Portable Emission Measurements of Snowcoaches and Snowmobiles in Yellowstone National Park

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EXECUTIVE SUMMARY

The University of Denver carried out a ten day, winter emissions collection program in Yellowstone National Park that concentrated on measuring the in-use emissions from commercial snowcoaches and snowmobiles operating out of the town of West Yellowstone, MT. Between January 25 and February 3, 2006 we instrumented ten snowcoaches and two snowmobiles with a portable emissions analyzer and collected approximately 22 hours of emissions and vehicle activity data. This report and all of the data sets collected are available for download at www.feat.biochem.du.edu.

- Snowcoach carbon monoxide (CO), hydrocarbon (HC) and nitrogen dioxide (NO_2) emissions from the ten coaches tested this year were 60%, 83% and 54% less than the nine coaches measured in 2005. The average age of this year's fleet was nearly 5 years newer, 9 out of 10 snowcoaches in 2006 were port fuel injected (only 4 out 9 were in 2005) and the route driven less demanding.

- When combined with the previous year's data, emission trends generally decrease with decreasing age. Carbureted engines produce more excess emissions than throttle body injected engines which produce more emissions than port fuel injected engines. Emissions continue to decrease with age among the port fuel injected engines as the newest models continue to improve on capping the extent of excess emissions during power enrichment excursions.

- As observed during last year's testing the carbureted vintage Bombardier had the highest overall emissions and a Bombardier that had been upgraded to a modern port fuel injected engine had the lowest overall emissions. However, this year's carbureted Bombardier did not exhibit the huge HC emissions that were observed previously.

- Despite driving all of the snowcoaches over the same route and with the same passenger loading large variations in CO and HC emissions were still observed. For one set of five nearly identical snowcoaches (same make, engine and track system) CO emissions varied from 310 grams/mile to 12 grams/mile and HC emissions varied from 2.4 grams/mile to 0.3 grams/mile. We believe that the large variation in readings is most likely a result of load differences produced by changes in the snow conditions.

- Passenger loading appears to be only a minor influence on the overall CO and HC emissions of a snowcoach. More important factors are snow conditions, fuel injection technology, power to weight ratio of the vehicle and the overall surface area of the track and ski system.

- We successfully instrumented two snowmobiles a 2006 Arctic Cat T660 and a 2004 Ski Doo Legend GT and drove them over the same road course as the snowcoaches. Observed emissions validated emission trends observed with the

remote sensing and PEMS measurements collected in 2005. The smaller, higher revving Arctic Cat engine had lower CO emissions but higher HC and NO_x emissions than the larger, lower revving Ski Doo engine. Measured fuel economies from these two snowmobiles were 25.1 and 28.3mpg, much higher than either the previous measurement or estimates used previously.

- The transient emissions behavior of these two snowmobiles is quite different with the Ski Doo snowmobile's higher CO emissions being a result of power enrichment excursions during accelerations. These higher transient emissions are probably not observed during BAT certification testing since it is a steady state test.

- Through two seasons of testing we have found that emissions variability is much greater among the snowcoach fleet where even modern coaches with advanced emissions control equipment have days with very large excess emissions. The 4-stroke snowmobiles have very high power to weight ratios and do not appear to experience these emission extremes. When comparing this years snowmobile and snowcoach PEMS measurements the 4-stroke snowmobiles had on average lower gram/mile emissions for all species and lower gram/mile/person emissions for CO and HC than the average snowcoach.

Updated comparison of snow vehicle emissions.

Data	Instrument	Mean grams/gal[a,b]			Mean g/mile (Estimated g/mile)[c]			Estimated g/mile/person[d]		
		CO	HC	NO_x	CO	HC	NO_x	CO	HC	NO_x
1999 Mean 2-stroke Snowmobile	Remote Sensor	1100	1400	NA	(85)	(110)	NA	71	92	NA
2005 Mean 4-stroke Snowmobiles	Remote Sensor	670	80	80	(27)	(3.2)	(3.2)	21	2.5	2.5
2006 Mean 4-stroke Snowmobiles	PEMS				19	1.0	4.0	15	0.8	3.1
2005 Mean Snowcoach	PEMS				300	10	24	37	1.2	3.0
2006 Mean Snowcoach	PEMS				120	1.7	11	15	0.2	1.4
2005 & 2006 Mean Snowcoach	PEMS				230	6.7	19	28	0.8	2.3

[a] grams/gallon calculations for the snowmobiles assume a fuel density of 726 g/l.
[b] Snowmobile NO emissions have been converted to NO_2.
[c] Snowmobile g/mile estimates use 13 mpg for 2-strokes and 25 mpg for 4-strokes.
[d] 2006 data obtained from the National Park Service Public Use Statistics Office.

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INTRODUCTION

Large growth in wintertime snowmobile visits to Yellowstone National Park in the 1990's led to a series of lawsuits and environmental impact statements resulting in the adoption of a Temporary Winter Use Plans Environmental Assessment (EA).[1-4] The temporary winter use plan will be in effect for three winter seasons beginning in December of 2004. It allows motorized winter visits on snowcoaches and a limited number (up to 720/day in Yellowstone and an additional 140/day in Grand Teton) of guided snowmobiles which meet a Best Available Technology (BAT) standard.[5] Additionally the EA allows the National Park Service (NPS) the opportunity to collect additional data on the BAT approved snowmobiles and snowcoaches in use in the park.

During the winter season of 2004 - 2005 in-use emission measurements were made in Yellowstone National Park of nine snowcoaches using a portable emissions monitoring system (PEMS) and 965 measurements of BAT approved snowmobiles using a remote sensing device.[6,7] These measurements built on previous snowmobile measurements but were the first in-use emission measurements for snowcoaches.[8,9] The 2005 measurements found that BAT approved 4-stroke snowmobiles now used in the park have reduced carbon monoxide (CO) and hydrocarbons (HC) emissions at the west entrance by 61% and 96% respectively when compared with 2-stroke snowmobiles. That the extreme operating conditions encountered by snowcoaches in the park helps to produce large and variable tailpipe emissions of CO, HC and nitric oxide (NO_x) emissions. The study also found that while comparing emissions on a per person basis helps reduce the effect of the snowcoach emissions, it still highlighted the need to modernize the snowcoach fleet.

We have always felt that in-use emission measurements are the only avenue that can lead one to a meaningful emissions picture. However, the very nature of in-use emission measurements include many factors that contribute to a vehicle's emissions and it is impossible to control for all of these. The operating conditions found during last years measurements were certainly outside the working limit of most emission laboratories. The 2005 work provided a first look at the real emission range and uncovered some of the factors responsible and provided realistic limits for the modeling exercises.

The 2005 snowcoach measurements concentrated its effort on collecting emissions from a majority of snowcoaches (seven) that were operated by the park's concessionaire, Xanterra Parks and Resorts out of the north entrance to the park. One diesel coach was owned and operated out of the north entrance by the National Park Service and the final coach tested was privately owned and operated out of the west entrance. Of these nine coaches only four (1 diesel and 3 gasoline) were newer than 1999 model year vehicles and because of inlet line freezing problems we only collected reasonable amounts of emissions data from only two of the three gasoline snowcoaches. The other five coaches were all manufactured before 1993. Because all but one of these coaches were measured while transporting paying customers there are gaps in our data collection when we had monitoring problems and each snowcoach had variable passenger loads and routes.

We returned in January 2006 to perform additional PEMS measurements on snowcoaches and snowmobiles. This report will discuss these additional measurements and how they were designed to eliminate a few more of the uncontrolled variables from the 2005 measurements in addition to increasing the number of coaches that we have emissions data on. More control over how the coaches were operated and the route driven was accomplished in 2006 by renting each coach, thus allowing us the opportunity to collect complete emission records from each coach over the same route with the same passenger loads. Additionally we were interested in how important was the age of a snowcoach in determining its emissions? Is it the age of the snowcoach (i.e. model year or how many miles it's been driven) or the technological age of the fuel management system what is more important to determining its overall emissions? What factor does passenger load play in determining the overall road load of a snowcoach and therefore its emissions? How repeatable are vehicle emissions if similar snowcoaches are driven over the identical route? Is the emission distribution measured in 2005 representative of the privately operated snowcoaches?

If time allowed in addition to the snowcoach measurements we were interested in trying to duplicate the PEMS measurements on one or two snowmobiles driven over the same route as the snowcoaches. If successful this would allow a direct comparison between the two vehicles operating emissions. Last years simplistic attempt to instrument an Arctic Cat snowmobile was partially successful and helped to highlight a number of problem areas that would need to be addressed to install the Montana system on a snowmobile and successfully acquire emissions data over the longer route in 2006.[6,7]

SNOWCOACHES

Joseph-Armand Bombardier has the distinction of being a founding father of both the snowcoach and the Ski-Doo snowmobile.[10] The historical snowcoaches best known now as Bombardiers, or Bombs for short, began serving Yellowstone National Park in the mid 1950's and were manufactured until 1981. A number of these coaches are still operated by the park's concessionaire and private operators. They consist of a rear-mounted engine that drives a twin track from a forward mounted drive axle. Twin skis are used to steer and a metal cabin holds around 10 passengers. Today these older coaches have been joined by a fleet of modern wheeled vehicles (15 passenger vans to 30+ passenger buses) that have been converted to over-the-snow use by adapting various track/ski systems as wheel replacements.

Modern vehicles sold in the United States are required by the Federal Government to meet stringent laboratory emissions standards. The improving national air quality is a strong testament to the fact that these standards have worked to make large reductions in vehicle emissions.[11, 12] Many recent studies have demonstrated that not only do new vehicles have very low initial emissions, but they now maintain these low levels many years longer than previous models.[13] However, there are circumstances under which vehicles can be operated outside of the laboratory parameters causing tailpipe emission levels to increase dramatically. Snowcoaches in use in Yellowstone National Park are potentially just those types of vehicles and operation modes. The coaches in use in the park experience extremes of temperature, load and fuel consumption that fall well outside of all of the original emission design goals and testing parameters.

This seasons measurements would be conducted at the west entrance to the park with the majority of snowcoaches tested being from the West Yellowstone MT private fleet. The town of West Yellowstone MT has the largest concentration of privately operated snowcoaches with more than forty snowcoaches for rent. All of the trips into the park enter through the west entrance with the majority of trips being roundtrip excursions to Old Faithful. Snowcoach entries during the 2005-2006 season totaled 2,463 coach trips transporting 19,856 passengers.[14] This was an increase in coach trips of 11.9% and a 15.3% increase in the total number of passengers they carried.

Experimental

On-board emission measurements were made on ten commercial snowcoaches located in West Yellowstone MT from January 25 – February 1, 2006. Measurements were made with a commercially available Clean Air Technologies International, Inc. Universal Montana PEMS (see Figure 1).[15] This unit is capable of testing electronically controlled sparked ignition vehicles and compression ignition vehicles that utilize heavy-duty engine controls. The system measures, in real-time, the gaseous species using twinned analyzer benches. Each bench includes a nondispersive infrared (NDIR) analyzer to measure CO, CO_2 and HC, measured and reported as propane. Electrochemical cells are used on each bench to measure oxygen (O_2) and NO (see Appendix A for the Montana's accuracy, repeatability and noise specifications). Both benches measure the same exhaust

Figure 1. Photograph of the Montana system ready for sampling in a coach. Pictured are the video screen at left, compact flash card top center, GPS receiver connector top right and the exhaust lines exiting the cabin through the side window.

sample and the resulting concentrations are averaged between the two analyzers except during zeroing. The bench's alternate zero checks so that one analyzer is always on-line at all times. On compression ignition engines, the HC measurements are not considered accurate because, without a heated sample line, it is believed that only a fraction of the heavier hydrocarbons reach the sample cell in gaseous form.[15] The HC data are therefore not reported for the diesel snowcoach. Particulate matter (PM) emissions are measured on compression ignition engines using a real-time laser light scattering monitor. The system contained a light-duty engine computer scanner and a GPS receiver. The data are stored on a second by second basis to a compact flash memory card. The analyzer was calibrated with a certified gas cylinder containing 12.93 % CO_2, 3.17 % CO, 1515 ppm propane, and 1515 ppm NO (Scott Specialty Gases, Plumsteadville, PA).

Tailpipe concentration data including CO_2 directly measure mass emissions per gallon of fuel. To convert into mass emissions per mile, a measure of the vehicle exhaust flow is needed. The Montana system indirectly measures the exhaust flow by calculating the intake air mass flow and using mass balance equations to obtain the exhaust flow. On late model vehicles, the Montana's engine scanner allow the intake air mass flow to be obtained from the engine intake mass airflow sensor via the engine control unit on-board diagnostic (OBD) port. On older vehicles this parameter is determined from engine design (displacement and compression ratio) and operating parameters collected through a set of three temporarily mounted sensors using a speed-density method.[16] The three sensors collect engine rpm (inductive or optical pickup), engine intake air temperature (thermistor) and the absolute intake manifold pressure (pressure transducer). The use of the Montana system to record gram/mile emission factors for the gaseous species measured has been shown to correlate well with laboratory grade equipment.[15] The laser light scattering particulate measurement has been successfully compared to both gravimetric filter methods and a real-time TEOM-1105 particulate monitor with good results.[15]

The Montana system labels the second-by-second data as valid when engine data are available and the analyzer benches are reporting satisfactory operating parameters. However, we learned with use that the software does not require any exhaust gas to be present for it to report valid gram/sec emissions data. These episodes are easy noted by large oxygen concentration measurements and the absence of the other exhaust gases. Also flow restrictions caused by water freezing in either the intake or exhaust lines sometimes produced large positive or negative emissions values that were not marked as invalid by the software. These events were often noted by the operator in the field notebook.

Therefore the database contains two fields (*Org_validity* and *Valid_g_s*) that addresses data validity (see Appendix B). *Org_validity* is the flag originally produced by the Montana system and signifies valid data by a "YES" when engine data are available and the analyzer benches are reporting satisfactory operating parameters. The additional field *Valid_g_s* has been added to denote the data that we have included in our analysis. Because the data was collected from privately rented coaches this year the differences between these two data sets is very small with less than nine minutes of data invalidated. Appendix D contains a listing by coach as to the sections of data that we have invalidated for this analysis and the reasons for this designation. All of the data will be available for download from www.feat.biochem.du.edu and using the *Org_validity* flag data can be selected using any criteria desired.

A major difference in this years testing program was that we were able to individually rent each snowcoach that we tested. This made installation and operation of the analyzer simpler since we did not have to contend with scheduled passenger service. All of the coaches were driven over the identical route from the west entrance of the park, up the Madison River valley to Madison Junction and then toward Old Faithful stopping at the Cascades of the Firehole River turnout and then returning via the same route (32.5 miles roundtrip). If any data collection problems were encountered the drive would be stopped until those issues were resolved and in one instance a short segment of the drive was repeated. Figures 2 and 3 provide a map and an adjusted altitude profile of this route. Any inconsistencies in the trace symmetry are a result of the inaccuracies associated with the GPS altitude measurement. Each coach was loaded with the equivalent of eight passengers utilizing the researchers and 160 1bs of sand per additional passenger. The ten sampled coaches included one diesel and nine gasoline powered snowcoaches utilizing 4 different track configurations. We generally needed 1 to 2 hours of time with each coach to install and calibrate the analyzer and 1 to 2 hours to complete the roundtrip drive.

