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INSTANTANEOUS AND SHORT TERM EMISSION RATES OBSERVED DURING MODAL ACCELERATION TESTING

By

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ABSTRACT

Information from two U.S. Environmental Protection Agency (EPA) and two California Air Resources Board (CARB) data sets that included hard acceleration events are presented. The first EPA data set was collected on the CDS acceleration cycle from 1986 to 1987 and included 23 vehicles of 1983 and 1984 model years, of which 13 were carbureted and 10 fuel injected. The second EPA data set included 5 vehicles and was collected in 1992 on current technology vehicles using the CARB acceleration cycle (ACCEL1). The two CARB data sets were comprised of 10 and 9 vehicles, all fuel injected, ranging in model year from 1987 to 1991. These data sets were collected from 1990 to 1991 on the ACCEL1 cycle, which is comprised of 10 acceleration events. The two CARB and the second EPA data sets were collected in one or two second intervals, whereas the first EPA emissions data were integrated by mode (i.e. accelerations, cruises, etc.).

For each individual vehicle in the CARB data sets, the time-based instantaneous emission rate distributions are presented. The maximum observed for hydrocarbons was 0.25 g/s, for carbon monoxide (CO) 7.1 g/s, and for oxides of nitrogen (NO_x) 0.26 g/s. The 95th percentile, representing a typical open loop or enrichment event for these data sets, ranged from 0.04 to 0.15 g/s for hydrocarbons, 1.1 to 6.1 g/s for CO, and 0.01 to 0.16 g/s for NO_x. All these ranges are at least one order of magnitude greater than a time-based equivalent emission standard for hydrocarbons and NO_x, and two orders of magnitude for CO.

For the first EPA data set, a difference in modal emission rates was evident for carbureted and fuel injected vehicles. For these acceleration modes, carbureted vehicles typically emitted 2.5 times more hydrocarbons, 1.5 times more CO, and 1.4 times more NO_x than fuel injected vehicles.

The events that showed similar speed-time characteristics in the CARB and first EPA data sets were compared (up to 6 MPH/second and 30 MPH, the maximum speed of the CDS). For the first EPA data set, the ratio of emissions of a hard acceleration event to an FTP-like acceleration event was 2.2 for hydrocarbons, and 2.9 for CO. The NO_x emissions did not appear to be affected. The CARB data sets showed a greater influence on CO emissions for the low-speed hard-acceleration events relative to the FTP-like acceleration events. The hard acceleration events weres higher than the FTP-like events by 2.5 to 3.3 times for CO. For NO_x and hydrocarbons the results were mixed for these events. When these events are compared with events with similar accelerations but higher speeds the differences reach 304% for hydrocarbons, 420% for CO, and 191% for NO_x. These findings suggest that there is an important emitting potential of acceleration events greater than those encountered in the FTP.

INTRODUCTION

For the past 20 years, the Federal Test Procedure (FTP) has been the standard mobile source emissions certification cycle. A number of studies have been performed to evaluate its representativeness. Studies conducted in Australia in the early 80's in the cities of Melbourne, Sydney, and Perth, showed that actual driving behavior was substantially different from the FTP.[1] More recent studies conducted in a number of U.S. cities have shown that the on-road driving domain significantly exceeded the FTP driving domain.[2,3,4] Such studies included Baltimore, Los Angeles and Spokane (Figure 1).

Recently, models have been proposed to predict emissions under open loop, hard accelerations or high engine loads.[5,6] These studies have used emission rates from a very limited vehicle fleet. One of the main objectives of this paper is to provide additional information on emission rates observed during hard acceleration events, with emphasis on the variation that may occur on individual vehicles.

This presentation is an extension of the paper[7] on Modal Acceleration Testing on Current Technology Vehicles, presented at "The Emission Inventory: Perception and Reality" specialty conference conducted in Pasadena, California, October 18-20, 1993. The results of four (three additional) data sets are presented; two from the U.S. Environmental Protection Agency (EPA) and two from the California Air Resources Board (CARB). The vehicles of the first unpublished EPA study included model years of 1983 to 1984, and the testing was conducted circa 1987. The fleets in the two CARB studies ranged in model years from 1988 to 1990 and were tested in 1991. More recently EPA conducted modal studies similar to the two CARB studies. The vehicle fleet included model years from 1991 and 1992, with most of the testing performed in 1992.

This report also analyzes the differences between carbureted vs. fuel injected vehicles subject at different acceleration rates. A comparison with the CARB studies is performed for some events that share similarities in terms of speed and acceleration patterns.

EPA ACCELERATION CYCLE DEFINITION AND TEST VEHICLES

The testing was performed to assess the potential emissions during acceleration events. EPA developed an acceleration cycle (CDS) with a total duration of 520 seconds, and a distance of 1.7 miles. The acceleration cycle was separated into eleven subcycles, each with 4 modes: idle, acceleration, cruise, and deceleration. These subcycles included accelerations in 0.5 MPH/second intervals from 1 MPH/second to 6 MPH/second. The accelerations were from 0 MPH to 15 MPH for the first 7 subcycles, and from 0 MPH to 30 MPH for the rest of the subcycles. The first 7 subcycles included idles and cruises of 10 seconds, the remaining subcycles included idles and cruises of 20 seconds. Table 1 describes each subcycle and mode, and the speed-time trace is presented in Figure 2 (for convenience CARB-ACCEL1 is also presented in this figure).

EPAa, mode integrated data set

The 23 vehicles used for this project were 1983 or 1984 model year, automatic transmission, 13 carbureted and 10 fuel injected, with engine sizes ranging from 1.5 L to 5.0 L. The data set was integrated in periods of 5 to 20 seconds depending on the specific mode. The basic characteristics of the vehicles are presented in Table 2. The emission results on this data set were generated by the Automotive Testing Laboratory during 1987 under contract to EPA.[8]

CARB ACCELERATION CYCLE DEFINITION AND TEST VEHICLES

For the purpose of this presentation, moderate to hard accelerations are defined to be from 3.3 MPH/s (1.5 m/s^2, the maximum on the FTP) to 6 MPH/s (2.7 m/s^2), and low to moderate speeds are defined to be below 30 MPH. High speeds are defined to be above 45 MPH. Table 3 describes each mode[a] of the ACCEL1 Cycle, designed to represent diverse acceleration driving modes. ACCEL1 has 44% high speeds, and reaches or exceeds 4 MPH/s (1.8 m/s^2) 11% of the time. Both conditions occur simultaneously 5% of the time, representing very high load events. 11% of the cycle time is at idle. The speed-time profile is presented in Figure 2.

CARB1, every second data set
The 10 vehicles used for the 1 second data collection were newer technology, automatic transmission, fuel injected, rear wheel drive vehicles with engine sizes ranging from 2.3 L to 5.7 L. With the exception of the 1988 Corvette, the vehicles were of model years 1989 or 1990.

CARB2, every 2 seconds data set
The 9 vehicles used for the 2 second data integration with replication included 7 automatic transmission vehicles, and 2 manual transmission vehicles. All of these were fuel injected, rear wheel drive, with engine sizes ranging from 2.3 L to 4.9 L.

EPAb, every second data set
The vehicle set included 5 cars, ranging in model year from 1991 to 1992, including 2 light duty trucks.

The main characteristics of the vehicles on the 3 data sets are presented in Table 4.

EMISSION RATES, STANDARDS AND REFERENCES

Emission rates are usually expressed as grams of pollutant per traveled mile. For this analysis it is convenient to express the emissions in alternative units, such as total grams per a given event. For example if one wants to assess the impact of adding a specific event to a conventional driving test, the total grams emitted during the event can be compared to the total grams emitted for the full cycle. To compare the emissions to a reference, the current Federal and California motor vehicle certification standards were used. For the purpose of comparing events, a cycle-based standard was calculated by multiplying the current standard by 7.5 miles (the distance over the FTP). This value is a cycle-based equivalent to the distance-based standard. It is also important to be able to compare the instantaneous emissions to a reference, since events that trigger high emissions may occur in very short periods of time. Accordingly, average time-based standard were calculated, expressed as the average emission per second during an FTP cycle. These emission references are presented in Table 5.

