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Remote Sensing in Four Cities to Determine the Change in On-Road Vehicle Fleet Emissions Over Time

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COORDINATING RESEARCH COUNCIL, INC.

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E-23 Remote Sensing in Four Cities to Determine the Change in On-Road Vehicle Fleet Emissions Over Time

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Executive Summary

The objectives of Project E-23 are to follow vehicle conditions and emissions using remote-sensing measurements of on-road vehicles at selected sites to identify trends over a multi-year period, and use the information to estimate high exhaust emitter populations.

Based on remote- sensing measurements made at a single site in each of four cities, average fleet on-road tailpipe emissions have declined sharply from 1999 to 2006.

Deterioration rates calculated from remote- sensing measurements from this project and from a much larger collection of remote- sensing measurements in St. Louis from 1999 to 2006 were very much lower than predicted by MOBILE6.2 for carbon monoxide (CO), especially for newer vehicles. MOBILE6.2 nitrogen oxide (NO_x) emission deterioration rates were flat over the 1994 to 2002 model years while the remote sensing deterioration rates for NO were decreasing for newer model years; and for 2000 and newer model years, were much lower than the MOBILE6.2 deterioration rates. Volatile organic compound (VOC) on-road emissions deterioration rates from MOBILE6.2 were lower than hydrocarbon (HC) deterioration rates measured from remote sensing for 1993 to 1997 model year vehicles; for more recent model year vehicles, rates were similar.

Average fleet on-road tailpipe emissions from newer vehicles were lower at the same age as older vehicles.

The ratios of the highest 95th and 90th percentile emissions to the average emissions of vehicles, at a given model year and age, from 2000-2006 were nearly constant and were the same for all four E-23 sites with measurements in at least four years. Therefore, emissions of the highest emitting vehicles have declined at the same rate as the average fleet emissions. Or, equivalently, at a fixed emissions cut point, in grams per kg of fuel, the percentage of the fleet exceeding that cut point has decreased considerably from 1999 to 2006.

Introduction

CRC Project E-23 was created to observe changes in fleet on-road tailpipe emissions over time. The project used remote sensing at selected sites in four separate cities. At each site, at least 20,000 remote sensing measurements were made during a week at the same time of the year for a number of years.[1] A protocol was established and followed to set the measurement procedures, site and instrument descriptions, quality control procedures, and data reporting. CRC E-23 reports were issued for each year of measurement in each of the cities. The reports list the methodology and calculations, the database definitions, quality control procedures, and an analysis of results. These reports are available at the CRC website and at the University of Denver FEAT website.[2] The latter website also has links to the data collected. A summary of information from these reports and the protocol for collecting and reporting data are shown in Appendix A.

On-road remote sensing pioneered by Professor Donald Stedman in 1989, measured tailpipe emissions from vehicles as they drive by. The technique allows many vehicles to be measured, thereby eliminating many sources of selection bias which can occur when only few vehicles are tested; for example when vehicles are selected for laboratory testing. Since vehicle emissions distributions are highly skewed, sampling errors lead to erroneous conclusions about fleet emissions when results are extrapolated from measurements on small samples of vehicles.[3]

Remote sensing measures tailpipe emissions over a very short time, about one-tenth of a second of exhaust flow, which typically represents 4 to 12 cylinder firings of exhaust on a four-cylinder vehicle and twice that on an eight-cylinder. However, fleet average remote sensing measurements by model year correlate extremely well with fleet average inspection maintenance (I/M) emission measurements which reflect emissions measurements integrated

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[1] This report analyzes results from measurements made 1999 to 2006. Measurements were started in 1997. Measurements at the same sites are available in Chicago and Denver in 1997 and 1998, although the Denver measurements were made in studies outside of E-23. Early Phoenix measurements were made at an inappropriate site, and the first site used in Los Angeles had to be changed due to road construction. The conclusions reached in this report would not be changed by including the earlier data from Chicago and Denver.

[2] www.crcao.org and http://www.feat.biochem.du.edu/reports.html

[3] T. Wenzel, B.C. Singer , R.S. Slott, Some issues in the statistical analysis of vehicle emissions, *Journal of Transportation and Statistics* ; V. 3 ; Issue 2 ; September 2000

over a range of driving conditions. Stedman, et al., showed that three separate years of model year average remote sensing values of CO, HC, and NO measured at a site in Denver (using 25,000 measurements in 1996 and 1999, and 35,000 measurements in 1997) correlate very well with corresponding average values from IM240 tests in Denver for the whole fleet measured in the respective prior year.[4] Correlations remained excellent when six months' prior IM240 or even one month's prior IM240 data were compared to the remote sensing emissions using E-23 remote sensing measurements from 2001.[5] Pokahel presented correlations between the 1998 E-23 measurements in Phoenix and Chicago and the 1998 Arizona and Illinois IM240 data, respectively.[6] These correlations confirm that the E-23 protocol (based on 20,000 vehicle measurements) at the E-23 sites should be sufficient to model on-road hot stabilized vehicle fleet emissions.[7]

When spark ignition (SI) engine vehicles burn gasoline some CO from incomplete combustion and NO are also produced. HC also are emitted from the engine as partial combustion products or unburned fuel. The emissions produced in the engine depend on air/fuel ratio and engine design. However, even in well maintained modern vehicle SI engines, spikes of engine-out emissions occur after fuel cutoff during decelerations and during sudden accelerations.[8]

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[4] P. J. Popp, S. S. Pokharel, G. A. Bishop and D. H. Stedman, On-Road Remote Sensing of Automobile Emissions in the Denver Area: Year 1, Prepared for Coordinating Research Council, Inc., December 1999, CRC Project No. E-23-4-99.

[5] S. S. Pokharel, G. A. Bishop and D. H. Stedman, On-Road Remote Sensing of Automobile Emissions in the Denver Area: Year 3, Prepared for Coordinating Research Council, Inc., January 2002, CRC Project No. E-23-4.

[6] S. S. Pokharel, RSD Versus IM240 Fleet Average Correlations, Tenth CRC On-Road Vehicle Emissions Workshop, March 27-29, 2000.

[7] Correlation of HC and CO remote sensing measurements averaged by model year with corresponding IM240 values of were also found in St. Louis as part of the Gateway Clean Screening Program (P. McClintock, "Gateway Clean Air Program Annual RapidScreen Report January 2001 - December 2001", Prepared for Missouri Department of Natural Resources, July 2002, pages 42-43) and in Denver, Colorado using independent measurements (P. McClintock, "The Denver Remote Sensing Clean Screening Pilot", ESP report for the Colorado Department of Health, December 1999, pages 58-60), and in Vancouver, British Columbia (ESP, "Draft Preliminary Analysis of Remote Sensing Device Feasibility in the Greater Vancouver Regional District" Prepared for The Aircare Steering Committee, May 2004, pages 33-37).

[8] T. Hands, M. Peckham and B. Campbell, SAE Technical Paper Series 2001-01-3540 Transient SI Engine

Modern SI engine vehicles are equipped with catalytic converters to convert engine-out emissions to CO_2, nitrogen and water. When emission control and fuel metering systems are working, vehicle tailpipe emissions are extremely low. However, if fuel system components are not working properly and the air/fuel ratio is either too rich (high CO) or too lean (high NO), much higher emissions come from the engine. If the catalytic converter is no longer working properly, higher emissions of multiple pollutants will come out the tailpipe.

Higher emissions also occur during cold start conditions when the catalyst has not warmed up to operating temperature. When making remote- sensing measurements for Project E-23, sites were chosen to minimize the number of vehicles which may be in cold start. For example, the off ramp of a freeway was chosen in Denver as the E-23 site.

Wenzel and Ross have classified high-emitting vehicles operating under hot stabilized conditions according to their fuel rate, engine out emissions, and tailpipe out emissions.[9] All types of high emitters fell into two groups: vehicles which were sensitive to fuel/throttle fluctuations, and vehicles which were chronically high emitters. The former type of high emitters' emissions would be variable, and their emissions would depend on the driving conditions.

Remote- sensing measurements show that a relatively small percent of measurements contribute a disproportionate amount of the emissions measured. Since emissions vary with driving conditions for some high emitters, and day to day in other high emitters, emission distributions found in remote- sensing measurements are lower limit estimates of the percent of high tailpipe emitters in the fleet for the pollutant measured.

One parameter useful to help characterize a vehicle's driving condition is vehicle specific power (VSP). VSP is the instantaneous power per unit mass of the vehicle and can be calculated from speed, acceleration, and road grade -- measurements easily obtained during

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Emissions Measurements on the FTP75 Drive Cycle with a Fast Response CO Instrument, Reprinted from General Emissions and Gasoline Emission Control Systems (SP–1644), International Fall Fuels and Lubricants Meeting and Exposition, San Antonio, Texas, September 24-27, 2001.

[9] T. Wenzel and M. Ross, SAE Technical Paper Series 981414, Characterization of Recent-Model High-Emitting Automobiles, Reprinted from Advances in General Emissions (SP-1367), International Spring Fuels and Lubricants Meeting and Exposition, Dearborn, Michigan, May 4-6, 1998.

remote- sensing campaigns.[10] When VSP is greater than zero, VSP is linearly related to the amount of fuel delivered to the engine for a single vehicle[11]. When multiple vehicles were examined, the slope and intercept of the linear relationship were found to be related to vehicle and fuel parameters similarly to the PERE equation.[12] [13] The PERE equation is a physically derived equation based on the premise that for a given vehicle, (engine out) running emissions formation is dependent on the amount of fuel consumed

Engine-out emissions would be expected to be related to the fuel rate and hence to VSP. One possible objection to VSP calculated from remote- sensing measurements is that speed and acceleration are measured when the emissions have left the tailpipe rather than when the emissions are generated in the engine. However, under the driving conditions at E-23 sites, speed and acceleration measured at the time emissions leave the tailpipe introduces a very small error according to experiments with two remote sensors at the E-23 site in Phoenix in 2000.[14]

When vehicle emissions are averaged by both VSP and model year, the effect of VSP on fleet emissions can be seen from large numbers of remote sensing measurements made in the 2002 Virginia remote sensing pilot.[15] The relationship of average emissions to VSP is shown in Appendix C, Figures 1 through 3.[16]

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[10] J.L. Jimenez-Palacios, Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing, MIT Thesis, February 1999; Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies J. L. Jiménez, P. McClintock, G.J. McRae, D. D. Nelson and M. S. Zahniser, 9th CRC On-Road Vehicle Emissions Workshop, San Diego,CA, April 21, 1999.

[11] J.L. Jimenez-Palacious, ibid.

[12]; R.S. Slott, Converting Remote Sensing Results to Gram/Mile, 13th CRC On-Road Vehicle Emissions Workshop, San Diego, CA April 7-9, 2003; C.E. Lindhjem, A.K. Pollack, R.S. Slott, R.F. Sawyer, CRC Project E-68, Analysis Of EPA's Draft Plan For Emissions Modeling In Moves And Moves GHG, Prepared for Coordinating Research Council, Inc., February 2004, Section 3-4.

[13] E. Nam, Advanced Technology Vehicle Modeling in " PERE," EPA420-D-04-002, March 2004.

[14] R.S. Slott, Phoenix 2000 Paired Remote Sensing Readings - Measuring Load Before and After Tailpipe Measurements, 12th CRC On Road Workshop, San Diego, CA, April 2002.

[15] R.S. Slott, D. Stedman and S. Pokharel, Interpreting Remote Sensing NOx Measurements, Fall Fuels & Lubricants Meeting, San Antonio, TX, September 24-27, 2001; R. Slott, Emission Trends Observed in E-23; 12th CRC On Road Workshop, San Diego,CA, April 2002.

[16] P. McClintock and R. Klausmeier, Virginia Remote Sensing Device Study – Final Report, Prepared for:

E-23 Measurement Sites

Sites were chosen so vehicles measured would be in a light acceleration mode to avoid fuel cut off and would be very unlikely to be in cold start. The E-23 1998 Phoenix site did not have these characteristics. Since many vehicles were in deceleration at low VSP, the campaign had too low percent of valid measurements. The Phoenix site was changed after the first year of measurements due to low vehicle capture rate caused by driving conditions. Only measurements from the second site are used in this report.

The first site used in Los Angeles in Riverside could not be continued because of road construction. The E-23 site used in Los Angeles at La Brea had been chosen for an earlier study and the 1999 data reported here were gathered for that study.[17] Data from the LaBrea site are used in this report.

A site chosen for a separate two-year E-23 study in Omaha had many vehicles in deceleration at low VSP and showed high HC even for new vehicles. Data from this site were not used in this report.[18]

All the measurements in this report were obtained by the Denver University group. Equipment and site descriptions, criteria for accepting a valid measurement and definitions of fields in the database are described in E-23 reports. The protocol for making measurements, reporting data, and quality assurance is included in Appendix A.

As a percent of attempted measurements, E-23 sites had between 70% and 80% valid CO, HC, NO, and speed measurements with readable license plates. The license plate information was sent to state agencies. The agencies provided information about the vehicles (model year, model, the vehicle identification number (VIN), etc.).[19]

Virginia Department of Environmental Quality, February 2003.

[17] Smog Check II, California Inspection and Maintenance Review Committee, See Part III, Appendix F, June 19, 2000.

[18] R. S. Slott, Analysis of Remote Sensing Data to Determine Deterioration Rates for OBDII Equipped Vehicles, Prepared for Coordinating Research Council, Inc., :June 2006.

[19] Except for the 1999 Los Angeles site which had lower percent valid readings but that data had been obtained for a different study.

For each site the month and years when measurements were made, the average speed, acceleration, VSP, the road slope, and the thousands of measurements are shown in Table A1 in Appendix A. Although each E-23 site was measured at the same time of the year and under the same driving conditions, variations in driving conditions took place during measurement campaigns. The variations in speed and VSP for each year of measurements between 1999 and 2006 are described in charts in Appendix A, along with plots of acceleration as a function of integer speed.

Although each site generally had consistent driving distributions, there were site- to- site differences in distributions of speed, VSP, and acceleration as a function of speed. The Phoenix site had the highest VSP and speed values.

Hourly speed distribution plots can indicate when traffic congestion is taking place ahead of the site, and this occasionally occurred at the Chicago site. A linear increase in acceleration with speed predicts congestion behind the remote- sensing instrument. This is seen in the Los Angeles site which was on a metered on ramp.

Traffic congestion at remote- sensing sites similar to the Chicago and Los Angeles/LaBrea E-23 sites did not significantly affect emissions distributions categorized by vehicle age and VSP.[20]

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[20] R. S. Slott, Effect of Traffic on Remote Sensing Measurements, 14th CRC On Road Workshop, E-23 Meeting, San Diego, CA, available from Coordinating Research Council, Alpharetta, Georgia, March 2004.

Fleet Average Measurements at E-23 Sites

Table 1 shows the fleet average remote sensing measurements at E-23 sites as reported in E-23 reports.

Table 1: Results of Fleet Average Remote Sensing Measurements at E-23 Sites							
City	Year	Month	%CO, avg	HC ppm, adj avg	NO ppm, avg	MYR, avg	Vehicle Age
Chicago	1997	Sept	0.45	130	400	1992.7	6.1
Chicago	1998	Sept	0.39	130	405	1993.6	6.2
Chicago	1999	Sept	0.35	109	378	1994.3	6.5
Chicago	2000	Sept	0.26	94	316	1994.9	6.9
Chicago	2002	Sept	0.23	80	262	1997.4	6.4
Chicago	2004	Sept	0.17	72	236	1999.2	6.6
Chicago	2006	Sept	0.13	58	125	2001	6.8
Denver	1996	Dec95-Jan96	0.53	180	860	1989.2	7.9
Denver	1997	Dec96-Jan97	0.51	160	620	1990.3	7.8
Denver	1999	Jan-Feb	0.45	125	600	1992.4	7.7
Denver	2000	Dec-Jan	0.43	115	511	1993.4	7.7
Denver	2001	Jan	0.34	112	483	1994.6	7.5
Denver	2003	Dec-Jan	0.35	88	456	1996.4	7.7
Denver	2005	Jan	0.23	50	371	1998.1	8
Denver	2007	Jan-Feb	0.19	46	278	2000	8.1
Omaha	2004	Sept	0.20	176	267	1998.9	6.9
Tulsa	2003	Sept	0.27	85	265	1997.6	7.2
LA-Riverside	1999	June-July	0.55	200	370	1992.4	8.1
LA-Riverside	2000	May-June	0.50	120	420	1993.3	8.2
LA-Riverside	2001	June	0.39	100	400	1994.5	8
LA-LaBrea	1999	Nov	0.58	230	475	1992.4	8.5
LA-LaBrea	2001	Oct	0.44	150	411	1994.4	8.4
LA-LaBrea	2003	Oct	0.34	120	320	1996.5	8.3
LA-LaBrea	2005	Oct	0.22	80	240	1998.9	7.9
Phoenix-Site1	1998	Nov	0.28	110	360	1993.3	6.6
Phoenix-Site2	1999	Nov	0.31	85	572	1994	6.9
Phoenix-Site2	2000	Nov	0.27	99	448	1995.3	6.6
Phoenix-Site2	2002	Nov	0.22	66	327	1997.4	6.5
Phoenix-Site2	2004	Nov	0.18	49	245	1999.4	6.5
Phoenix-Site2	2006	Nov	0.11	56	203	2001.4	6.5
Vehicle Age = Measurement year+1-model year (MYR)							

HC remote-sensing measurements were observed to have an offset from zero. The reason for this is unknown. The results in Table 1 had HC measurements adjusted to zero for the cleanest new model vehicles, as described in the E-23 reports. The NO emissions were made using a different technique before 1998 than subsequent NO measurements.