Figure 2. Aerial view of the route driven by all of the vehicles in this study.

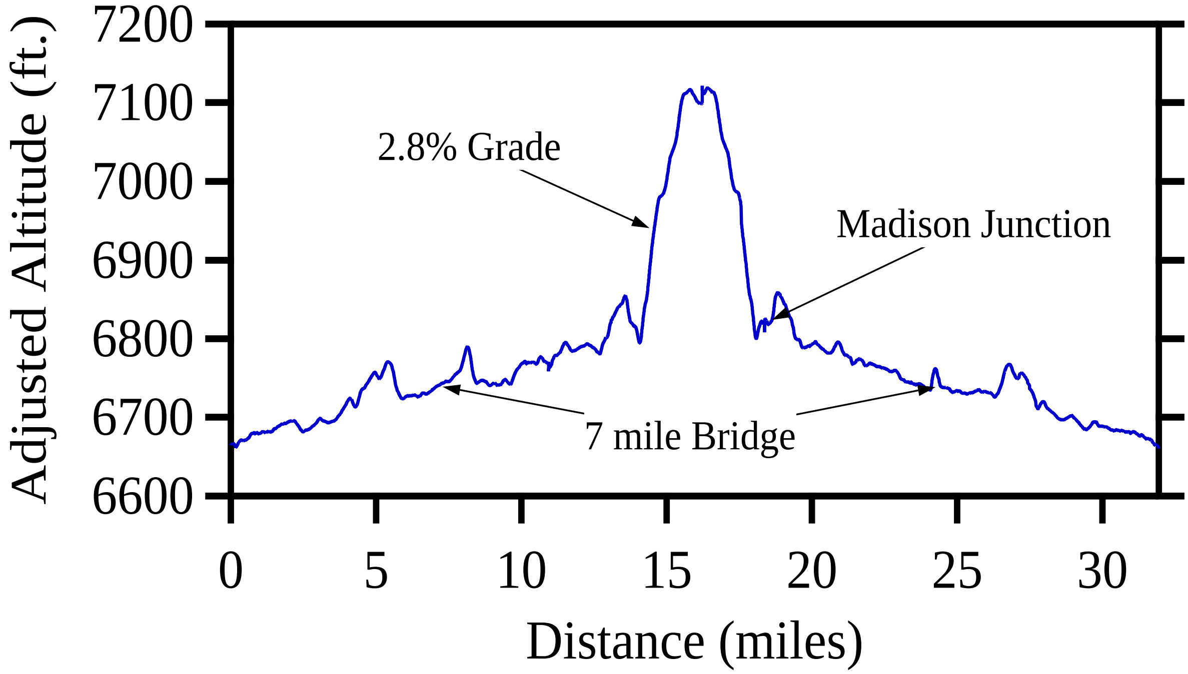

Figure 3. Adjusted altitude versus distance as recorded by the GPS unit on January 30th for the route shown in Figure 2. Maximum altitude has been adjusted to match the USGS maps.

Table 1 provides summary information for each of the snowcoaches tested. Figures 4 - 9 are pictures of six of the snowcoaches tested. They represent all of the various types of vehicles and track combinations tested. In all, one diesel bus and five 2000 model year and newer Mat-trax equipped vans were sampled, two vintage Bombardiers (one a traditional carbureted engine, the second converted to a modern fuel injected emissions controlled engine) and two 1994 Snowbuster van conversions. All of the vehicles in this years test fleet were port fuel injected with the exception of the vintage Bombardier which was carbureted.

Table 1. Snowcoach sampling dates and vehicle information listed in increasing age.

Owner Date Sampled Time	Year Make Type	Vin Engine Fuel Type	Drive Track Type
Alpen Guides 2/1/06 10:40 - 12:49	1956 Bombardier	Kitty Carbureted 5.7L V-8 Gasoline	2WD Twin Tracks Ski's
Yellowstone Exp. 1/27/06 11:07 - 13:09	1994 Dodge Ram 250 Van	2B4HB25Y1RK125878 PFI 5.2L V-8 Gasoline	2WD Snowbuster
Yellowstone Exp. 1/27/06 15:03 - 16:54	1994 Dodge Ram 350 Van	2B5WB35Y8RK169448 PFI 5.2L V-8 Gasoline	2WD Snowbuster
3-Bear Lodge 1/30/06 14:28 - 16:45	2000 Ford E350 Van 2	1FBSS31S9YHA03291 PFI 6.8L V-10 Gasoline	2WD Mat-Trax/Ski's
Yellowstone SCT 1/30/06 9:24 - 10:55	2000 Ford E350 Van	1FBSS31S9YHB47925 PFI 6.8L V-10 Gasoline	4WD Mat-Trax
3-Bear Lodge 1/31/06 9:40 - 11:29	2001 Ford E350 Van 5	1FBSS31S01HA64230 PFI 6.8L V-10 Gasoline	4WD Mat-Trax
Alpen Guides 1/29/06 13:54 - 15:35	1952 Bombardier 2002 Engine	Cygnet PFI 5.3L V-8 Gasoline	2WD Twin Tracks Ski's
Buffalo Bus Co. 1/26/06 15:15 - 16:52	2003 Ford E350 Van	1FBSS31S93HA60681 PFI 6.8L V-10 Gasoline	4WD Mat-Trax
Buffalo Bus Co. 1/26/06 12:03 - 13:41	2004 Ford E350 Vanterra	1FDSE35S14HA21903 PFI 6.8L V-10 Gasoline	4WD Mat-Trax
NPS 1/25/06 14:27 - 16:13	2006 International Bus	1HVBTAFM66W230769 DI 6L V-6 Turbo Diesel	2WD Cleated Mat-Trax

Figure 4. Vintage Bombardier that utilizes a rear engine, forward driven twin track and twin steering ski arrangement. The sample and data lines enter the cabin through a rear roof hatch.

Figure 5. A 1994 Dodge Van with a rear driven Snowbuster track/ski conversion. Visible are the exhaust exit line and the engine diagnostic data cable.

Figure 6. A 2000 Ford Van with a rear driven Mat-trax and ski conversion. Visible is the exhaust exit line.

Figure 7. A 2000 Ford Van with a 4 wheel drive Mat-trax conversion. Visible is the exhaust sampling line.

Figure 8. A 2004 Ford VanTerra conversion coach with a 4 wheel drive Mat-trax conversion. Visible is the insulated exhaust exit line.

Figure 9. The National Park Service "New Yellow Bus", a 2006 International Bus.

Installation of the analyzer required routing the gas sampling and exhaust lines in and out of the vehicle and installing the power, OBD or sensor array cables and the GPS receiver. The exhaust tail pipes of the coaches were typically located behind and above the track of the vehicle. Snow was constantly kicked up into this area and an L-shaped extension was used when needed to extend the tailpipe distance from the track and protect the sampling probe. Fiberglass, aluminum insulating tape and aluminum dryer vent tubing were used at the probe-hose interface for extra insulation and protection. The sample line was wrapped in oversized foam pipe insulation and routed the shortest distance possible through a window into the cabin. The extra space in the opened window was plugged with foam rubber. A plastic tee was installed into both ends of the foam insulation allowing air to flow through the insulation. Because of power limitations, we could not electrically heat the sampling line. We instead relied on a 12-volt rechargeable motorcycle battery powered fan to continuously draw warm air out of the cabin and pass it through the oversized pipe insulation to warm the line. New this year was an additional battery powered fan to blow warm air over the exhaust exit lines. Figure 10 shows a rear view of a coach with the tailpipe extension, insulated sample line and the rear window sealed with the foam rubber.

Figure 10. Rear view of a coach showing the tailpipe extension, insulated sample line and the temporary foam insulation installed to seal the side window.

The Montana portable system was usually placed in the seat behind the driver. The exhaust lines, power and GPS receiver lines were routed out of the window next to the analyzer. Power was taken either from the 12V cigarette lighter outlet, or from a power cable run from the battery in the engine compartment. All of the externally mounted lines and wires were held in place by right angle brackets held to the vehicle by strong magnets. The magnet/bracket assemblies were coated with electrical tape to keep the lines in place without scratching the vehicle. For the modern vehicles the OBD data line was duct taped along the floor to the dash area and connected to the data port. In the Bombardiers, the lines were routed via a rear roof hatch. The Montana system also records location and altitude from an integrated GPS receiver. The GPS antenna was mounted to the roof of the vehicle by a permanent magnet.

The integrated GPS receiver is relied upon for recording all of the vehicle speeds and distances covered. Because the drive wheels used in the track systems are all smaller than the wheels they replace the speed/odometer readings are not correct. The only caveat when summing the GPS distances is recognizing that the GPS receiver we used had a stationary variation of approximately a half a meter. In calculating distance traveled, any change in location that is less than or equal to 0.5 meters was summed as 0 meters.

Each coach was instrumented at the owner's garage and then driven to the west entrance area. At this point sand bags were loaded to bring the total passenger load to eight (researchers plus sand bags equal eight not counting the driver). The coach was now driven out to the main road and data collection was started and continuously recorded during the round trip. If at anytime during the roundtrip we developed any problems that resulted in data not being collected the snowcoach would be stopped until the problem was corrected and then the trip was resumed. In this way we were assured of having very few gaps in our data collection between the ten coaches. In only one instance (YEXP R350) did we have problems that resulted in a large data gap that required us to backtrack to a previous point and repeat that section of the course. The drivers were instructed to drive the snowcoaches as they normally would while conducting a tour, with the exception that we made fewer and shorter stops than a tour group would. Each trip included a restroom break at the Madison warming hut either before or after reaching the turn around point. On several days the scheduling allowed us to test snowcoaches both in the morning and afternoon.

Results

Eight days of sampling snowcoaches in Yellowstone National Park resulted in the collection of 19 hours of second-by-second data (68,467 records) with 18.4 hours of valid gram per second data for CO, HC, and NO_x and an additional 1.8 hours of valid PM data from the park service diesel powered bus. The entire valid gram per second data includes at least engine rpm, intake air temperature and absolute intake manifold pressure. Additionally recorded from some of the engines were speed, acceleration, percent throttle, torque, coolant temperature and fuel economy. The GPS receiver reported its fix status, number of satellites visible, time, longitude, latitude and altitude. The database format is defined in Appendix B and is available for download from www.feat.biochem.du.edu. Appendix C lists the weather data reported for the West

Yellowstone area and the overnight grooming information for the road segment from the west entrance to Madison Junction.

Table 2 details the valid data collected for each of the ten coaches instrumented during this study and driven over the snowcoach test route. The NO data is measured as NO but is reported by the Montana unit as NO_2 (NO_x) for all of the g/mi, g/gal and g/kg snowcoach emission values. The fuel specific emissions have been calculated by summing the second by second g/sec emission and fuel consumption values. To convert to gallons we have assumed a density for gasoline of 2800 grams/gallon and for diesel fuel 3200 grams/gallon. The amount of idling will vary between the different coaches due to the different amount of animal or vehicle interruptions that were encountered. A very small number of records have been invalidated, mostly due to problems acquiring the engine data, and they are listed in Appendix D.

Table 2. Summary of the valid second by second data collected over the snowcoach route.

Vehicle	Sampled		Mean Speed	Fuel Use	Gram/mile Emissions			
	Hours	Miles	(mph)	(mpg)	CO	HC[a]	NO_x	PM[a]
AG Kitty	1.63	32.0	22.2	4.4	310	3.7	36	NA
YEXP R250	1.44	32.5	22.9	2.4	84	1.9	22	NA
YEXP R350	1.74	32.5	20.7	2.3	45	2.8	15	NA
3BL Van2	1.89	32.5	19.4	2.4	260	2.4	1.5	NA
YSCT Van	1.45	32.0	23.4	2.7	310	1.5	1.7	NA
3BL Van5	1.73	32.6	22.5	3.0	12	0.30	1.4	NA
AG Cygnet	1.48	32.3	24.1	5.7	5.0	0.40	2.8	NA
BBC Van	1.58	32.7	22.6	3.2	65	1.4	0.32	NA
BBC Vanterra	1.59	32.7	21.9	3.4	46	0.86	0.12	NA
NPS Bus	1.66	32.4	22.1	1.9	6.6	NA	31	0.33
Totals and Time-Weighted Means	16.2	324	22.1	3.1	120	1.7	11	0.33

[a] HC data are not considered valid for the diesel vehicle (NPS Bus) and PM data were only collected from this vehicle.

For the purposes of the dispersion emissions modeling Table 3 breaks out the measurement time, distance and average speed for three self-defined operation modes of idle, low speed and cruise. Note that some data are lost between Tables 2 and 3 due to the additional requirement in Table 3 that the GPS receiver must have a valid fix. Idle has been defined by restricting the GPS measured distances change between readings of less than or equal to 0.5 meter. The low speed driving mode was defined as the GPS measured speed being greater than idle and less than or equal to 15 mph. Cruise mode was selected for GPS measured speeds of greater than 15 mph. Table 4 is the companion table and gives the measured mass emission rates for the three modes defined in Table 3.

Table 3. Valid data distributed for three GPS defined driving modes.

