Results from Yellowstone National Park

Winter Air Quality Study
2004-2005

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Summary results

Ambient monitoring during the winter activity season at Old Faithful and at the West Entrance shows that the air pollutants carbon monoxide (CO) and fine particulate matter (PM) concentrations have continued to decrease over the last four winters. Partly that is due to poor snow conditions for much of the winter season 2004-2005, which limited the amount of snowmobile traffic into the park, but it also is a result of lower emission snowmobiles.

- CO was lower again this season at both monitoring stations and is well below the level of the standard.
- PM2.5 was also lower this season 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.

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, further reductions in emissions will be needed.

- Odor and noise have been noticeably reduced by the 4-stroke engine snowmobiles, based on research observations. Likewise, visible smoke and PM2.5 have been greatly reduced. 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.

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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, but including snow coaches, 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 on air quality of implementing the Yellowstone Winter Use Plan. 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

Monitoring Design

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 and 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 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 (http://www.deq.state.mt.us/AirMonitoring/sites/QueryAQsitelocation2.asp). Data was retrieved from EPA AQS database and directly from the State of Montana, Department of Environmental Quality. All data collection, validation, and quality assurance steps were performed by the State of Montana.

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 (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 at the West Entrance and from 1.2 ppm to 0.6 ppm 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

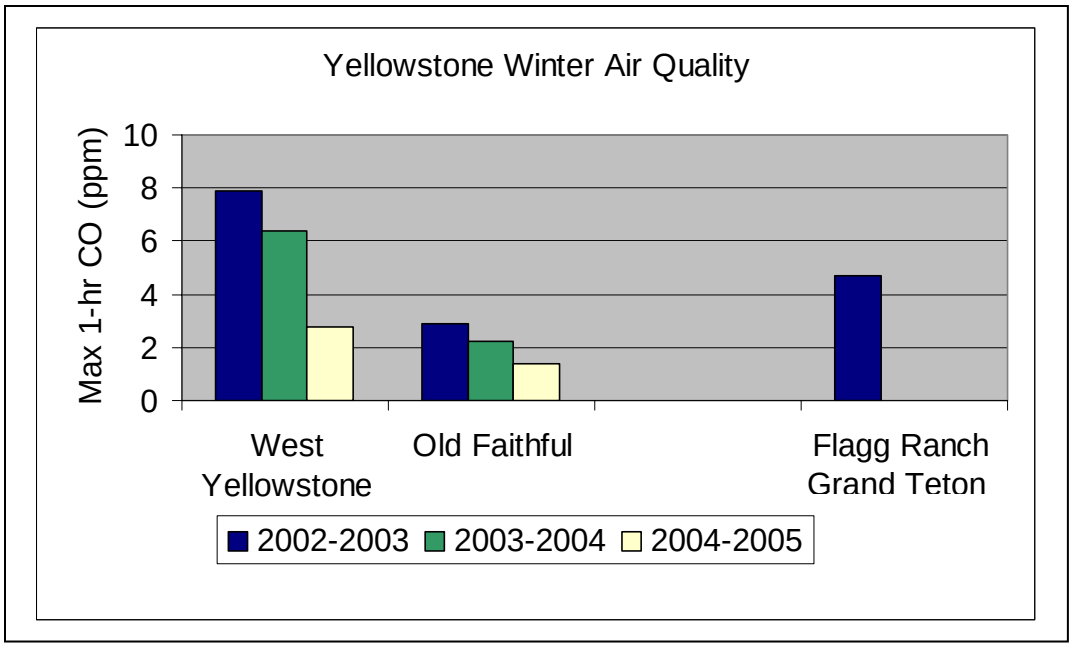


Figure 1. Comparison of the maximum 1-hour carbon monoxide concentrations at monitoring sites over the last three winters. Concentrations have decreased in each of the years.

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. 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 2003-2004, 4-stroke snowmobiles and guided tours were initiated[4]. These measures appear to have been effective in reducing the high CO concentrations near the entrance station.

Tables 3 & 4 summarize particulates as PM 2.5 and carbon monoxide concentrations for time periods relevant to the national standards. None of the observed pollutants exceeded the levels of national standards during the reporting periods. The West Entrance has larger CO concentrations than either the Flagg Ranch 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 (See appendix A for more discussion). Both air pollutants, CO and PM2.5, have decreased considerably at locations in Yellowstone NP where snowmobile traffic is heavy.

The snowmobile traffic pattern at the West Entrance is such that relatively high pollutant levels are seen in the morning and afternoon “rush hours”, however, when these values are averaged over 8 hours with lower night-time or mid-day values, the averages are less than the levels of the national standard.

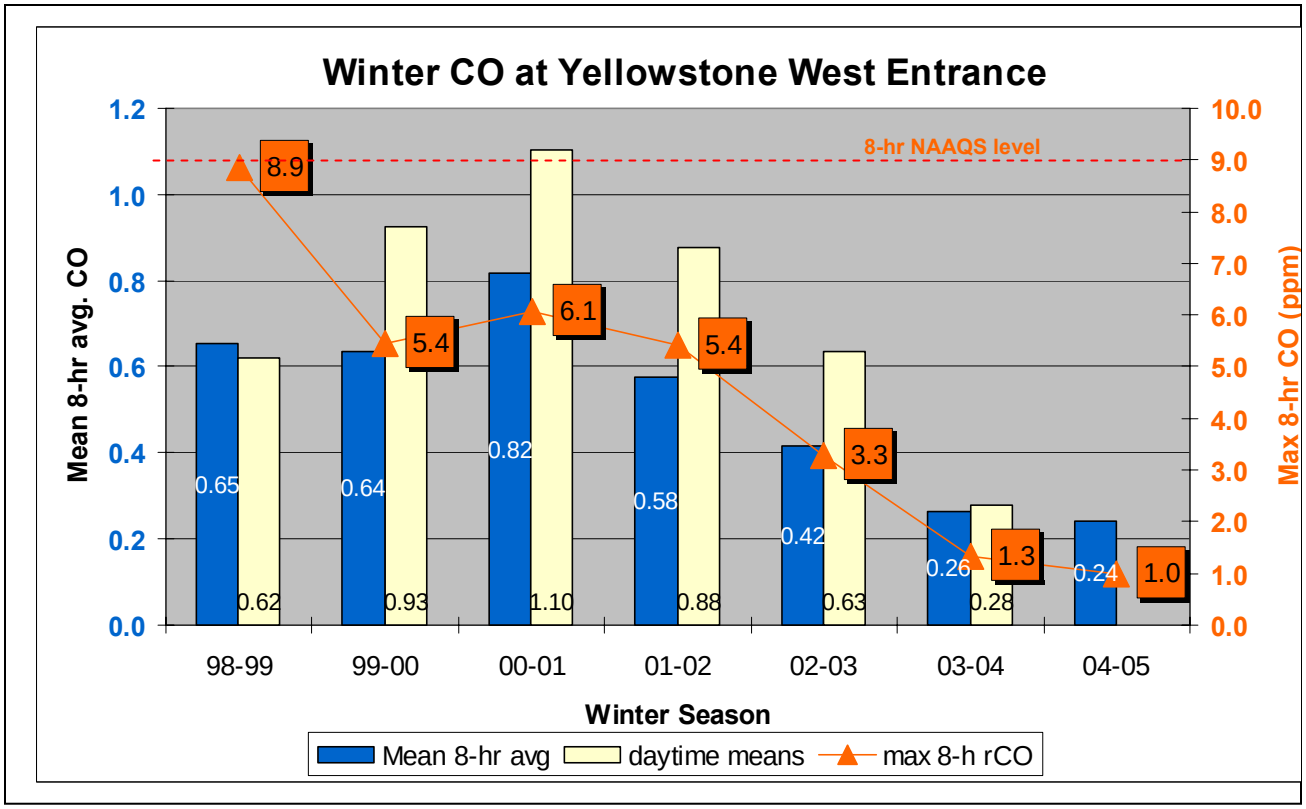


Figure 2. Summary of CO concentrations over 7 winters. Since snowmobile traffic through the West Entrance has two periods of activity during the day, long averaging periods bring in many hours when CO is near the background. When only daytime hours are used for the averages, the 8-hour CO values are higher. Recent years have recorded a decrease in CO.

