National Park Service
U.S. Department of the Interior

Air Resources Division

Results from Yellowstone National Park

Winter Air Quality Study
2004-2005

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Summary Results

Ambient monitoring during the winter activity season was conducted at Old Faithful and at the West Entrance for the air pollutants, carbon monoxide (CO) and fine particulate matter (PM2.5). Summertime measurements at the West Entrance and vehicle entrance counts were used to compare to the winter season. Results from the ambient monitoring and a closely related emissions study are presented:

- CO was lower during the winter 2004-2005 season than in previous years at both monitoring stations and is well below the level of the national standard.
- PM2.5 was also lower this season than in previous years at the West Entrance. Both locations are below the level of the standard.
- The historical decreasing trend in the number of snowmobiles is mimicked by decreasing CO concentrations and is the primary reason for the lower ambient CO concentrations.
- Sources of PM2.5 other than snowmobiles are contributing to the observed PM at Old Faithful.
- Summer traffic with wheeled-vehicles contribute a much smaller amount of CO and PM than winter activity by snowmobiles and snow coaches, despite much greater numbers of vehicles in summer.

Recommendations

- Most of the gain in air quality can be attributed to the smaller number of snowmobiles. Peak air pollutant concentrations are down about 70% and mean concentrations are now similar to those from summer-time activities. Since the current numbers are below the allowed number of snowmobiles in the current Winter Use Plan, CO concentrations will go up if traffic increases. To maintain the currently allowed number of snowmobiles without degrading air quality further, further reductions in emissions will be needed.

- Odor and noise have been noticeably reduced by the 4-stroke engine snowmobiles, based on researcher observations. Likewise, visible smoke and PM2.5 have been greatly reduced. Emission measurements confirm these observations. The Park should continue with plans for cleaner snow vehicles and limits on the number of snowmobiles.

- The entrance station continues to be a hold-up in traffic that concentrates snowmobiles in a small area when they are operating at their least efficiency, at idle and during startup. Since almost all the snowmobile traffic is guided groups, additional efforts should be made to move the groups through without stopping at the gates.

- The greatest amount of PM2.5 at Old Faithful is now from Snow Lodge and from the uncontrolled wood stoves in the warming huts. These fires blanket the Old Faithful area in visible smoke and can easily be smelled at the geyser viewing area and beyond. The warming huts should be heated by either clean-burning stoves or other devices, such as infrared heaters.

- Madison Junction has a concentrated amount of snow vehicle activity since most vehicles from the West Entrance and Mammoth area stop there to use the facilities. This area may be a hotspot for CO and PM concentrations. Activity there should be monitored to avoid unnecessary buildup of pollutants.

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Introduction

A snowmobile warming up on a cold morning in Yellowstone National Park before a trip to Old Faithful.

The effects of winter vehicle exhaust, primarily snowmobiles, on air quality became an issue in the later 1990's at Yellowstone National Park. For the last three years, ambient air quality monitoring has been conducted at two locations in the Park as part of the adaptive management plan to determine the impact of implementing the Yellowstone Winter Use Plan on park air quality. Several changes were expected to reduce the emissions from the snowmobiles, primarily the reduction in allowed daily entries and the clean engine technology that was required. Pre-sales of entry passes and guided groups for rental snowmobiles were also required. These actions appear to have greatly decreased measured concentrations of CO and PM at congested vehicle traffic points last winter season[1].

This report summarizes the monitoring data from winter 2004-2005 and gives a historical perspective of monitoring data. The primary interest is trends in air quality that might reflect winter use policy and comparison to the national standards set by the Environmental Protection Agency (EPA).

Monitoring Design

Digital camera view of the parking lots at Old Faithful from the monitoring shelter. In earlier years the lot in the view would fill. About 150 snowmobiles can fit in the lot partially hidden by the trees in the right foreground.

Two ambient monitoring locations were used, one at Old Faithful and another at the West Entrance. The Old Faithful monitoring shelter was located to the east of the main parking lot for the Visitor Center and south of the Old Faithful geyser. Instrumentation at the site included a Beta Attenuation Monitor (BAM) for collection of PM2.5, a Carbon Monoxide (CO) analyzer, wind speed/wind direction sensors, ambient temperature, and a relative humidity sensor. A digital camera was installed on the weather tower that overlooked a portion of the main vehicle parking lot at the visitor center. Images and current data are available from a web site (http://www2.nature.nps.gov/air/WebCams/parks/yellcam/yellcam.htm). The NPS field support contractor, Air Resource Specialists, operated the station, processed and validated the data, and provided a data transmittal report. For full details on the monitoring, maps of locations, winds roses, data plots, and data tables, please consult the contractor data report[2].

The Old Faithful shelter was located within 50 feet of one of the warming huts in the Old Faithful visitor area. The warming huts were warmed by wood-burning stoves from about 7:00 am until late afternoon. The digital camera image above was taken from the Old Faithful monitoring site showing two snowmobiles entering the smaller close-in parking lot. In previous years this view would have captured a large number of snowmobiles parked in the main lot, however, usage was down and few vehicles parked there.

The State of Montana collected carbon monoxide, $PM_{2.5}$, and meteorological data at the West Entrance of the park in a cooperative effort. Their shelter is located near the out-bound lane on the northeast side of the entrance canopy. Data was retrieved from EPA AQS database and directly from the State of Montana, Department of Environmental Quality (http://www.deq.state.mt.us/AirMonitoring/index.asp). All data collection, validation, and quality assurance steps were performed by the State of Montana, DEQ.

Results and Discussion

A busy day at Old Faithful as snowmobiles and snow coaches crowd into the parking lot at the visitor center. 2-12-2005 JDR

Concentrations and statistical summaries

Monitoring began on December 1, 2004 so that background concentrations could be obtained. In addition, the monitoring was continued past the winter season so that a full year of data can be obtained for comparison. For just the winter period, tables 1 & 2 below summarize particulates as PM 2.5 and carbon monoxide (CO) concentrations for time periods relevant to the national standards. None of the observed pollutants exceeded the levels of the national standards during the reporting period. The West Entrance has larger CO concentrations than either the Grand Teton, Flagg Ranch location (monitored in winter 2002-2003) or Old Faithful areas. In contrast, the Old Faithful area has greater PM2.5 values; sometimes much greater values. Wood fireplace smoke or another unknown emission source appears to be present at Old Faithful since the highest PM concentrations occur outside the daytime snowmobile activity period (See appendix A for additional discussion).

Both air pollutants, CO and PM2.5, have decreased considerably in the last two years at locations in Yellowstone NP where snowmobile traffic is heavy (table 3 and figure 1). The maximum 1-hour CO has decreased from 8.6 ppm to 2.8 ppm at the West Entrance and from 2.9 ppm to 1.4 ppm at Old Faithful. The snowmobile traffic pattern is such that relatively high pollutant levels are seen in the morning and afternoon "rush hours" at the entrances[2]. However, when these values are averaged over 8 hours with the lower night-time or mid-day values, the concentrations are above the background (0.1 – 0.2 ppm), but much less than the exceedance level for the national standard (http://www.epa.gov/air/criteria.html). The 8-hour maximum CO decreased from 3.3 ppm to 1.0 ppm (11% of standard) at the West Entrance and from 1.2 ppm to 0.6 ppm (7% of standard) at Old Faithful. At Old Faithful there is an enhancement in the CO concentrations during the 10 am to 3 pm period when snowmobiles are present in the parking lot, however, these concentrations are also well below the standards and have decreased in the last two years.

Air Quality Summary Tables

Table 1. Comparison by site of carbon monoxide concentrations over the last three years.

Park →		Yellowstone						Grand Teton	
Location →		Old Faithful			West Entrance			Flagg Ranch	
Statistic	Winter season → parameter ↓	**2004 -2005**	2003 - 2004	2002 - 2003	**2004 -2005**	2003 - 2004	2002 - 2003	**2002 - 2003**	Units
Max 1-hr	**CO**	**1.4**	**2.2**	**2.9**	**2.8**	**6.4**	**8.6**	**4.7**	ppm
% of Std	**CO**	**4%**	6%	8%	**8%**	18%	25%	13%	
Max 8-hr	**CO**	**0.6**	**0.9**	**1.2**	**1.0**	**1.3**	**3.3**	**1.7**	ppm
% of Std	**CO**	**7%**	10%	13%	**11%**	14%	37%	19%	
Average	**CO**	**0.12**	0.26	0.24	**0.24**	0.26	0.57	0.25	ppm
90th percentile	**CO**	**0.29**	0.5	0.5	**0.43**	0.5	1.3	0.6	ppm

Standard	Pollutant	1-hr CO (ppm)[1]		8-hr CO (ppm)[1]	
National AAQS	CO	---	**35**	**---**	**9**
Montana AAQS	CO	---	**23**	**---**	**9**

1 Not to be exceeded more than once per year.
Link to EPA NAAQS standards: http://www.epa.gov/air/criteria.html

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Table 2. Comparison by site of particulate matter concentrations over the last three years.

Park →		Yellowstone						Grand Teton			
Location →		Old Faithful			West Entrance			Flagg Ranch			
Statistic	Winter season → parameter ↓	**2004 -2005**	2003 - 2004	2002 - 2003	**2004 -2005**	2003 - 2004	2002 - 2003	2004 -2005	2003 - 2004	**2002 - 2003**	Units
Max 1-hr	**PM2.5**	**38**	151	200	**21**	29	81	NA	NA	8	ug/m3
Max Daily (24-hr)	**PM2.5**	**7**	17	32.1	**6.0**	8.0	18.6	NA	NA	8	ug/m3
98th percentile	**PM2.5**	**9**	**9**	**21.3**	**6.0**	**7.0**	**16.9**	**NA**	**NA**	**9**	ug/m3
% of Std	**PM2.5**	**14%**	14%	33%	**9 %**	11%	26%	NA	NA	14%	
Avg	**PM2.5**	**4**	4.9	6.9	**2.9**	4.0	8.2	NA	NA	5	ug/m3

Standard	Pollutant	24-hr $PM_{2.5}$ 98%tile (ug/m^3)[1]
National AAQS	PM 2.5	**65**
Montana AAQS	PM 2.5	**65**

NA = Not Available, no monitoring during the period

1 The 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 65 ug/m^3.

2 The winter 98th percentile is given only to demonstrate the improvement between winter seasons. Comparison with the annual standard is not shown. For consistency, the 24-hour day is used to average the hourly PM2.5 data.