Vehicle	Hours Sampled (Miles Traveled)			Mean Low Speed 0 < GPS Speed ≤ 15 mph	Mean Cruise Speed GPS Speed > 15 mph
	Idle	Low Speed	Cruise		
AG Kitty	0.19 (0)	0.14 (1.2)	1.30 (30.7)	9.1	23.6
YEXP R250	0.02 (0)	0.11 (0.8)	1.31 (31.7)	7.3	24.3
YEXP R350	0.17 (0)	0.22 (1.7)	1.35 (30.8)	7.5	22.9
3BL Van2	0.21 (0)	0.25 (2.6)	1.43 (30)	10.2	21.0
YSCT Van	0.08 (0)	0.15 (1.3)	1.22 (30.6)	8.9	25.2
3BL Van5	0.27 (0)	0.19 (1.6)	1.26 (31)	8.5	24.6
AG Cygnet	0.14 (0)	0.12 (1.0)	1.23 (31.4)	8.5	25.5
BBC Van	0.13 (0)	0.15 (1.3)	1.30 (31.4)	8.7	24.1
BBC Vanterra	0.09 (0)	0.09 (0.8)	1.40 (31.9)	9.1	22.7
NPS Bus	0.19 (0)	0.18 (1.6)	1.30 (30.9)	9.0	23.8
Totals and Weighted Means	1.49 (0)	1.60 (14)	13.1 (310)	8.8	23.7

Discussion

Two immediate observations about this year's data set that can be made are that the overall fleet is newer than last years fleet and overall emissions are lower (see Table 2). Overall emissions were 300, 10 and 24 grams/mile for CO, HC and NO_x for the nine snowcoaches measured in 2005 compared to 120, 1.7 and 11 grams/mile for this year's fleet. Excluding the two Bombardiers from both data sets, because they perfectly complement each other technology wise, the average model year for the 2006 fleet is 2000.25 and for the 2005 data set it was 1995.4. All but one of the snowcoaches tested in 2006 were port fuel injected while only 4 of the 9 snowcoaches from the 2005 data set were. Keep in mind that these snowcoaches were driven over a much different route than most of the data collected in 2005. The one coach from the 2005 data set that was driven over this year's route was a vintage Bombardier that has been upgraded with a modern port fuel injected engine. Though we tested different vehicles in the two years these

Table 4. Mass emissions data for the three driving modes defined in Table 3.[a]

Vehicle Measured	Species	Idle			Low Speed			Cruise		
		mg/s	g/gal	g/kg	g/mi	g/gal	g/kg	g/mi	g/gal	g/kg
AG Kitty	CO	400	2700	980	240	1000	360	310	1400	490
AG Kitty	HC	13	91	33	6.1	25.1	9.0	3.3	15	5.3
AG Kitty	NO_x	0.1	0.7	0.2	35	140	52	36	160	58
YEXP R250	CO	44	61	22	47	64	23	84	200	73
YEXP R250	HC	2.7	3.8	1.4	1.8	2.5	0.9	1.8	4.5	1.6
YEXP R250	NO_x	4.0	5.6	2.0	14	20	7.0	23	55	20
YEXP R350	CO	39	49	18	41	52	19	44	110	39
YEXP R350	HC	20	25	8.8	4.3	5.4	1.9	2.3	5.8	2.1
YEXP R350	NO_x	0.3	0.3	0.1	8.6	11	3.9	16	39	14
3BL Van2	CO	5.2	26	9.4	100	210	75	270	690	250
3BL Van2	HC	0.6	3.0	1.1	1.7	3.4	1.2	2.5	6.2	2.2
3BL Van2	NO_x	0	0.1	0.1	1.4	2.8	1.0	1.5	3.7	1.3
YSCT Van	CO	1.0	5.9	2.01	9.3	25	9.0	330	900	320
YSCT Van	HC	0.1	0.7	0.2	0.3	0.9	0.3	1.5	4.1	1.5
YSCT Van	NO_x	0	0	0	1.0	2.6	0.9	1.7	4.7	1.7
3BL Van5	CO	2.4	13	4.7	3.8	11	3.8	12	39	14
3BL Van5	HC	0.4	2.1	0.7	0.7	1.8	0.6	0.3	0.9	0.3
3BL Van5	NO_x	0	0	0	3.5	9.8	3.5	1.2	3.8	1.4
AG Cygnet	CO	2.6	24	8.7	7.8	43	15	4.9	28	10
AG Cygnet	HC	0.4	3.6	1.3	0.6	3.4	1.2	0.4	2.2	0.8
AG Cygnet	NO_x	0	0	0	1.4	7.7	2.8	2.9	17	5.9
BBC Van	CO	-0.2	-0.9	-0.3	0.1	0.2	0.1	67	220	79
BBC Van	HC	0.3	1.8	0.6	0.7	2.2	0.8	1.4	4.7	1.7
BBC Van	NO_x	0.1	0.5	0.2	0.0	0.1	0.0	0.3	1.1	0.4
BBC Vanterra	CO	-0.1	-0.5	-0.2	8.8	26	9.1	47	160	58
BBC Vanterra	HC	0.3	1.5	0.5	0.5	1.5	0.5	0.9	3.0	1.1
BBC Vanterra	NO_x	0.2	0.9	0.3	0.1	0.4	0.1	0.1	0.4	0.2
NPS Bus	CO	3.9	17	5.4	24	31	9.8	5.7	9.5	3.4
NPS Bus	NO_x	12	53	17	50.5	66.1	20.7	30	50	18
NPS Bus	PM	0.03	0.1	0.04	0.4	0.5	0.2	0.3	0.6	0.2
Time-Weighted Means	CO	57	360	130	51	140	50	120	370	130
Time-Weighted Means	HC	4.1	16	5.6	1.8	4.4	1.6	1.5	4.7	1.7
Time-Weighted Means	NO_x	1.6	7.0	2.2	12	25	8.6	11	33	12
Time-Weighted Means	PM	0.3	0.1	0.04	0.4	0.5	0.2	0.3	0.6	0.2

[a] g/gal and g/kg results are calculated from the reported g/sec emissions and fuel consumption and the density of gasoline is assume to be 2800 grams/gallon and for diesel 3200 grams/gallon.

vehicles had the lowest overall emissions in each year's data set. Also similar to last year the carbureted Bombardier was the worst emissions performer again this year.

When comparing the driving modes between the two data sets one can see that the 2005 data contains a significantly larger amount of idle data. This is a result of snowcoaches serving real tourist and the repeated stops and starts that involves. For the three self defined driving modes listed in Table 3 the 2005 data set had time distributions of 31.5% for idle, 16.3% for low speed and 52.2% for cruise. This compares to the 2006 data of 9.2% for idle, 9.9% for low speed driving and 80.9% of the time spent in cruise mode. The increased time spent idling in 2005 does increase the overall emission values for a few of the higher emitting snowcoaches, but this is on the order of a few percent and is not a major factor. The distribution by mileage was 9.4% and 90.6% in 2005 compared to 4.3% and 95.7% for low speed and cruise driving respectively. Again the additional stopping involved with real tourist increases the distance observed in the low speed driving mode.

The route differences also show up in additional mileage and slightly higher speeds (on average about 10% higher) for the 2005 data. The route to Old Faithful from the north entrance is 22 miles longer compared to the route from the west entrance and the coaches we instrumented this season did not travel all the way to the Old Faithful area. There are a number of possibilities for the higher speeds observed from the north entrance including more aggressive driving, more miles to cover in roughly the same amount of time or a more open and less congested route.

Figure 11 compares the overall vehicle emissions collected for both years of measurements arranged by fuel and fuel management technology. The model years are only denoted when the model year of the vehicle changes, so bars lacking a model year designation are the same model year as the previous bar. Starting from the left of the figure the first two vehicles are vintage Bombardiers with carbureted engines, followed by four throttle body injected 1991 and 1992 vans, followed by eleven port fuel injected vehicles from 1994 to 2004 and ending with the two diesel vehicles. The asterisks under the bars of the top graph signify data collected snowcoaches in 2006. Generally the emissions for CO and HC decline for the gasoline vehicles as you go from the older to the newer vehicles this is less so for NO_x. There is a reason why all vehicles are now port fuel injected and that technology clearly has better emission performance than either of the two older fuel injection technologies. The two diesel vehicles are the first and third highest NO_x emitters.

We purposely included two vintage Bombardiers in the measurement fleet this year, one carbureted and one with an upgraded fuel injected engine. In the 2005 data these two vehicles were the emission bookends with the carbureted vehicle being the highest CO and HC emitter and the upgraded Bombardier being the lowest emitting vehicle for all three pollutants. The question was how representative were the measurements for these two classes of vehicles. The short answer is that the data collected this year is not unlike the data collected last year. While the carbureted Bombardier measured this year had lower CO and much lower HC emissions than last years vintage Bombardier, the end result was that the carbureted vehicle was still at the high end of the emission range

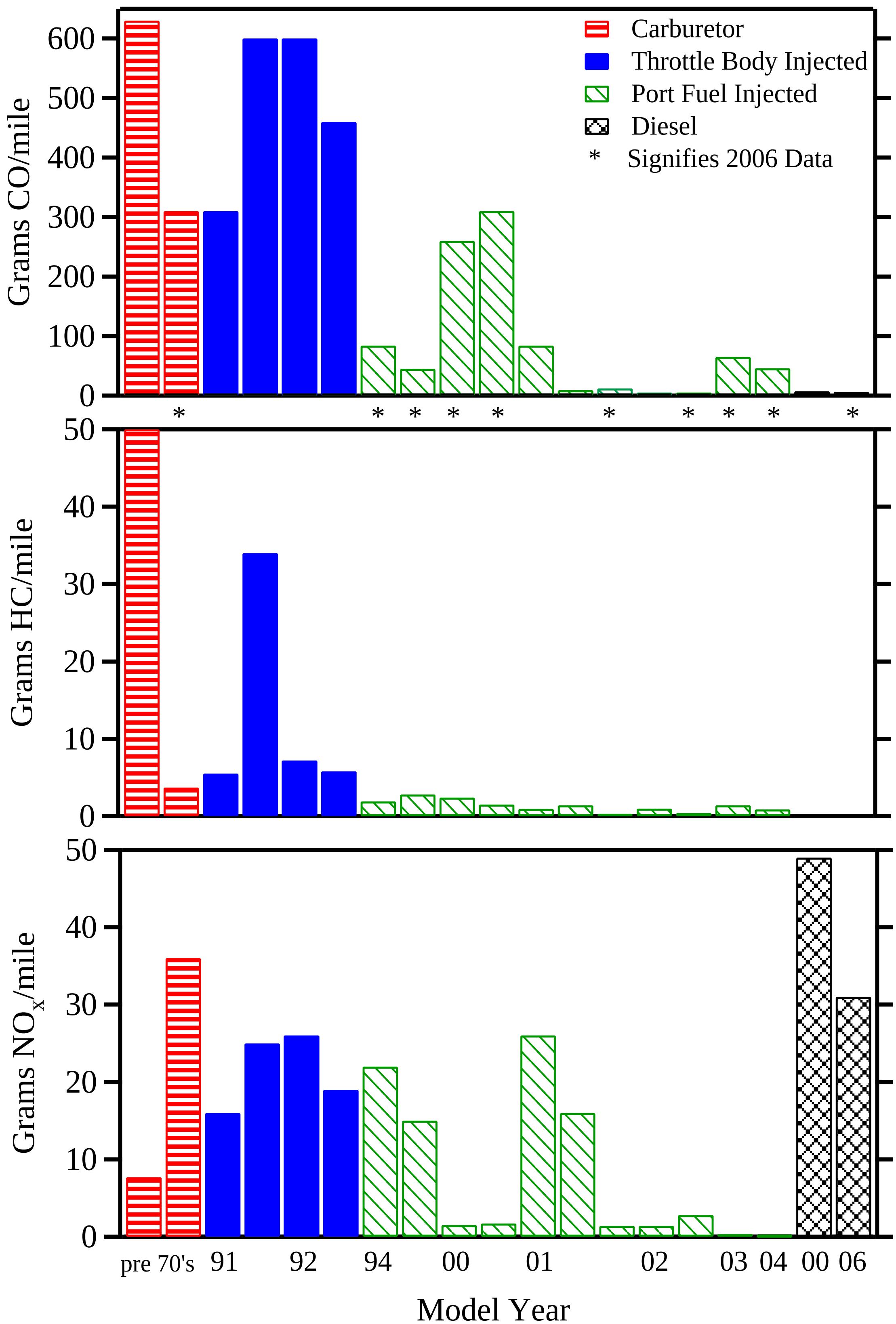

Figure 11. Overall 2005 and 2006 snowcoach emissions comparison arranged by fuel and fuel management technology. Within each technology class the vehicles are ordered left to right by model year.

observed. Since the two carbureted vehicles are nearly identically configured the emission differences observed could be related to maintenance issues, especially the HC emissions. Conversely the upgraded Bombardier was again one of the lowest emitting coaches measured. Anecdotal observations of the operation performance of the Bombardier's suggest that they have an unmatched power to weight ratio over the van conversions. This is based on the observation of their ability to comfortably manage the roundtrip drive while operating in overdrive much of the trip and their fuel economy results. No other type of snowcoach was noted as being able to operate in this high a gear for as large a fraction of time as the upgraded Bombardiers. The better power to weight ratio directly results in lower emissions and increased fuel economy (see Table 2). Even the carbureted Bombardier has better fuel economy than any of the other gasoline coaches.

We had hoped to obtain more measurements between model years 1992 and 2000, however, there are very few commercial coaches being used in West Yellowstone in that age range. The two 1994 Dodge snowcoaches tested though do provide a nice comparison with the four 1991 and 1992 Chevy snowcoaches tested in 2005. Both the Dodge and the Chevy vans were identically converted using a Snowbuster twin tracks and skis arrangement. The major difference is that the two Dodge snowcoaches were port fuel injected while the Chevy vans were throttle body injected. A throttle body injector is really just a computerized adaptation of the carburetor. A single fuel injector is positioned over the throttle body (this is where a carburetor would be bolted) and a computer controls the fuel injection for all of the cylinders. This is an improvement over a carburetor, though multi-port fuel injection is far superior especially for controlling HC emissions during decelerations. The CO and HC emissions are much lower for the two Dodge vans while the NO_x emissions are similar. The emission differences observed for CO and HC suggest that fuel management technology and not age alone is a more important consideration for achieving lower emissions.

If we exclude the carbureted snowcoaches from the following discussion then load is the single biggest factor that comes into play when attempting to explain the observed differences in emissions between the various snowcoaches. The loads that these engines are required to meet are a result of a complicated combination of factors. First is the power to weight ratio of the vehicle, how heavy is the vehicle (including the passengers) and the track system, how much horsepower does the engine produce and how efficiently is that power transferred to the snow. As previously mentioned the Bombardier's seem to excel in this area most likely because the vehicle itself is lighter (one penalty paid is their interior noise is much higher when underway). The second and most variable is the snow conditions. This includes whether the road was groomed the night before, the nightly and daytime temperature, road surface exposure to sunshine all which relate to how hard the snow surface is and the depth and wetness of any new snow that may have fallen. The CO emission plot for the YSCT Van in Appendix E illustrates how snow conditions affect power demand. Most of the CO excursions in this plot are for climbing hills, however, the largest CO excursions take place in both directions through a burned area where the road is fully exposed to the sun and the snow conditions were softer. Thirdly is the type of track system that the snowcoach is equipped with. The surface area of the track system directly influences how far the coach will sink into the snow surface. The large twin tracks on the Bombardier's and Snowbuster conversions should perform better under softer conditions than the Mat-Trax conversion because of the larger surface area of the track. The last influence we will list is the route and how it is driven. Of course the hillier the terrain the more work required from the engine, however even downgrades can dramatically increase loads when the driver is allowing a vehicle to lug along in too high a gear or is pushing the vehicle to higher than necessary speeds.

In gasoline engines CO and NO_x emissions are generally positively correlated with the amount of work the engine is required to do. Of course CO and NO_x will trade off with NO_x increasing until a load point is reached that tips the engine into a power enrichment mode when CO emissions will dominate. This load point is determined by all of the previously discussed factors, however when reached the engine asks for and receives additional fuel to try and meet the necessary power demand. During power enrichment excursions the fuel management computer is running blind because the main feed back sensor, the oxygen sensor, is reading zero and cannot help to determine how much extra fuel has been added. By and large the newer the gasoline powered snowcoach the lower the CO emissions are in Figure 11 indicating that engine designers are continuing to get better at capping the CO emissions during these power enrichment excursions. Diesel powered coaches when challenged generally do not experience a fuel induced power enrichment that results in increased CO emissions, however, the extra fuel will often result in more particles emitted at these times. The emission graphs of the NPS Bus in Appendix E shows this with NO_x emissions being relatively constant the entire trip and PM emissions increasing crossing the burned area and at a few of the uphill locations.