The following charts show the dramatic decline in fleet average emissions for the sites in the E-23 cities with at least four years of measurement. The year of measurement has been adjusted by the month for these charts. The fleet average emissions reflect a decreasing trend in each of the sites. The lines represent the best fit slope for the data points. The dashed lines are the 95% confidence limits for the slope. Emissions differences between the sites can be due to differences in a number of factors including average age of the vehicles, fuel composition, ratio of light- duty trucks to passenger cars, driving conditions at the site, I/M programs, etc.

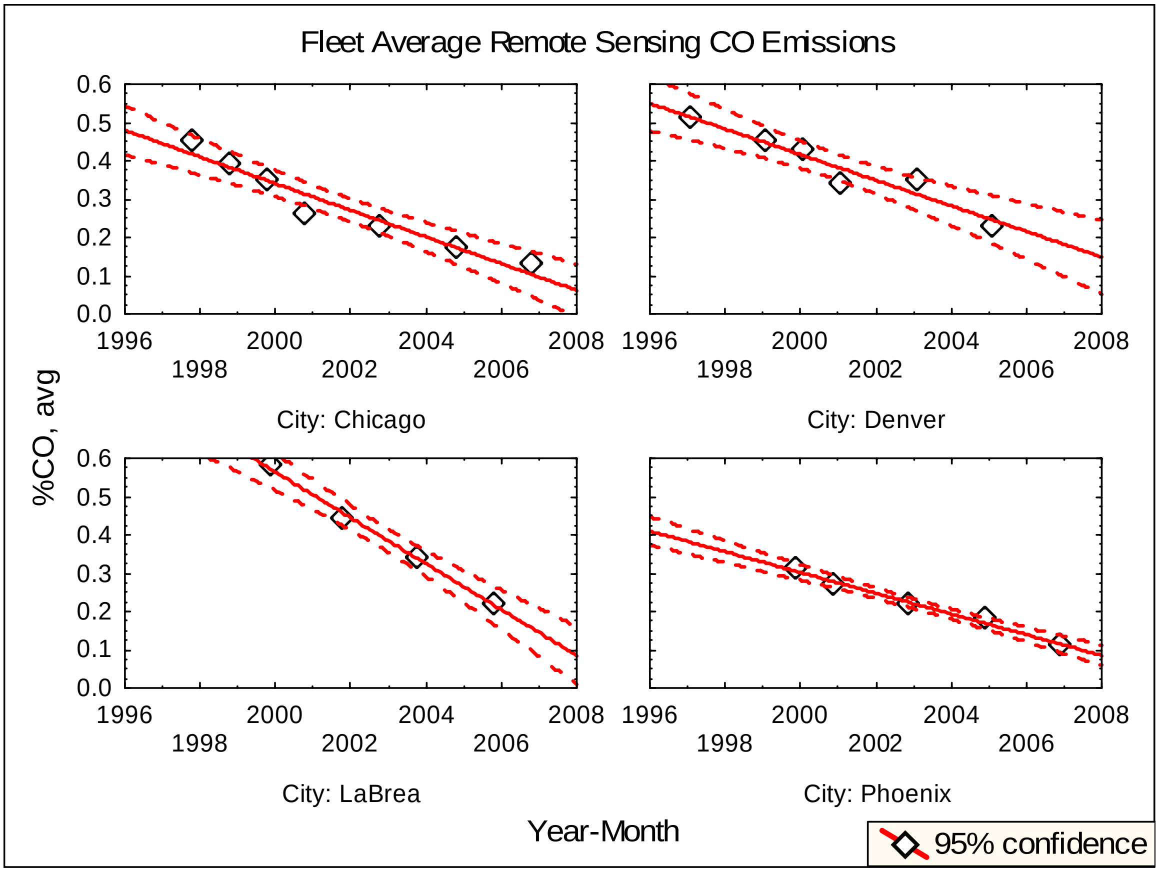


Figure 1: Fleet Average CO Emissions by Remote Sensing at E-23 Sites

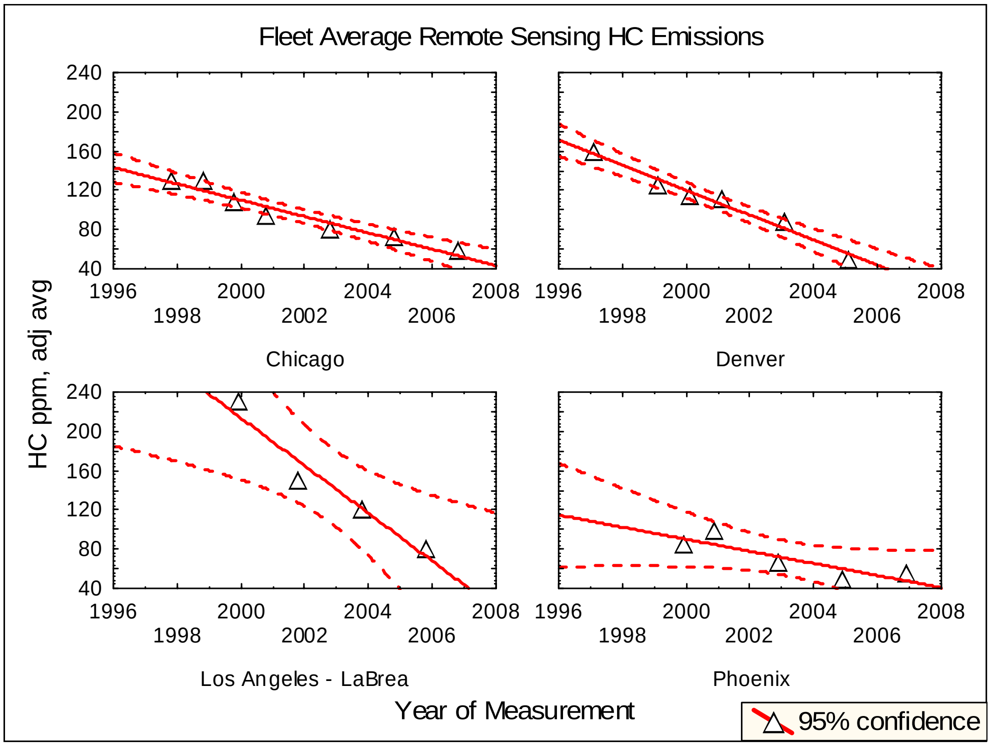


Figure 2: Fleet Average HC Emissions by Remote Sensing at E-23 Sites

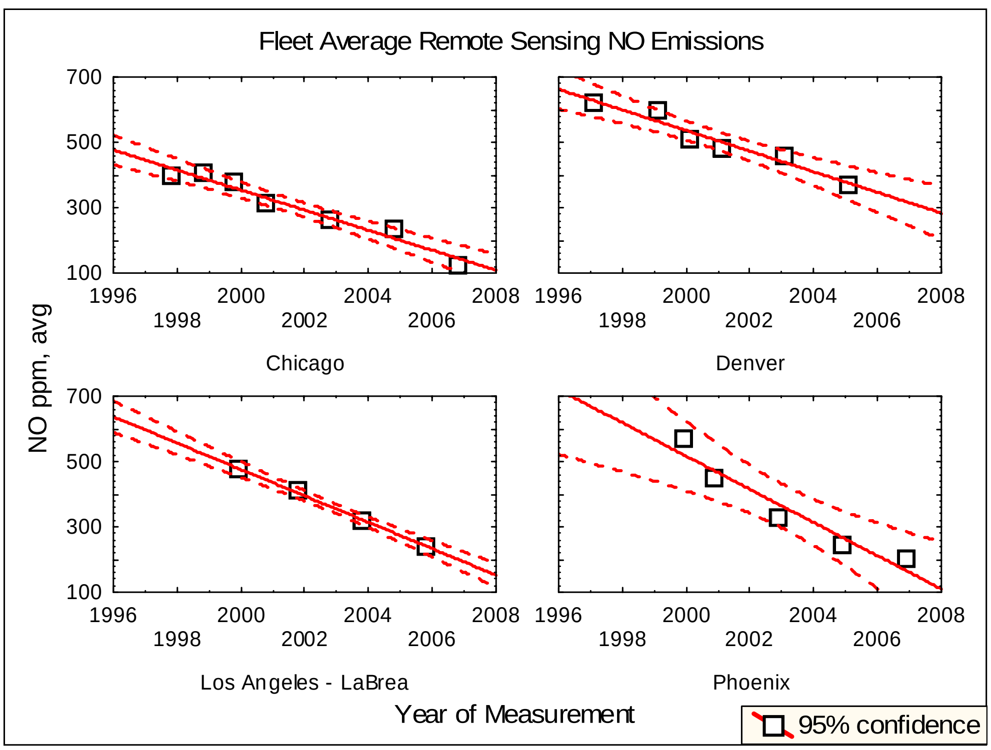


Figure 3: Fleet Average NO Emissions by Remote Sensing at E-23 Sites

Filtering Data for Analysis and Adjusting HC Emissions

This report analyzes remote sensing measurements of light- duty vehicles. To eliminate non-light- duty vehicles which may have been measured at E-23 sites, records were removed if the vehicle was not confirmed as a passenger car or light- duty truck. Only measurements having valid speed, CO, HC, and NO measurements were included in the analysis. To minimize driving variability at a site speed, acceleration, and VSP outliers were also removed. These filtering operations resulted in eliminating only a small percent of the E-23 measurements, as shown in Table B2.

HC emissions were adjusted for offset by setting the average of the first model years to zero. The methodology for filtering and offset is described in Appendix B.

Remote- sensing measurements can be reported as percents, grams per gallon of fuel, or grams per kilogram of fuel. In the rest of this report, remote- sensing emissions are reported in grams/kilogram of fuel.

Comparison of Vehicle Emission Deterioration Rates from MOBILE6.2 and Remote Sensing for 1994-2002 Model Year Vehicles during Years 2000-2006

Emissions are currently estimated in all states but California with EPA's MOBILE6.2. MOBILE6.2 on-road emissions estimates are based primarily on laboratory dynamometer measurements from recruited vehicles. The dynamometers are programmed to simulate specific driving cycles. Measurements are made under carefully controlled conditions so results are precise. Concerns have been raised, however, about the relevance of the results to the real on-road fleet because of the possibility of vehicle selection bias and the relation of the driving cycles to real world vehicle use.

EPA has been working on an improved vehicle emissions computer model, MOVES. EPA plans to include data from I/M programs, remote sensing, and on-road vehicles using real time data acquisition.

There are significant differences between remote sensing and laboratory dynamometer measurements. Remote sensing measures emissions in less that a second over a limited driving condition range. The laboratory dynamometer measurements used in MOBILE6.2 cover a much wider range and time of vehicle operation. Since vehicle emissions of both well maintained and especially high-emitting vehicles vary with driving conditions, an exact match between remote sensing and MOBILE6.2 vehicle emissions would not be expected. Nevertheless, fleet remote sensing measurements averaged by model year correlate very well with fleet IM240 measurements, so the on-road emission levels of fleet model year averaged remote- sensing measurements should be similar to MOBILE6.2 estimates.

Remote- sensing data should be able to provide a check on MOBILE6.2 estimates of vehicle deterioration. Deterioration rates are not directly available from MOBILE6.2. However, they can be obtained as the slopes of multi-year MOBILE6.2 vehicle emissions estimate outputs.

MOBILE6.2 CO, HC, and NO_x emissions are expressed in grams/mile by dividing emissions by the number of miles in a simulated driving cycle. Remote- sensing measurements are expressed in grams/kg fuel or, equivalently, in percent relative to CO_2 emitted. In this analysis, MOBILE6.2 emissions were converted to grams/kg fuel by dividing the grams/mile by the miles/gallon fuel efficiencies listed in MOBILE6.2 output and converting gallons to kg fuel.[21]

MOBILE6.2 Deterioration Rates

MOBILE6.2 runs for years 2000 to 2006 in I/M areas using default conditions as supplied by EPA.[22] Evaporative and start emissions were not included for this analysis. Figure 4 shows the emissions in gm/kg fuel for passenger cars categorized by model year for vehicles up to fifteen years of age. Light- duty trucks 2 and 3 have similar levels of emissions on a gm/kg fuel basis for this model year range. Fuel economies for the light- duty trucks were lower than the passenger cars, offsetting their higher gram/mile emissions when emissions are expressed in gm/kg fuel.

[21] 40 CFR 600.113-78 gives a carbon content value of 2,421 grams (g) of carbon per gallon of gasoline.

[22] Ed Glover, US EPA.

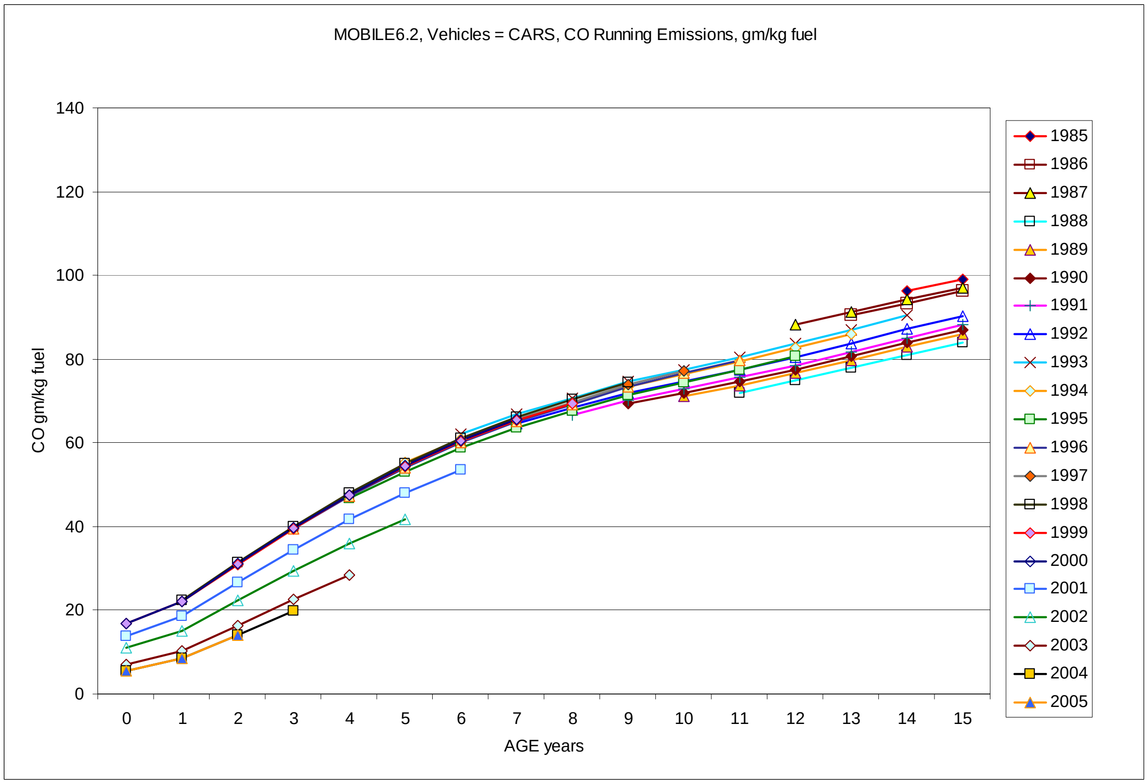


Figure 4: CO gm/kg fuel Emissions for Passenger Cars from MOBILE6.2

Figure 4 shows that according to MOBILE6.2, the average CO gm/kg fuel emissions of passenger cars in model years 1988 to 2000 follow a similar line during 2000 to 2006; vehicles of the same age have very similar average emissions.[23] The 1985 to 1987 model year vehicles have slightly higher average emissions at the same age than newer model years. Starting in 2001, newer model year vehicles have lower average emissions at the same vehicle age than their older model year counterparts.

By assuming linear deterioration over the 2000 to 2006 period, slopes of the emissions versus model year can be calculated.[24] Figure 5 shows CO gm/kg fuel emission deterioration rates for model year passenger cars 1994 to 2002. The shape of the CO gm/kg fuel emissions versus age plots indicates that deterioration rates initially increase and then decrease with increasing model year as vehicles aged in 2000 to 2006. Deterioration rates for different model years do not correspond to the same age ranges in Figure 5 since the deterioration rates were obtained from 2000 to 2006 MOBILE6.2 runs to correspond to the E-23 and St.

[23] Among 10 to 15 year- old vehicles, the older model year 1998 vehicles have the lowest average emissions.

[24] The linear assumption is valid. R2 values for the linear equations were 0.975 or higher for these model years.

Louis remote- sensing measurement years.

