National Park Service
U.S. Department of the Interior

Air Resources Division
Denver, CO

Winter Air Quality in Yellowstone National Park
2005 - 2006

Air Resources Report NPS/ARD—2007/D-1207

ON THE COVER

One of the classic Bombardier snowcoaches with a new low-emission engine is pictured on the cover during an emissions testing run into the park. *Photo: John Ray*

Winter Air Quality in Yellowstone National Park
2005 - 2006

Air Resources Report NPS/ARD—2007/001

Dr. John D. Ray
National Park Service
Air resources Division
PO Box 25287
Denver, CO 80227-0287

January 2007

U.S. Department of the Interior
National Park Service
Air Resources Division
Denver, Colorado

Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available from the Air Resources Division website (http://www2.nature.nps.gov/air/publications) on the internet, from the NPS Technical Information Center (http://etic.nps.gov/welcome.aspx), or by sending a request to the address on the back cover.

Please cite this publication as:

Ray, J. D., 2007. Winter Air Quality in Yellowstone National Park: 2005 – 2006, Air Resources Technical Report NPS/ARD—2007/D-1207, National Park Service, Denver, CO.

NPS/ARD D-1207, January, 2007

Results from Yellowstone National Park

Winter Air Quality Study: 2005-2006

Executive Summary

The air quality in Yellowstone National Park was monitored at two locations as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less (PM2.5). Emission measurements[10,11] in the last two years have indicated that snowmobiles and snow coaches may have approximately equal contributions to the concentrations of CO.[10, 11, 12] Detailed entry counts of each type of vehicle at the west entrance were used in the analysis.[8]

The West Entrance near the town of West Yellowstone, MT is the primary indicator for overall air quality and the relationship to traffic, because detailed entry counts could be obtained at that site. Old Faithful is a destination for most of the winter use vehicles; they are present mid-day and that area represents the highest density of winter vehicles.

This report is an update to prior air quality and emission studies. The notable findings this year are:

- Air quality at both locations is good during the winter and is now well below the national ambient air quality standards

- The CO concentrations were about the same as last year despite an increase in the total number of winter vehicle entries (over last year's shorter season) at the west entrance.

- Even though summer traffic volumes[7] are nearly 60 times higher than winter traffic volumes, the highest hourly CO concentrations at both locations occur during the winter. However, the mean CO concentrations in winter have decreased over the last several years to be less than a factor of 2 higher than the summer concentrations.

- PM concentrations now correlate only weakly to traffic counts at the West Entrance and not at all at Old Faithful. This reflects lower emissions by winter vehicle although other local sources remain.

- The combination of reduced winter vehicle entries to the park and reduced emissions by the snowmobiles, using Best Available Technology (BAT), have greatly reduced the CO concentrations. Air quality has been stable or improving over the last three winters when the BAT requirement has been in affect.

Recommendations

- Monitoring could be reduced. The particulate monitoring measures more PM2.5 from summer wildfires than from motor vehicles. The PM2.5 and meteorological measurements at Old Faithful could be reduced to just winter-time CO without compromising the adaptive management metrics.

- The question of how much CO concentrations will increase if snowmobile traffic is allowed to increase up to the winter use plan limit is unresolved. It is recommended that the monitoring at the West Entrance continue and better vehicle counting and identification methods be used.

- Efforts should continue to keep the amount of vehicle queuing at the West Entrance to a minimum and to spread out the entry of vehicles. The direct emissions testing indicates that older snowcoaches are now more polluting than BAT snowmobiles.[12] Some effort should be made to equalize the snowcoach emissions (such as a snowcoach BAT) and to take advantage of the lower emissions that are possible as observed with newer snowcoaches or those retrofitted with new engines.

Air quality monitoring shelter at Old Faithful located next to the warming hut. *Photo: John Faust*

Contents

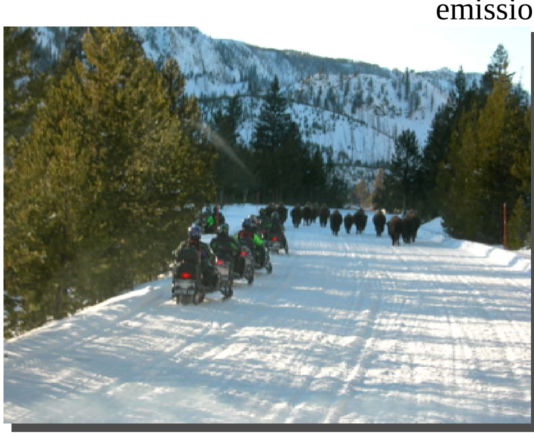
Page

Figures

Page

Background

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 on air quality of implementing the Yellowstone Winter Use Plan.[9] Several changes were expected to reduce the emissions from the snowmobiles, primarily the reduction in allowed daily entries and the cleaner engines using best available technology (BAT). Pre-sales of entry passes and guided groups for rental snowmobiles were also required which also influenced air quality. These actions appear to have greatly decreased measured concentrations of carbon monoxide (CO) and particulate matter less than 2.5 micrometers in size (PM2.5) at congested vehicle traffic points last winter season.[1]



A guided snowmobile group meets bison on the road, Feb. 2006.
Photo: John Ray

The US Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards[3] (NAAQS) for CO and PM2.5 based human health effects.[2] This report summarizes the CO and PM2.5 monitoring data from winter 2005-2006 and gives a historical perspective of monitoring data at the park. 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).

.

Methods

In-park monitoring

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 (see Figure 1 for location). Instrumentation at the site included a PM2.5 monitor (specifically a Beta Attenuation Monitor), 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.[4,5]

Webcam view of Old Faithful parking lot, Feb. 2006.

.

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 heated by wood-burning stoves from about 6:30 am until mid-afternoon. The digital camera image (to the left) was taken from the Old Faithful monitoring site showing snowmobiles in the 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 west entrance canopy (Figure 2).

Data were retrieved from EPA database and directly from the State of Montana, Department of Environmental Quality (DEQ) (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.

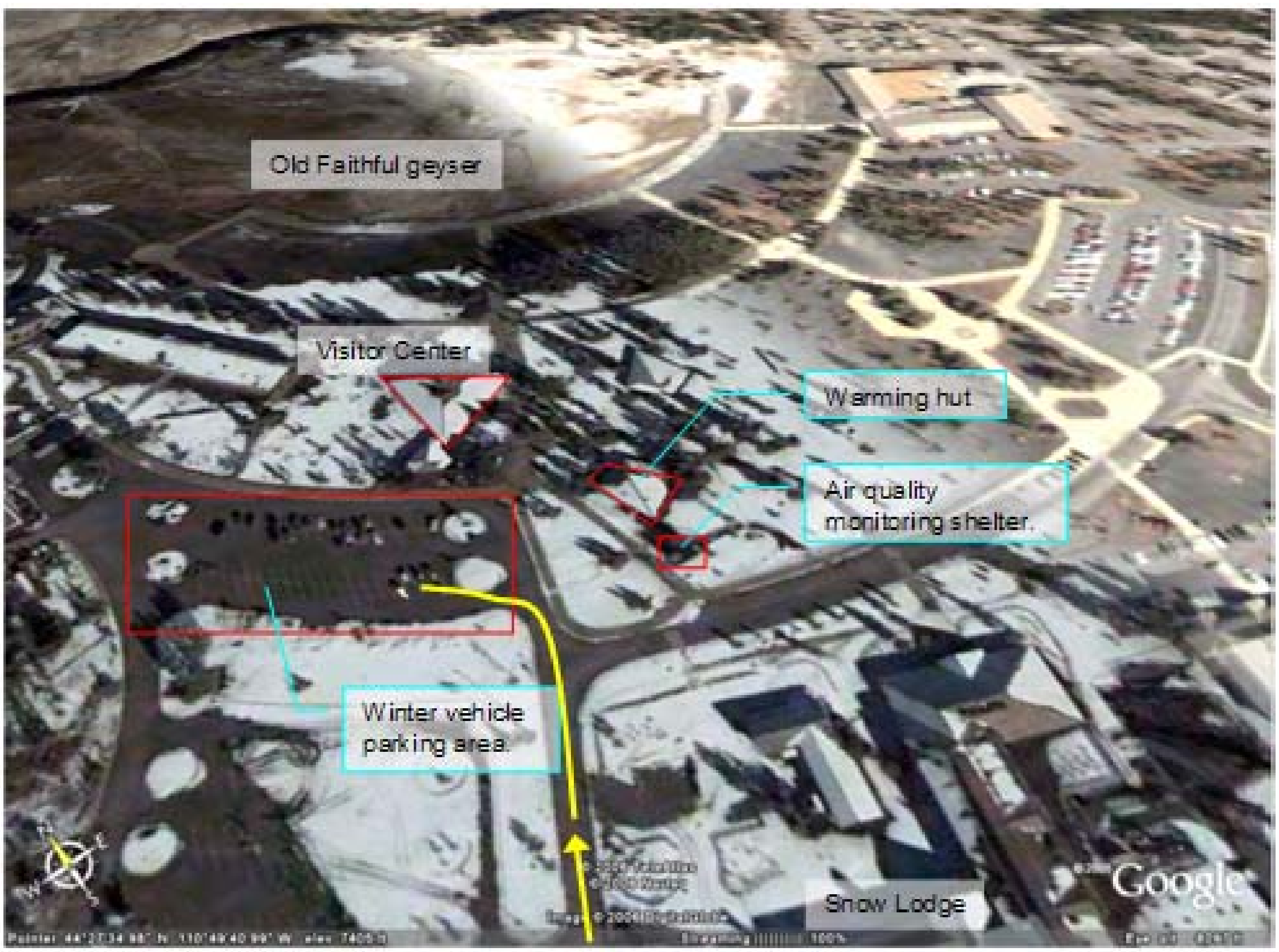


Figure 1. Aerial view of Old Faithful area showing the location of the winter vehicle parking and the air quality monitoring station. Old Faithful geyser is in the upper background.

Figure 2. Aerial view of the West Entrance area near the town of West Yellowstone. The air quality monitoring station is on the north side of the road near the roofed entrance structure. Winter vehicles queue up on the west side of the gate.

Results

Summary statistics

In past reports, the statistics in have been presented for the winter period of mid-December to mid-March.[1] The last four winters are compared in the tables for carbon monoxide (CO) and for particulate matter of 2.5 μm or less (PM2.5) in Tables 1 and 2. Both CO and PM2.5 are emitted from snowmobiles and snow coaches; details on emissions are available in a separate report.[6,10,12] Table 3 presents the concentrations for the national and state standards for these pollutants.[3]

Although CO concentrations in the late 1990's had approached the 8-hour standard, the current CO concentrations are only about 10% of the 8-hour standard

Table 1. Statistical comparison of CO between Yellowstone NP winter monitoring stations.

Location →	Old Faithful				West Entrance				
Winter season → Statistic CO	2005-2006	2004-2005	2003-2004	2002-2003	2005-2006	2004-2005	2003-2004	2002-2003	Units
Max 1-hr	**1.6**	1.6	2.2	2.9	**2.1**	2.8	6.4	8.6	ppm
% of Std	**4%**	4%	6%	8%	**6%**	8%	18%	25%	%
Max 8-hr	**0.5**	0.8	0.9	1.2	**0.9**	1.0	1.3	3.3	ppm
% of Std	**6%**	7%	10%	13%	**10%**	11%	14%	37%	%
Average	**0.18**	0.12	0.26	0.24	**0.23**	0.24	0.26	0.57	ppm
90th percentile	**0.26**	0.29	0.5	0.5	**0.40**	0.43	0.5	1.3	ppm

Table 2. Statistical comparison of PM2.5 between Yellowstone NP winter monitoring stations.

Location →	Old Faithful				West Entrance				
Winter season → Statistic PM2.5	2005-2006	2004-2005	2003-2004	2002-2003	2005-2006	2004-2005	2003-2004	2002-2003	Units
Max 1-hr	**56**	38	151	200	**44**	21	29	81	$\mu g/m^3$
Max Daily (24-hr)	**9**	6	16	37	**7**	6	8	15	$\mu g/m^3$
98th percentile[&]	**9**	9	9	21	**6**	6	7	17	$\mu g/m^3$
% of Std	**13%**	14%	14%	33%	**10%**	9%	11%	26%	%
Average	**3.5**	4.0	4.9	6.9	**1.9**	2.9	4.0	8.2	$\mu g/m^3$

[&] Based on NAAQS standard at the time of the measurement (65 ug/m^3)

Table 3. Ambient Air Quality Standards (AAQS) for carbon monoxide (CO) and particulate matter less than 2.5 micrometers (PM2.5).

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

Standard	Pollutant	24-hr PM2.5 98th percentile (μg/m³) [2]
National AAQS	PM 2.5	**65**
New NAAQS [3]	PM 2.5	**35**
Montana AAQS	PM 2.5	**65**
Wyoming AAQS	PM 2.5	**65**

1 Not to be exceeded more than once per year.
Link to EPA NAAQS standards: http://www.epa.gov/air/criteria.html ; WY DEQ http://deq.state.wy.us/aqd/standards.asp ; MT DEQ http://www.deq.state.mt.us/AirMonitoring/citguide/appendixb.html
2. The 3-year average of the 98th percentile of 24-hour concentrations at each monitor within an area must not exceed 65 ug/m³. The winter 98th percentile in the associated tables 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.
3. Revised by EPA Oct. 2006.

while the PM2.5 is about 13% of the old standard (26% of the new standard of 35μg/m³). These concentrations are above the background concentrations for the region, but are less than the NAAQS for human health. CO concentrations have remained about the same while PM2.5 concentrations are up slightly at the two monitoring locations from previous winter. At the present concentrations, these pollutants are not thought to represent a health hazard to park staff or visitors. Concentrations may be briefly higher next to or behind operating vehicles, however.

The West Entrance used to be much higher for CO that Old Faithful, however, now the concentrations are nearly the same. For PM2.5 the Old Faithful site continues to have higher concentrations. However, the highest PM occurs in early morning or at night at Old Faithful when snowmobiles aren't present; local sources are believed to contribute.

Seasonal Variations

The Old Faithful monitoring station operated throughout 2005 so that a complete winter-to-winter cycle could be determined. The winter and other seasons are broken out in Tables 4 and 5 for the Old Faithful station. The seasons are partly defined by the park's road opening and closing dates.

