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To the Graduate Council:

I am submitting herewith a thesis written by Ryan Maloney entitled "Ozone Monitoring and Canopy Effect in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

Dr. Wayne T. Davis, Major Professor

We have read this thesis and recommend its acceptance:

Dr. Terry Miller, Dr. Joshua Fu

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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We have read this thesis
and recommend its acceptance:

Dr. Terry Miller

Dr. Joshua Fu

Accepted for the Council:

Dr. Anne Mayhew

Vice Provost and Dean of Graduate Studies

Original signatures are on file with official student records

Ozone Monitoring and Canopy Effect in the Great Smoky Mountains National Park

A Thesis Presented for the Master of Science Degree
The University of Tennessee, Knoxville

Ryan Maloney
May 2003

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I want to express my deepest gratitude to my major professor, Dr. Wayne Davis. His mentorship and experience helped me to not only complete my project, but also laid a foundation on which to build my career as a professional. I wish to thank my committee members, Dr. Terry Miller and Dr. Joshua Fu, whose insights and time were invaluable. The members of my committee made my studies worthwhile and I am grateful for the opportunity to have been associated with such an extraordinary group of educators. I also want to acknowledge the National Park Service and EPA for their funding of the project and Jim Renfro for his aid in my collection of data. I also wish to thank Lesley Grimes and John LaRue of Knox County Air Pollution Control for all the support they provided.

I want to give a special thanks to my family, especially my parents, Steve and Donna Maloney, for their love and support. For without them none of this would have been possible. Lastly, I thank God for the blessings and opportunities he has bestowed upon me.

ABSTRACT

Vegetative uptake of ozone, or canopy effect can cause considerable differences in ozone concentration. The ability to quantify and determine the presence of canopy effect is of importance when relating ozone exposure to a health effects study being conducted in Great Smoky Mountains National Park. The concentrations seen inside and outside of the canopy differed by as much as 13 ppb and 16%. The canopy effect was quantified and evaluated to determine if the ozone concentrations measured at the trailhead at New Found Gap warranted an adjustment to accommodate for the different ozone concentrations the participants of the hiker-health study were exposed to while hiking. The ozone monitor at the New Found Gap trailhead was also investigated for the presence of a canopy effect. The monitor showed no significant effect from the bordering trees. However, the hikers, when on the trail, were within the canopy where lower than ambient ozone concentrations were present. The final recommendation was to lower ambient ozone concentrations measured at New Found Gap by 13% for the time spent on the trail by one of the three approaches presented.

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CHAPTER 1

INTRODUCTION

Plant covered surfaces, including forests in particular, have long been considered efficient sinks for pollutants (Fowler et al., 1989). Within a plant covered surface or canopy, ozone concentrations will be different than those observed in open, unobstructed areas outside of the canopy. This is known as the canopy effect and can best be defined as the reduction or loss of ozone due to vegetative uptake and deposition in the forested canopy. The amount of ozone uptake depends on a multitude of factors such as the density and surface area of the canopy, the type vegetation, wind speed, soil properties, temperature, and relative humidity.

Time of day plays an important role in ozone deposition. In France, a study within a coniferous canopy concluded, "during dry daytime conditions ozone uptake was controlled mainly by the canopy stomatal conductance for ozone" (Lamaud et. al., 2001). Lamaud also concluded, "during dry nights ozone deposition is mostly controlled by dynamical turbulence." This is logical because stomata are inactive during the night and deposition is then likely to occur at the surface of vegetative components and at the soil surface (Lamaud et. al., 2001).

Wind dynamics can also play a major role in the concentrations of ozone observed within forested canopies. The variation of ozone concentration in a forested canopy is affected by wind speed. In Sweden, research was conducted on a wind-exposed edge of a spruce forest where ozone gradients were measured inside and outside of canopy. The study found that when winds were greater than 1.5 ms^{-1} the forest was well mixed, permitting a substantial uptake of ozone by plants and other surfaces. Also, the replacement of deposited ozone within the canopy was fast due to good ventilation provided by high wind speeds. It was concluded that the uptake and relatively fast replacement of ozone gave slightly lower concentrations inside the canopy compared to outside the canopy (Pleijel et. al. 1996). In the same study, when wind speeds were less than 1.5 ms^{-1}, the ozone concentrations were substantially lower inside the forest than outside. Wind speeds less than 1.5 ms^{-1} provided restricted airflow into the forest but not enough to restrict ozone deposition (Pleijel et. al. 1996).

The loss of ozone will be generalized for purposes of this study and taken to describe the dry deposition of ozone to plant, soil, and all other surfaces within the canopy. Many studies involving plant physiology have compared ozone flux above and below the canopy for various types of trees and crops but focus mainly on stomata uptake. Plant physiology is a subject that will not be discussed. The research presented will be geared toward the issues that needed to be addressed while monitoring ozone at New Found Gap in the Great Smoky Mountains National Park in support of a health study conducted on hikers.

The GSMNP sees regional transport of ozone from metropolitan areas in North Carolina, Georgia, Ohio and Tennessee. New Found Gap is at an elevation of 5048 feet above mean sea level and ozone concentrations persist at high levels; typically no lower than 40 ppbv because it is in a regional transport zone for ozone. The elevation at New Found Gap is typically higher than the inversion layer that forms during the night that traps tropospheric ozone above and below the inversion. Below the inversion layer NO_x scavenging occurs and ozone reacts with NO and forms NO_2, depleting O_3; however, above the inversion, ozone is trapped overhead and persists in the upper troposphere at high concentrations where it can be transported over long distances. Because of this phenomenon and the generally high ozone concentrations in the east Tennessee area, the GSMNP has exceeded the NAAQS 8-hr ozone standard of 80 ppbv 142 times from 1998 through 2001.

The need to quantify a canopy effect arose when an EPA funded hiker-health study began in the summer of 2002 in the Great Smoky Mountains National Park (GSMNP). The study was to take volunteer day-hikers and measure lung function, specifically forced expiratory volumes (FEV), before and after the participants hiked a portion of the Appalachian Trail from New Found Gap (NFG) to Charlie's Bunion (CB). To keep it simple, the goal was to relate FEV with ambient air quality. The trail runs along the ridge tops and is mostly forested so to determine the actual concentrations seen by the day hikers it was necessary to determine if a canopy effect was present. The data collected showed the canopy effect to be real and monitor location as well as the possible need for an adjustment factor for ambient concentrations became important issues.

The objective of this study was to quantify the probable canopy effect and to determine if the portable monitor used in the study was also influenced by a canopy effect because of monitoring site characteristics. The continuous monitors located in the GSMNP and wind data from the nearest meteorological station at Clingmans Dome approximately 4 miles away, were used to check for any pattern in the differences in concentrations observed by the portable monitor located at NFG and the continuous monitors located at nearby peaks.

CHAPTER 2

BACKGROUND

The purpose of this chapter is to familiarize the reader with the portable ozone monitor used for the study, and the calibration and co-location procedures associated with the instrument. Discussion of the continuous monitors located within the GSMNP and monitoring site description will also be presented. Lastly, this section will include wind data observed from the Clingmans Dome, which will be important in determining if the portable ozone monitor at New Found Gap saw a canopy effect.

2.1 Portable Ozone Monitor

The instrument used for this study was manufactured by 2B Technologies. It is based on the absorption of ultraviolet light at 254 nanometers by ozone. This wavelength is ozone specific, as other gases typically found in ambient air do not absorb light at this wavelength. The instrument operates by drawing ambient air through the inlet by an internal air pump at 1 l/min. The airflow is controlled by a solenoid valve, which alternates to send the air directly into the absorption cell or through an ozone scrubber and then to the absorption cell. The absorption cell has a mercury lamp on one end and a photodiode on the opposite end. The photodiode measures the intensity of light in the air that has passed through the cell. The resulting intensity of light which passes through the cell associated with the air which has passed through the ozone scrubber (I_o) and the intensity resulting from the ambient air that was passed directly into absorption cell (I) are used to calculate the ozone concentration from the measurements of I and I_o according to the Beer-Lambert Law:

$$C_{O_3} = \frac{1}{s\,l}\ln\left(\frac{I_o}{I}\right)$$

where l is the absorption cell path length and σ is the absorption cross-section for ozone at 254 nm.

To ensure the accuracy of the instrument co-locations and calibrations were performed periodically. The 2B ozone monitor was co-located with Knox County's continuous ozone monitor at Spring Hill Elementary for four days between the hours of 9:00 and 16:00. The two monitors agreed well for each of the days for the period of July 23-26, 2002. On 7/25/02, heavy rainfall was experienced while sampling; it is most likely the reason for the lower correlation between the monitors. Plots of ozone concentration versus time and 2B ozone concentration versus the continuous monitor's ozone concentration were done for each co-location day (Figures A.1-A.8). The four days gave the following r^2 values when plotting the two monitors against one another.

Table 2.1. Co-location Correlations

Date	r^2
7/23	0.993
7/24	0.979
7/25	0.896
7/26	0.997

A co-location study was also performed at Look Rock Monitoring Station. Co-location at this site was not possible because our monitor experienced a canopy effect due to differential heights of the sampling inlets. The inlet for Look Rock's continuous monitor was located on a thirty-foot tower above the surrounding canopy. The sampling inlet for the portable monitor was 30 feet below in canopy; the sampling inlets could not be placed side by side and affected the co-location study at this site. Plots of ozone concentration versus time and 2B ozone concentration versus the LR continuous monitor's ozone concentration were done for the sampling period (Figure A.9 & A.10).

Dynamic calibrations were performed at the Knox County Air Pollution Control Laboratory on three different occasions during the course of the project. An EPA certified/audited ozone generator was used to zero and span the instrument. The ozone generator produced concentrations of 0, 400, 300, 170, 90, and 70 ppbv in that order. During the first calibration (prior to starting the monitoring project at NFG), the instrument's zero was corrected followed by plotting the known concentrations from the generator against the monitor's response. Once the slope was determined (i.e. 1.03), the span was adjusted accordingly (Figure A.11). The span was adjusted using the lower region of the plot for ozone concentrations of 70, 90, and 170 ppbv as these concentrations were representative of the concentrations seen in the field. (Figure A.12). Calibrations checks were performed two additional times during the course of the project.

The second dynamic calibration showed the portable analyzer to be accurate and no adjustment was necessary. The ozone generator produced concentrations of 0, 400, 170, 90, and 70 ppbv in that order. The zero was within 0.5 ppbv and was not adjusted. The span was not adjusted either as concentrations were within a few ppb (Figure A.13).

The third dynamic calibration was performed at the end of the sampling period. The ozone generator produced concentrations of 0, 400, 300, 170, 90, and 70 ppbv in that order. The post project calibration showed the monitor to be within 4% of the ozone generator (Figure A.14). The ozone concentrations measured at NFG for the latter part of the project were considered accurate and warranted no adjustment.

The monitor's zero was confirmed before each sampling day as well. An ozone scrubber cartridge provided by the manufacturer (MSA #466204) was placed on the inlet to scrub ozone and provide zero air for the monitor. All these steps validated the instrument and provided a high level of confidence in the 2B ozone monitor.

2.2 High Elevation Continuous Monitors in the GSMNP

The portable ozone monitor sampling location was at New Found Gap (elev. 5048 ft) in the GSMNP and the high elevation continuous ozone monitors within the park provided a good benchmark to compare against. There are five monitors in the park with which the portable monitor was compared. These include: Look Rock (LR) (elev. 2700 ft), Cove Mountain (CM) (elev. 4150 ft), Clingmans Dome (CD) (elev.6600 ft), Barnett Knob (BK) (elev. 4700 ft), Purchase Knob (PK) (elev. 4900 ft), and Mt. Mitchell (MM) (elev. 6650 ft). The map contained in Figure 2.1 shows the locations of the monitoring sites, with the exception of the Mt. Mitchell site, which is located off the map at a distance of 55 miles from the New Found Gap location.

Plots of the 1-hr ozone concentrations obtained from each of the monitors listed were made for each of the sampling days in which health effect studies were conducted on the GSMNP health study (Figures B.1-B.30). This was done by obtaining ozone as well as PM 2.5 data for the monitors from EPA's air now website and putting it into an Excel[R] spreadsheet which incorporated all of the project data from each sampling day. The data included ozone and $PM_{2.5}$ from the portable monitors at NFG, ozone concentrations from LR, CM, CD, PK, MM, and BK, $PM_{2.5}$ from Look Rock's TEOM, as well as temperature and relative humidity measured at the trailhead. The intent was to check for variation of ozone concentration between the continuous monitors as well to see if the ozone concentrations observed at NFG by portable monitors were reasonable. In general, the concentrations at New Found Gap were found to be similar to those measured at the other high elevation sites.

2.3 Wind Data

Wind data is reported by hour from the Clingmans Dome meteorological tower and gives wind direction and speed and was obtained for each of the days on which the hiker health study was conducted. This data provided the prevailing wind patterns for the study site. These data were analyzed by breaking the wind directions into 22.5-degree segments. The frequencies within those segments were plotted using Microsoft Excel's radial plot. Plots for 24 hour (Figure 2.2), 8:00-18:00 (Figure 2.3) morning (Figure 2.4), and afternoon (Figure 2.4), were all used to better understand

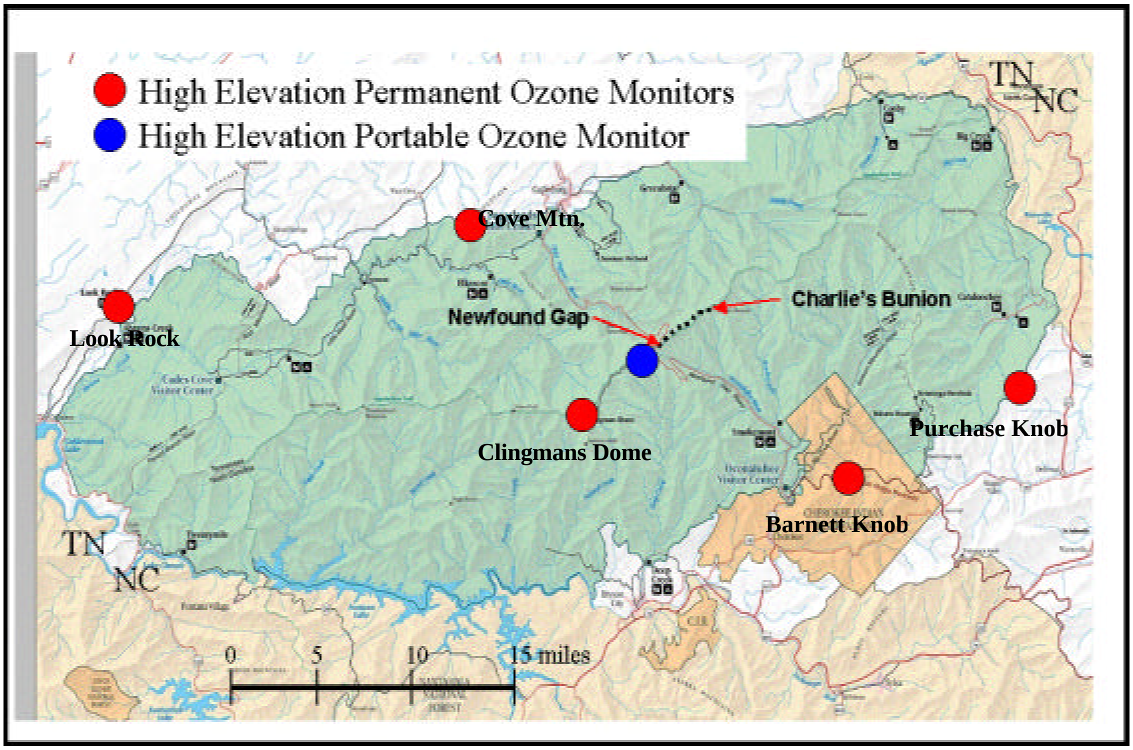

Figure 2.1. Ozone Monitors within the GSMNP

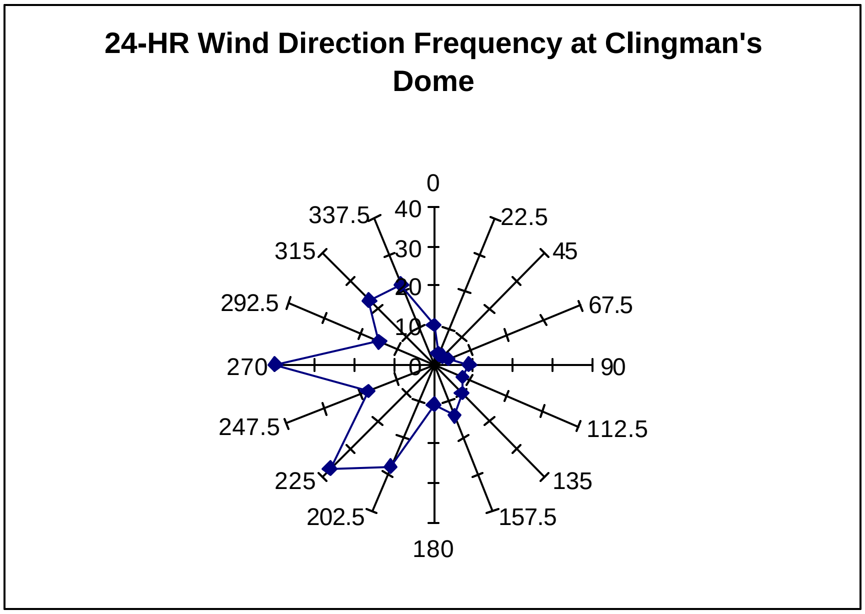

Figure 2.2. 24-HR Wind Direction Frequency at CD

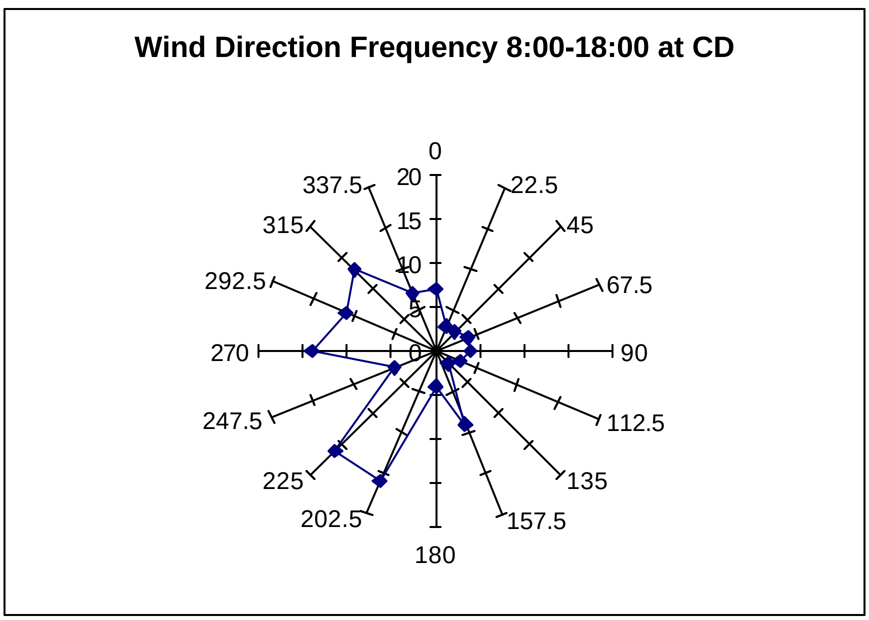

Figure 2.3. Wind Direction Frequency 8:00-18:00 at CD

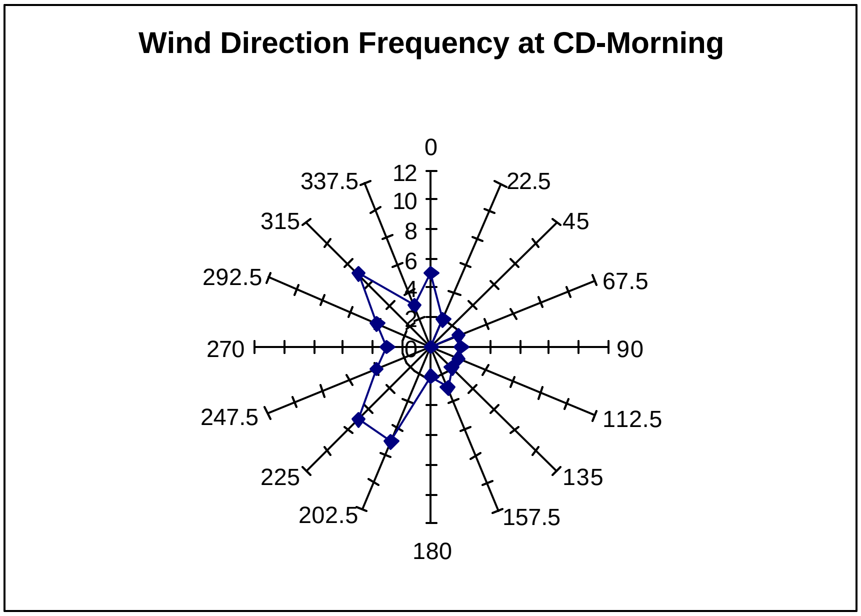

Figure 2.4. Wind Direction Frequency at CD-Morning

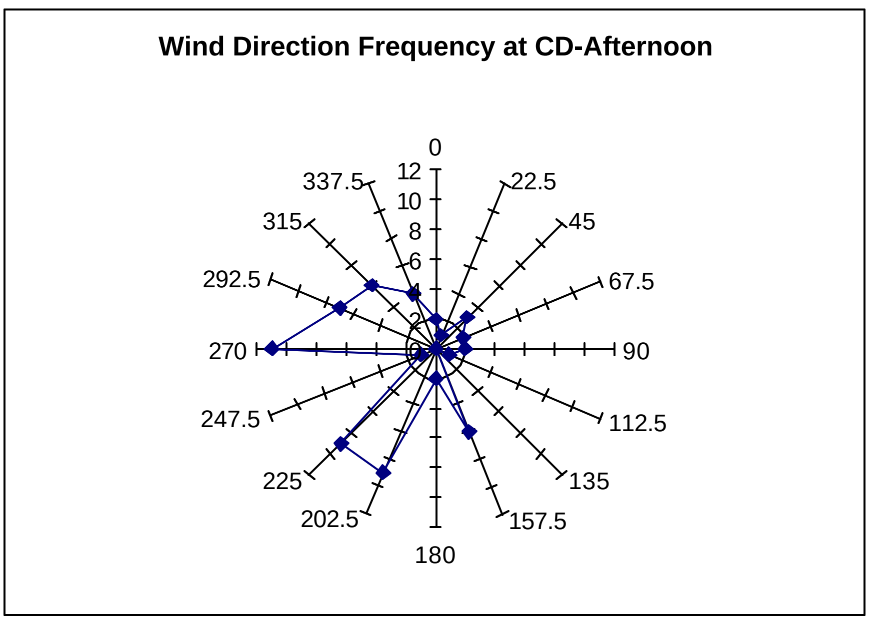

Figure 2.5. Wind Direction Frequency at CD-Afternoon

wind dynamics at the sampling site. The following plots show the frequency of winds by direction.

A total of 30 days were included in the NFG hiker health study (Table B.1). The predominate wind directions for the sampling period of August 10-October 29, 2002 for the 24 hours were 270 degrees and 225 degrees, which are winds coming from west and south west directions, respectively. The wind data were then used to see if wind patterns for other periods within the day were consistent with the 24-hour frequencies. This was accomplished by plotting daytime, nighttime, project sampling period (almost the same as daylight) and morning and afternoon wind- roses. The plots provide a general idea of wind direction and how it changes throughout the day. Since some of the plots are more relevant than others only plots for the sampling period (8:00-18:00 EDT), morning (8:00-12:00 EDT), and afternoon (13:00-18:00 EDT) wind roses were included in the text. The nighttime and daylight wind roses can be found in the Appendix C, Figure C.1 and C.2.