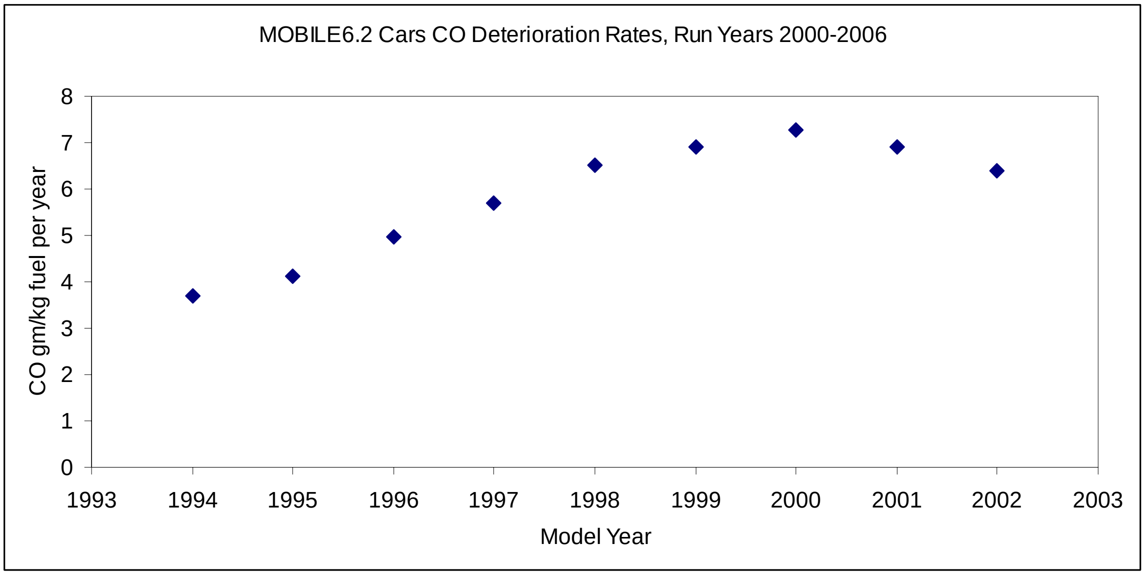


Figure 5. Slopes of CO gm/kg fuel Emissions versus Age for Passenger Cars from MOBILE6.2

Figures 6 and 7 show how MOBILE6.2 estimated VOC and NO_x gm/kg fuel emissions vary with vehicle age for passenger cars from 2000 to 2006.[25]

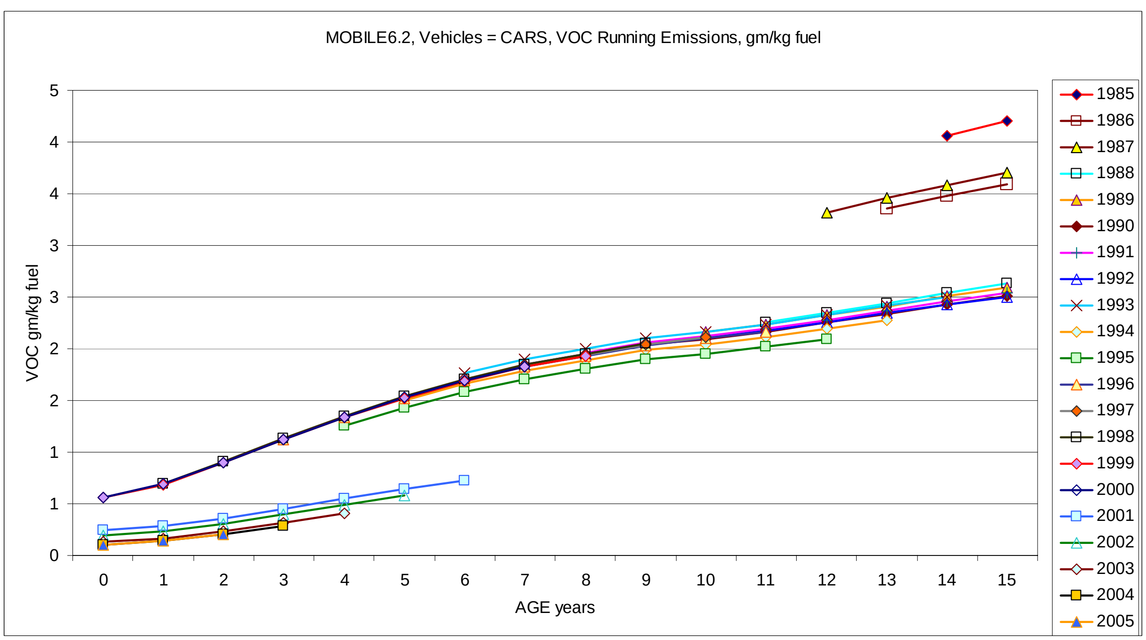


Figure 6: VOC gm/kg fuel Emissions for Passenger Cars from MOBILE6.2

[25] Similar charts with different, but similar, gm/kg fuel emissions levels are seen for the light- duty trucks.

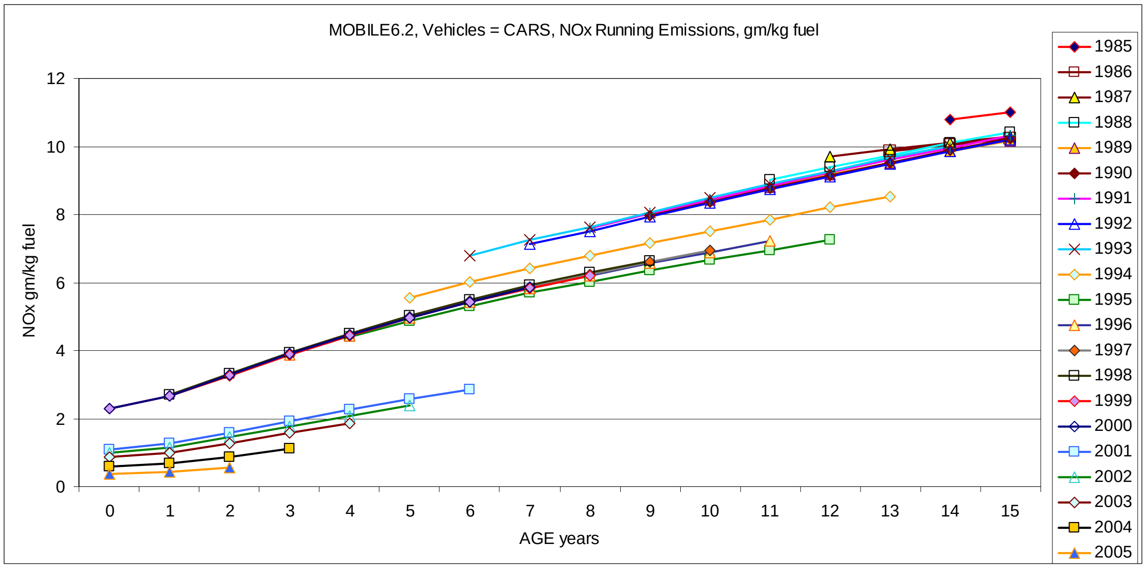


Figure 7: NO_x gm/kg fuel Emissions for Passenger Cars from MOBILE6.2

Deterioration Rates from Remote Sensing in St. Louis

The best 2000-2006 remote- sensing data for comparison with MOBILE6.2 come from St. Louis because over three million remote- sensing measurements per year were gathered at multiple sites at all times of the year during these years.[26] The St. Louis remote- sensing data were limited to those measurements with VSP between 5 and 20 kW/tonne. Measurements from sites during hours with high cold start emissions were omitted. Figure 8 shows the CO gm/kg fuel for the St. Louis remote- sensing data.

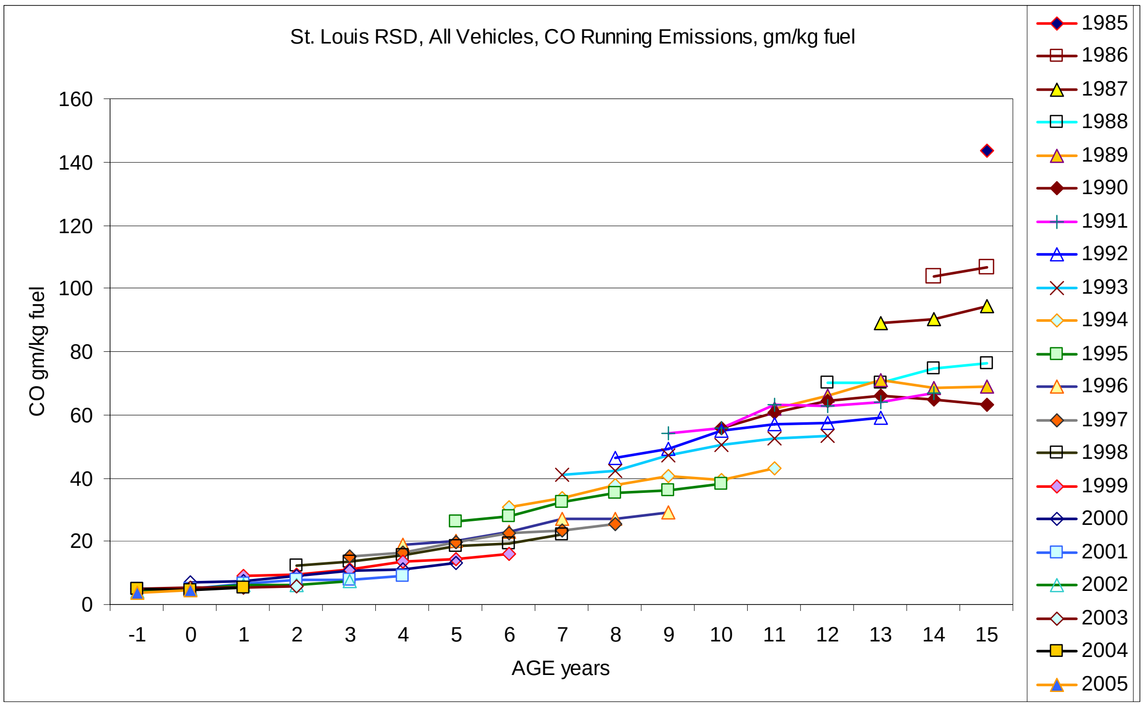


Figure 8: CO gm/kg fuel Emissions from Remote Sensing in St. Louis

The level of CO emissions seen in the St. Louis remote- sensing data is similar to what was estimated by MOBILE6.2 for late 1980's and early 1990's model years. However, CO emissions for more recent model years are much lower than MOBILE6.2 estimates, as are deterioration rates.

[26] Data furnished courtesy of Missouri DNR by Peter McClintock.

A consequence of the low deterioration rates observed from remote- sensing measurements in recent model year vehicles is that the average fleet CO emissions are lower than the fleet CO emissions in older model year vehicles of the same age. This can be seen more clearly in Figure 9. For example, among four- year old vehicles, 2001 model year vehicles have lower average CO emissions than 2000 model year vehicles, etc.

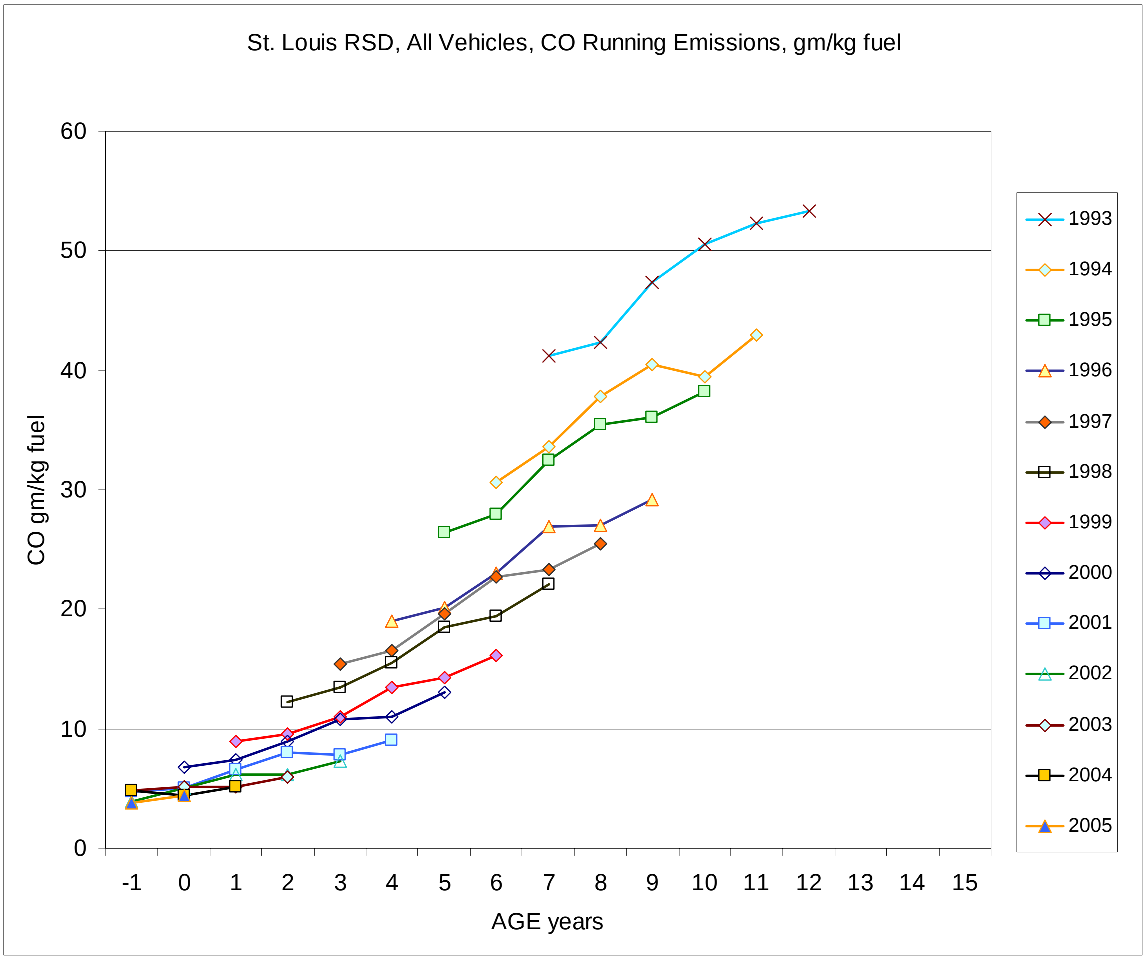


Figure 9: CO gm/kg Fuel Emissions from Remote Sensing in St. Louis

NO_x emissions observed from remote- sensing measurements in St. Louis had a similar shape to the CO emissions. This is shown in Figure 10.

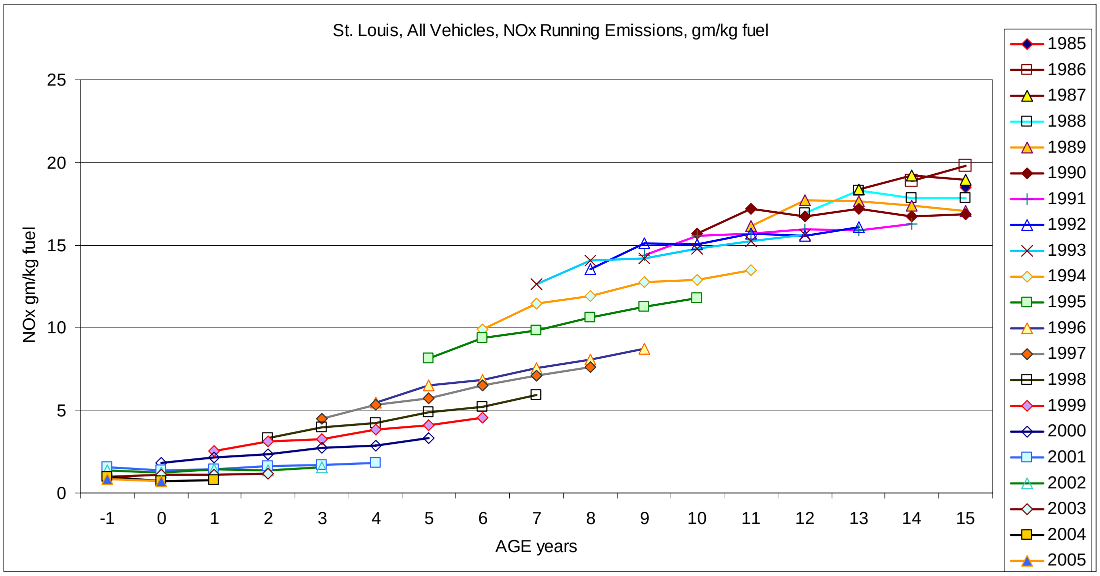


Figure 10: NO gm/kg fuel Emissions from Remote Sensing in St. Louis

Hydrocarbon emissions observed from St. Louis remote sensing fall on almost a single line when plotted against vehicle age, as shown in Figure 11.

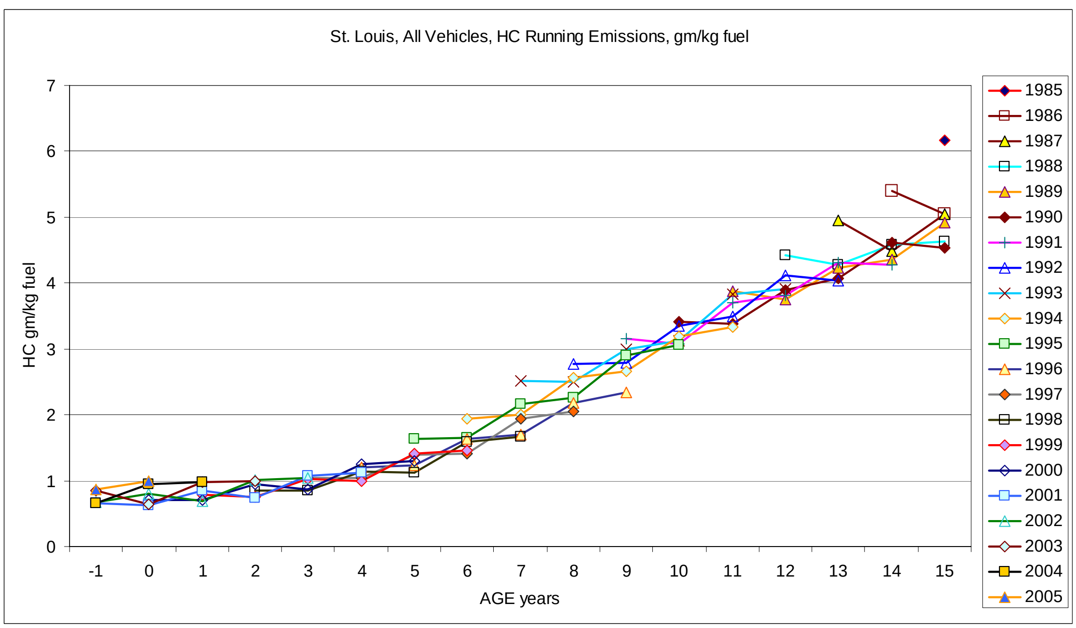


Figure 11: HC gm/kg fuel Emissions from Remote Sensing in St. Louis

A comparison of the gm/kg fuel emission deterioration rates by model year between MOBILE6.2 and St. Louis remote sensing is shown in Table 2.

