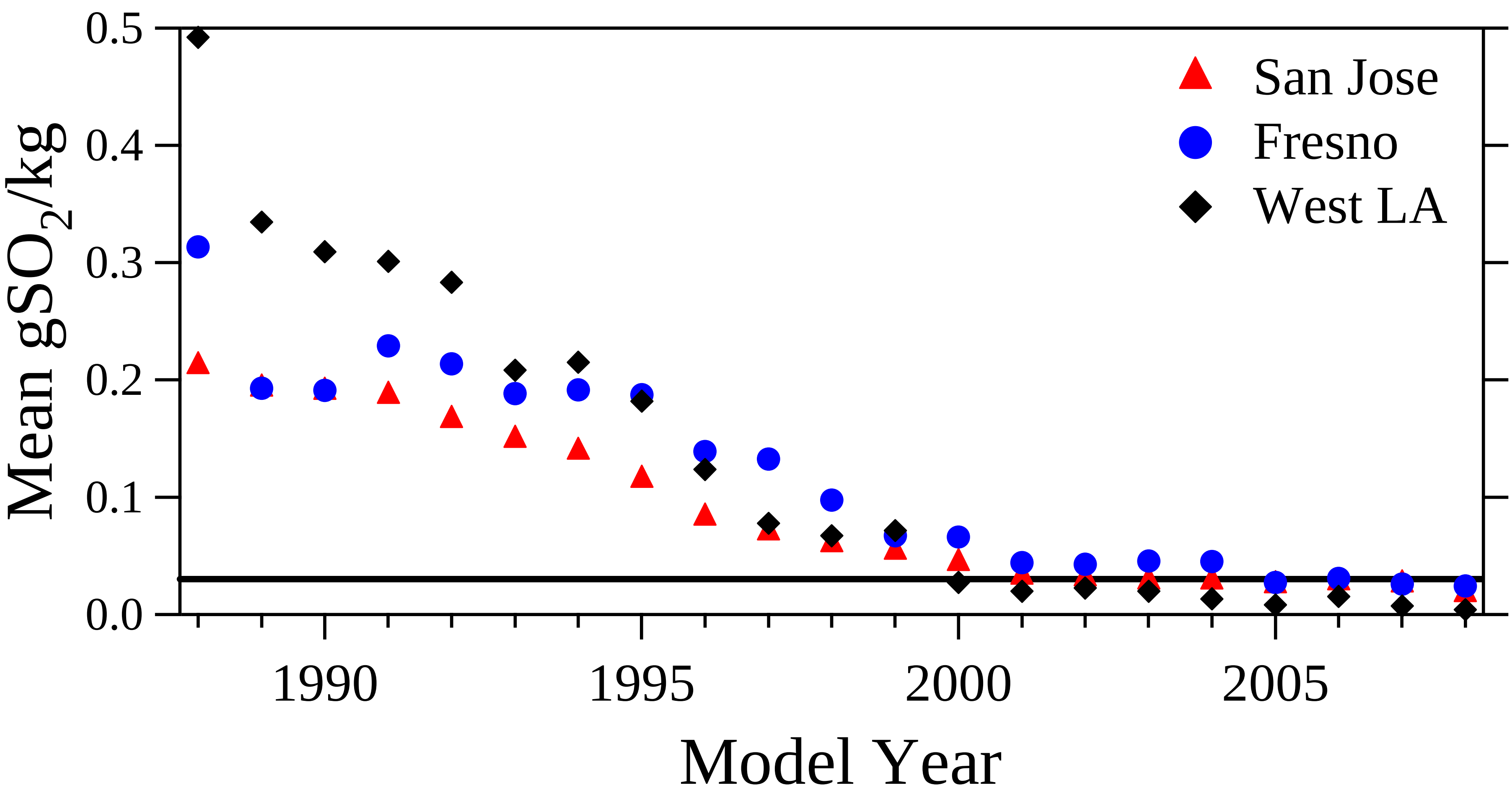
2007 National Ammonia Inventory Comparison

City	Mean gNH_3/kg	National* NH_3 Short Tons
San Jose / Fresno	0.49	210,000
West LA	0.79	330,000