3 Link to EPA NAAQS standards: http://www.epa.gov/air/criteria.html

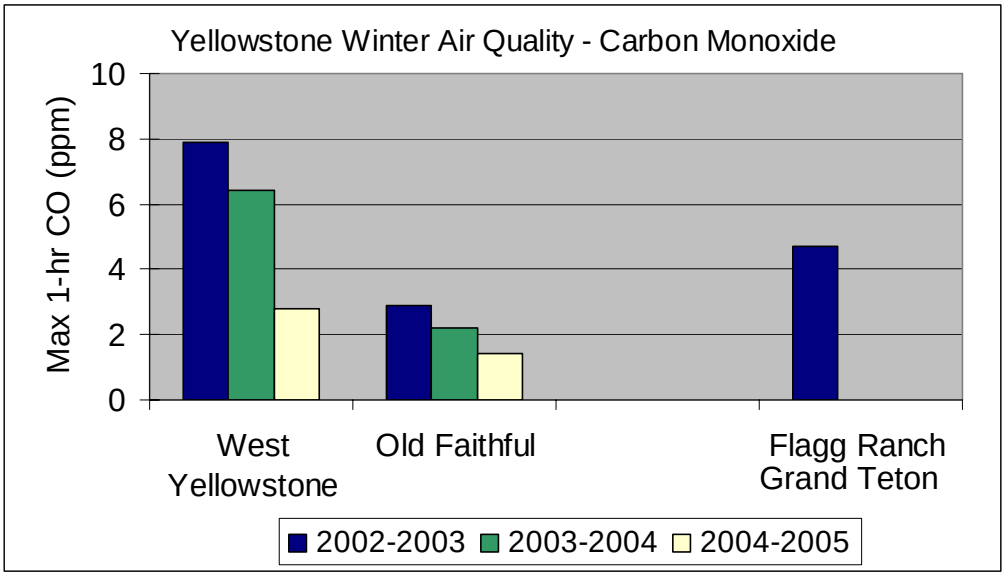


Figure 1. Comparison of the maximum 1-hour carbon monoxide concentrations at monitoring sites over the last three winters. Concentrations have decreased in each of the years.

PM2.5 concentrations have also decreased at both locations (tables 2 & 4). At the West Entrance the PM2.5 concentration 98th percentile for the winter season decreased from 16.9 ug/m3 in 2002-2003 to 6.0 ug/m3 (9% of standard) in 2004-2005. This was a decrease of 65%. Old Faithful had PM2.5 decrease by 58% from 21.3 ug/m3 to 9.0 ug/m3. The smaller decrease at Old Faithful may be due to local point sources that have not changed (see Appendix A). The switch to 4-stroke engines for the snowmobiles resulted in a 96% reduction in hydrocarbon emissions[5] that contribute to particulate matter in the air. Local point source emissions or snowmobile activity in nearby West Yellowstone account for some of the measured PM2.5 at the entrance gate. This is seen in evening and overnight spikes in PM concentrations when no snowmobiles are present at the gate. Thus, both monitoring locations have a PM source component from snowmobiles that has decreased with the lower number of snowmobiles and lower emission factors. PM2.5 at both locations is well under the national ambient air quality standard.

CO Concentrations at the West Entrance

Since 1998 when continuous CO monitoring started at the Yellowstone West Entrance[3], CO has declined from values near the 8-hour NAAQS standard to peak concentrations of about 1 ppm CO (figures 2 & 3). The mean 8-hour CO concentrations continued to climb through the 2000-2001 season, and then began to decline. If only the daytime hours (8 am to 6 pm), when snowmobile traffic is present, are examined then the mean 8-hour CO concentrations are higher, but still peak in 2000-2001. Starting in 1999-2000, efforts were made to limit the number of snowmobiles queuing up at the entrance station. In 2002-2003 4-stroke snowmobiles became available as rentals and between one-third and one-half of snowmobile entrance traffic was 4-stroke sleds. In 2003-2004, 4-stroke snowmobiles and guided tours were initiated[4] with the result that approximate 80% of snowmobiles were 4-stroke. During the winter of 2004-2005, greater than 90% of snowmobiles were 4-stroke. These measures appear to have been effective in reducing the high CO concentrations near the entrance station.

Table 3. Trends summary for CO by monitoring location.

Location	Winter Period Years	1-hr CO (ppm)[1]		8-hr CO (ppm)[2]	
		1st Max	2nd Max	1st Max	2nd Max
West Entrance	1998-1999	18.2	11.1	8.9	4.3
	1999-2000	13.5	11.3	5.4	4.7
	2000-2001	17.9	17.4	6.1	6.0
	2001-2002	16.0	12.5	5.4	4.9
	2002-2003	8.6	8.4	3.3	2.1
	2003-2004	6.4	3.1	1.3	0.8
	2004-2005	2.8	2.6	1.0	0.9
Old Faithful	2002-2003	2.9	2.0	1.2	1.0
	2003-2004	2.2	1.7	0.9	0.9
	2004-2005	1.4	1.4	0.6	0.5
Flagg Ranch [#]	2002-2003	4.7	3.1	1.7	1.1

[#] Flagg Ranch monitor in Grand Teton NP near the Yellowstone south entrance only operated one winter.

Table 4. Trends summary for PM2.5 from three winters of continuous analyzer measurements.

Location	Winter Period Years	24-hr $PM_{2.5}$ (ug/m^3)[3]	
		1st Max	98th% Conc.
West Entrance	2002-2003	18.6	16.9
	2003-2004	8.0	7.0
	2004-2005	6.0	6.0
Old Faithful	2002-2003	32.1	21.3
	2003-2004	16.5	14.5
	2004-2005	4.0	5.4
Flagg Ranch [#]	2002-2003	16.4	10.7

[#] Flagg Ranch monitor in Grand Teton NP only operated one winter.

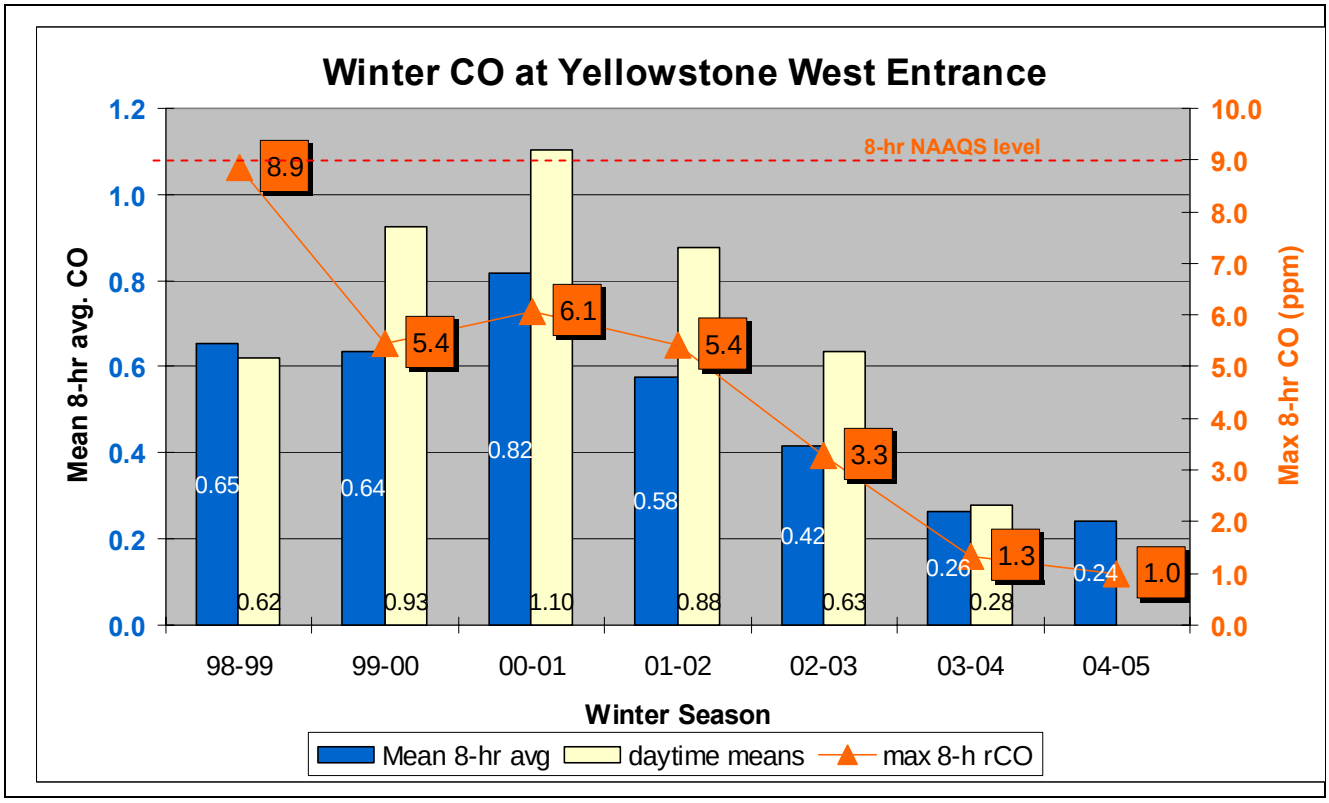


Figure 2. Summary of CO concentrations over 7 winters. The daytime mean CO is greater than that for the 8-hr mean for the whole day. The maximum daily 8-hr mean for each season (in orange, separate scale) is much higher. Each statistical summary shows decreasing concentrations.

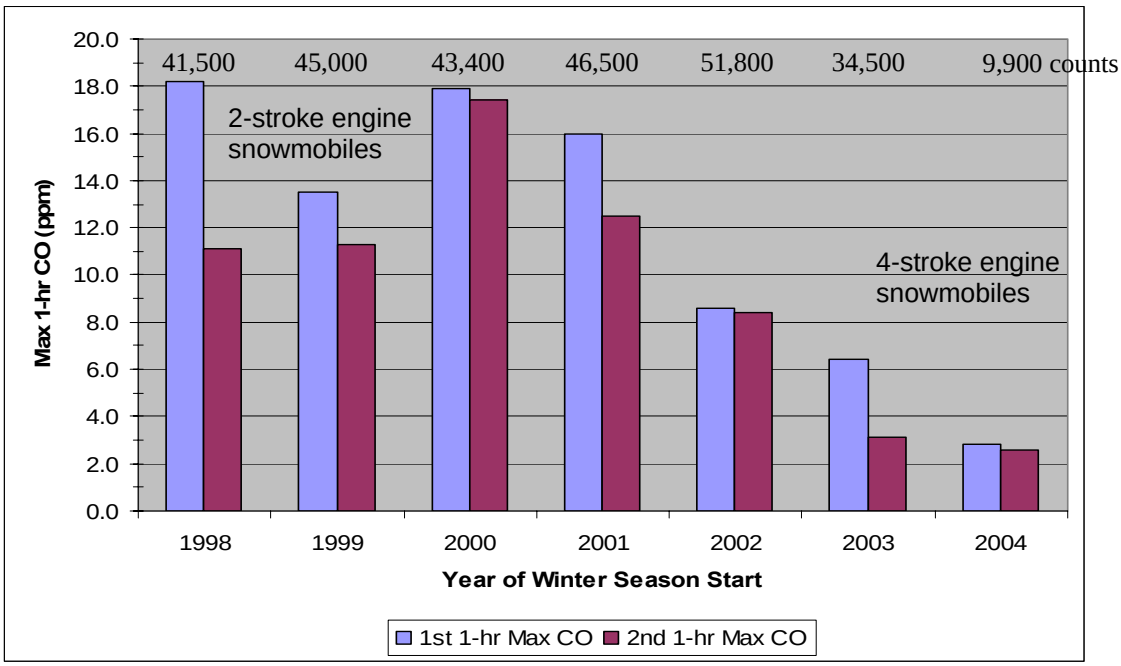


Figure 3. The 1-hour maximum CO concentrations at the West Entrance are much higher than the 8-hour values because the peak values occur over just a few hours during daytime. The overnight concentrations go down to about 0.2 ppm and reduce the averages. Numbers at the top are the number of snowmobiles and snow coaches that entered the West Entrance for each season.