As shown in Table 2, CO deterioration rates measured by remote sensing for 1994 to 2002 vehicles were much lower than MOBILE6.2, especially for the 1996 and later model years. NO deterioration rates measured by remote sensing were higher than estimated by MOBILE6.2 for 1994 to 1997 vehicles. The 1999 and newer vehicles had much lower NO emission deterioration rates according to remote sensing than estimated by MOBILE6.2. In the 2001-2002 model year vehicles, the deterioration rates decreased to almost zero. HC emissions deterioration rates over 2000-2006 observed by remote sensing for 1998 and later vehicles were similar to those predicted by MOBILE6.2. Remote sensing deterioration rate measurements for earlier model years were higher than predicted by MOBILE6.2.

Table 2. Deterioration Rates, gm/kg fuel per year from 2000-2006

Comparison between MOBILE6.2 (M6.2) and St. Louis Remote Sensing (RSD StL)						
	CO		NO		VOC or HC	
Model Year	M6.2	RSD StL	M6.2	RSD StL	M6.2	RSD StL
2002	6.4	0.8	0.29	0.04	0.08	0.10
2001	6.9	0.9	0.31	0.07	0.08	0.10
2000	7.3	1.2	0.53	0.29	0.19	0.13
1999	6.9	1.5	0.51	0.39	0.18	0.15
1998	6.5	2.0	0.49	0.50	0.17	0.18
1997	5.7	2.1	0.41	0.62	0.15	0.22
1996	5.0	2.1	0.41	0.62	0.13	0.25
1995	4.1	2.5	0.35	0.71	0.10	0.31
1994	3.7	2.3	0.37	0.66	0.09	0.30

Deterioration Rates from E-23 Remote Sensing

Charts of emissions as a function of vehicle age by vehicle model year for E-23 sites are shown in Appendix D. These charts also show that emissions of the vehicle fleet in more recent model years stay cleaner than older average emissions at the same age.

Deterioration rates from E-23 cities were calculated and are shown in Table 3. The deterioration rates in this table were based on fleet average remote- sensing measurements from sites at a single vehicle age and model year with over 100 measurements. Only deterioration rates with R2>0.5 for a linear trend were included in Table 3.

Considerable scatter is seen in the E-23 deterioration rates from city to city. This is not unexpected because of the limited number of measurements taken. However, when the average deterioration rate of all four E-23 sites was used, the E-23 deterioration rate was seen to be nearly identical to the St. Louis remote sensing deterioration rate for CO and similar in shape versus model year for HC and NO. The St. Louis, E-23 average, and MOBILE6.2 deterioration rates for 1994 to 2002 model year vehicles for CO, NO, and HC are shown in Figures 12 through 14.

Table 3. Deterioration Rates from Years 2000-2006

	CO gm/kg fuel						
Model Year	MOBILE6.2	St. Louis	Chicago	Denver	LA - LaBrea	Phoenix	E23 Avg
2002	6.4	0.8	0.3			0.3	0.3
2001	6.9	0.9	1.0		0.5	0.8	0.8
2000	7.3	1.2	1.8		0.6	0.8	1.1
1999	6.9	1.5	1.7	1.3	1.0	0.9	1.2
1998	6.5	2.0	1.6	1.6	1.6	1.6	1.6
1997	5.7	2.1	2.0	2.4	0.7	1.6	1.7
1996	5.0	2.1	1.1	2.5	1.3	1.6	1.6
1995	4.1	2.5	1.7	3.5	0.5	3.1	2.2
1994	3.7	2.3		3.9	1.1	3.0	2.7
	NO gm/kg fuel						
2002	0.29	0.04					
2001	0.31	0.07			0.05	0.05	0.05
2000	0.53	0.29	0.40	0.18	0.10	0.13	0.20
1999	0.51	0.39	0.39	0.22	0.19	0.10	0.23
1998	0.49	0.50	0.46	0.34	0.29	0.17	0.32
1997	0.41	0.62	0.46	0.43	0.18	0.20	0.32
1996	0.41	0.62	0.38	0.41	0.27		0.35
1995	0.35	0.71	0.39	0.58	0.30		0.42
1994	0.37	0.66	0.80	0.57	0.23		0.53
	HC Adjusted gm/kg fuel						
2002	0.08	0.10					
2001	0.08	0.10	0.37	-0.12	0.18	0.35	0.20
2000	0.19	0.13	0.29		0.16	0.36	0.27
1999	0.18	0.15	0.31		0.18	0.26	0.25
1998	0.17	0.18	0.31	0.20	0.24	0.28	0.26
1997	0.15	0.22	0.35	0.17	0.28	0.32	0.28
1996	0.13	0.25	0.51	0.17	0.33		0.34
1995	0.10	0.31	0.41	0.27	0.59		0.42
1994	0.09	0.30	0.50	0.26	0.59		0.45

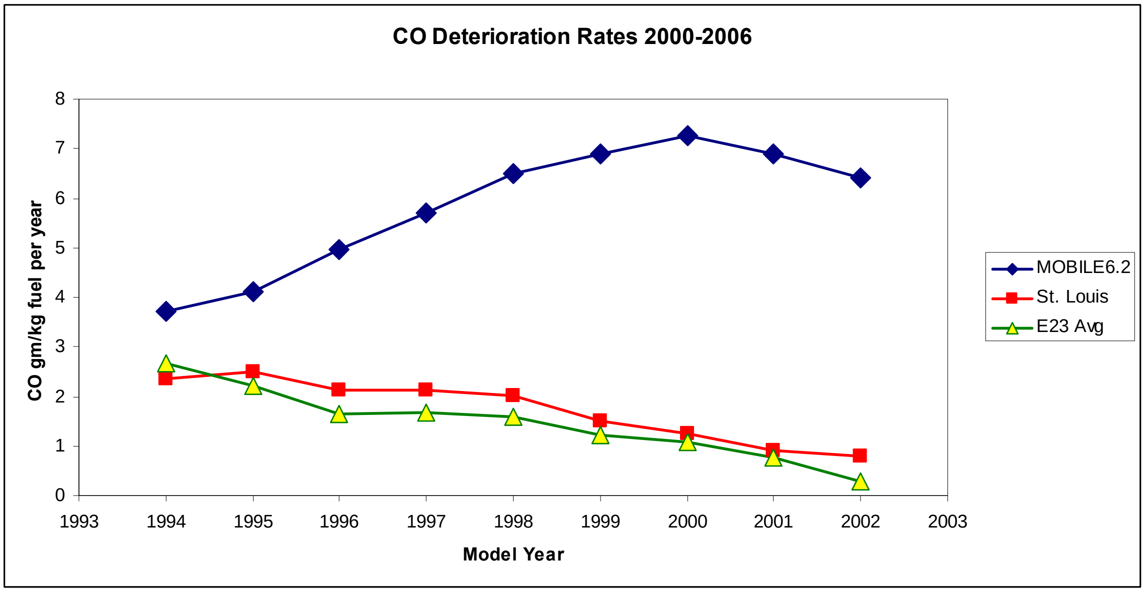


Figure 12: Comparison of MOBILE6.2 and Remote Sensing CO Deterioration Rates

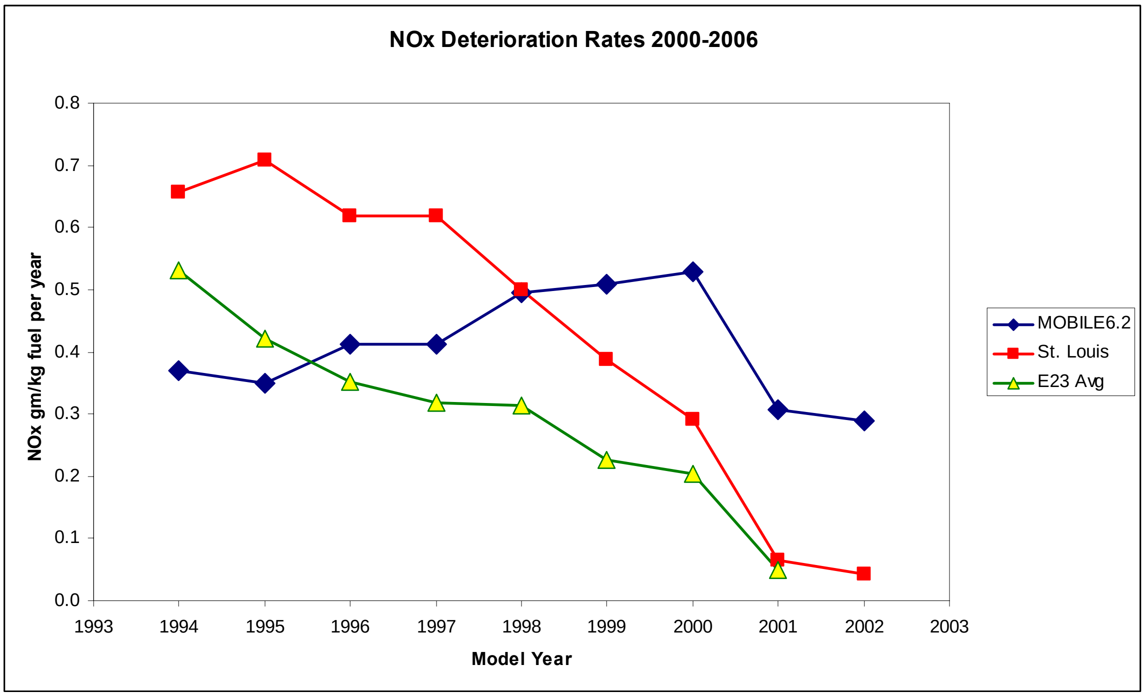


Figure 13: Comparison of MOBILE6.2 and Remote Sensing NO_x Deterioration Rates

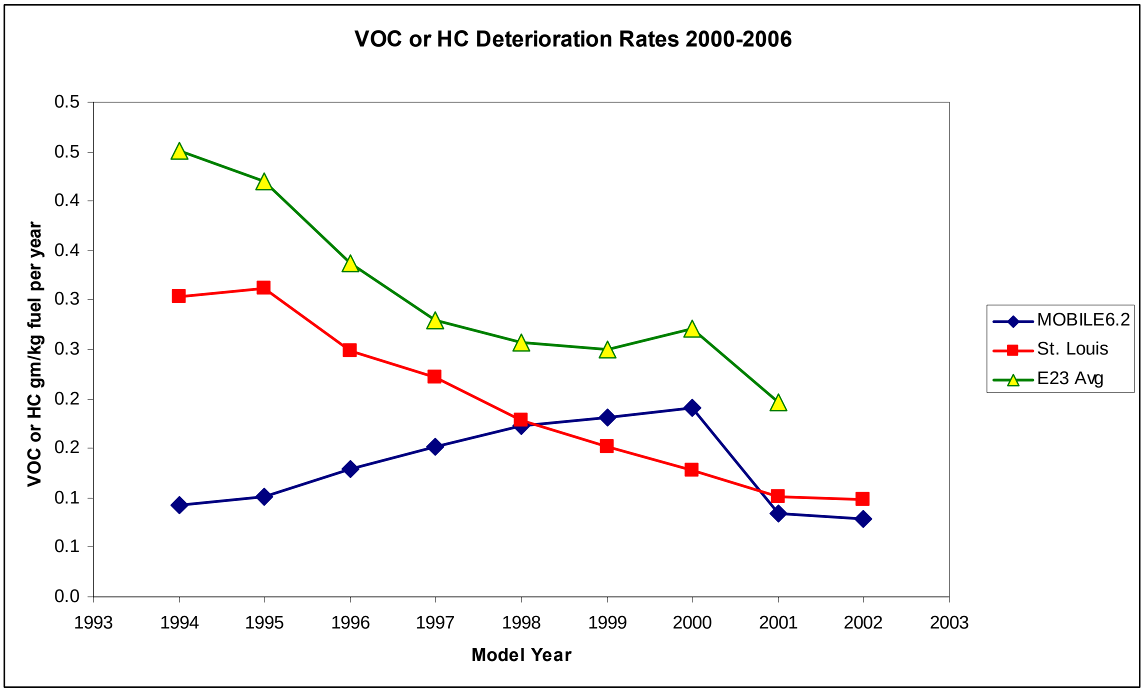


Figure 14: Comparison of MOBILE6.2 and Remote Sensing HC Deterioration Rates

High Emitter Distributions in Remote Sensing Measurements

Average remote-sensing measurements categorized by model year and vehicle age show that on-road vehicle emissions in newer model years are lower. Furthermore, emissions from the more recent model year fleet deteriorate slower. This section describes what is happening to high emitter populations in relation to average emissions categorized by model year and age.

High emitters at any model year and vehicle age (model year x age pair) are here defined as the vehicles whose remote sensing emissions are at the 75th, 90th, and 95th percentiles. The following analysis for CO and NO is based on the use of the percentiles divided by average emissions for a model year x age pair at an E-23 site using only model year x age pairs with over 100 measurements.

Due to the nature of multiyear measurements, model year and age trend analyses are limited since model year and age are confounded.

The more years of measurements at an E-23 site, the greater the model year x age pairs. Between 1987 and 2000 model years, Denver and Chicago data have at least four model year x age pairs for each model year and for each age, while Los Angeles and Phoenix have only two. This is illustrated in Table 4 for Denver. The block of data used in the analysis is enclosed in the outlined rectangle.

Table 4: Block of Denver Model Year x Age Pairs used in Analysis for Table 5

A “1” in a cell of the Table indicates measurements made

MYR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Totals
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
1986	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
1987	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	4
1988	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	4
1989	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	5
1990	0	0	0	0	0	0	0	1	1	1	1	0	1	0	1	6
1991	0	0	0	0	0	0	1	1	1	1	0	1	0	1	0	6
1992	0	0	0	0	0	1	1	1	1	0	1	0	1	0	0	6
1993	0	0	0	0	1	1	1	1	0	1	0	1	0	1	0	7
1994	0	0	0	1	1	1	1	0	1	0	1	0	1	0	0	7
1995	0	0	1	1	1	1	0	1	0	1	0	1	0	0	0	7
1996	0	1	1	1	1	0	1	0	1	0	1	0	0	0	0	7
1997	1	1	1	1	0	1	0	1	0	1	0	0	0	0	0	7
1998	0	1	1	0	1	0	1	0	1	0	0	0	0	0	0	5
1999	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	5
2000	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	4
2001	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	3
2002	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3
2003	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
2004	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
2005	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2006	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
All Grps	6	7	7	7	7	7	7	7	7	7	7	7	6	5	1	95

Table 5 shows that average emissions of the 75th, 90th, and 95th percentiles divided by the mean for CO for each model year x age pair measured during 1999-2006 are essentially the same for all four E-23 sites. The average CO tracks the 75th percentile. The 90th is 2.5 times the mean and the 95th is a little over 4 times the mean. The high emitter populations are following the average emissions. A CO high emitter from a 1999 model year fleet is emitting a lot less CO than a high emitter from a 1989 fleet.

Table 5: Average Model Year x Age pair CO Emission Percentiles Divided by the Mean				
	Denver	**Chicago**	**Los Angeles**	**Phoenix**
75th/avg	1.0	1.1	1.0	1.0
90th/avg	2.5	2.6	2.4	2.6
95th/avg	4.4	4.2	4.1	4.5
At least	4 MYR-Age pairs	4 MYR-Age pairs	2 MYR-Age pairs	2 MYR-Age pairs
Age Range	2-14	2-14	1-15	1-15
MYR Range	1987-2000	1987-2000	1987-2003	1986-2004
VSP Range	5-15 kW/t	5-15 kW/t	5-15 kW/t	5-30 kW/t

Table 6 shows the percentile/average NO emissions for the E-23 cities. The similarity of the ratios across the four cities indicates that high emitter NO emissions for model year x age pairs are also proportional to the mean.

Table 6: Average Model Year x Age pair NO Emission Percentiles Divided by the Mean				
	Denver	**Chicago**	**Los Angeles**	**Phoenix**
75th/avg	1.3	1.3	1.2	1.2
90th/avg	2.9	2.6	2.6	2.7
95th/avg	4.3	3.7	4.2	4.4
At least	4 MYR-Age pairs	4 MYR-Age pairs	2 MYR-Age pairs	2 MYR-Age pairs
Age Range	2-14	2-14	1-15	1-15
MYR Range	1987-2000	1987-2000	1987-2003	1986-2004
VSP Range	5-15 kW/t	5-15 kW/t	5-15 kW/t	5-30 kW/t

This analysis was not used for HC emissions. When the HC emissions were adjusted by setting the average of the newest three model years to zero, many of HC emissions averages for newer vehicles were less than zero or very close to zero.

Higher Emitter Percentile/Average Emission Trends with Model Year and Vehicle Age

The average 95th and 90th percentile/mean for 1987 to 2000 were similar for all E-23 sites. To see the trends of the 95th and 90th percentile/averages with model year and vehicle age, information from all four E-23 sites with four or more years of measurements were pooled. Table 7 shows that selecting 1987 to 2001 model years used at least 12 model year x vehicle age pairs for each model year. Table 7 also shows the age range corresponding to the model year and the model year range corresponding to the age for the data used in this trend analysis.

Table 7: Pooled Data from E-23 Sites with at least four years of measurements

MYR	Age Means	N	Age Range	
1987	13.2	12	11	15
1988	12.4	13	10	15
1989	12.0	16	9	15
1990	11.4	18	8	15
1991	10.9	20	7	15
1992	10.1	21	6	15
1993	9.4	22	5	14
1994	8.4	22	4	13
1995	7.4	22	3	12
1996	6.4	22	2	11
1997	5.4	22	1	10
1998	5.0	19	2	9
1999	4.0	19	1	8
2000	3.8	15	1	7
2001	3.5	12	1	6
AGE	Model Year Means	N	Model year Range	
1	1999.3	11	1997	2001
2	1998.6	14	1996	2001
3	1998.0	16	1995	2001
4	1997.4	18	1994	2001
5	1996.9	20	1993	2001
6	1996.4	22	1992	2001
7	1995.4	22	1991	2000
8	1994.4	22	1990	1999
9	1993.4	22	1989	1998
10	1992.4	22	1988	1997
11	1991.4	22	1987	1996
12	1990.8	20	1987	1995
13	1990.0	19	1987	1994
14	1989.8	15	1987	1993
15	1989.4	10	1987	1992

Figures 15 and 16 show the change in CO and NO 95th percentile/average with model year and age.