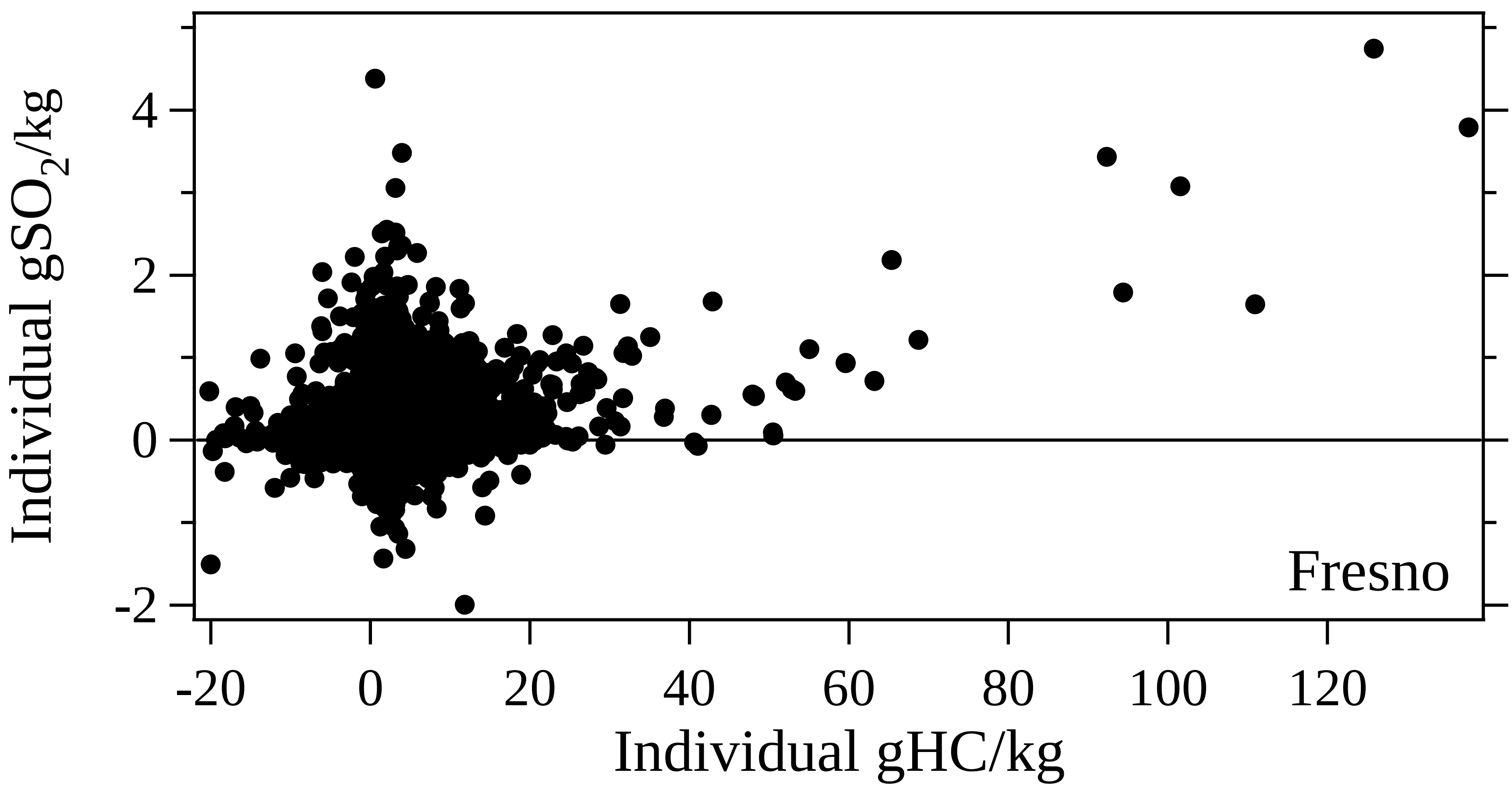
The US EPA 2007 Estimate is 307,000 short tons.