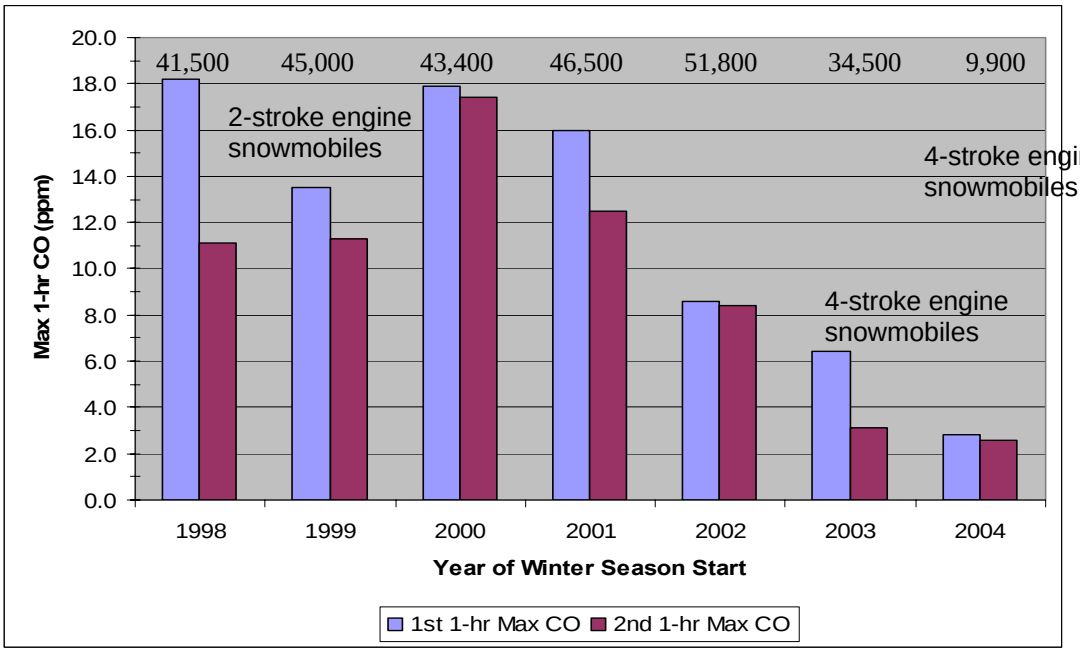


Figure 3. The 1-hour maximum CO concentrations at the West Entrance are much higher than the 8-hour values because the peak values occur over just a few hours during daytime. The overnight concentrations go down to about 0.2 ppm and reduce the averages. Peak CO concentrations have decreased since 2000. Numbers at the top are the number of snowmobiles and snow coaches that entered the West Entrance for each season.

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

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

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[3].

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.

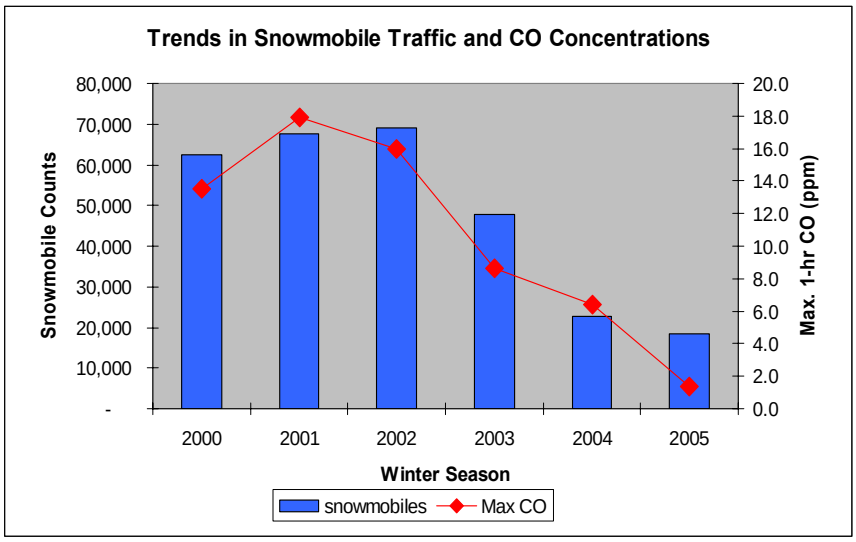


Figure 4. The number of snowmobiles entering the park each season is compared to the observed peak CO concentrations in this chart. Fewer snowmobiles and cleaner engines have brought the CO concentrations down.

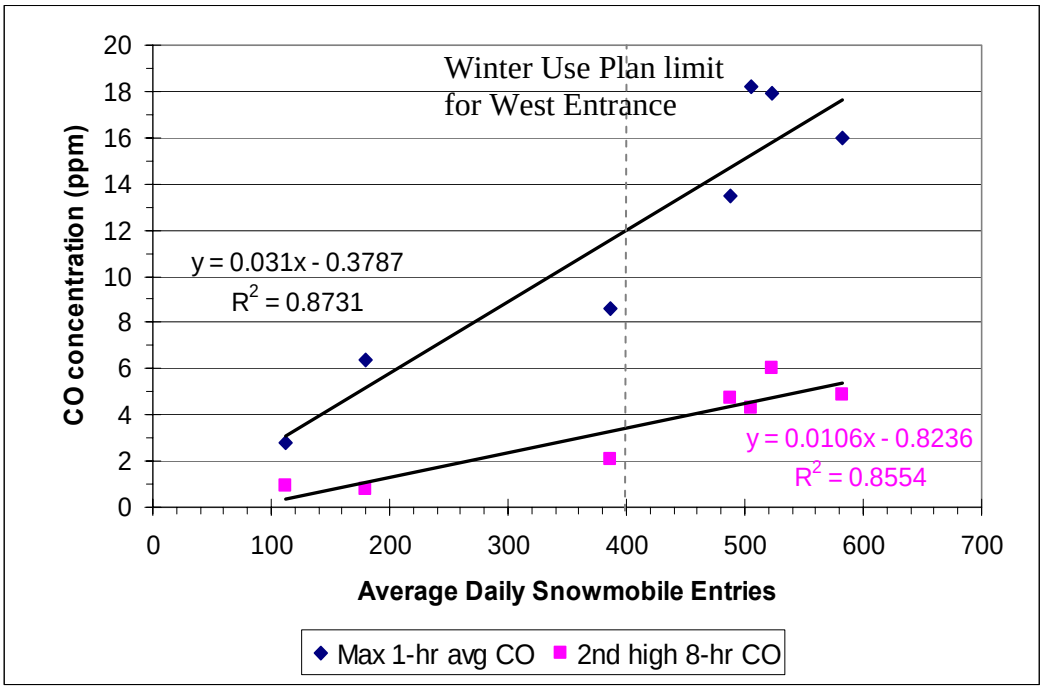


Figure 5. Relationship between daily average snowmobile counts and the maximum CO concentrations observed for the season. The amount of snowmobile traffic accounts for 87% of the variability. Weather, engine type, and number of snow coaches account for the rest of the variability.