The plots show a trend for winds to have an origin out of the west and southwest in the afternoon. The morning shows more variability and while no single direction dominates, more of the winds come from the southwest and northwest directions. The relevance of wind direction and how it pertains to the canopy effect will be discussed in Chapter 3.

CHAPTER 3

METHODOLOGY

This chapter reviews the methodology for investigating the presence of a canopy effect. Part one explains how the canopy effect was quantified. Part two of this chapter describes the monitor location, wind speed and direction effects, and how these factors were hypothesized and analyzed to determine if they created a canopy effect.

3.1 Quantifying the Canopy Effect

The canopy effect is real and quantifying it is not a simple matter. Wind speed plays a part when measuring ozone within a canopy. When wind speeds are high, ozone uptake and its replenishment are increased according to the literature. Low wind speed will allow more ozone uptake than replenishment giving a larger difference between inside and outside canopy concentrations. To quantify the canopy effect, the difference between ozone concentrations inside and outside of the canopy were made with the portable ozone analyzer. This was accomplished by walking with the instrument rigged to the frame of a backpack approximately 50 yards into the canopy at the trailhead and back out at 5-10 minute time intervals at New Found Gap (Figure 3.1). A similar experiment performed at the Look Rock monitoring Station in the GSMNP measured ozone above and below the canopy at that location, by walking up to the top of the observation tower and then back down into the canopy. A reduction in ozone concentration was observed in both cases at New Found Gap and Look Rock. The results of these experiments prompted the question of monitor site selection and if the ozone monitoring site, itself, would also be under the influence of a canopy effect.

3.2 Canopy Effect and 2B Portable Ozone Monitor

The amount of reduction within the canopy is important because the ozone monitoring at NFG is intended to be representative of the concentrations that volunteers of the hiker health study are exposed to as they hike to and from Charlie's Bunion along the four-mile trail. If in fact the portable ozone monitor was influenced by a canopy effect, the volunteer hikers could be exposed to higher concentrations than observed while hiking the trail from New Found Gap to Charlie's Bunion, on the

Figure 3.1. Portable Ozone Monitor in Canopy

other hand, if a canopy effect does not exist at the monitor site then hikers might be exposed to less ozone while hiking due to the canopy effect along the trail. For purposes of the health study a correction factor might be needed to compensate for the lower concentrations.

3.2.1 Monitor Site Description

The portable ozone monitor was setup at the trailhead of the Appalachian Trail at New Found Gap. The site was in a grassy area on the other side of a wooden railed fence. Trees to the northeast, east, south, and southwest border the site. To the west and northwest is the NFG parking lot.

Figure 3.2. Monitoring Site at NFG

3.2.2 Methodology for Determining Canopy Effect on Portable Ozone Monitor

Several analyses took place to determine if the portable monitor was influenced by a canopy effect. The data were first compared to the ozone concentrations recorded by the permanent ozone monitors at Clingmans Dome and Barnett Knob. These two stations are the closest to New Found Gap. Clingmans Dome is approximately 4 miles southwest of the site and Barnett Knob is in Cherokee at a distance of approximately 10 miles southeast of the site. CD and BK were selected to compare the portable ozone monitor at NFG on the basis that these monitors were generally unaffected in regard to canopy influence due to their unobstructed ridge top locations, as well as being at high elevation and reasonably short distances from the NFG site. The ozone concentrations from these sites are reported hourly. During the health study, hourly ozone concentrations at CD were higher than NFG 75% of the time. The mean ozone concentrations at CD and NFG were 54 ppb and 48 ppb, with a standard deviation of 15 and 14 respectively. Scatter plots were made for CD versus NFG (Figure 3.3) and BK versus NFG (Figure 3.4) on the following page. The scatter plot for CD versus NFG showed decent correlation and from the slope of the best-fit line (i.e. 1.09) the ozone concentrations at CD were 9% higher than NFG on average. NFG was higher than BK 80% of the time during the health study. For each hour the difference and percent difference between the monitors were tabulated.

Wind data from the Clingmans Dome site gave wind speed and direction, as well as the standard deviation of wind direction. The wind data is reported as hourly vector wind speed (ms^{-1}), vector wind direction (degrees), and standard deviation or

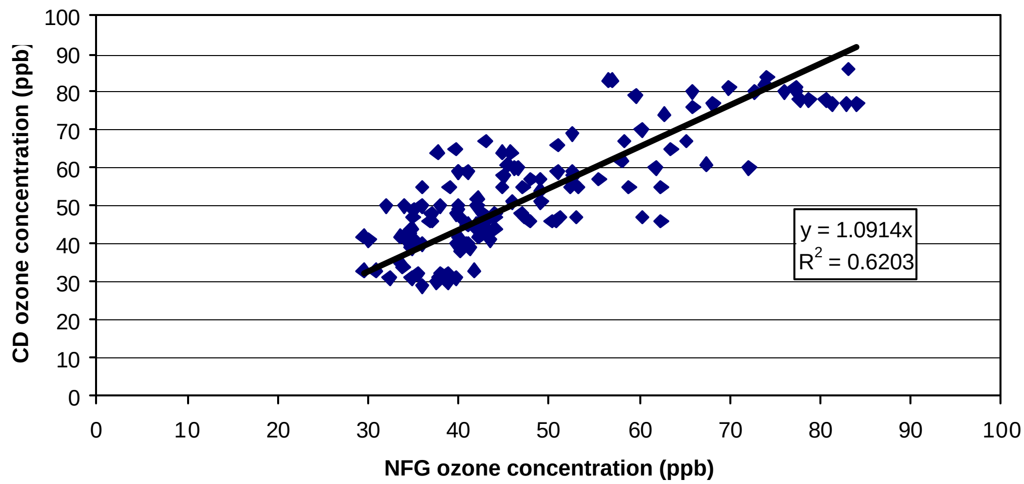

Figure 3.3. NFG vs. CD

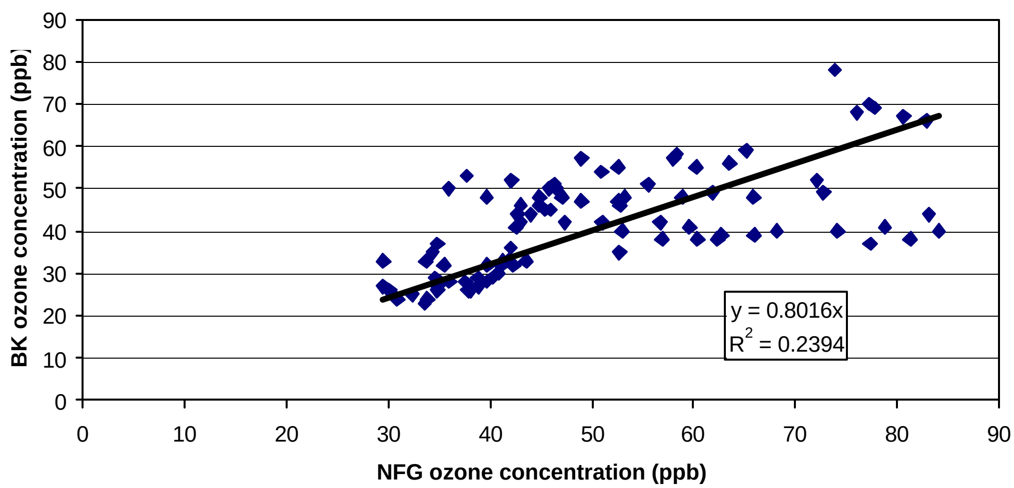

Figure 3.4. NFG vs. BK

sigma theta (degrees). It was assumed that the CD wind data would be representative of the wind at NFG. The wind data were compared to ozone concentration differences between the monitors. By ranking the data, it was possible to set up groups based on the differences of ozone concentrations between NFG and continuous monitors at CD and BK. The data were divided into four groups: >20 ppbv, 5-19 ppbv, +5 through –5 ppbv and < -5 ppbv. The range of +5 through – 5 ppbv was considered to be equivalent to CD. Ozone concentrations were considered to be reliable within 5ppbv. The positive ranges indicate higher concentrations at CD or BK than at NFG. Negative values are obtained when the concentrations at NFG are higher than CD or BK. Using these groups, it was easier to look at wind speed and direction and how they correlate with ozone loss. As mentioned previously, trees border the monitoring site from 45 degrees to 240 degrees. Winds originating from these directions, especially the east, are hypothesized to have a possible influence from the canopy in regard to ozone concentrations, since the wind would have blown through the trees in approaching the monitor.

It was suspected that wind speed and standard deviation of the wind direction might have an influence on ozone loss. After the groups were formed, and the wind direction was examined to see if it was passing through the vegetation bordering the site, wind speed was the next parameter to analyze. From the review of literature, high wind speeds should provide an environment less conducive for canopy effect, and conversely lower wind speeds should provide a more substantial canopy effect. Last, the standard deviation of wind direction (sigma theta) was looked at; this shows the wind variability for the hour. A higher sigma theta means that winds were more variable within that hour of observation. This, in theory, provides less confidence in the prevailing wind direction for the hour and most likely influence from the canopy will not be significant.

CHAPTER 4

DISCUSSION OF RESULTS

This chapter summarizes the results from the analyses conducted to estimate the effect of the canopy. The objectives of the chapter include to 1) quantify and give a range for ozone loss within the canopy via observations at New Found Gap and Look Rock in the GSMNP, and 2) determine the influence, if any, of the canopy on the portable ozone monitor at NFG.

4.1 Quantification of the Canopy Effect

The trail from New Found Gap to Charlie's Bunion was hiked to determine ozone variation and canopy effect along the four-mile stretch. Canopy specific studies were done on the front and back end of the hikes. On the following page, Figure 4.1 illustrates the route taken to and from the GSMNP to hike the trail and the ozone concentrations experienced that day. A GPS unit was used to track the routes during the hike. Position and time were recorded so it was easy to relate the ozone concentration to a location. The ozone monitor was placed in the bed of the truck at the Sugarland's Visitor Center, so that the ambient ozone concentration could be measured while driving from the visitor's center to NFG and the GPS unit was turned on. From this ozone concentrations and location were observed throughout the trip up and down the mountain to NFG. The numbers in the figure represent a 2-mile average of ozone concentration along the roads. The green numbers were on the way up the mountain from Sugarland's (elevation 1295) to Newfound Gap (elevation 4908). The concentrations at Sugarland's were lower in the morning than at NFG

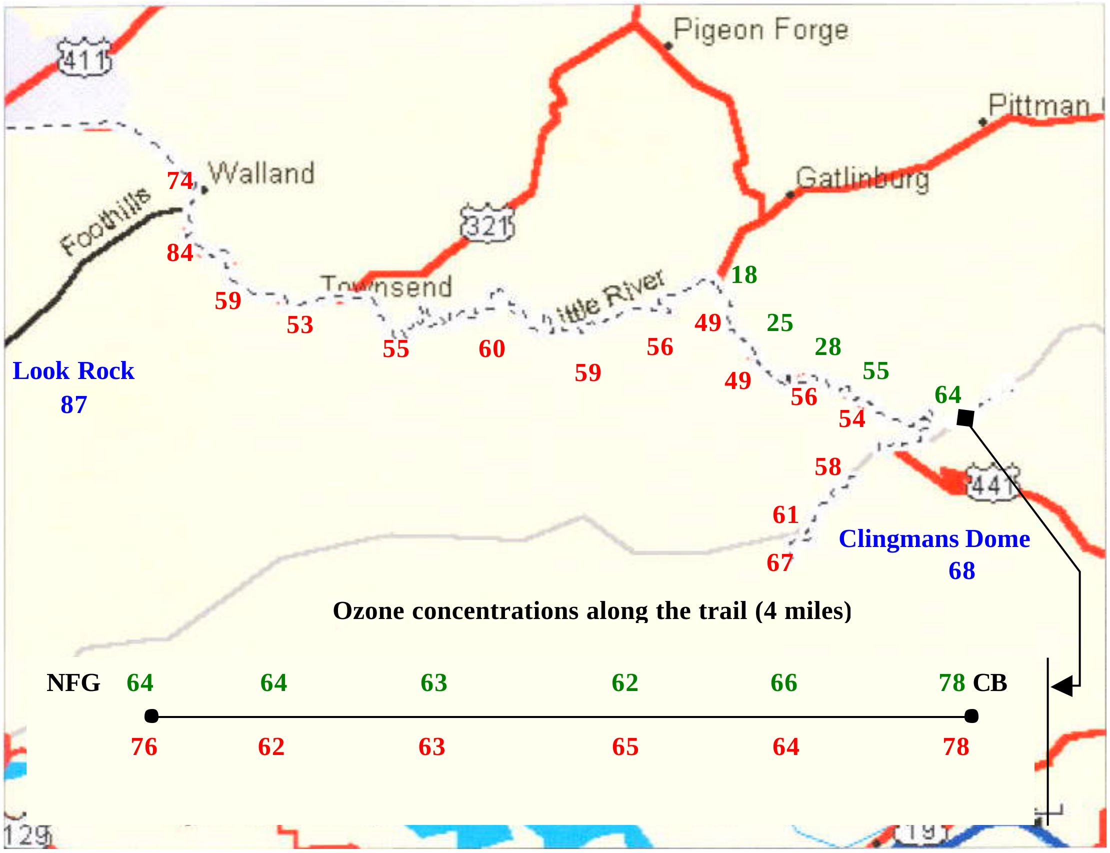

Figure 4.1. Hiking Routes and Ozone Concentrations

because of the inversion that occurred overnight creating a boundary layer and subsequent ozone scavenging near the surface of the low lying areas (i.e. near the Sugarland's Visitor Center). As the day proceeded and temperatures rose, vertical eddies from differential temperatures mixed the layers and more uniform concentrations were seen at lower elevations. The concentrations in red were on the way back from Charlie's Bunion over to Clingmans Dome and then back down the mountain to Sugarland's and over to Walland and demonstrate the statement above. The inset in the map is a straight-line representation of the 4-mile trail from New Found Gap to Charlie's Bunion; the concentrations were based on 1-mile averages to and from CB. The blue concentrations were those that were observed at the Look Rock and Clingmans Dome continuous monitors. Our monitor agreed very well with the two monitors during the period in which the portable monitor was in the vicinity of the continuous monitors. The inset on Figure 4.1 shows the difference in ozone concentration that hikers experienced while hiking on the trail and when they reached the destination of CB and NFG. The inset clearly showed that the ozone concentrations on the trail were 13 ppb lower than the concentrations at NFG and CB. The 1-mile average ozone concentration on the trail in route to CB was 66 ppb and at CB the concentration was 78 ppb. The same was observed when returning to NFG, the concentration on the trail was 62 ppb compared to 76 ppb when out of the canopy at the NFG trailhead. Figures D.4 and D.5 were the 10-second ozone measurements made while hiking from NFG to CB and back.

The canopy effect was measured by walking with the portable ozone monitor at five-minute intervals 50 yards into the forest at the NFG trailhead and back out of the canopy where the monitors were located during the health study. The canopy on the trail from NFG to CB consisted of a combination of coniferous and deciduous trees and shorter shrubbery. From the studies conducted at NFG trailhead it was determined that there was a definite canopy effect as one moved from the clearing into the forested area (Figure 4.2 & 4.3). Walking into and out of the canopy at the trailhead of the Appalachian Trail at New Found Gap on 6/11/02 gave the following results. An average of 8-ppbv difference in concentration was observed depending on wind direction. In the morning the difference was less significant, with the average difference around 5-ppbv and percent difference of 9% when in clearing of the New Found Gap Parking Lot. There was a more substantial difference in afternoon with an average difference of 11 ppbv and percent difference of 15%. The data collected at New Found Gap (Figures 4.2 & 4.3) was labeled **O** and **C** and represented the data collected outside of the canopy and within the canopy, respectively.

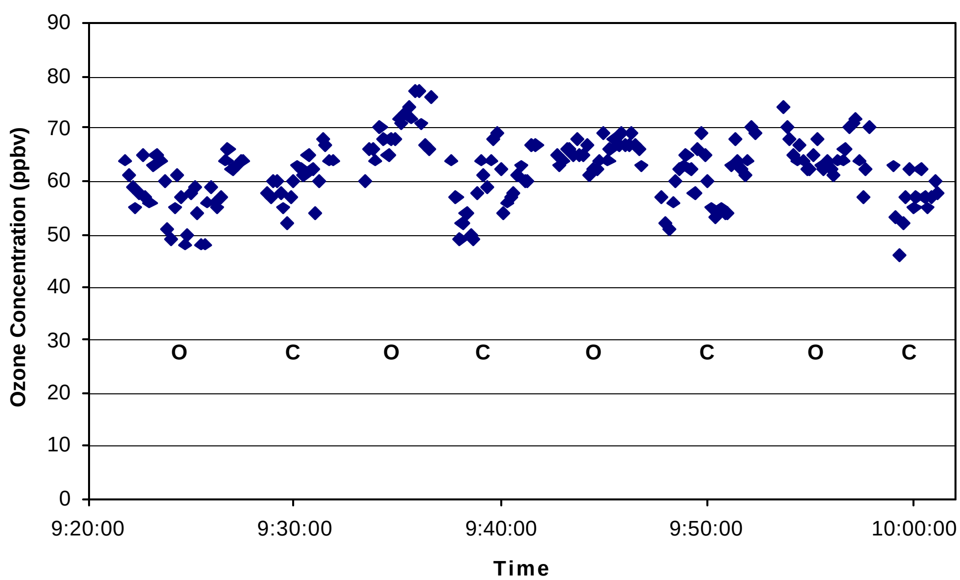

Figure 4.2 Morning Canopy Effect At NFG 6/11/02

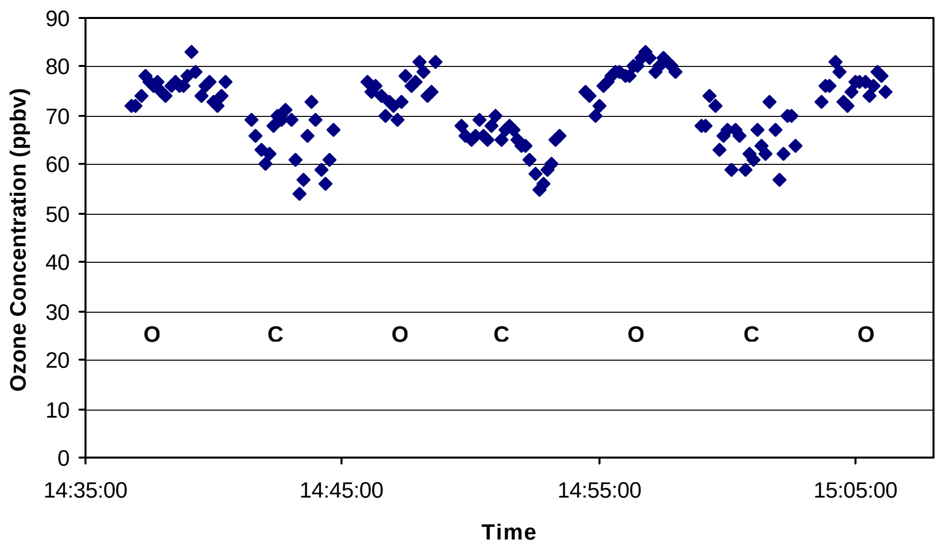

Figure 4.3 Afternoon Canopy Effect at NFG 6/11/02

The canopy effect at NFG was measured during five separate events (Table 4.1 on the following page). The difference and the percent difference were calculated for each event by straddling in canopy measurements with the average of two out of canopy measurements to account for any change in ozone during the event. The effect from the canopy was found to have a range from 3-13 ppbv based on the 5 sets of data collected at New Found Gap. The average difference was 9 ppb and the average percent difference was 13 %. According to previous studies the high end of the range should coincide with wind speeds below 1.5 ms^{-1} and the low range coincides with higher wind speeds, those above 2 ms^{-1}. The wind data from CD from the morning of 6/11/02 showed the winds blowing from 67 degrees north of east at 1 ms^{-1}, the wind speed was not above 2 ms^{-1} but the wind was passing through the canopy. In the afternoon on 6/11/02 the winds originated from 280 degrees with a speed of 0.3 ms^{-1}. The difference between in and out of canopy measurements in the

Table 4.1. Canopy Effect Summary

Date	NFG (O) O_3 (ppbv)	Canopy (C) O_3 (ppbv)	Difference (ppbv)	Percent Difference (%)
6/11/2002	58			
6/11/2002		60	3	5
6/11/2002	70			
6/11/2002		59	8	12
6/11/2002	66			
6/11/2002		60	5	8
6/11/2002	65			
6/11/2002	76			
6/11/2002		65	11	14
6/11/2002	75			
6/11/2002		64	12	16
6/11/2002	78			
6/11/2002		66	12	15
6/11/2002	76			
7/30/2002	38			
7/30/2002		35	4	10
7/30/2002	40			
7/30/2002	36			
7/30/2002		30	6	17
7/30/2002	36			
8/22/2002	73			
8/22/2002		67	11	14
8/22/2002	83			
8/22/2002		69	13	15
8/22/2002	80			
8/22/2002	75			
8/22/2002		64	12	16
8/22/2002	77			

morning and afternoon was due to easterly winds passing through the canopy and depleting ozone, minimizing the effect from the canopy, while the westerly winds in the afternoon with a low wind speed maximized the ozone loss to the canopy.

Greater differences in regard to canopy effect were observed at Look Rock (Figure 4.4). The difference at Look Rock was 21 ppbv and there was a percent difference of 34%. The canopy effect was measured at Look Rock by walking up the observation tower on the site for out of canopy ozone concentrations, labeled **O** and back down the tower below the canopy for in canopy ozone concentrations, labeled **C.** The observation tower most likely gave unaffected ozone concentrations that were clear of any canopy effect and/or the vegetation at Look Rock's lower elevation (2700 ft) may have provided a denser canopy and hence more ozone deposition. These data also showed why LR was not a suitable site for co-location studies as mentioned previously.

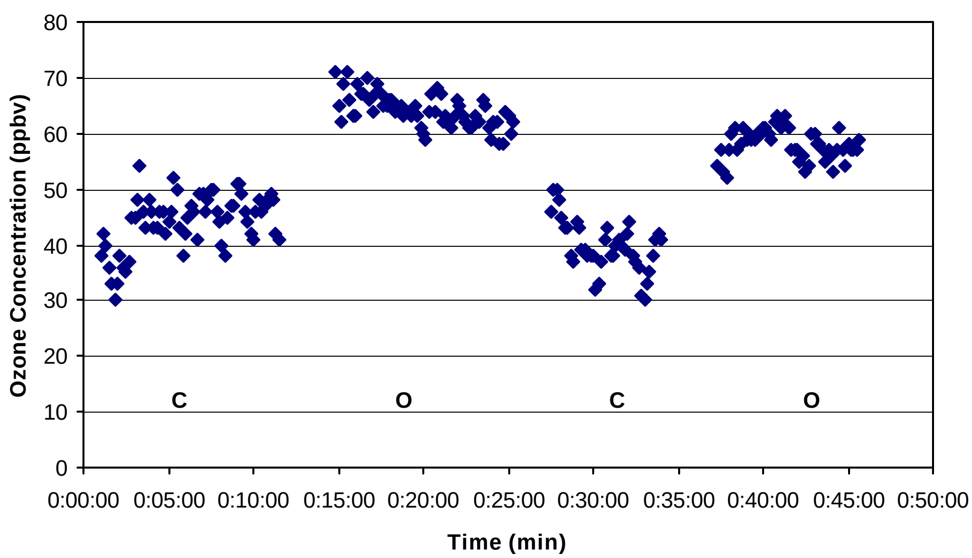

Figure 4.4 Canopy Effect at Look Rock in GSMNP

At New Found Gap the range was from 3-13 ppbv, and at Look Rock a 21 ppbv difference was observed. Given that Look Rock out of the canopy concentrations were sampled from the Look Rock observation tower and the out of the canopy ozone concentrations at NFG were taken at ground level, it can be hypothesized that the lower range of canopy effect at NFG can be attributed to a well mixed atmosphere in which ozone is reacting with the surrounding terrain, depleting the out of canopy concentrations and giving less of a difference between in and out of canopy ozone concentrations. The Look Rock site, depending on wind direction, would most likely have air masses that did not experience the mixing because of its location on the leading edge of the mountains from the valley on the Tennessee side.