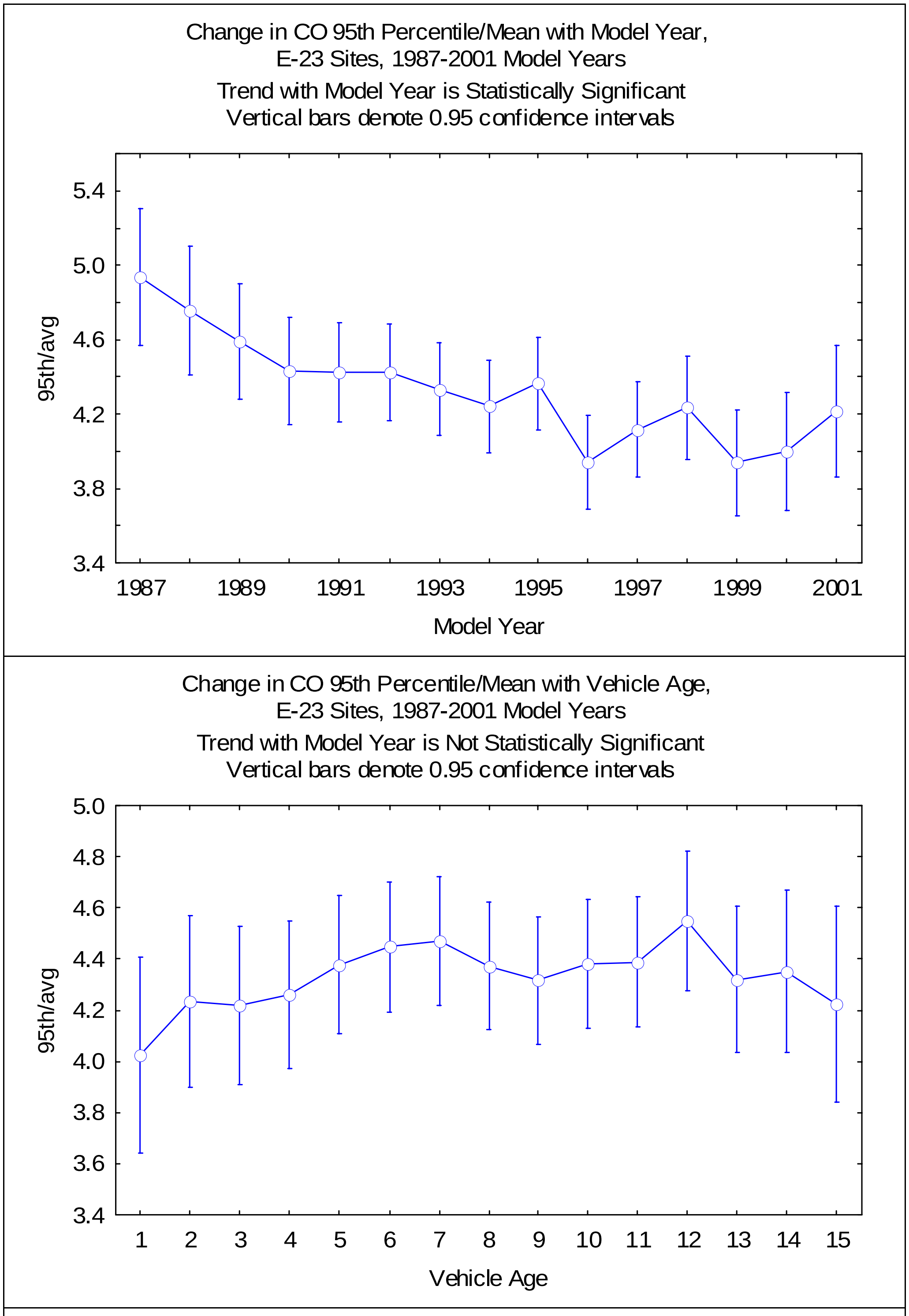
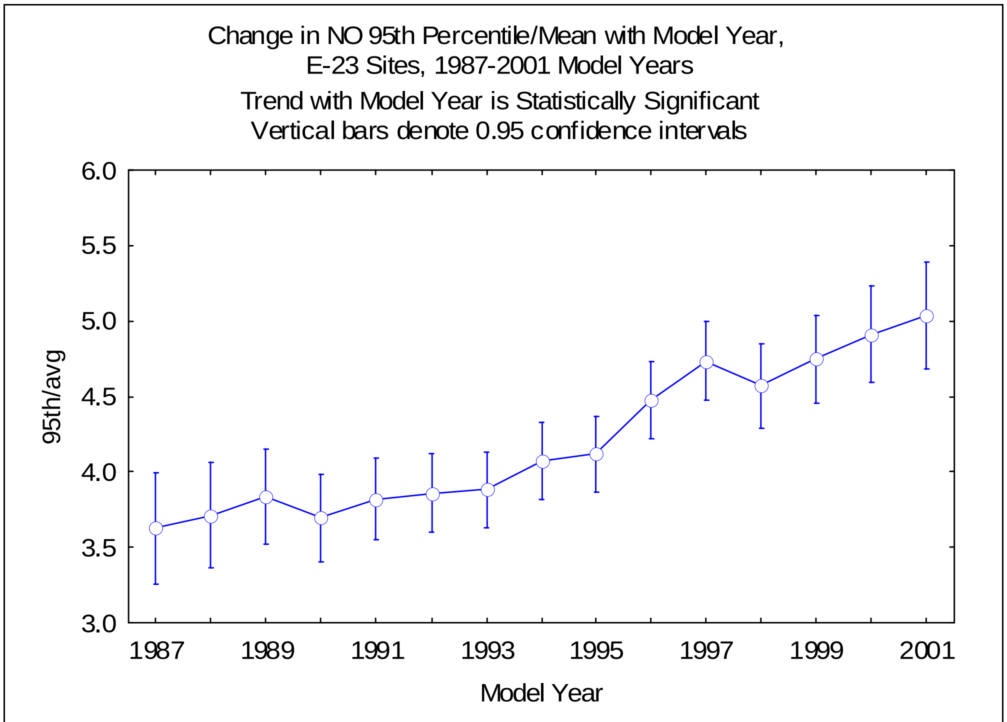


Figure 15: Change in CO 95th Percentile/Average Emissions, E-23 Sites



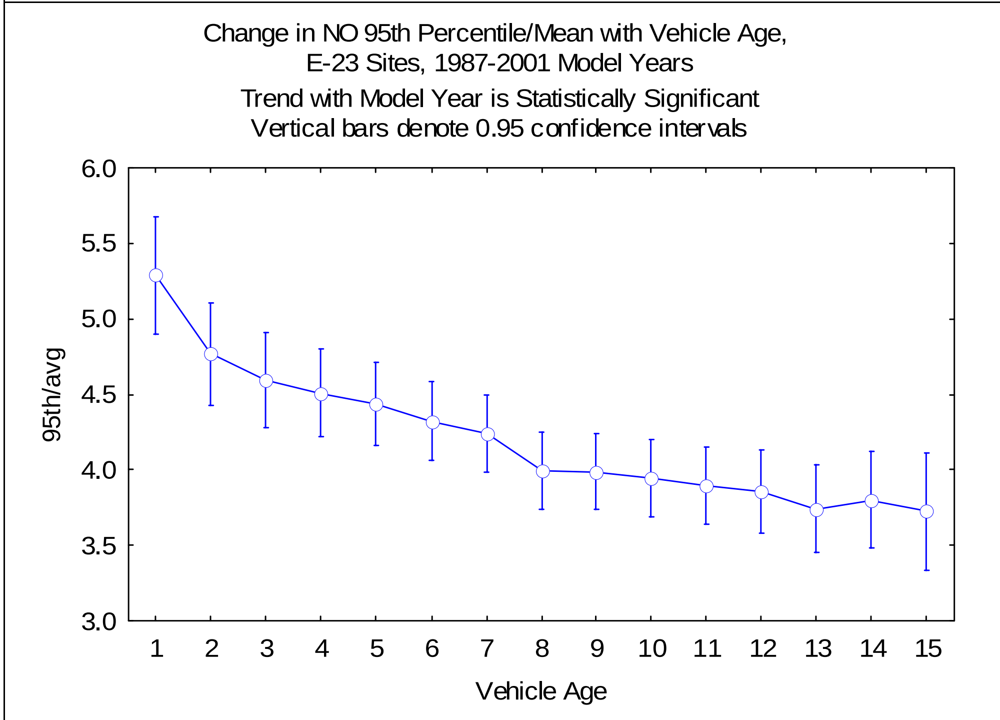


Figure 16: Change in NO 95th Percentile/Average Emissions, E-23 Sites

A summary of the trends for CO and NO 95th and 90th percentile/average with model year and age is shown in Table 8.

Table 8: Trends of Percentile/Average Emissions with Model Year and Vehicle Age		
Model Year 1987-2001, Vehicle Age 1-15		
Change with	Model Year	Vehicle Age
CO		
95th/Average	newer models lower	no change
90th/Average	newer models lower	no change
NO		
95th/Average	newer models higher	lower vehicle age higher
90th/Average	newer models lower after 1997	no change

The highest CO emitters relative to the average CO are still decreasing while the opposite is taking place for the NO emitters. As vehicles age, the ratio of emissions for the high CO emitters to the fleet average stays the same, while that ratio for the high NO emitters is declining with vehicle age.

Conclusions

Based on remote sensing measurements made at a single site in each of four cities, average fleet on-road tailpipe emissions have declined sharply from 1999 to 2006.

Remote- sensing measurements made over a number of years can be used to estimate fleet deterioration rates. The remote sensing based deterioration rates can be used as a check on the accuracy of deterioration rates used in vehicle emissions models.

Average fleet on-road tailpipe emissions from newer vehicles were lower at the same age as older vehicles.

The ratios of the highest 95th and 90th percentile emissions to the average emissions of vehicles, at a given model year and age from 2000-2006, were nearly constant and were the same for all four E-23 sites with measurements in at least four years. Therefore, emissions of the highest emitting vehicles have declined similarly to the average fleet emissions. Or, equivalently, at a fixed emissions cut point, in grams per kg of fuel, the percentage of the fleet exceeding that cut point has decreased considerably from 1999 to 2006.

Recommendations

Project E-23 has shown the value of historical fleet tailpipe emissions measurements. By accumulating remote- sensing data at a single site, historical trends in fleet emission deterioration rates and high emitter populations can be followed. By using multiple sites that show similar trends, the certainty of the conclusions is reinforced. Remote sensing at multiple sites is a cost effective way of monitoring emissions to provide a check on agency computer models.

Continuing to monitor the Chicago, Los Angeles/ LaBrea, and Phoenix sites extends the historical records. Tulsa should be added to the list. Tulsa was an E-23 site in 2003 and the Denver University team went back unsupported in 2005, so two years of data have already been accumulated.

Additional pollutants should be monitored as technology becomes available. SO_2 and ammonia can now be monitored in addition to CO, HC, and NO emissions.

Data from large-scale, remote-sensing programs, such as the St. Louis program, are useful supplements to E-23 data. The St. Louis remote-sensing activity has ended, but other data may be available from Texas, Colorado, and Los Angeles programs.

Appendix A: Summary of E-23 Reports

Table A1 shows the average speed, acceleration, VSP, the road grade slope, and the numbers of measurements made at the E-23 sites. The distribution of speed, acceleration, and VSP is shown in charts at the end of this Appendix. The average emissions and vehicle age for each year of measurements are in Table 1.

Table A1: Summary of Average Conditions at E-23 Sites						
		Speed	Accel	VSP	slope	thousands
City	Year	mph	mph/s	kW/t	degrees	of records
Chicago	1997	25.1	0.1	5.3	1.5	18
Chicago	1998	24.7	0.8	9.3	1.5	23
Chicago	1999	25.8	0.2	6.0	1.5	23
Chicago	2000	24.5	0.5	7.9	1.5	22
Chicago	2002	24.2	-0.4	-6.9	1.0	22
Chicago	2004	24.3	0.4	6.0	1.0	22
Chicago	2006	23.9	0.4	5.9	1.0	22
Denver	1996	21.9	-0.2	8.6	4.6	21
Denver	1997	21.8	0.1	10.4	4.6	28
Denver	1999	20.6	0.2	9.9	4.6	26
Denver	2000	21.9	0.1	10.1	4.6	23
Denver	2001	22.3	-0.8	5.9	4.6	20
Denver	2003	20.2	0.1	10.7	4.6	21
Denver	2005	23.5	-0.5	8.1	4.6	20
Denver	2007	22.5	0.1	10.4	4.6	21
Omaha	2004	42.6	0.4	18.4	2.7	21
Tulsa	2003	24.1	0.1	7.8	2.6	20
Riverside	1999	24.1	0.4	13.2	4.4	17
Riverside	2000	23.7	0.7	14.0	4.4	20
Riverside	2001	24.0	-0.3	8.9	4.4	18
LaBrea	1999	17.6	1.4	9.0	2.0	13
LaBrea	2001	18.3	1.4	10.3	2.0	20
LaBrea	2003	17.0	1.9	11.6	2.0	19
LaBrea	2005	17.7	1.7	11.4	2.0	19
Phoenix	1998	37.2	-0.7	2.7	2.7	12
Phoenix	1999	34.6	1.2	17.5	1.4	19
Phoenix	2000	34.0	1.1	16.6	1.3	21
Phoenix	2002	34.7	2.2	25.1	1.3	24
Phoenix	2004	36.1	1.9	23.7	1.3	24
Phoenix	2006	35.6	1.3	18.2	1.3	22

<u>Some observations from E-23 reports:</u>

The E-23 reports noted the decrease in the emissions of newer vehicles and the lowering rate of emissions deterioration. In the later reports, the increasing lack of sensitivity to VSP level was noted. As the fleet became cleaner, fewer measurements were responsible for 50% of the emissions; the fleet emissions distribution was becoming more skewed.

The analyses were shown to be the same when repeated measurements of vehicles observed many times were used or when only a single measurement from each vehicle was used. HC emissions were adjusted by setting the cleanest and newest models to zero and subtracting or adding the difference from zero for these vehicles to all other HC measurements in that campaign.

The Denver 1999 report correlated the fleet remote- sensing measurements by model year with the emissions measured in the Colorado IM program. Excellent correlation was obtained. Later reports repeated the correlations in Chicago and in Phoenix where IM240 data were available.

An analysis of instrument noise was first reported in the Year 2 Phoenix report. The levels of instrument noise were low compared to the vehicle- to- vehicle variation.

VSP was used to adjust emissions at a site from one year to another.

A sawtooth pattern of CO emissions with model year among older vehicles was noticed in the Denver 2000 report. This was attributed to the biennial I/M program. The amplitude was equivalent to about a 10% effect of the program, but the effect did not appear to carry over to the next biennial period. The Chicago 1999 measurements were made in the middle of an I/M program change from an annual “Basic” program to an “Enhanced” biennial program. A comparison was made of vehicles which had taken the new test to those which had not showed a small reduction in CO emissions, but no effect on NO emissions.

The LaBrea 2003 report included a comparison of manual and automatic transmission vehicles. The manual transmission vehicles had twice the CO, 40% higher HC, and 20% more NO emissions. Measurements at the LaBrea site were made at an uphill on-ramp to a freeway after a metering stoplight.

In 1999 at the Phoenix site, multiple remote sensors were used at different points on a ramp. This allowed analysis of the sensitivity of the location for speed and acceleration measurements which were used in the VSP estimate; the emissions measurements were not sensitive to the location where the speed and acceleration measurements were taken when the instruments were ten meters apart.

E-23 protocol for gathering data and quality control

A data definition/dictionary is required. The data definition/dictionary explains in detail the codes, units and other information about each field. See appendices in CRC-23-4, "On-Road Remote Sensing of Automobile Emissions in the Los Angeles Area: Year 1" for examples of reporting validation criteria, temperature & humidity, and calibration frequency.

Site Description

Mandatory

1. Include in the report a road map with features affecting traffic flow.
2. Report any change in the position of the light source, detector, etc., from previous year(s). The site should be set up the same as in the previous year(s).
3. Report any change in traffic flow from previous year(s).
4. Report the altitude of the site and the road grade. Include a field in the database showing the road grade in percent for all measurements.
5. Picture of site (digital) including all cones, etc., that would influence motorists' driving patterns.

Desired

1. Note whether motorists change driving behavior as a result of the remote- sensing measurements. Compare motorists' behavior with previous years' measurements.

Instruments

Mandatory

1. Report a description of remote- sensing equipment used; report any changes from previous year(s).
2. Name of operator and van. If more than one operator or van are used, key and record which operator and/or van was used for each measurement.
3. Calibration procedures and frequency. Frequency at least twice per day. Report the times of calibration.

Measurements

Mandatory

1. Report remote sensing: %CO2, %CO, %NO, %HC, maximum CO_2, and all error terms; restarts; report negative emission numbers. Include a field showing whether HC is reported as propane or hexane (P or H).
2. Report Speed, acceleration.
3. Report Time and date of measurement.

4. Report license plate: record all plates including in-state, out-of-state (OS); dealer plate (D); paper plate (PP); obscured plate (OP), and no plate visible (NVP).
5. Report hourly temperature, barometric pressure, and relative humidity.
6. Describe how plume strength is determined and flagged, and report criteria for rejecting measurement attempts.