Winter vehicle entry counts to the Park

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.

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.

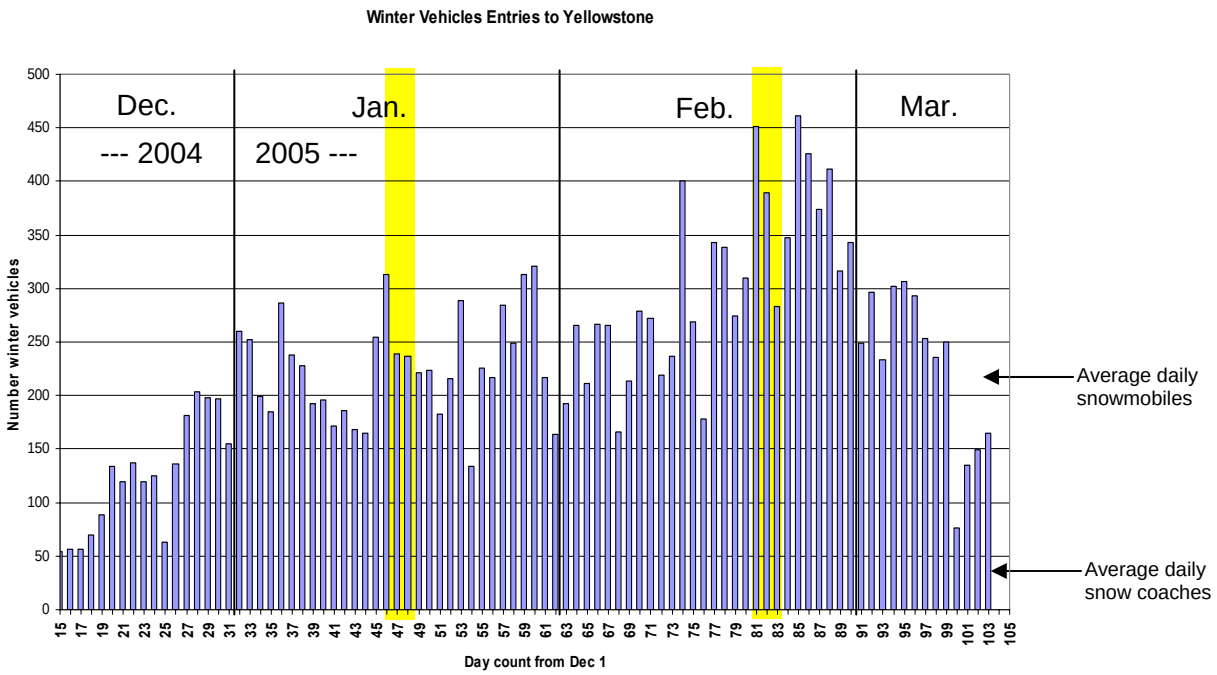


Figure 6. The number of snowmobiles and snow coaches entering the Park is recorded daily. The busy Martin L. King and President's Day 3-day weekends are highlighted in yellow. The maximum daily number of snowmobiles is below the limits of 720 per day in the Winter Use Plan

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. There is no way to separate the contribution of the snowmobiles and snow coaches to the observed CO and PM. The winter traffic is spread out throughout the week (figure 7b), although Saturday and Wednesday tend to be slightly busier.

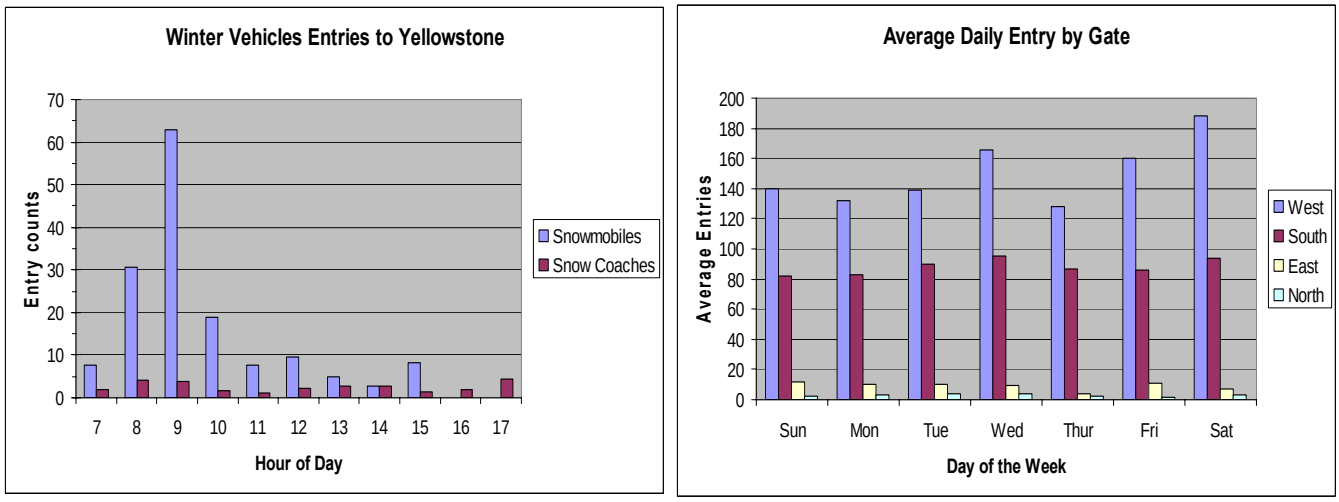


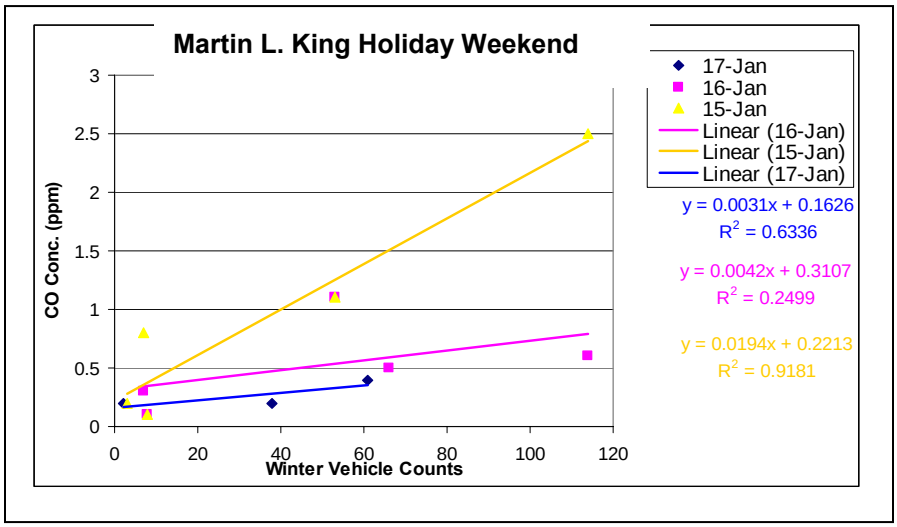
Figure 7. A. Winter vehicle entry counts by hour at the West Entrance. B. Average daily entry counts by day of the week over the winter season 04-05 for all gates. Saturday and Wednesday tend to be the busiest days.