For CO, the winter periods have the highest concentrations, summer maximums are about half the winter maximums, and the period in the Fall, when park roads are closed has the lowest concentrations. The seasonal average and the 90th percentile CO, a robust statistical metric for the higher concentrations, are closer in summer and winter than the maximum values. These seasonal concentrations are consistent with observations reported in the winter 2004-2005 report that winter CO concentrations are now in the approximate range of the summer CO concentrations.[1]

The Yellowstone PM2.5 concentrations follow a very different pattern than the CO for the seasonal values. The summer period has some extended PM2.5 high concentrations compared to the winter. A review of regional wildfires and the transport of smoke plumes based on satellite aerosol images leads to the conclusion that the high PM during summer comes not from automobile traffic, but from wildfire smoke plumes. The air quality for PM2.5 is actually worse during the summer than at other times of the year at Yellowstone.

Table 4. Statistical comparison of CO (ppm) for different seasons in Yellowstone NP.

Location ➔	**Old Faithful**					
Season ➔ / **Statistic CO**	**Winter 04-05**	**Spring 2005**	**Summer 2005**	**Fall 2005**	**Dec. 2005**	**Winter 05-06**
Max. 1-hr	1.57	0.79	0.78	0.28	1.02	**1.6**
Max. 8-hr	0.80	0.28	0.37	0.17	0.50	**0.50**
Season average	0.24	0.18	0.20	0.11	0.19	**0.18**
90th percentile	0.39	0.22	0.27	0.15	0.32	**0.26**
Period	Dec 15 – Mar 15	Mar 16 – Apr 19	Apr 20 – Oct 31	Nov 1 – Nov 30	Dec 1 – Dec 14	Dec 15 – Mar 15

Table 5. Statistical comparison of PM2.5 (μg/m^3) for different seasons in Yellowstone NP.

Location ➔	**Old Faithful**					
Season ➔ / **Statistic PM2.5**	**Winter 04-05**	**Spring 2005**	**Summer 2005**	**Fall 2005**	**Dec. 2005**	**Winter 05-06**
Max. 1-hr	38.0	28.0	39.0	36.0	27.0	**56.0**
Max. Daily(24-hr)	6.0	6.6	14.0	11.0	11.0	**8.9**
98th percentile	9.0	6.6	11.1	11.0	11.0	**8.5**
Season average	4.0	4.2	5.7	3.7	3.9	**3.5**

Table 6. Number of vehicles entering park for different seasons based on monthly use statistics[7].

Period	Vehicles**	Months
Winter 04-05	11,314	Dec-Mar
Spring 05	5,271	Apr
Summer 05	661,114	May-Oct
Fall 05	24,121	Nov
Winter 05-06	14,475	Dec-Mar

** These vehicle counts correspond roughly to the season labels in tables 4&5. The monthly public use statistics don't provided for finer resolution. The assumption is that much of the traffic ends up at Old Faithful.

The bison on the Yellowstone roads in winter get very close to the visitor vehicles. Photo: J. Ray

Summer particulate matter concentrations were higher than winter because of Western wildfire smoke.

The second point to recognize is that the PM2.5 concentrations are well below the national standard for both the 24-hour average and the annual average.

The air quality in the winter periods can be compared to other seasons for both the West Entrance and Old Faithful. In Figure 3, CO concentrations for four winter periods are compared to summer when there is wheeled-vehicle traffic and to periods between summer and winter when the park is closed (no traffic). Table 6 gives the reported traffic counts for each period. The winter background CO concentration is roughly 0.1 to 0.2 ppm for the Yellowstone area. During the Fall period, when the park is closed, both locations have 8-hour maximum CO concentrations that are lower than either the summer or winter periods. There is still contractor and park staff activity in the park that may account for the above background values plus some mobile source activity from the town of West Yellowstone. Summertime CO concentrations are well above the concentrations during the park-closed periods. The Old Faithful area concentrates summer traffic, which is reflected in its higher measured CO than the West Entrance. All of the winter periods have higher CO concentrations than summer.

A comparison of CO and PM over the different seasonal periods at Old Faithful (Figure 4) illustrates how PM2.5 concentrations are unexpectedly high during summer. The Spring period, when the park was closed, had almost as high of PM2.5 daily maximum as the winter period which supports the conclusion that much of the PM2.5 at Old Faithful is unrelated to winter vehicle use.

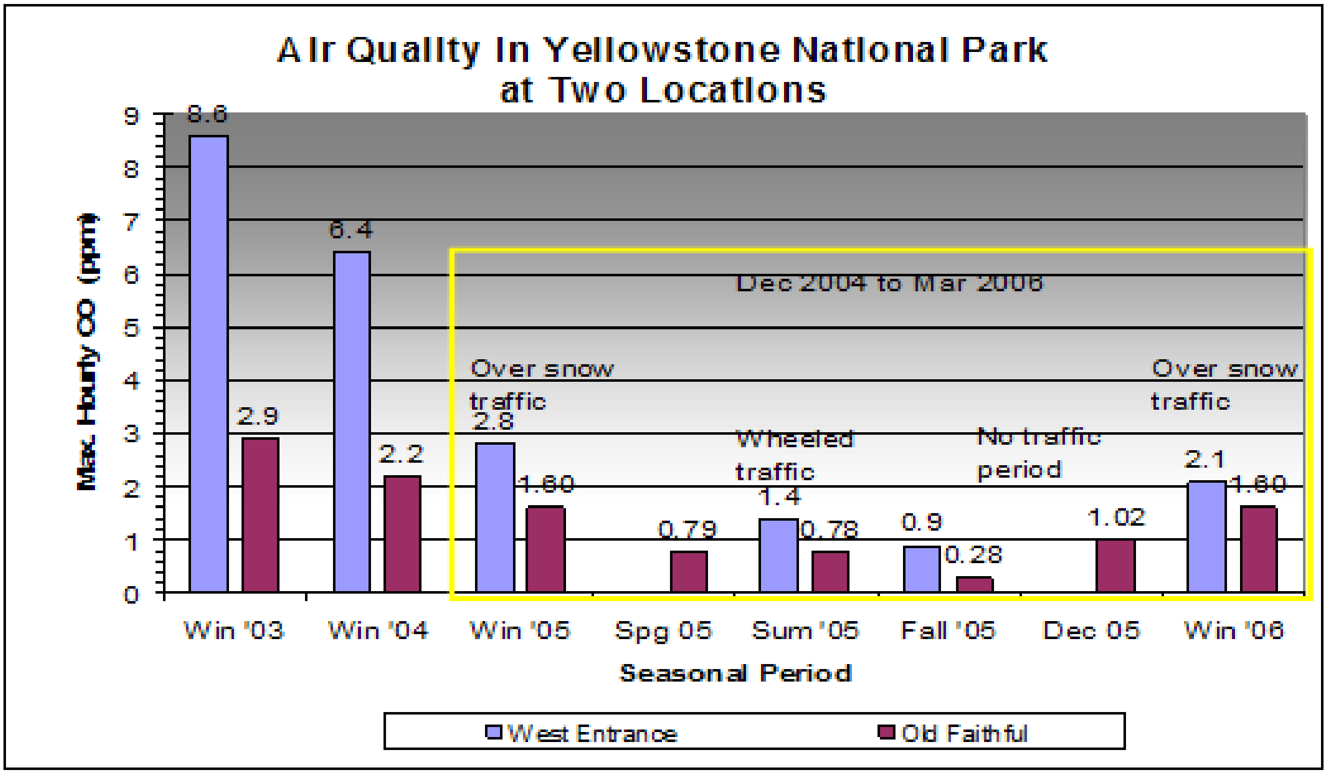


Figure 3. CO concentrations at two locations are compared to the seasonal periods at Yellowstone. Lowest CO concentrations are when the park is closed in the Fall. Winter CO peak concentrations are still higher than in the Summer when traffic volume is much higher.

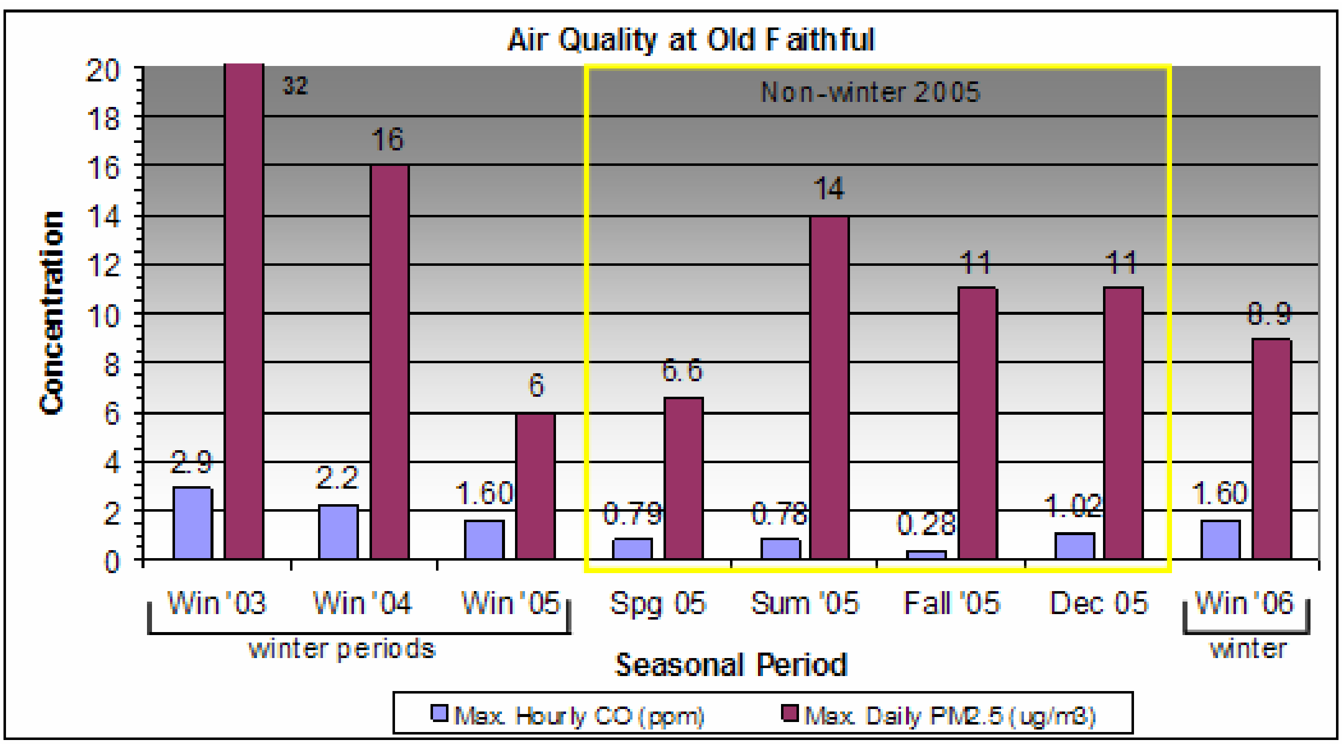


Figure 4. Old Faithful is a high traffic area both summer and winter. Summer concentrations of CO are low, but the PM2.5 goes high in July and into the Fall from wildfire smoke that is transported to the park.

Winter air quality has improved in recent years and is now approaching the concentrations seen in summer.

Traffic effects on air quality

The effects of winter traffic on air quality are best characterized at the West Entrance where both air quality data and detailed traffic counts are available. There is a general trend in the second highest 8-hour CO and the 98th percentile of daily maximum PM2.5 that follows the changes in winter traffic and the vehicle emissions (Figure 5). For the west entrance, the winter of 2000-2001 was a high point for snowmobile use and CO concentrations have decreased since then. Over the last three winters the CO concentrations at the West Entrance have been flat. The PM2.5 follows a similar pattern at both the West Entrance and Old Faithful locations. The changes that have driven the decreases in CO and PM2.5 concentrations are smaller numbers of snowmobiles entering the park and a switch to cleaner-emitting snowmobiles that meet the BAT, mostly by using 4-stroke engines in the snowmobiles. The reduction in aerosol emissions (unburned oil and fuel) from the snowmobiles has been especially noticeable as reduced odor and reduced PM2.5.

Tables A-1 to A-5 in appendix A provide the detail used in the figures on the numbers of vehicles and the air quality indicator concentrations from 1998 to 2006. The West Entrance is broken out from the totals, because there is a monitoring station at that entrance and none at the other entrances.

The daily pattern of air pollutants at the West Entrance (Figure 6) follows the times for entrance and exit of the winter vehicles.[1,8] The peak in the CO concentration is centered on the same 9 am hour as the peak in snowmobile counts. The secondary CO peak at 5 pm corresponds to the rush of snowmobiles exiting the park. The delay in the PM2.5 peak (10 am) and the long tail in the afternoon and evening suggests another PM source besides snowmobiles is contributing.

The entrance counts[8] illustrate a difference in when the snowmobiles enter the park compared to the snow coaches (Figures 7 & 8). Snowmobiles come in groups lead by guides; the period between 8-11 am is when most of the traffic enters. Snow coaches are more spread out during the day, although the West, North, and East gates tend to get most entries during the morning. The snowcoach traffic starts a little earlier and has a second peak midday.