Desired

1. General wind direction and speed.
2. Any other factors that could affect measurements, such as when there was water on the road.

<u>Database Format</u>

Mandatory

1. Use format and units described in LA 1998 report.

<u>DMV Data</u>

Mandatory

1. Report date DMV data returned from DMV.
2. Report how current the DMV data in that file are (i.e., when was the most recent DMV update to the file received by the investigators, especially for vehicles that have changed ownership).
3. Report VIN, Model Year, Make, Model, Fuel Type, Vehicle Type (define terms used by DMV), Zip Code if available.

Desired

1. VIN decoded data.

<u>Report Changes That Could Affect Analysis</u>

Mandatory

1. Fuel.
2. I/M program.

Desired

1. Local economy.
2. Site socioeconomics.

Driving Condition Distributions at E-23 Sites

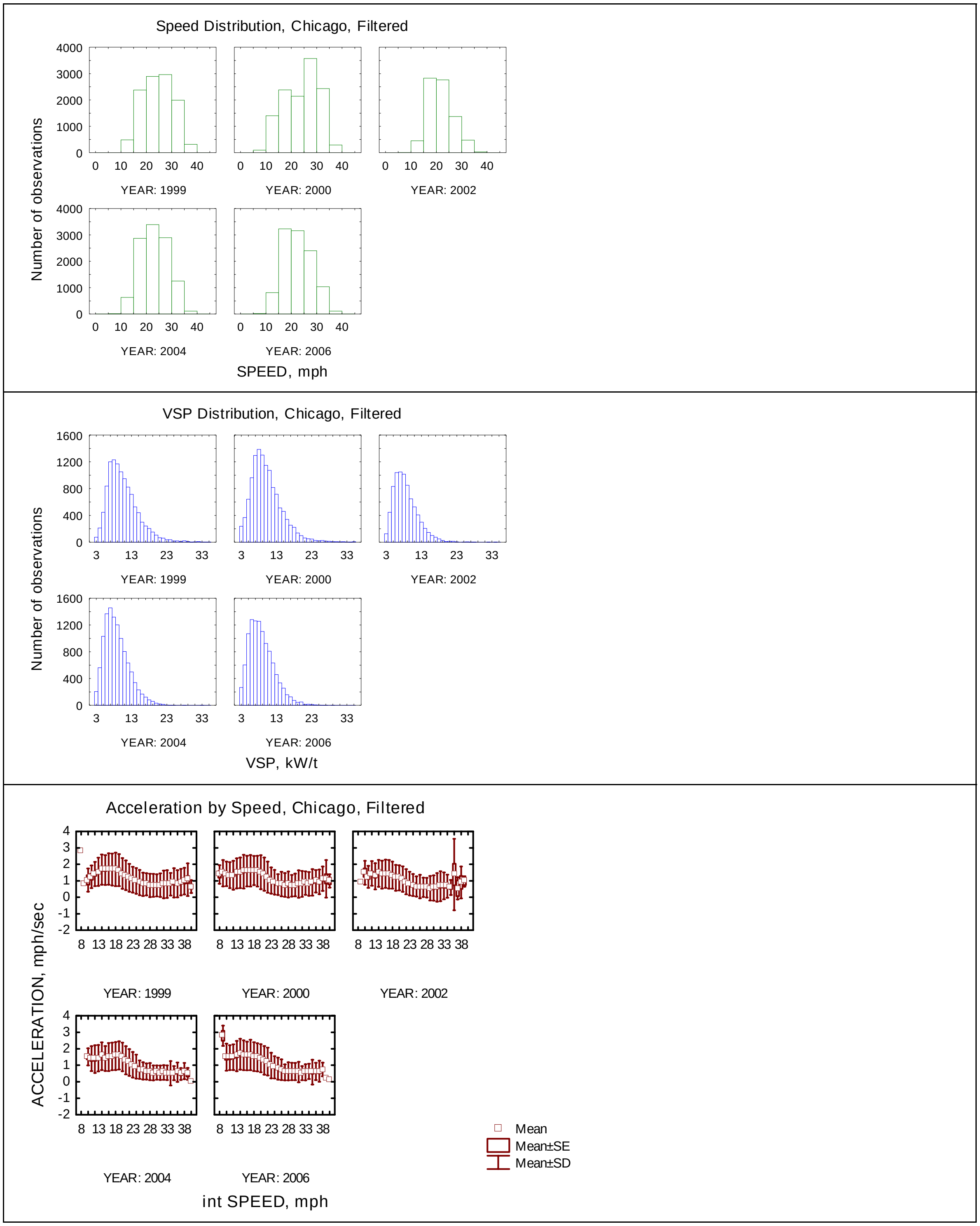


Figure A1 Driving Conditions at Chicago

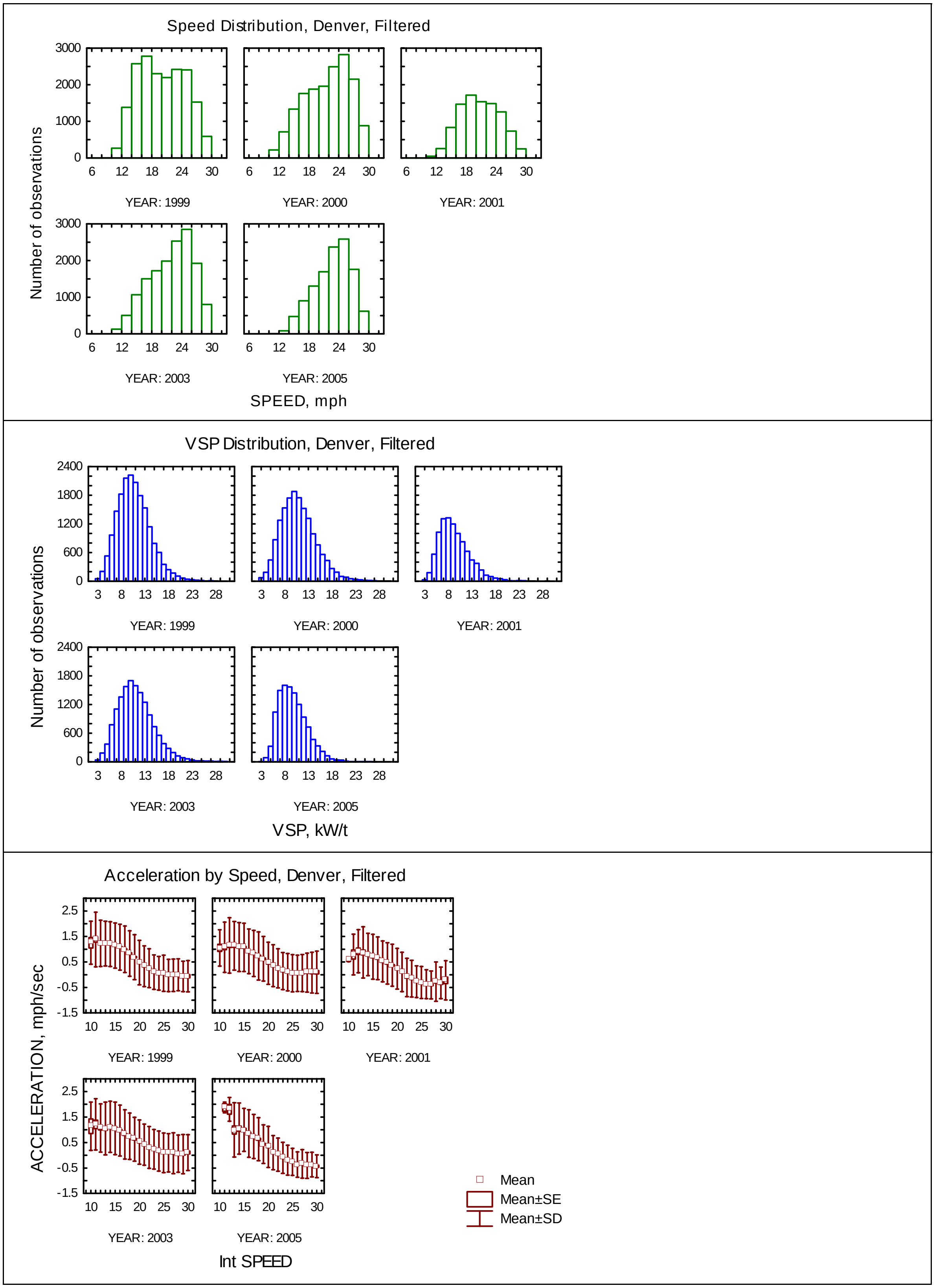


Figure A2: Driving Conditions at Denver

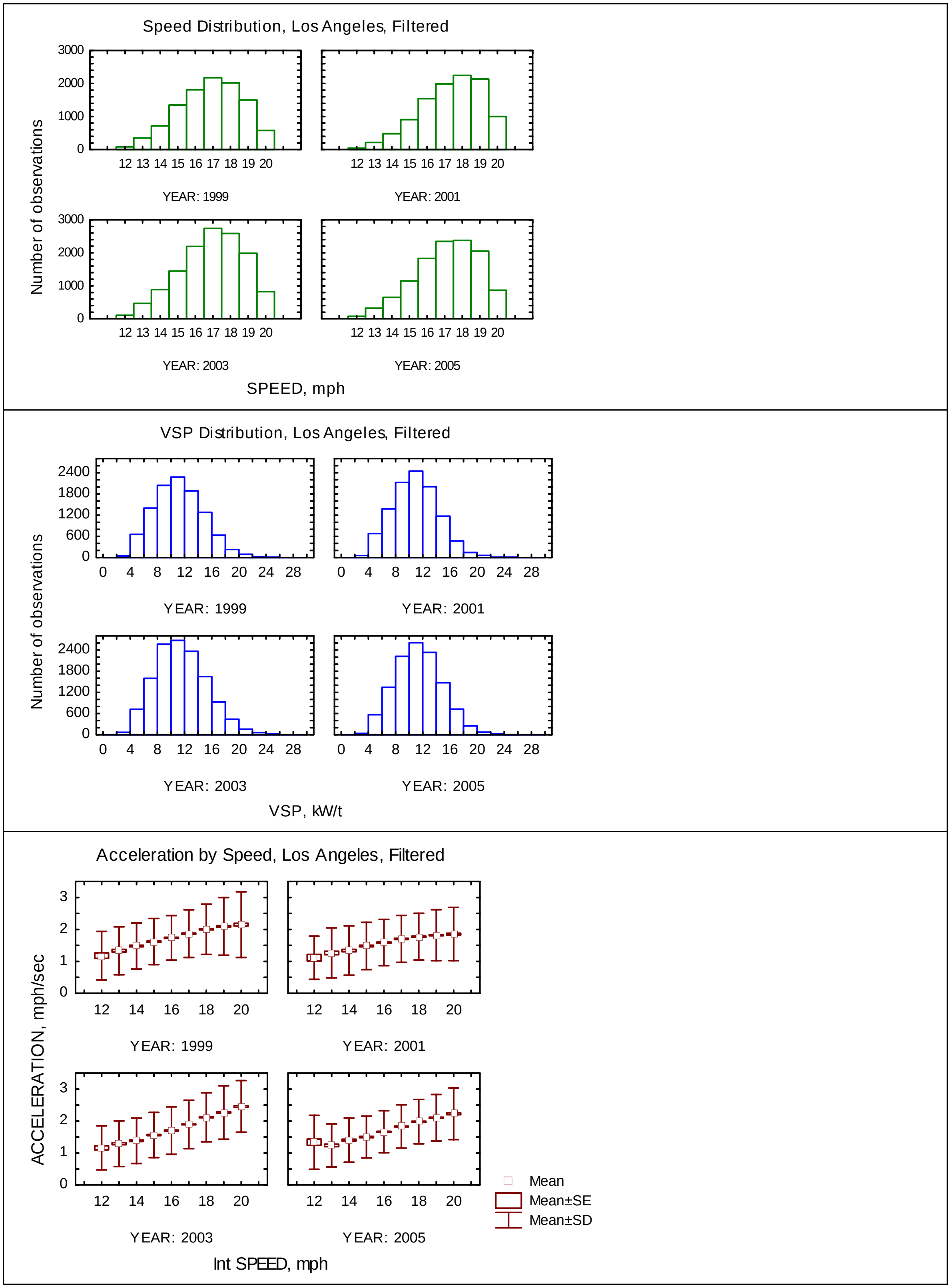


Figure A3: Driving Conditions at Los Angeles LaBrea

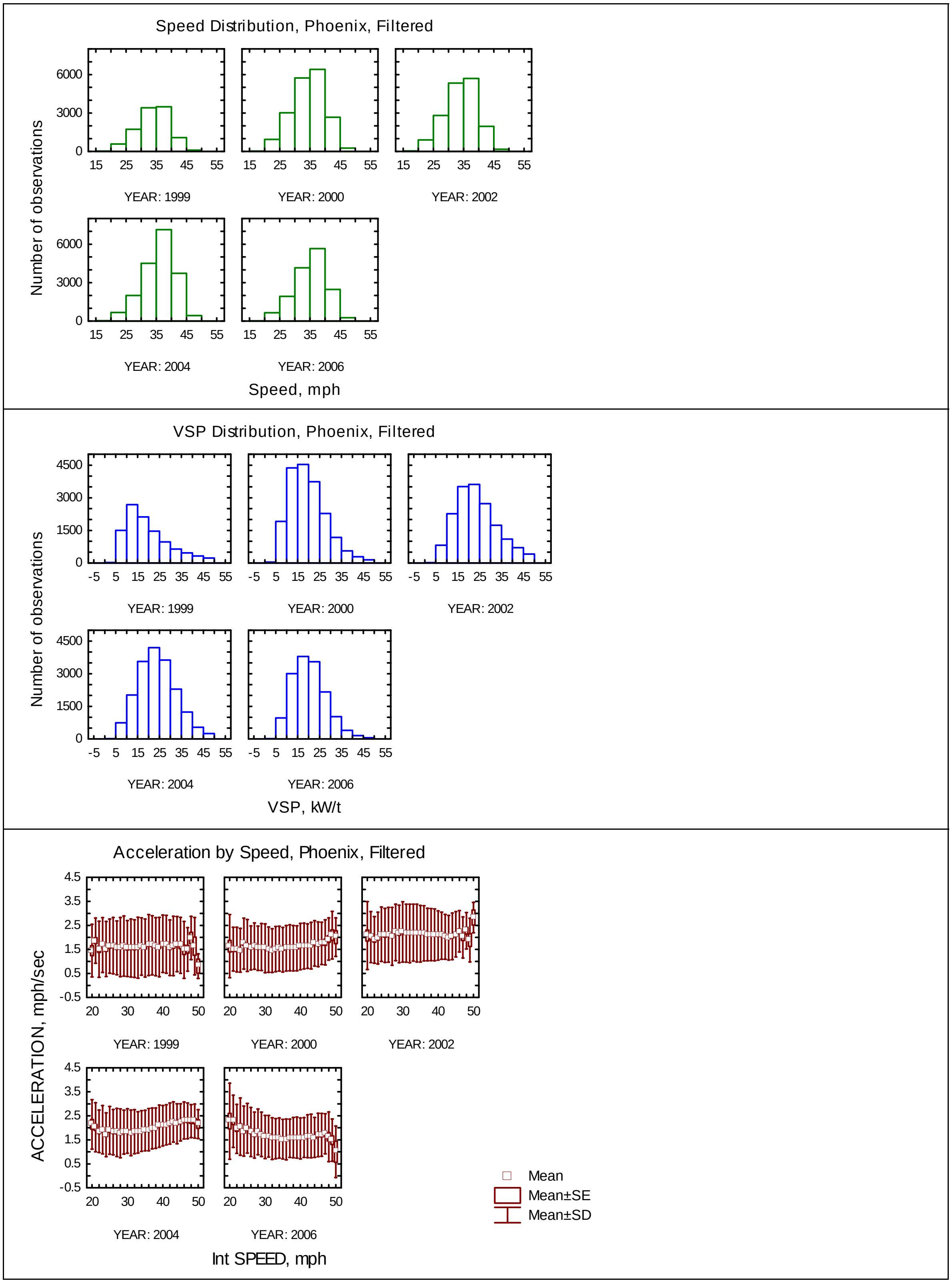


Figure A3: Driving Conditions at Los Angeles LaBrea

Appendix B: Filtering Data and HC Adjustments

Three filters were applied.

Validity Filter

Emissions measurements included in the analysis had to have valid HC, CO, NO, CO_2, speed, and acceleration.

Vehicle Type Filter

Remote- sensing measurements were made on any vehicle with a tailpipe located near the pavement.[27] Therefore, the measurements included not only light- duty gasoline passenger cars and trucks, but also light- duty diesel vehicles, heavy- duty trucks, buses, and other vehicles. Since E-23 was interested in the light- duty fleet, a way of filtering out the other vehicles was needed. To estimate the vehicle type and fuel used, an approach was used based on the first eight digits of the vehicle identification number (VIN).[28]

In order to assign vehicle type, passenger car (P) or truck (T), the first eight digits in the VIN of the vehicles measured were compared with the first eight digits of the VIN (F8VIN) of vehicles inspected in the Missouri Clean Air Program.[29] The Missouri vehicles with assignments of P or T and must have been less than 8500 lbs to have been in the inspection program.[30] Many vehicles would have the same first eight VIN digits. Using Missouri I/M

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[27] Heavy duty diesel vehicles have been measured with remote sensing devices which are set to be able to measure exhaust from tailpipes near the top of the cab. A recent study on cross border traffic at Nogales used this technique. (review draft available at http://www.jac-ccc.org/PDN-ARP/Mobile%20Srcs/NOGALES%20firstdraft_whole%20report_14nov05_finaldraft.pdf.)