There were five coaches tested in 2006 of the same make, model (different model years 2000, 2000, 2001, 2003 and 2004) and that were equipped with the same 6.8L V-10 port fuel injected engine. This is the same type of van that Southwest Research Inc. did dynamometer testing on.[17] All used Mat-Trax conversions, however one of the five was a two wheel drive conversion with front steering ski's. There are also small differences in how they were driven with the two newest coaches spending large amounts of time during the trip on cruise control. There may also be slight differences in the transmissions that we are not aware of. However, these five snowcoaches represent the best group to do a side by side emission comparison. They all should have very similar power to weight ratios with the same engine, body style, passenger loading and track system and all were driven over the same route. These five coaches averaged 140, 1.3 and 1.0 grams/mile for CO, HC and NO_x respectively, however, there was a factor of 25 differences in CO emissions between the lowest and highest. The only major differences in the conditions under which these coaches were tested were the snow/road conditions and the authors believe that provides the most likely explanation for the large observed emission differences.

Figure 12 compares the CO emissions from these five coaches over the entire roundtrip. The emission graphs are ordered from oldest snowcoach (top) to newest (bottom). The elevation profile was recorded by snowcoach 3BL Van2 and has been adjusted to

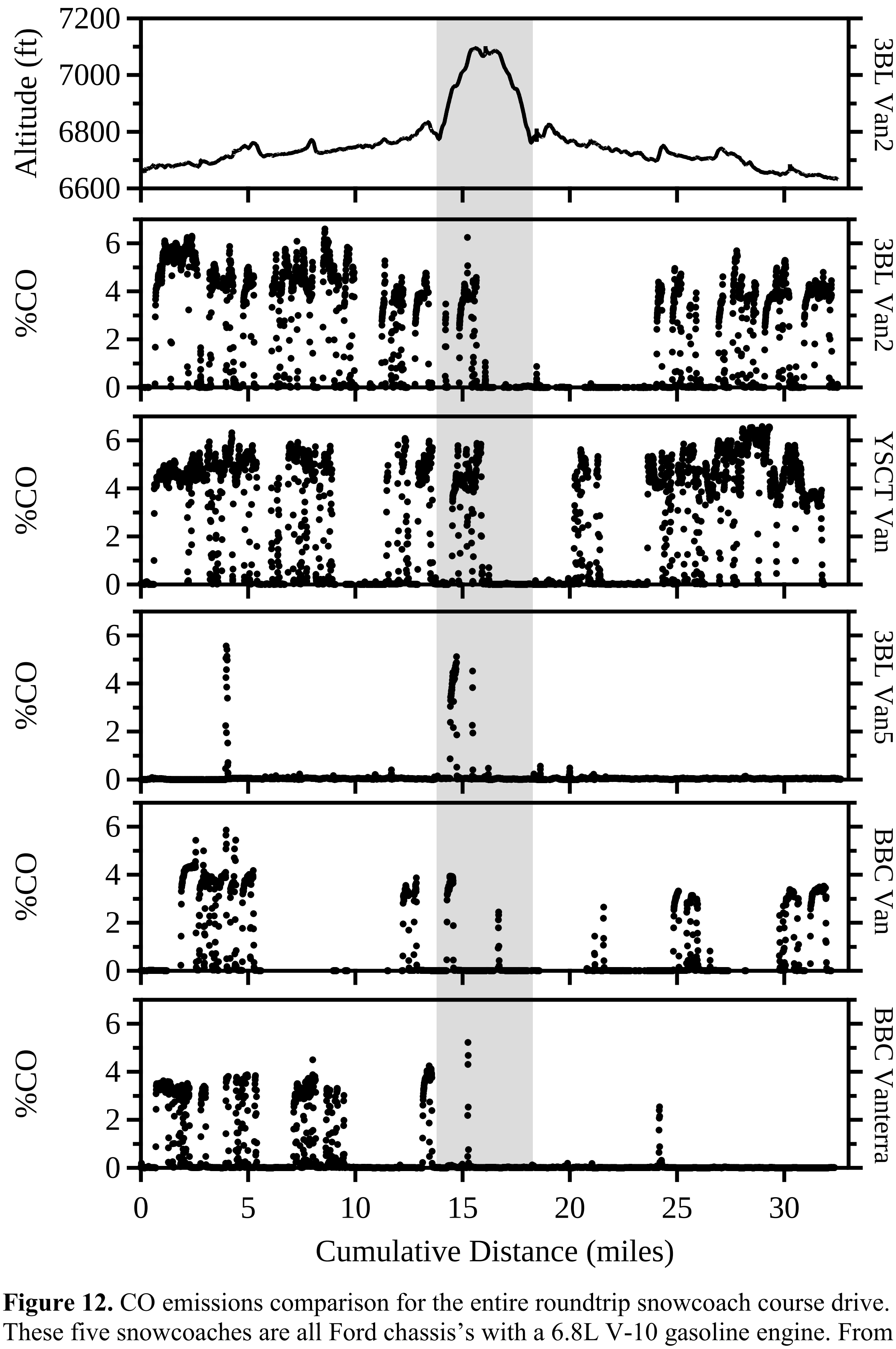

Figure 12. CO emissions comparison for the entire roundtrip snowcoach course drive. These five snowcoaches are all Ford chassis's with a 6.8L V-10 gasoline engine. From the top are model year's 2000, 2000, 2001, 2003 and 2004.

approximately match the USGS maps altitude at the highest point. Since the top three snowcoaches stopped at Madison Junction after climbing the hill and the two BBC snowcoaches stopped prior to climbing the hill the cumulative distances from the two BBC coaches have been adjusted to compensate for this. Each spike of CO emissions in Figure 12 corresponds to a power enrichment excursion. One noticeable difference between the model years is that the 03 and 04 coaches do a better job of limiting the CO emissions to about 4% during the excursions compared to the 2000 and 2001 snowcoach where the %CO approaches 6%. This improvement lowers the overall CO emissions for the newer snowcoaches. Also it's clear that the downhill grade of the return trip results in lower loads and fewer power enrichment excursions.

The two 2000 model year snowcoaches (the top two emission graphs in Figure 12) had overall CO emissions of 260 and 310 grams/mile respectively and they were both driven on the same day (1/30). The only major difference between these two drives and the other three coaches drives were the snow/road conditions for January 30th. Weather data recorded by the Park Service at the west entrance and data reported by the West Yellowstone SNOTEL site (see Appendix C) show overnight temperatures that were similar to many of the days with 3" of snow, but this snow was wetter than on the other days with 0.5" of equivalent water reported. Anecdotal comments that day about snow conditions included notebook comments of "heavy fresh snow" and comments from one of the operators about having to call for a snowcoach exchange after a particularly underpowered two wheel drive snowcoach was bogging down too much to complete the roundtrip to Old Faithful. Comments from the drivers and owners correlate the soft wet conditions encountered on January 30th with much higher fuel consumption by the snowcoaches indicating more time spent in power enrichment modes.

It is not clear whether to expect the two wheel drive coach (3BL Van2) to have higher or lower power demands. If we look at the two different driving modes broken out in Table 4 we can see that the two wheel drive model was the only snowcoach with elevated CO emissions during the low speed portion of the drive indicating that larger engine loads are required during starts than for the four wheel drive models. However, it's the cruise mode driving that result's in the four wheel drive van having the highest CO emissions. That difference appears to be the result of the four wheel drive van being driven more aggressively (Table 2 shows a four mile an hour difference in overall average speeds). That is also likely the explanation for the only large differences in emissions between these two snowcoaches around mile 21 where the YSCT Van crosses the load point while the 3BL Van2 does not.

3BL Van5 was the lowest emitting snowcoach of these five, a 2001 four wheel drive model was driven the morning after the two 2000 models. Weather data overnight for Tuesday January 31st differs between the two sites with the west entrance data reporting colder overnight temperatures and more snow. We noted in the notebook that the overnight grooming had left the road noticeably smoother and harder than the previous day. All of the various engine parameters available show that this snowcoaches work load was 15 to 20% less than the two driven on January 30th. Figure 12 shows that other than the climb up from the Gibbon River this snowcoach only enters power enrichment one other time. The two newest snowcoaches were both driven during the afternoon of Thursday January 26th. There was no fresh snow that day and the road had not been groomed overnight. These coaches ended up with CO emissions in between the other two groups.

Figure 13 graphs the CO emission data for the other four gasoline powered snowcoaches measured and Table 5 tabulates the amount of off-cycle (as defined in last years report as CO emissions greater than 3%) driving for each coach. The diesel powered snowcoach has been left out of Figure 13 because its CO emissions are never elevated (see Table 5). The elevation profile data has been taken from the YEXP R350 snowcoach and note that the y-axis for the carbureted snowcoach (AG Kitty) is almost double the other snowcoaches. As previously mentioned the upgraded Bombardier almost never experiences power enrichment events, even on the hill. While the carbureted Bombardier has much larger CO emission maximums it spends about the same amount of driving time above 3%CO as the newer YSCT Van. At lower power demands however, the carburetor is no match for the fuel injected oxygen sensor controlled vehicle as it is able to maintain essentially zero emissions when on-cycle. The carbureted Bombardier compensates for more time spent at higher emissions with much better fuel economy (see Table 2) than the newer YSCT van so that the total CO emissions for the two are identical. Notice also that this year's vintage Bombardier does spend an appreciable amount of time (more than 60%, see Table 5) below 3% CO. The carbureted Bombardier tested in 2005 never operated below 3% CO and this may or may not be a maintenance related issue. Also the ten snowcoaches on this route average less than half the time spent above 3% CO than the nine snowcoaches tested in 2005.

Table 5. Percentage of off-cycle driving times calculated assuming a 3% CO cut point.

Vehicle	Total Driving (Seconds)	Total Seconds with %CO > 3	Percent Off-Cycle
AG Kitty	5851	2252	38.5
YEXP R250	5170	82	1.6
YEXP R350	6253	5	0.1
3BL Van2	6792	1955	28.8
YSCT Van	5221	2063	39.5
3BL Van5	6215	54	0.9
AG Cygnet	5330	3	0.1
BBC Van	5700	587	10.3
BBC Vanterra	5714	461	8.1
NPS Bus	5961	0	0.0
Means	5821	1121	12.8

We can also compare the emissions amongst all of the coaches during the climb up the hill from the Gibbon River to the turn around at the Firehole River Cascades (see Figure 2). This 2.1 mile segment (which accounts for about 6.5% of the total trip distance) is on a north facing slope and has the steepest grade (2.8%) on the roundtrip. Table 6 and

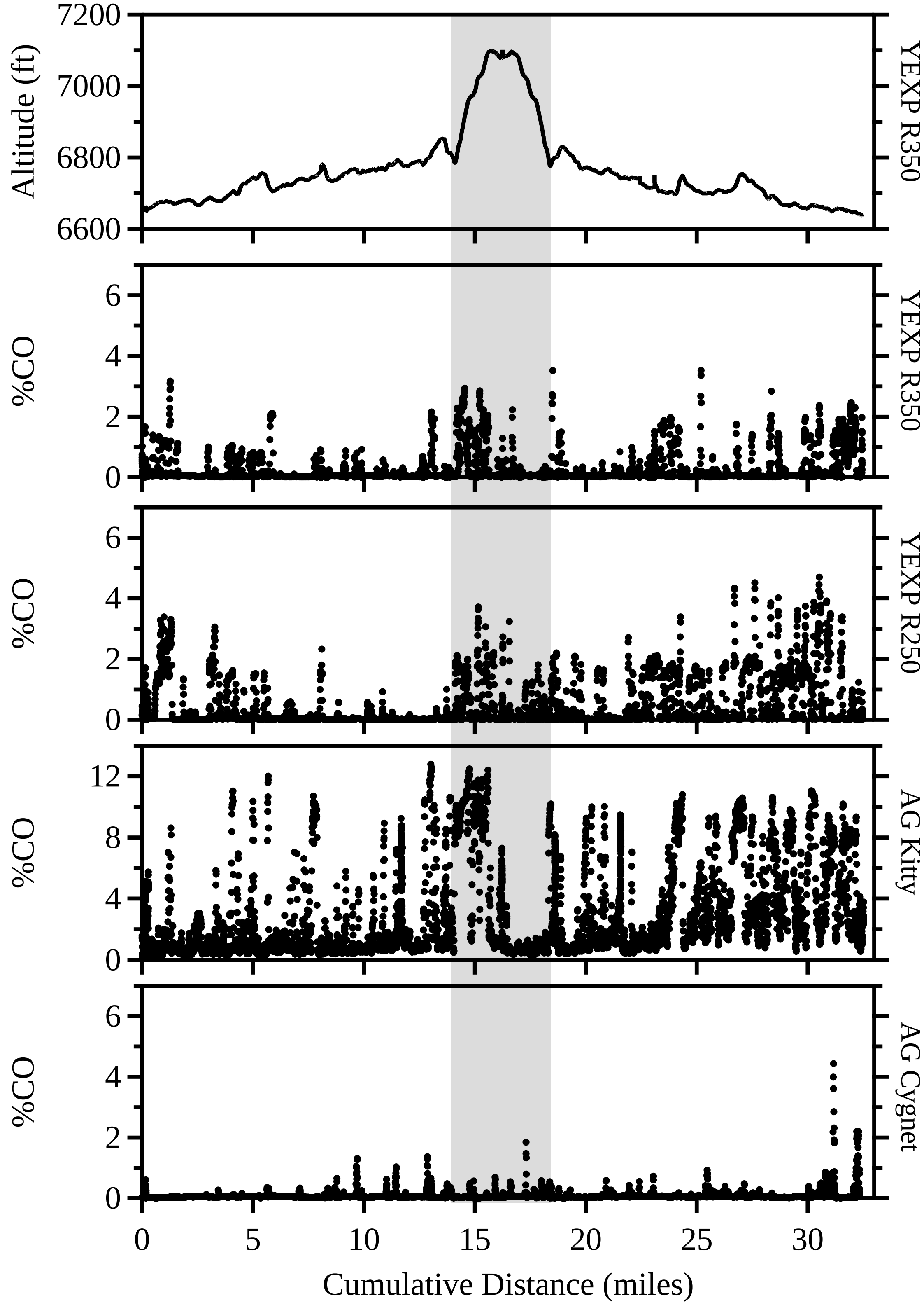

Figure 13. CO emissions comparison for the entire roundtrip snowcoach course drive for the remaining four gasoline powered snowcoaches. From the top are two 1994 Dodge conversion vans, a vintage carbureted Bombardier and an upgraded fuel injected Bombardier.