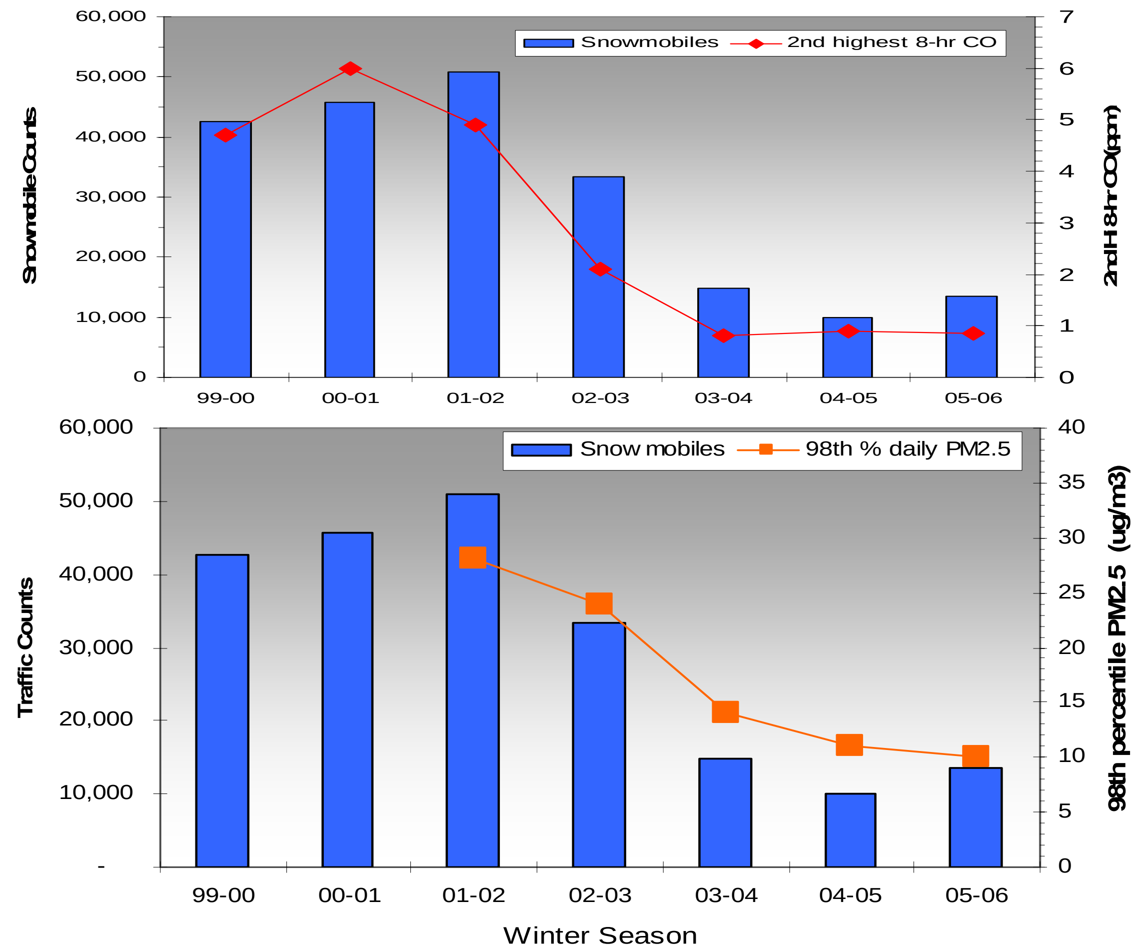


Figure 5. Pollutant concentrations and traffic counts for the West Entrance for seven winter seasons. The traffic counts are based on summing the monthly data from the public statistics[7] website.

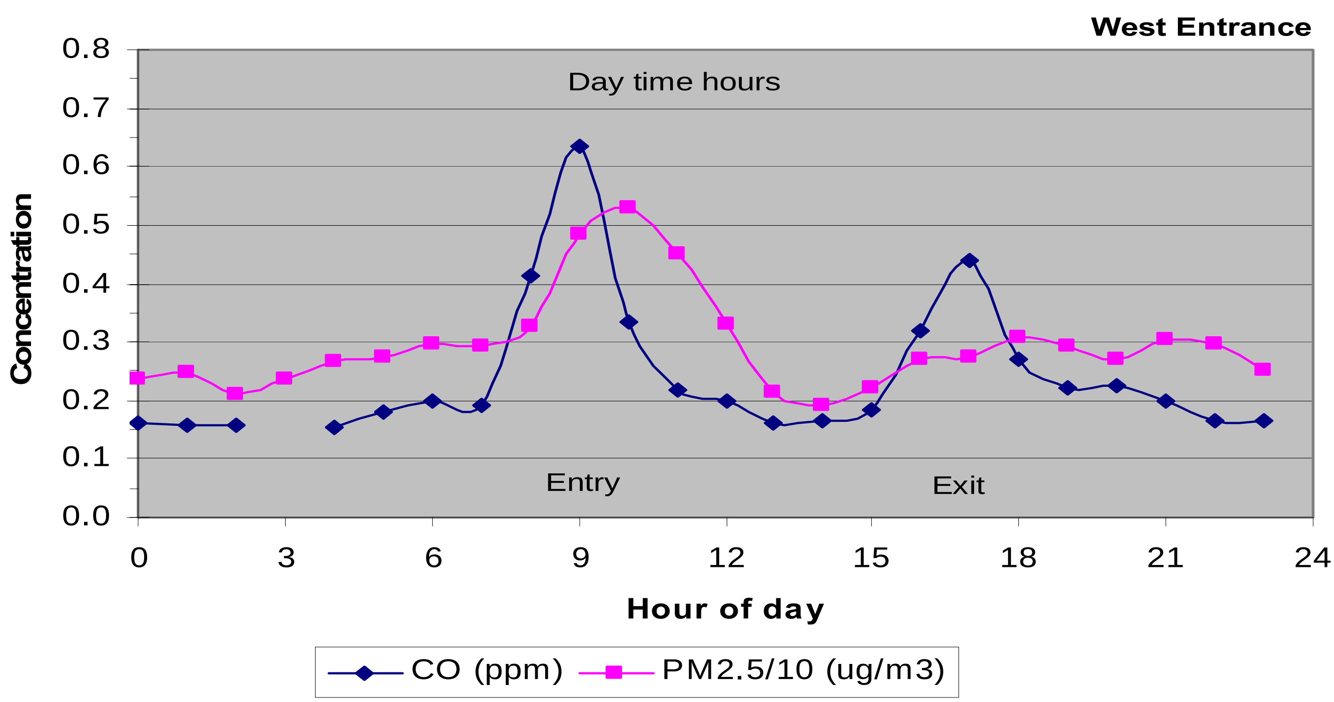


Figure 6. Average CO and PM2.5 at the West Entrance by hour of day. The yellow box is the period when entrance counts are recorded. There are no records for the exit counts.

Peak snowmobile entry is 9-10 am; arrival at Old Faithful is about 2 hours later. Counts are for entry only, no exit counts are recorded. The CO hourly data has peaks for entry and exit. The exit peak is smaller, because snowmobile traffic does not stop, is more spread out, and traveling at higher speed. PM also has a double peak, but with a 1-hour lag. The afternoon peaks are much more spread out and continue well after dark when there is no traffic exiting the park. This is most likely from wood smoke from nearby West Yellowstone beginning to overlap with the vehicle emissions.

Incremental Pollutant Changes with Traffic Volume

The change in CO with the change in traffic volume over the last eight years is plotted in Figure 9. This plot suggests a high sensitivity to the number of snowmobiles[1] that enter the west entrance each day. The dashed lines show a possible relationship, excluding the three years with full BAT requirements. More than just the volume of traffic

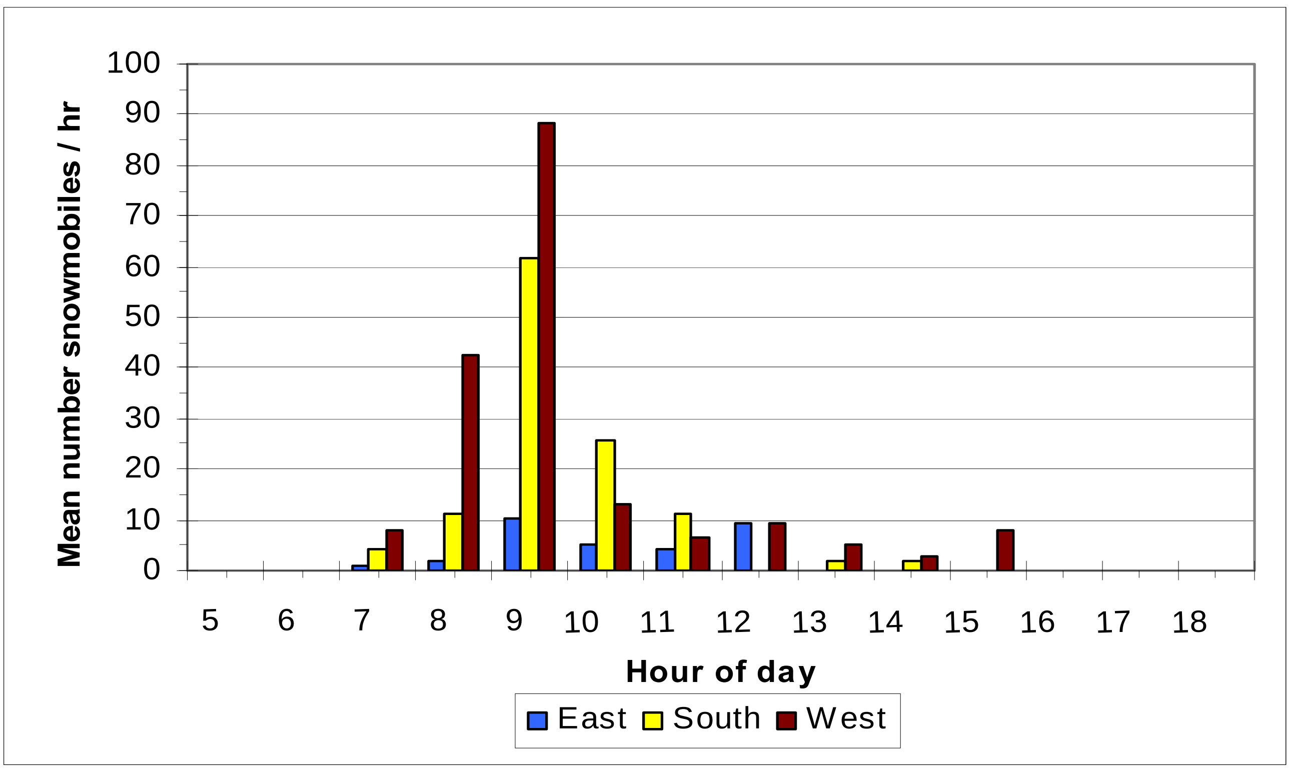


Figure 7. Average entrance counts for snowmobiles. Red-brown bars are the west entrance daily mean counts by hour. (Hourly traffic counts are not available for the North; all traffic in early morning).

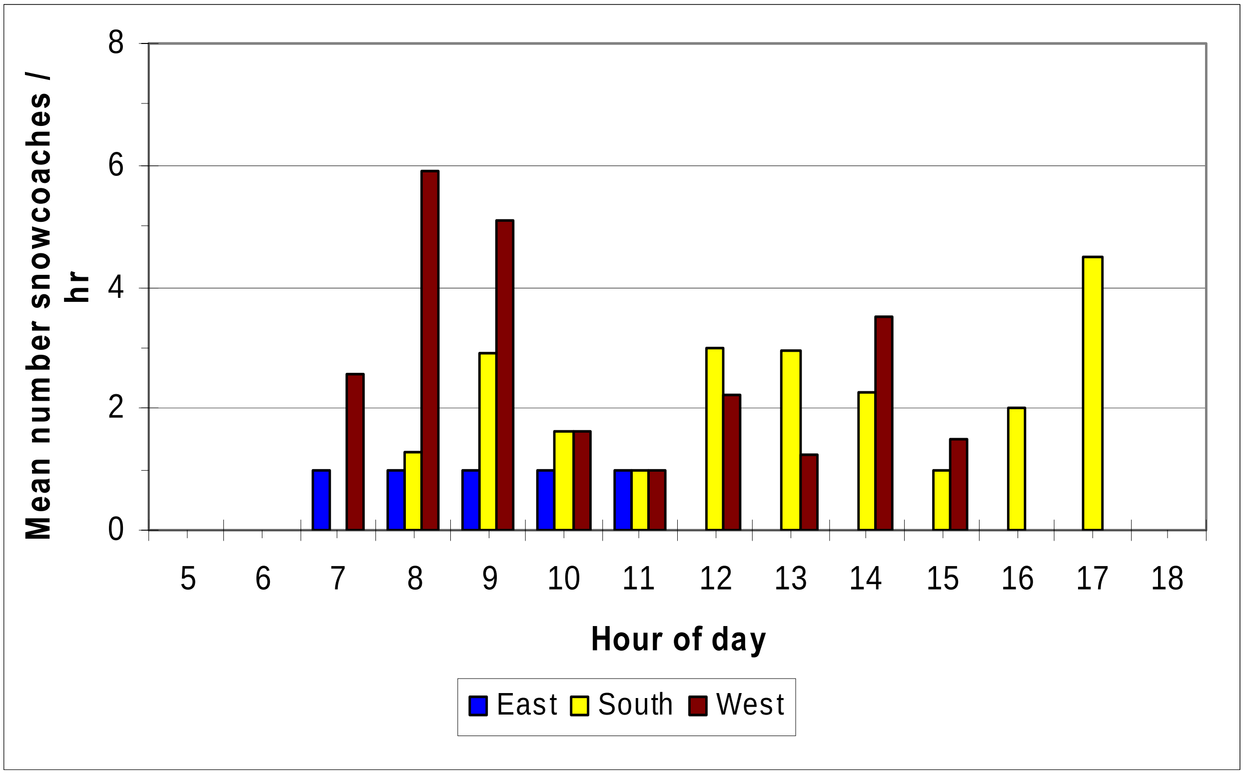


Figure 8. Average entrance counts for snowcoaches. Dark red are the west entrance daily mean counts by hour. (No hourly counts are available for the North.)

changed over the period in the chart. Only the three open circle points labeled "last 3 winters, 4 stroke" represent BAT snowmobiles. The CO concentrations in the last three years appear to be relatively insensitive to the variability of the daily mean number of snowmobiles. The dashed lines in Figure 9 are a non-linear fit to the number of snowmobiles when 2-stroke engines predominated.

Monthly maximum CO concentrations were compared to the monthly traffic totals for the last two winters (Figure 10) for only BAT snowmobiles. Although reasonable regressions were obtained, the slopes were very different for the last two winters. The 2005-2006 winter CO concentrations were much less sensitive to changes in the amount of traffic through the entrance gate. The mean CO had a dual daily peak that corresponded to peak traffic through the entrance. PM2.5 did not show such a pattern.