RESULTS

EPAa Acceleration Subcycles
Figure 3 presents the mean total emission per subcycle including the 95% C.I. stratified by carbureted and fuel injected vehicles. As described previously in Table 1, Subcycle 6 has similar acceleration conditions to the FTP, with maximumn acceleration of 3.5 MPH/s (1.6 m/s^2) reaching a speed of 30 MPH. Subcycle 11 represents a hard acceleration of 6 MPH/s (2.7 m/s^2) for a similar speed range. Comparisons between these two subcycles are relevant to assess the potential emission of hard accelerations at these speeds. Overall, for hydrocarbons the hard acceleration subcycle was 1.8 times greater than the FTP-like subcycle, and for CO approximately 2.5 times higher. The NO_x emissions were slightly higher on the FTP-like subcycle. The carbureted vehicles showed less differences among these two subcycles (56% for hydrocarbons and 76% for CO) than the fuel injected vehicles (175% for hydrocarbons and 386% for CO), again with minimal impact on NO_x. Carbureted vehicles typically emitted 2.5 times more hydrocarbons, 1.5 times more CO, and 1.4 times more NO_x than fuel injected vehicles. In terms of mean emission per distance, the carbureted vehicles showed differences between

[a] In the subsequent, we will refere to distinct groups of events, that include idles, accelerations, cruises and/or decelerations, as subcycles for the EPA-CDS cycle and as modes for the CARB-ACCEL1 cycle.

the hard acceleration subcycle and the FTP-like subcycle of 114% for hydrocarbons and 182% for CO. The fuel injected vehicles showed 214% for hydrocarbons and 467% for CO for the two subcycles. The impact on NO_x was minimal, at 5% for carbureted vehicles and 22% for the fuel injected vehicles. These results are presented in Figure 4.

Using the total emissions per specific mode (idle, acceleration, cruise, or deceleration) divided by the mode duration, it was possible to have time-resolved emission rates. Although crude compared to second-by-second modal emissions, it is possible to distinguish the highest emission rates. These emission rates are roughly one third to one half of the peak instantaneous emission rates as will be presented later in this paper. Figure 5 shows mean time-based emission rates for carbureted and fuel injected vehicles as well as the speed-time profile. The high emissions potential during short periods of acceleration events is evident. Also evident are the higher emissions of carbureted vehicles compared to fuel injected. For the particular case of subcycles 7 to 11, fuel injected vehicles demostrate delayed CO excursions, apparently higher during the cruise modes than during the acceleration modes. This may be a consequence of CO sampling response and/or integration methodology.

CARB1, CARB2, and EPAb Acceleration Modes

The 10 modes of the ACCEL1 cycle were analyzed by mass output, in grams per mode. This was necessary to assess the potential impact that an event would have if appended to a current standardized cycle. The equivalent gram per cycle standards (Table 5) are used to assess the potential increase in total output mass if a similar mode were appended to the current certification cycle. Figure 6 shows the mode-based emissions for each pollutant. The lowest emission modes were modes 1 and 3 for the CARB1 and CARB2 sets. In the EPAb set, mode 4 includes the emissions of mode 3, hence showing the highest emissions for this set. Because of this grouping, this particular mode was not used in this analysis. For the CARB sets, modes 2 and 10 demostrated the greatest emissions increase potential for hydrocarbons (33% to 35%), while EPAb mode 2 presented a 22% potential increase. For CO, modes 6, 8, and 10 presented the higher potential (70% to 90%, relative to the California standard). A similar pattern emerged in EPAb set (120% related the Federal standard), although in general the vehicles were cleaner. Modes 6, 8 and 10 were designed to simulate acceleration on a metered ramp or from a low speed cruise to high speed. Mode 10 corresponds to a worst case wide open throttle acceleration. Large potential for NO_x emissions were found in modes 2 and 6, reaching 22% for the CARB2 set. The potential increase was minimal for the EPAb set at levels no higher than 3%.

Figure 7 shows the mean emission per distance by mode. It is evident that only the FTP-like mode 1 is close to complying with the emission rate standards, with the exception of the EPAb data set which met the Federal NO_x emission rate standard (with the exception of mode 6).

CARB1 and CARB2 Instantaneous and Short Term Emission Rates

For each individual vehicle in the CARB1 and CARB2 data sets, the time-based instantaneous emissions rate distributions are presented. The maximum observed for hydrocarbons was 0.25 g/s, for CO 7.1 g/s, and for NO_x 0.26 g/s. As mentioned before, events with simultaneous high speeds and hard acceleration occur 5% of the time on the ACCEL1 cycle, representing very high load events. For this reason the 95th percentile was selected to represent a typical open loop or enrichment event for these data sets. For hydrocarbons the 95th percentile ranged from 0.04 to 0.15 g/s, with median of 0.07 g/s. For CO the median was 3.6 g/s with a range of 1.1 to 6.1 g/s. For NO_x the median was 0.05 g/s and the range 0.01 to 0.16 g/s. All these ranges are at least one order of magnitude higher than a time-based equivalent emission standard for hydrocarbons and NO_x, and two orders of magnitude for CO. Figures 8, 9, and 10 show the boxplots for the instantaneous hydrocarbons, CO, and NO_x emission rates observed during the ACCEL1 cycle for the CARB1 and CARB2 sets.

Comparison of Similar Subcycles and Modes

The EPA CDS acceleration cycle has 3 subcycles that are similar to the CARB ACCEL1 cycle. Subcycle 5 includes an acceleration from idle to 15 MPH at 3 MPH/s (1.3 m/s^2), subcycles 7 and 11 range from idle to 30 MPH at 3.5 MPH/s (1.6 m/s^2) and 6 MPH/s (2.7 m/s^2) respectively. In the ACCEL1 cycle modes 1 and 3 correspond to 3 MPH/s (1.3 m/s^2) and 6 MPH/s (2.7 m/s^2) from idle to a nominal 30 MPH. The respective subsequent modes (2 and 4), run from 30 MPH to a nominal 60 MPH, at 5 MPH/s (2.2

m/s^2) and 6 MPH/s (2.7 m/s^2). Figures 3 and 6 present the mean total emissions per subcycle and mode respectively. The emissions on the FTP-like subcycle 6 and mode 1 are comparable, for the fuel injected vehicles in EPAa, CARB1 and CARB2 data sets. The hydrocarbons are within 36%, CO at 12% and NO_x at 22%. During the low speed hard acceleration events subcycle 11 and mode 3 are within 67% for hydrocarbons, 80% for CO, and 5% for NO_x. When these modes are compared with modes with similar accelerations but higher speeds the differences reach 304% for hydrocarbons, 420% for CO, and 191% for NO_x. Figure 4 and 7 show the emissions per distance. Here subcycle 6 and mode 1, and subcycle 11 and mode 3 also show relatively similar emission rates.

Figure 11 presents the mean time-based emission for subcycles 5, 6, and 11 for EPAa carbureted and fuel injected vehicles, along with the mean time-based and instantaneous emission rates for modes 3 and 4 for CARB1 fuel injected vehicles. For modes 3 and 4 the emission rates calculated for the specific idle, acceleration, and cruise events are roughly one third to one half of the peak instantaneous emission rates. NO_x emissions present a delay or phase shift with respect to the speed-time profile. Also the NO_x rates were very similar in magnitude to the EPAa data set (within 5%) for the acceleration of 6 MPH/s (2.7 m/s^2).

Test-to-Test Variability and Methods Comparison

Table 6 shows test to test variability for the CARB2 data set. It also shows the average absolute difference in terms of the mean, for the real-time integrated emissions, as well as for the total emissions calculated from the sampling bags. test to test differences of real-time data were 20% for hydrocarbons, 13% for CO, and 25% for NO_x. A similar pattern was observed for the integrated bag emissions. A comparison between the real-time integrated emissions and the Tedlar bag integrated samples was performed. The R^2s were very good between the two methods 0.98 for hydrocarbons and 0.97 for CO and NO_x. Emissions of hydrocarbons were overestimated by the real-time method by 13%. In the case of CO the second-by-second method underestimated the values by 12%. NO_x data was overestimated by the real-time method by 23%.

CONCLUSIONS AND RECOMMENDATIONS

These findings illustrate the high emitting potential of acceleration events greater than those encountered in the FTP. In particular, the combination of high-speed and hard-acceleration increases the potential for the emission in short periods of time. Differences in emission rates were evident for carbureted and fuel injected vehicles in the transitional subcycles close to the FTP boundaries.

A single hard acceleration event could be equivalent to 22% to 35% of the total equivalent standard for hydrocarbons, up to 90% of the total for the CO California equivalent standard (or between 120% to 185% of the Federal equivalent standard). NO_x emissions could reach 20% over the California equivalent standard.

It is necessary to consider these findings while modeling the mobile source emission inventory. The authors are aware of ongoing research by CARB, EPA, and the California Department of Transportation focusing on hard accelerations, high speeds, and high loads that may include the generation of second-by-second emission rates.

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DISCLAIMER

The contents of this paper/report and the authors' findings do not necessarily reflect the views and policies of the California Air Resources Board. The mention of contractors and commercial products is not to be constructed as either an actual or implied endorsement of such individual products.