[28] R. Slott, Analysis of Remote Sensing Data to Determine Deterioration Rates for OBDII Equipped Vehicles, CRC Project Number E-23-8, EPA Contract No. 68-C-02-048, September 2006. The first eight digits of the VIN are similar to a signature for the characteristics for the vehicle.

[29] This technique is described in detail for the 2003/2004 MO IM program in the report: R.S. Slott, Analysis of Remote Sensing Data to Determine Deterioration Rates for OBDII Equipped Vehicles, Prepared for: Coordinating Research Council, Inc., Project E-23-8, June 2006; P. McClintock provided F8VIN data from the 2005/2006 MO IM program.

[30] From GATEWAY CLEAN AIR PROGRAM RULES: "Vehicles 26 years old and older are exempt from the

classifications, a few F8VINs were associated with both P and T categories. In this analysis a F8VIN was only used if 75% of the F8VIN vehicles were categorized as P or T.

Although almost all the vehicles measured were passenger cars (P) and light- duty trucks (T), occasionally buses or gasoline powered heavy- duty trucks (GVWR >8500 lbs.) would also be measured. Since these vehicles could add uncertainty to the analysis, an attempt was made to remove them using the F8VIN. Colorado Department of Motor Vehicles (DMV) supplies information on the vehicle's fuel and weight for license plates identified in Denver. The effectiveness of the MO IM F8VINS in removing vehicles over 8500 pounds and vehicles running on diesel fuel was checked against the Denver DMV data. Applying the F8VIN filter to the Denver data, eliminated 63% of vehicles assigned weights over 8500 pounds and 75% of vehicles labeled as diesel by Denver DMV.

A summary of the effect of applying the first eight character VIN filter from the Missouri I/M database years 2003 to 2006 is shown in Table B1.

Table B1: Percent Missing Due Only to Type Filtering

City	Phoenix	Denver	Chicago	LA
Not P or T	3,110	1,058	808	909
P	41,088	30,173	37,979	29,800
T	38,918	22,490	15,243	16,240
Total	83,116	53,721	54,030	46,949
% Filtered	3.7%	2.0%	1.5%	1.9%

Driving Conditions Filter

High HC and CO emissions can occur at low VSP as shown in Appendix C, Figures 1-3. To prevent these low fuel rate emissions from adding large uncertainties in the year-to-year

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emissions testing requirement. In addition, the two newest model year vehicles are exempt from testing, as long as the odometer has less than 6,000 miles registered at time of purchase and the vehicle is not being purchased as used. For example, in 2007, new model 2006 and 2007 vehicles are exempt. In addition, historic vehicles, are also exempt from testing. Diesel, propane or other alternate fuel vehicles remain exempt, as do motorcycles and vehicles with a gross vehicle weight rating (GVWR) of over 8,500 pounds. http://www.gatewaycleanair.com/needtest/needtest.htm emission trends, measurements with VSP less than 3 kW/t were excluded. Examination of E-23 unfiltered data shows a few unreasonably high and low speed and acceleration measurements. These values were not included in the analysis.

VSP filters were used to estimate fleet emissions in the St. Louis, MO, clean screening program.[31] VSP filtered (5 to 20 kW/t) remote sensing measurements accurately predicted vehicles' failure during a California dynamometer tailpipe test performed when the vehicles were pulled over to take the test a very short time later.[32]

The summary of driving condition filters is shown in Table B2.

Table B2: Summary of Data Filtering Operations

City	Chicago	Denver	Los Angeles	Phoenix
Valid HC, CO, NO, speed, and acceleration	Yes	Yes	Yes	Yes
Type	P or T	P or T	P or T	P or T
VSP, kW/t	>3	>3	>3	>3 and <50
AGE, years	1-15	1-15	1-15	1-15
Speed, mph	8-40	10-30	12-20	20-50
Acceleration, mph/sec	0 to 8	-1 to 6	0 to 5	0 to 13
Years	1999, 2000, 2001, 2003, 2005	1999, 2000, 2002, 2004, 2006	1999, 2001, 2003, 2005	1999, 2000, 2002, 2004, 2006

[31] P. M McClintock, Gateway Clean Air Program Annual RapidScreen Report, January – December 2002, Prepared for: Missouri Department of Natural Resources, July 2003.

[32] A. Burnette, G. Manne, Impact Of VSP Filtering on RSD Prediction of Roadside ASM Failure, CRC On-Road Workshop, March 28 – 30, 2006.

Adjusting HC Values

A plot of HC emissions versus age and years of measurement in Denver shows a shift of the emissions for new vehicles. This has previously been reported.[33] In this report, the first three years of emissions for the newest vehicles are set as the baseline. One year of measurement is selected as the basis and the other years' HC is adjusted so that the first three years of any vehicle is at the basis year. An example is shown below.

Denver filtered HC gpkg was plotted against age for various years of measurement in Denver. Average tailpipe emissions from newer vehicles should approach zero gm/kg fuel for HC as they do for CO and NO. However, in different measurement campaigns at the same Denver site, average tailpipe HC emissions of newer vehicles differed in each year. This was seen also for HC remote-sensing emissions in Chicago, Los Angeles, and Phoenix.

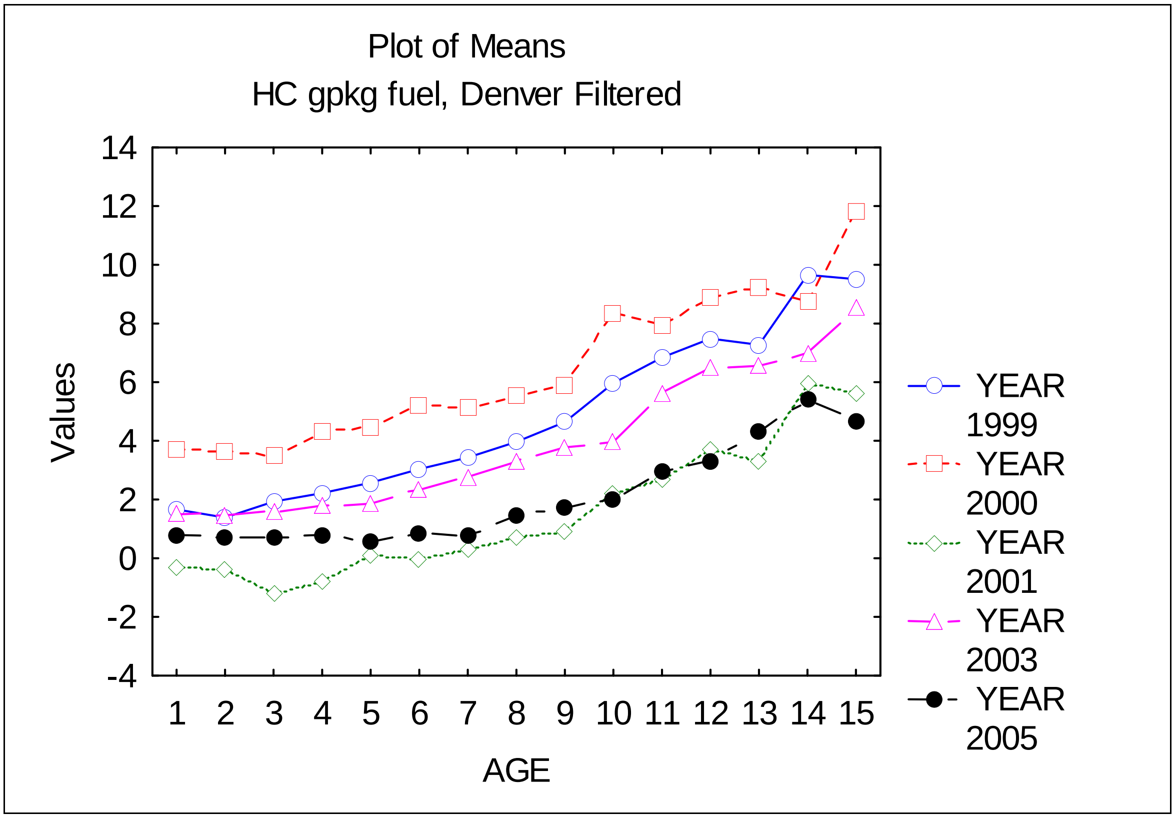


Figure B1: Unadjusted HC Remote Sensing Emissions in Denver

[33] See any papers or E-23 reports by Stedman, et al.

HC emissions were adjusted at each site so that all the years of measurement at that site lead to the same new vehicle average emission level. The calculation used in this analysis was to average the average emissions from AGE 1, 2, and 3 year old vehicles for each measurement year. One measurement year was selected as the base year. The difference in the average emissions of the AGE 1, 2, and 3 year old vehicles between the base year value and each measurement year was calculated, and this value was subtracted from all emission values for that measurement year.

The result of this calculation for Denver is shown below.

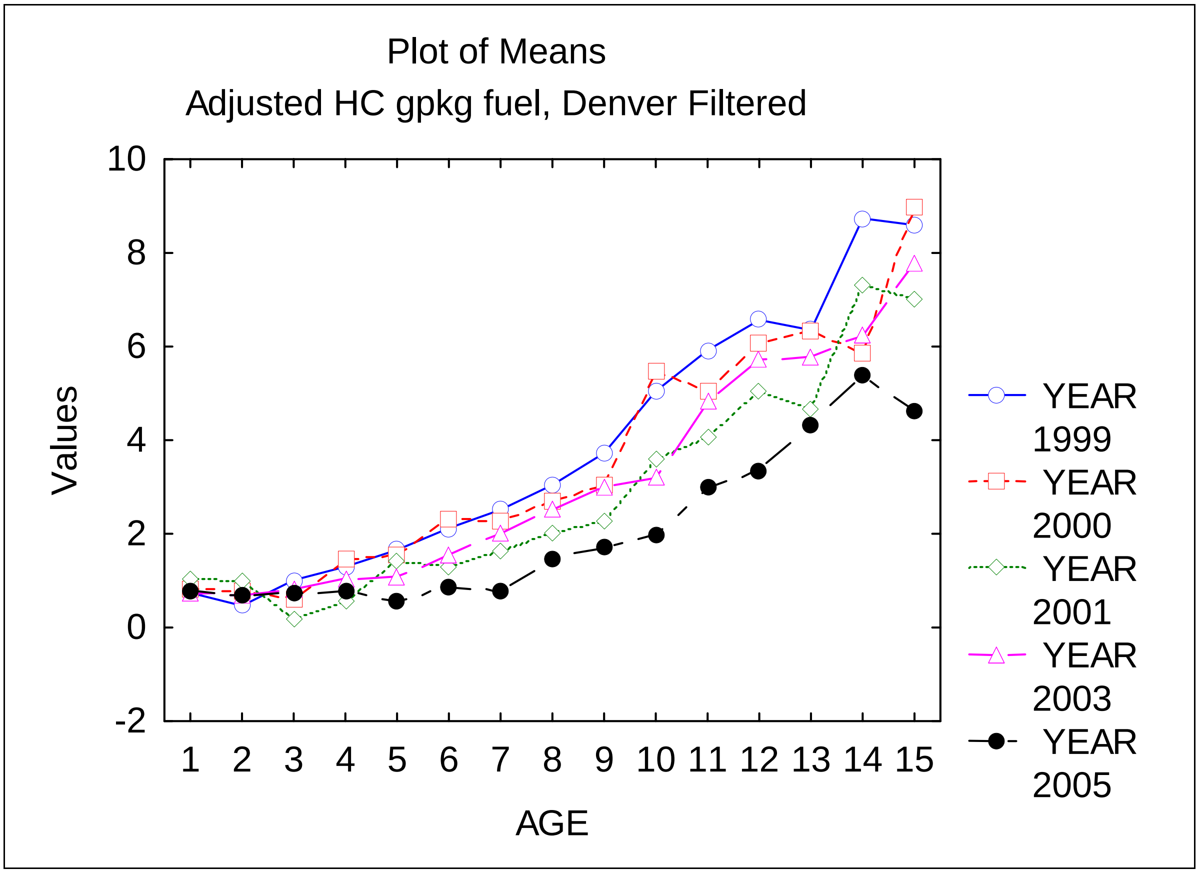
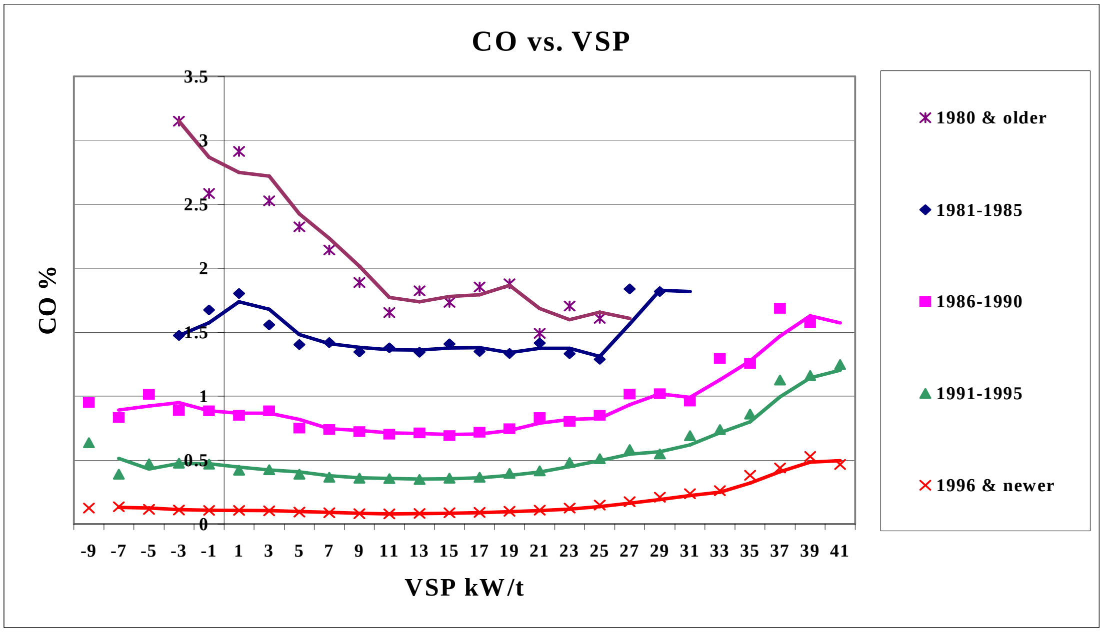


Figure B2: Adjusted HC Remote Sensing Emissions in Denver

Appendix C: Effect of VSP on Remote Sensing Emissions, Data from 2002 Virginia Remote Sensing Pilot Program



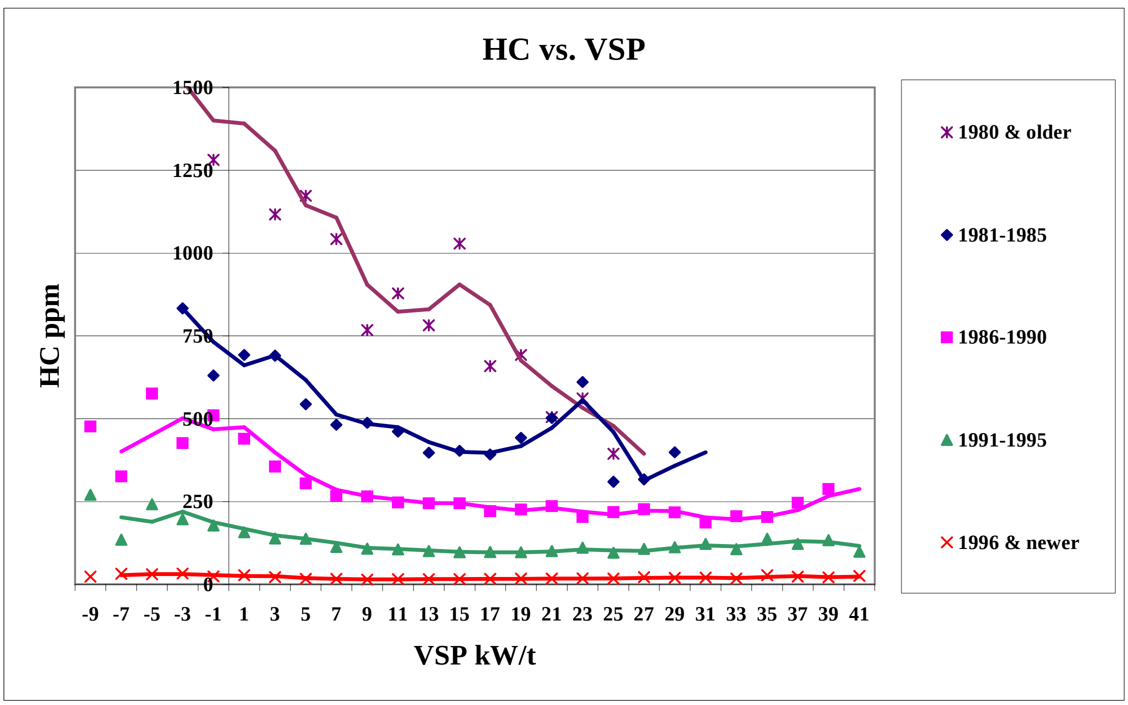


Figure C1: CO and HC Emissions by VSP from P. McClintock and R. Klausmeier, Virginia Remote Sensing Study, Presented to CRC E23 Project Group, April 7, 2003