4.2 Canopy Effect at the New Found Gap Monitoring Site

From the canopy field studies, the canopy effect had indeed been present when walking into and out of the canopy and the amount of difference between inside and outside had appeared to depend on wind direction. Wind direction was not as significant as first thought in the differences between the portable monitor at NFG and the monitors at CD and BK.

Plotting wind direction versus the 1-hr O_3 difference between NFG and CD (ΔO_3) best reveals the lack of evidence in support of attributing these differences to a canopy effect (Figure 4.5). One can also note that the wind directions of 135 through 225 degrees (these directions are within the 45-240 degree range in which trees border the site) experience the highest frequency of difference between the CD and

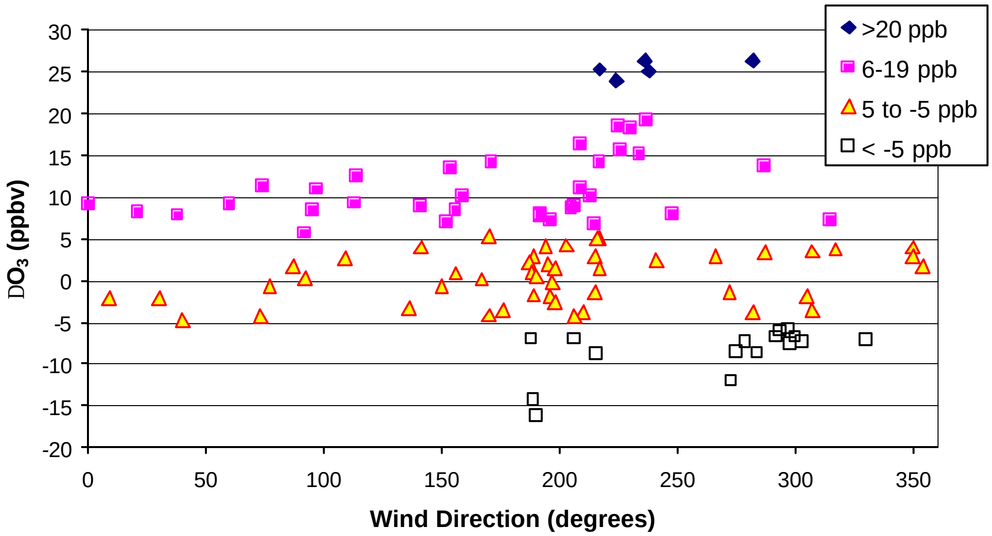

Figure 4.5. Wind Direction vs DO_3

NFG monitors, that might indicate a canopy effect from those wind directions, however those same directions also see lower differences, which discredits the idea that the differences stem from wind direction.

For the same data set, wind speeds were plotted against the difference in ozone concentration. It would be expected that if the portable ozone monitor at NFG saw a canopy effect, the wind speed would also indicate this by the degree of difference and corresponding wind speed. At lower wind speeds a more appreciable difference between CD and NFG would be present, and at higher wind speeds less of a difference. It is shown that this was not the case at NFG (Figure 4.6). In fact, the data from NFG does not support the hypothesis that wind speed plays a role in ozone depletion from the canopy. This plot contributes further to the evidence against an overall canopy effect at the monitoring site at NFG. From Figure 4.6, the data is at best inconclusive with respect to determining whether wind speed creates a canopy effect at the monitor.

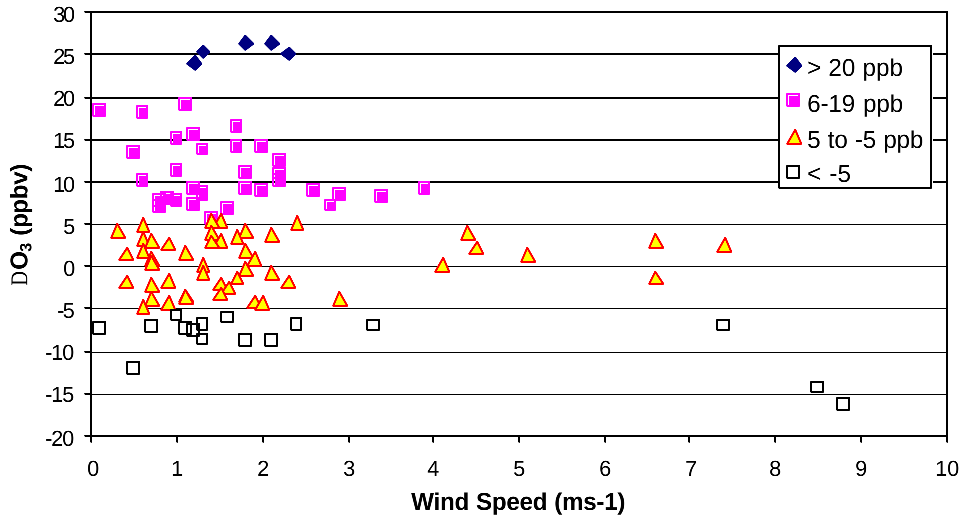

Figure 4.6. Wind Speed vs DO_3

The monitor at NFG showed results of minimal influence from the canopy that borders the monitoring site on the basis of wind speed and direction. In a mountain setting wind direction is seldom constant, so having constant winds blowing through the canopy bordering the site is unlikely, and is the most probable reason of the lack of correlation between wind direction and ΔO_3. Wind variation may negate a canopy effect at NFG. Within an hour, high wind variation may negate any canopy effect, and low wind variation for a direction of wind that blows through the canopy promotes ozone loss to the canopy. There is a slight trend for the change of ozone to decrease with increased values of sigma theta (σ_θ). However, the lack of correlation between wind variation (σ_θ) and ΔO_3 (Figure 4.7), reveals that the difference in ozone concentration was not just an issue of canopy effect on the portable monitor when wind direction was blowing through the canopy at low wind speeds with low wind variation for that hour as suspected, but lends itself to the fact that ozone

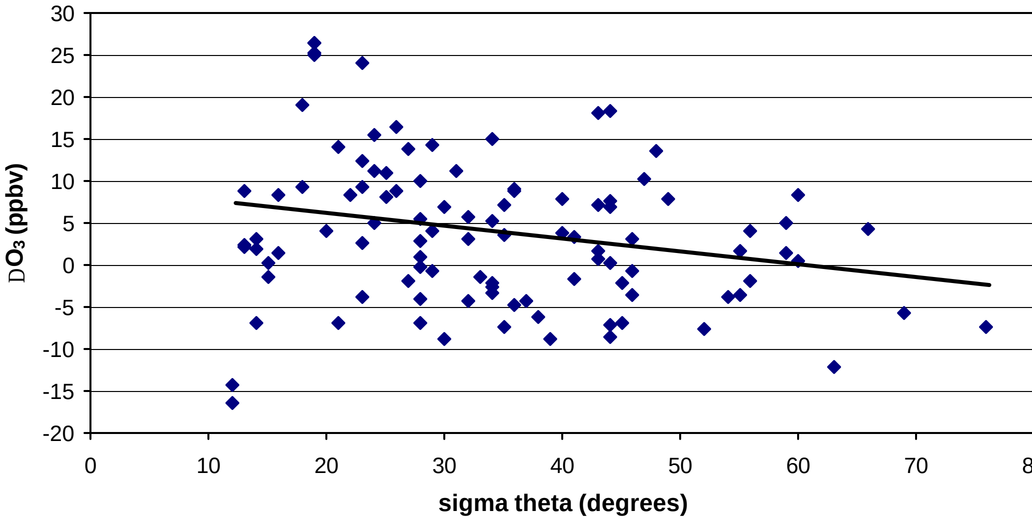

Figure 4.7. DO_3 **vs Sigma Theta**

concentrations can vary by as much as 20 ppb in the GSMNP depending on location (Appendix B) and meteorological conditions.

Wind speed and wind variability (σ_θ) showed a strong relationship. The reason for the relationship between WS and σ_θ pertains to atmospheric stability conditions. Atmospheric stability is classified into six stability classes (A through F) where class A is the most unstable and class F is the most stable (Wark, Warner, and Davis, 1998). Stability classes A and B typically occur under daytime conditions and high solar radiation. Wind speeds are low and turbulence from vertical eddies due to incoming solar radiation create a well-mixed atmosphere. In regard to the canopy effect on the monitor at NFG higher wind variations typically occurred at lower wind speeds (Figure 4.8), which as mentioned previously would keep the wind from blowing consistently through the canopy at those lower speeds, as well as providing good mixing in the atmosphere and therefore minimizing the effect of the canopy.

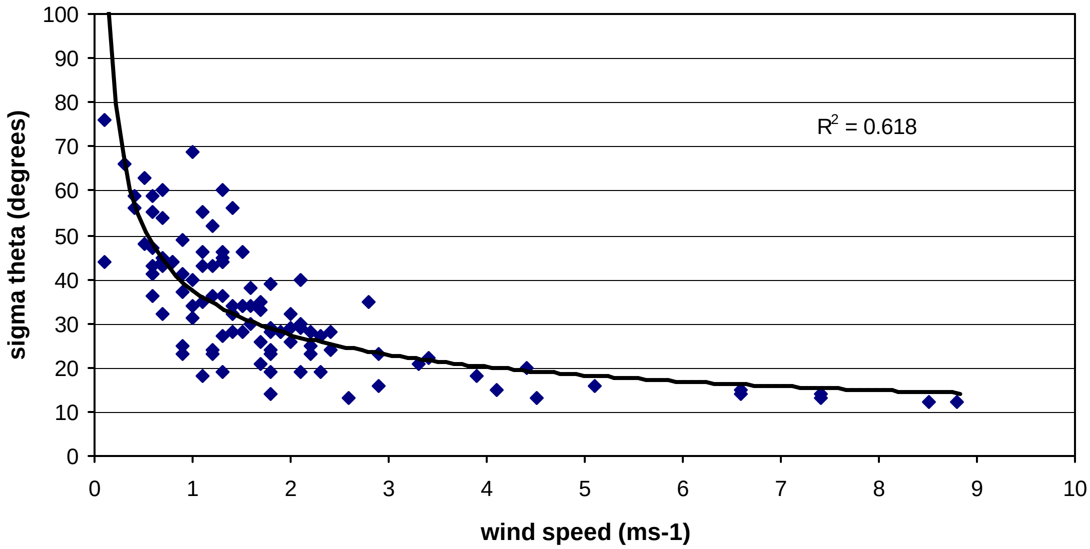

Figure 4.8. Wind Speed vs Sigma Theta

The portable ozone monitor at New Found Gap was determined to have minimal influence from the canopy. Although some directions did seem to show some influence from the canopy, the main wind direction, which was east, where it was hypothesized that the canopy effect would have shown the most appreciable differences, did not produce these results. The reason for this was 1) easterly winds were not the prominent wind direction and 2) the differences in ozone concentration from east winds did not demonstrate a strong canopy effect.

It was shown in Chapter 3 (Figure 3.3) that Clingmans Dome experienced higher ozone concentrations than Barnett Knob and New Found Gap 98% and 75% of the time during the health study, respectively. Barnett Knob was also lower than the concentrations observed at NFG 80% of the time (Figure 3.4). The fact that the concentrations at BK were consistently lower than CD and NFG is probably one of the strongest indications of lack of effect from the canopy. Concentrations measured at NFG were most often lower than CD and when the ozone concentrations were higher, only a few of the values were outside of the plus or minus 5 ppbv range which was established as an acceptable range between the monitors. Also, for the daily plots that were made for each sampling day (Appendix B), the portable ozone monitor observations were almost always within the range of the existing monitors in the GSMNP. Statistically, no strong correlation existed between the 4 variables of WD, WS, σ_θ, and ΔO3. The strongest relationship was between WS and σ_θ. Based on the data collected one can say that the monitor at NFG does not experience a canopy effect.

4.3 Options for Handling the Canopy Effect while on the Trail

It was determined that the monitor at NFG was not under the influence of a canopy effect. However, the canopy effect is real and affects the ozone concentrations that the day hikers are exposed to while on the trail. There are three approaches that have been identified as possible ways to account for the canopy effect while hiking from NFG to CB.

The first and simplest approach would be to apply a 13% correction to ozone concentrations measured at NFG based on the average canopy effect discussed in section 4.1, thus each ozone concentration measured would be reduced by 13%. This method would most likely under predict the concentrations that the day hikers were exposed to because of the time spent in the open areas of NFG before and after the hike and at CB during the hike.

The second approach utilizes an average ozone concentration over the duration of the hiker's participation in the study. The ozone exposure from the time the hikers leave the Health Team to the time they return to complete their lung function tests are averaged (O_{3NFG}). From the hikers' travel logs, the time spent on the trail (t_{trail}) can be separated from the time spent at NFG and CB (t_{NFG} and t_{CB}) to determine the time the hiker spent in and out of the canopy. The average concentration in the canopy was 13% lower than ambient concentrations; therefore, to account for the time spent in the canopy the ozone concentrations measured at NFG were multiplied by 0.87. Summing the percentages of the total time spent in and out of the canopy multiplied individually by O_{3NFG} would give a corrected ozone concentration (O_{3c}). The maximum difference between the corrected ozone concentration and the ozone concentration measured at NFG is 13%, assuming the hiker spent no time at NFG and CB and 100% of the time on the trail. The equation that represents the hiker's ozone exposures is as follows:

$$O_{3c} = \left(\left(\frac{t_{trail}}{t_T}\right)\left(0.87O_{3_{NFG}}\right)\right) + \left(\left(1 - \left(\frac{t_{trail}}{t_T}\right)\right)\left(O_{3_{NFG}}\right)\right)$$

where

O_{3c} = corrected ozone concentration

O_{3NFG} = average ozone concentration measured at NFG between initial and final lung function tests

t_T = ($t_{trail} + t_{NFG} + t_{CB}$) total time of exposure between initial and final lung function tests

t_{trail} = total time spent on trail

t_{CB} = time spent at CB

t_{NFG} = time spent at NFG

The third method would be to use a time-weighted average based on the 15-minute average ozone observations obtained at NFG. This approach would be the most accurate and the most rigorous. The time-weighted average would account for the time spent before and after the hike at NFG and the ozone concentration at those times. It also would account for the time spent at CB and the ozone concentration at that time. In addition to the open areas, the trail would have time-weighted averages for exposure on the way out to CB and on the way back. This equation would only be limited by the ozone concentration averaging time of 15 minutes at the NFG trailhead and the accuracy of the hiker's travel logs. Below is the time-weighted equation for the hikers' ozone exposure.

$$O_{3_C} = \left[\frac{\sum_{i=1}^{n} \left(O_{3_i} t_i\right)}{T_t} \right] + \left[\frac{\sum_{j=1}^{0} \left(\left(0.87\, O_{3_j}\right) \times t_j\right)}{T_t} \right] + \left[\frac{\sum_{k=1}^{p} \left(O_{3_k} t_k\right)}{T_t} \right] + \left[\frac{\sum_{l=1}^{q} \left(\left(0.87\, O_{3_l}\right) \times t_l\right)}{T_t} \right] + \left[\frac{\sum_{m=1}^{r} \left(O_{3_m} t_m\right)}{T_t} \right]$$

where

O_{3C} = time averaged ozone concentration of hiker

$O_{3\,i,j,k,l\,\&\,m}$ = ozone concentration measured at NFG in 15 min. increments

t_t = total time of exposure

t_i = 15 min. increments at NFG at the beginning of the hike

t_j = 15 min. increments on the trail going to CB

t_k = 15 min. increments for the time spent at CB

t_l = 15 min increments for the time spent on the trail on the way back

t_m = time spent at NFG at the end of the hike in 15 min. increments

Ultimately, the decision to correct the ozone concentrations will rest on the health team. The health team will have to decide if the hiking logs provide sufficient information to determine time spent in and out of the canopy. In any event, the ozone concentrations measured at NFG are probably more correct than a majority of studies where ambient ozone monitors are correlated with health effects. The on-trail ozone concentrations were tabulated for each 15-minute period for every sampling day (Appendix B, Table B.2-B.30).

CHAPTER 5

CONCLUSIONS AND RECOMENDATIONS

This report has analyzed the effects of the canopy on ozone monitoring at New Found Gap in the Great Smoky Mountains National Park. The conclusions drawn from the research conducted can be used in the EPA funded hiker-health study to account for canopy effects. The following conclusions were reached in this study:

- The canopy effect is present when walking into and out of forested areas. Ozone loss due to deposition within the canopy when compared to the NFG monitoring site is estimated to typically be in the range of 5 to 11 ppb, with a high of 13 ppb and a low of 3 ppb, and an average of 8 ppb. The average percent difference observed was 13%.
- Although the monitor may at times be under the influence of a broader canopy effect, due to the presence of forested lands in all directions from the parking lot area, the data in this study has quantified the effect of the canopy between the monitoring site and the trail. Thus, the portable ozone monitor at NFG is at a suitable monitoring site.
- The weak correlation between wind direction and difference in ozone concentration between the monitors at New Found Gap and Clingmans Dome indicates the canopy effect is of minimal influence on monitoring results at NFG. Ozone concentrations at CD were 9% higher than NFG on average because of elevation

difference, and probably more importantly, sampling height differences. It is suspected that loss of ozone may occur over large forested areas depleting ozone concentrations at ground level. When ozone measurements are made from a tower 10 meters above the surface, such as at CD, the ozone concentrations at that height within the air mass are less affected than those measured at the ground.

- Sigma theta or wind variation may also negate the canopy effect at the NFG monitoring site. High sigma thetas dilute the effect of the canopy in two ways: 1) vertical mixing of ozone from turbulent eddies caused by high solar radiation may occur, and 2) varying horizontal winds do not consistently pass through the canopy bordering the site at NFG.
- The portable monitor at NFG was almost always within the range of the other existing monitors in the GSMNP. This shows that ozone concentrations can vary with location and that differences in concentration may or may not be associated with a canopy effect.

The ozone concentrations within the canopy that volunteer hikers are exposed to during the four-mile trek from New Found Gap to Charlie's Bunion and back are not the same as the concentrations measured at NFG or CD. Some ozone is lost to the canopy via reaction and deposition. In regard to canopy effect and the continuation of monitoring at New Found Gap for the hiker-health study, it is recommended that the ozone concentrations measured at NFG trailhead be adjusted by 13 % to account for the canopy effect for the portion of time that the hikers are in the canopy. The decision to apply the correction factor and the way it is applied will be the responsibility of the Hiker-Health Team. For hiker study days in which the portable ozone monitor at NFG was not available it is recommended that the ozone measurements made at CD be used as a substitute for those missing data. Since it was determined that ozone concentrations at CD were on average 9% higher than at NFG, one would simply multiply CD's ozone concentration by 0.91 to arrive at the corrected concentration at NFG. To determine the ozone exposure to a hiker on the trail the 13% correction factor needs to be applied as well. Multiplying 0.91 and 0.87 gives 0.79, which is the factor to use for a hiker on the trail between NFG and CB to adjust for the difference between NFG and CD and for the canopy effect at NFG.

The data presented in this study should provide the hiker health study researchers with the information needed to make an informed decision on how the canopy effect should be applied to determine ozone exposure to the hikers. This study was conducted during periods in which leaf growth and cover were essentially at their full growth. If future hiker health studies are conducted in early spring or late fall where leaves are not yet at full growth or have already fallen, additional canopy effect studies would be needed.

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5. Wark, K., Warner, C.F., Davis, W.T., Air Pollution: its origin and control. Third Edition 1997.