Relationship between snowmobile traffic and CO

Both snowmobiles and snow coaches, that are used for winter transport in Yellowstone, emit carbon monoxide and nitrogen oxides (NOx). The 2-stroke engine snowmobiles that have traditionally been used are very inefficient and emit unburned oil and gas plus much higher concentrations of CO than the typical wheeled vehicles used by summer visitors[4,5].

The observed ambient CO concentrations have followed the number of winter vehicles entering the park (figure 4). On a daily basis, the wind speed, wind direction, and boundary layer stability determine how high the concentrations build up. A rough relationship between the number of daily snowmobiles at the West Entrance and the maximum CO concentrations accounts for 87% of the variability. This suggests that an increase in the average daily snowmobile traffic up to the allowed limit under the Winter Use Plan would result in greater carbon monoxide concentrations. The 2002-2003 winter season had approximately the 400 snowmobiles per day average when there was a mix of 2-stroke and 4-stroke engine snowmobiles. Based on that, the predicted CO concentration would likely be in the 6 to 8 ppm* range for the maximum winter season 1-hr concentration.

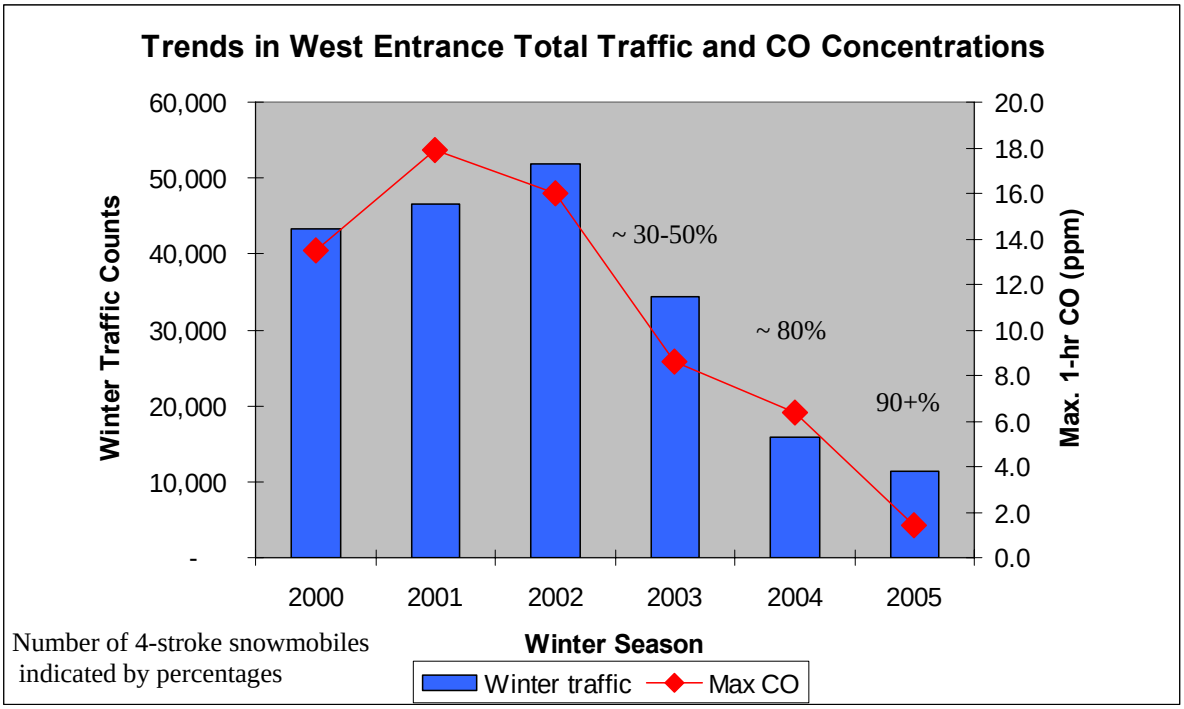


Figure 4. The number of snowmobiles entering the park at the West Entrance each season is compared to the observed peak CO concentrations in this chart. Fewer snowmobiles and cleaner engines have brought the CO concentrations down. The change is approximately 0.4 ppm/1000 sleds. 90% of the variability can be accounted for by the number of snowmobiles.

* Rough estimate assuming average snowmobiles emissions[5] are about half of those in 2001 and the CO concentrations change with number of sleds estimated from figure 4. There is also a small background offset and a fixed contribution from coaches.

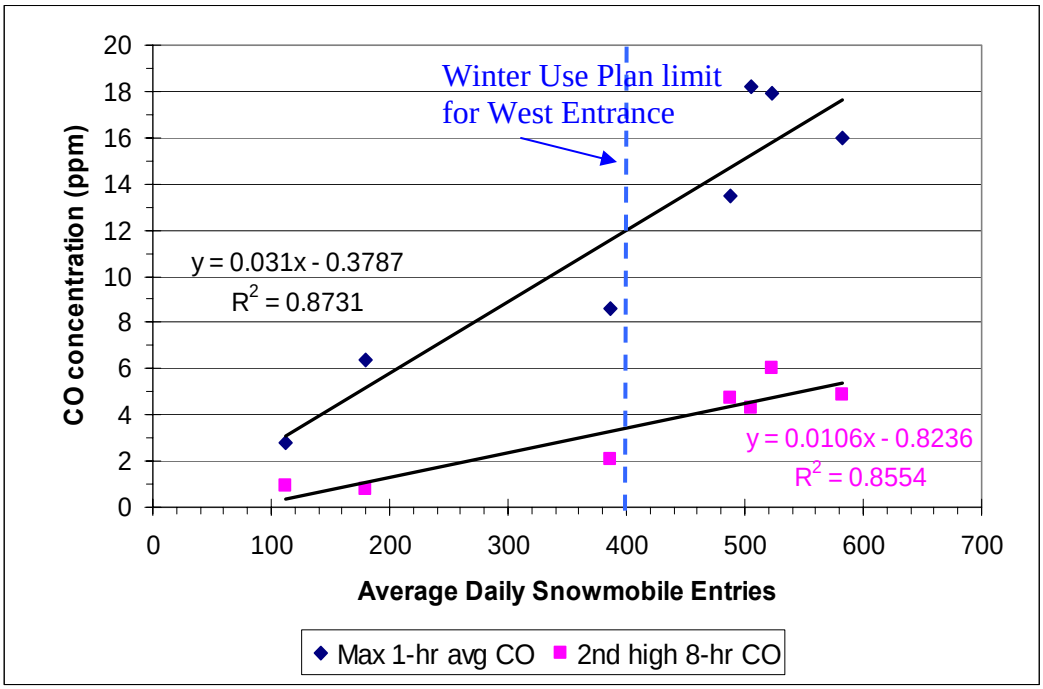


Figure 5. Relationship between daily average snowmobile counts and the maximum CO concentrations observed for the season. The amount of snowmobile traffic accounts for 87% of the variability. Weather, engine type, and number of snow coaches account for the rest of the variability.

Winter vehicle entry counts and air quality

The Yellowstone bison can't read, but like the Park interpretive signs anyway. The roadway is a corridor for bison travel in winter.

The patterns of winter vehicle entry into the Park affect the air quality. In 2004-2005 the early season snow was thin so the West Entrance didn't open from snowmobile traffic until January 1, 2005. As a result, the number of snowmobiles entering the park was also down for the season. Improving snow conditions in February led to larger numbers of visitors (figure 6).

At the West Entrance there is a rush of traffic in the morning (figure 7a) centered on 9 am. In past years that has led to lines of snowmobiles waiting to enter. This season the guided groups approached the entry gate, the guide presented the paperwork, and the whole group proceeded to enter and leave the gate area. A second busy period is during the departure from about 3 – 5 pm. Records are not kept for the number of vehicles leaving the park. The CO and PM concentrations follow the activity pattern and peak in the morning at 9 am and in the afternoon at 4-5 pm[2]. In previous years, the bi-modal pattern was much more pronounced, since the average concentrations were roughly 4 times higher.

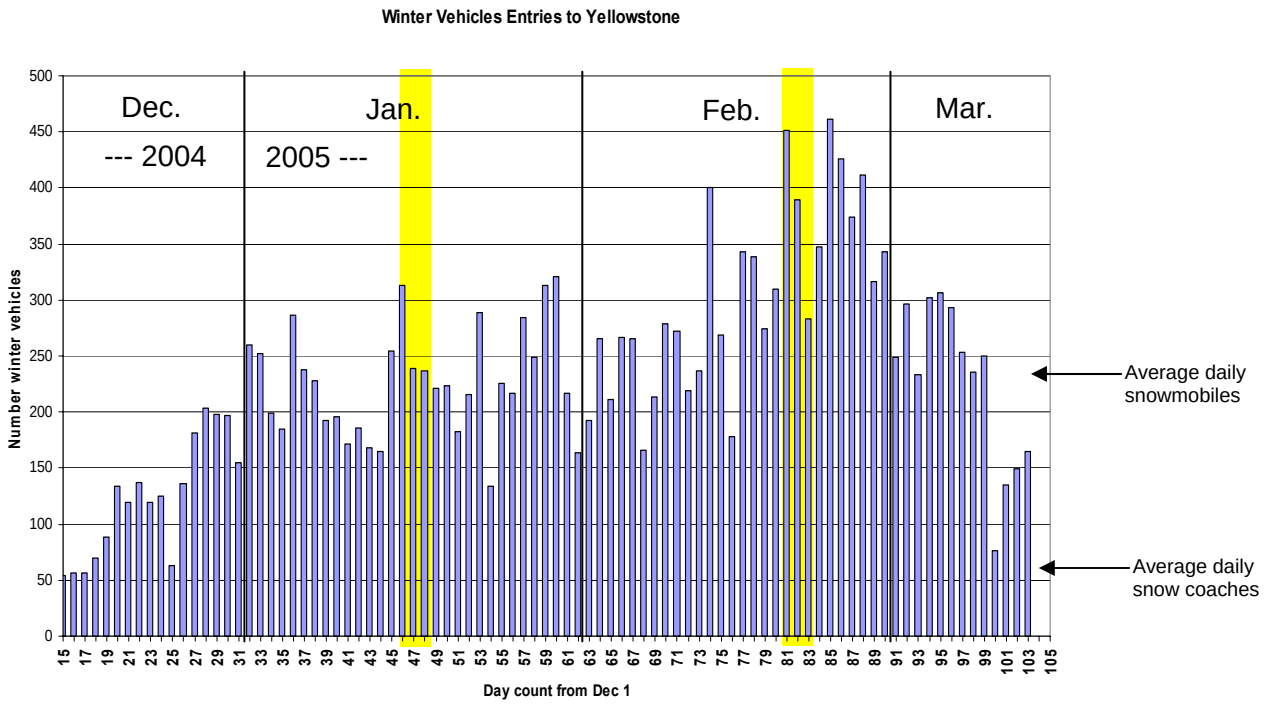


Figure 6. The number of snowmobiles and snow coaches entering the Park is recorded daily. The busy Martin L. King and President's Day 3-day weekends are highlighted in yellow. The maximum daily number of snowmobiles is below the limits of 720 per day in the Winter Use Plan

The peak period for snow coach entry at the West Entrance is between 8-9 am; however, activity is spread out through a longer period of the day than for the snowmobiles. The winter traffic is spread out throughout the week (figure 7b), although Saturday and Wednesday tend to be slightly busier. During 3-day holiday weekends, when Monday is the holiday, it tends to be Saturday and Sunday that are the busy days (figure 6). The day with the maximum activity for the season was a Wednesday after President's Day weekend