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Table 1. CDS acceleration cycle, subcycles and modes description.

	mode number	mode description	acceleration MPH/s	(m/s2)	speed MPH	duration seconds	distance miles
	0	crank	0.0	(0.0)	0	0	0.000
Subcycle 1	1	idle	0.0	(0.0)	0	10	0.000
Subcycle 1	2	acceleration	1.0	(0.4)	0-15	15	0.034
Subcycle 1	3	cruise	0.0	(0.0)	15	10	0.042
Subcycle 1	4	deceleration	-1.0	(-0.4)	0-15	15	0.028
Subcycle 2	5	idle	0.0	(0.0)	0	10	0.000
Subcycle 2	6	acceleration	1.5	(0.7)	0-15	10	0.023
Subcycle 2	7	cruise	0.0	(0.0)	15	10	0.042
Subcycle 2	8	deceleration	-1.5	(-0.7)	0-15	10	0.018
Subcycle 3	9	idle	0.0	(0.0)	0	10	0.000
Subcycle 3	10	acceleration	2.0	(0.9)	0-15	8	0.020
Subcycle 3	11	cruise	0.0	(0.0)	15	10	0.042
Subcycle 3	12	deceleration	-2.0	(-0.9)	0-15	8	0.013
Subcycle 4	13	idle	0.0	(0.0)	0	10	0.000
Subcycle 4	14	acceleration	2.5	(1.1)	0-15	6	0.015
Subcycle 4	15	cruise	0.0	(0.0)	15	10	0.042
Subcycle 4	16	deceleration	-2.5	(-1.1)	0-15	6	0.010
Subcycle 5	17	idle	0.0	(0.0)	0	10	0.000
Subcycle 5	18	acceleration	3.0	(1.3)	0-15	5	0.012
Subcycle 5	19	cruise	0.0	(0.0)	15	10	0.042
Subcycle 5	20	deceleration	-3.0	(-1.3)	0	5	0.009
Subcycle 6	21	idle	0.0	(0.0)	15	10	0.000
Subcycle 6	22	acceleration	3.5	(1.6)	0-30	9	0.044
Subcycle 6	23	cruise	0.0	(0.0)	30	20	0.167
Subcycle 6	24	deceleration	-3.5	(-1.6)	0-30	9	0.031
Subcycle 7	25	idle	0.0	(0.0)	0	20	0.000
Subcycle 7	26	acceleration	4.0	(1.8)	0-30	8	0.040
Subcycle 7	27	cruise	0.0	(0.0)	30	20	0.167
Subcycle 7	28	deceleration	-4.0	(-1.8)	0-30	8	0.027
Subcycle 8	29	idle	0.0	(0.0)	0	20	0.000
Subcycle 8	30	acceleration	4.5	(2.0)	0-30	7	0.035
Subcycle 8	31	cruise	0.0	(0.0)	30	20	0.167
Subcycle 8	32	deceleration	-4.5	(-2.0)	0-30	7	0.024
Subcycle 9	33	idle	0.0	(0.0)	0	20	0.000
Subcycle 9	34	acceleration	5.0	(2.2)	0-30	6	0.029
Subcycle 9	35	cruise	0.0	(0.0)	30	20	0.166
Subcycle 9	36	deceleration	-5.0	(-2.2)	0-30	6	0.021
Subcycle 10	37	idle	0.0	(0.0)	0	20	0.001
Subcycle 10	38	acceleration	5.5	(2.5)	0-30	6	0.030
Subcycle 10	39	cruise	0.0	(0.0)	30	20	0.166
Subcycle 10	40	deceleration	-5.5	(-2.5)	0-30	6	0.019
Subcycle 11	41	idle	0.0	(0.0)	0	20	0.001
Subcycle 11	42	acceleration	6.0	(2.7)	0-30	5	0.023
Subcycle 11	43	cruise	0.0	(0.0)	30	20	0.166
Subcycle 11	44	deceleration	-6.0	(-2.7)	0-30	5	0.017
	45	idle	0.0	(0.0)	0	20	0.000

Table 2. CDS acceleration cycle test vehicle fleet (EPAa).

Vehicle Number	Model Year	Manufacturer & Model		Engine Size (L)	Carburetor Fuel Injection	Transmission
300	1983	Nissan	Sentra	1.6	2V	5MT
301	1983	Ford	Escort	1.6	2V	Auto
302	1983	Nissan	Sentra	1.6	2V	5MT
303	1983	Honda	Accord	1.8	3V	5MT
304	1983	Nissan	Stanza	2.0	2V	Auto
305	1983	Pontiac	Grand Prix	3.8	2V	Auto
306	1983	Toyota	Corrolla	1.6	2V	5MT
307	1983	Chevrolet	Cavalier	2.0	TBI	5MT
308	1983	Chevrolet	Chevette	1.6	2V	Auto
309	1983	Dodge	Aries	2.2	2V	Auto
310	1983	Chevrolet	Monte Carlo	5.0	4V	Auto
311	1983	Oldsmobile	Ciera	2.5	TBI	Auto
312	1983	Chevrolet	Celebrity	2.5	TBI	Auto
313	1983	Honda	Civic	1.5	3V	Auto
314	1983	Dodge	Aries	2.2	2V	Auto
315	1983	Chevrolet	Citation	2.5	TBI	Auto
316	1983	Toyota	Celica	2.4	PFI	5MT
317	1983	Mazda	B-2000	2.0	2V	5MT
318	1983	Ford	Crown Victoria	5.0	TBI	Auto
319	1983	Audi	5000S	2.1	PFI	Auto
320	1984	Chirysler	E-Class	2.2	TBI	Auto
321	1983	Ford	LTD S.W.	5.0	TBI	Auto
322	1984	Ford	Tunderbird	3.8	TBI	Auto

Table 3. ACCEL1 acceleration cycle modes description.

	maximum acceleration MPH/s	(m/s2)	speed range MPH	duration seconds	distance miles	comments
mode 1	3	(1.3)	0-33	41	0.244	FTP-like acceleration
mode 2	5	(2.2)	30-63	85	0.851	merging in freeway/ passing a slower vehicle
mode 3	6	(2.7)	0-35	25	0.152	metered ramp
mode 4	6	(2.7)	30-64	52	0.703	merging in freeway/ passing a slower vehicle
mode 5	6	(2.7)	45-68	69	0.749	merging in freeway/ passing a slower vehicle
mode 6	5	(2.2)	0-66	46	0.569	metered ramp
mode 7	4	(1.8)	32-65	60	0.587	merging in freeway/ passing a slower vehicle
mode 8	5	(2.2)	15-64	31	0.383	merging in freeway
mode 9	5	(2.2)	42-65	52	0.590	merging in freeway/ passing a slower vehicle
mode 10	6	(2.7)	0-63	44	0.352	wide open throttle

Table 4. ACCEL1 acceleration cycle test vehicle fleet.

Vehicle Number	Model Year	Manufacturer & Model		Engine Size (L)	Transmission	Inertial Weight (lb)	Odometer (miles)
CARB1							
1	1990	Volvo	240DL	2.3	auto	3375	14912
2	1989	Nissan	240SX	2.4	auto	3125	29310
3	1988	Chevrolet	Corvette	5.7	auto	3625	24246
4	1990	Mercury	Cougar LS	3.8	auto	3875	18015
5	1990	Lincon	Town Car	4.9	auto	4250	6432
6	1990	Ford	Mustang	4.9	auto	3750	15411
7	1989	Jeep	Wagoneer	4.0	auto	3875	34162
8	1990	Ford	LTD	4.9	auto	4000	16897
9	1989	BMW	325I	2.5	auto	3375	30078
10	1990	Lexus	LS400	4.0	auto	4000	10099
CARB2							
1	1990	Volvo	240DL	2.3	auto	3375	9080
2	1989	Nissan	240SX	2.4	auto	3125	20815
3	1989	Isuzu	Isuzu	2.6	auto	3250	28233
4	1991	Ford	Crown Vic	4.9	auto	4000	2444
5	1990	Ford	TBIRD	3.8	auto	3875	17179
6	1989	Ford	Mustang	4.9	auto	3750	28128
7	1988	Ford	Mustang	4.9	manual	3750	33556
8	1988	BMW	325I	4.1	auto	3375	37327
9	1987	BMW	325I	4.1	manual	3375	39004
EPAb							
1	1992	Ford	Crown Vic	4.6	auto		
2	1992	Dodge	Dakota	5.2	auto		
3	1991	Mercedes-Benz	300E	3.0	auto		
4	1991	Nissan	Sentra	1.6	auto		
5	1991	GMC	Sonoma	2.8	auto		

Table 5. Emission standards for gasoline and diesel passenger cars and cycle-based and time-based equivalents, 1982-1992.

	Federal			California		
	HC	CO	NOx	HC	CO	NOx
Standard g/mile	0.41	3.4	1.0	0.41	7.0	0.7
Standard cycle-based equivalent g/cycle	3.075	25.5	7.5	3.075	52.5	5.25
Standard time-based equivalent g/sec	0.002	0.019	0.005	0.002	0.038	0.004

Note: Cycle-based and time-based equivalents assume 7.5 miles and 1372 seconds per cycle.