APPENDICES

APPENDIX A

COLOCATION AND DYNAMIC CALIBRATION OF 2B PORTABLE OZONE MONITOR

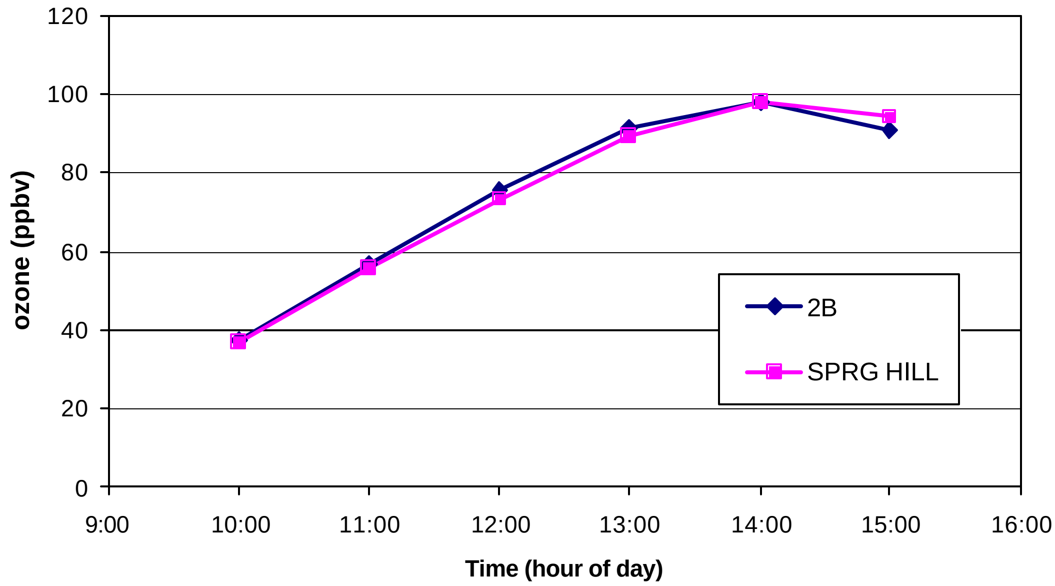

Figure A.1. Co-location at Spring Hill Elementary 7-23-02

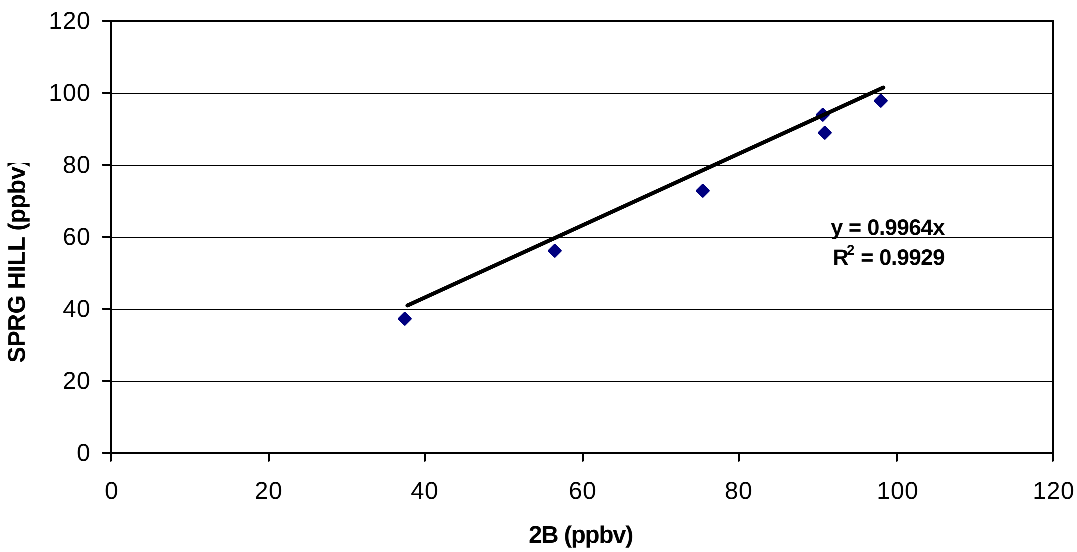

Figure A.2. 2B vs Continous Ozone Monitor at Spring Hill 7/23/02

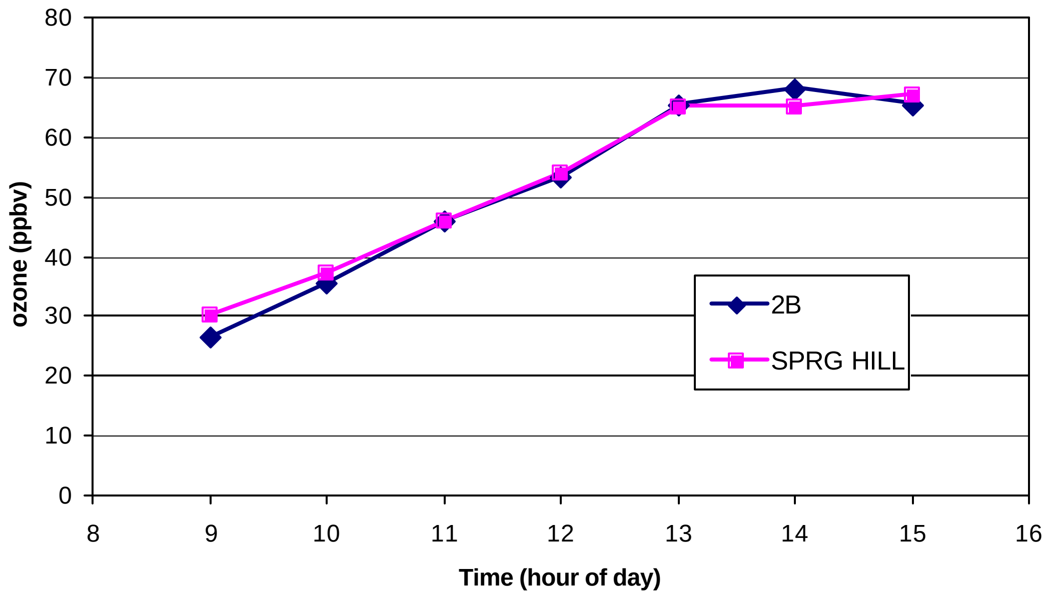

Figure A.3. Co-location at Spring Hill Elementary 7-24-02

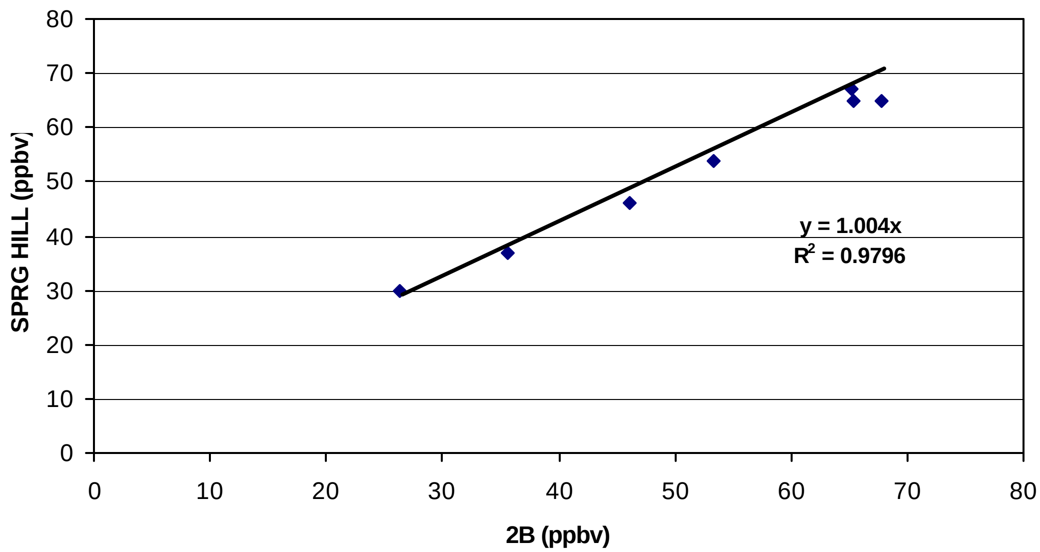

Figure A.4. 2B vs Continuous Ozone Monitor at Spring Hill 7/24/02

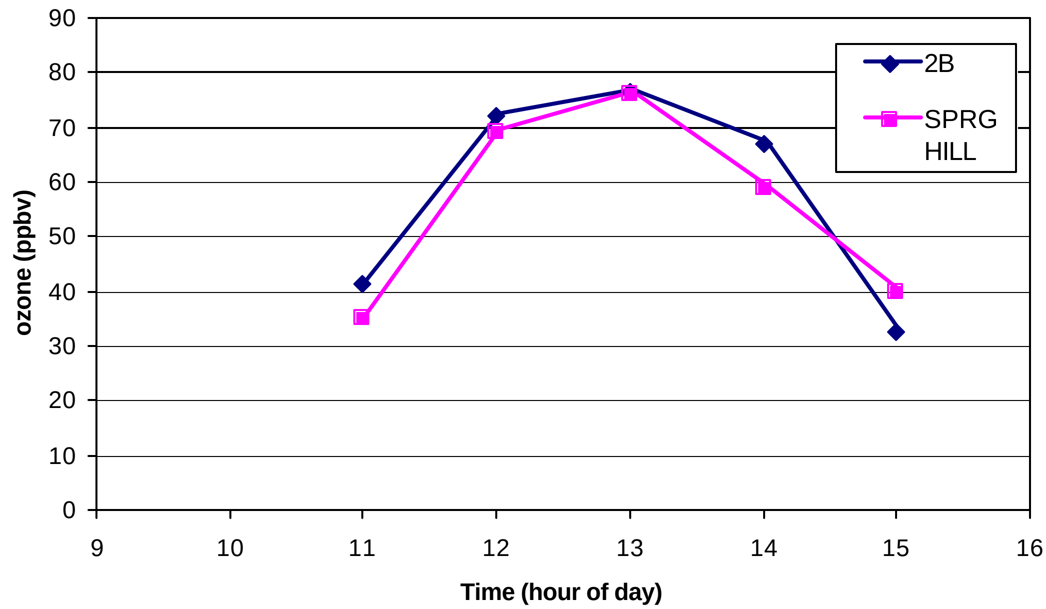

Figure A.5. Co-location at Spring Hill Elementay 7/25/02

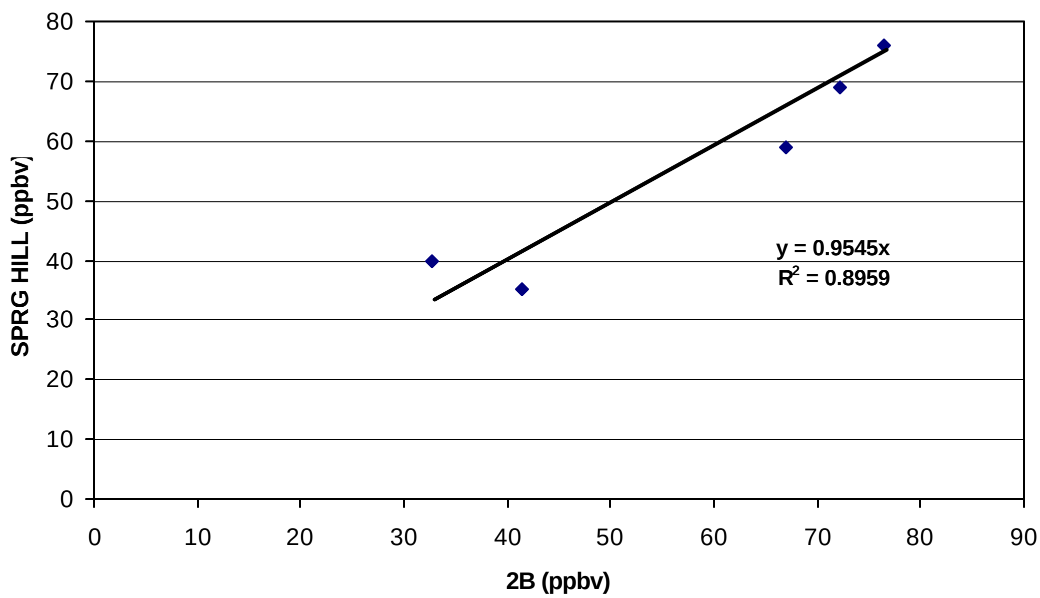

Figure A.6. 2B vs Continuous Ozone Monitor at Spring Hill 7/25/02

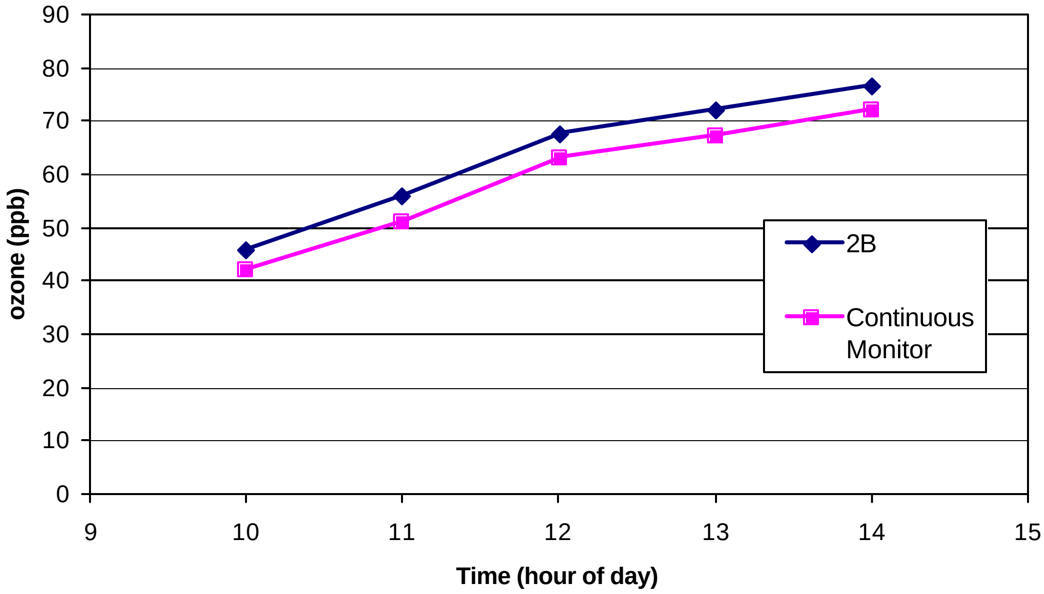

Figure A.7. Co-location at Spring Hill Elementary 7-26-02

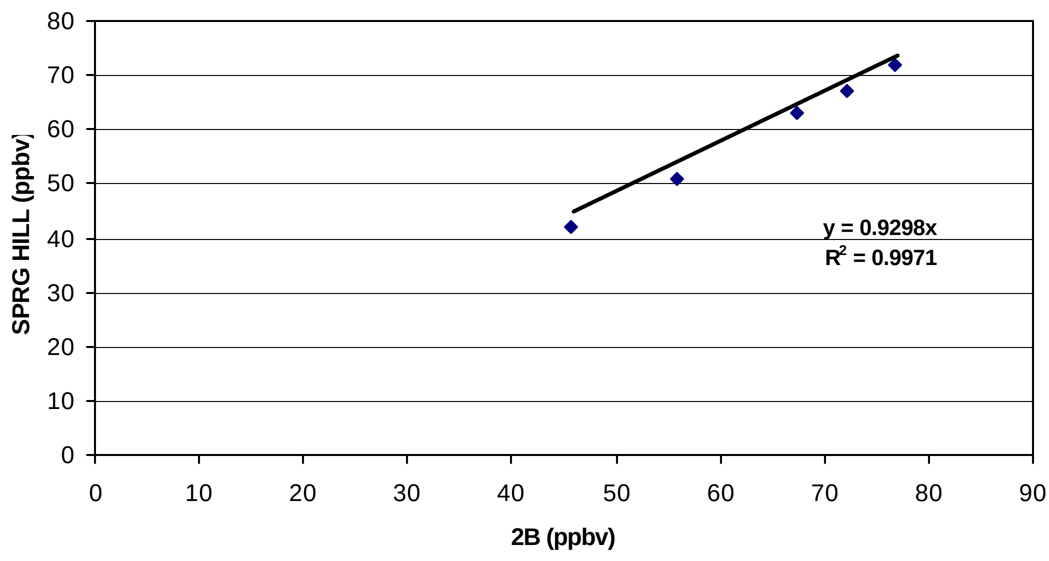

Figure A.8. 2B vs Continuous Ozone Monitor at Spring Hill 7/26/02

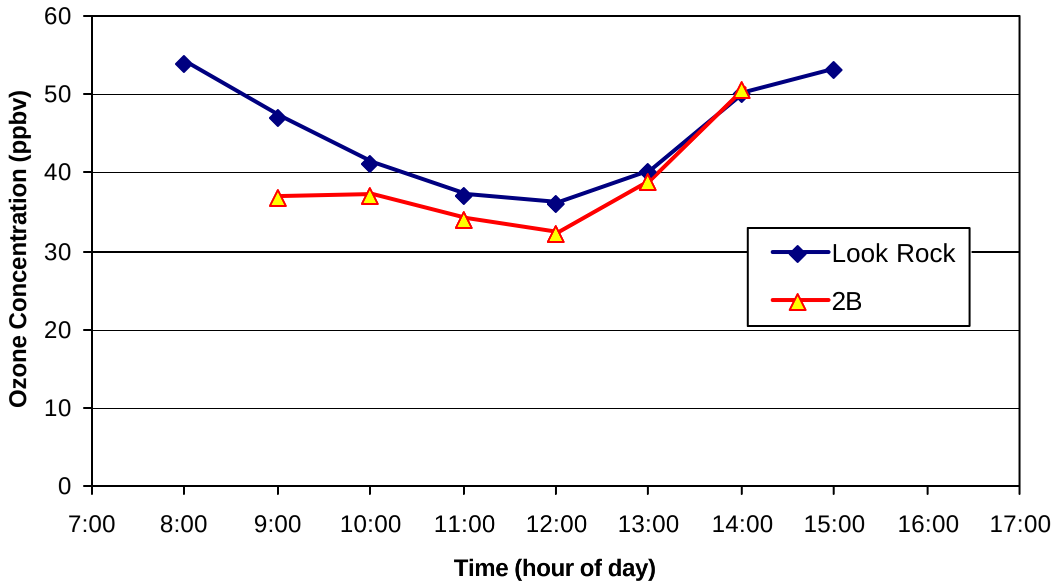

Figure A.9. Hourly Comparison of Look Rock and 2B

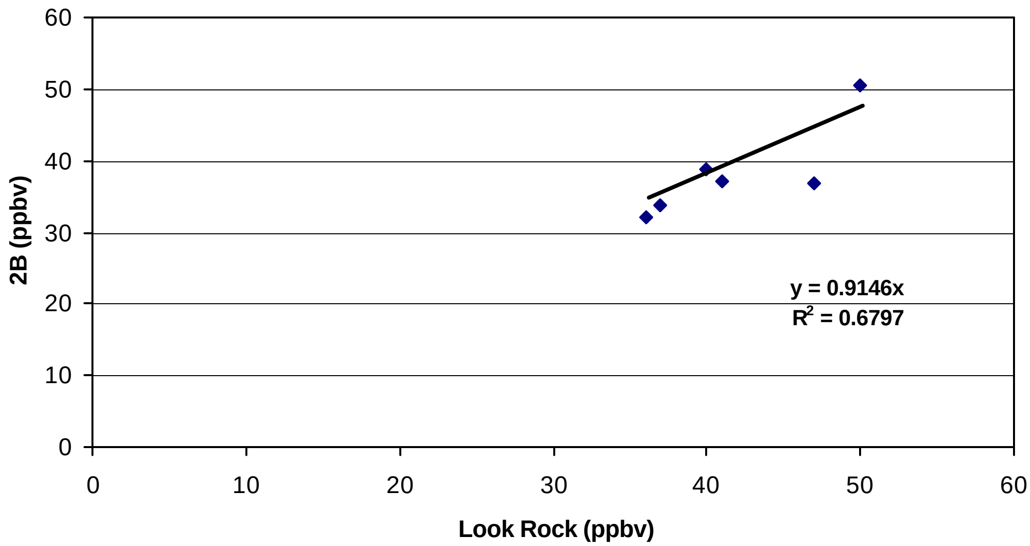

Figure A.10. Contnuous Ozone Monitor at Look Rock vs 2B Ozone Monitor

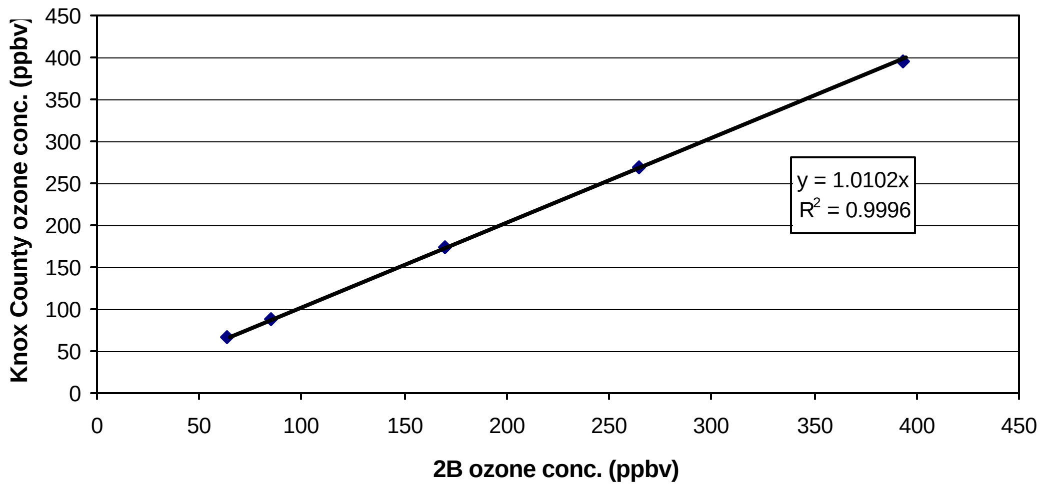

Figure A.11. Dynamic Calibration 6/4/02 (70-400 ppb)

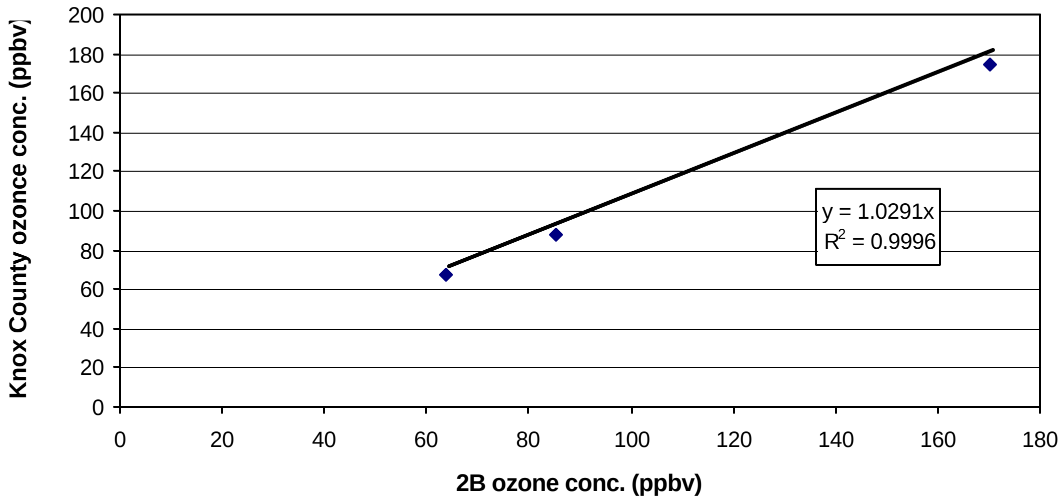

Figure A.12. Dynamic Calibration 6/4/02 (70-170 ppb)

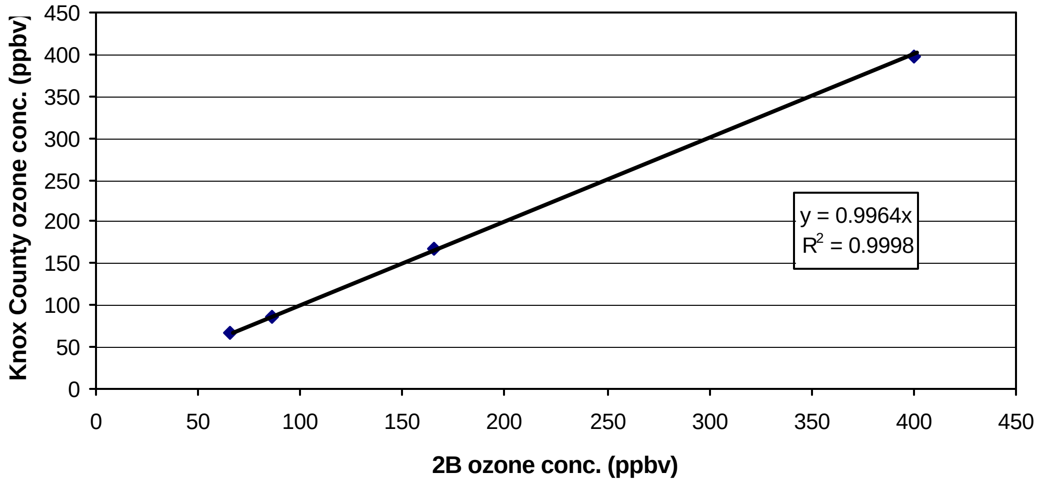

Figure A.13. Dynamic Calibration 8/13/02

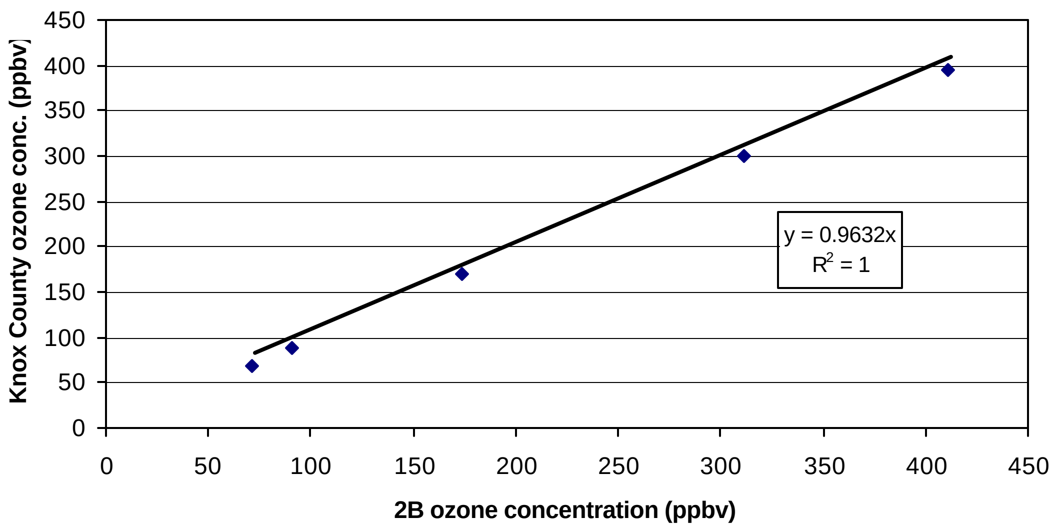

Figure A.14. Post Project Calibration 12/3/02

APPENDIX B

SAMPLING SCHEDULE AND DAILY PLOTS FOR SAMPLING DATA

Table B.1. Hiker Health Study Sampling Dates at NFG

Date	Day of Week
8/10/02	Saturday
8/12/02	Monday
8/15/02	Thursday
8/18/02	Sunday
8/21/02	Wednesday
8/24/02	Saturday
8/27/02	Tuesday
8/30/02	Friday
8/31/02	Saturday
9/02/02	Monday
9/05/02	Thursday
9/08/02	Sunday
9/11/02	Wednesday
9/14/02	Saturday
9/17/02	Tuesday
9/20/02	Friday
9/21/02	Saturday
9/23/02	Monday
9/29/02	Sunday
10/02/02	Wednesday
10/06/02	Sunday
10/08/02	Tuesday
10/12/02	Saturday
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10/23/02	Wednesday
10/26/02	Saturday