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.

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).

In figure 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 only 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.

a.



b.

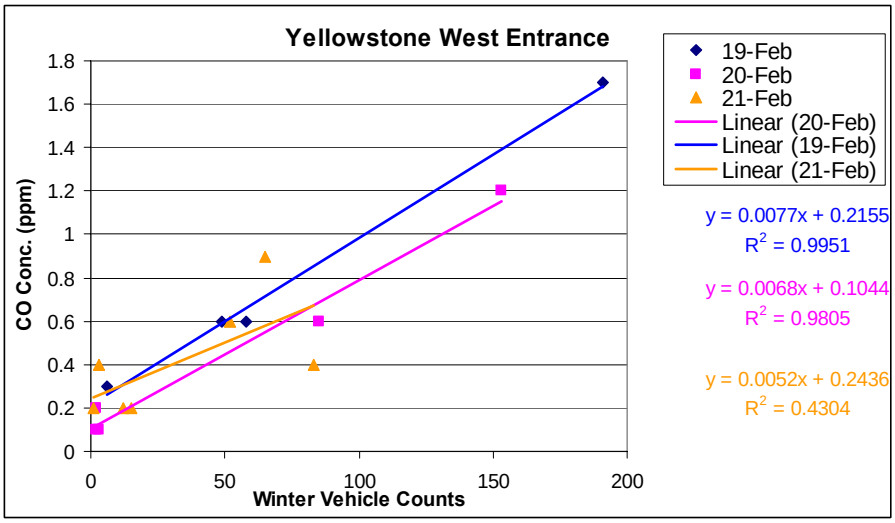


Figure 8a & b. The CO concentrations at the West Entrance correlate to the number of winter vehicles entering each hour over two different 3-day holiday weekends. The concentration of CO per snowmobile varies by day, however, as weather conditions change.

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.

The highest mean hourly CO concentrations occur during the winter months when snow vehicles are in use (figure 10). During the last two seasons the CO concentrations have been significantly reduced. The peak month for CO is February which corresponds to peak snowmobile traffic.

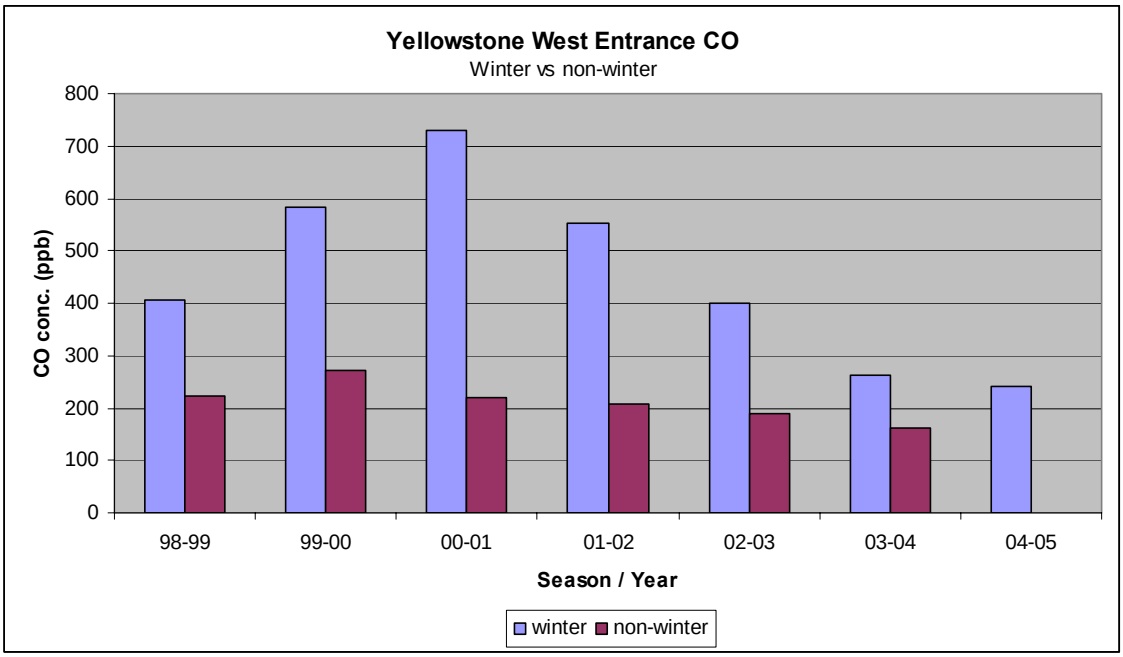


Figure 9. Comparison of the CO concentrations (in ppb) between the winter periods and the summer periods at the West Entrance. The amount of traffic and numbers of visitors is much greater during the summer.

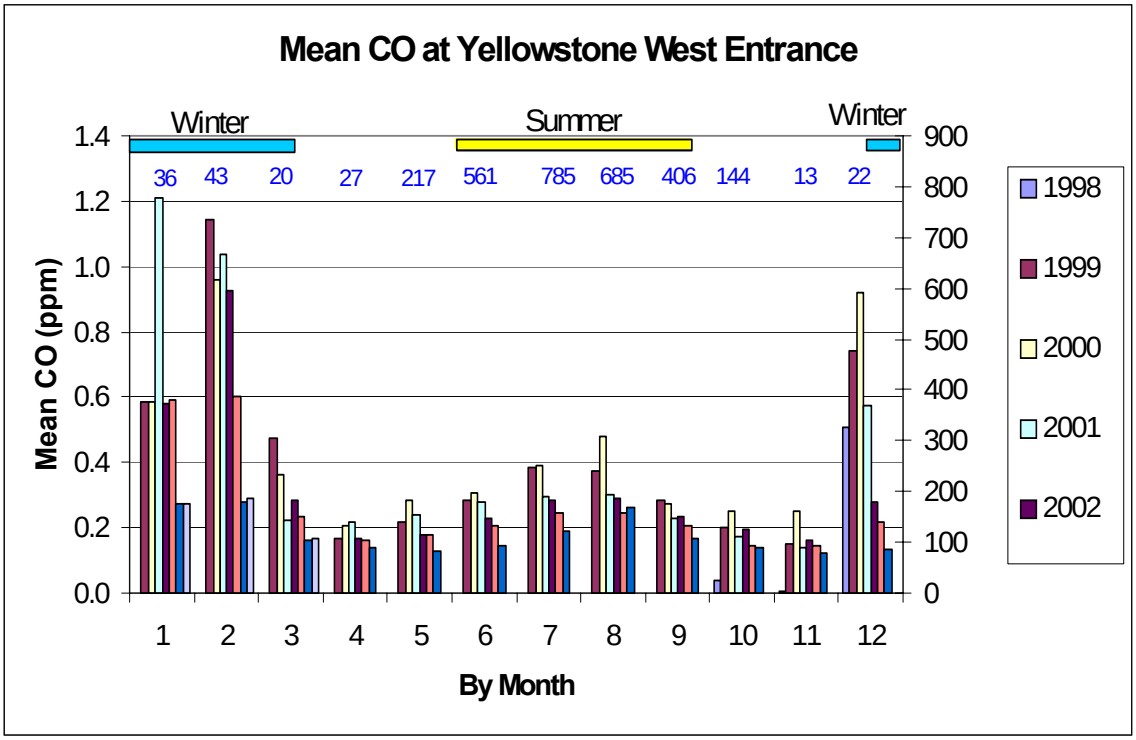


Figure 10. April and November tend to have the lowest CO concentrations at the West Entrance. The winter months have had very high CO until the last two years. The winter CO and the maximum summer time CO are now very similar. The numbers represent the average number of visitors[7] (in thousands) per month for 1998-2004.