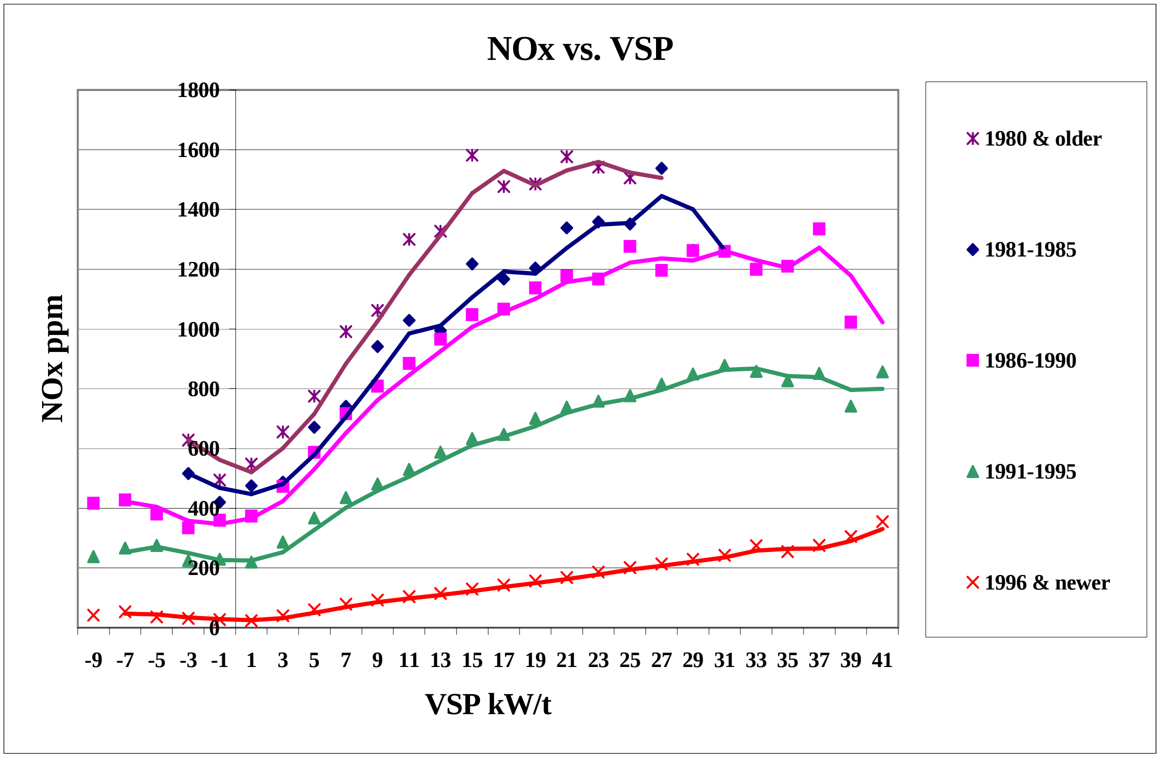


Figure C2: NO Emissions by VSP from P. McClintock and R. Klausmeier, Virginia Remote Sensing Study, Presented to CRC E23 Project Group, April 7, 2003

Appendix D: Charts Showing Lower Fleet Emissions over Time, E-23 Sites

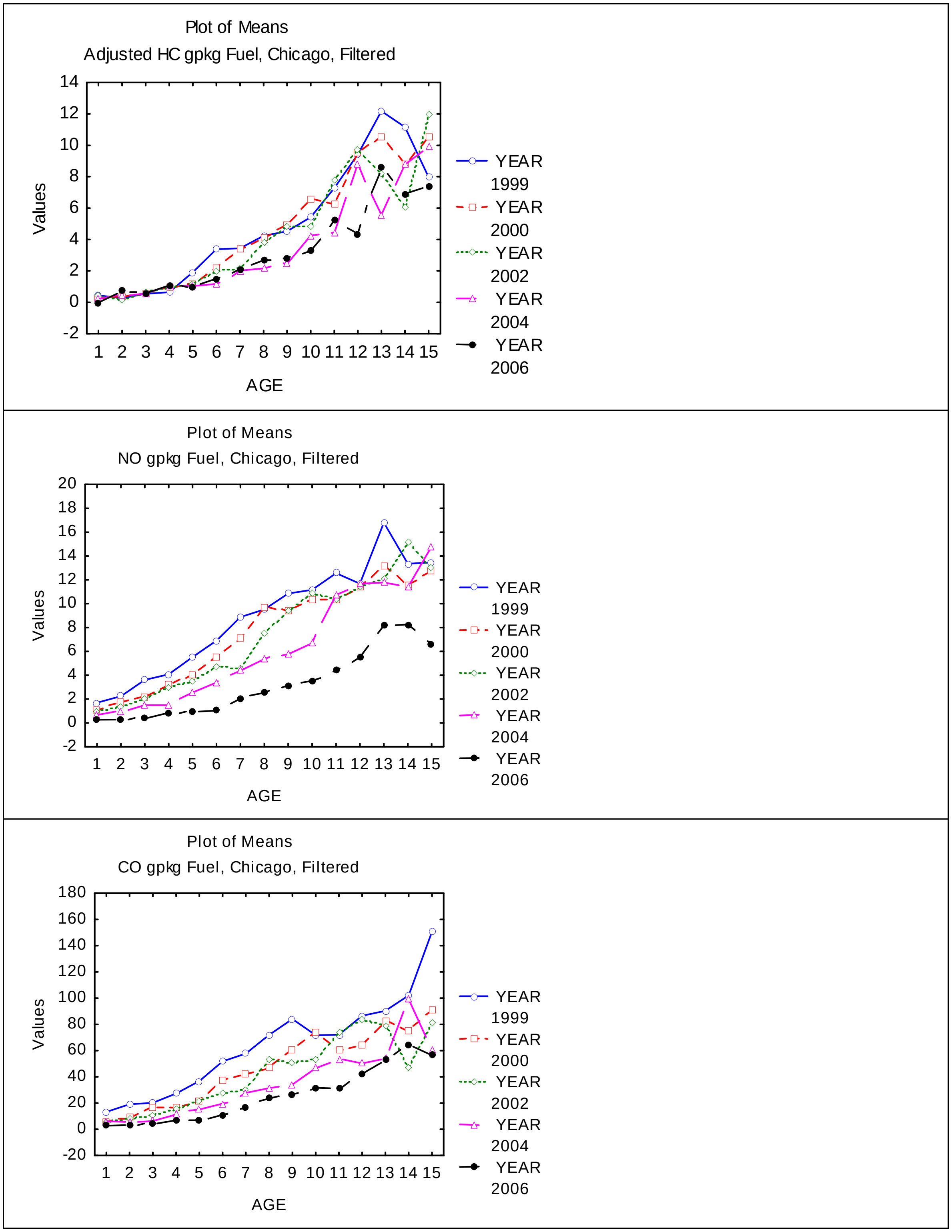


Figure D1: Emissions Lower at the Same Age for Newer Model Years, Chicago

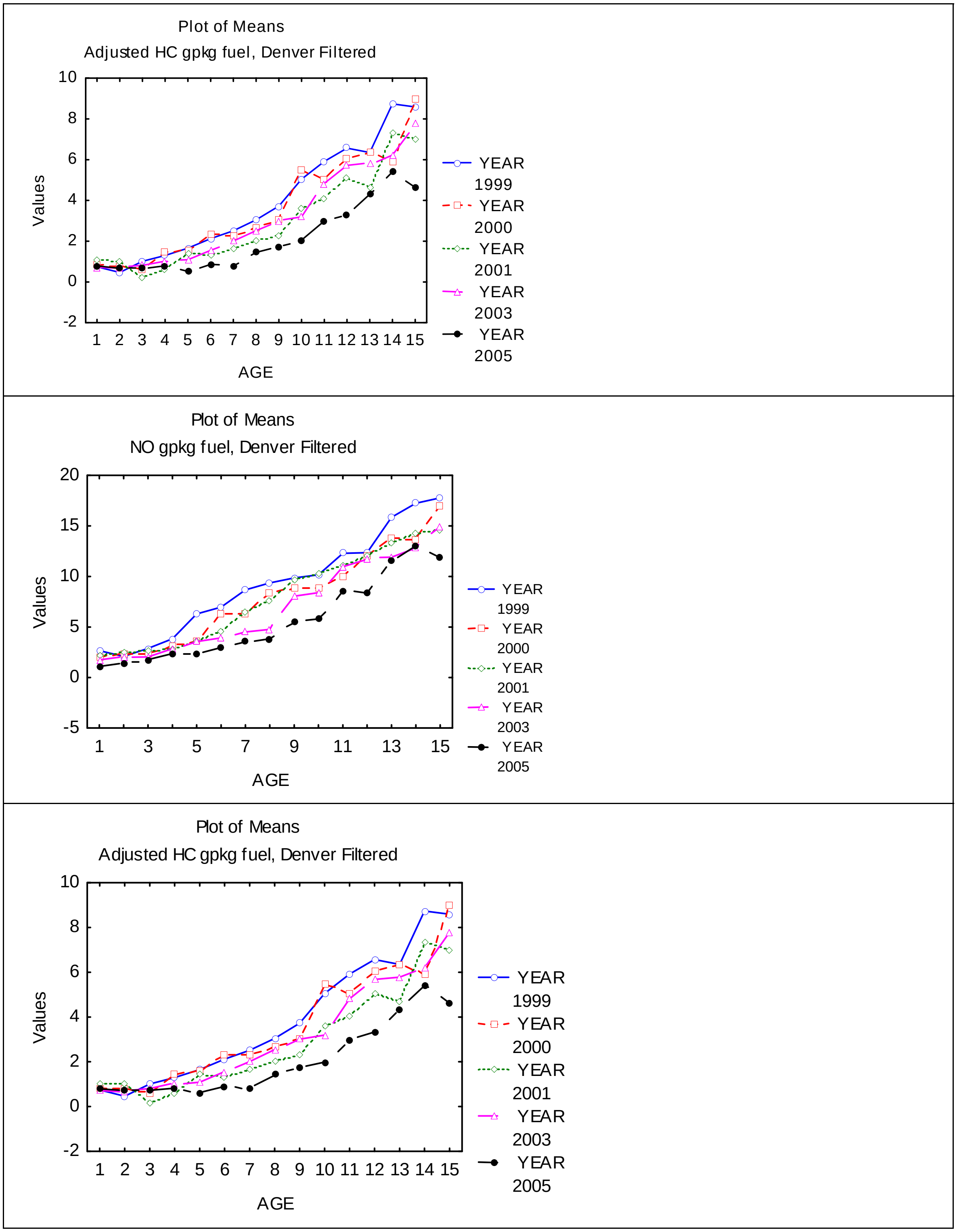


Figure D2: Emissions Lower at the Same Age for Newer Model Years, Denver

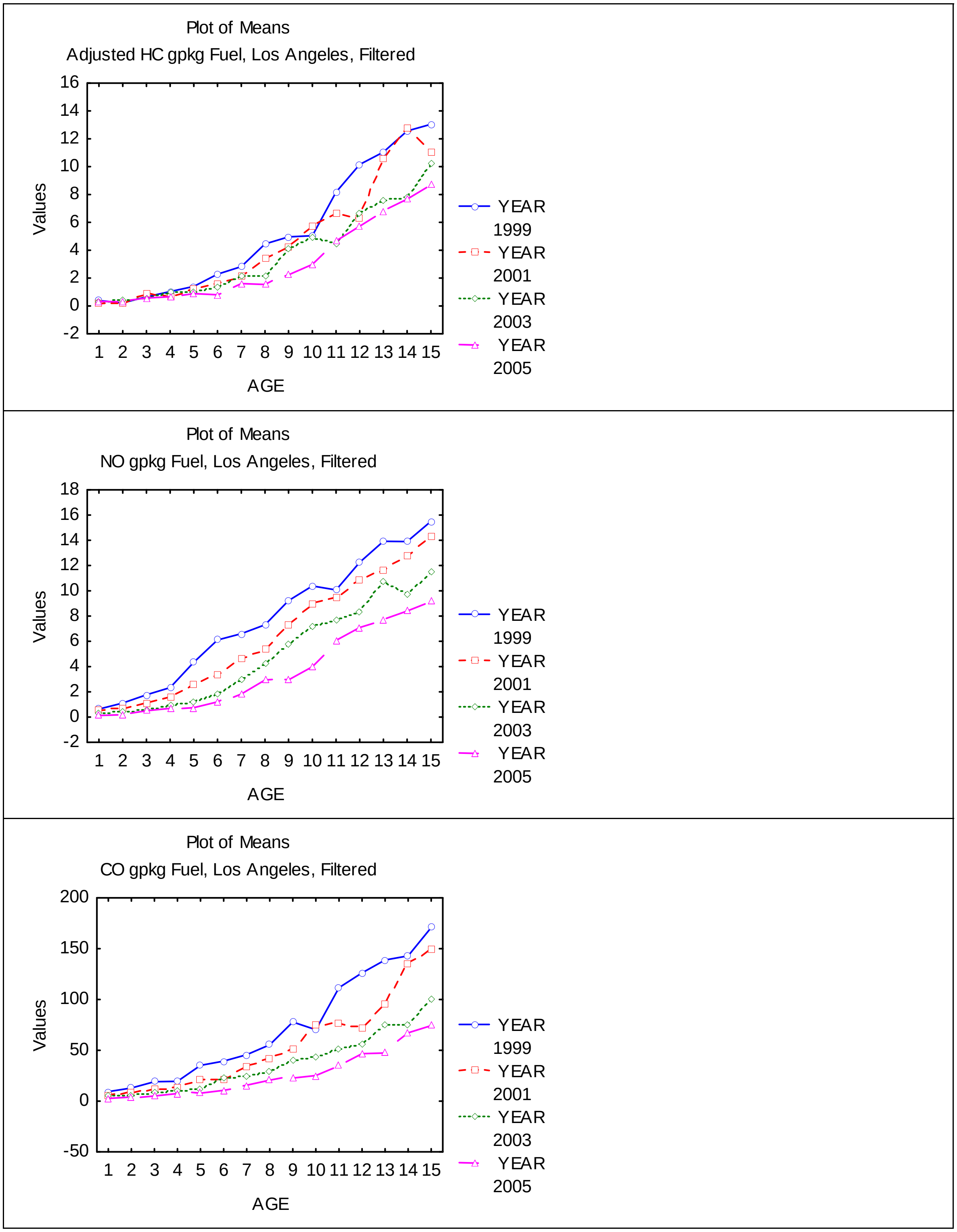


Figure D3: Emissions Lower at the Same Age for Newer Model Years, Los Angeles

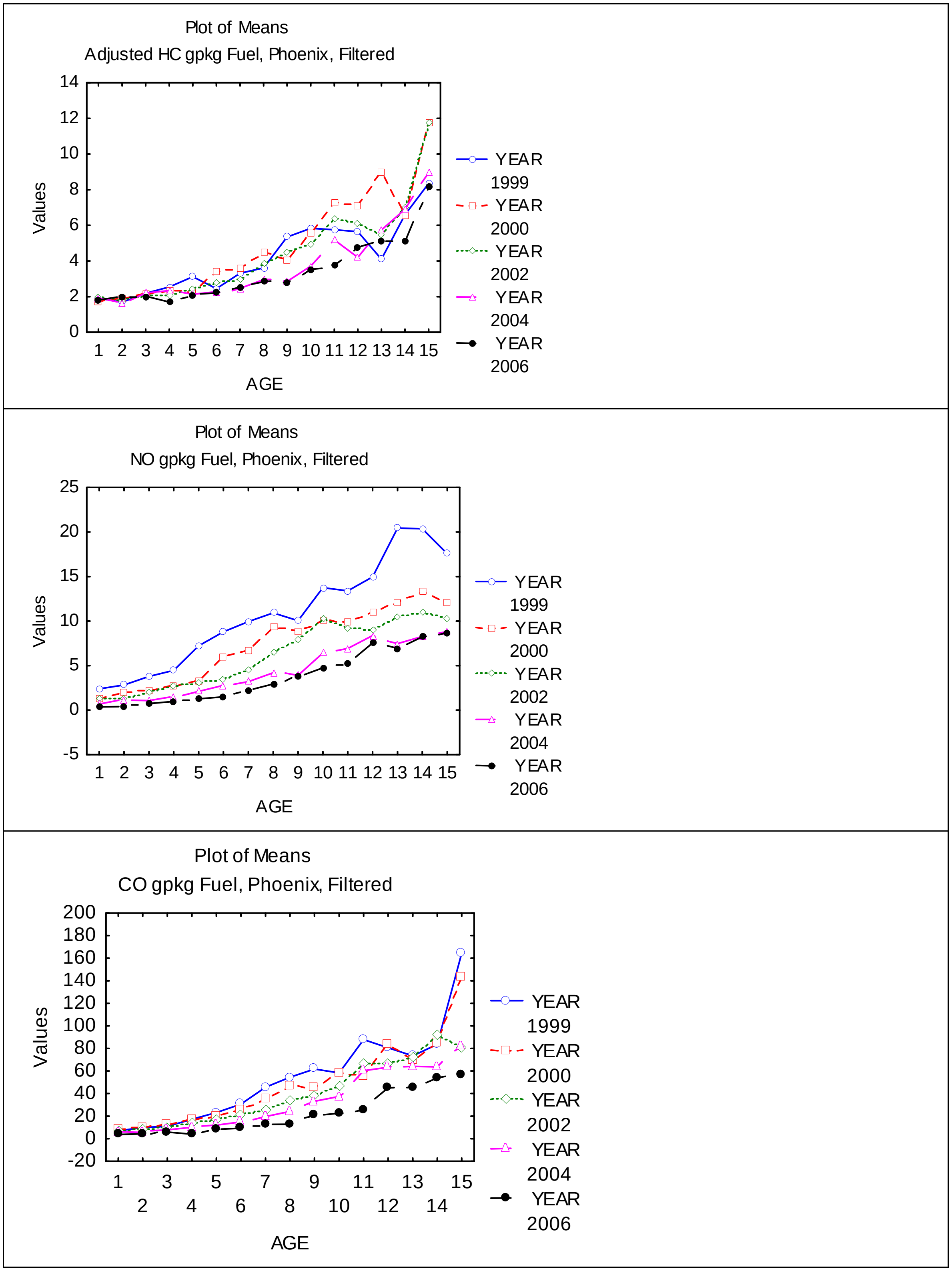


Figure D4: Emissions Lower at the Same Age for Newer Model Years, Phoenix