Figure 14 give a tabular and graphical intercomparison for the ten snowcoaches tested. Generally the relationship established between the ten tested snowcoaches for their overall emissions in Table 2 is seen in the emissions data collected during this uphill drive. The only exception is the enhanced NO_x emissions from the two 1994 Dodge snowcoaches. Figure 14 also emphasizes the benefit of newer catalyst in lowering the HC and NO_x emissions for the 2000 and newer gasoline vehicles. By comparing the percent of total emissions with the trip distance of 6.5% in Table 5 you can get a feel for which emissions from which coaches are enhanced during this portion of the drive. We would expect that the CO emissions would be enhanced during this uphill drive due to the need for additional power to climb the hill. Seven of the ten coaches have CO emission totals that are above 6.5%, however only four of the snowcoaches exceed it by significant amounts. You can see for example that the diesel power bus emits roughly the same fraction of CO, NO_x and particulate matter on the hill as it did during the rest of its drive. However, 3BL Van5 in one of only two of its power enrichment excursions emitted the majority of its CO emissions during this portion of the drive.

Table 6. Gram/mile emissions and the percent of the total trip emissions for the 2.1 mile drive from the Gibbon River to the turn around at the Firehole River Cascades for the ten tested snowcoaches.

Vehicle	gCO/mile (% of Total)	gHC/mile (% of Total)	gNO_x/mile (% of Total)	gPM/mile (% of Total)
AG Kitty	790 (16.7%)	6.6 (11.7%)	17 (3.1%)	NA
YEXP R250	130 (10.4%)	2.6 (9.0%)	32 (9.2%)	NA
YEXP R350	160 (23.4%)	4.7 (10.8%)	33 (13.8%)	NA
3BL Van2	220 (5.5%)	1.9 (5.1%)	1.6 (7.0%)	NA
YSCT Van	350 (7.2%)	1.5 (6.9%)	2.1 (8.1%)	NA
3BL Van5	97 (51.9%)	0.67 (14.2%)	1.4 (6.5%)	NA
AG Cygnet	2.4 (3.2%)	0.47 (7.7%)	3.8 (8.7%)	NA
BBC Van	84 (8.4%)	1.3 (6.1%)	0.15 (3.0%)	NA
BBC Vanterra	15 (2.2%)	0.59 (4.4%)	0.01 (0.7%)	NA
NPS Bus	8.4 (8.3%)	NA	41 (8.6%)	0.31 (6.0%)
Totals and Time-Weighted Means	190 (13.3%)	2.3 (8.3%)	14 (6.9%)	0.31 (6.0%)

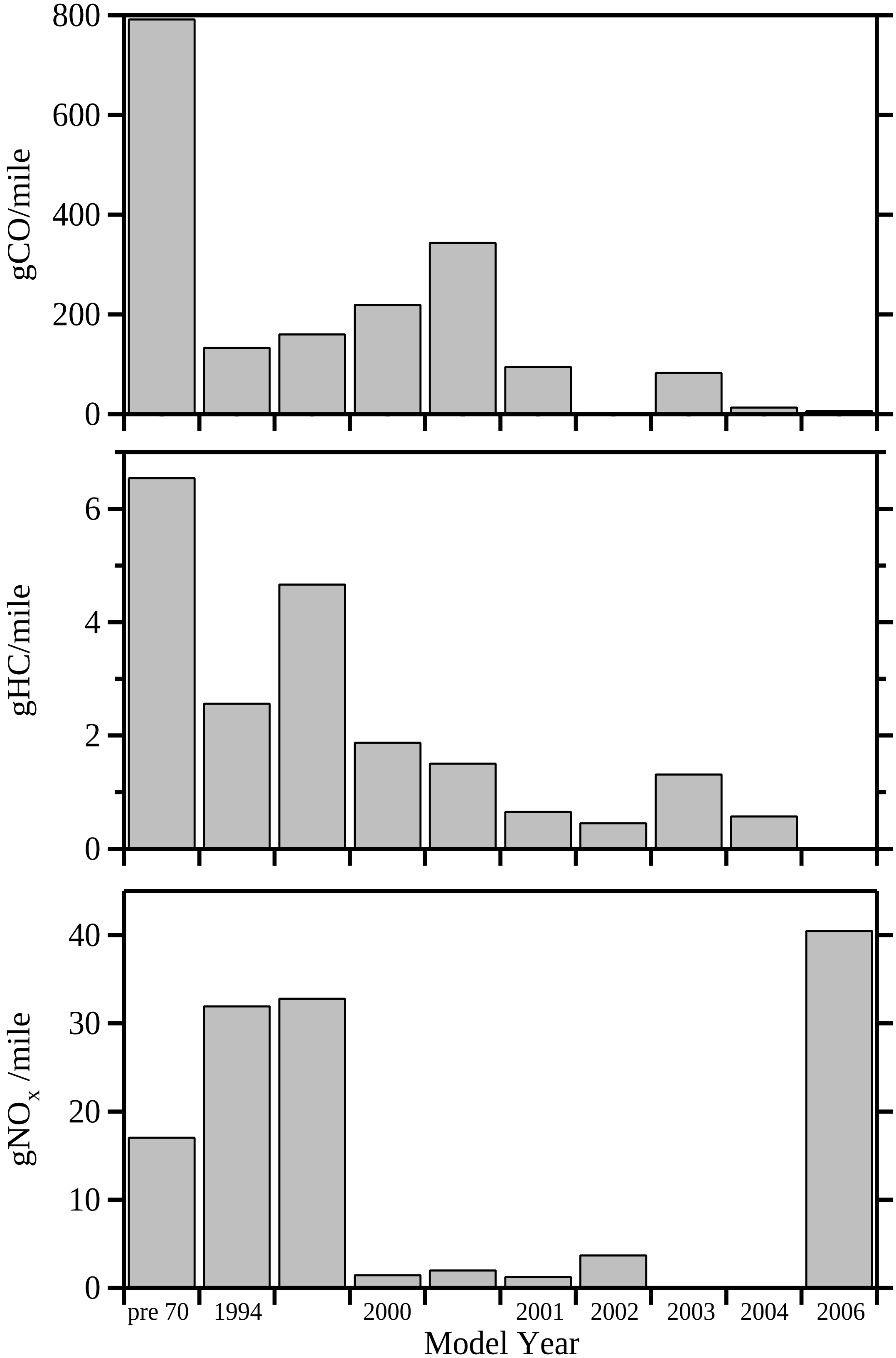

Figure 14. Gram/mile emissions comparison for the ten snowcoaches tested during the 2.1 mile drive from the Gibbon River to the turn around at the Firehole River Cascades.

SNOWMOBILES

Previous snowmobile emission comparisons have been made in the gate area at the west entrance to the park using the University of Denver s remote sensing devices.[8,9] The gate area was chosen because it provided a driving mode that limited the amount of snow spray trailing the snowmobiles and was one of the prime areas of employee exhaust exposure. As part of the 2005 emission measurements we made a crude attempt to instrument a 2002 Arctic Cat snowmobile with the Montana portable emissions monitoring system.[6,7] Through several missteps we finally succeeded in collecting emissions from a 2.3 mile drive.

For the previous work the PEMS unit was simply placed on the back seat of the snowmobile and a coat was used for its only insulation. The lack of proper insulation resulted in a number of problems from sample and exhaust line freezing problems to IR detector benches not being able to maintain their internal temperature requirements. These problems were compounded by using the Arctic Cat's accessory power plug which was limited to a 10amp draw as the instruments power source. Under normal operation the Montana system likes 10 to 12 amps of 12volt power and higher current is often needed when the instrument is cold. As a part of the 2006 measurement campaign we left open the possibility if time permitted, to try and repeat the PEMS measurements of a snowmobile driven over the same course as the snowcoaches.

Experimental

On-board emission measurements were made on two snowmobiles, a 2006 Arctic Cat T660 Touring and a 2004 Ski Doo Legend GT on February 2 and 3 2006. Measurements were made with the Clean Air Technologies International, Inc. Universal Montana portable emissions monitoring system previously described. The Montana unit was encapsulated inside a specially constructed clam-shell foam chest (see Figure 15). The bottom of the chest was lined with two side by side 115v heating pads leaving enough pad to overlap the rear input and exit lines (see Figure 16). Each snowmobile was outfitted with a 1kw gasoline powered generator (Honda EU-1000) to power the heating pads and a AC-DC converter to provide the 12v power for the Montana unit. The generator was arranged on the snowmobile so that its exhaust was directed to the opposite side of the snowmobile from the zero air input line. To prevent freezing of the analyzers exhaust lines we did not install any extension tubing to those ports opting for the exhaust and water to dribble out the bottom of the chest. We also installed thicker walled insulation on the snowmobile exhaust intake line due to the lack of any source of warm air to blow over this line as during the snowcoach testing.

Each snowmobile was driven over the same course as the snowcoach testing described in the previous section (see Figure 2 for route). Because the Montana unit was packed inside an insulated chest during the drive it was impossible to monitor its operation. Each snowmobile would be driven some distance (usually four to five miles) and we would stop and undo the top of the insulated chest and check to see if the analyzer was

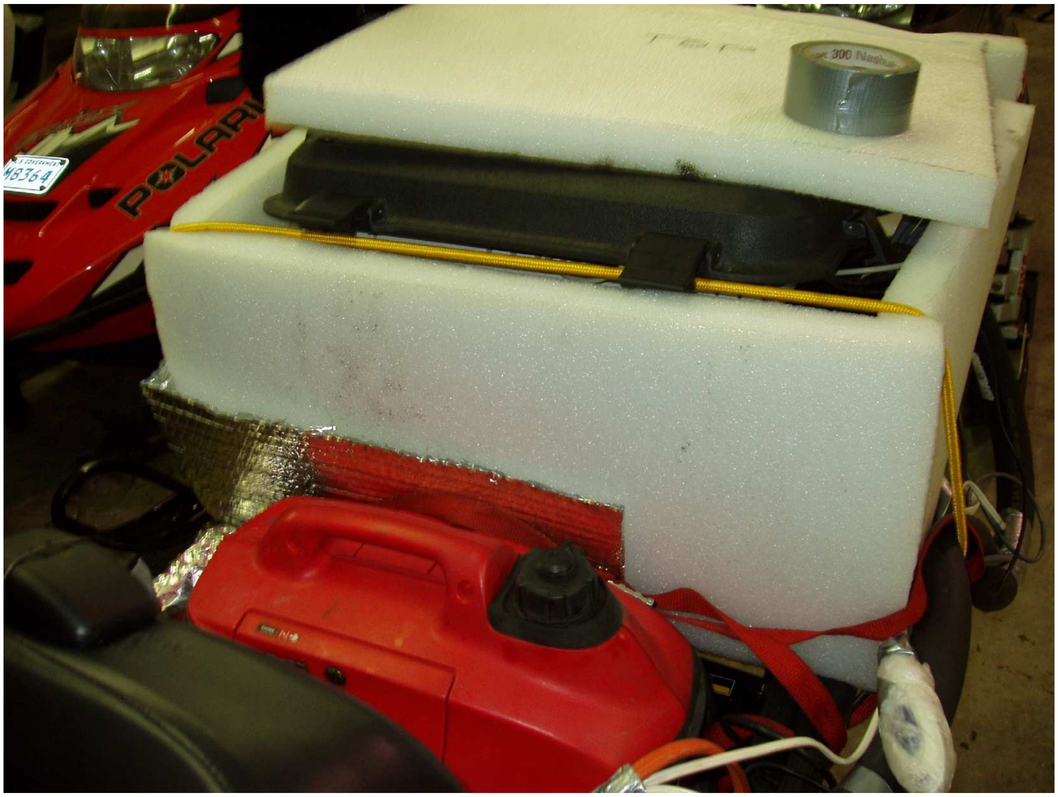

Figure 15. Insulated clam-shell chest with the Montana unit inside with the generator wedged behind the back seat of the Arctic Cat snowmobile.

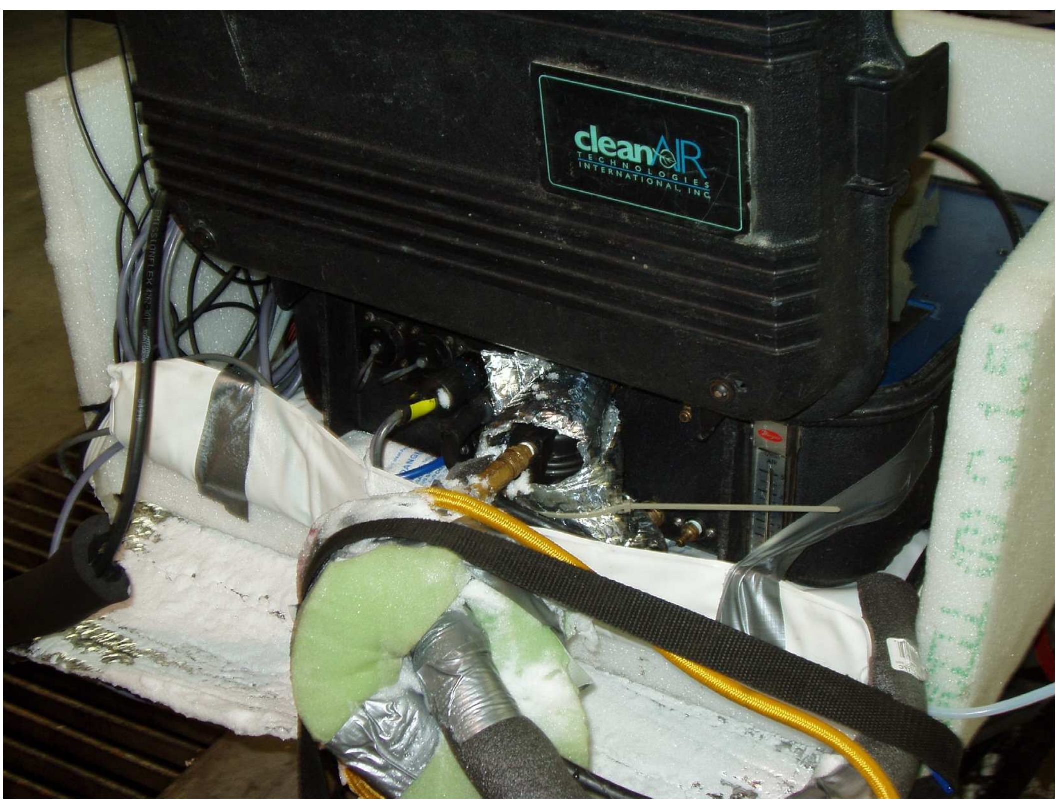

Figure 16. Insulated calm-shell with top removed showing the rear of the unit and one of the heating pads.

Figure 17. This is a rear view of the Montana unit packed aboard the Arctic Cat snowmobile during testing.

performing properly. If we found the unit functioning properly we would repack the chest and continue the drive, if we found a problem we would attempt to fix it before continuing. This is no substitute for being able to monitor operation during actual use since this only checks all the connections during idle. This proved to be a major limitation as not having access to real-time feedback was one of the reason we had to scrap the first roundtrip drive on the Arctic Cat snowmobile when the rpm pickup moved and only reliably worked at idle. This was only discovered back at the garage after the drive upon post processing the data collected.