During July and August there is a summer peak of CO that corresponds to peak visitation for wheeled vehicles (cars, trucks, campers). 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 August, the busiest visitation month.

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.

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

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

References

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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). http://www.feat.biochem.du.edu/assets/publications/Auto_improvement_est_37_2003.pdf

7. National Park Service, Public Use Statistics, http://www2.nature.nps.gov/stats/

Appendices

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

Appendix B. Winter images from air quality monitoring at Old Faithful.

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

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. 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 extend that has happened, yet, high spikes in PM still occur at Old Faithful.

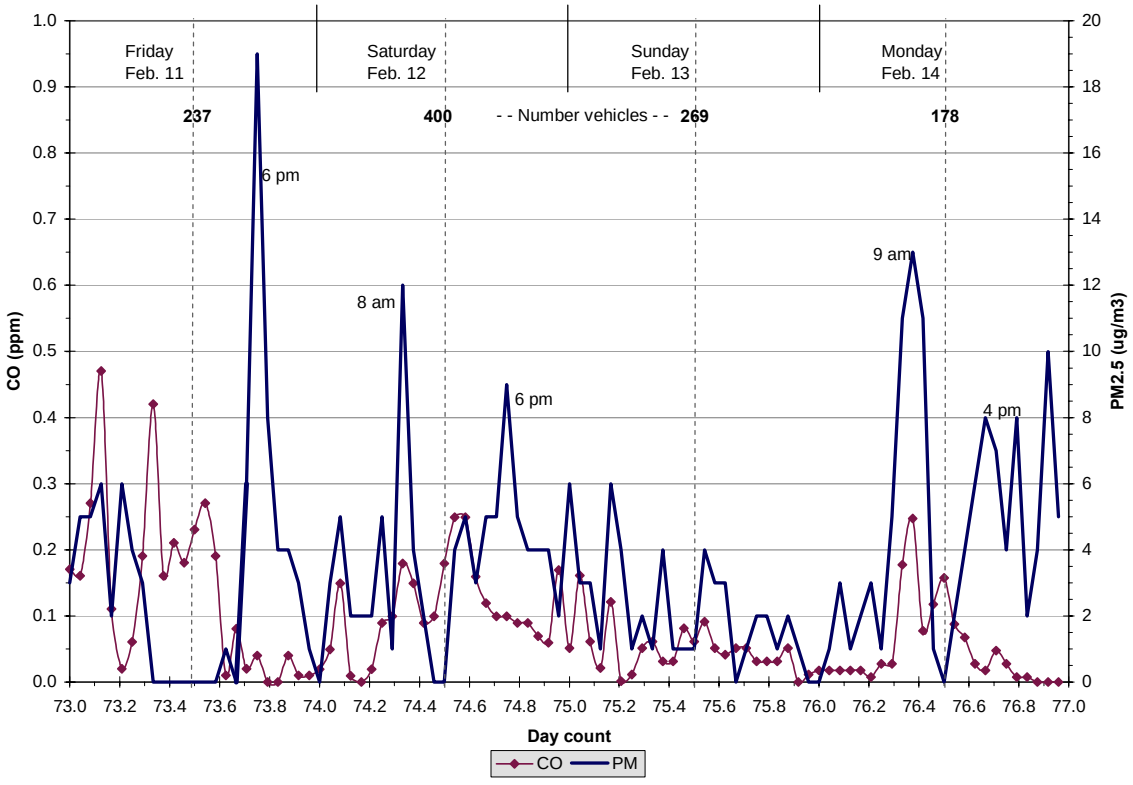


Figure A1. Comparison of CO and PM2.5 concentrations over the busy February 12-14 weekend at Old Faithful. Shaded areas are times when snowmobiles were typically present.

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.