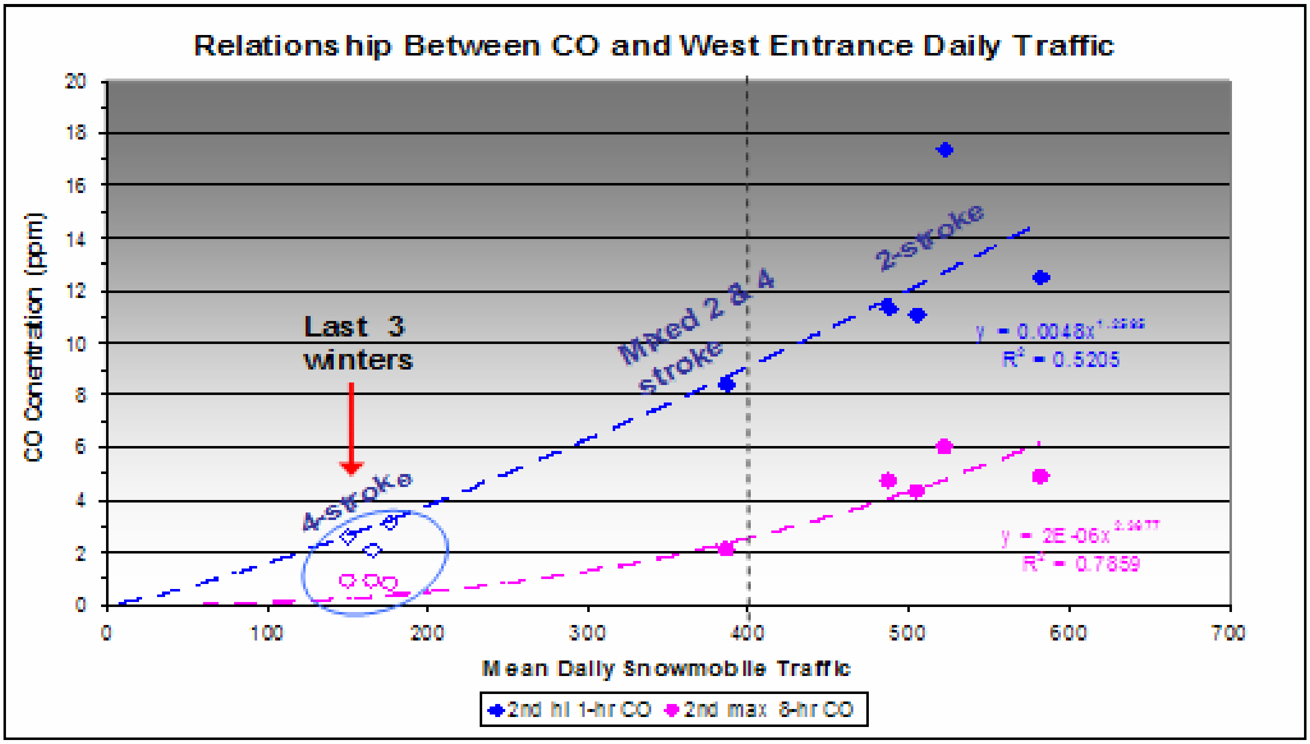


Figure 9. Relationship between winter peak 1-hour CO concentrations and average daily snowmobile entrance counts at West Yellowstone for two CO statistics. Based on data[7] from 1998 to 2006. Note the switch-over in snowmobile engine types from 2-stroke to 4-stroke. The regression model (dashed lines) only use the years with 2-stroke engine snowmobiles. Dotted line is current daily limit.

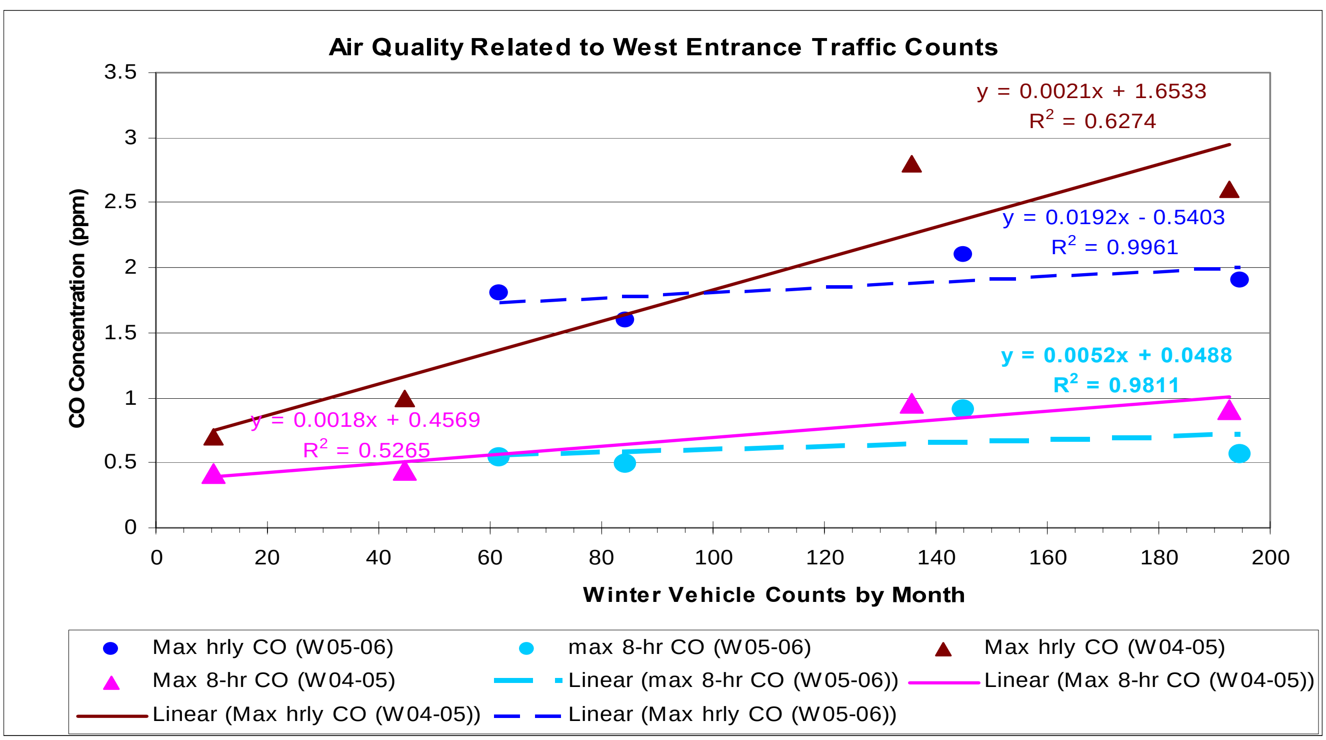


Figure 10. Relationship of monthly CO concentrations to monthly average winter vehicle counts[7] at the West Entrance for BAT snowmobiles and uncontrolled snowcoaches is a more realistic estimation approach. Winter 2004-2005 data are the sold lines in red; winter 2005-2006 data are the dotted lines in blue.

Snowmobiles parked at Old Faithful visitor center.

Unlike in the winter of 2004-2005, the variation in snowmobile traffic over a few busy weekends for winter 2005-2006 did not have a linear relationship with CO concentrations based on the limited daily totals of vehicle entry that were available for the busiest weekend, so no relationship could be investigated. If the range from 1-hour regression models for both winters in Figure 10 is used to estimate by extrapolation the expected maximum hourly CO concentration for the allowable number of snowmobiles per day through the entrance, the CO might range between 2.5 and 7 ppm.

It seems unlikely that all the meteorology, traffic patterns, and alternate emissions sources can be accounted for from the observational data. Computer modeling takes many of these factors into account and is likely to be a better approach for estimating the affect of traffic volume on CO concentrations. In Appendix C, results from the computer model of the various Winter Use Plan alternatives are used to construct a CO concentration relationship with the equivalent number of BAT snowmobiles. Clearly, the emissions from the snowcoaches must be taken into account to estimate the CO concentrations. EIS alternatives current, 1, and 4 (see appendix C) yielded estimated seasonal high CO concentrations of 1.9, 6.4, and 8 ppm based on analysis of the model output. Thus, increasing numbers of winter vehicles are expected to increase the CO and PM2.5 concentrations above the present values.

The pollutant and entrance count data for the West Entrance have been examined carefully for the winter 2005-2006 to determine relationships. As before, it was difficult to get good linear relationships between the traffic counts and daily pollutant measurements with the limited breakout by time and vehicle of the entrance records. There does seem to be some relationship between the observed maximum CO concentrations for a winter season and the mean daily traffic (Figure 9). During the period plotted in Figure 5 there was a change from 2-stroke to 4-stroke BAT snowmobile engines (labeled in Figure 9) and the entrance procedures changed. It seems very likely also that the build up of pollutants near the gate is related to the length of the queue and the relationship is non-linear. At lower traffic volume, when there is no queue; pollutant build-up would be expected to be less.

Seasonal Traffic and Air Quality

The monthly and seasonal changes in amount of traffic and the peak monthly air pollutants can be see in Figures 11 and 12. Note the log scale for the number of vehicles on the y-axis; summer traffic is 60 times the amount of winter traffic.[7] The peak CO concentrations are 2-3 times larger in winter than summer for the last two winters despite the much larger number of vehicles in summer (Figure 11).

The winter to summer difference in PM2.5 is even more dramatic (Figure 12), but it has little to do with vehicle traffic. Western wildfires bring smoke into Yellowstone, sometimes from distances of hundreds of miles. This has a bigger effect on summer air quality than the motor vehicle traffic at the locations we measured.

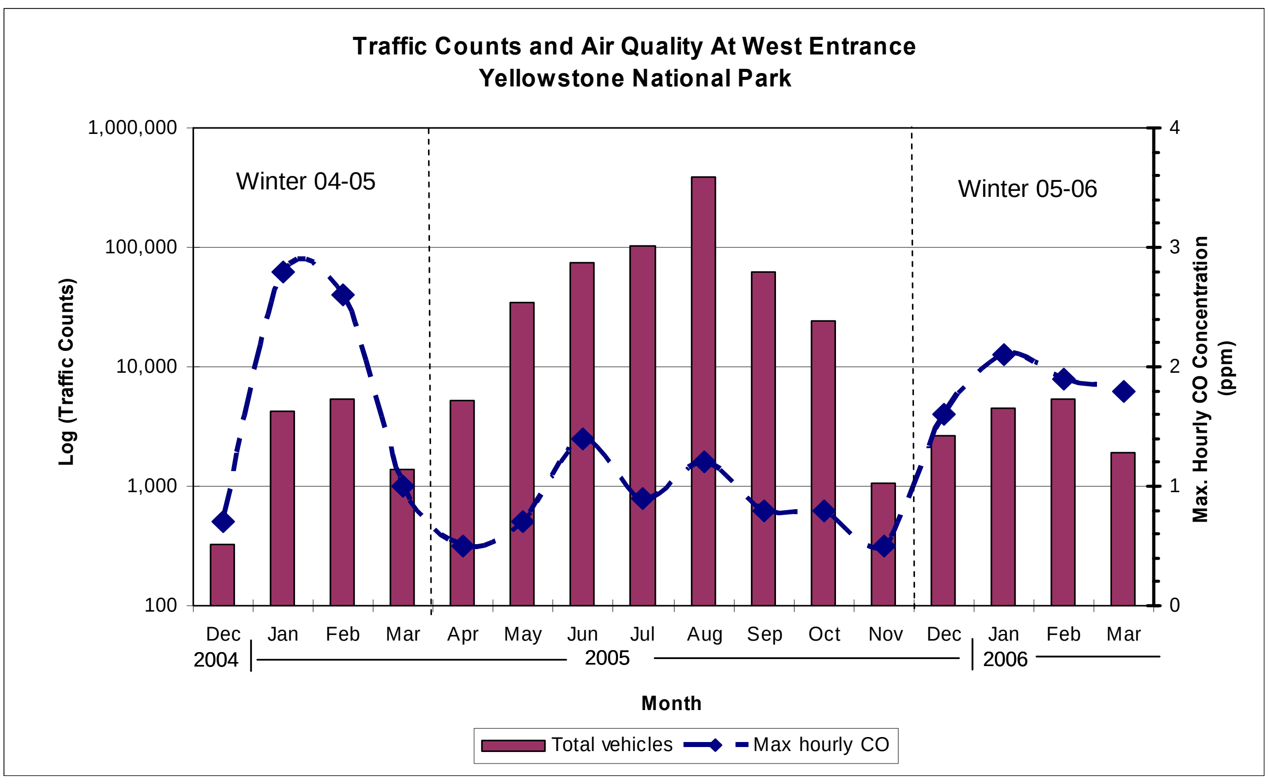


Figure 11. Comparison of vehicle traffic in the West Entrance compared to CO concentrations by month. CO concentrations are highest during the winter periods when total number of vehicle counts is small (note the logarithmic scale on the y-axis). Lowest CO periods correspond to the lowest traffic periods in late March and November.

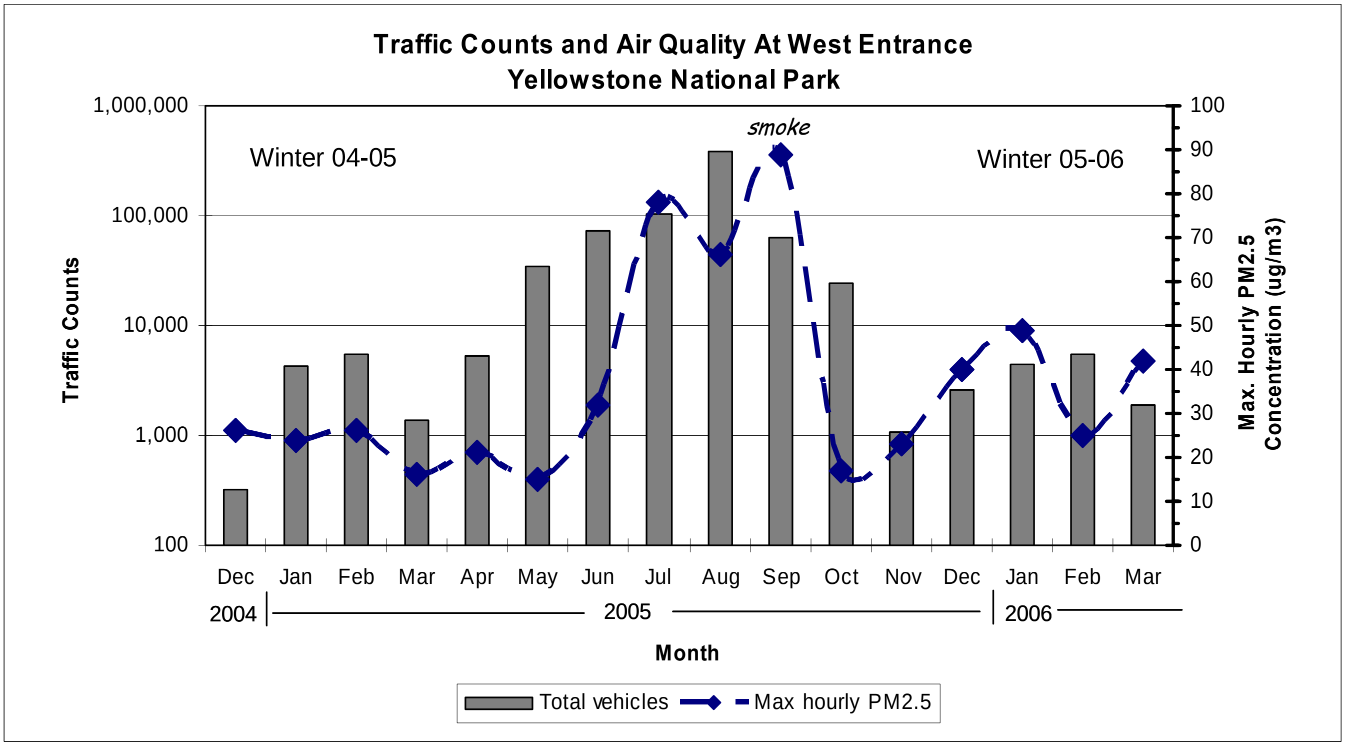


Figure 12. Comparison of vehicle counts at the West Entrance with maximum hourly PM2.5 by month. The PM concentration seems to have little to do with the traffic counts. The highest PM is during the summer months when wildfire smoke is thought to be the major contribution.