Table 6. Test to test variability and methods comparison, CARB2 n = 9 by 2 tests, real-time and bag Integrated emissions.

(a) Test to test variability

	Overall Mean grams	Absolute Mean Difference grams	Absolute Mean Difference to Overall Mean Ratio
between the 2 real-time integrated repeats			
HC	7.55	1.49	0.20
CO	310.9	39.4	0.13
NOx	7.64	1.92	0.25
between the 2 bag integrated repeats			
HC	6.53	1.13	0.17
CO	321.2	35.5	0.11
NOx	5.87	1.36	0.23

(b) Real-time -vs- bag integrated methods

	Multiple R	R Square	a	b
HC	0.99	0.98	0.87	-0.02
CO	0.99	0.97	1.12	-28.41
NOx	0.99	0.99	0.77	0.01

y= ax+ b   y= test-bag   x= test-real-time

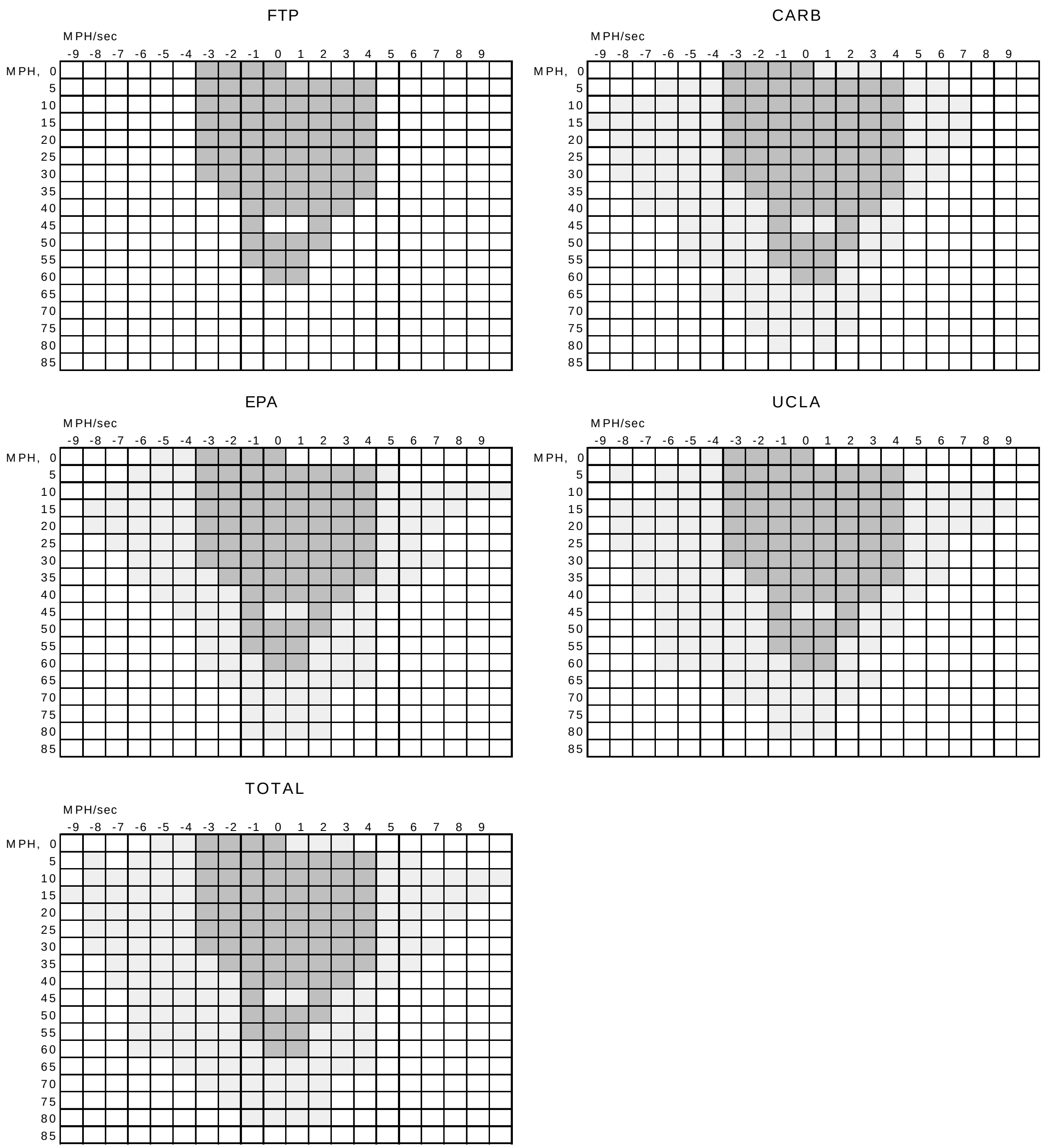

Figure 1. Speed-acceleration driving domain of the FTP; Los Angeles by studies developed by CARB and UCLA; Baltimore developed by EPA; and the union of the total domains.

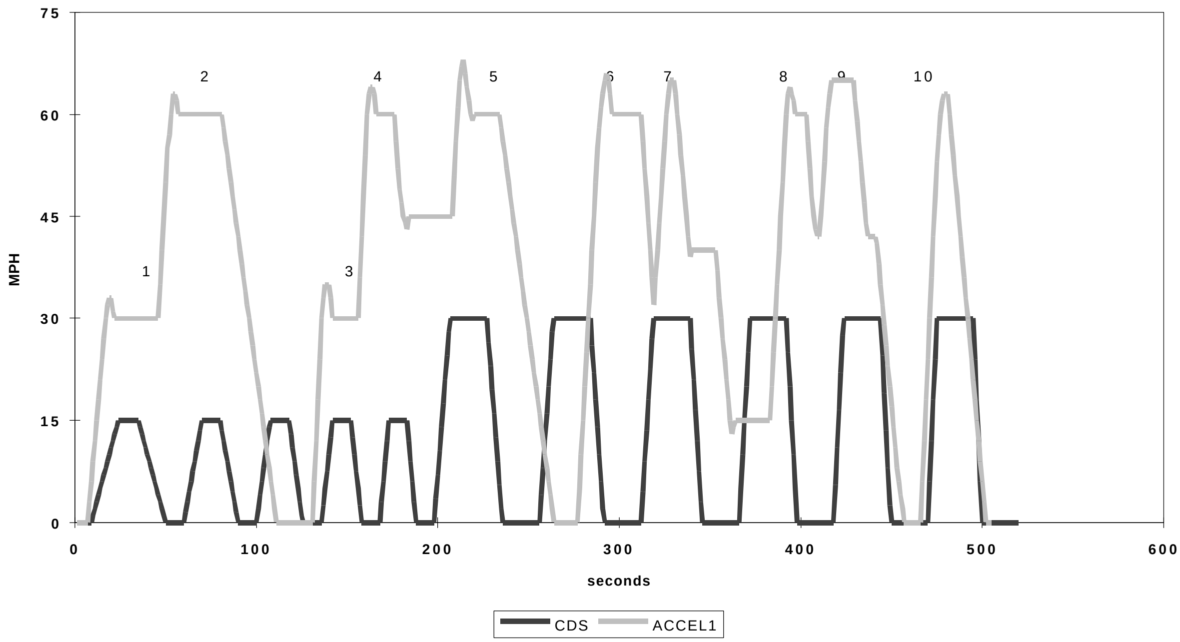

Figure 2. EPA-CDS and CARB-ACCEL1 cycles time-speed traces (the numbers indicate the mode in the ACCEL1 cycle)