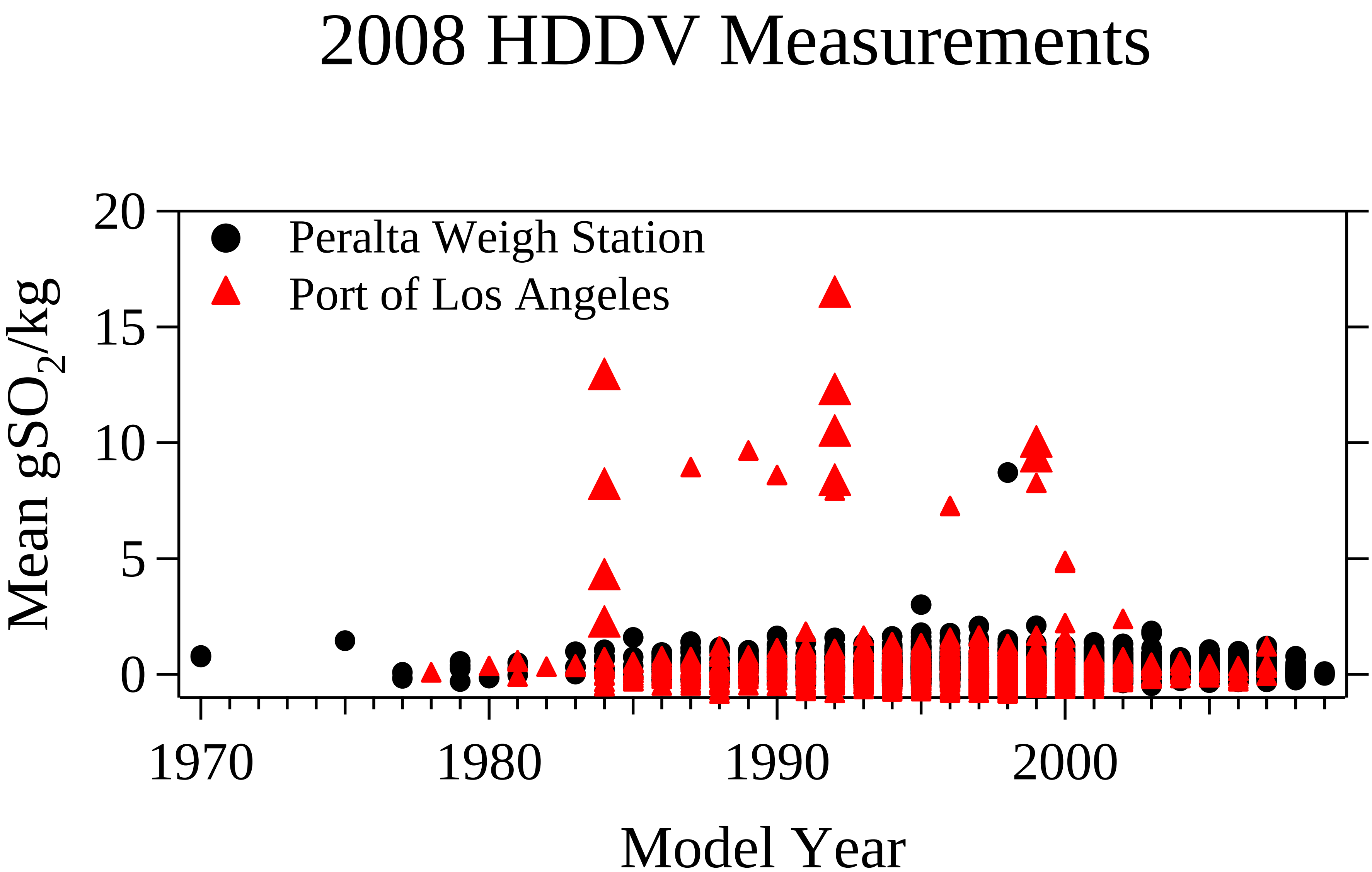
*Assumes 378,000,000 gal/day of gasoline and a density of 6.073 lbs/gallon and NH_3 emissions are negligible from cold start gasoline and all diesel vehicles.