Air pollutant concentration visualizations

Color coding concentrations for every hour and day during the winter is a good way see the time-of-day relationships. The differences between the two monitoring sites and the relationship, or lack of relationship, between pollutants and winter vehicles are easily seen with the color coded plots in Figures 13 and 14. The shaded areas bounded by dashed lines are approximate nighttime periods or low traffic periods. Labels mark when the highest traffic periods are for the two monitoring sites.

West entrance traffic enters the park mostly between 7-10 am, arrive at Old Faithful between 11am and 3pm, and exit the west gate between 4 and 6 pm. Peak PM2.5 concentrations (Figure 13) seem to have little to do with the peak traffic periods at either site. Old Faithful has a local source that shows up most evenings (see the 2004-2005 report for details[1]). The magnitude of the evening PM concentrations and length of time gets larger as the season progresses. CO is much more directly related to traffic at the west entrance as seen in Figures 6 and 7 and illustrated by the red and yellow areas in Figure 14.

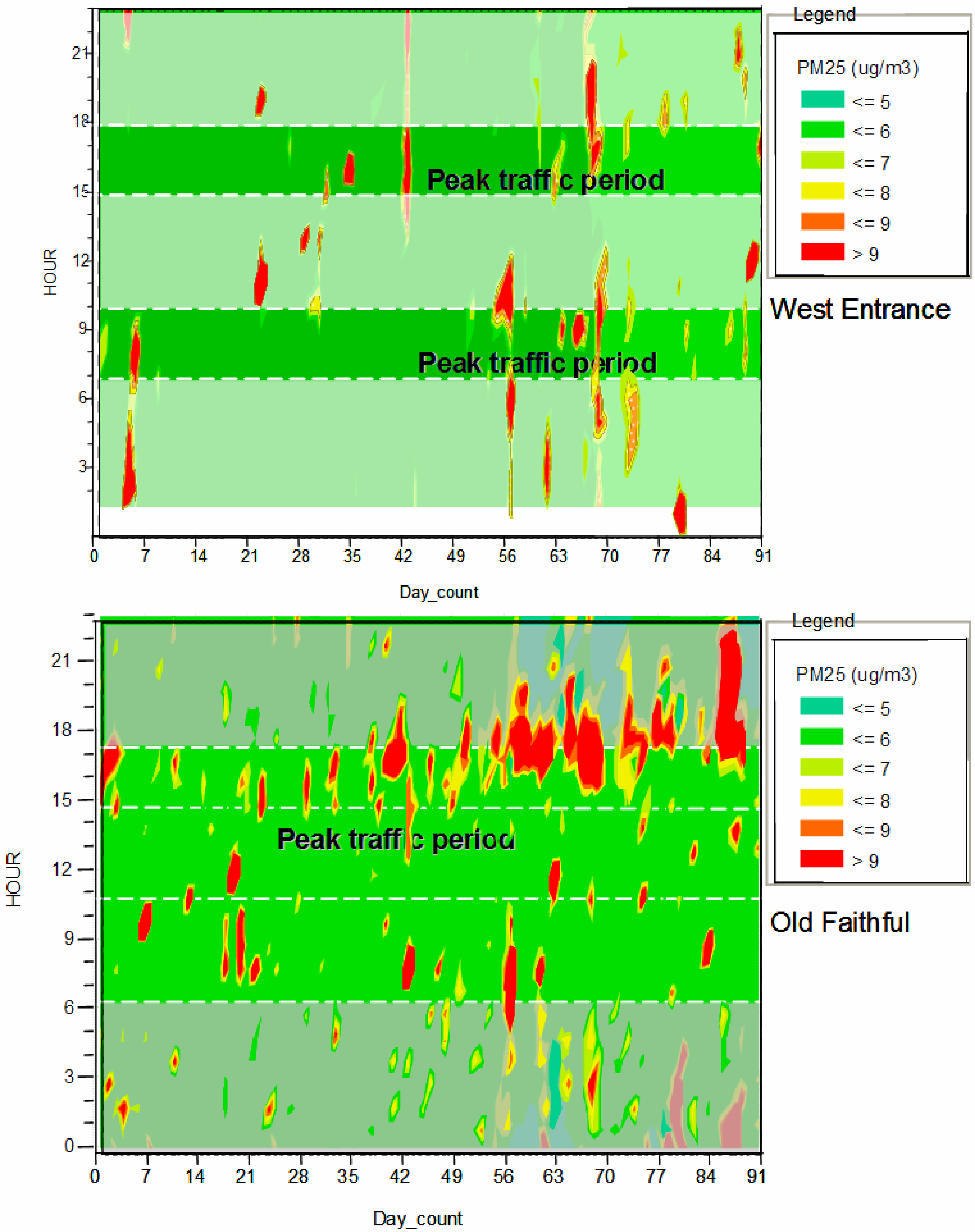


Figure 13. Ambient PM2.5 hourly concentrations for every hour of the 2005-2006 winter season. Day counts start on Dec. 15 and end Mar. 15 of the next year.

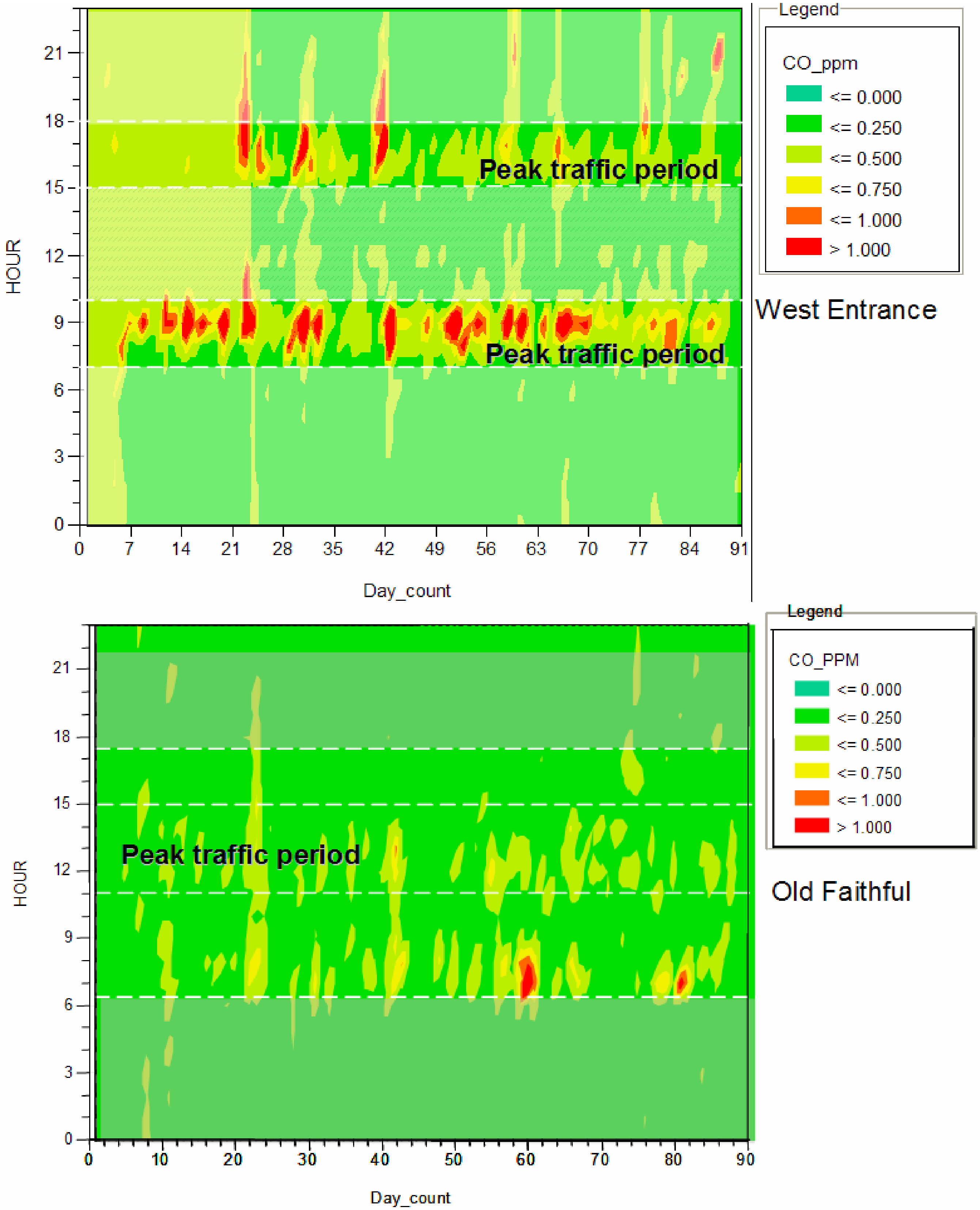


Figure 14. Ambient CO concentrations for every hour of the day for the 2005-2006 winter season. Day counts start on Dec. 15 and end Mar. 15 of the next year

The peak CO concentration periods are primarily during the peak traffic periods. At both sites the CO goes down to low values overnight. Old Faithful has a CO local source that starts in the morning near daybreak. The timing of this source corresponds to the normal time when the maintenance staff light up the wood-burning stoves in the warming hut. Snow Lodge also has early morning emissions and more prominent emissions of PM that start around diner time and go into the evening that correspond to observed and photographed smoke emissions from the kitchen vents. Local sources to Old Faithful were examined in more detail in the 2004-2005 winter air quality report.[1]

Winter vehicle traffic along the road to Old Faithful. Photo: J. Ray

Discussion

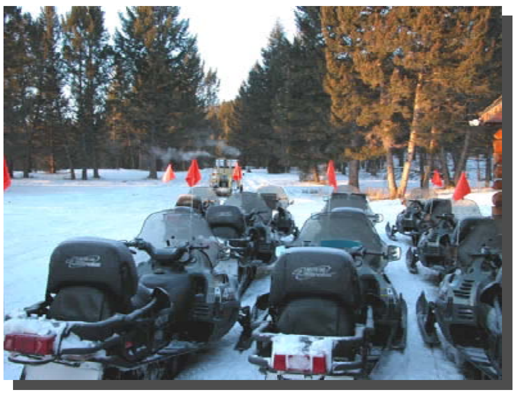
Old Faithful is the destination for most of the winter vehicle traffic. The geyser display is magical in the winter. Photo: J. Ray

Direct measurements at two locations within Yellowstone National Park, the West Entrance and Old Faithful, show that air quality has improved over the last several years. The magnitude of peak CO events and the overall concentration and number of events have decreased. Although the West Entrance continues to have higher CO concentrations than those at Old Faithful, the difference is becoming smaller. At Old Faithful, the total number of winter vehicles present during mid-day is greater than at the peak hours at the West Entrance, however, arrival and departures are spread out temporally and the vehicles do not usually idle for long. Along the roads leading to Old Faithful, the vehicles are spread out and at lower density. The exceptions are when the vehicles stop in clumps to view or let wildlife pass and the stops made at the warming huts and thermal-feature parking lots.

The enhancement in CO concentrations by the snowmobile and snowcoach traffic is clearly seen in the dual daily peaks at the West Entrance, the high spikes that occur only during the winter, and the overall increase in CO when low traffic periods are compared to the winter open season. The PM2.5 is less clearly related to the winter vehicle traffic in the last few seasons. Although there is some enhancement and dual daily peaks at about the same time as the CO peaks at the West Entrance, there are also peaks in early morning and in the evening when there is no traffic through the gate. At Old Faithful, the PM2.5 does not relate closely to traffic and has high concentrations when winter vehicle traffic is not present. The fact that other PM2.5 sources than snowmobiles have become dominate is mainly because of the lower PM2.5 emissions by the BAT snowmobiles.

The analysis of the monitoring data has been unable to estimate with any great certainty the incremental level of air pollution with traffic volume of the BAT snowmobiles. A 32% increase in winter vehicle traffic through the West Entrance this winter (2005-2006) had a very small influence on the air quality, however, much of that was because of more use days rather than larger daily traffic. It is likely that meteorological differences between the winters are playing a part in determining the changes in CO concentrations near the entrance so that small changes in daily traffic volume are obscured.

The air quality monitoring data shows that the plan to reduce both the number of snowmobiles and their emissions has been a successful strategy towards improving the air quality in Yellowstone. If it can be assumed that the amount of air pollution from wheeled mobile sources in the park during the summer is an acceptable level, then winter use vehicles will need to have lower emissions or fewer vehicles be admitted. It would be better to have either a pollutant concentration limit or a total emissions limit for mobile sources that would be protective of the clean air in the Yellowstone natural area. The number of snowmobiles currently entering the park during the winter is below the allowable limits set in the winter use plan.[9] The snowmobile BAT has reduced emissions, but snowmobiles are still much dirtier than light-duty cars and trucks.[11, 12] The emissions tests on winter vehicles entering Yellowstone by the University of Denver researchers[6] clearly shows that both the snowmobiles and the snowcoaches are high pollutant emitters compared to summer vehicles. The small amount of change in air quality over the last three winters suggests that additional measures will have to be taken or the present air pollutant concentrations are likely to be the continuing condition.