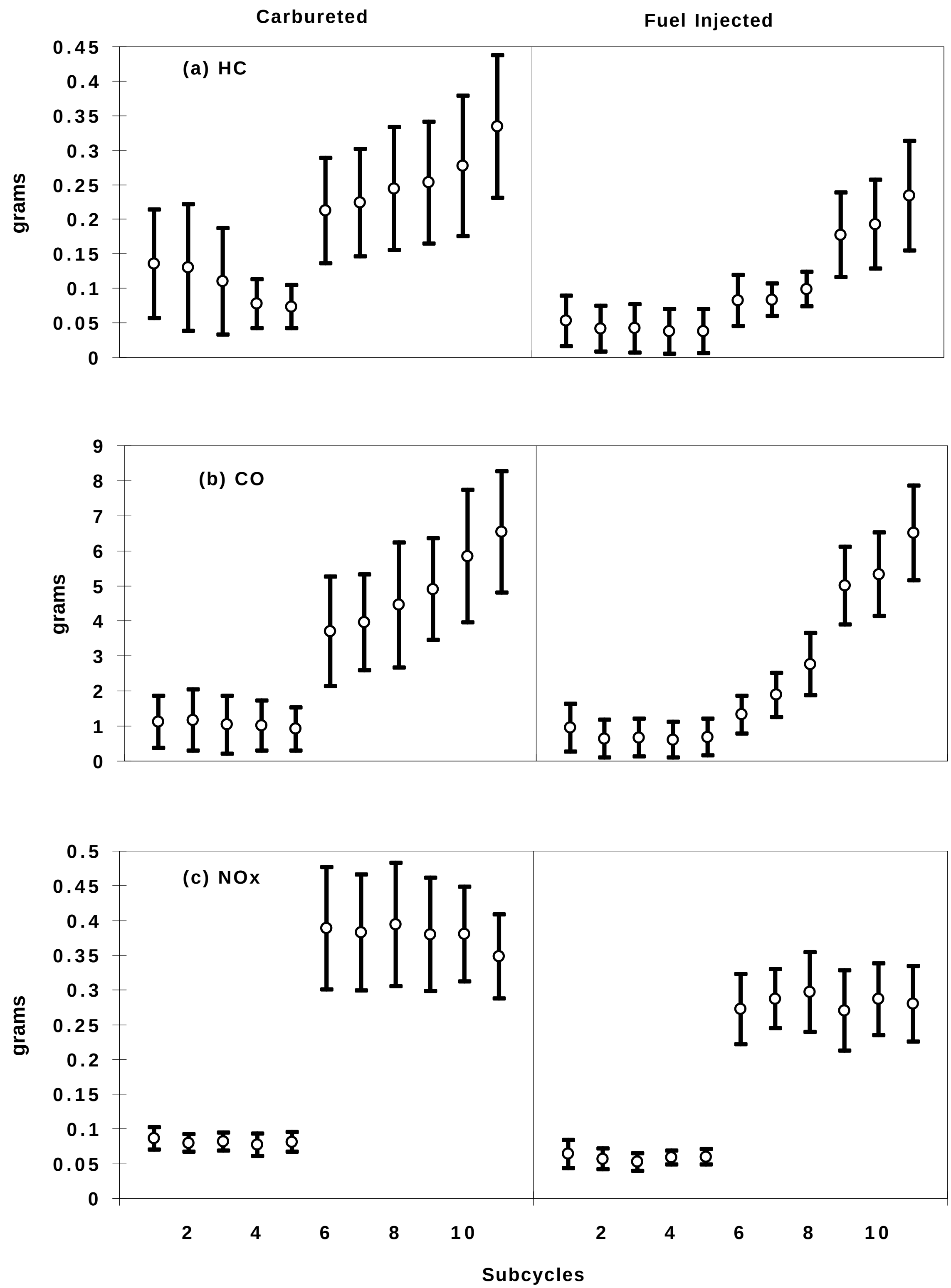

Figure 3. Mean total emission per subcycle, the error bars correspond to the 95% C.I., for carbureted vehicles n = 13, for fuel injected n = 10, EPAa set.

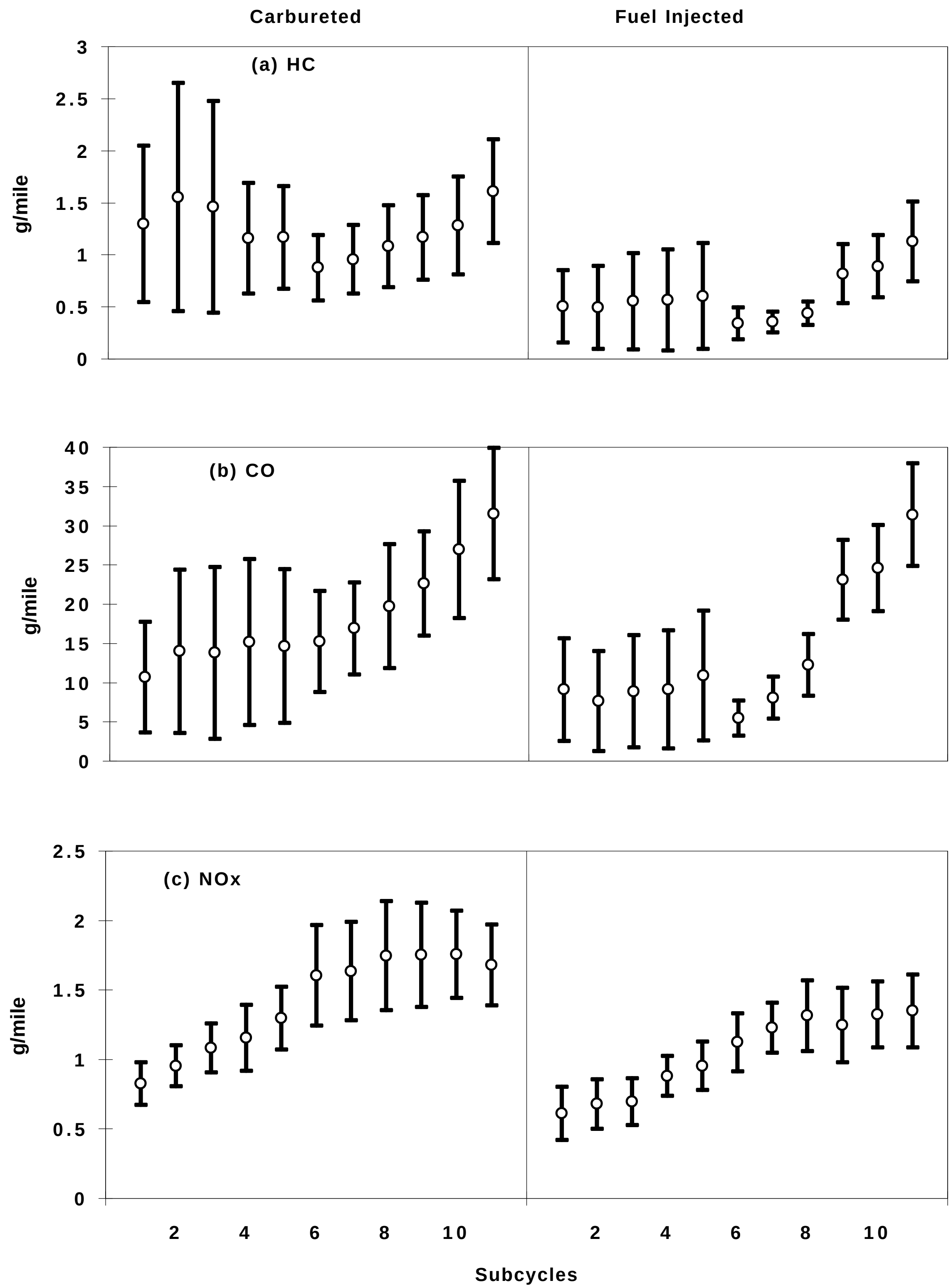

Figure 4. Mean emission per distance per subcycle, the error bars correspond to the 95% C.I., for carbureted vehicles n = 13, for fuel injected n = 10, EPAa set.