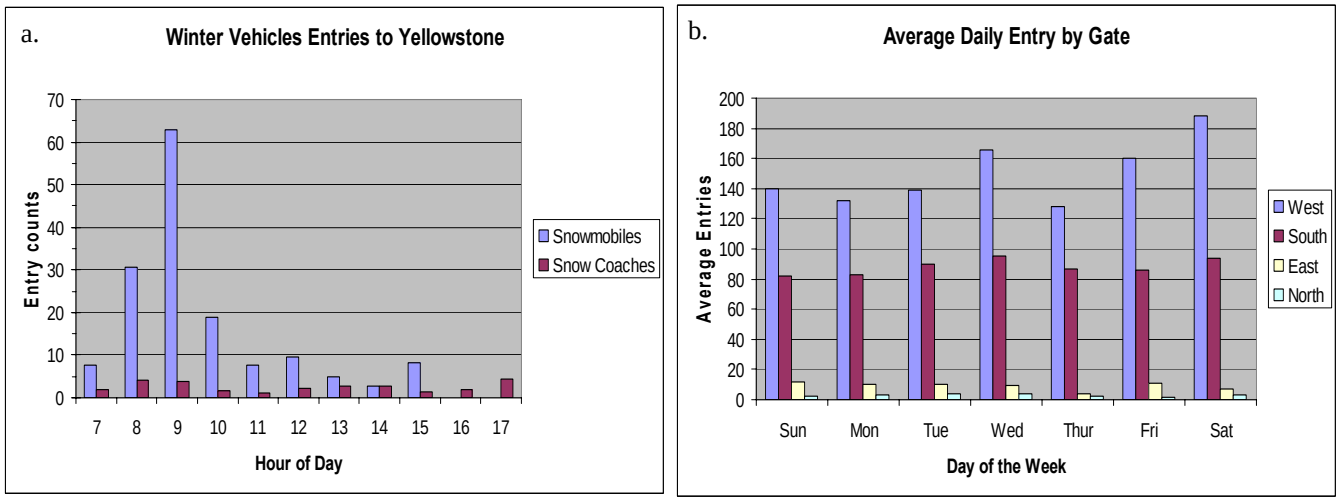
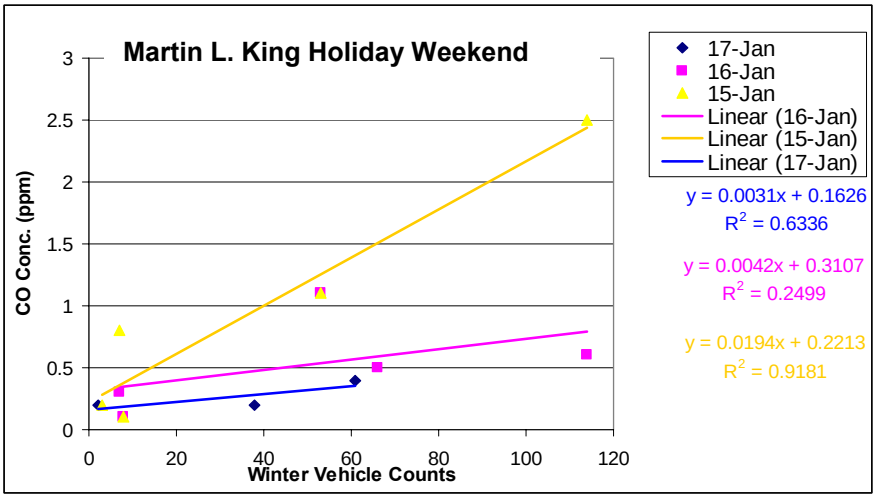


Figure 7. a). Winter vehicle entry counts by hour at the West Entrance. b). Average daily entry counts by day of the week over the winter season 04-05 for all gates. Saturday and Wednesday tend to be the busiest days.

Based on emission factors and the estimate that 4-stroke snowmobiles are 90% of the sleds in 2004-2005, the annual contribution of the 2-stroke snowmobiles was 11%, the 4-strokes snowmobiles 44%, and the snow coaches 45% to the observed CO at the West Entrance❖. Thus, the snow coaches may account for half of the currently observed CO which would help explain why the ambient concentrations have just followed the decrease of snowmobile entry counts.

At Old Faithful the winter traffic is spread out over a longer time as vehicles arrive from different entry gates. In 2002-2003 that led to an easily observable hump in the CO concentrations mid-day[2]. During 2004-2005, there was only a slight increase in the CO during the mid-day period[2]. The PM pattern is much more complex at Old Faithful. Peak PM values tend to be in late afternoon and carry over into the evening. Mid-day PM tends to be low. Other sources than the snowmobiles and snow coaches are likely to be the reason for this (see appendix A for more).

a.



b.

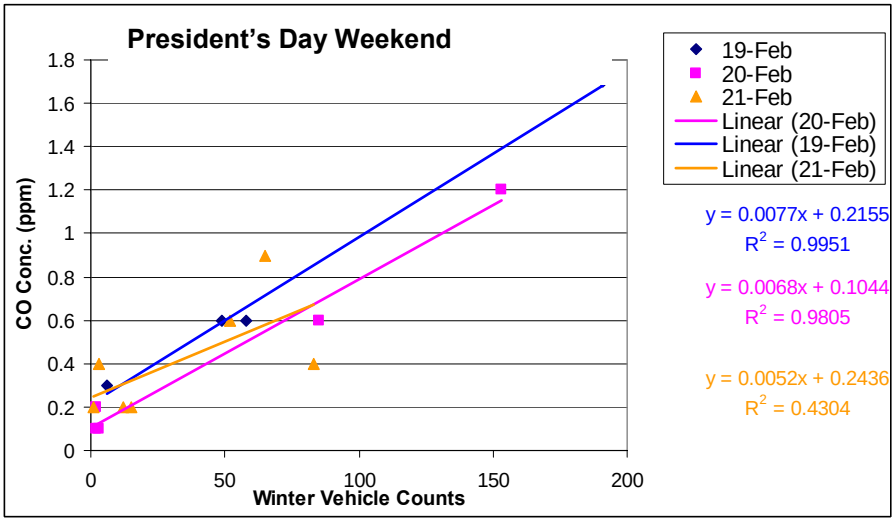


Figure 8a & b. The CO concentrations at the West Entrance correlate to the number of winter vehicles entering each hour over two different 3-day holiday weekends. The concentration of CO per snowmobile varies by day, however, as weather conditions change.

❖ Using the average g/mi emissions by vehicle type[5], the traffic counts[7], and percentages of each vehicle type. This weights the emissions heavily towards the cruise mode, whereas much of the emissions around the entrance station may be from idle mode. 4-stroke sleds put out 4.7 times more CO at idle than during cruise, but the average snow coach puts out 2.7 times less CO during idle mode. The net result for idle mode is a shift to more emissions from the snowmobiles and less from the snow coaches. A more detailed analysis should come from the computer modeling exercise that is planned.

Data for the West Entrance was examined over two 3-day holiday weekends when personal exposure monitoring was being conducted[8] by other researchers. In figures 6 & 8, the relationship between CO concentrations and hourly snowmobile counts at the West Entrance is examined. This represents what might happen on busy weekends when mostly 4-stroke engine snowmobiles are entering the park. Each day has its own combination of weather conditions, traffic patterns, and atmospheric stability so the relationship varies daily. Using an average slope for the two weekends, the predicted maximum hourly CO would be about 3.3 ppm. If the least favorable conditions (highest slope in figure 8a) are used, such as on January 15, then the maximum 1-hr would in excess of 7 ppm for 400 snowmobiles per day.

Comparison of winter and summer air quality

There is a considerable difference between the snowmobile traffic through the West Entrance in winter and the much larger amount of wheeled-vehicle traffic during the extended summer season (figure 9). CO concentrations from automobiles peaked in 2000 and have been decreasing since then, though at a much smaller rate than seen for the snowmobiles. This is attributed to the automobile fleet switchover to newer vehicle models with lower CO emissions[6]. The Yellowstone background CO concentration is between 100-200 ppb (0.1 – 0.2 ppm) which is close to the detection limits of the CO analyzers being used. Summertime mean CO concentrations are in the 150-300 ppb range which is slightly above the observed background and far from the CO NAAQS standard. Wintertime mean CO concentrations are approaching the summer values and are in the 200-300 ppb range. Maximum 8-hour CO concentrations are often a factor of 10, or more, above the mean values.

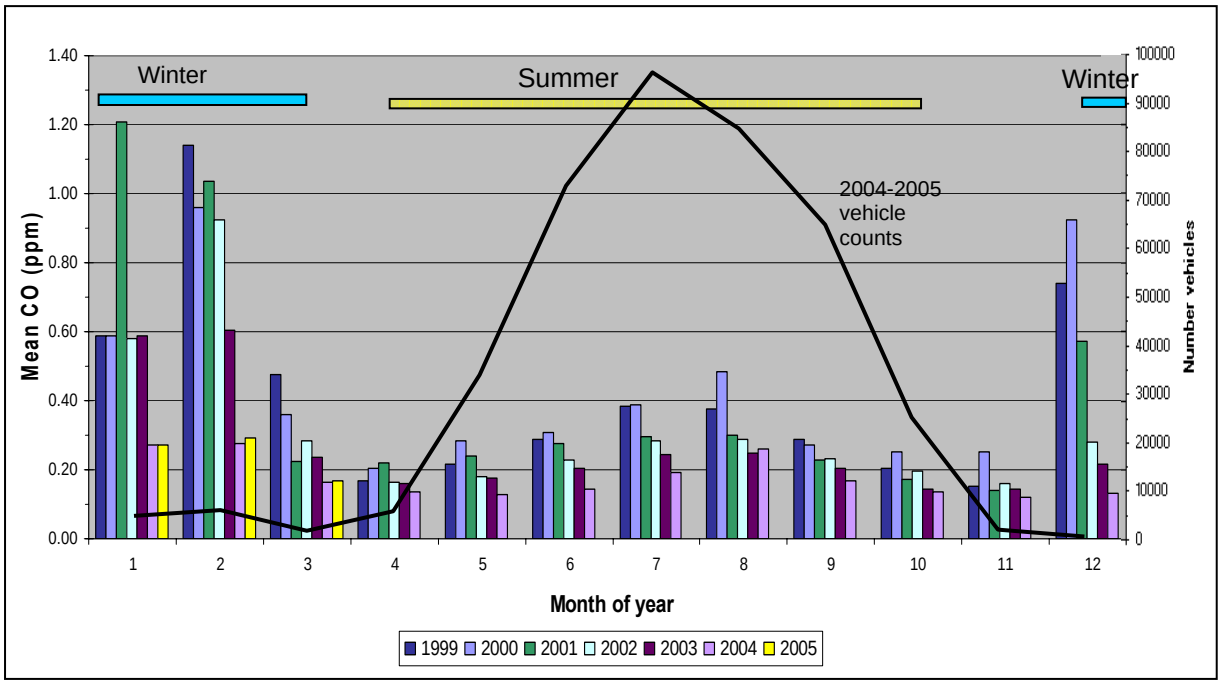


Figure 9. Monthly mean CO concentrations and traffic counts at the West entrance gate. The winter months had high CO until the last two years. The winter CO and the maximum summer time CO are now very similar. The line represents the number of vehicles per month[7] for 2004-2005 entering the park at the West Entrance.