Sulfur Dioxide Emission by Model Year

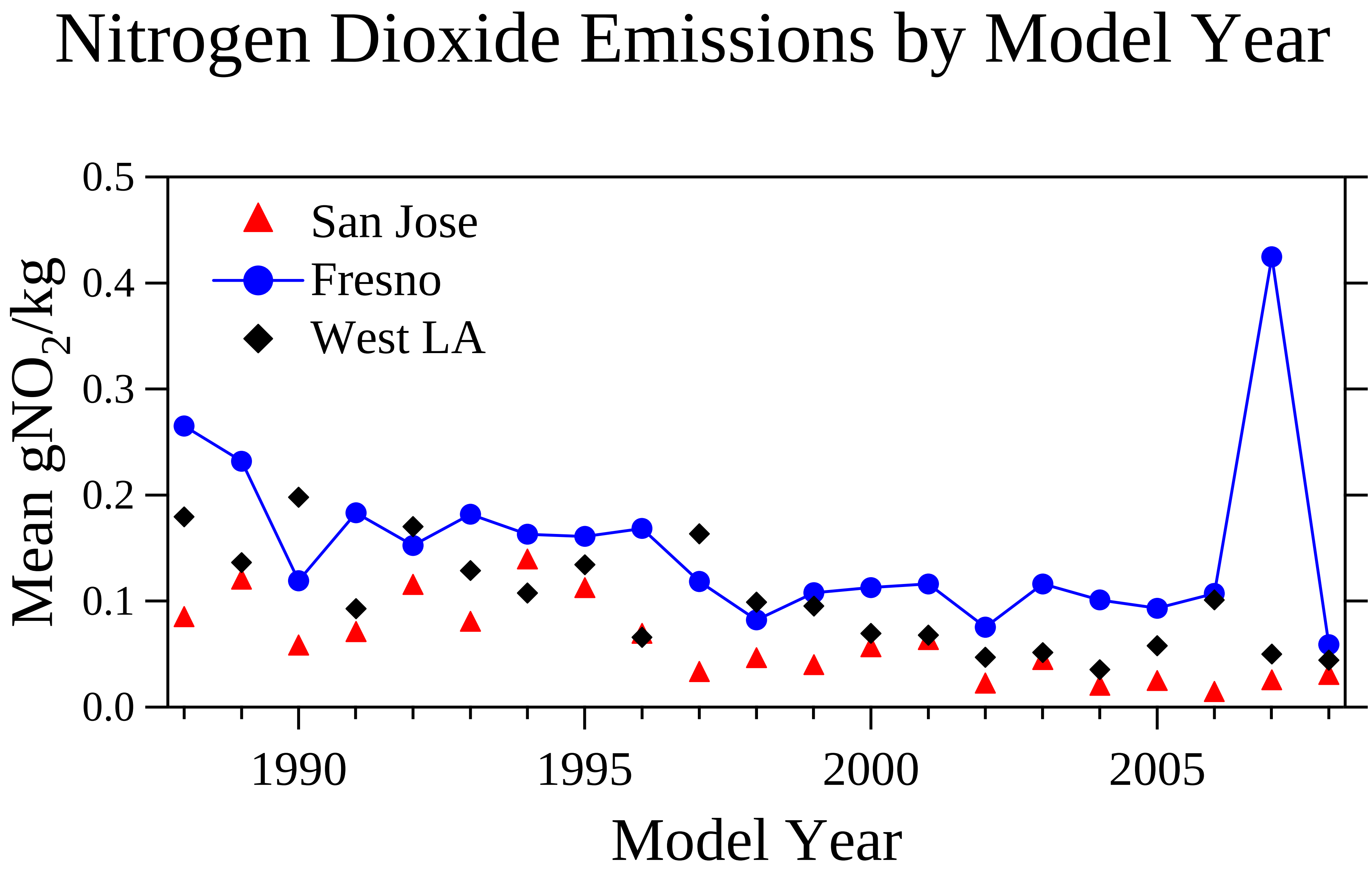


Hydrocarbon Interference





2008 HDDV Measurements
Peralta Weigh Station
Port of Los Angeles
Mean gSO2/kg
20
15
10
5
0
1970
1980
1990
2000
Model Year



Nitrogen Dioxide Emissions by Model Year
Mean gNO2/kg
0.0
0.1
0.2
0.3
0.4
0.5
San Jose
Fresno
West LA
1990
1995
2000
2005
Model Year

Fresno 2007 Model Year Fleet Comparison

Group	Samples	Mean %IR Opacity	Mean gNH_3/kg	Mean g/kg $NO/NO_2/NO_x$	Mass Ratio NO_2/NO_x
Sprinters	57	**0.6 ± 0.2**	0.02 ± 0.01	2.1 ± 0.2 4.9 ± 0.6 **8.0 ± 0.8**	0.61
Other Diesels	22	**1.2 ± 0.7**	0.02 ± 0.01	12.1 ± 0.9 1.4 ± 0.4 **19.9 ± 1.2**	0.07
Non-Diesels	792	**0.4 ± 0.04**	0.14 ± 0.02	0.22 ± 0.08 0.08 ± 0.01 **0.42 ± 0.12**	0.19

Conclusions

- Similar reductions in regulated emissions since 1999 were found at the San Jose and West LA sites.
- New vehicles emit large percentages of their reactive nitrogen as ammonia (up to 80% at the West LA site). Largest ammonia emissions occur in ~15 year old vehicles and is heavily influenced by driving mode.
- Sulfur dioxide emissions show an unexpected model year dependence for older vehicles, likely due to a hydrocarbon interference.
- Nitrogen dioxide emissions are usually less than 5% of the total NO_x, except for a group of diesel powered ambulances observed in Fresno.

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