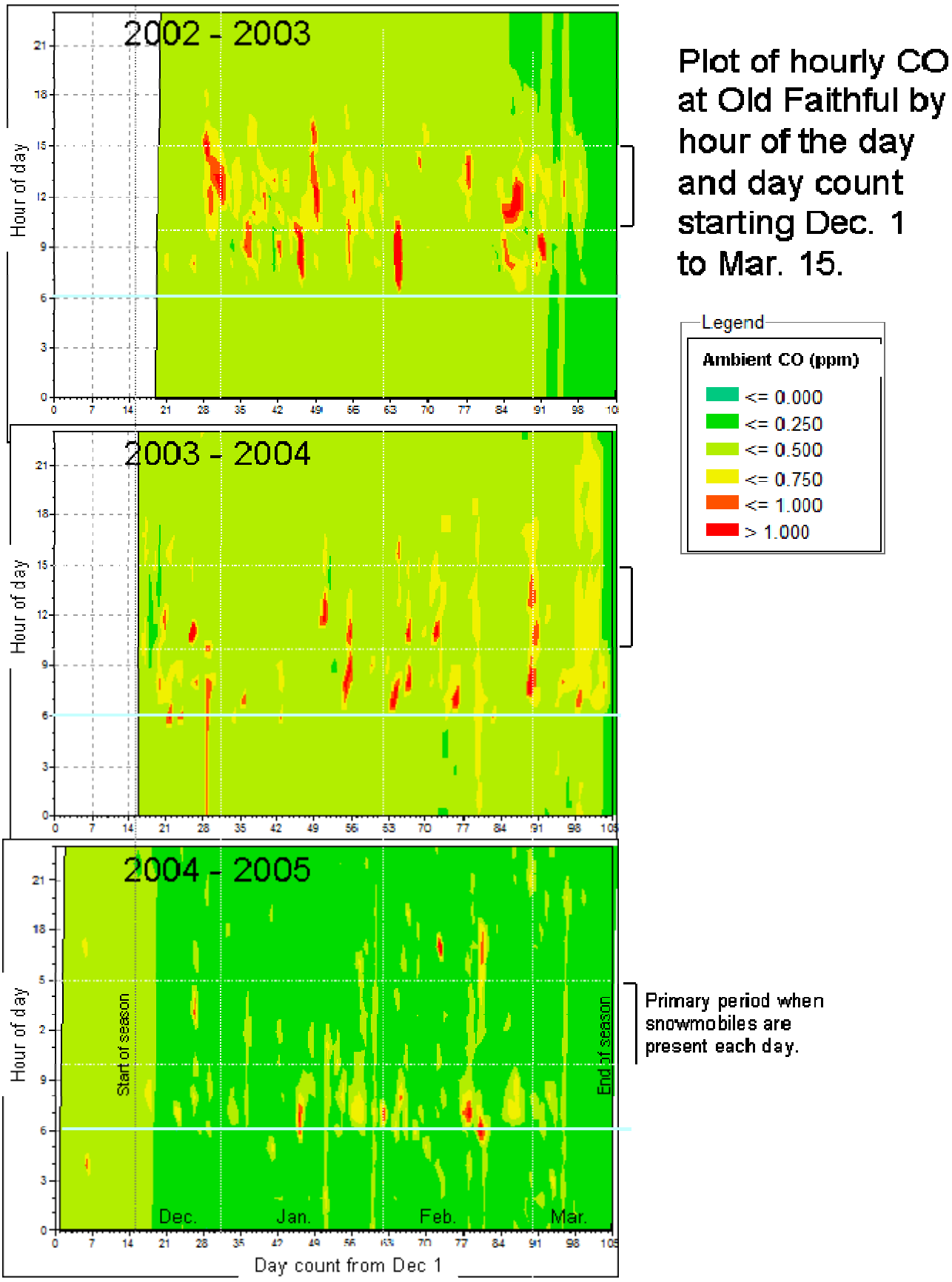


Figure A2. CO concentrations plotted for three winters as a function of day and the hour of the day. Scale is the same for each plot. CO events greater than 1 ppm are in red.

In figure A2, a contour plotting technique is used to get a good overview of the data. 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). 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 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.

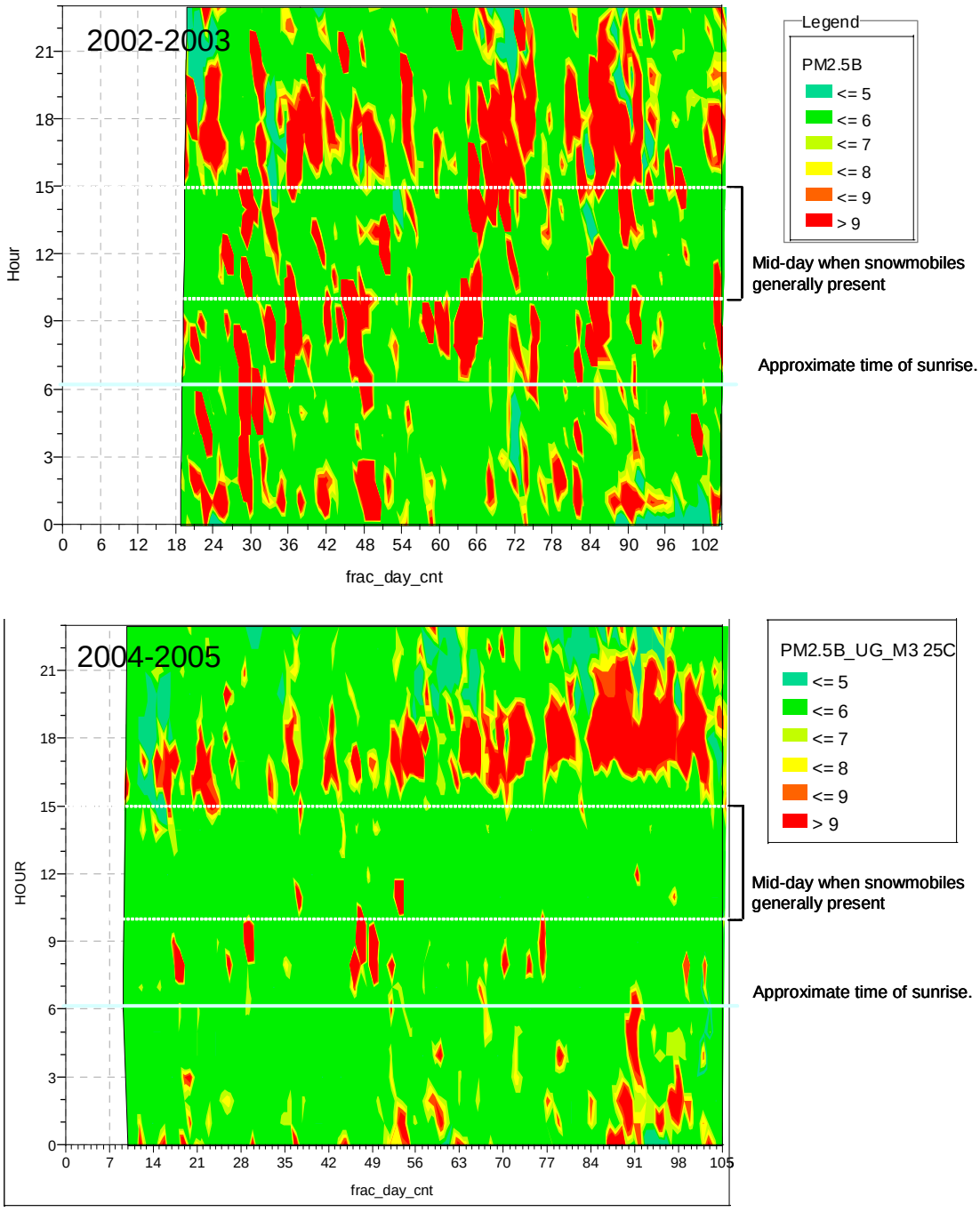


Figure A3. Concentrations of PM2.5 by day and hour at Old Faithful. Dotted lines show when the active snowmobile period is (10am to 3pm). Solid blue line is a rough indicator of when sunrise occurs. The 2002-2003 winter had predominantly 2-stroke snowmobiles and 2004-2005 winter was almost entirely 4-stroke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

Further information is given in 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.

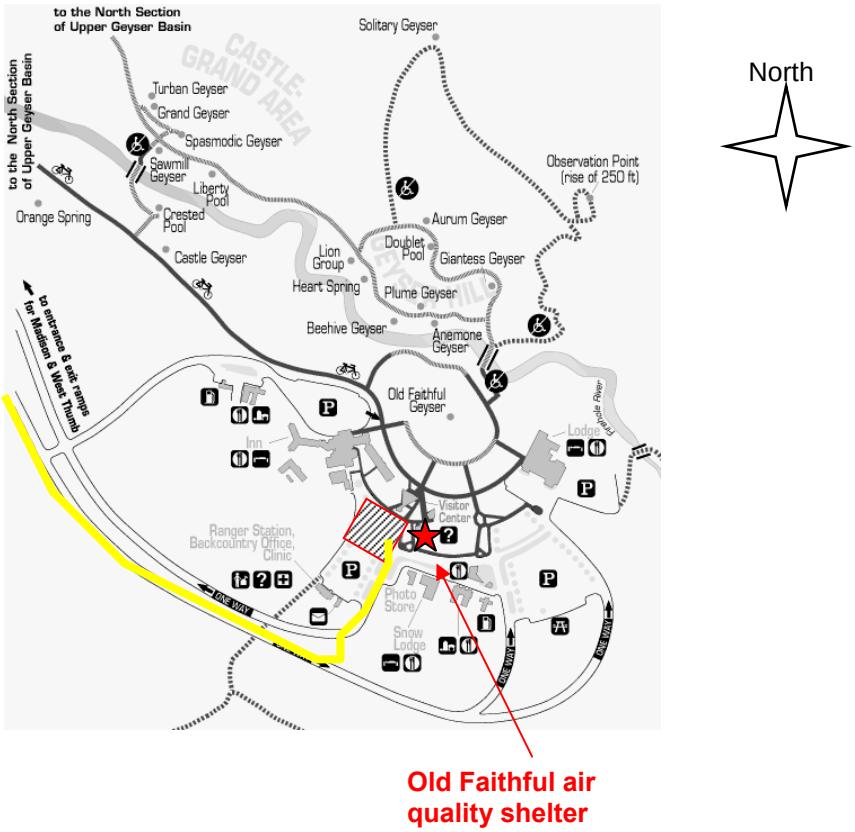


Figure A4. Location of air quality shelter at Old Faithful. Entry route and parking area for the snowmobiles is shown. Shelter is downwind and across from the parking area.