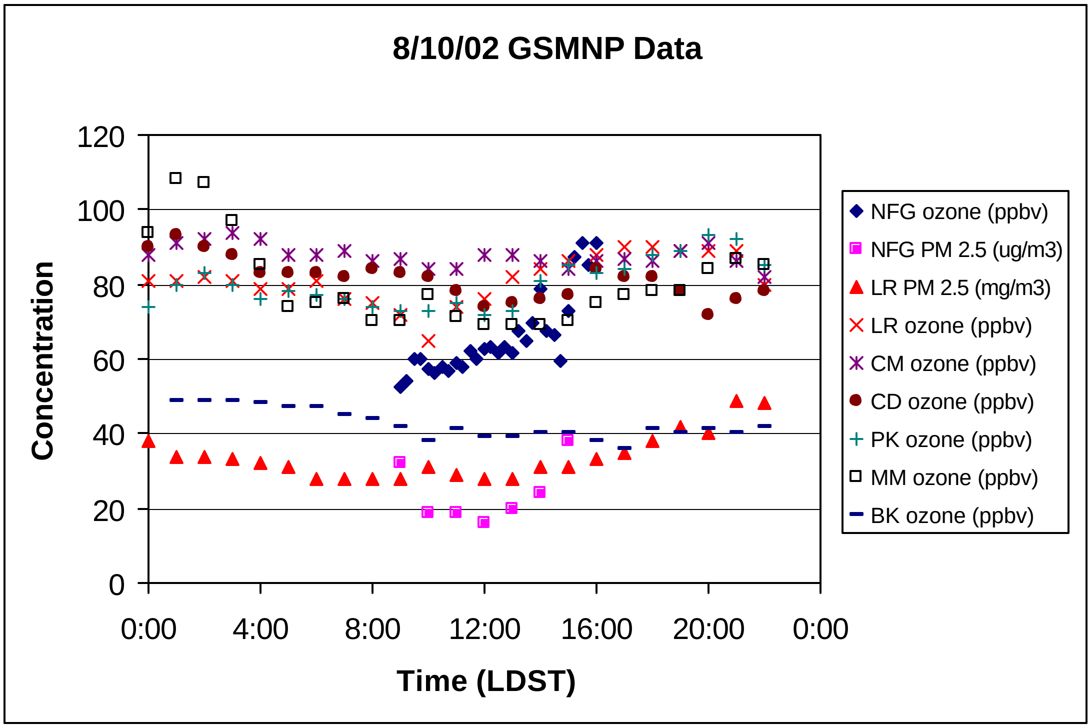


Figure B.1. GSMNP PROJECT DATA 8/10/02

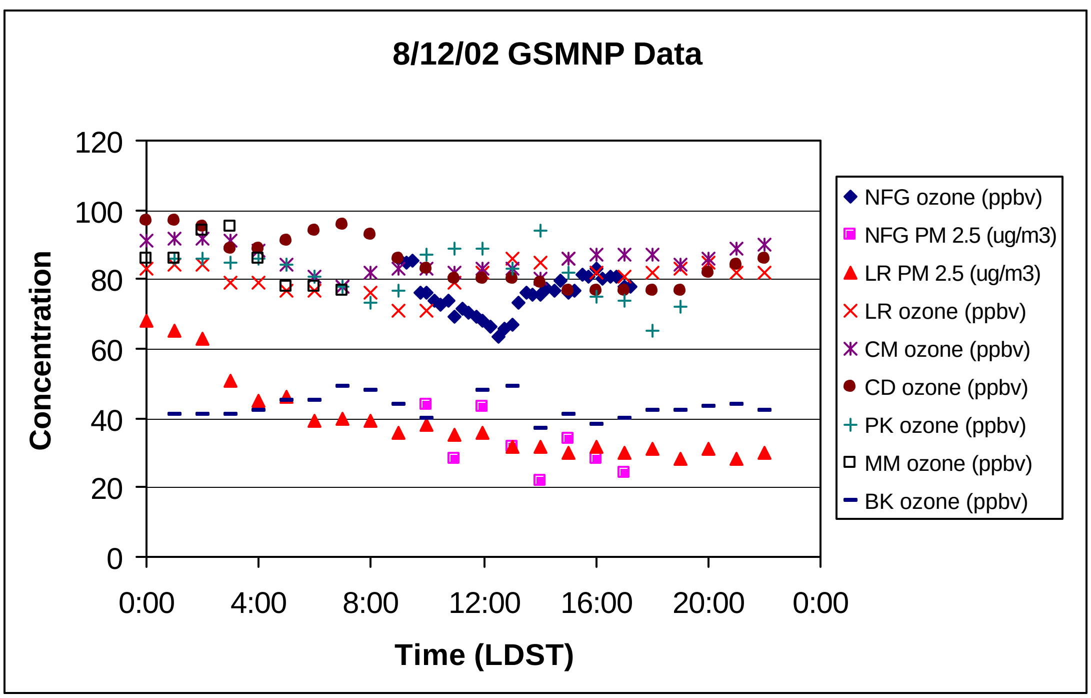


Figure B.2. GSMNP PROJECT DATA 8/12/02

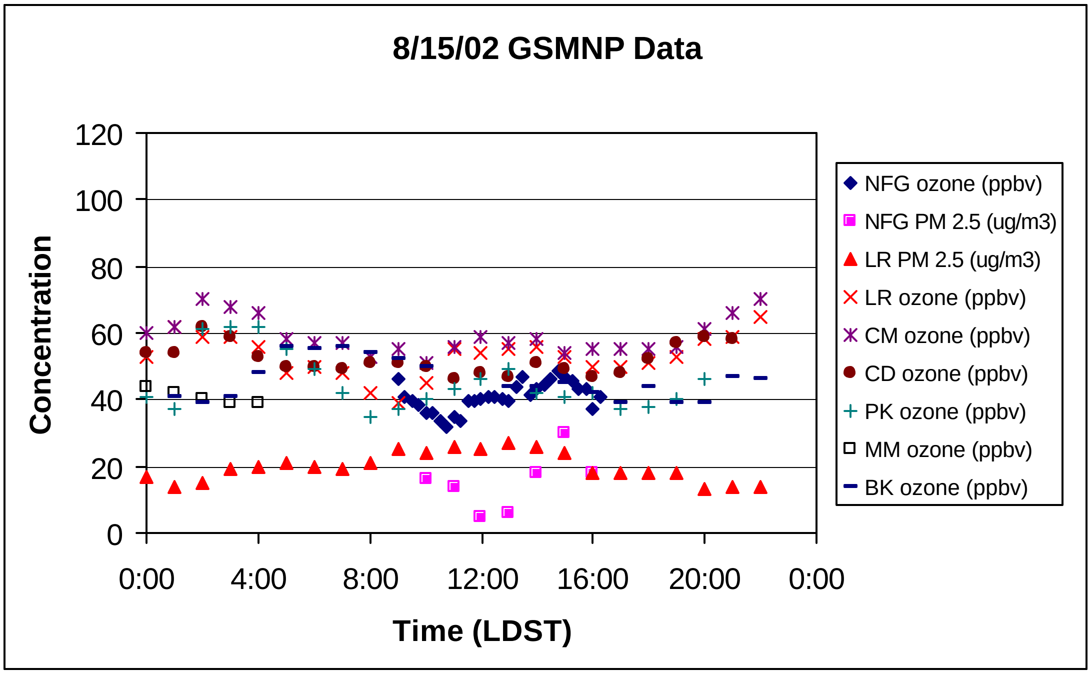


Figure B.3. GSMNP PROJECT DATA 8/15/02

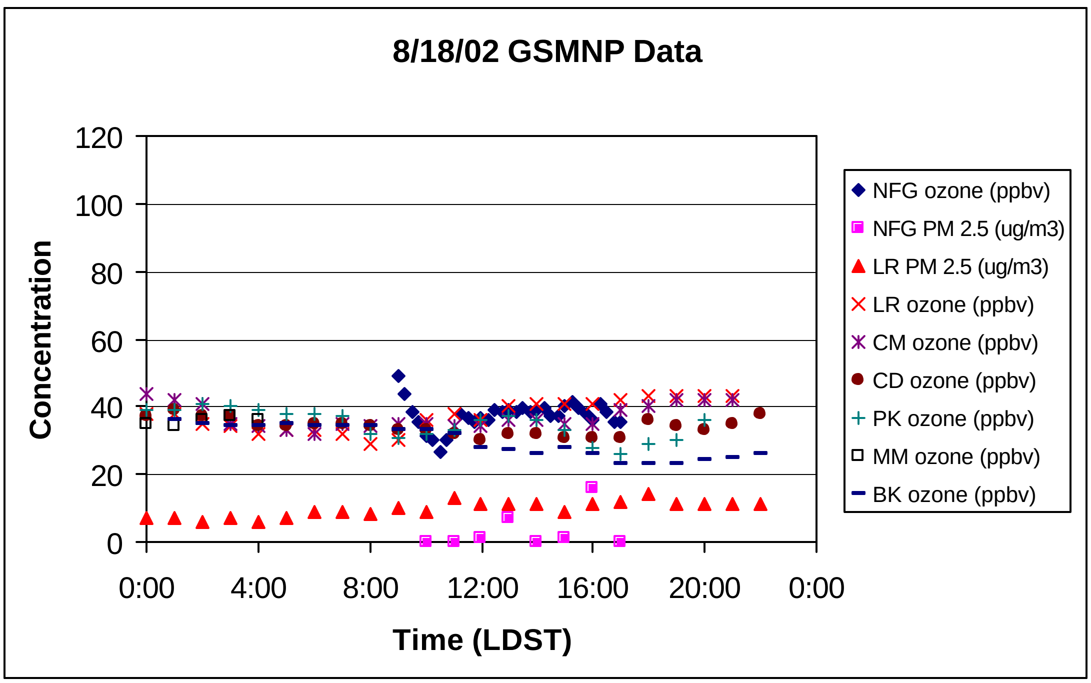


Figure B.4. GSMNP PROJECT DATA 8/18/02

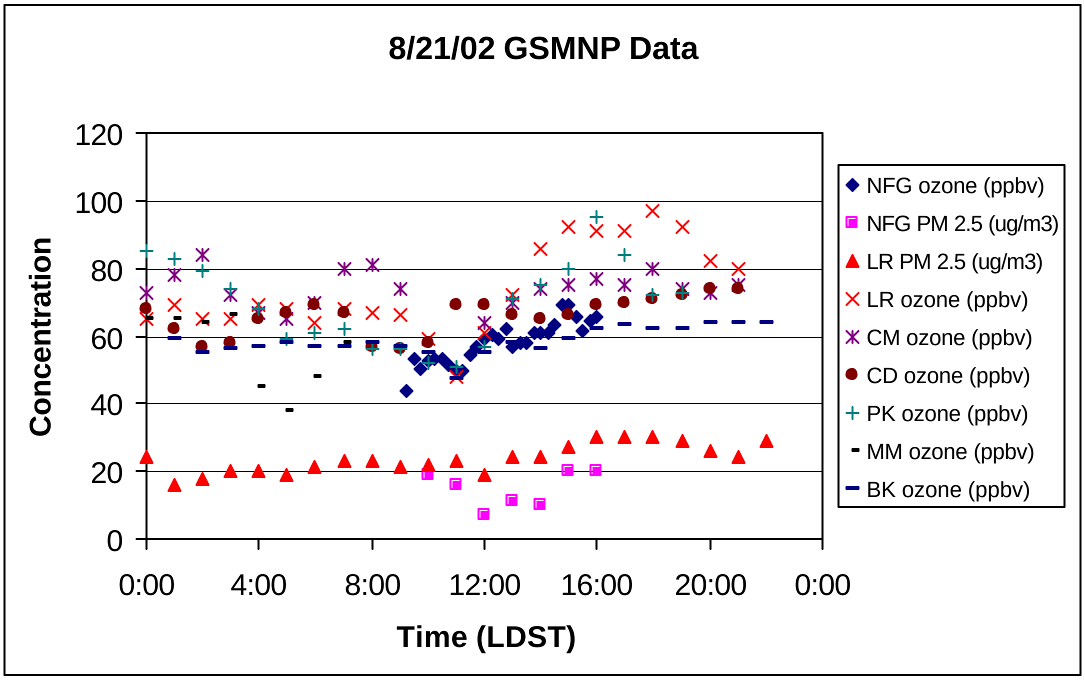


Figure B.5. GSMNP PROJECT DATA 8/21/02

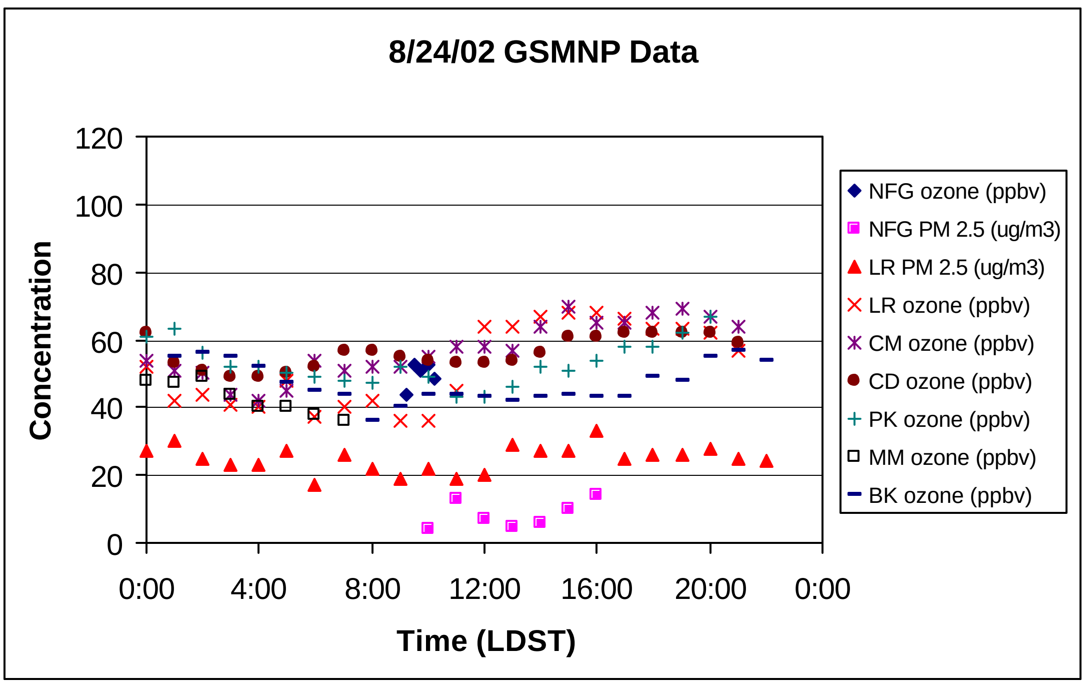


Figure B.6. GSMNP PROJECT DATA 8/24/02

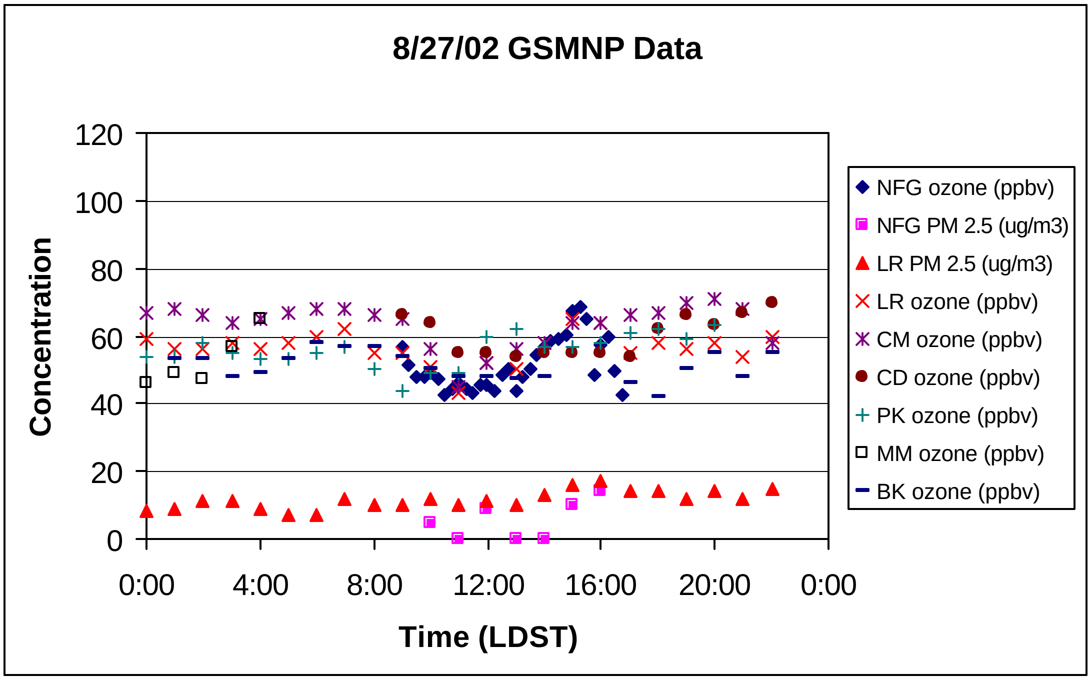


Figure B.7. GSMNP PROJECT DATA 8/27/02

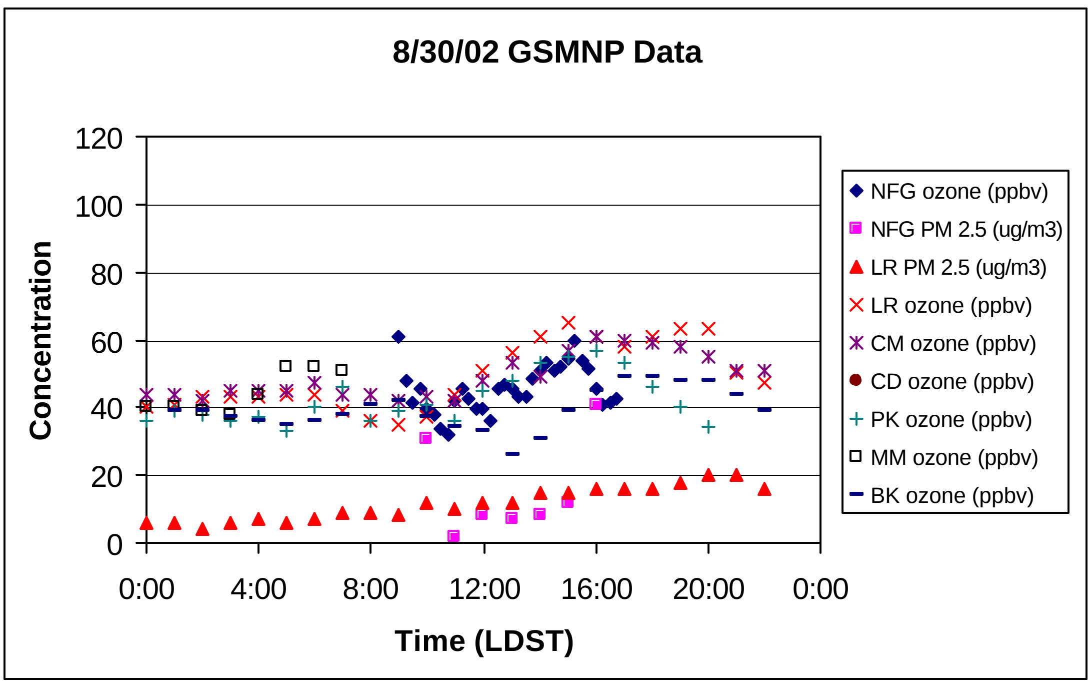


Figure B.8. GSMNP PROJECT DATA 8/30/02

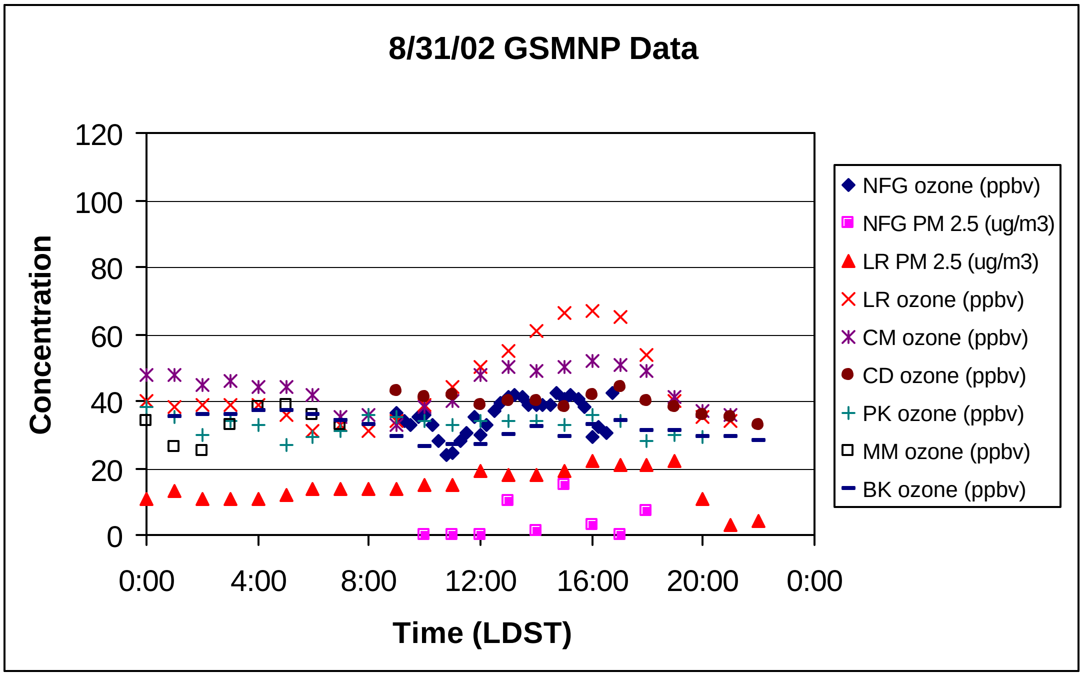


Figure B.9. GSMNP PROJECT DATA 8/31/02

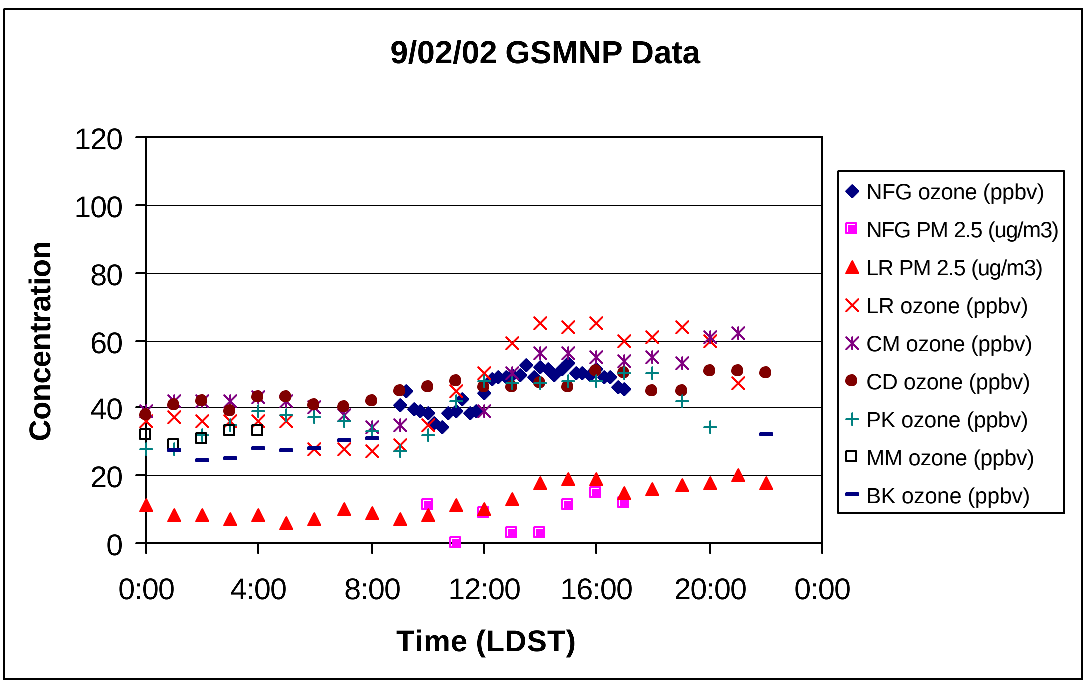


Figure B.10. GSMNP PROJECT DATA 9/02/02

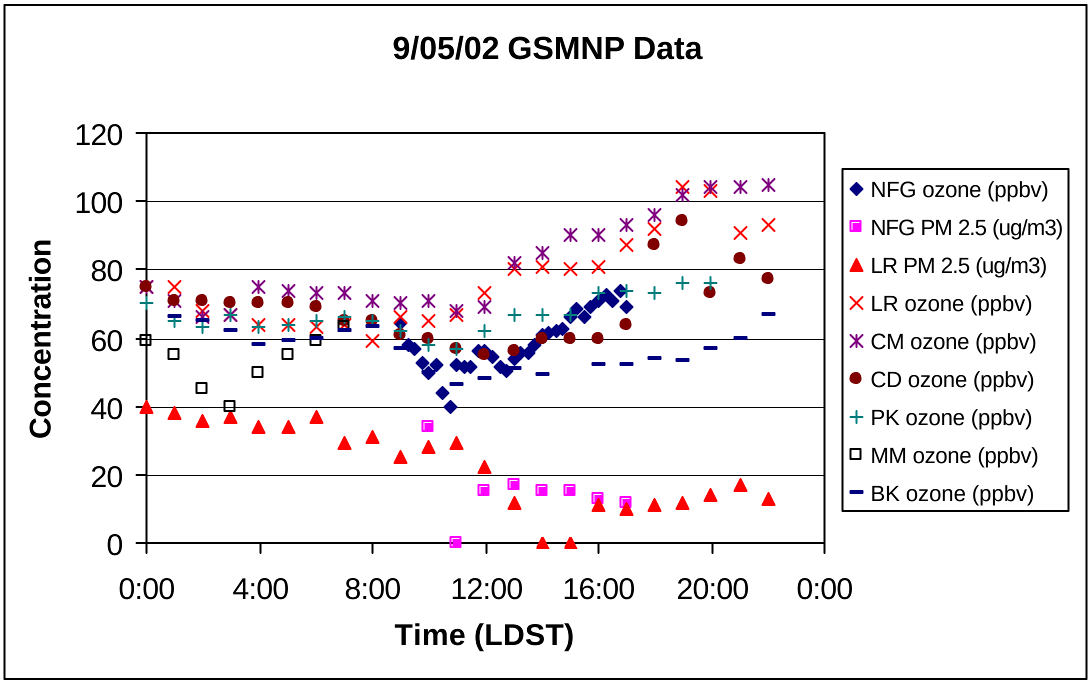


Figure B.11. GSMNP PROJECT DATA 9/05/02

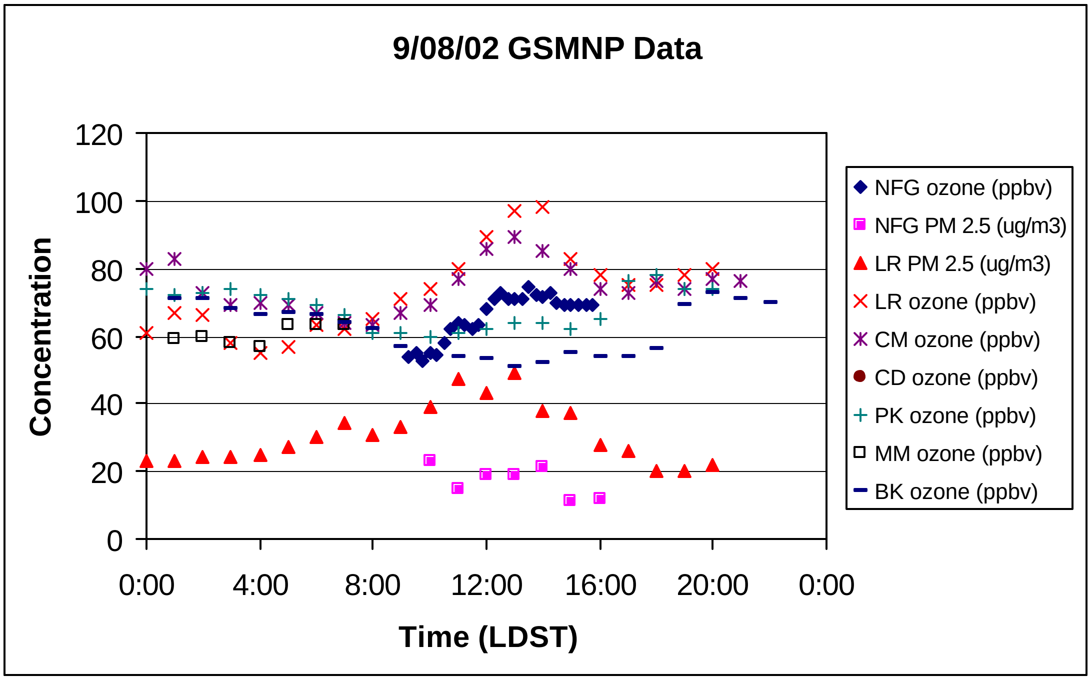


Figure B.12. GSMNP PROJECT DATA 9/08/02

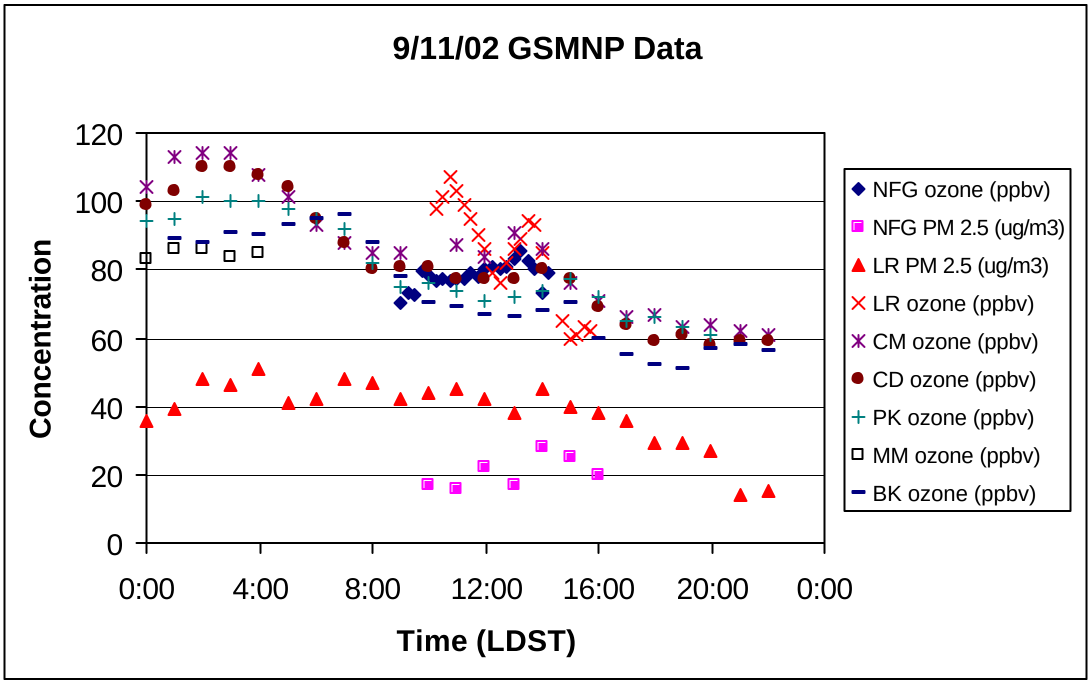


Figure B.13. GSMNP PROJECT DATA 9/11/02

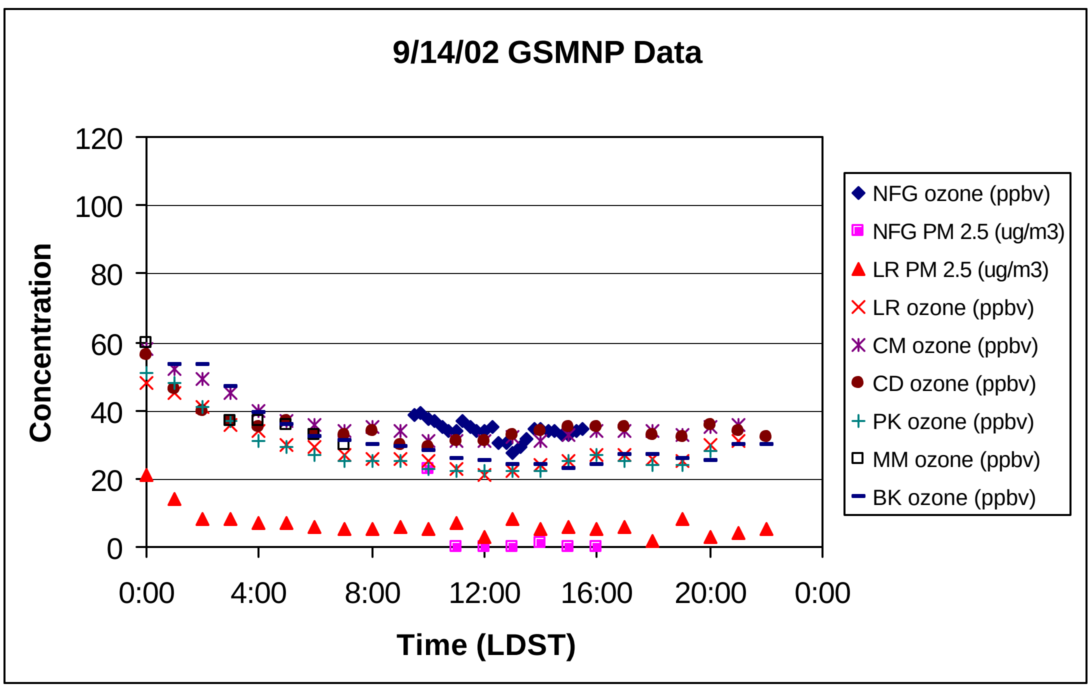


Figure B.14. GSMNP PROJECT DATA 9/14/02

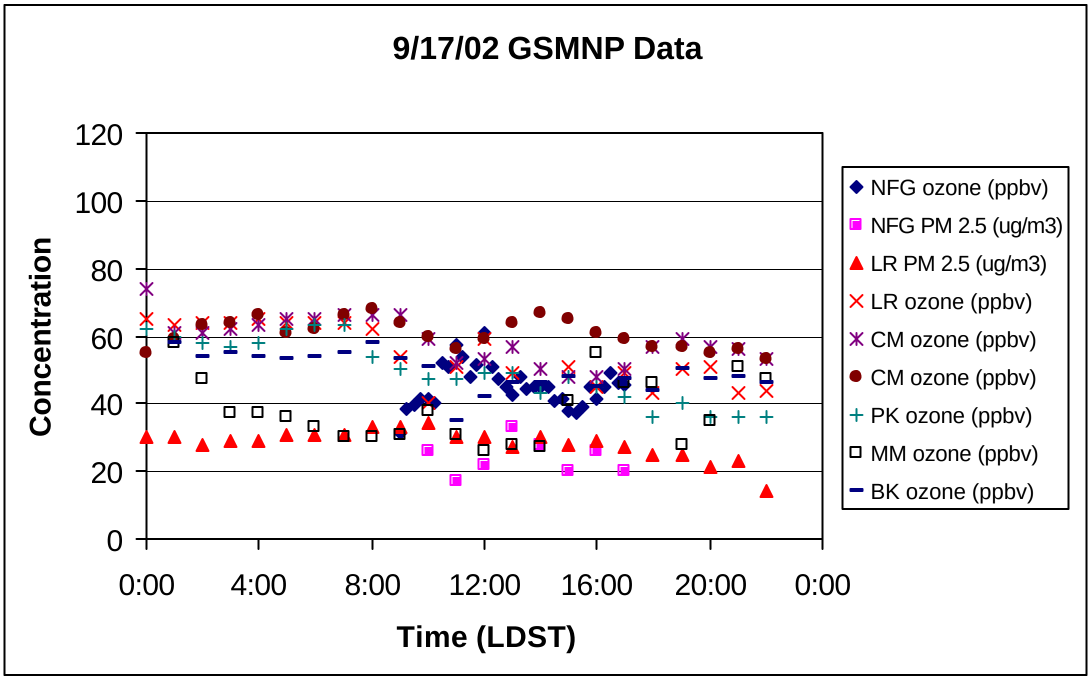


Figure B.15. GSMNP PROJECT DATA 9/17/02

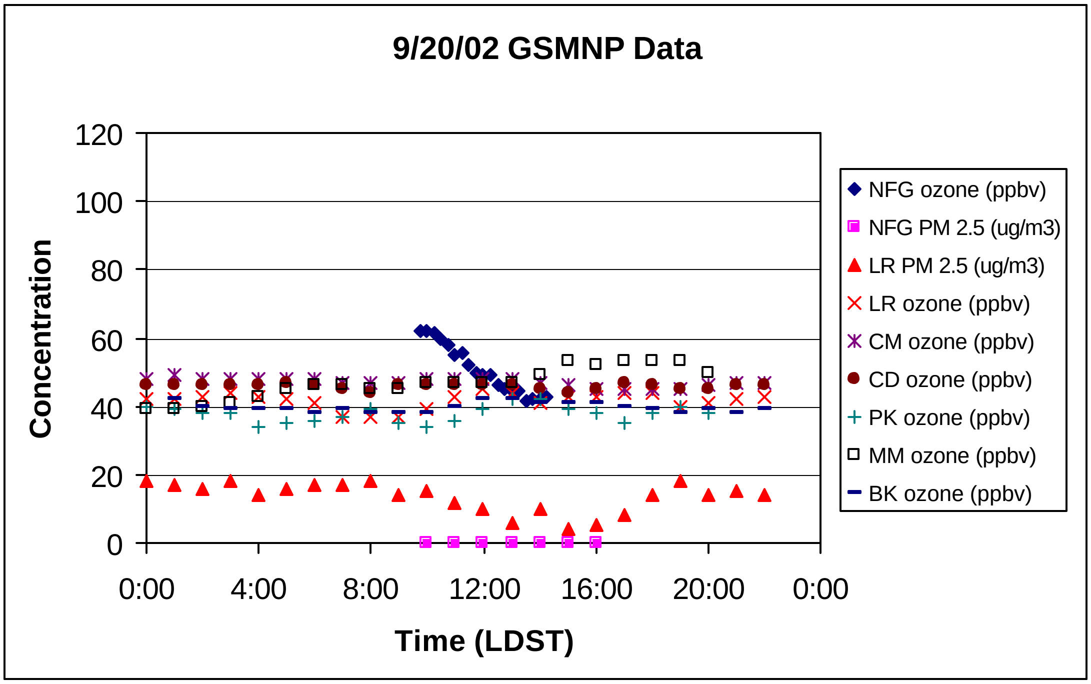


Figure B.16. GSMNP PROJECT DATA 9/20/02

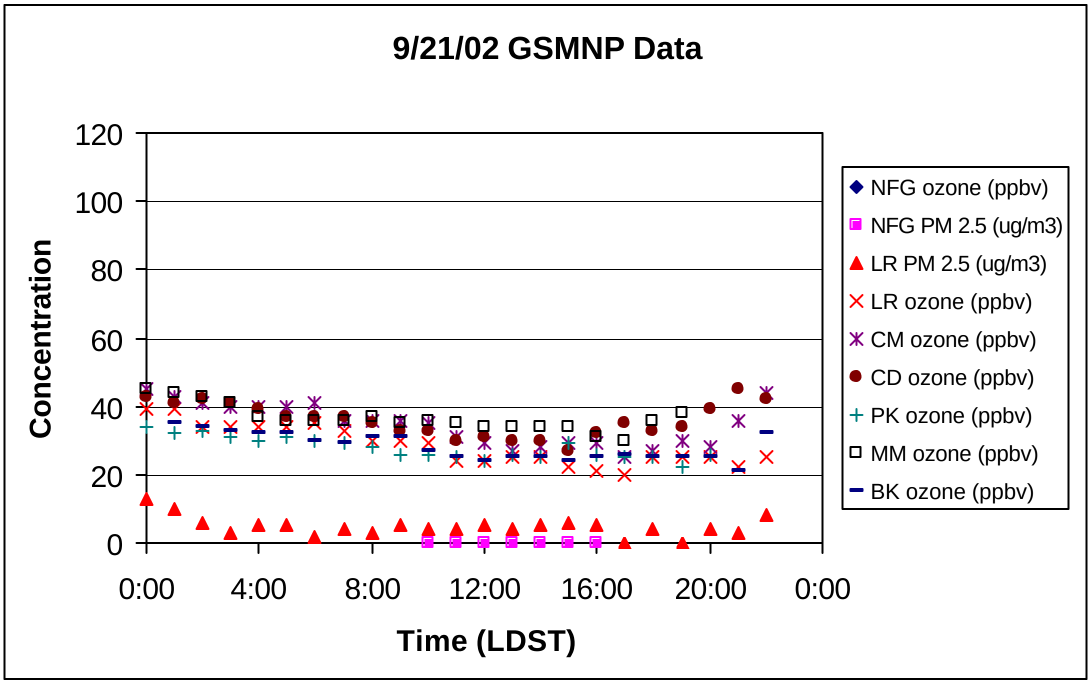


Figure B.17. GSMNP PROJECT DATA 9/21/02

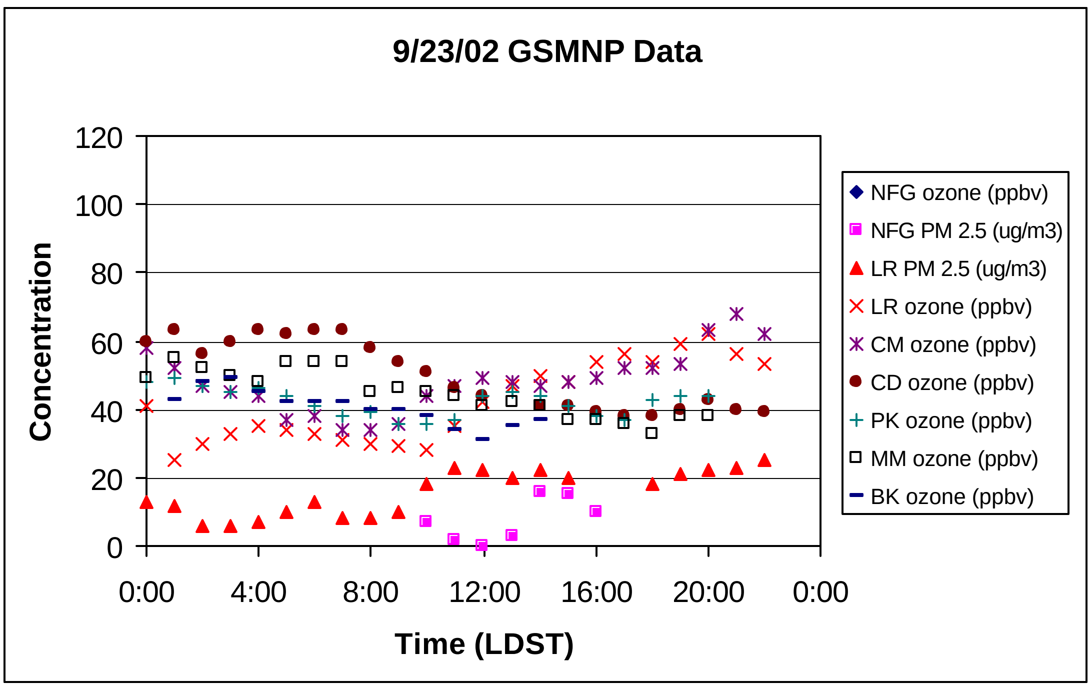


Figure B.18. GSMNP PROJECT DATA 9/23/02

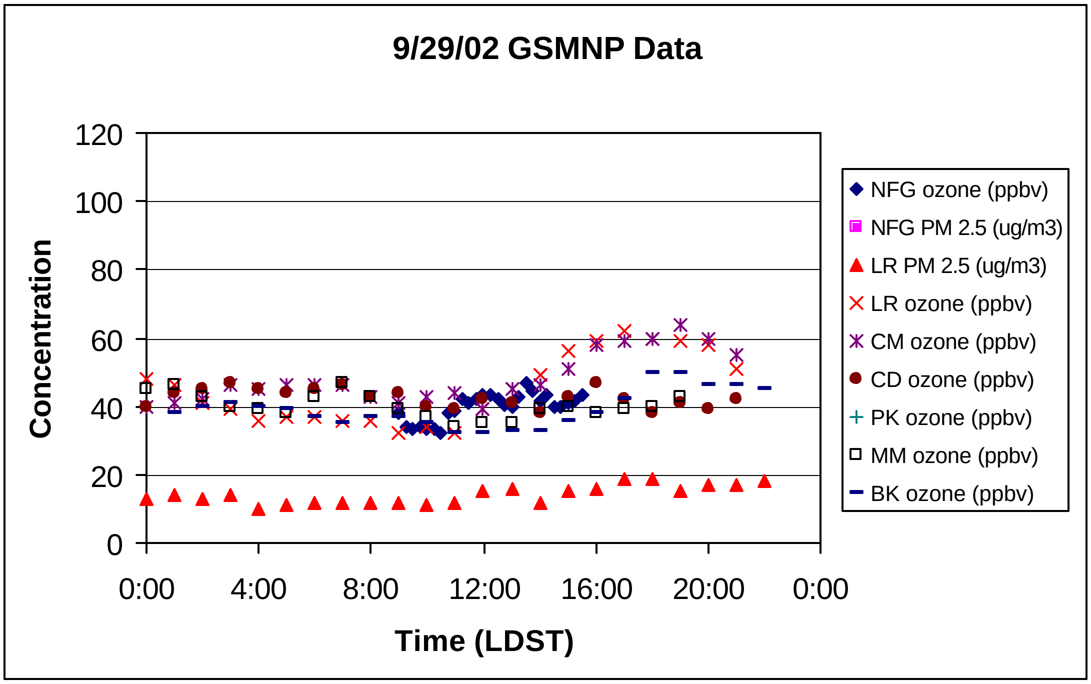


Figure B.19. GSMNP PROJECT DATA 9/29/02

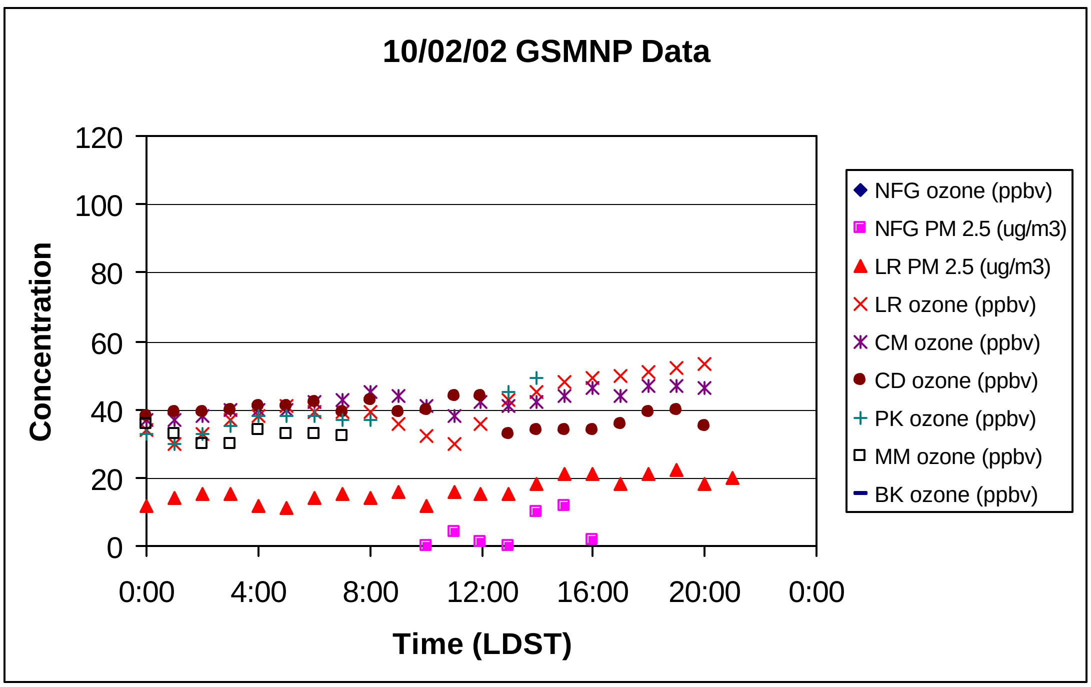


Figure B.20. GSMNP PROJECT DATA 10/02/02

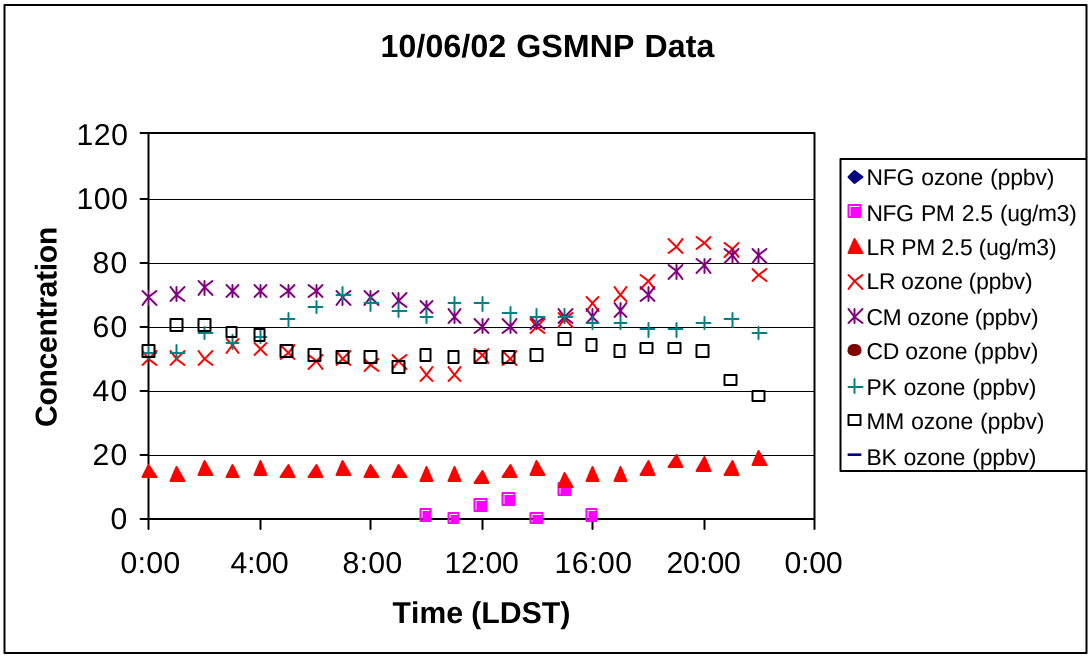


Figure B.21. GSMNP PROJECT DATA 10/06/02

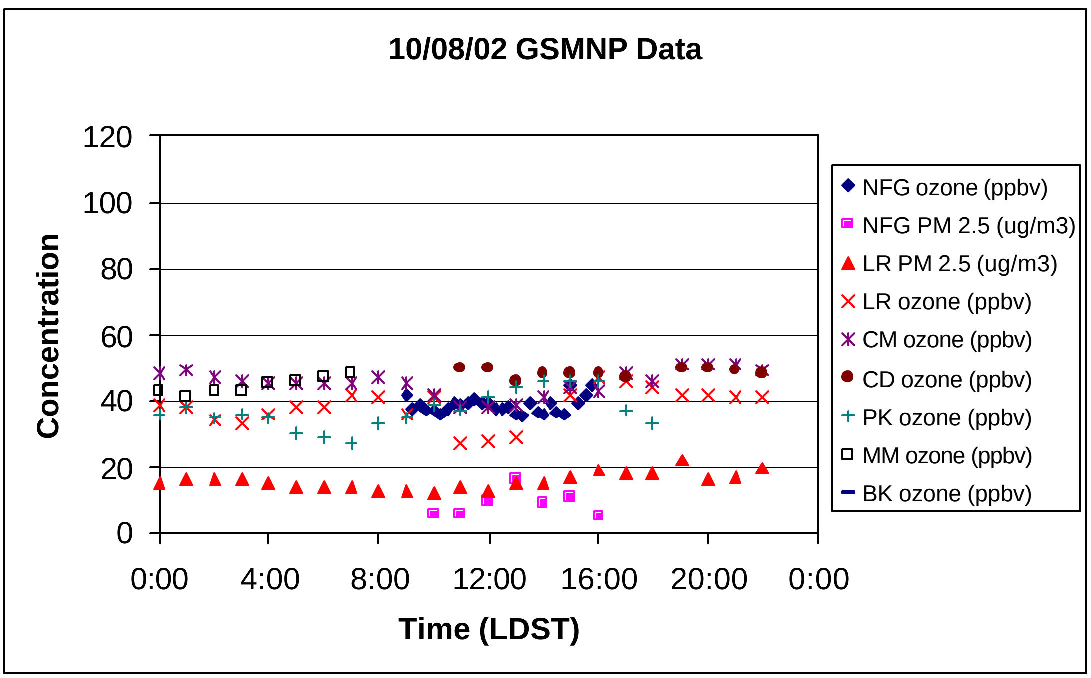


Figure B.22. GSMNP PROJECT DATA 10/08/02

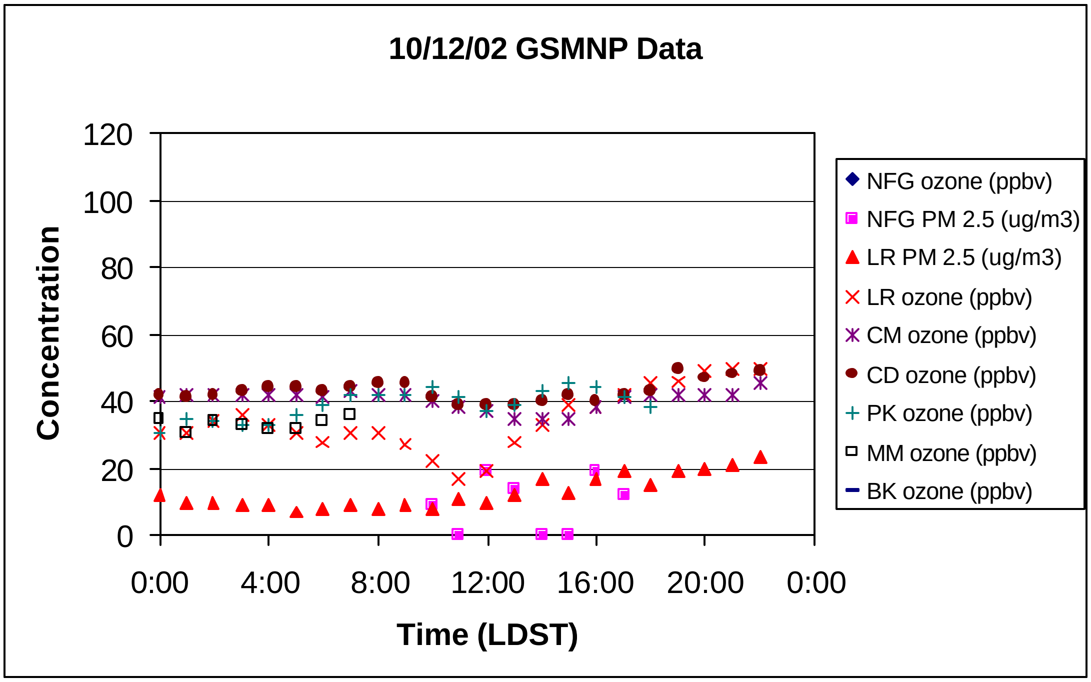


Figure B.23. GSMNP PROJECT DATA 10/12/02

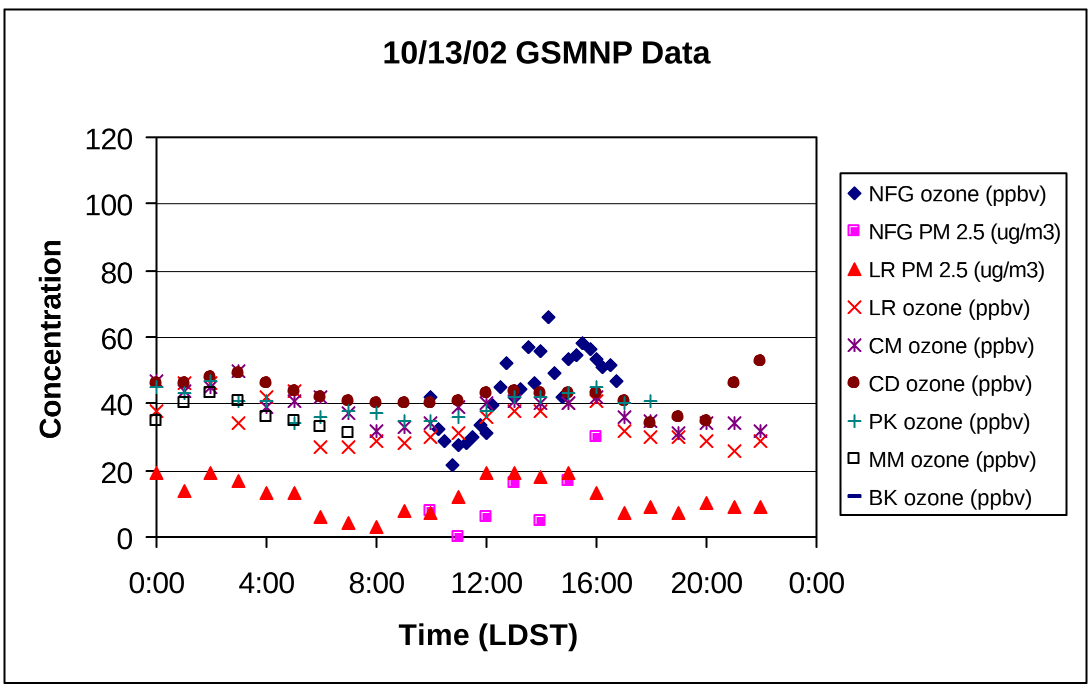


Figure B.24. GSMNP PROJECT DATA 10/13/02

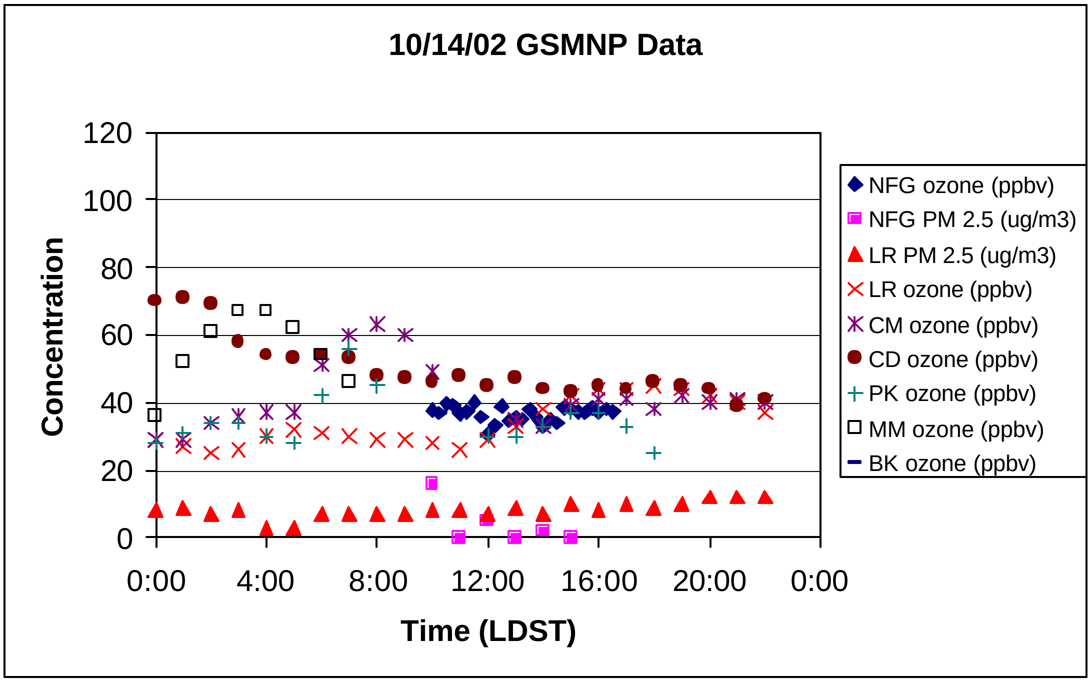


Figure B.25. GSMNP PROJECT DATA 10/14/02

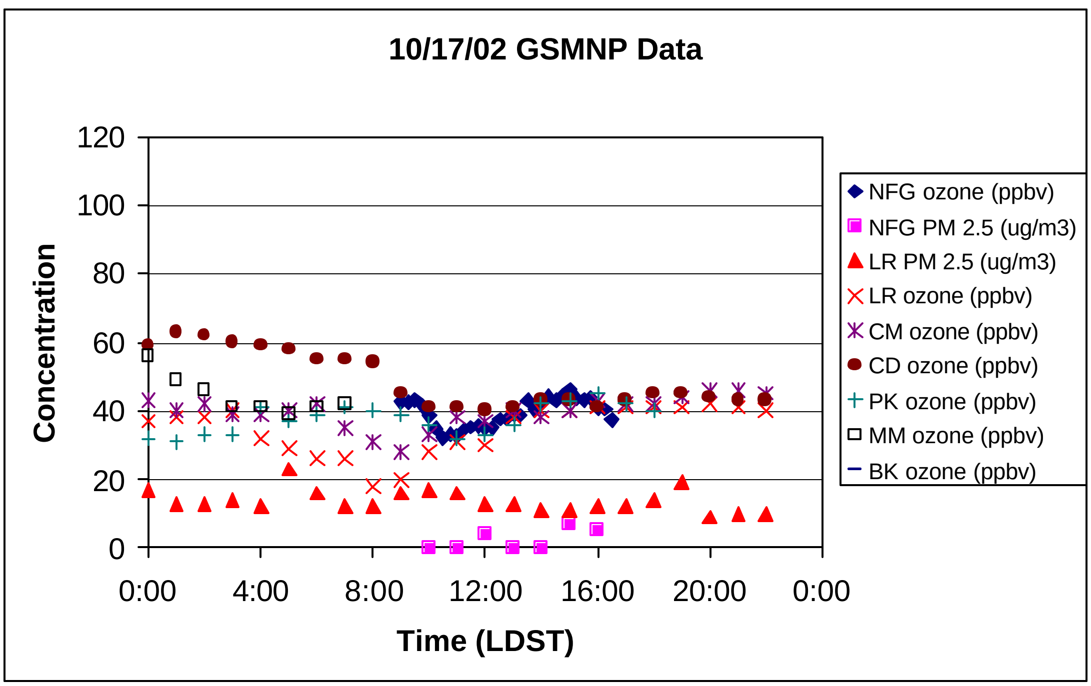


Figure B.26. GSMNP PROJECT DATA 10/17/02

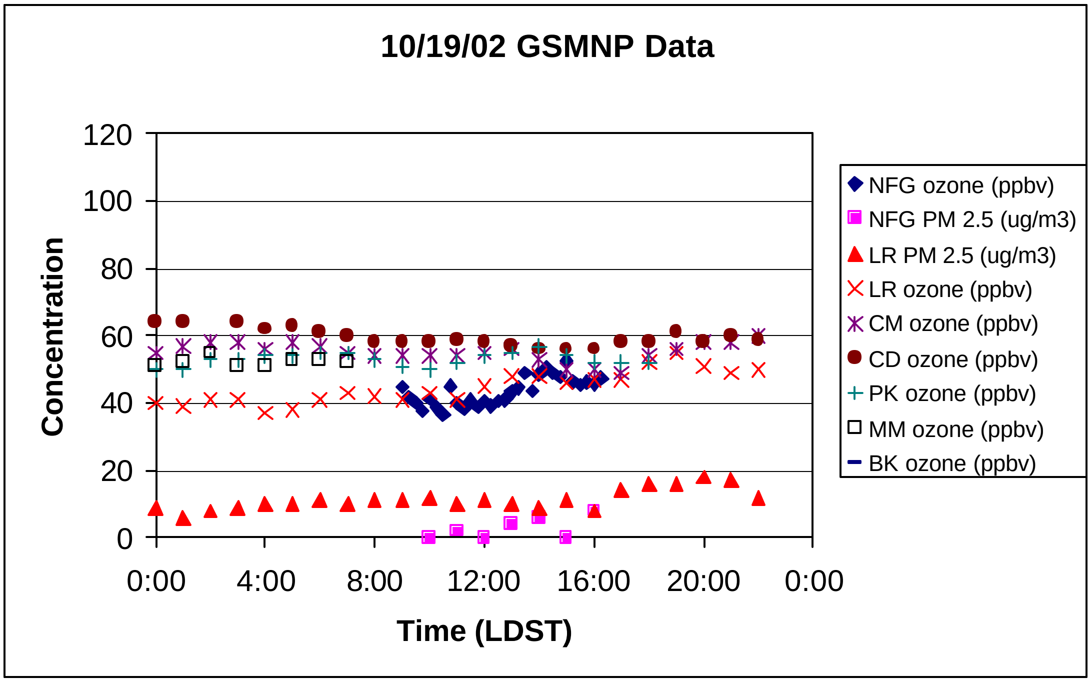


Figure B.27. GSMNP PROJECT DATA 10/19/02

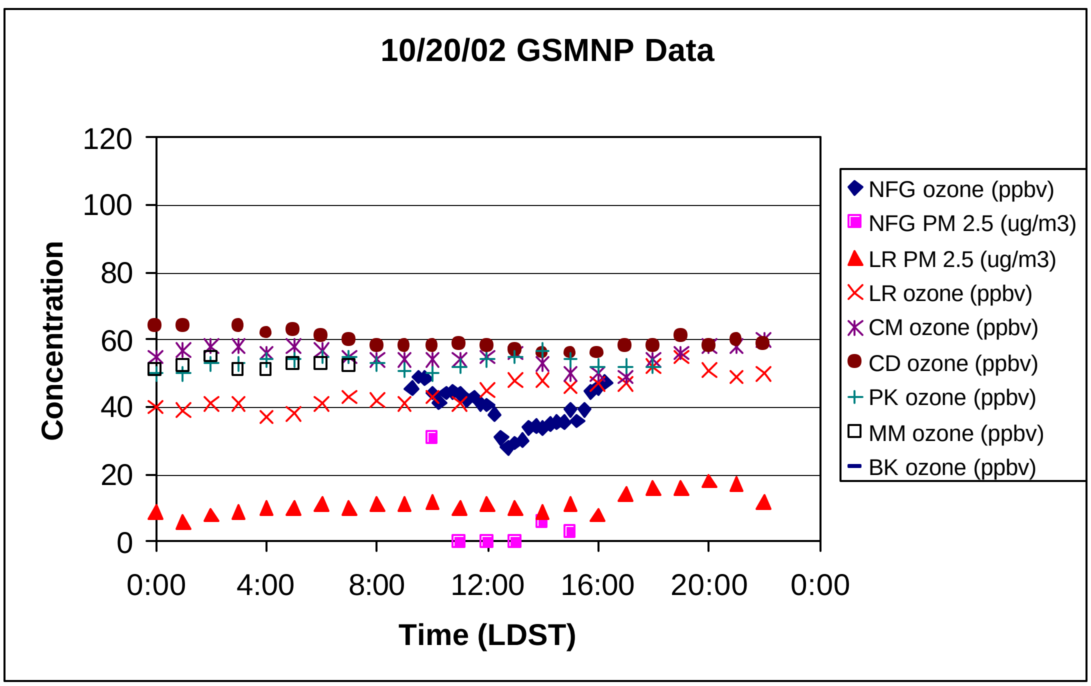


Figure B.28. GSMNP PROJECT DATA 10/20/02

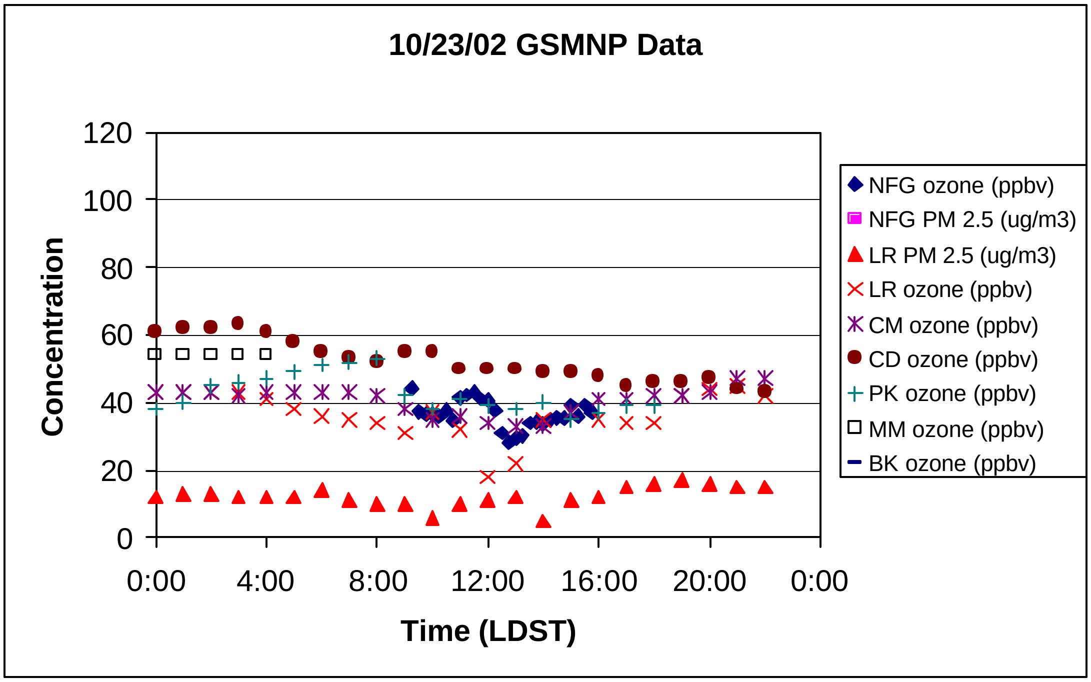


Figure B.29. GSMNP PROJECT DATA 10/23/02

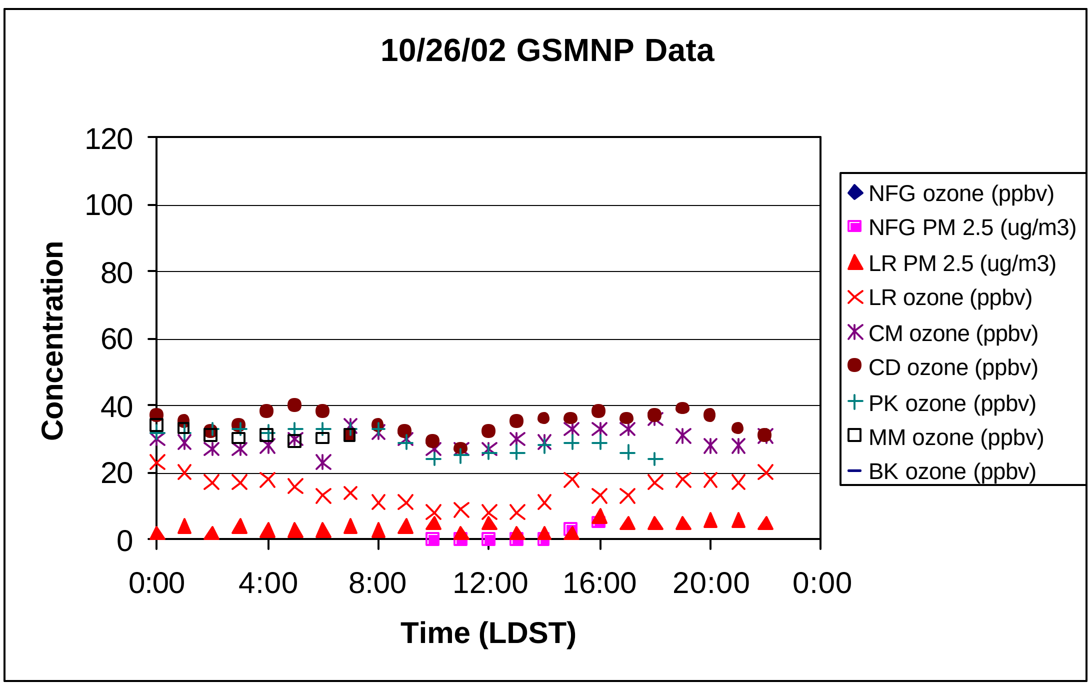


Figure B.30. GSMNP PROJECT DATA 10/26/02

Table B.2. OZONE CONCENTRATIONS ON THE TRAIL 8/10/02

Date	Time*	NFG O_3 (ppbv)	O_3 on trail (ppbv)
Aug 10 2002	9:00	52	45.5
Aug 10 2002	9:15	54	47.3
Aug 10 2002	9:30	60	52.2
Aug 10 2002	9:45	60	52.2
Aug 10 2002	10:00	57	49.9
Aug 10 2002	10:15	56	48.7
Aug 10 2002	10:30	58	50.2
Aug 10 2002	10:45	57	49.3
Aug 10 2002	11:00	59	51.0
Aug 10 2002	11:15	58	50.2
Aug 10 2002	11:30	62	53.9
Aug 10 2002	11:45	60	52.2
Aug 10 2002	12:00	63	54.5
Aug 10 2002	12:15	63	55.1
Aug 10 2002	12:30	62	53.7
Aug 10 2002	12:45	63	55.1
Aug 10 2002	13:00	62	53.7
Aug 10 2002	13:15	68	58.9
Aug 10 2002	13:30	65	56.3
Aug 10 2002	13:45	70	60.6
Aug 10 2002	14:00	79	68.4
Aug 10 2002	14:15	68	58.9
Aug 10 2002	14:30	67	58.0
Aug 10 2002	14:45	60	51.9
Aug 10 2002	15:00	73	63.5
Aug 10 2002	15:15	87	76.0
Aug 10 2002	15:30	91	79.2
Aug 10 2002	15:45	85	74.0
Aug 10 2002	16:00	91	79.5

* 9:00 represents 9:00 – 9:15 local time.

Table B.3. OZONE CONCENTRATIONS ON THE TRAIL 8/12/02

Date	Time	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 12 2002	9:00	86	74.8
Aug 12 2002	9:15	85	73.7
Aug 12 2002	9:30	86	74.5
Aug 12 2002	9:45	76	66.1
Aug 12 2002	10:00	76	66.1
Aug 12 2002	10:15	74	64.4
Aug 12 2002	10:30	73	63.2
Aug 12 2002	10:45	74	64.1
Aug 12 2002	11:00	69	60.0
Aug 12 2002	11:15	71	62.1
Aug 12 2002	11:30	70	61.2
Aug 12 2002	11:45	69	60.0