Snowmobiles park in long lines at the warming huts at Madison Junction. Photo: J. Ray

Acknowlegments

We are grateful for Montana DEQ's assistance and for allowing us to use data back to 1998 when they started West Entrance monitoring station.

Literature Cited

1. 2004-2005 Yellowstone Winter Air Quality Overview Report, NPS Air Resources Division, March 2005. Available from: **http://www2.nature.nps.gov/air/Pubs/index.cfm**

2. EPA CO and PM effects on health http://www.epa.gov/air/urbanair/6poll.html

3. EPA National Ambient Air Quality Standards (NAAQS) http://www.epa.gov/ttn/naaqs/

4. Data Transmittal Report for the Yellowstone National Park Winter Use Air Quality Study, 2004-2005 – Mar. 15, 2006, Air Resource Specialists, Ft Collins, CO (August, 2006). Available from: http://www2.nature.nps.gov/air/Pubs/index.cfm

5. Data Transmittal Report for the Yellowstone National Park Winter Use Air Quality Study, 2005-2006 – Draft Aug, 2006, Air Resource Specialists, Ft Collins, CO (August, 2006). Available from: http://www2.nature.nps.gov/air/Pubs/index.cfm .

6. DU emission reports: FEET web site www.du.edu/feet/

7. National Park Service, Public Use Statistics, Yellowstone visitor and vehicle count statistics http://www2.nature.nps.gov/mpur/

8. Private communication, Hourly records of vehicle entries collected by ranger staff

9. Yellowstone Winter Use Plan and other Winter Use Technical Documents http://www.nps.gov/yell/parkmgmt/winterusetechnicaldocuments.htm

10. Winter Motor-vehicle Emissions in Yellowstone National Park**,** Bishop, G., Burgard, D. A., Dalton, T. R. Stedman, D. H., and Ray, J. D., Environ. *Science & Technol.*, 39, 2505-2510, 2006.

11. AIR QUALITY MODELING REPORT SNOWMOBILE AND SNOWCOACH EMISSIONS, Table 6-2, page 32, Air Resource Specialists, Ft Collins, CO (November, 2006). Available from: http://www.nps.gov/yell/parkmgmt/winterusetechnicaldocuments.htm .

12. Portable Emission Measurements of Snowcoaches and Snowmobiles in Yellowstone National Park, G. A. Bishop, R. Stadtmuller., D. H. Stedman, and J. D. Ray, Final Report, University of Denver, Dept. of chemistry and Biochemistry, Denver, CO (Jan 2007).

13. Terry M. Spear and Julie Hart (Montana Tech of The University of Montana) and Dale J. Stephenson (Boise State University), **Yellowstone**

Winter Use Personal Exposure Monitoring, Draft Report, June 2006. http://www.nps.gov/yell/parkmgmt/winterusetechnicaldocuments.htm

14. Sive, B., D. Shively, and B. Pape, **Spatial Variations of Volatile Organic Compounds Associated with Snowmobile Use in YNP**, October 25, 2003. http://www.nps.gov/yell/parkmgmt/upload/sive_report.pdf

15. C-3. State of WY, Dept of Environmental Quality, Flagg Ranch monitoring station, Data available from the EPA Air Quality System database, Site ID=560390999 http://deq.state.wy.us/aqd/ ; http://www.epa.gov/air/data/index.html

16. C-4. P. Warneck, **Chemistry of the Natural Atmosphere**, Academic Press, New York, pp. 158-159, 1988.

Data Access

Air monitoring and emission study reports, journal publications, and data: http://www2.nature.nps.gov/air/studies/yell/20042005yellAQwinter.cfm

Hourly CO, PM2.5, and meteorological data: http://12.45.109.6/

MT DEQ's West Entrance monitoring station data and station information: http://www.deq.state.mt.us/AirMonitoring/index.asp

Other MT DEQ monitoring stations: http://www.deq.state.mt.us/AirMonitoring/sites/QueryAQsitelocation.asp

Old Faithful area webcam, current weather, and current pollutant data: (http://www2.nature.nps.gov/air/WebCams/parks/yellcam/yellcam.htm

Yellowstone AQ0506_FINAL_Report_V6.6.doc
JDR 1-30-2007

Appendices

Winter Air Quality Study: 2005-2006

John D. Ray, Ph.D.
Atmospheric Chemist
NPS Air Resources Division

Appendix A - Statistical Data Tables

These tables contain the detail that is in the graphics of the main report.

Table A-1. Traffic counts[7] and air quality values for the West Entrance of Yellowstone for the winter seasons ending in the year listed.

Year	Snowmobiles	Snowcoaches	Total	Average traffic per day†	CO 1-hr 1st max	CO 8-hr 2nd max.
1998	40,869	706	41,575	467	- -	- -
1999	44,213	767	44,980	505	18.2	4.3
2000	42,620	777	43,397	488	13.5	4.7
2001	45,689	816	46,505	523	17.9	6.0
2002	50,888	889	51,777	582	16.0	4.9
2003	33,458	998	34,456	387	8.6	2.1
2004	14,704	1,142	15,846	176#	6.4	0.8
2005	10,229	970	11,199	150#	2.8	0.9
2006	13,455	1,401	14,856	165#	2.1	0.9

Source: NPS Public Use Statistics web site

† Assumes a season of Dec. 15 to Mar. 15 to get the average daily traffic. Actual open days for West Entrance may differ by year.

\# Uses actual days and hourly records to calculate totals.

Table A-2. Additional detail for West Entrance CO statistics.

Location	Winter Period Years	1-hr CO (ppm)		8-hr CO (ppm)	
		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
	2001-2002	16	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	0.9
	2005-2006	2.1	2.1	0.91	0.86

Table A-3. Total traffic[7] for all entrances to Yellowstone for the winter seasons ending in the year listed.

Year	Snowmobile totals	Snowcoach totals	Total
1998	60,110	1,326	64,204
1999	62,878	1,396	63,927
2000	62,531	1,535	69,188
2001	67,653	1,591	70,787
2002	69,196	1,605	49,404
2003	47,799	1,653	24,076
2004	22,423	2,058	17,753
2005	15,695	1,926	23,819
2006	21,893	1,965	23,858

Source: NPS Public Use Statistics web site

Table A-4. PM2.5 statistics at monitoring stations.

Location	Winter Period Years	24-hr $PM_{2.5}$ $(ug/m^3)^3$ 1st Max	98th% Conc.
West Entrance	2002-2003	15	16.9
	2003-2004	8	7.0
	2004-2005	6	6.0
	2005-2006	7	6.3
Old Faithful	2002-2003	37	21.3
	2003-2004	16	9.0
	2004-2005	6	9.0
	2005-2006	9	8.5
Flagg Ranch [#]	2002-2003	16	10.7

Appendix B - Comparison of Hourly Data to Short-term Minute Data

Some very useful information was collected by researchers at the West Entrance kiosks as part of a winter personal exposure monitoring study.[13] Although only Feb. 18-21 is covered by the measurements, there is detailed data from right at the kiosk rather than at the side of the exit lane where the air quality monitoring station is located. Tables VII and VIII are directly from the personal monitoring study[13] and a reproduced here only for convenience. Short statements on the methods used are also directly from the Spear et al.[13] report

Table VII. Real Time Carbon Monoxide Concentrations

Date	Location	Start	Stop	CO Avg (ppm)	CO 8 Hour TWA	CO Peak (STEL)
2/18/2006	Kiosk A	8:19 AM	11:38 AM	0.36	0.29	26 ppm @ 10:26 AM
2/19/2006	Kiosk A	7:39 AM	12:57 PM	2.10	0.94	49 ppm @ 9:12 AM
2/20/2006	Kiosk A	8:20 AM	11:24 AM	1.11	0.61	91.0 ppm @ 9:04 AM

Source: Spear et al., 2006.

Table VIII. Respirable Dust (PM_4) Results for February 18, 19, and 20, 2006

Date	Monitoring Parameters						
	Location	Start Time	Stop Time	Avg. (mg/m^3)	8-hr TWA (mg/m^3)	Max (mg/m^3)	Min (mg/m^3)
2-18-06	A	07:59:05	11:42:25	0.018	0.008	0.188	0.002
2-18-06	B	08:00:20	11:43:42	0.018	0.008	0.154	0.002
2-19-06	A	07:19:32	11:02:42	0.016	0.008	0.081	0.001
2-19-06	B	07:19:18	11:02:28	0.009	0.004	0.026	0.002
2-20-06	A	07:46:45	11:17:45	0.013	0.006	0.135	0.004
2-20-06	B	07:46:30	11:17:30	0.007	0.003	0.014	0.002

Source: Spear et al., 2006.

Method: A TSI DustTrak® model 2080 was used in conjunction with a 9mm nylon cyclone to fractionate particulate aerosols and allow for the collection of 4 micron sized particles at 50% efficiency (PM_4).

Table IX. Real Time Particle Mass Concentration Data $PM_{2.5}$

Date	Location	Cut Point	Start Time	Stop Time	Avg. Conc (ug/m^3)	Max (ug/m^3)	Time of Max
2/18/2006	Kiosk A	$PM_{2.5}$	7:52 AM	12:05 PM	5.3	60.0	7:59 AM
2/19/2006	Kiosk A	$PM_{2.5}$	7:49 AM	11:09 AM	4.4	32.1	8:53 AM
2/20/2006	Kiosk A	$PM_{2.5}$	7:54 AM	12:20 PM	4.3	13.9	8:06 AM

Source: Spear et al., 2006.

Method: A Thermo-Electron® (MIE) DataRAM™ was used to obtain real time particle mass concentration data. Previous studies have shown that $PM_{2.5}$ measurements from real time instruments are well correlated and highly predictive of measurements from the gravimetric sampling method for aerosols in workplace environments.

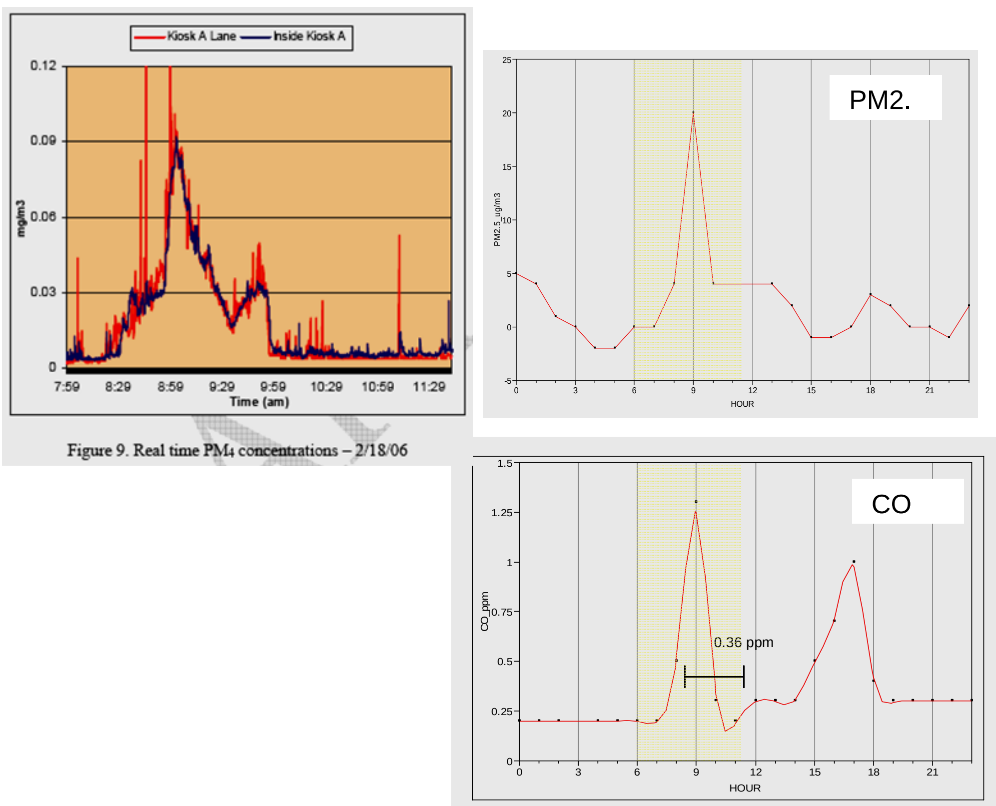


Figure B-1. Detailed particulate matter data from the West Entrance kiosk (top left) are compared to the hourly air quality monitoring station (right two plots) for Feb. 18, 2006. The yellow shaded areas are the overlap periods.

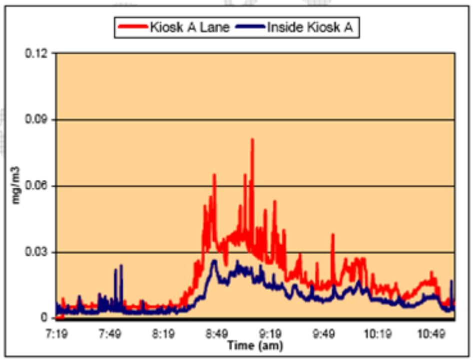


Figure 10. Real time PM4 concentrations – 2/19/06

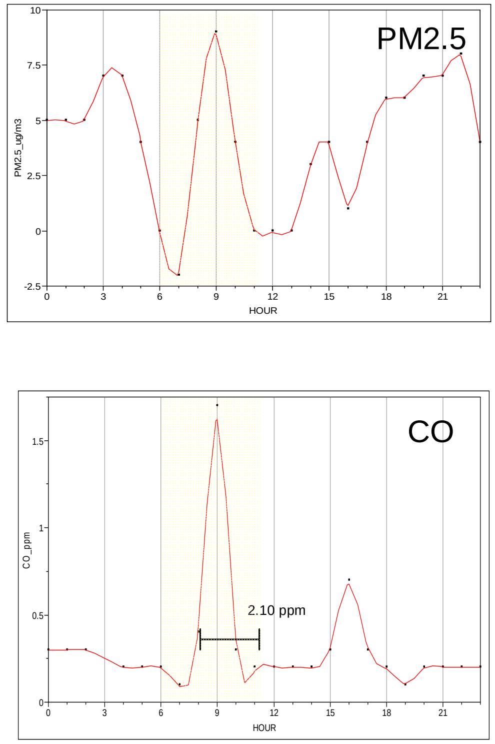


Figure B-2. Detailed particulate matter data from the West Entrance kiosk (top left) are compared to the hourly air quality monitoring station (right two plots) for Feb. 19, 2006. The yellow shaded areas are the overlap periods.