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 that 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.

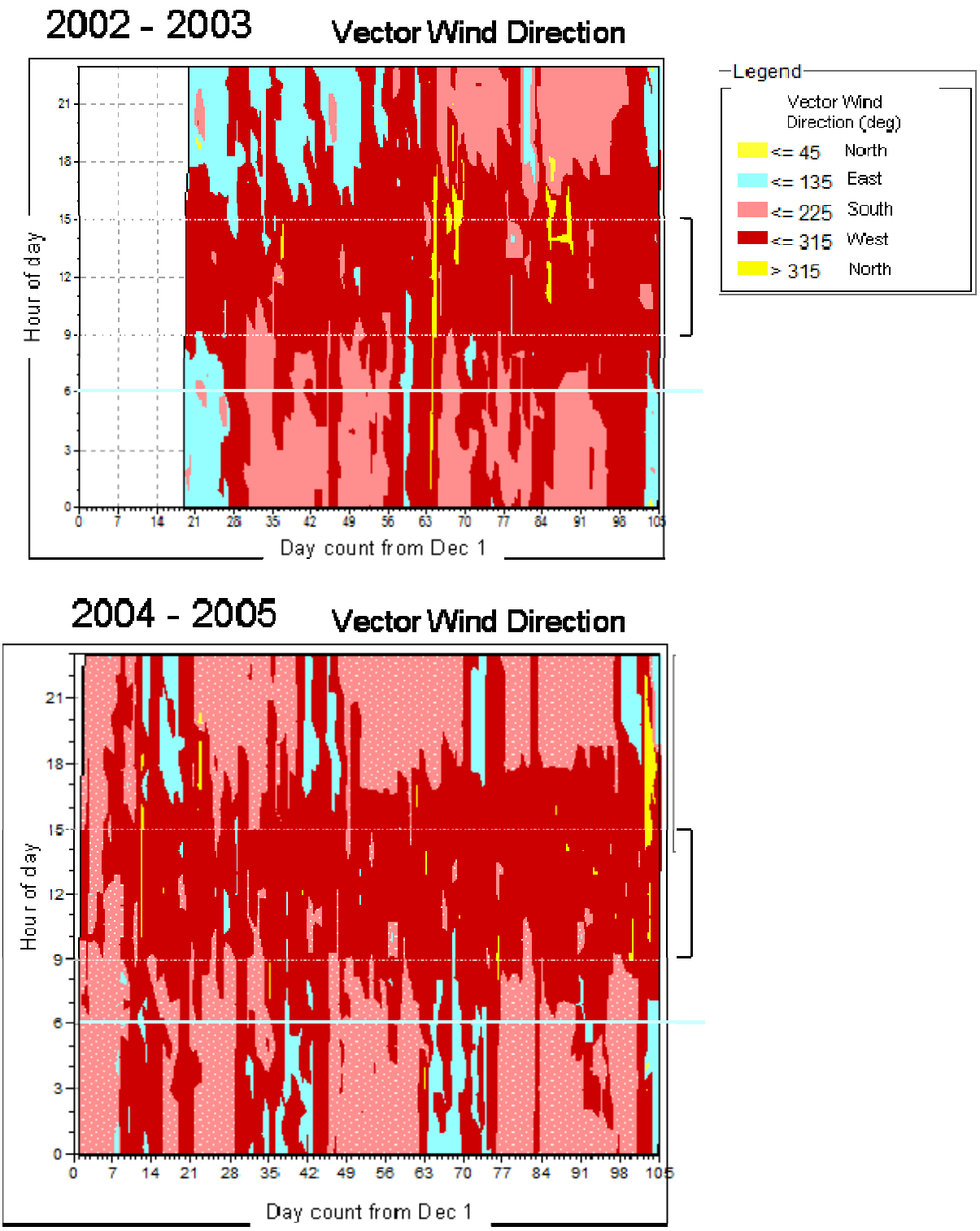


Figure A5. Wind direction by sectors at Old Faithful. Busy traffic periods are bounded by the dotted lines. Compare to average conditions in figure A6 for wind speed and figure A7 for wind rose.

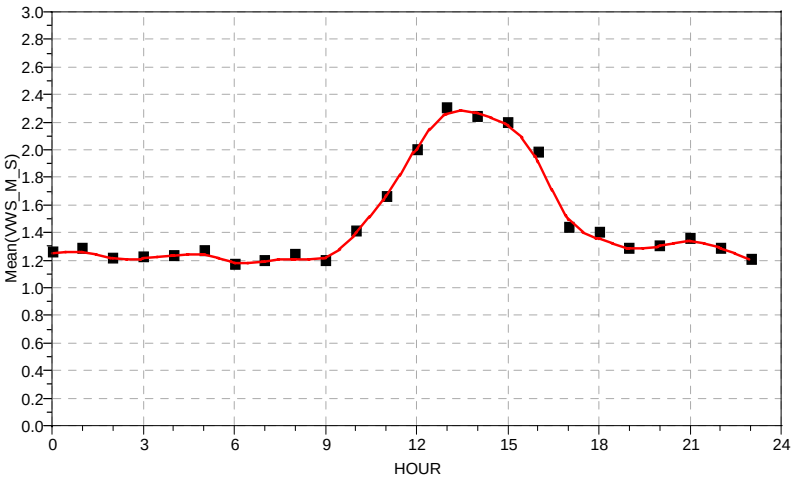


Figure A6. Mean wind speed by hour of the day for the winter season 2004-2005 at Old Faithful. Peak winds are in the afternoon between 1 to 3 pm. Overnight winds are consistent at 1.2 m/s.