During July and August there is a summer peak of CO that corresponds to peak visitation for wheeled vehicles (cars, trucks, campers). The lower CO concentrations observed in summer correspond to cleaner emission vehicles even though their numbers are much greater and to higher mixing-layer heights from summertime temperatures. There has been a decrease in summer CO concentrations over the last 5 years as the vehicle fleet in general has reduced emissions[6]. The winter CO mean concentration in February now is nearly equal to the mean CO in July, the busiest visitation month. If the summer

concentrations represent the acceptable limits of CO and PM2.5 air pollution concentrations, then the present snowmobile entry traffic is close to the acceptable numbers unless additional emission controls are required.

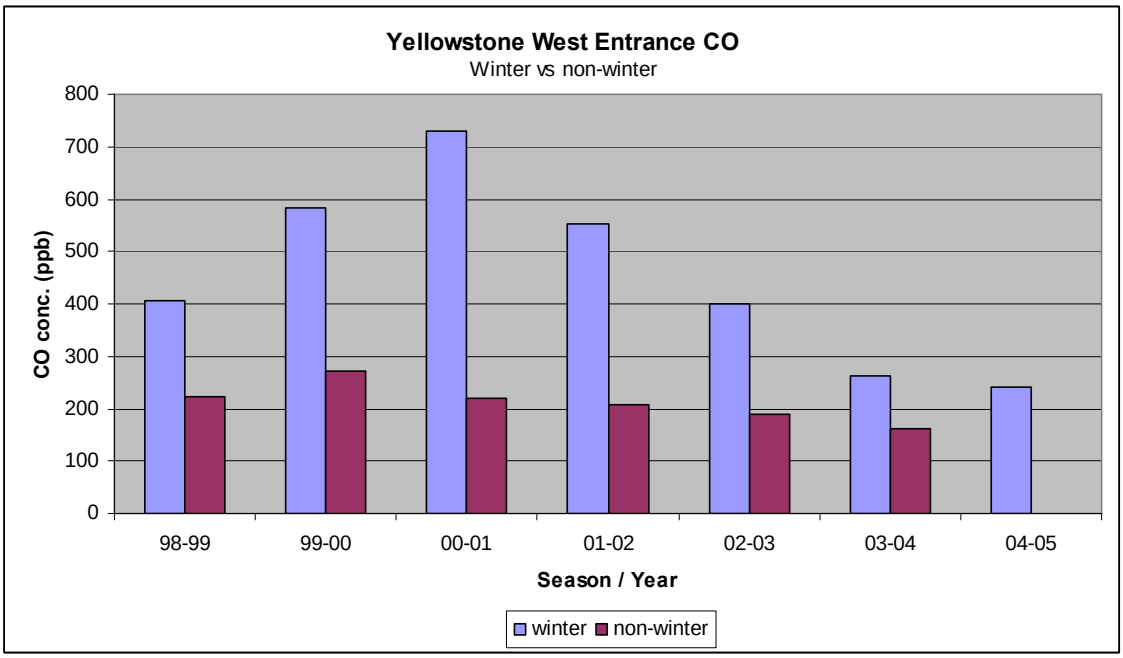


Figure 10. Comparison of the CO concentrations (in ppb) between the winter periods and the summer periods at the West Entrance. The amount of traffic and numbers of visitors is much greater during the summer.

The highest mean CO concentrations occur during the winter months when snow vehicles are in use (figure 10). The peak year for summer traffic was 2000 when the mean CO was about 260 ppb (0.26 ppm). Peak winter CO was the 2000-2001 season when CO was about 730 ppb (0.73 ppm). During the last two seasons the CO concentrations have been significantly reduced to around 200 ppb. The background CO concentration for Yellowstone is estimated at less than 100 ppb, which represents clean rural air. Thus, at the West Entrance of Yellowstone the CO concentrations are elevated to a small extent above the background for most of the year.

Emissions by winter vehicles

An old Bombardier snow coach heads out for Old Faithful with a full load of visitors.

In a closely related study[5], conducted by the University of Denver and the NPS Air Resources Division to measure the emissions from snow mobiles and snow coaches, the emissions of individual pollutants were determined under actual use conditions (table 5). The change to 4-stroke engines in snowmobiles had the largest impact on the hydrocarbon emissions (down 96%), however, CO also decreased (down 57%). Based on this decrease in CO emission, snowmobile entries at 400 per day might be expected to have a maximum concentration above 5 ppm.

The current fleet of snow coaches includes a variety of different types and ages of vehicles, some dating back to periods when almost no controls were required on engine emissions. The current fleet may be slightly more polluting for CO than the 4-stroke snowmobiles on a per passenger basis. Modern cleaner snow coaches have 98.9% lower CO emissions and 99.9% lower hydrocarbons than 2-stroke snowmobile engines per passenger. It is appropriate to consider both the emissions per vehicle and the vehicle emissions on a per passenger basis in deciding what is the preferred mode of winter travel in the Park. Since snow coach entry counts have been increasing and the fleet average emissions per coach are larger than the typical snowmobile, snow coach contributions to CO and PM should not be ignored. For the immediate future, moving towards newer, cleaner emission snow coaches can have a positive affect on air quality.

Table 5. Emissions in gm/mile/person from winter vehicles visiting Yellowstone National Park[5].

	Snowmobile	Snowmobile	Snowmobile	Snowcoach	Snowcoach
Pollutant	average 2-stroke	average 4-stroke	cleanest 4-stroke	average	cleanest
CO	65	28	25	42	0.7
HC	81	3.4	3.1	1.7	0.1
NO	- -	2.4	2.8	3.1	0.2

Conclusions

The ambient concentrations of PM2.5 and CO have been found to relate closely to the amount of winter traffic and the amount of emissions by type of vehicle. The reduction in the amount of snowmobile traffic has been a very large part of the observed reduction in air pollution. Cleaner engines are a significant part as well. This is readily apparent to an observer, because the visible blue-plume and odor from the 2-stroke snowmobiles is absent in the 4-stroke engine snowmobiles. The present program to control winter use appears to be working from an air quality standpoint.

Both locations being monitored for ambient air quality have greatly improved in the last two years. Some of this gain in air quality will be lost if larger numbers of snowmobiles return to the Park. The increase in snow coach traffic should also be watched carefully and requirements for low-emission vehicles continued.

The monitoring at Old Faithful is being continued through the summer to determine the air quality conditions when the area is very busy with traffic and visitors. Because the area is heavily traveled during the summer, there is the potential for higher CO concentrations than at the West Entrance. The data from the West Entrance from summer monitoring indicate that wheeled vehicles are much less polluting.

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3. Yellowstone National Park Winter Use Plan,
http://www.nps.gov/yell/planvisit/winteruse/index.htm

4. **Air Quality Concerns Related to Snowmobile Usage in National Parks**, NPS-Air Resources Division, Feb. 2000. Available from: http://www2.nature.nps.gov/air/Pubs/pdf/snowmobile_report.pdf

5. **In-use Emission Measurements of Snow Coaches and Snowmobiles in Yellowstone National Park**, Gary Bishop et al, July, 2005. (final report being reviewed)

6. Pokharel, S., G. A. Bishop, D. H, Stedman, and R. Slott, **Emissions Reductions as a Result of Automobile Improvement**, *Envion. Sci. Technol*., **37**, 5097-5101 (2003).
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8. **Yellowstone Winter Use Personal Exposure Monitoring, Final Report**, Terry M. Spear and Dale J. Stephenson, June 1, 2005. (report being reviewed)

Appendices

Appendix A. Detailed analysis of air quality at Old Faithful.

Appendix B. Winter images from air quality monitoring at Yellowstone

This report is available on the NPS Air Resources Division web site at:
http://www2.nature.nps.gov/air/Pubs/index.cfm

Results from Yellowstone National Park

Winter Air Quality Study
2004-2005

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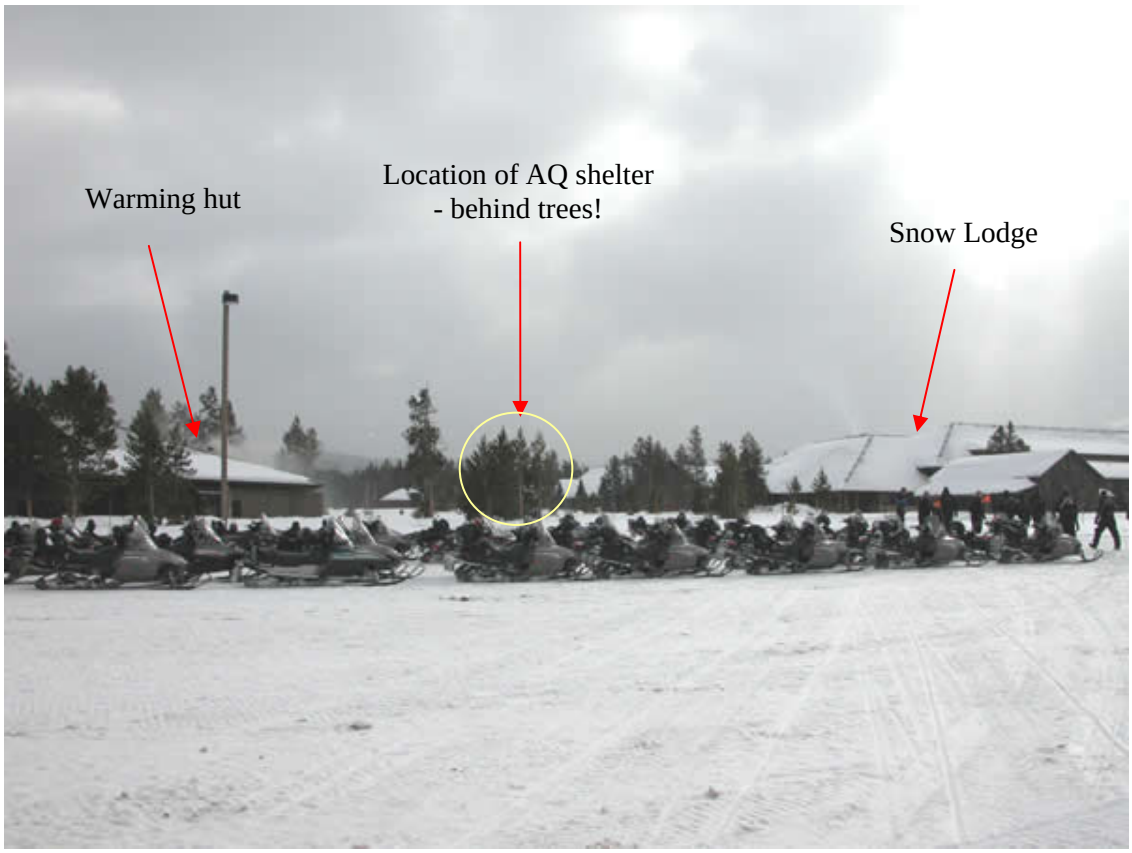
Appendix A

Detailed Analysis of Air Quality at Old Faithful

The air pollutant concentrations are generally lower at Old Faithful than at the West Entrance. Is this because of a lower density in snowmobiles? Also, why are high concentrations of PM seen at Old Faithful when the CO is not higher? To some extent these are questions about what is the source of the air pollutants. It was noticed during a visit to the monitoring station on a busy winter weekend that the 1-minute average and hourly average concentrations of CO and PM2.5 did not correlate well. Figure A1 gives an example of this over a three day period.