Aug 12 2002	12:00	68	59.2
Aug 12 2002	12:15	66	57.7
Aug 12 2002	12:30	63	55.1
Aug 12 2002	12:45	66	57.1
Aug 12 2002	13:00	67	58.0
Aug 12 2002	13:15	73	63.5
Aug 12 2002	13:30	76	66.1
Aug 12 2002	13:45	75	65.5
Aug 12 2002	14:00	76	65.8
Aug 12 2002	14:15	77	67.3
Aug 12 2002	14:30	77	66.7
Aug 12 2002	14:45	80	69.3
Aug 12 2002	15:00	76	66.1
Aug 12 2002	15:15	77	67.0
Aug 12 2002	15:30	81	70.8
Aug 12 2002	15:45	81	70.2
Aug 12 2002	16:00	83	72.2
Aug 12 2002	16:15	80	69.6
Aug 12 2002	16:30	81	70.5
Aug 12 2002	16:45	81	70.5
Aug 12 2002	17:00	78	67.9
Aug 12 2002	17:15	78	67.9

* 9:00 represents 9:00 – 9:15 local time.

Table B.4. OZONE CONCENTRATIONS ON THE TRAIL 8/15/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 15 2002	9:00	N/A**	
Aug 15 2002	9:15	46	40.3
Aug 15 2002	9:30	41	35.4
Aug 15 2002	9:45	39	34.2
Aug 15 2002	10:00	38	33.4
Aug 15 2002	10:15	36	31.3
Aug 15 2002	10:30	36	31.3
Aug 15 2002	10:45	33	29.0
Aug 15 2002	11:00	32	27.6
Aug 15 2002	11:15	35	30.2
Aug 15 2002	11:30	34	29.3
Aug 15 2002	11:45	40	34.5
Aug 15 2002	12:00	39	34.2
Aug 15 2002	12:15	40	34.8
Aug 15 2002	12:30	41	35.4
Aug 15 2002	12:45	41	35.4
Aug 15 2002	13:00	40	34.8
Aug 15 2002	13:15	40	34.5
Aug 15 2002	13:30	44	38.3
Aug 15 2002	13:45	47	40.9
Aug 15 2002	14:00	42	36.3
Aug 15 2002	14:15	43	37.7
Aug 15 2002	14:30	45	38.9
Aug 15 2002	14:45	46	40.3
Aug 15 2002	15:00	48	42.1
Aug 15 2002	15:15	47	40.6
Aug 15 2002	15:30	46	39.7
Aug 15 2002	15:45	43	37.4
Aug 15 2002	16:00	43	37.4
Aug 15 2002	16:15	37	32.2
Aug 15 2002	16:30	41	35.7

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.5. OZONE CONCENTRATIONS ON THE TRAIL 8/18/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 18 2002	9:00	49	42.9
Aug 18 2002	9:15	44	38.3
Aug 18 2002	9:30	38	33.4
Aug 18 2002	9:45	35	30.7
Aug 18 2002	10:00	31	27.3
Aug 18 2002	10:15	30	26.1
Aug 18 2002	10:30	26	22.9
Aug 18 2002	10:45	30	26.4
Aug 18 2002	11:00	32	28.1
Aug 18 2002	11:15	38	32.8
Aug 18 2002	11:30	37	31.9
Aug 18 2002	11:45	35	30.7
Aug 18 2002	12:00	37	31.9
Aug 18 2002	12:15	36	31.6
Aug 18 2002	12:30	39	33.9
Aug 18 2002	12:45	38	33.4
Aug 18 2002	13:00	39	33.9
Aug 18 2002	13:15	39	33.6
Aug 18 2002	13:30	39	34.2
Aug 18 2002	13:45	38	33.4
Aug 18 2002	14:00	39	33.9
Aug 18 2002	14:15	39	34.2
Aug 18 2002	14:30	37	32.2
Aug 18 2002	14:45	37	32.2
Aug 18 2002	15:00	40	34.8
Aug 18 2002	15:15	41	36.0
Aug 18 2002	15:30	39	34.2
Aug 18 2002	15:45	38	33.1
Aug 18 2002	16:00	36	31.6
Aug 18 2002	16:15	41	35.4
Aug 18 2002	16:30	39	33.6
Aug 18 2002	16:45	36	31.0
Aug 18 2002	17:00	36	31.0

* 9:00 represents 9:00 – 9:15 local time.

Table B.6. OZONE CONCENTRATIONS ON THE TRAIL 8/21/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 21 2002	9:00	N/A**	
Aug 21 2002	9:15	44	38.3
Aug 21 2002	9:30	53	46.1
Aug 21 2002	9:45	50	43.5
Aug 21 2002	10:00	52	45.5
Aug 21 2002	10:15	53	46.1
Aug 21 2002	10:30	53	46.4
Aug 21 2002	10:45	52	45.0
Aug 21 2002	11:00	50	43.2
Aug 21 2002	11:15	50	43.2
Aug 21 2002	11:30	54	47.3
Aug 21 2002	11:45	57	49.3
Aug 21 2002	12:00	59	51.3
Aug 21 2002	12:15	60	52.5
Aug 21 2002	12:30	59	51.6
Aug 21 2002	12:45	62	54.2
Aug 21 2002	13:00	57	49.6
Aug 21 2002	13:15	58	50.2
Aug 21 2002	13:30	58	50.2
Aug 21 2002	13:45	61	53.1
Aug 21 2002	14:00	61	52.8
Aug 21 2002	14:15	61	53.1
Aug 21 2002	14:30	63	54.8
Aug 21 2002	14:45	69	60.3
Aug 21 2002	15:00	69	60.0
Aug 21 2002	15:15	66	57.1
Aug 21 2002	15:30	62	53.7
Aug 21 2002	15:45	64	56.0
Aug 21 2002	16:00	66	57.1
Aug 21 2003	16:15	63	54.8

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.7. OZONE CONCENTRATIONS ON THE TRAIL 8/24/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Aug 24 2002	9:00	N/A ***	
Aug 24 2002	9:15	44	38.3
Aug 24 2002	9:30	52	45.5
Aug 24 2002	9:45	51	44.1
Aug 24 2002	10:00	53	45.8
Aug 24 2002	10:15	48	42.1
Aug 24 2002	10:30	49.1	42.7
Aug 24 2002	10:45	49.1	42.7
Aug 24 2002	11:00	48.2	41.9
Aug 24 2002	11:15	48.2	41.9