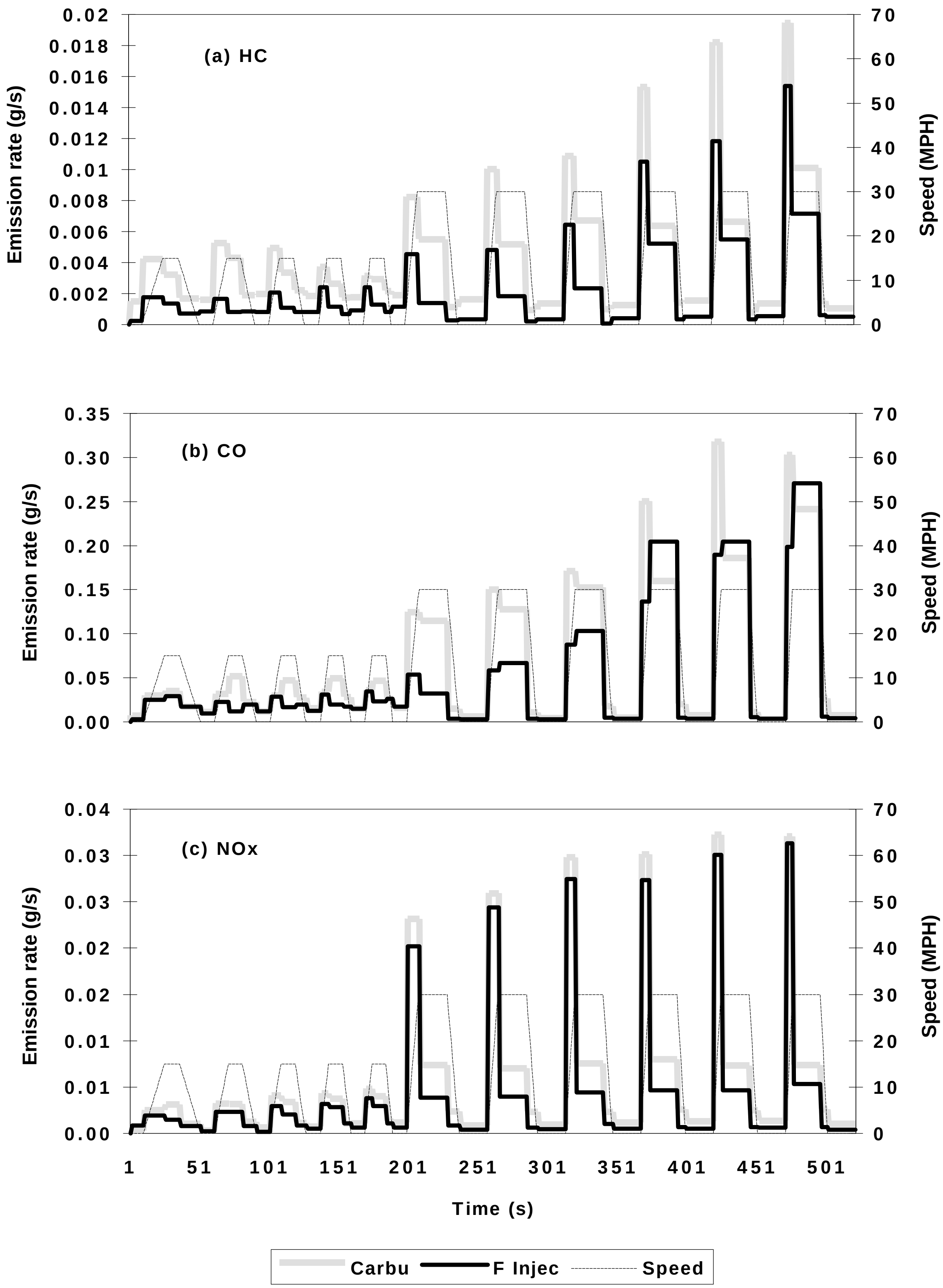

Figure 5. Mean time-base emission rates for carbureted (n = 13) and fuel injected (n = 10) vehicles, EPAa set. The continuous dotted lines correspond to the CDS cycle speed trace.

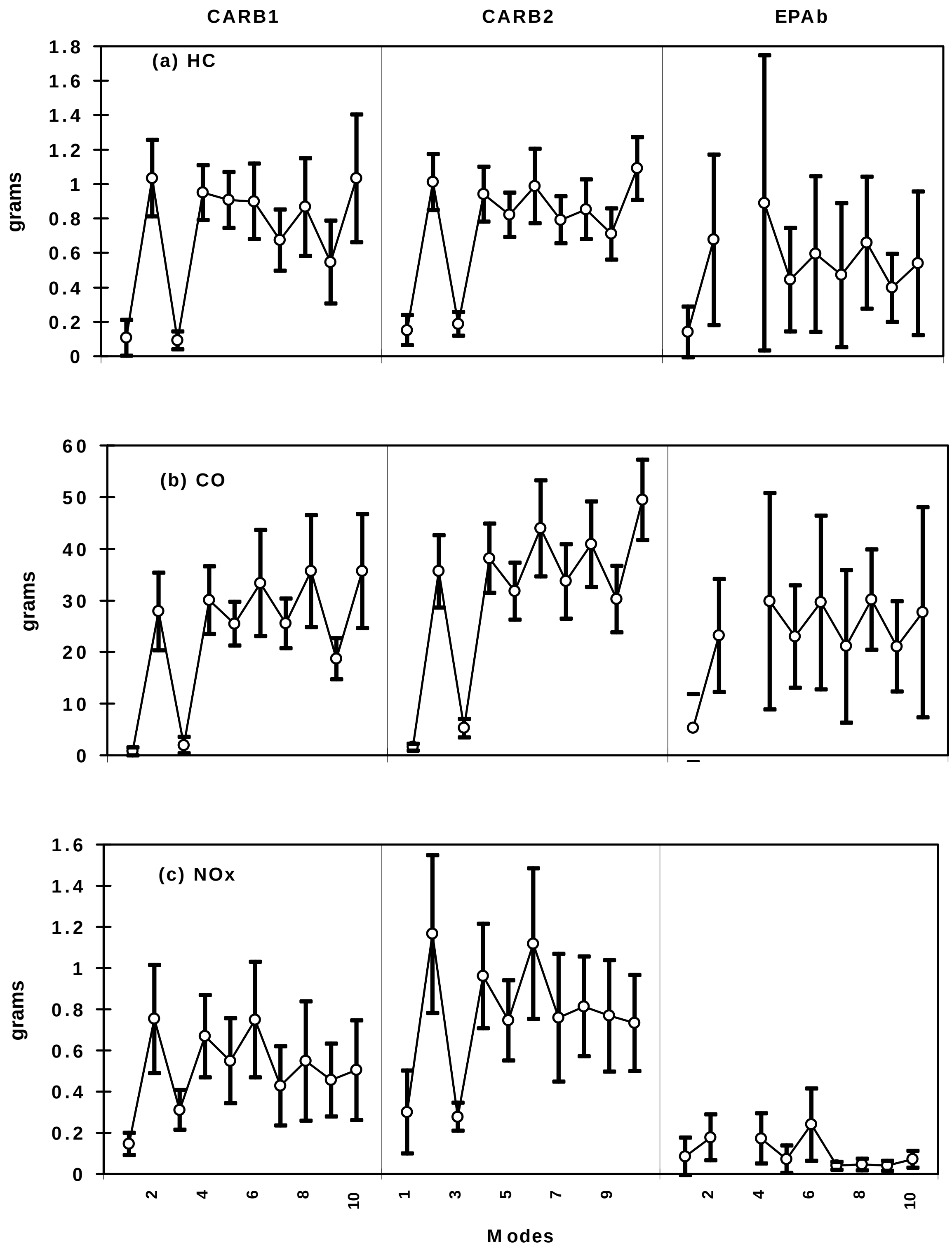

Figure 6. Mean total emission per mode, the error bars correspond to the 95% C.I., for CARB1 set n = 10, for CARB2 set n = 9 by 2 tests, and for EPAb n = 5. In the EPAb set mode 4 also includes the emissions of mode 3.

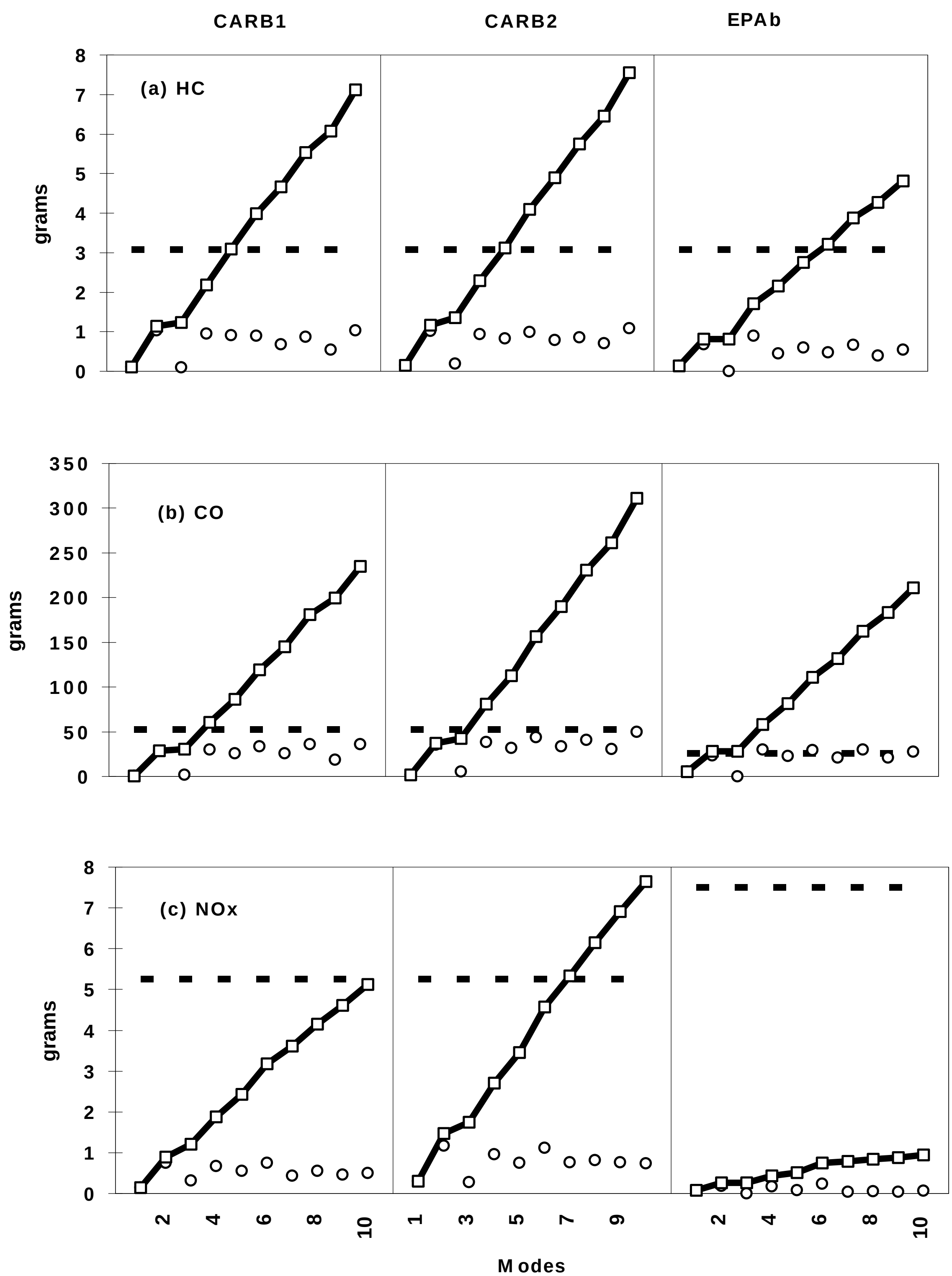

Figure 7. Cummulative emissions for CARB1 set n = 10, for CARB2 set n = 9 by 2 tests, and for EPAb n = 5. The dotted line corresponds to the equivalent standard per cycle, the individual marks correspond to the modes total emission.