Snowmobile parking area at Old Faithful in the close-in lot. The view is looking east towards the air monitoring shelter and the warming hut. 10:50 am 2-8-05 Old Faithful geyser and the visitor center are to the left of the picture (north).

The monitoring support contractor reported[2] that CO and PM2.5 did not correlate over the whole season at Old Faithful and the correlation at the West Entrance was slightly better, but still extremely poor. This lack of correlation was also noted in winter 2002-2003 when there were still lots of 2-stroke snowmobiles that had visible exhaust and odor. Measurements of the 4-stroke engine snowmobiles at the West Entrance using a remote sensing technique has shown that the PM in the exhaust is significantly lower than previously. Dramatic reductions in PM would therefore be expected. To some extent that has happened, yet high spikes in PM still occur at Old Faithful.

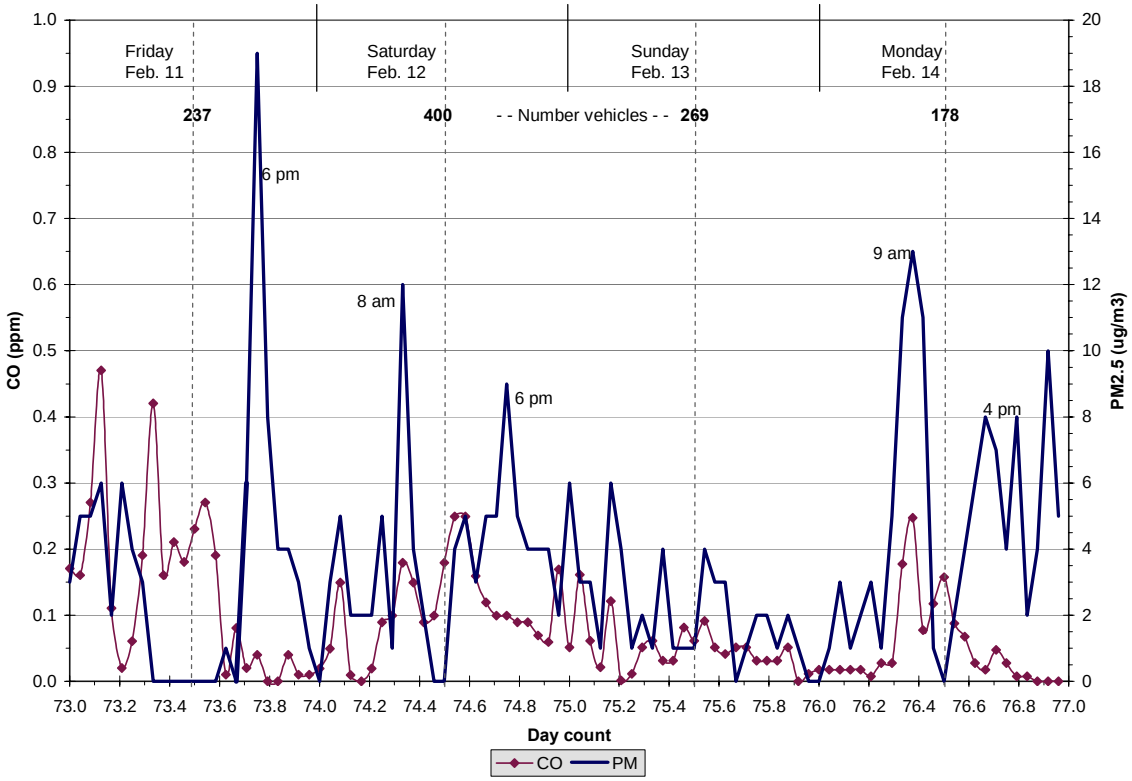


Figure A1. Comparison of CO and PM2.5 concentrations over the busy February 12-14 weekend at Old Faithful. Shaded areas are times when snowmobiles were typically present mid-day. The day count is from December 1. The number of vehicles was estimated from the gate counts for that day.

The weekend of February 11-14 is used to illustrate the independence of the CO and PM at Old Faithful (figure A1). The CO has a peak during the typical busy traffic periods on each day, although it is not always the highest CO of the day. PM has some moderate peaks on only two of the days during mid-day and some large peaks early in the morning or in the evening. As seen in the time series plot, the correlation between CO and PM2.5 at Old Faithful is poor. The two pollutants do not appear to be coming from the same source. The smoke from the wood stoves in the warming huts, which are only active morning through mid-afternoon, also do not appear to be registering.

In figure A2, a contour plotting technique is used to get a good overview of the data for the whole season. CO concentration is plotted by the day count since December 1 and by the hour of the day. The result is a color-coded contour map of CO concentrations over a 3 month period for each of the three years of monitoring data. The plots have the 10 am to 3 pm period when snowmobiles are typically present marked in light yellow (brackets).

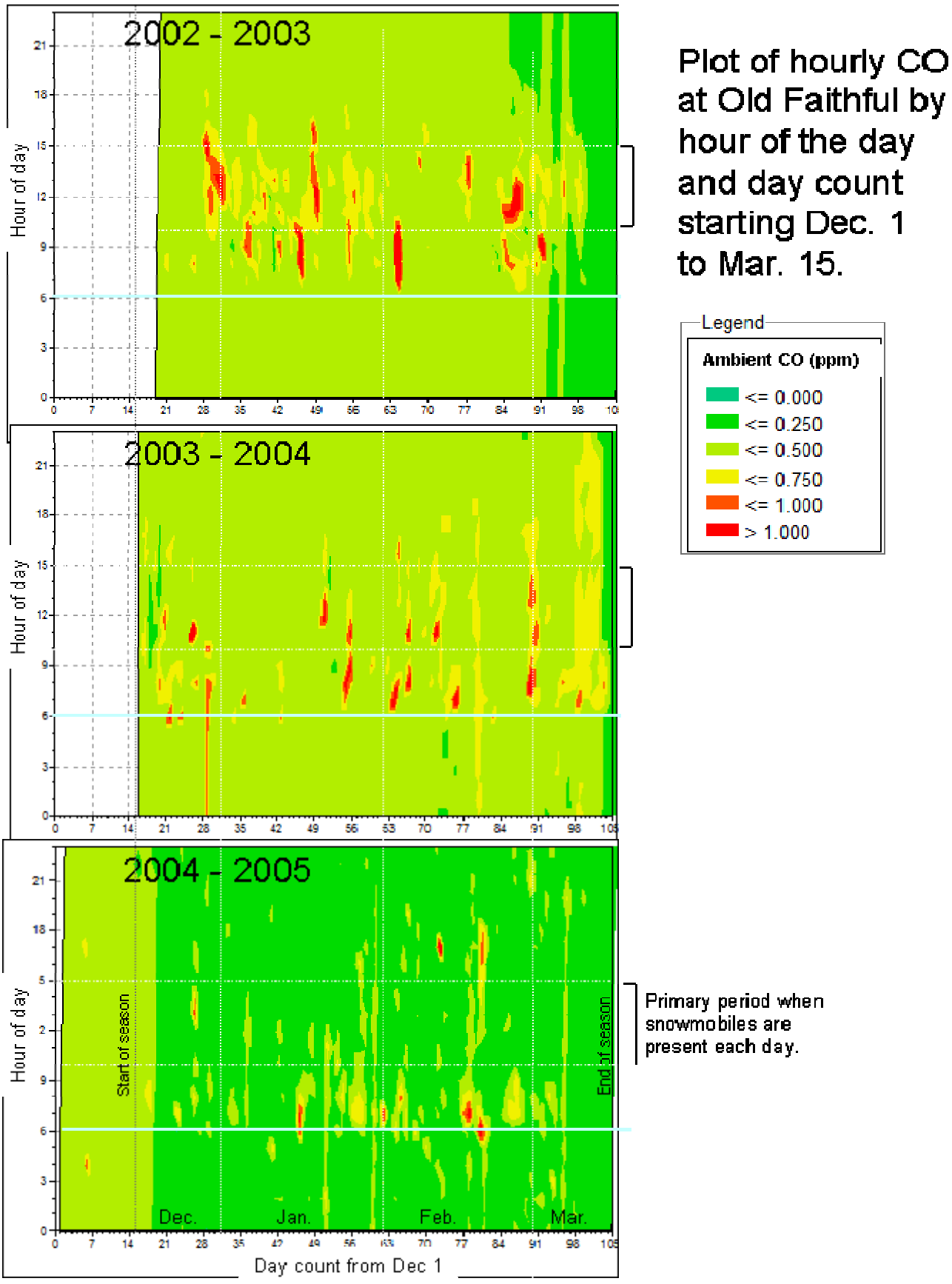


Figure A2. CO concentrations plotted for three winters as a function of day and the hour of the day. Scale is the same for each plot. CO events greater than 1 ppm are in red.

Progressively fewer and smaller red events (CO greater than 1 ppm) are seen over the three years. In 2004-2005 most of the red events occur outside the period when snowmobiles are typically present. A very busy time for all three years for CO events is between 6 am and 10 am. Since there are usually no winter vehicles in the parking lot during these early morning hours, the source of the CO and PM at these times must be something else.