Because the snowmobile exhaust exits from underneath the front engine compartment of each of the snowmobiles special care was needed to insert the exhaust probe so that it would remain attached during the drive. The Ski Doo exhaust pipe was the more difficult of the two snowmobiles to attach the exhaust probe to. We were only able to insert the probe a few inches into the muffler leaving most of the probe dragging on the snow on the outside. This is reflected in the data with higher measured oxygen concentrations in the exhaust stream meaning that the instruments sensors had to measure a more dilute exhaust stream which will increase some of the measurement errors. Also because of the exposed probe the Ski Doo was driven at lower average speeds over the course than the Arctic Cat for fear of ripping the probe out.

Because of the lack of an engine diagnostic interface that we could communicate with, each snowmobile's engine parameters were acquired using the Montana's sensor array. This involved installing an optical rpm pickup to sense the engine rpm from the cam shaft, teeing a pressure transducer into the intake manifold air pressure sensor to obtain the intake manifold pressure and a attaching a thermistor to the intake manifold to sense the intake air temperature. We had two major problems with the Arctic Cat data collection, first keeping the rpm optical pickup from moving during driving and after solving that problem the retro reflective tape came off the cam shaft during the drive. The combination of mishaps resulted in having to scrap one entire roundtrip drive and then losing about 3.5 miles of data on the second roundtrip drive.

Results

Sampling from the two snowmobiles resulted in the collection of 5 hours of second-by-second data (17,902 records) with 4.3 hours of valid gram per second data for CO, HC and NO. Approximately 51 minutes of data are included in the database file that was collected in addition to driving the snowcoach course. Only the data collected over the snowcoach course are included in the following analysis and comparisons with the snowcoach emissions data. Each record in the database includes the second by second emissions data, engine rpm, intake air temperature and absolute intake manifold pressure. The GPS receiver reported its fix status, number of satellites visible, time, longitude, latitude and altitude. The snowmobile data is included in the same database as the snowcoach measurements and is fully defined in Appendix B and is available for download from http://www.feat.biochem.du.edu.

Table 7 provides a summary of information on the two snowmobiles tested and Table 8 details the emissions data collected during the drive along the snowcoach route. The NO data is measured as NO but is reported by the Montana unit as NO_2 (NO_x) for all of the g/mi, g/gal and g/kg emission values. The mileage accumulated by the Ski Doo snowmobile is slightly over estimated due to a couple of hiccups in the GPS reported positions. Near Madison junction and later just after seven mile bridge the GPS reported positions veer off the roadway to the north and track a course parallel to the roadway for a time before rejoining the road. This behavior is likely due to the GPS receiver having some satellites blocked by the drivers back. These sections of GPS data have been changed to a "NO Fix" designation in the database and a corrected distance travel in meters has been inserted at the end of each of these sections.

Table 7. Snowmobile sampling dates and vehicle information.

Owner Date Sampled	Year Make Model	Engine Identifier Odometer / Fuel Type
NPS 2/2/06	2006 Arctic Cat T660 Touring	PFI 0.66L 3 cylinders M8325 334 miles / Gasoline
Yellowstone Adventures Rental 2/3/06	2004 Ski Doo Legend GT	PFI 1L 2 cylinders Rental #46 23,000 miles / Gasoline

Table 8. Summary of the valid second by second data collected for each snowmobile.

Vehicle	Sampled		Mean Speed	Fuel Use	Gram/mile Emissions		
	Hours	Miles[a]	(mph)	(mpg)	CO	HC	NO_x
Arctic Cat	1.5	29.1	23.7	25.1	15	1.6	7.7
Ski Doo	2.0	33.2	19.5	28.3	22	0.6	1.4
Totals and Time-Weighted Means	1.7	31.4	21.2	27	19	1.0	4.1

[a] Mileage calculated using the GPS data.

For comparison purposes the snowmobile data has been broken out into the same three self-defined operating modes as the snowcoach data. Tables 9 and 10 provide the operating and emissions data for the idle (defined as a GPS measured movement less than or equal to 0.5 meter), low speed (GPS measured speed greater than idle and less than 15 mph) and cruise (GPS measured speed greater than 15 mph) modes.

Table 9. Valid data distributed for three GPS defined driving modes.

Vehicle	Hours Sampled (Miles Traveled)			Mean Low Speed 0 < GPS Speed ≤ 15 mph	Mean Cruise Speed GPS Speed > 15 mph
	Idle	Low Speed	Cruise		
Arctic Cat	0.23 (0)	0.14 (1.2)	1.1 (27.9)	8.5	25.4
Ski Doo	0.33 (0)	0.41 (3.8)	1.2 (29.4)	9.3	22.9
Totals and Weighted Means	0.29 (0)	0.34 (3.2)	1.2 (28.7)	9.1	24.0

Table 10. Mass emissions data for the three driving modes defined in Table 12.[a]

Vehicle Measured	Species	Idle			Low Speed			Cruise		
		mg/s	g/gal	g/kg	g/mi	g/gal	g/kg	g/mi	g/gal	g/kg
Arctic Cat	CO	66	1400	510	21	350	130	13	340	120
Arctic Cat	HC	2.5	52	19	2.3	39	14	1.5	39	14
Arctic Cat	NO_x	0.41	8.5	3.2	7.5	120	46	7.7	200	73
Ski Doo	CO	46	550	200	53	1100	390	15	540	190
Ski Doo	HC	1.8	22	8.1	1.1	23	8.1	0.44	15	5.5
Ski Doo	NO_x	0.23	2.7	1.0	0.50	11	3.7	1.3	47	17
Time-Weighted Means	CO	54	880	330	45	940	330	14	440	160
Time-Weighted Means	HC	2.1	34	13	1.4	27	9.6	0.94	27	9.5
Time-Weighted Means	NO_x	0.30	5.1	1.9	2.2	39	14	4.4	120	43

[a] g/gal and g/kg results are calculated from the reported g/sec emissions and fuel consumption and the density of gasoline is assume to be 2800 g/gallon.

Discussion

In 2005 we successfully measured a 2.3 mile drive using the Montana analyzer from a 2002 Arctic Cat T660 Touring snowmobile. During that drive the overall emissions were 17, 1.9 and 9.7 grams/mile for CO, HC and NO_x respectively.[6,7] In part our lack of success, as evidenced by such a short drive, was a result of our off the cuff attempt to collect that data. With the lessons learned the follow-up measurements this year were extremely successful with data from two 32 mile drives collected from two different snowmobiles.

The first was on a 2006 model year Arctic Cat T660 Touring snowmobile owned by the National Park Service and it confirmed the prior years measurements with very similar values measured (15, 1.6 and 7.7 grams/mile for CO, HC and NO_x). These reflect emission reductions from last year's measurements of 12%, 16% and 21% for CO, HC and NO_x. In addition the 2006 model got 13% better fuel economy (25.1 mpg compared to 21.9) which was a major contributor to the pollutant reductions. Because of the distance of the short drive in 2005 we were uncomfortable using 21.9 mpg for a fleet average fuel economy and instead used a more conservative value of 18 mpg. However, this years measurements are greater still than last years and suggest that the 18 mpg that we allowed the snowmobile fleet to average in our emission comparisons with the snowcoaches may be too conservative.[6,7]

In addition to the Arctic Cat snowmobile we also completed the snowcoach course drive on a rented 2004 Ski Doo Legend GT. The Ski Doo had higher overall CO emissions of 22 grams/mile, but lower HC and NO_x emissions of 0.6 and 1.4 grams/mile respectively. We believe the emission differences are a result of how the engine operation is designed in the two snowmobiles. The Arctic Cat snowmobile is a 3 cylinder engine with smaller displacement (0.66L) yet that operates at significantly higher rpm's (>6000 rpm's at cruise) than the larger displacement (1L) 2 cylinder Ski Doo engine (~4000 rpm's at cruise). The smaller displacement and higher operating rpm's of the Arctic Cat's Suzuki engine will likely lead to both higher HC and NO_x emissions. The fraction of surface area and therefore the size of the HC quench layer will increase as displacement decreases. Combine this with higher rpm's and therefore more cylinders per minute compared to the Ski Doo engine and you have higher HC emissions from the Arctic Cat engine. The smaller displacement and higher rpm's in the Arctic Cat probably also result in higher internal cylinder compression than the Ski Doo engine. NO_x emissions are produced through a combination of excess oxygen, cylinder temperature and cylinder pressures. In the Arctic Cat engine there is plenty of excess oxygen present and when this is combined with adequate cylinder temperatures and the likely higher cylinder pressures the result is more NO_x made during combustion.

The differences in CO emissions are a more complicated story as the fuel management of these two engines is quite different. The Arctic Cat engine seems to have two operational ranges for CO emissions idle and all other modes. Figure 18 plots an eight minute segment of CO emissions and GPS measured speed for the Arctic Cat snowmobile. At idle this snowmobile emits between 3 and 5% CO which quickly drops to less than 1%

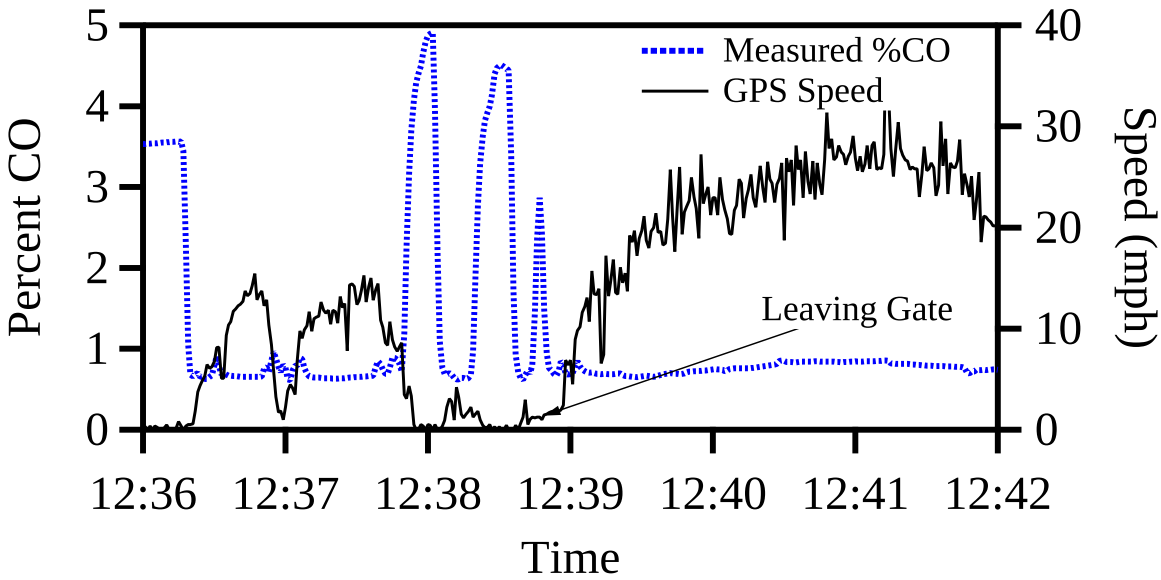

Figure 18. CO emissions and GPS measured speed for the 2006 Arctic Cat snowmobile entering and leaving the west entrance gate area.

upon increasing the throttle even small amounts. This can be seen in the three CO emission peaks that start around 12:38. The first increase in CO emissions is a result of the snowmobile entering the gate area and stopping for the first time. The snowmobile is only idled for a few seconds when it is given a small amount of throttle and moves forward a short distance and is stopped a second time. Even this short acceleration event is accompanied by a large drop in CO emission only for those emissions to rise again as the snowmobile returns to the idle state. A second throttle increase moves the snowmobile again and finally a third event is accompanied by the snowmobile accelerating to cruising speed and leaving the gate area. Each throttle event is accompanied by a rapid decrease in CO emissions that stabilizes at these low levels for as long as the throttle is maintained.

This similar driving event produces quite a different CO emissions response from the Ski Doo snowmobile. Figure 19 is a time slice similar to Figure 18 with the exception that the problems with inserting the probe lead to higher oxygen values that diluted the measured exhaust stream. Figure 19 shows the measured %CO emissions and the %CO emissions corrected for the excess air along with the measured GPS speed. Unlike the Arctic Cat snowmobile the Ski Doo snowmobile idles at lower CO emissions of between 2 and 3%. Whenever the throttle is applied the Ski Doo snowmobile CO rapidly increases to between 4.5 and 5.5% and if the throttle position is maintained the CO emissions begin to exponentially decrease. We observe these increases in CO emissions anytime the throttle position is increased. This means that the more transient the operation of the Ski Doo snowmobile the higher the CO emissions will be as it will spend more operation time at the higher levels. This can be seen when you compare the CO emissions in Table 10 between the cruise and low speed operations mode. The low speed operation has a factor of 3.5 times higher CO emissions than in cruise mode. These transient emissions are not

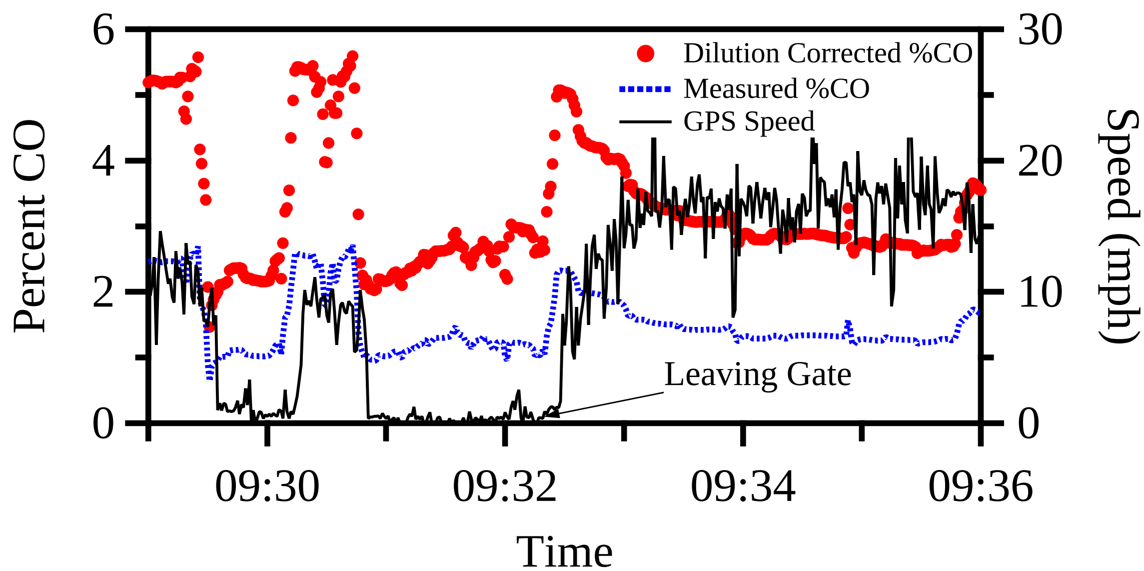

Figure 19. Measured and dilution corrected CO emissions and GPS measured speed for the 2004 Ski Doo snowmobile entering and leaving the west entrance gate area.

included in the current BAT certification process since that engine dynamometer test is a steady state test and that allows the Ski Doo snowmobile to pass BAT certification easily. The remote sensing measurements collected in 2005 at the west entrance accurately captured this large difference in transient emissions between the Arctic Cat and Ski Doo snowmobiles.