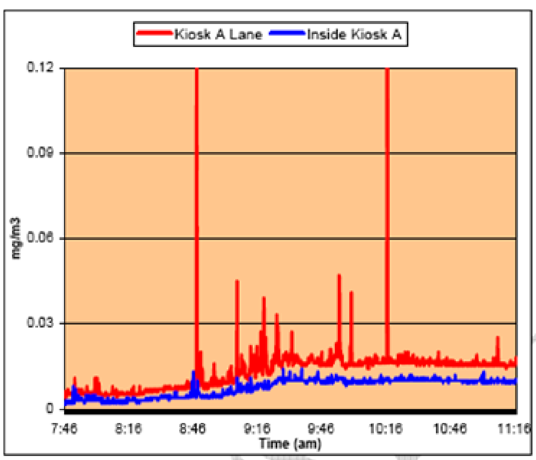


Figure 11. Real time PM4 concentrations – 2/20/06

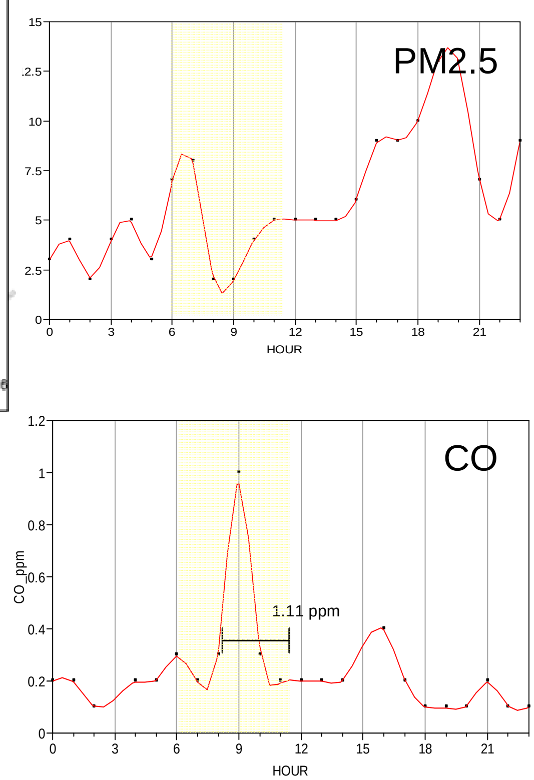


Figure B-3. Detailed particulate matter data from the West Entrance kiosk (top left) are compared to the hourly air quality monitoring station (right two plots) for Feb. 20, 2006. The yellow shaded area is the overlap period.

Discussion

In Figures B1 to B-3 the data from one weekend during the winter 2005-2006 are presented from the personal exposure monitoring (Spear et al., 2006) at a high time resolution and the hourly air quality monitoring station data provided for comparison along side. At the higher time resolution individual vehicles or groups of vehicles can be seen as short-term spikes in the PM data record, usually at much higher concentrations than observed at the monitoring station that is 50+ feet away. The inside kiosk PM concentrations are lower than outside, but not as dramatically as one might expect from the kiosk's positive-pressure clean-air ventilation system.

The hourly PM and CO data generally follow the more detailed record measured directly at the kiosk. In the detailed record, there are some very large PM emitters and a buildup on some days when traffic through the gate is heavy.

Date	Snowmobiles	Snowcoaches
2-18	249	25
2-19	239	23
2-20	186	15

If the 1-minute or 5-minute CO data were recorded at the West Entrance monitoring station and vehicle entrance records had a similar time interval, then high emitter vehicles could probably be identified and the relationship between traffic counts and pollutant levels understood better.

Appendix C - Estimating Change in Pollutant Concentrations with Traffic Volume

The sensitivity of the CO concentrations to the number of vehicles is a desireable factor to know for planning purposes. Direct measurements of the air quality and counts of traffic on an hourly basis are inadequate to estimate this factor, however. A modeling exercise was conducted by a contractor for the different alternatives proposed in the Environmental Impact Statement that may be able to estimate a factor (http://www.nps.gov/yell/parkmgmt/winterusetechnicaldocuments.htm). For each alternative with different numbers of snowmobiles and snowcoaches allowed to enter at the West Entrance there were estimated CO concentrations. A simple plot of number of allowed snowmobiles versus expected CO concentration suggested a roughly linear

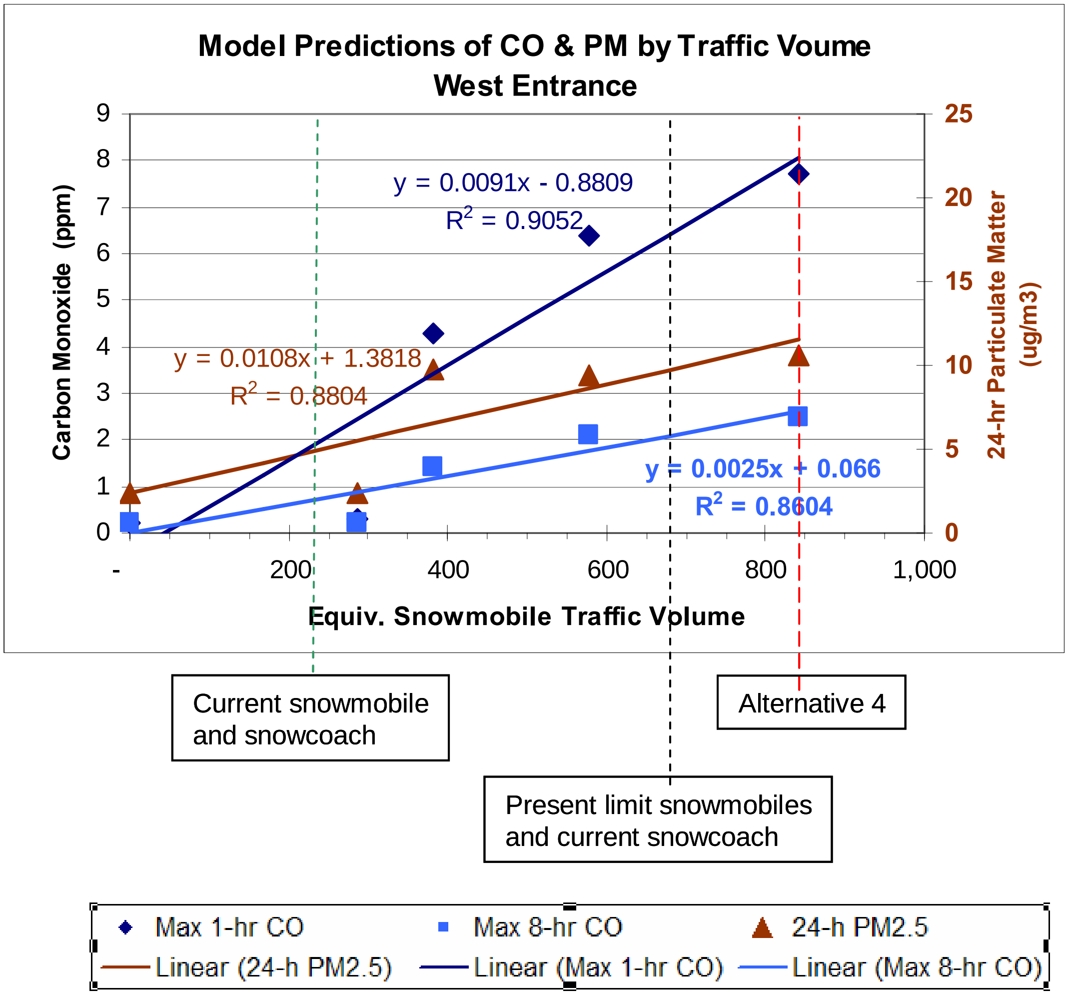


Figure C-1. Calculated equivalent snowmobile numbers are plotted against the predicted CO concentrations from the alternatives used in the diffusion modeling exercise for Yellowstone National Park. Emission factors, number of vehicles, and expected CO concentrations are from the report[11].

relationship. The percent of contributing emissions by vehicle type can be found in Table 6-2 of the modeling report, which points out the need to consider both snowmobile ands snowcoaches when estimating CO concentrations. Using the emission factors for BAT snowmobiles and BAT snowcoaches (model report Tables 4-2 and 4-3), an equivalence was calculated for how many snowmobiles would be allowed for each alternative. Figure C-1 shows this relationship for hourly and 8-hour CO concentrations and 24-hour PM2.5. The model predicted concentrations are from model report Table 5-1. Three linear relationships are obtained for expected pollutant concentrations by the number of snowmobile equivalents entering the West Entrance per day.

For the current average number of daily snowmobile and snowcoaches (155, 15) entering the West gate the model estimates about 1.9 ppm CO (238 equivalent snowmobiles per day). This compares well with the measured value during the winter of 2005-2006 of 2.0 ppm. Under the temporary winter use plan, the West entrance could have 400 BAT snowmobiles per day and the present number of snowcoaches or an equivalent to 678 snowmobiles, for which the estimated peak CO concentration is approximately 6.4 ppm. For the 8-hour CO average the concentration works out to 2.1 ppm or roughly 23% of the NAAQS standard. The factor for increased CO per 100 snowmobiles is 0.9 ppm CO. For PM2.5 at the current usage, the 678 equivalent snowmobiles works out to about 10 ug/m3 which is about 28% of the new PM2.5 24-hour NAAQS standard. Although the air quality remains sensitive to the number of winter vehicles, having a BAT requirement, that reduces the pollution emissions, does keep the concentrations to levels that might reasonably be found in a rural environment. Remote, cleaner areas of the United States would be expected to have CO concentrations 2 to 4 times lower and more isolated locations in the Northern Hemisphere can be a factor of 10 times lower[C-4]. The concentration of pollutants drops with dilution and distance from a source, so at a distance of 1 mile the CO concentrations might be closer to area background levels of 0.1 to 0.2 ppm. This kind of drop off in concentrations was observed by other researchers in Yellowstone and Grand Teton for CO[C-3] and for VOCs[C-2].

Table C-1. Change in carbon monoxide with distance from the road (Sive et al, 2003)

Distance from road	**500m**	**50 m**
CO (ppm)	0.138	0.286

In conclusion, the modeling exercise for the winter use alternatives provides an estimate of the CO and PM2.5 ambient concentrations near the West Entrance as a function of the traffic volume. A relationship was developed using the relative emissions of snowmobiles and snowcoaches and expressed as an “equivalent snowmobile” for the estimates. The estimated peak winter concentrations of CO for the current conditions, alternative 1, and alternative 4 are 1.9 ppm, 6.4, and 8 ppm. There is quite of bit of difference between these alternatives for the air quality. This approach could be used to develop air quality estimates for various combinations of snowmobiles, snowcoaches, and BAT requires, including a year by year estimate to account for a BAT phase-in.

Modeling report[11] Table 3-1

Summary of Preliminary Alternatives

	Alternative 1: Current Plan	Alternative 2: Snowcoaches Only	Alternative 3: Eliminate Most Road Grooming	Alternative 4: Enhanced Recreational Use	Alternative 5: Provide for Unguided Access	Alternative 6: Mixed Use
Highlights	Allows for nearly historic levels of snowmobile use but requires commercial guides. This Alternative mimics the temporary winter use plan currently in place, with three primary changes: 1) Snowcoaches must meet BAT standards; 2) Daily limit on snowcoaches; and 3) Sylvan Pass is closed to through travel under 3 of 4 options for this Alternative (see Table 3-2).	Emphasizes snowcoach access; prohibits recreational snowmobiling. Road grooming would continue.	Prohibits road grooming or packing on most road segments in Yellowstone National Park. The road from the South Entrance to Old Faithful would be the only oversnow motorized access route Yellowstone.	Allows for increased snowmobile use, relative to historic numbers. Commercial guides would be required for most snowmobilers; some could also visit the park after completing a non-commercial or unguided guide training course.	Balances snowmobile and snowcoach access and accommodates some visitors who wish to have an unguided snowmobile experience. Features a seasonal limit as well as a flexible daily limit	Emphasizes plowing Yellowstone's lower elevation, west-side roads to allowed wheeled commercial vehicle access. Continue to allow oversnow vehicle access through the South Entrance and on the east side of the park.
Daily Snowmobile Limits in YNP	720 snowmobiles per day West: 400 South: 220 North: 30 East: 40 Old Faithful: 30 Cave Falls Road: 50 snowmobiles (no BAT or guiding)	Snowmobiles prohibited. Cave Falls Road closed to snowmobiles	South: 250 snowmobiles per day. Cave Falls Road closed to snowmobiles	1,025 snowmobiles per day West: 600 South: 250 North: 25 East: 100 Old Faithful: 50 Cave Falls Road: 75 snowmobiles (no BAT or guiding)	540 snowmobiles per day West: 290 South: 145 East: 40 North: 40 Old Faithful: 25 Cave Falls Road: 50 snowmobiles (no BAT or guiding) Seasonal entry limit would be put in place: no more than 27,540 snowmobiles and 5,291 snowcoaches per season in YNP. Daily commercial snowmobile and snowcoach entries could exceed above limits by 20% on busy days (up to 518 commercial snowmobiles and 100 snowcoaches) per day, but such entries would count against seasonal limit above.	350 snowmobiles per day South: 250 Old Faithful/Norris: 100 100 wheeled vehicles Cave Falls Road: 50 snowmobiles (no BAT or guiding)

Notes:
BAT = Best Available Technology; CDST = Continental Divide Snowmobile Trail; YNP = Yellowstone National Park;
GTNP = Grand Teton National Park; Targhee NF = Targhee National Forest
Refer to Appendix J, Alternatives Discussion for details on snowmobile and snowcoach limits and technology, guiding requirements, side roads, etc.