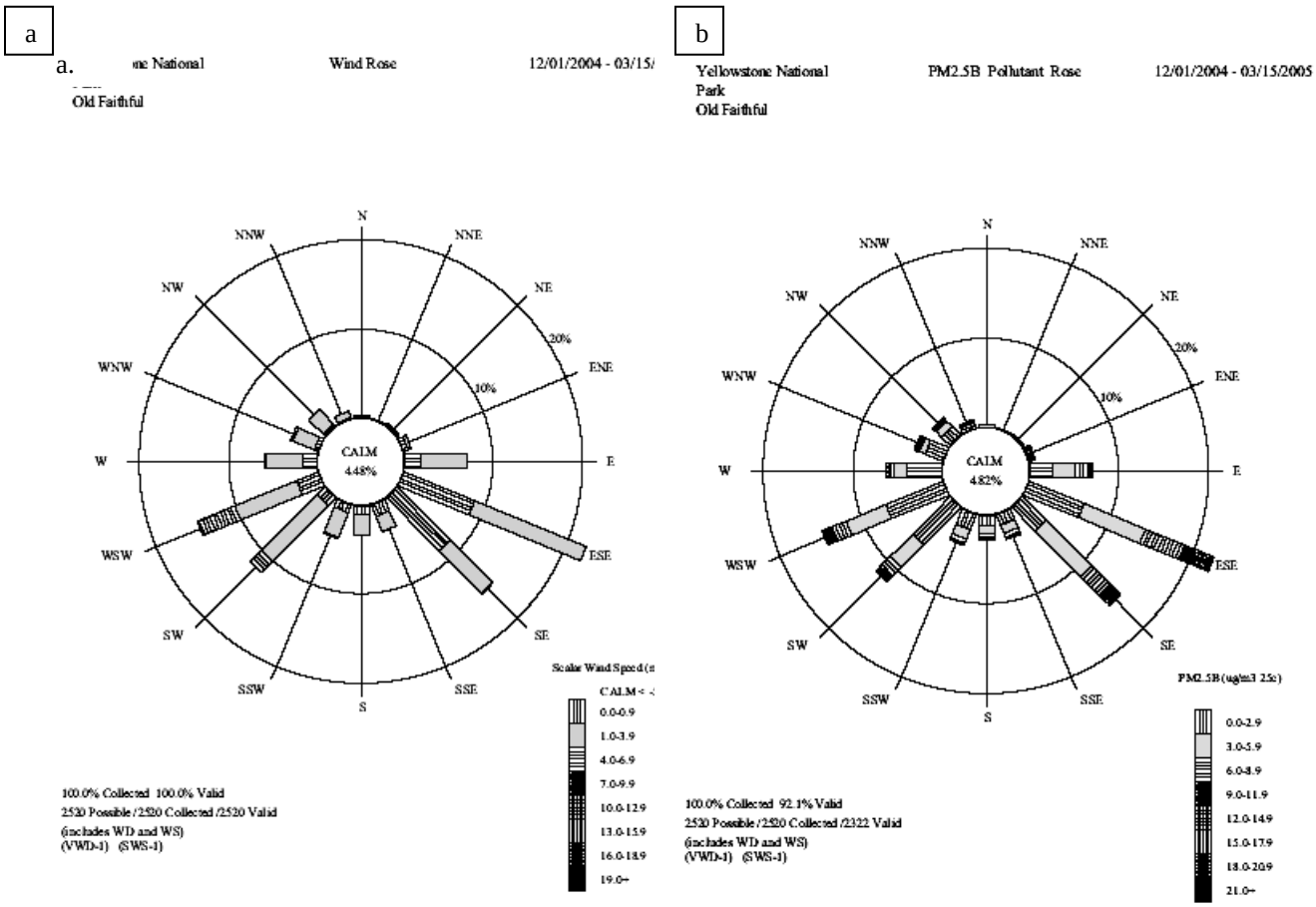
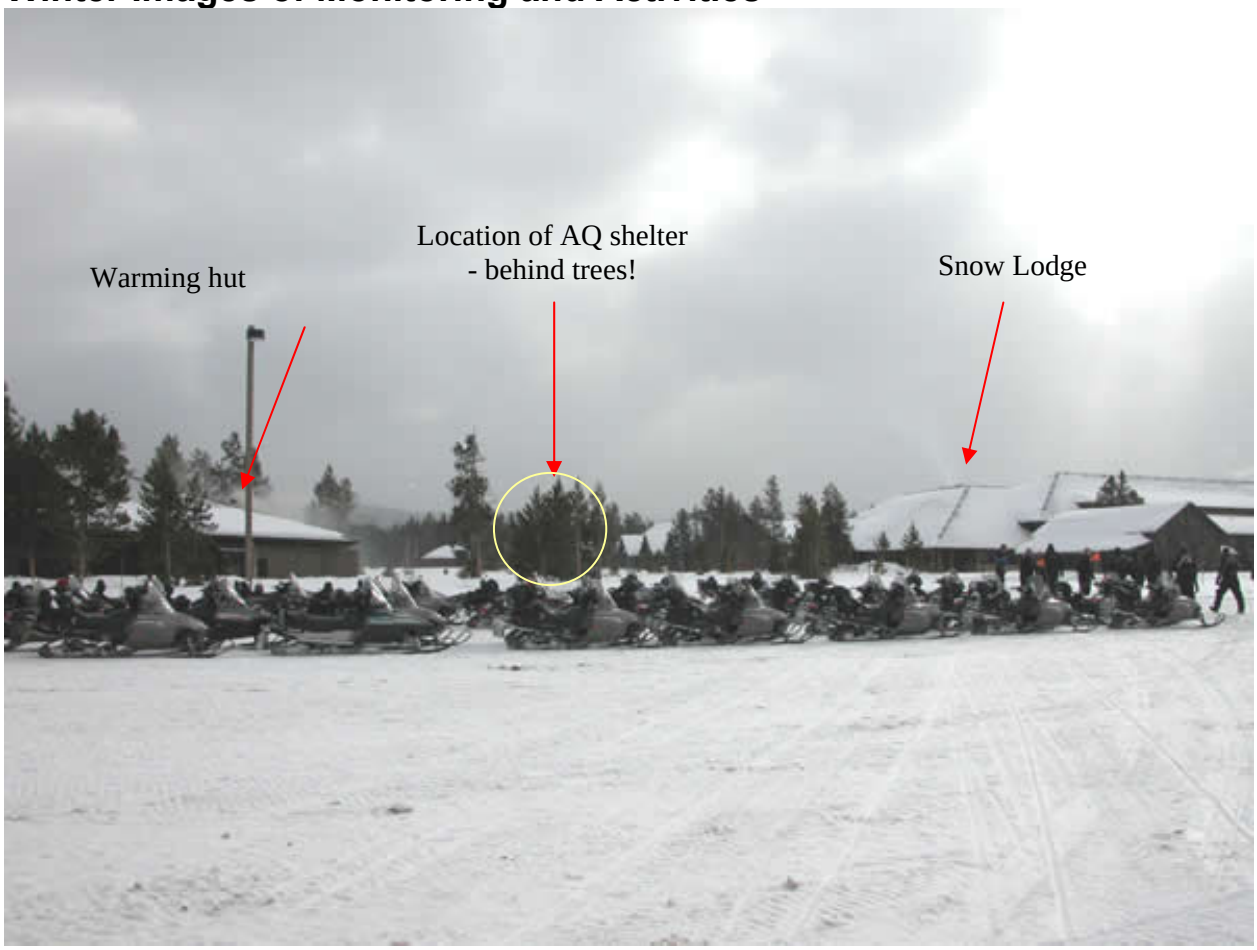


Figure A7. Wind rose (a) and pollutant rose (b) for Old Faithful. Winds are primarily from the SW and SE.

Appendix B

Winter Images of Monitoring and Activities



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

Picture of the monitoring shelter with the warming hut in the background.
Smoke is seen blowing away from the monitoring station in the SW winds.

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.

View to the south of Snow Lodge from 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.

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.

At Madison Junction most snowmobile groups stop to rest. Long lines of snowmobiles park with their engines off during the morning hours.