Table 11 collects all of the PEMS and remote sensing measurements that have been made on snowmobiles in Yellowstone National Park over the past two winters for comparison. We have chosen to label the remote sensing measurements as low speed even though at the entrance some idle measurements are included and at the exit we have capture some cruise mode. The trends observed between the two makes of snowmobile are consistent between the two methods used. The Arctic Cat is lower on CO and has much higher NOx emissions than the Ski Doo. The 2006 Arctic Cat snowmobile looks very similar to the measurements that we collected in 2005 from a 2002 model year Arctic Cat snowmobile. Some of the differences observed between the PEMS measurements and the remote sensor are a result of only measuring a single snowmobile with the PEMS unit. We have no way of predicting how representative that single snowmobile is compared with all the others that are used in the Park. Other differences are a result of the remote sensing device averaging a wider range of driving modes than the individual modes we are able to select from the PEMS data.

Finally unlike the measurements collected on the snowcoaches snow conditions and their effects on loads are less of an issue for the snowmobiles. The emission graphs in Appendix E for the two snowmobiles tested show few if any changes in emission operations over the round trip drives. This is a result of the combination of a high power to weight ratio and a large track/ski surface gives the snowmobiles a big advantage over

Table 11. 2005 and 2006 snowmobile emission measurement comparisons

Vehicle Measurement / Year	Idle g/kg[a]			Low Speed g/kg[a,b]			Cruise g/kg[a]		
	CO	HC	NO_x	CO	HC	NO_x	CO	HC	NO_x
2002 Arctic Cat T660 PEMS / 2005	470	24	2.4	NA	NA	NA	140	16	80
2006 Arctic Cat T660 PEMS / 2006	510	19	3.2	130	14	46	120	14	73
2004 Ski Doo Legend GT PEMS / 2006	200	8.1	1.0	390	8.1	3.7	190	5.5	17
Arctic Cat Fleet[c] Entrance RSD / 2005				190 ± 4	26 ± 3	29 ± 0.9			
Arctic Cat Fleet[c] Exit RSD / 2005				210 ± 4	NA	46 ± 1.2			
Ski Doo Fleet[c] Entrance RSD / 2005				490 ± 21	28 ± 10	2.6 ± 0.6			
Ski Doo Fleet[c] Exit RSD / 2005				520 ± 24	NA	4.1 ± 0.8			

[a]PEMS g/kg results are calculated from the reported g/sec emissions and fuel consumption.
[b]RSD g/kg results are calculated from the measured ratio's assuming a carbon fraction of 0.86.
[c]Fleet remote sensing measurements exclude the guide snowmobile measurements.
[d]Errors are reported as the standard error of the mean.

the snowcoaches that leads to repeatable trip emissions irrespective of snow conditions.

COMPARISON OF SNOW VEHICLE EMISSIONS

In the 2005 report we compared the over the snow vehicle emissions on a per person basis using the visitor statistics obtained from the National Park Service Public Use Statistics Office. We have updated that comparison by combining the two years worth of data and using the entrance statistics collected for the 2005-2006 winter season in Table 12. The 4-stroke snowmobile values are averages of the entrance and exit remote sensing measurements collected during 2005.[6,7] The remote sensing snowmobile NO measurements have been converted to NO_2 emissions for a direct comparison with the PEMS measurements. The 2006 mean snowmobile emissions are the time weighted measurements from this years Arctic Cat and Ski Doo snowmobile measurements (see Table 8). To convert the snowmobile gram/gallon measurements to grams/mile estimates we have assumed a 2-stroke fuel economy of 13 miles per gallon and for 4-strokes 25 miles per gallon.[9] The 25 miles per gallon estimate is an average from the three snowmobiles that have now been instrumented with the PEMS unit. The 2005, 2006 and combined snowcoach emissions are a time weighted average of all the data collected.[6,7] Snowmobile entries for 1999 were 62,878 with 76,271 passengers for a 1.2 persons/snowmobile average. Snowmobile entries for 2006 were 21,916 with 28,833 passengers for a 1.3 persons/snowmobile average. Snowcoach entries for 2006 were 2,463 with 19,856 passengers for a 8.1 persons/coach average.

Changes produced by the addition of this year's comparison are that the average persons per snowcoach dropped slightly from last year increasing per person snowcoach emissions. The 2006 snowcoach emission measurements are significantly lower than last years measurements but because the route this year was shorter the combined average is still dominated by the measurements collected in 2005. The combined data results in the per person emissions for either the 4-stroke snowmobiles or the snowcoaches being significantly reduced from the 2-stroke snowmobile era. Both the remote sensing and PEMS snowmobile emission measurements have lower gram/mile emissions for all species when compared to the mean 2005/2006 snowcoach emissions data. When comparisons are made on a per person basis the PEMS snowmobile measurements are lower or the same for CO and HC and higher for NO_x while the remote sensing measurements are only lower for CO emissions.

This comparison should not be considered as an absolute comparison. The snowmobile data is most likely more robust and representative of that fleets average emissions because of the large number of remote sensing measurements that have been collected. Also the snowmobile emissions have been shown to not really be a function of age or model year and we believe that because of the excellent power to weight ratio they are also less susceptible to changing snow conditions. The mean snowcoach emission factors are more elusive because even with 19 snowcoaches now measured that is still a minority of the fleet operating in the Park. As mentioned in last years report these 19 coaches should not be taken to be representative of the fleet average trips taken in Yellowstone Park during the 2005-2006 winter season. This fleet still probably under represents the number of passengers transported in vintage carbureted Bombardier's and over represents the number of passengers transported in diesel coaches.

Table 12. Estimated gram/mile/person emissions for Yellowstone winter transportation options.

Data	Instrument	Mean grams/gal[a,b]			Mean g/mile (Estimated g/mile)[c]			Estimated g/mile/person[d]		
		CO	HC	NO_x	CO	HC	NO_x	CO	HC	NO_x
1999 Mean 2-stroke Snowmobile	Remote Sensor	1100	1400	NA	(85)	(110)	NA	71	92	NA
2005 Mean 4-stroke Snowmobiles	Remote Sensor	670	80	80	(27)	(3.2)	(3.2)	21	2.5	2.5
2006 Mean 4-stroke Snowmobiles	PEMS				19	1.0	4.0	15	0.8	3.1
2005 Mean Snowcoach	PEMS				300	10	24	37	1.2	3.0
2006 Mean Snowcoach	PEMS				120	1.7	11	15	0.2	1.4
2005 & 2006 Mean Snowcoach	PEMS				230	6.7	19	28	0.8	2.3

[a] grams/gallon calculations for the snowmobiles assume a fuel density of 726 g/l.
[b] Snowmobile NO emissions have been converted to NO_2.
[c] Snowmobile g/mile estimates use 13 mpg for 2-strokes and 25 mpg for 4-strokes.
[d] 2006 data obtained from the National Park Service Public Use Statistics Office.

We now though have a very good idea that port fuel injected coaches in general have much lower emissions but that even these vehicles can be negatively impacted by poor snow conditions (see Figure 12). We have also learned that the two emission extremes in snowcoaches exists between the vintage carbureted (at the high end) and port fuel injected (at the low end) upgraded Bombardier's as these vehicles occupied this location in both years study. This year's work has also reinforced the fact that the fuel economy of the 4-stroke snowmobiles is very good and a major reason for their decreased emissions.

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APPENDIX A: Montana System Specifications

Gas	Measurement Range	Accuracy	Repeatability	Noise (rms)	Resolution
HC n-Hexane	0 - 2000 ppm 2001 - 1500 ppm 15001 - 30000 ppm	±4 ppm abs. or ±3% rel. ±5% rel. ±8% rel.	±3 ppm abs. or ±2% rel. ±3% rel. ±4% rel.	2 ppm abs. or 0.8% rel.	1 ppm
HC Propane	0 - 4000 ppm 4001 - 30000 ppm 30001 - 60000 ppm	±8 ppm abs. or ±3% rel. ±5% rel. ±8% rel.	±6 ppm abs. or ±2% rel. ±3% rel. ±4% rel.	4 ppm abs. or 0.8% rel.	1 ppm
CO	0 - 10 % 10.01 - 15%	±0.02% abs. or ±3% rel. ±5% rel.	±0.02 abs. or ±2% rel. ±3% rel.	0.01% abs. or 0.8% rel.	0.001 vol. %
CO_2	0 - 16% 16.01 - 20%	±0.3% abs. or ±3% rel. ±5% rel.	±0.1% abs. or ±2% rel. ±3% rel.	0.1% abs. or 0.8% rel.	0.01 vol. %
NO_x	0 - 4000 ppm 4001 - 5000 ppm	±25 ppm abs. or ±4% rel. ±5% rel.	±20 ppm abs. or ±3% rel. ±4% rel.	10 ppm abs. or 1% rel.	1 ppm
O_2	0.00 - 25%	±0.1% abs. or ±3% rel.	±0.1% abs. or ±3% rel.	0.1% abs. or 1.5% rel.	0.01 vol. %

APPENDIX B: Explanation of the YNP_2006.dbf database.

The YNP_2006.dbf is a Microsoft Foxpro database file, and can be opened by any version of MS Foxpro, regardless of platform. The following is an explanation of the data fields found in this database:

Vehicle	Name of vehicle that includes the company and vehicle identifier.
Sheet_name	Companion excel spreadsheet name which contained the original records.
Date	Date of measurement, in standard format.
Time	Time of measurement, in standard format.
Time_sec	Time of measurement, in seconds.
Org_valid	Gram/sec validity flag reported at time of data collection (YES or NO).
Valid_g_s	Gram/sec validity flag used for calculations in the report after known leaks and instrument problems have been removed (YES or NO).
Bag_no	Virtual collection bag number for labeling data collection events.
Bg_dist_mi	OBD (if available) reported mileage accumulation for Bag_no.
Bg_time_s	Accumulated time in seconds for Bag_no.
Mph	OBD (if available) reported speed in miles per hour.
Accel	OBD (if available) reported acceleration in mph/sec.
Sensed_rpm	Sensor array (if used) measured engine rpm.
S_temp_c	Sensor array (if used) measured intake air temperature in centigrade.
S_map_kpa	Sensor array (if used) measured absolute intake manifold pressure in kilopascals.
Eng_rpm	OBD (if available) reported engine rpm.
Coolant_c	OBD (if available) reported coolant temperature in centrigrade.
Throttle	OBD (if available) reported percent throttle.
Map_kpa	OBD (if available) reported absolute intake manifold pressure in kilopascals.
Iat_c	OBD (if available) reported intake air temperature in centigrade.
Torque_lbf	OBD (if available) reported engine torque in foot-pounds.
Ntkair_g_s	Calculated grams per second of intake air.
Dryexh_g_s	Calculated grams per second of dry exhaust.
Totex_scfm	Calculated total exhaust flow in standard cubic feet per minute.
Fuel_g_s	Calculated fuel consumption in grams per second.
Fuel_mpg	OBD (if available) reported fuel economy in miles per gallon.

V_fuelmpg	Validity flag for OBD reported Fuel_mpg (YES or NO).
Nox_ppm	Mean NO emissions in parts per million.
HC_ppm	Mean HC emissions in parts per million in propane units.
CO_p	Mean percent CO emissions.
CO2_p	Mean percent CO_2 emissions.
O2_p	Mean percent O_2 emissions.
Pm_pfs	PM Percent full scale of back scattered laser light.
Pm_mg_m3	Calculated PM in milligrams per cubic meter of exhaust if valid.
Nox_g_s	Calculated NO_2 emissions in grams per second if valid.
Hc_g_s	Calculated HC emissions in grams per second if valid.
Co_g_s	Calculated CO emissions in grams per second if valid.
Co2_g_s	Calculated CO_2 emissions in grams per second if valid.
Pm_mg_s	Calculated PM emissions in milligrams per second if valid.
A_valid	Validity flag for analyzer bench A (Yes or No). This flag is misreported in all of our data sets. It is always No even when the data is used in the composite average.
A_stats	Decimal representation of a series of binary bench A status flags.
A_nox_ppm	Bench A reported NO emissions in parts per million if valid.
A_hcppm	Bench A reported HC emissions in parts per million if valid.
A_co_p	Bench A reported percent CO emissions if valid.
A_co2_p	Bench A reported percent CO_2 emissions if valid.
A_o2_p	Bench A reported percent O_2 emissions if valid.
B_valid	Validity flag for analyzer bench B (Yes or No). This flag is reported correctly in all of our data sets.
B_stats	Decimal representation of a series of binary bench B status flags.
B_nox_ppm	Bench B reported NO emissions in parts per million if valid.
B_hcppm	Bench B reported HC emissions in parts per million if valid.
B_co_p	Bench B reported percent CO emissions if valid.
B_co2_p	Bench B reported percent CO_2 emissions if valid.
B_o2_p	Bench B reported percent O_2 emissions if valid.
Gps_fix	Status of GPS receiver fix (No fix or Fix OK).
Gps_sats	If GPS receiver is lock in this reports the number of satellites used to calculate the receivers position.
Gps_time	Time reported by the GPS receiver.

Gpsspd_mph Calculated vehicle speed in miles per hour using the second by second GPS position data if available.

Lat_deg Latitude reported in decimal degrees.

Long_deg Longitude reported in decimal degrees.

Alt_m GPS reported altitude in meters if fixed.

Gpsdist_m Calculated changed in distance in meters from the last valid GPS location.

SC_course Indicates (YES or NO) whether the vehicle data is being collected on the snowcoach emissions course.

APPENDIX C: Weather and grooming records for the West Yellowstone area.

Data reported at the west entrance by the National Park Service

Date	Temperature		Precipitation		Skies	Groomed Night Before
	Minimum	Maximum	Conditions	New Snow		
1/25/06	-8	23		0”	Clear	Yes
1/26/06	-7	26		0”	Clear	No
1/27/06	-8	27	Lt Snow	3.5”	OC	Yes
1/28/06	NA	26	Lt Snow	1.5”	OC	Yes
1/29/06	NA	NA	Lt Snow	2”	BC	Yes
1/30/06	13	22	Lt Snow	3”	OC	Yes
1/31/06	9	21	Lt Snow	3”	Clear	Yes
2/1/06	19	25	Mod Snow	3”	OC	No
2/2/06	17	19		0.5”	Clear	No
2/3/06	13	25		0.5”	Clear	Yes

Data reported by SNOTEL[a] for the West Yellowstone site.