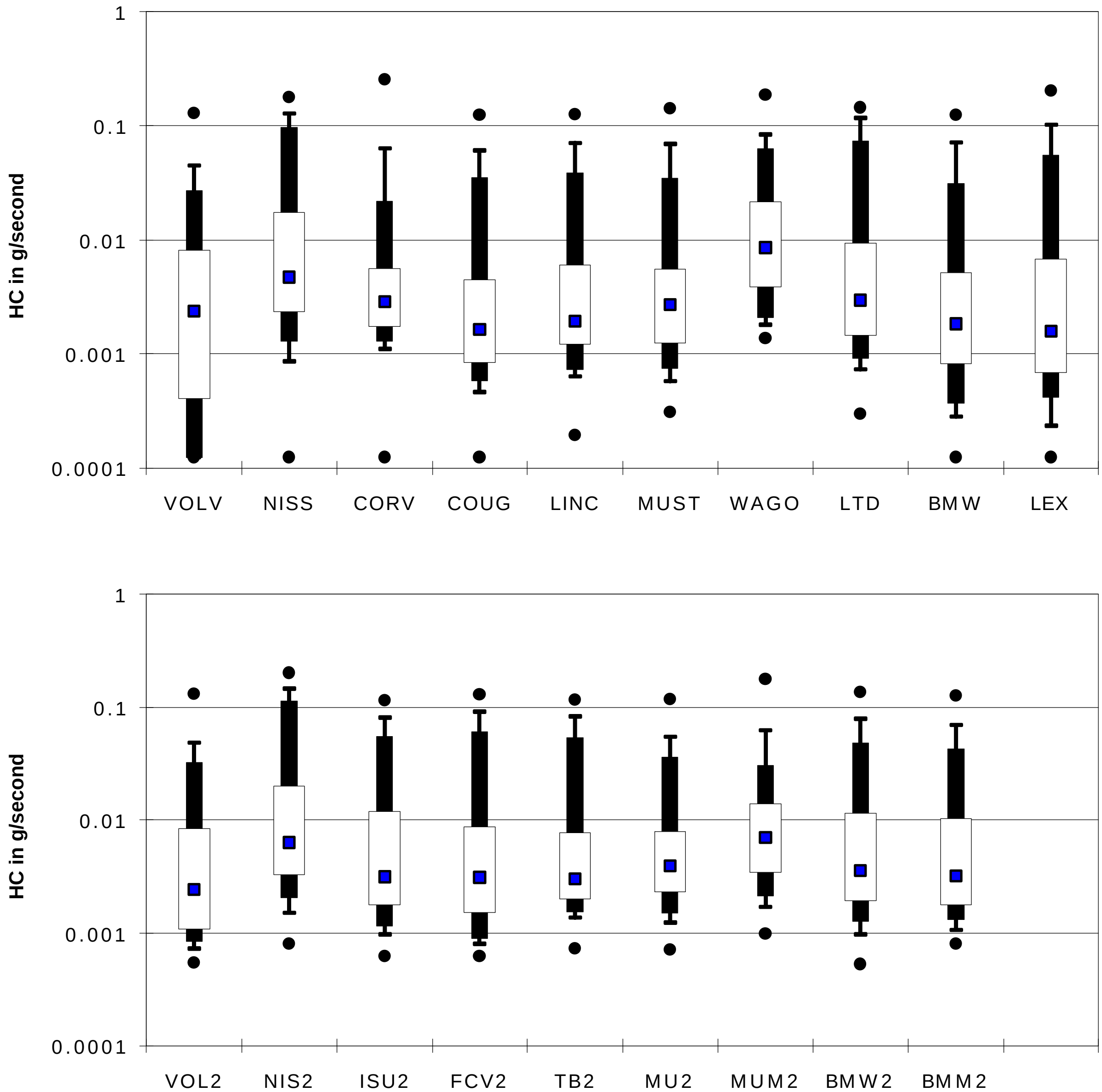

Figure 8. Boxplots for the instantaneus hydrocarbons emission rates observed during the ACCEL1 cycle. The boxplots include the 95, 90, 75, 50, 25, 10, 5 percentiles, as well as the maximum and minimum. CARB1 and CARB2 sets.

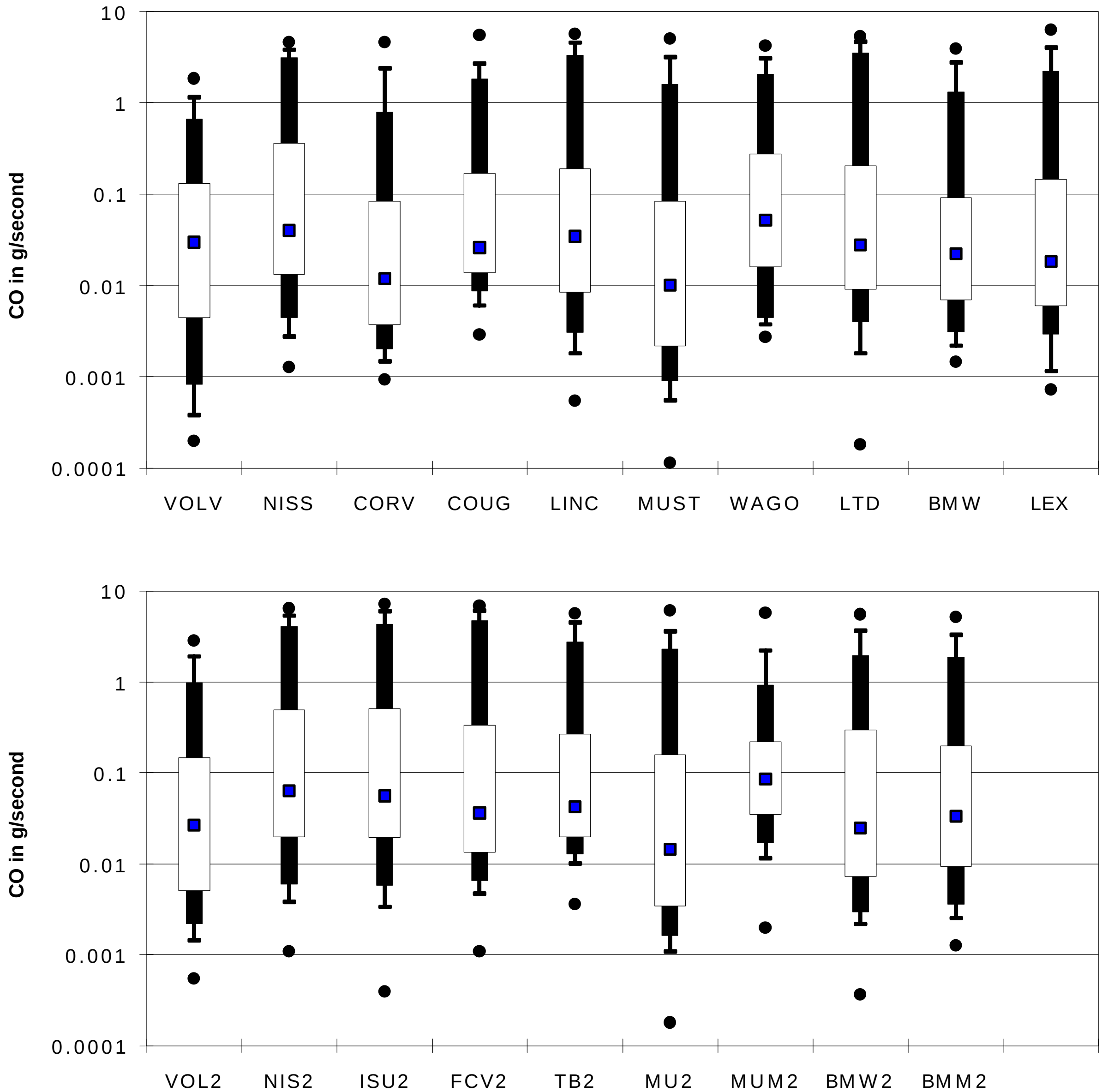

Figure 9. Boxplots for the instantaneous carbon monoxide emission rates observed during the ACCEL1 cycle. The boxplots include the 95, 90, 75, 50, 25, 10, 5 percentiles, as well as the maximum and minimum. CARB1 and CARB2 sets.