Aug 24 2002	11:30	48.2	41.9
Aug 24 2002	11:45	48.2	41.9
Aug 24 2002	12:00	48.2	41.9
Aug 24 2002	12:15	48.2	41.9
Aug 24 2002	12:30	48.2	41.9
Aug 24 2002	12:45	48.2	41.9
Aug 24 2002	13:00	49.1	42.7
Aug 24 2002	13:15	49.1	42.7
Aug 24 2002	13:30	49.1	42.7
Aug 24 2002	13:45	49.1	42.7
Aug 24 2002	14:00	51.0	44.2
Aug 24 2002	14:15	51.0	44.2
Aug 24 2002	14:30	51.0	44.2
Aug 24 2002	14:45	51.0	44.2
Aug 24 2002	15:00	55.5	48.2
Aug 24 2002	15:15	55.5	48.2
Aug 24 2002	15:30	55.5	48.2
Aug 24 2002	15:45	55.5	48.2

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.
*** N/A – portable and CD not available

Table B.8. OZONE CONCENTRATIONS ON THE TRAIL 8/27/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 27 2002	9:00	57	49.3
Aug 27 2002	9:15	51	44.7
Aug 27 2002	9:30	48	41.8
Aug 27 2002	9:45	48	41.5
Aug 27 2002	10:00	49	42.9
Aug 27 2002	10:15	47	40.9
Aug 27 2002	10:30	43	37.1
Aug 27 2002	10:45	44	38.6
Aug 27 2002	11:00	46	40.3
Aug 27 2002	11:15	44	38.6
Aug 27 2002	11:30	43	37.4
Aug 27 2002	11:45	46	39.7
Aug 27 2002	12:00	46	39.7
Aug 27 2002	12:15	44	38.3
Aug 27 2002	12:30	49	42.3
Aug 27 2002	12:45	50	43.5
Aug 27 2002	13:00	44	38.0
Aug 27 2002	13:15	48	41.5
Aug 27 2002	13:30	50	43.5
Aug 27 2002	13:45	55	47.6
Aug 27 2002	14:00	57	49.6
Aug 27 2002	14:15	59	51.0
Aug 27 2002	14:30	59	51.6
Aug 27 2002	14:45	60	52.5
Aug 27 2002	15:00	67	58.6
Aug 27 2002	15:15	69	59.7
Aug 27 2002	15:30	65	56.6
Aug 27 2002	15:45	48	42.1
Aug 27 2002	16:00	57	49.9
Aug 27 2002	16:15	60	51.9
Aug 27 2002	16:30	50	43.2
Aug 27 2002	16:45	43	37.1

* 9:00 represents 9:00 – 9:15 local time.

Table B.9. OZONE CONCENTRATIONS ON THE TRAIL 8/30/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 30 2002	9:00	61	52.8
Aug 30 2002	9:15	48	41.8
Aug 30 2002	9:30	42	36.3
Aug 30 2002	9:45	45	39.4
Aug 30 2002	10:00	39	34.2
Aug 30 2002	10:15	38	32.8
Aug 30 2002	10:30	34	29.3
Aug 30 2002	10:45	32	27.8
Aug 30 2002	11:00	42	36.5
Aug 30 2002	11:15	45	39.4
Aug 30 2002	11:30	42	36.8
Aug 30 2002	11:45	39	34.2
Aug 30 2002	12:00	39	34.2
Aug 30 2002	12:15	36	31.6
Aug 30 2002	12:30	45	39.4
Aug 30 2002	12:45	47	40.6
Aug 30 2002	13:00	45	39.4
Aug 30 2002	13:15	43	37.4
Aug 30 2002	13:30	43	37.4
Aug 30 2002	13:45	49	42.3
Aug 30 2002	14:00	51	44.4
Aug 30 2002	14:15	53	46.1
Aug 30 2002	14:30	51	44.4
Aug 30 2002	14:45	52	45.2
Aug 30 2002	15:00	54	47.3
Aug 30 2002	15:15	60	51.9
Aug 30 2002	15:30	54	46.7
Aug 30 2002	15:45	51	44.7
Aug 30 2002	16:00	45	39.4
Aug 30 2002	16:15	41	35.4
Aug 30 2002	16:30	37	32.2

* 9:00 represents 9:00 – 9:15 local time.

Table B.10. OZONE CONCENTRATIONS ON THE TRAIL 8/31/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Aug 31 2002	9:00	36	31.6
Aug 31 2002	9:15	34	29.6
Aug 31 2002	9:30	33	28.7
Aug 31 2002	9:45	35	30.5
Aug 31 2002	10:00	36	31.0
Aug 31 2002	10:15	33	28.4
Aug 31 2002	10:30	28	24.4
Aug 31 2002	10:45	24	20.9
Aug 31 2002	11:00	24	21.2
Aug 31 2002	11:15	28	24.7
Aug 31 2002	11:30	30	26.4
Aug 31 2002	11:45	35	30.5
Aug 31 2002	12:00	30	26.1
Aug 31 2002	12:15	33	28.7
Aug 31 2002	12:30	37	32.2
Aug 31 2002	12:45	39	34.2
Aug 31 2002	13:00	41	35.7
Aug 31 2002	13:15	42	36.5
Aug 31 2002	13:30	41	35.7
Aug 31 2002	13:45	39	33.9
Aug 31 2002	14:00	39	33.6
Aug 31 2002	14:15	39	33.9
Aug 31 2002	14:30	39	33.6
Aug 31 2002	14:45	43	37.1
Aug 31 2002	15:00	40	35.1
Aug 31 2002	15:15	42	36.3
Aug 31 2002	15:30	41	35.4
Aug 31 2002	15:45	38	33.1
Aug 31 2002	16:00	29	25.2
Aug 31 2002	16:15	32	28.1
Aug 31 2002	16:30	31	26.7
Aug 31 2002	16:45	31	26.7

* 9:00 represents 9:00 – 9:15 local time.

Table B.11. OZONE CONCENTRATIONS ON THE TRAIL 9/02/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 2 2002	9:00	41	35.4
Sept 2 2002	9:15	45	38.9
Sept 2 2002	9:30	40	34.5
Sept 2 2002	9:45	39	33.9
Sept 2 2002	10:00	39	33.6
Sept 2 2002	10:15	36	31.0
Sept 2 2002	10:30	34	29.9
Sept 2 2002	10:45	39	33.6
Sept 2 2002	11:00	39	33.9
Sept 2 2002	11:15	43	37.1