Summary of Preliminary Alternatives

	Alternative 1: Current Plan	Alternative 2: Snowcoaches Only	Alternative 3: Eliminate Most Road Grooming	Alternative 4: Enhanced Recreational Use	Alternative 5: Provide for Unguided Access	Alternative 6: Mixed Use
Daily Snowmobile Limits in GTNP and Parkway	140 snowmobiles per day Grassy Lake Rd: 50 CDST: 50 Jackson Lake: 40	Snowmobiles prohibited	Grassy Lake Rd: 50 CDST: Closed Jackson Lake: Closed	250 snowmobiles per day. Grassy Lake Rd: 75 CDST: 75 Jackson Lake: 100	140 snowmobiles per day Grassy Lake Rd: 50 CDST: 50 Jackson Lake: 40 All would be improved BAT.	90 snowmobiles per day. Grassy Lake Road: 50 Jackson Lake: 40 CDST: Closed.
Snowmobile Guide Requirements	YNP: 100% Commercially guided. GTNP and Parkway: Guides not required.	N/A	YNP: 100% Commercially guided. GTNP and Parkway: Guides not required.	YNP: 75% commercially guided; 25% either unguided or non-commercially guided. GTNP and Parkway: CDST: 50 commercially guided; 25 unguided. Jackson Lake and Grassy Lake Road: unguided	YNP: 80% commercially guided 20% unguided, with brief training. Unguided snowmobiles would be required to enter YNP prior to 10:30AM. GTNP and Parkway: Commercial guides may be allowed, but not required.	YNP: 100% commercially guided, both oversnow and wheeled vehicles. GTNP and Parkway: Commercial guides may be allowed, but not required.
Best Available Technology Requirements for Snowmobiles	YNP: All BAT. GTNP and Parkway: All BAT, except snowmobiles originating on Targhee NF using Grassy Lake Road.	N/A	YNP: All BAT. GTNP and Parkway: All BAT, except snowmobiles originating on Targhee NF using Grassy Lake Road.	YNP: all BAT. GTNP and Parkway: Jackson Lake: All BAT. Grassy Lake Road: All Non-BAT. CDST: 50 commercially guided BAT; 25 unguided 2006 model year or newer.	Improved BAT for snowmobiles (95% reduction in HC and 75% reduction in CO; NTE 72dBA), except snowmobiles originating on Targhee NF using Grassy Lake Road.	YNP: All BAT. GTNP and Parkway: All BAT, except snowmobiles originating on Targhee NF using Grassy Lake Road.
Maximum Snowmobile Group Size	8 with one guide; 17 with 2 guides	N/A	11 with one guide.	11 with one guide	11 with one guide	8 with one guide; 17 with 2 guides

Notes:
BAT = Best Available Technology; CDST = Continental Divide Snowmobile Trail; YNP = Yellowstone National Park;
GTNP = Grand Teton National Park; Targhee NF = Targhee National Forest
Refer to Appendix J, Alternatives Discussion for details on snowmobile and snowcoach limits and technology, guiding requirements, side roads, etc.

Summary of Preliminary Alternatives

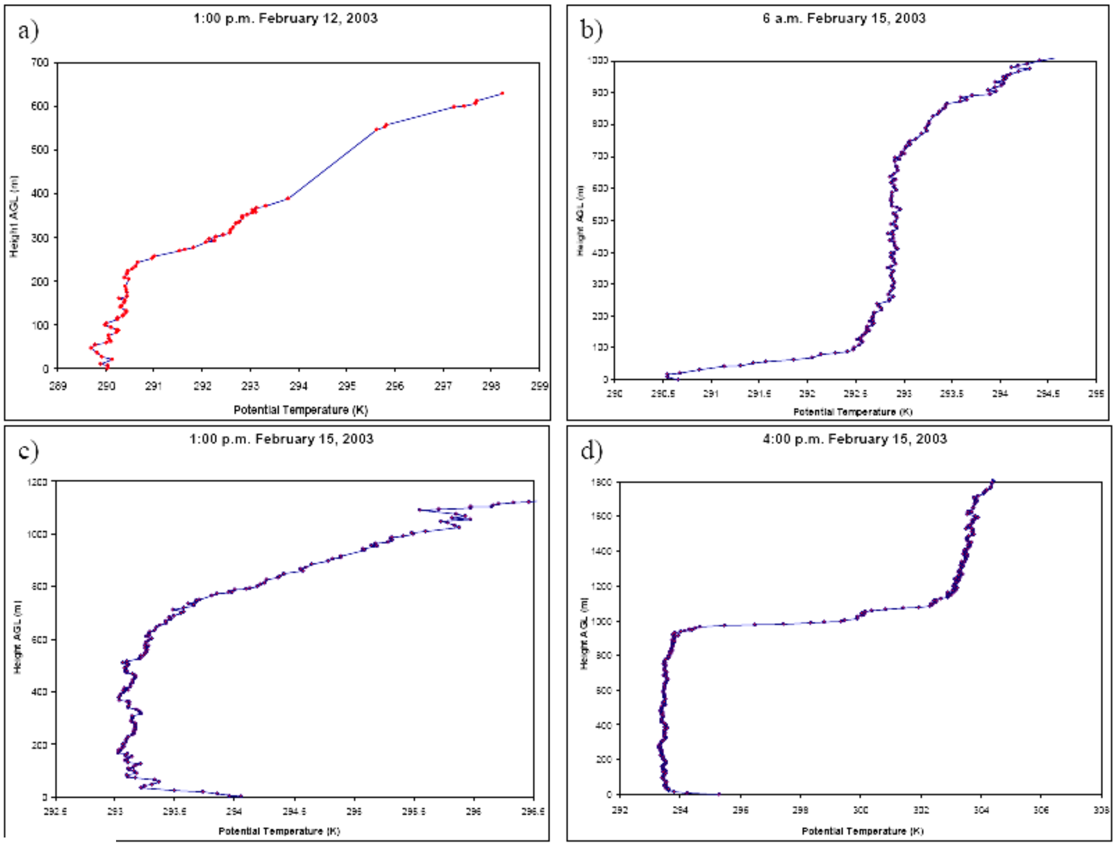
	Alternative 1: Current Plan	Alternative 2: Snowcoaches Only	Alternative 3: Eliminate Most Road Grooming	Alternative 4: Enhanced Recreational Use	Alternative 5: Provide for Unguided Access	Alternative 6: Mixed Use
Use of YNP Side Roads by Snowmobiles	Washburn Overlook and Freight Road: snowcoach only. Firehole Canyon Drive, Canyon North Rim Drive and Riverside Drive: open in afternoon to snowmobiles. Lake Butte and Canyon South Rim: open to snowmobiles. Virginia Cascades: ski only.	Virginia Cascades: ski only. All other side roads: snowcoach only	All closed (there are none on the road from South Entrance to Old Faithful).	All side roads open to snowmobiles. Virginia Cascades: ski only.	Washburn Overlook and Freight Road: snowcoach only. Firehole Canyon Drive, Canyon North Rim Drive and Riverside Drive open in afternoon to snowmobiles. Lake Butte and Canyon South Rim open to snowmobiles. Virginia Cascades ski only.	Canyon North and South Rim Drives, Lake Butte: Open to snowmobiles. Firehole Canyon, Riverside Drive, Fountain Freight Road, Washburn Hot Springs: Snowcoach only. Virginia Cascades: ski only.
Daily Snowcoach Limits in YNP and Snowcoach BAT	78 snowcoaches per day West: 34 South: 13 North: 13 East: 0 Old Faithful /Parkwide: 18 All meet snowcoach BAT	120 snowcoaches per day West: 55 South: 25 North: 17 East: 0 Old Faithful /Parkwide: 23 All meet snowcoach BAT	South: 20 All meet snowcoach BAT	115 snowcoaches per day West: 46 South: 15 North: 5 East: 4 Old Faithful /Parkwide: 35 Private: 10 All meet snowcoach BAT	83 snowcoaches per day West: 34 South: 10 North: 3 East: 2 Old Faithful /Parkwide: 34 All meet snowcoach BAT. Seasonal entry limit would be put in place.	40 snowcoaches per day South: 10 Old Faithful/Norris: 30 All meet snowcoach BAT.
Road Grooming	Continue road grooming, except Sylvan Pass would be closed.	Continue road grooming, except Sylvan Pass would be closed.	Only groom South to Old Faithful. All other segments ungroomed and closed to oversnow travel.	Continue road grooming	Continue road grooming	Plow Mammoth to West to Old Faithful. Groom Old Faithful to South to Lake to Canyon to Norris. Sylvan Pass would be closed.

Notes:
BAT = Best Available Technology; CDST = Continental Divide Snowmobile Trail; YNP = Yellowstone National Park;
GTNP = Grand Teton National Park; Targhee NF = Targhee National Forest
Refer to Appendix J, Alternatives Discussion for details on snowmobile and snowcoach limits and technology, guiding requirements, side roads, etc.

Appendix D - Winter Boundary Layer Heights from Vertical Soundings

A boundary layer inversion is quite likely during the winter months that would tend to limit the mixing of pollutants emitted at the surface. While the summer-time mixing height would be expected to be in the 1-2 km range during the day, the winter mixing height might only be from 500 to 1000m. A limited number of vertical soundings are available for Yellowstone. Some sample soundings from the Lake Range Station (Figure B-1) from Feb. 2003 illustrate this point. In Figure B-1a, the mixing height can be estimated from the potential temperature profile to be at about 250m at 1 pm. Three days later the development of the mixing layer can be seen. In B-1b a strong boundary layer is found at 6 am, just before sunrise, that is only about 80m high. By 1pm (B-1c) the mixing height has risen to 700 plus meters. By 4pm the mixing height is about 950m. Similar patterns to this are expected at other located in Yellowstone during the winter.

Pollutant concentrations are strongly affected by the mixing height. Early morning in the winter, especially on calm, cold days, are more likely to have high pollutant concentrations that are trapped in a shallow mixing layer. The data from the nearby air quality monitoring station demonstrates the shallow boundary layer development based on the difference in temperature at 3m and 10m (delta-T). Figure D-2 and D-3 show the changes in the boundary layer and the solar radiation. Just after sunrise the overnight boundary layer (as seen in Figure D-1b) begins to lift. By about 9am the layer is above 10m and develops as seen in Figures D-1c&d. During Feb. 2003 this type of boundary layer developed at least 90% of the days. It is likely that similar patterns occur throughout the park. The lower winter mixing layer puts a cap on the volume of air into which the surface pollutants can dilute.



Atmospheric soundings, Lake R.S. (WED2003 & SAT2003).

Figure D-1. Upper air soundings from the Lake Ranger Station 2-12-2003 to 2-15-03 using potential temperature. Values are plotted as height above ground level (AGL) in meters. (Ref: Sive et al, 2003)

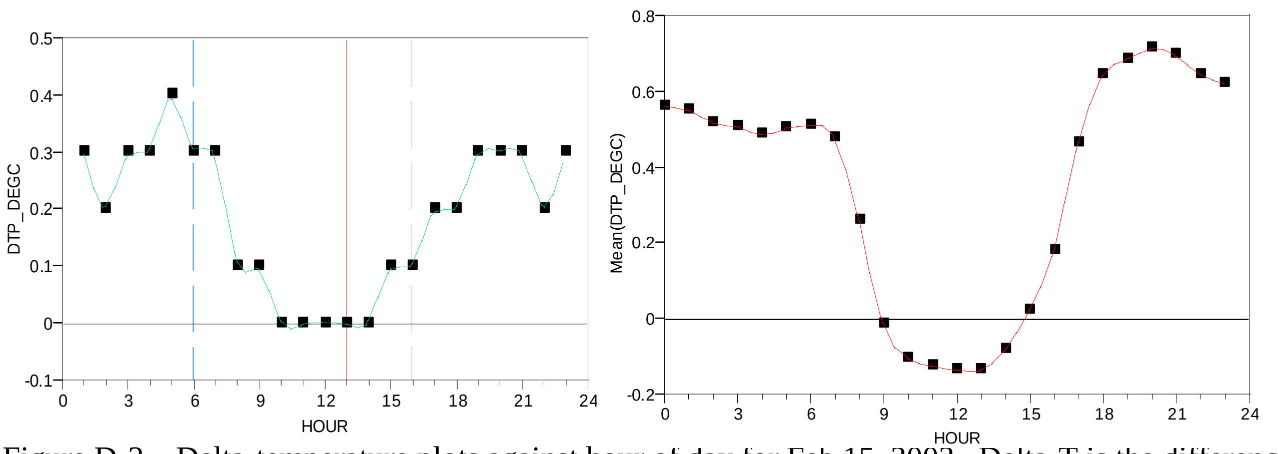


Figure D-2. Delta-temperature plots against hour of day for Feb 15, 2003. Delta-T is the difference in temperature between 10m and 3m on the air quality monitoring tower at the station near Lake (40m higher than the ranger station location). Vertical lines correspond to D-1 plots. The right plot is the average for Feb. 2003.

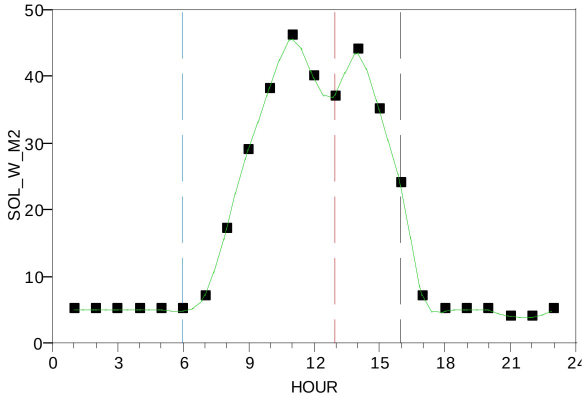


Figure D-3. Solar radiation by hour of day at the air quality monitoring station near Lake. Sunrise is about 6:30am and sunset about 5:30pm. Vertical lines correspond to D-1 plots.

The U.S. Department of the Interior (DOI) is the nation's principal conservation agency, charged with the mission "*to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities."* More specifically, Interior protects America's treasures for future generations, provides access to our nation's natural and cultural heritage, offers recreation opportunities, honors its trust responsibilities to American Indians and Alaska Natives and its responsibilities to island communities, conducts scientific research, provides wise stewardship of energy and mineral resources, fosters sound use of land and water resources, and conserves and protects fish and wildlife. The work that we do affects the lives of millions of people; from the family taking a vacation in one of our national parks to the children studying in one of our Indian schools.

NPS/ARD D-1207, January, 2007

National Park Service
U.S. Department of the Interior

Air Resources Division

Postcard from the 1950's showing snowcoaches parked near Old Faithful on a winter trip into Yellowstone National Park.

Air Resources Division
12795 W. Alameda Parkway
PO Box 25287
Denver, CO 80225-0287

www2.nature.nps.gov/air/

EXPERIENCE YOUR AMERICA T