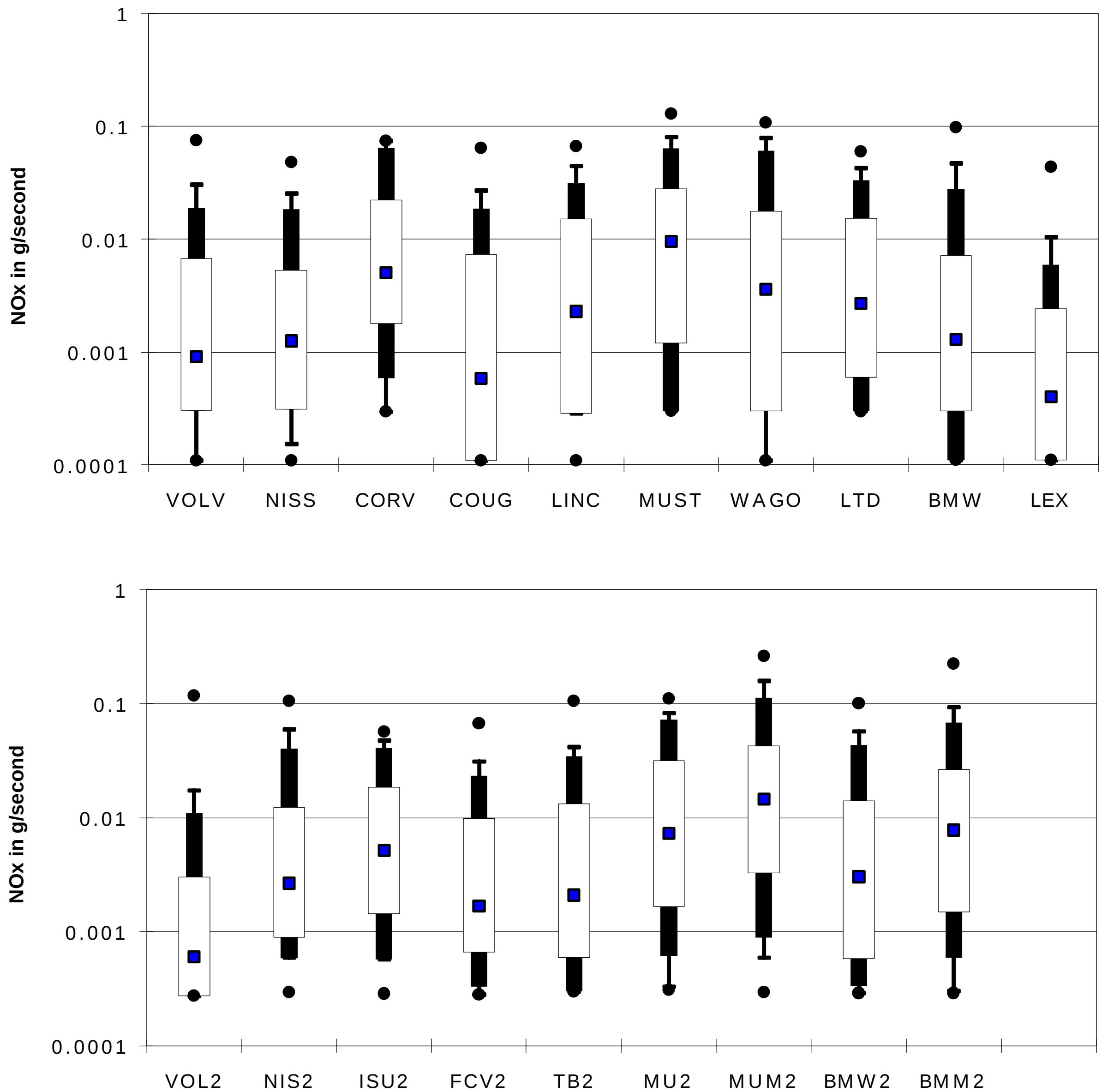

Figure 10. Boxplots for the instantaneus oxides of nitrogen emission rates observed during the ACCEL1 cycle. The boxplots include the 95, 90, 75, 50, 25, 10, 5 percentiles, as well as the maximum and minimum. CARB1 and CARB2 sets.

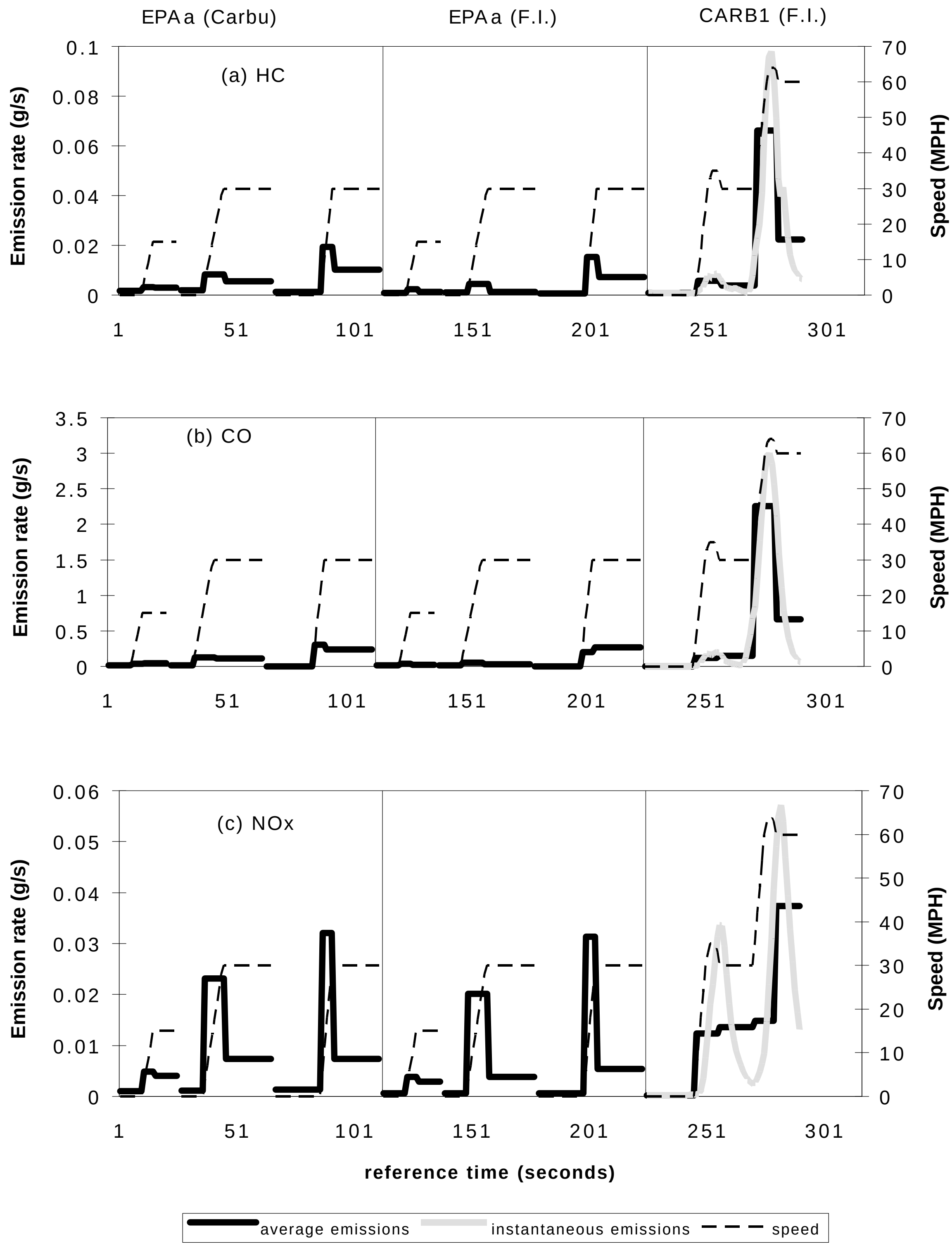

Figure 11. Mean time-based emission rates for subcycles 5, 6, and 11 for EPAa carbureted and fuel injected vehicles, and mean time-based and instantaneous emission rates for modes 3 and 4 for CARB1 fuel injected vehicles.