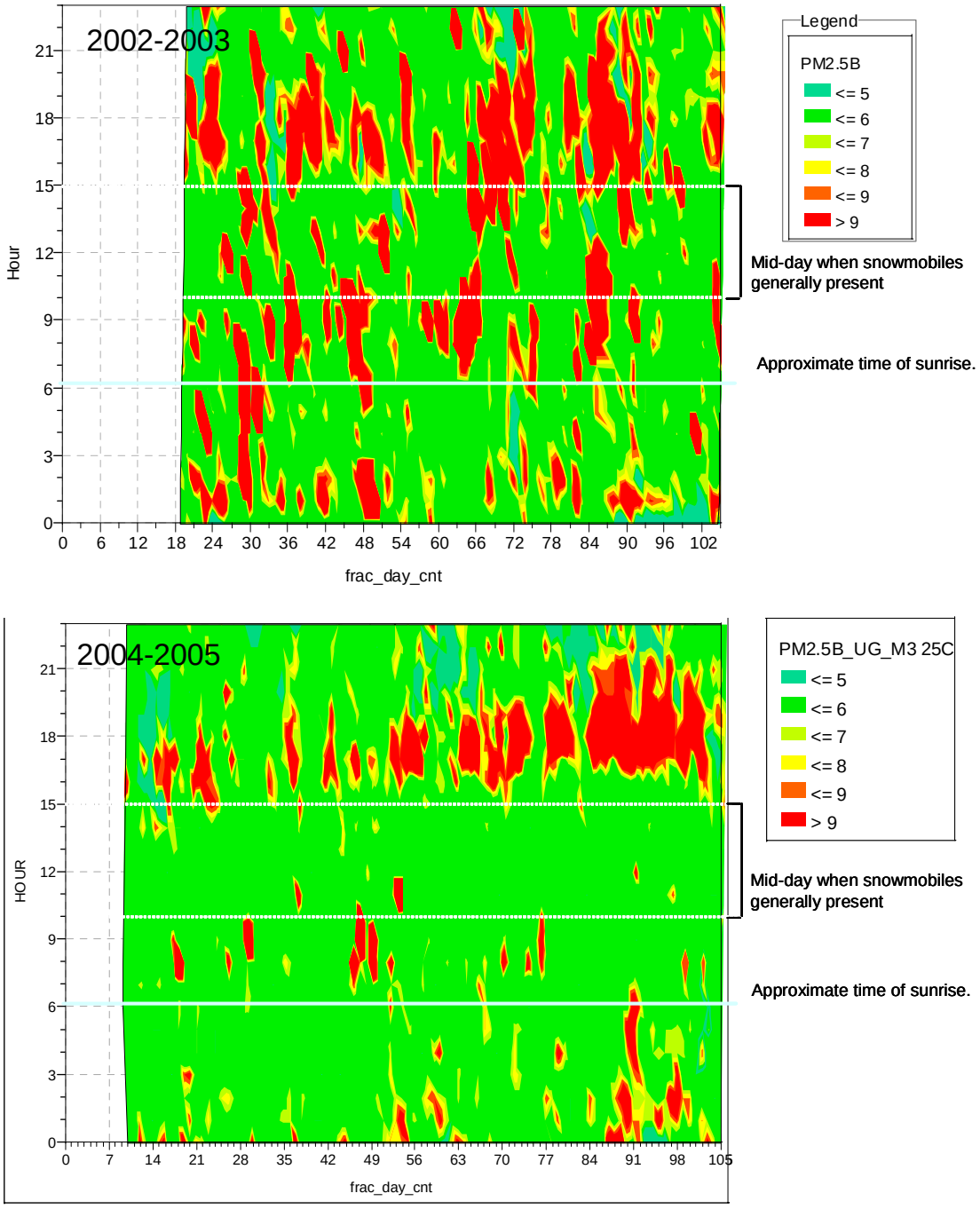
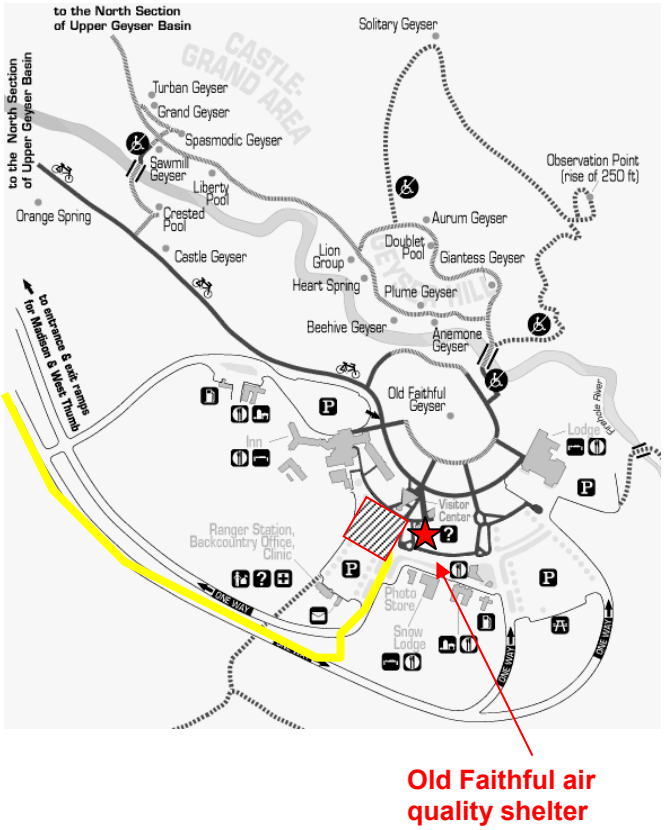


Figure A3. Concentrations of PM2.5 by day and hour at Old Faithful. Dotted lines show when the active snowmobile period is (10am to 3pm). Solid blue line is a rough indicator of when sunrise occurs. The 2002-2003 winter had predominantly 2-stroke snowmobiles and 2004-2005 winter was almost entirely 4-stroke snowmobiles.

Further information is given by the contour map for PM2.5 concentration for two winters: 2002-2003 and 2004-2005. (figure A3). During 2004-2005, mid-day PM events are rare and the majority of the high PM events are in the evening after almost all the snowmobiles are gone from the Old Faithful area. The PM

events tend to get later in the day and last longer as the season progresses. The night time and early morning events are mostly before the traffic arrives in the morning. In contrast, during the winter of 2002-2003 when snowmobiles were predominantly 2-stroke, there were many more mid-day PM events. The early morning and evening PM events were at times when snowmobiles were not present. This is consistent with a interpretation that a local stationary source was present in both years and that the mid-day mobile source had a large reduction in PM. Hydrocarbon emissions from snowmobiles that would be measured as PM decreased 96% during this period[5].

The direction of the wind gives some clues to the local stationary source (figure A4 and A5). During the mid-day the winds are from the west sector. In the early morning and at night they are much more likely to be from the south. Snow Lodge is to the south of the monitoring station. Activities in the early morning include the fuel-oil broiler becoming active to heat the lodge and water. The kitchen also begins preparing and serving meals. On some days when there are rentals, snowmobiles are turned on outside the lodge north entrance and warmed up in idle mode. In addition to these activities, to the north of the monitoring station, park maintenance staff starts up the wood-burning stoves in the warming huts between 6 – 7 am. At low wind speeds typical for overnight and early morning (figure 6), smoke from the wood stoves has been observed to hang in the area.



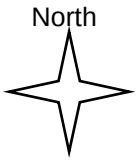


Figure A4. Location of air quality shelter at Old Faithful. Entry route and parking area for the snowmobiles is shown. Shelter is downwind and across from the parking area.

The main conclusion is that many of the PM events that are now observed by the monitoring equipment at Old Faithful are not due to snowmobile or snow coach activity. The lack of correlation between the CO (which does correlate to snowmobile activity at both the West Entrance and Old Faithful) and PM indicates that most of the PM is coming from other sources. During non-mid-day periods, the PM source appears to be from the Snow Lodge direction. During mid-day when snowmobiles are present, the CO and some portion of PM comes from snowmobiles. Comparing mid-day only PM to all periods, the contribution from snowmobiles is less than 12% of the PM observed at the monitoring station. During specific periods mid-day a contamination of PM from the warming-hut wood stoves occurs. The wood

smoke is most visible from the exhaust stovepipe during the period after startup. Smoke and odor were observed to hang in the area of the huts and to move northward towards the geyser. The reduction in PM at Old Faithful may reflect a cutback in the use of both warming huts in the last two years since the number of snowmobile riders has been much smaller.

Absent more specific source markers and direct counts of snowmobiles in the area, the indirect information will have to be used. The conclusion remains that most of the PM at Old Faithful is not coming from the winter vehicles. The visible smoke layer around the area and smoke odor from the uncontrolled old fashion wood stoves would seem to be avoidable. The Park should investigate another heating source for the warming huts or use newer stoves with emission controls. The connection of PM to activity at Snow Lodge would have to be investigated more. Since the level of 24-hr PM2.5 standard is not being exceeded, the basis for additional controls would have to be decided.

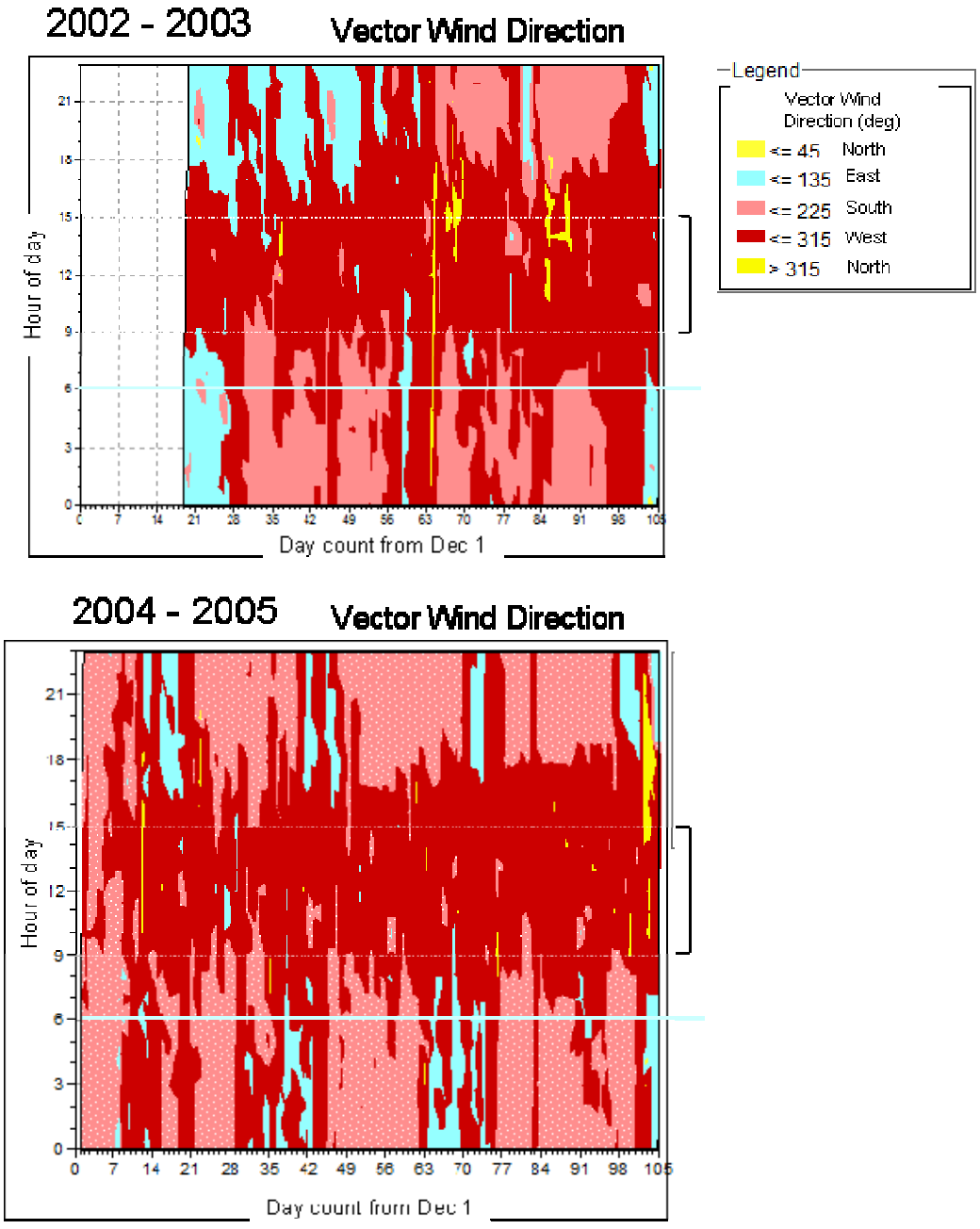


Figure A5. Wind direction by sectors at Old Faithful. Busy traffic periods are bounded by the dotted lines. Compare to average conditions in figure A6 for wind speed and figure A7 for wind rose.