Date	Temperature		Precipitation	
	Minimum	Maximum	Water Content	New Snow
1/25/06	5	35	0.0”	0.0”
1/26/06	26	34	0.2	2.4”
1/27/06	19	33	0.2”	1.0”
1/28/06	17	28	0.2”	1.1”
1/29/06	13	29	0.1”	0”
1/30/06	13	34	0.5”	3.1”
1/31/06	13	33	0.1”	0.1”
2/1/06	14	36	0.1”	2.2”
2/2/06	14	33	0.0”	1.9”
2/3/06	14	39	0.1”	0.5”

[a]http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=924&state=mt

APPENDIX D: Summary of invalidated snowcoach and snowmobile data.

This appendix includes every invalidated record that has been invalidated and the reasons for that classification. Note that many problems were intermittent in nature and may have caused problems with data collection over an extended period of time until resolved.

NPS Yellow Bus - 463 seconds of data invalidated.
14:15:33 - 14:23:15 - RPM sensor miss aimed (not on route).

YExp R350 - 2 seconds of data invalidated.
16:39:58 - RPM drop out.
16:40:06 - RPM drop out.

YSCT Van - 44 seconds of data invalidated.
10:09:16 - 10:09:18 - scanner problem.
10:09:59 - 10:10:00 - scanner problem.
10:13:33 - 10:13:40 - invalid RPM.
10:39:09 - 10:39:14 - RPM drop out.
10:39:53 - 10:39:58 - invalid RPM.
10:40:03 - 10:40:06 - RPM drop out.
10:43:33 - 10:43:39 - RPM drop out.
10:46:43 - 10:46:50 - invalid RPM.
10:47:37 - 10:47:39 - RPM drop out.

3BL Van5 - 1 second of data invalidated.
15:02:02 - RPM drop out.

Appendix E Emission Maps for Selected Winter Vehicles

One minute average emissions plotted along the 2006 course illustrate the variations in emissions that occur during travel. Each of the maps uses the same emission scale and color coding so that visual comparisons can be made. The emissions are plotted in gm/sec and averaged over one minute. For comparison, the gm/mile overall emissions are given in the table.

Two snowmobiles are compared in the figure E-1. Both had emissions in the lowest range of the scale and were relatively insensitive to snow conditions, hills, or acceleration. In figure E-2 and E-3 two gasoline snowcoaches and one diesel snowcoach are compared. The Bombardier ("Cygnet") with a retrofitted SUV engine and pollution control equipment had low emissions and no high-emission excursions. The NPS diesel bus had low CO emissions, but the NOx was high constantly and there were several PM excursions.

The high-emissions excursions tended to be in an area with wind blown snow that was often soften by snowshine or at the hill near the turn-around point. These are conditions when there is higher engine load.

Yellowstone NP 2006 - Emissions from Two Snowmobiles

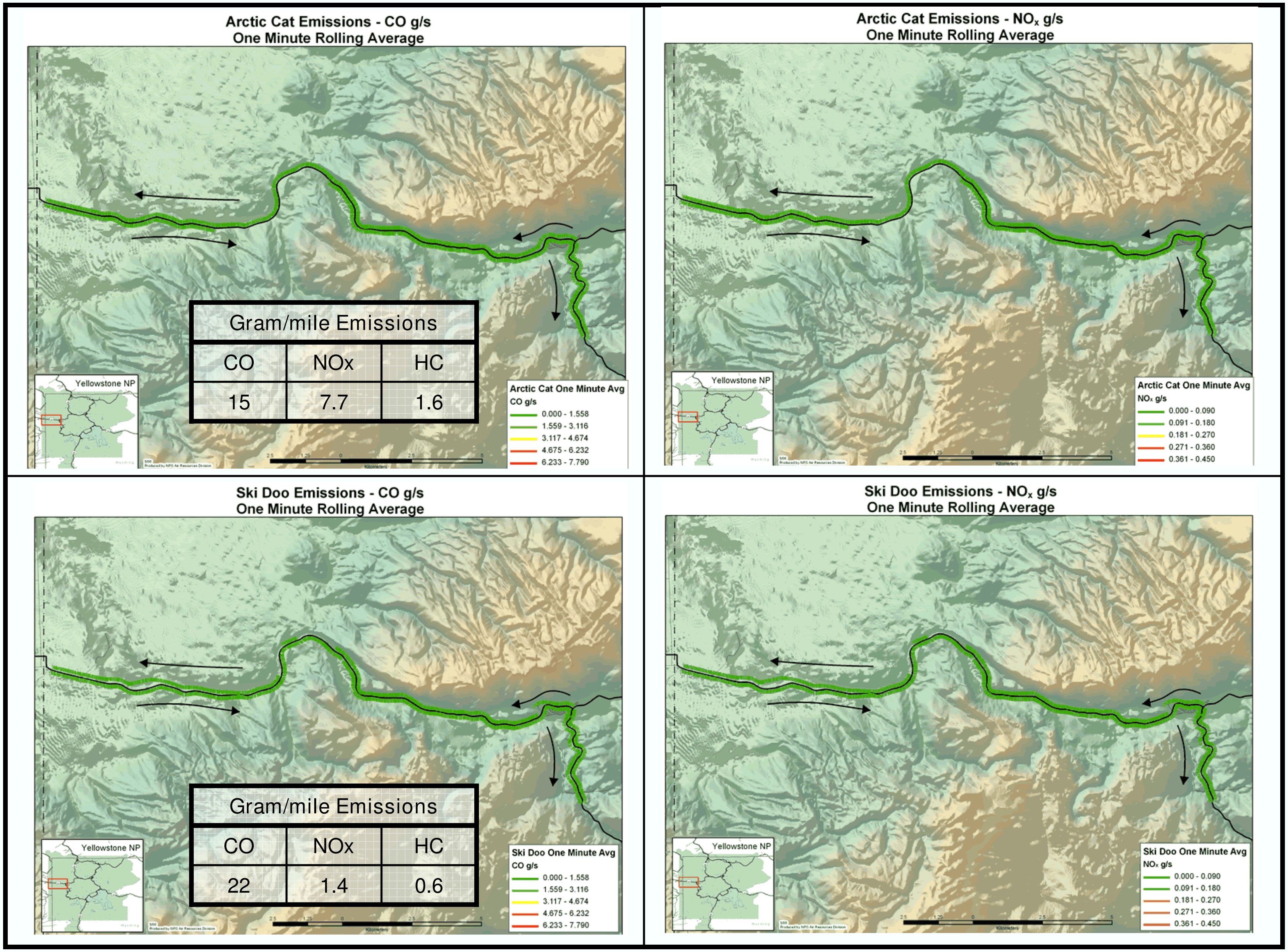
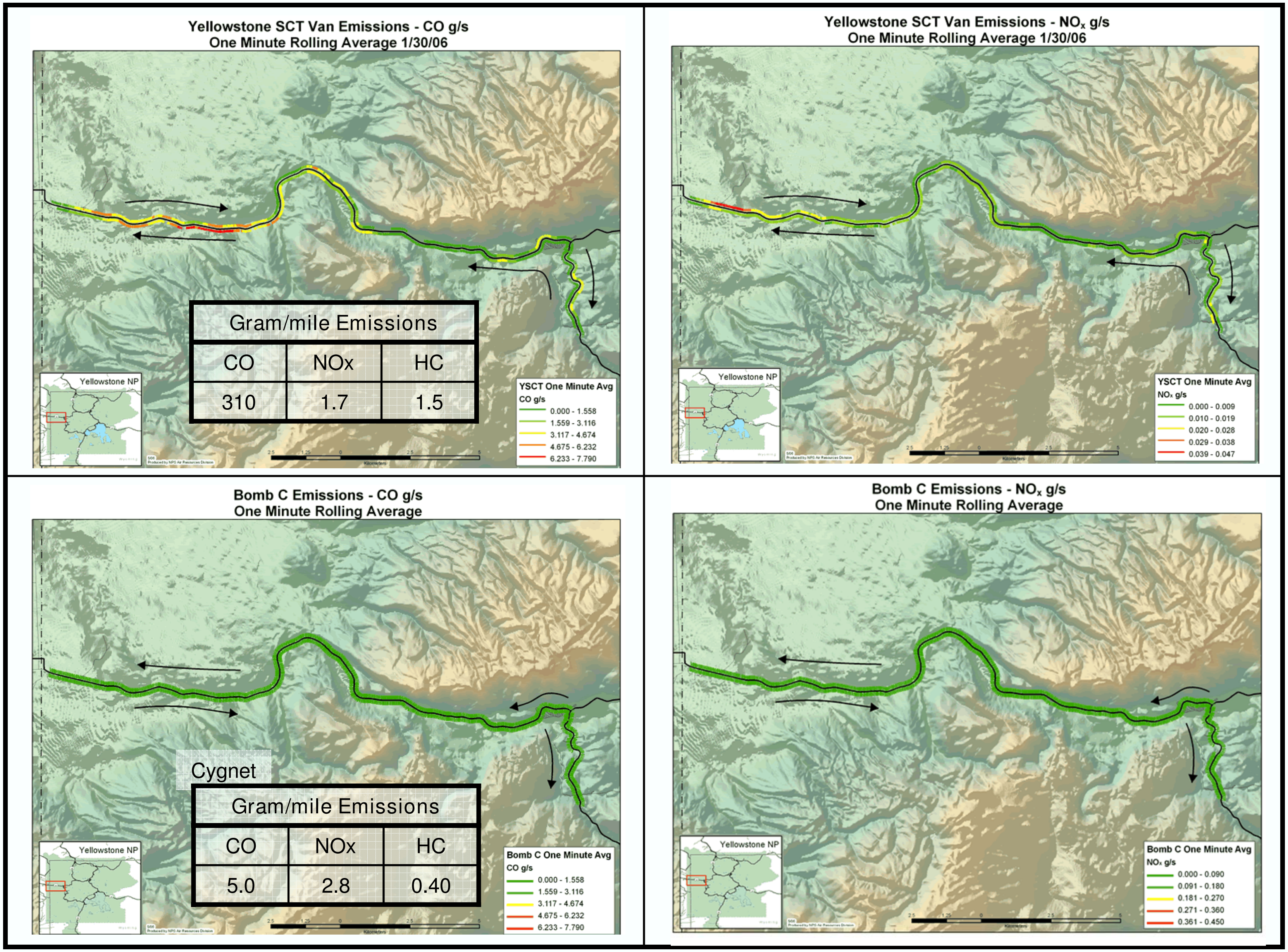


Figure E-1 Comparison of Arctic Cat and Ski Doo snowmobile emissions over the test course at Yellowstone.

Yellowstone NP 2006 - Emissions from Two Snowcoaches



Gram/mile Emissions

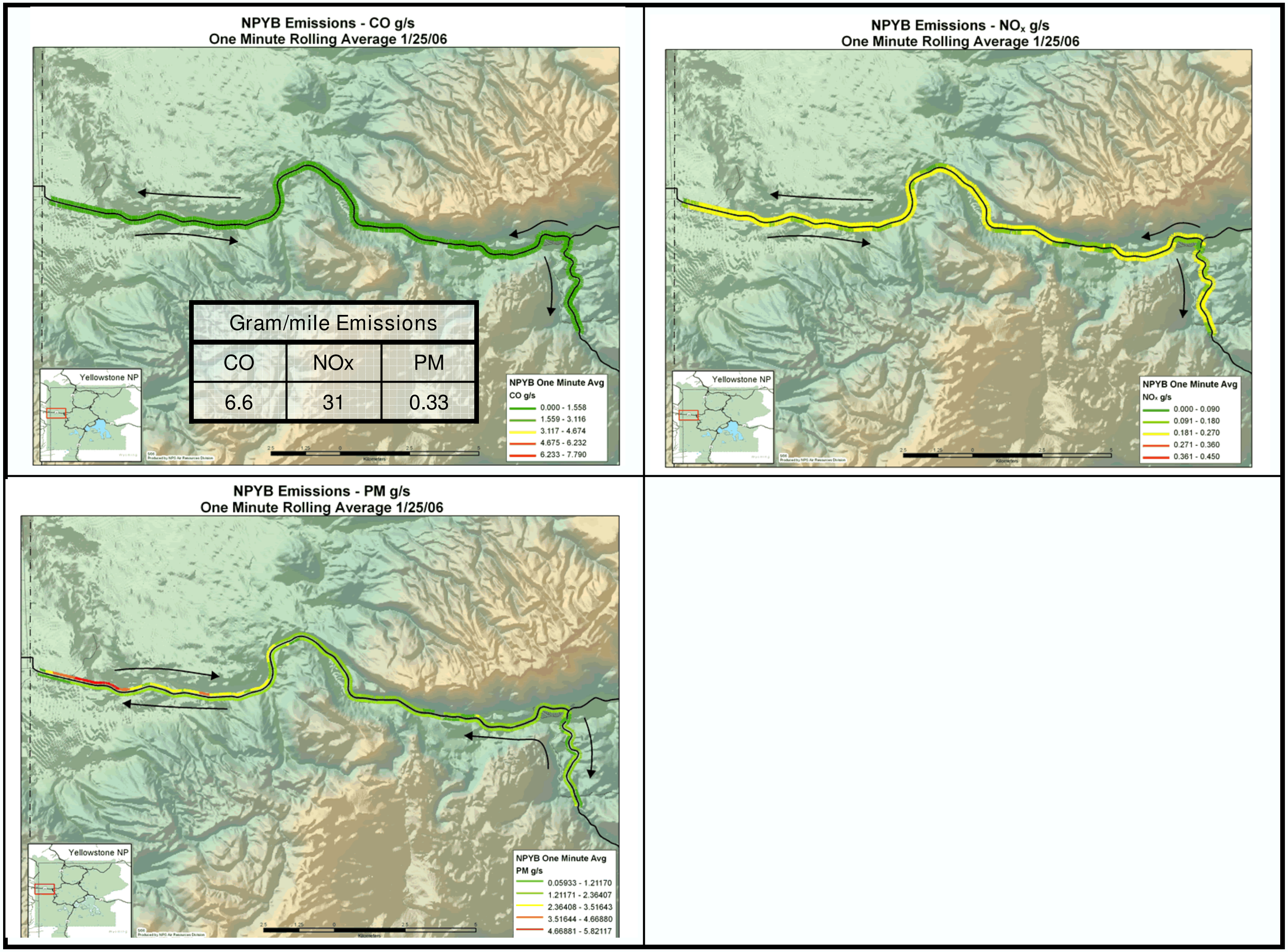
CO	NOx	HC
310	1.7	1.5

Gram/mile Emissions

CO	NOx	HC
5.0	2.8	0.40

Figure E-2 Comparison of high- and low-emission snowcoaches over the test course at Yellowstone.

Yellowstone NP 2006 - Emissions from NPS Yellow Bus



Gram/mile Emissions		
CO	NOx	PM
6.6	31	0.33

Figure E-3 Emission map of the NPS diesel snowcoach over the test course at Yellowstone.