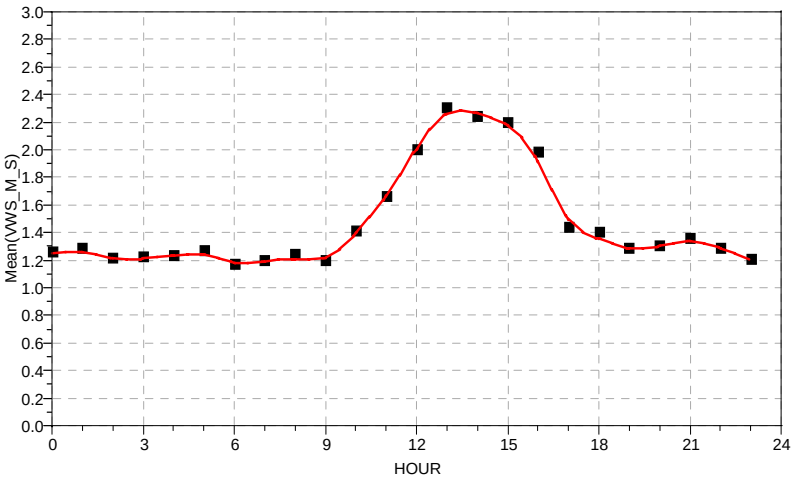


Figure A6. Mean wind speed by hour of the day for the winter season 2004-2005 at Old Faithful. Peak winds are in the afternoon between 1 to 3 pm. Overnight winds are consistent at 1.2 m/s.

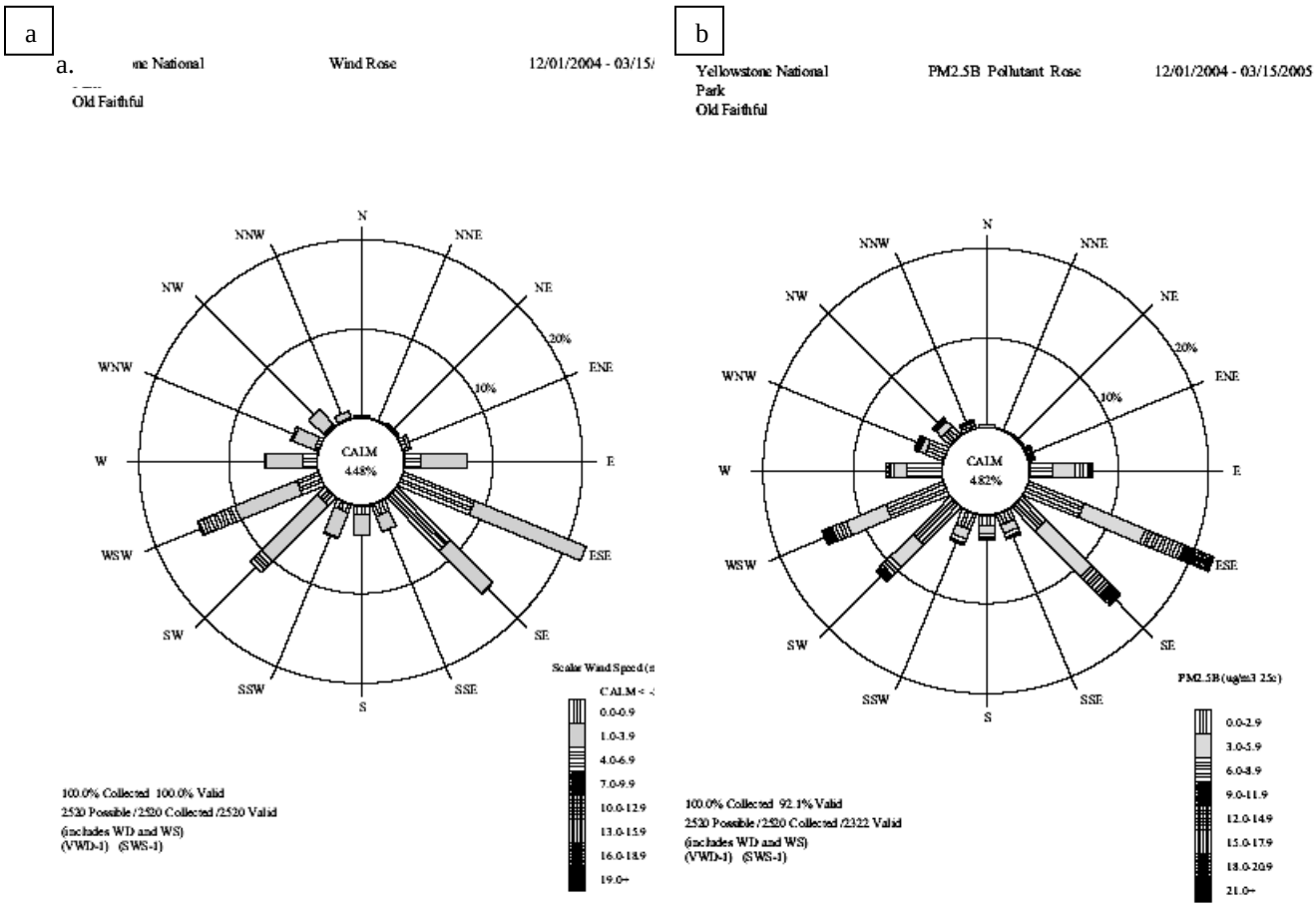


Figure A7. Wind rose (a) and pollutant rose (b) for Old Faithful. Winds are primarily from the SW and SE.

Conclusions

The winter vehicle activity at Old Faithful is spread over a larger area and happens over a broader mid-day period. As a result, the observed CO concentrations are lower than at the West Entrance even though the daily number of snowmobiles is probably greater. The CO concentrations were lower in winter 2004-2005.

The PM2.5 did not show as large a decrease as the CO concentrations in the last several years. A more detailed analysis indicates that much of the PM2.5 that is observed at the Old Faithful site is from local stationary sources rather than the snowmobiles.

National Park Service
U.S. Department of the Interior

Air Resources Division

Results from Yellowstone National Park

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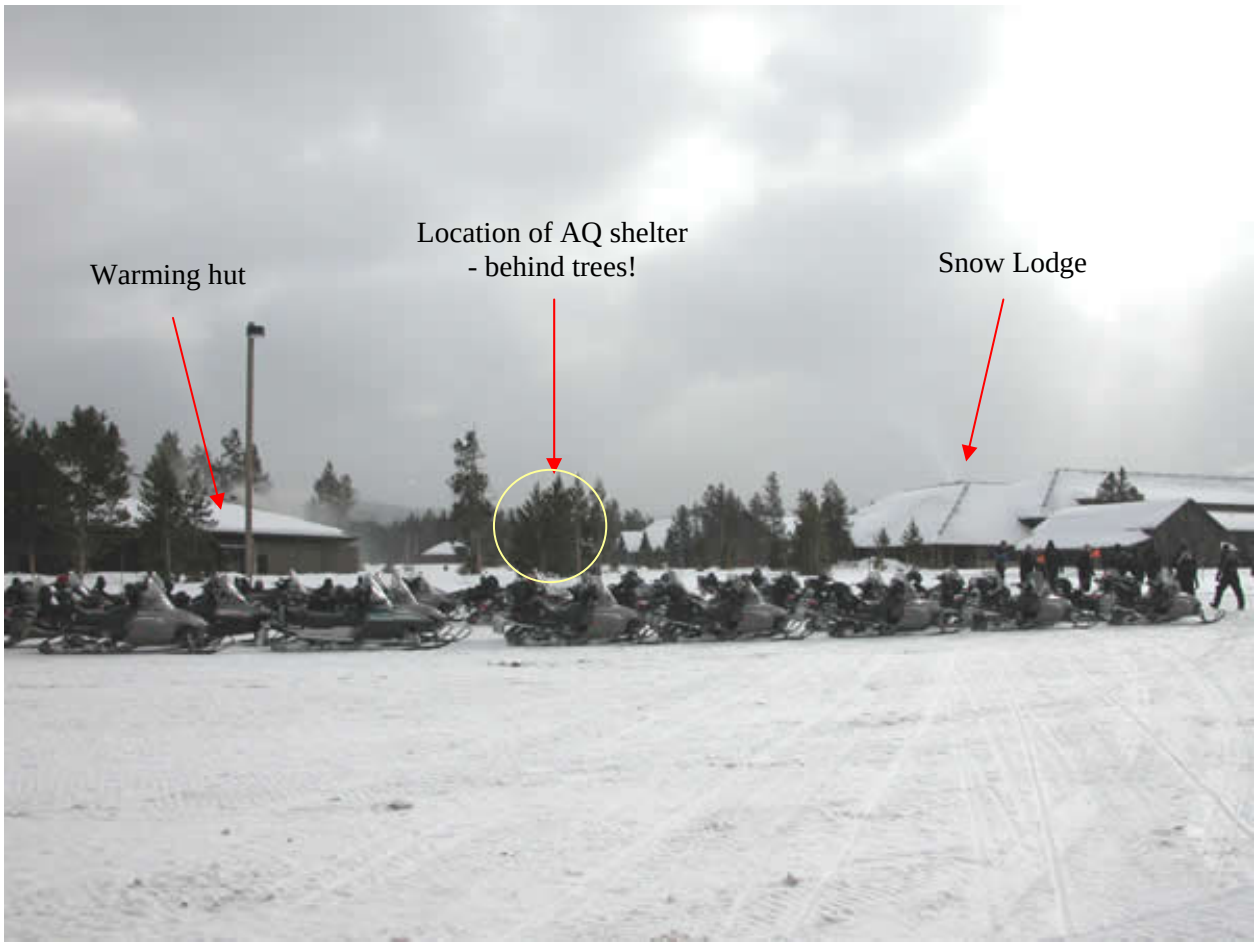
Appendix B

Winter Images of Monitoring and Activities

This section has pictures taken by the researchers during the snow coach emission study at Yellowstone. Images help to define the setting and the activity that is associated with the monitoring data.



Snowmobile parking area at Old Faithful in the close-in lot. The view is looking east towards the air monitoring shelter and the warming hut. 10:50 am 9-8-05 Old Faithful geyser and the visitor center are to the left of the picture (north).

Picture of the monitoring shelter at Old Faithful with the warming hut in the background.
Smoke is seen blowing away from the monitoring station in the SW winds. The digital camera housing can be seen on the tower.

The snowmobiles park in rows of 8 – 15 sleds. About 20 rows of sleds can park in the close-in lot before the overflow is forced into the outer lot. Snow coaches usually park next to the sidewalk by the visitor center.

This view is from the outer parking lot towards the close-in parking and the visitor center. The visible plume to the north is the Old Faithful geyser

View of the front of Snow Lodge where the Xanterra snow coaches drop off their passengers and park. The van in the center is outfitted with the exhaust emission monitoring equipment.

View of Snow Lodge to the south of the monitoring shelter. Smoke can be seen raising from the boiler room. The two large stacks are from the gas-fueled public area fireplaces which do not produce visible plumes. During the evening, smoke can be seen coming from the kitchen vents that are on the far side of the roof, right side.

View from the outer parking lot, looking east towards Snow Lodge.

At Madison Junction most snowmobile groups stop to rest. Long lines of snowmobiles park with their engines off during the morning hours. This busy location probably sees CO concentrations during morning hours that are higher than concentrations at Old Faithful.

A Bombardier from West Yellowstone is seen coming down a hill as it heads for Old Faithful.

Snowmobiles travel in groups with a guide. These snowmobiles came in from the South Gate and are on their way to Old Faithful. Each sled throws up snow so the following sleds hang back a safe distance.