Sept 2 2002	11:30	38	33.4
Sept 2 2002	11:45	39	33.9
Sept 2 2002	12:00	44	38.6
Sept 2 2002	12:15	49	42.3
Sept 2 2002	12:30	49	42.9
Sept 2 2002	12:45	49	42.6
Sept 2 2002	13:00	50	43.2
Sept 2 2002	13:15	50	43.2
Sept 2 2002	13:30	53	45.8
Sept 2 2002	13:45	49	42.9
Sept 2 2002	14:00	52	45.2
Sept 2 2002	14:15	52	45.0
Sept 2 2002	14:30	50	43.2
Sept 2 2002	14:45	51	44.7
Sept 2 2002	15:00	53	46.4
Sept 2 2002	15:15	50	43.5
Sept 2 2002	15:30	50	43.5
Sept 2 2002	15:45	50	43.2
Sept 2 2002	16:00	52	45.0
Sept 2 2002	16:15	49	42.9
Sept 2 2002	16:30	49	42.9
Sept 2 2002	16:45	46	40.0
Sept 2 2002	17:00	45	39.4

* 9:00 represents 9:00 – 9:15 local time.

Table B.12. OZONE CONCENTRATIONS ON THE TRAIL 9/05/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 5 2002	9:00	64	56.0
Sept 5 2002	9:15	58	50.5
Sept 5 2002	9:30	57	49.6
Sept 5 2002	9:45	53	45.8
Sept 5 2002	10:00	50	43.5
Sept 5 2002	10:15	52	45.5
Sept 5 2002	10:30	44	38.0
Sept 5 2002	10:45	40	34.8
Sept 5 2002	11:00	52	45.5
Sept 5 2002	11:15	51	44.7
Sept 5 2002	11:30	51	44.7
Sept 5 2002	11:45	56	48.7
Sept 5 2002	12:00	56	49.0
Sept 5 2002	12:15	55	47.6
Sept 5 2002	12:30	52	45.0
Sept 5 2002	12:45	50	43.8
Sept 5 2002	13:00	54	46.7
Sept 5 2002	13:15	55	48.1
Sept 5 2002	13:30	55	48.1
Sept 5 2002	13:45	58	50.2
Sept 5 2002	14:00	61	53.1
Sept 5 2002	14:15	62	53.7
Sept 5 2002	14:30	62	53.9
Sept 5 2002	14:45	63	54.5
Sept 5 2002	15:00	66	57.4
Sept 5 2002	15:15	68	59.5
Sept 5 2002	15:30	66	57.7
Sept 5 2002	15:45	69	60.0
Sept 5 2002	16:00	71	61.8
Sept 5 2002	16:15	72	62.9
Sept 5 2002	16:30	71	61.8
Sept 5 2002	16:45	74	64.4
Sept 5 2002	17:00	69	60.0
Sept 5 2002	17:15	73	63.2
Sept 5 2002	17:30	73	63.2

* 9:00 represents 9:00 – 9:15 local time.

Table B.13. OZONE CONCENTRATIONS ON THE TRAIL 9/08/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 8 2002	9:00	N/A**	
Sept 8 2002	9:15	54	46.7
Sept 8 2002	9:30	55	47.9
Sept 8 2002	9:45	53	45.8
Sept 8 2002	10:00	55	47.9
Sept 8 2002	10:15	55	47.6
Sept 8 2002	10:30	58	50.2
Sept 8 2002	10:45	62	53.9
Sept 8 2002	11:00	64	55.7
Sept 8 2002	11:15	63	55.1
Sept 8 2002	11:30	62	54.2
Sept 8 2002	11:45	63	54.8
Sept 8 2002	12:00	68	59.2
Sept 8 2002	12:15	71	61.5
Sept 8 2002	12:30	73	63.5
Sept 8 2002	12:45	71	61.5
Sept 8 2002	13:00	71	61.8
Sept 8 2002	13:15	71	61.5
Sept 8 2002	13:30	75	65.0
Sept 8 2002	13:45	72	62.6
Sept 8 2002	14:00	72	62.4
Sept 8 2002	14:15	73	63.2
Sept 8 2002	14:30	70	60.9
Sept 8 2002	14:45	69	60.0
Sept 8 2002	15:00	N/A**	
Sept 8 2002	15:15	N/A**	
Sept 8 2002	15:30	N/A**	
Sept 8 2002	15:45	N/A**	

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.14. OZONE CONCENTRATIONS ON THE TRAIL 9/11/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 11 2002	9:00	70	60.9
Sept 11 2002	9:15	73	63.8
Sept 11 2002	9:30	73	63.2
Sept 11 2002	9:45	79	69.0
Sept 11 2002	10:00	78	68.2
Sept 11 2002	10:15	77	66.7
Sept 11 2002	10:30	77	67.3
Sept 11 2002	10:45	77	66.7
Sept 11 2002	11:00	77	67.3
Sept 11 2002	11:15	77	67.0
Sept 11 2002	11:30	79	68.7
Sept 11 2002	11:45	78	67.6
Sept 11 2002	12:00	80	69.9
Sept 11 2002	12:15	81	70.2
Sept 11 2002	12:30	80	69.9
Sept 11 2002	12:45	81	70.5
Sept 11 2002	13:00	83	72.2
Sept 11 2002	13:15	85	74.2
Sept 11 2002	13:30	83	71.9
Sept 11 2002	13:45	80	69.9
Sept 11 2002	14:00	73	63.5
Sept 11 2002	14:15	79	68.7
Sept 11 2002	14:30	72.8	63.2
Sept 11 2002	14:45	72.8	63.2
Sept 11 2002	15:00	70.1	60.83
Sept 11 2002	15:15	70.1	60.83
Sept 11 2002	15:30	70.1	60.83
Sept 11 2002	15:45	70.1	60.83

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.

Table B.15. OZONE CONCENTRATIONS ON THE TRAIL 9/14/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 14 2002	9:00	N/A**	
Sept 14 2002	9:15	N/A**	
Sept 14 2002	9:30	39	33.6
Sept 14 2002	9:45	39	33.9
Sept 14 2002	10:00	38	32.8
Sept 14 2002	10:15	37	32.2
Sept 14 2002	10:30	35	30.7
Sept 14 2002	10:45	34	29.6
Sept 14 2002	11:00	34	29.6
Sept 14 2002	11:15	37	31.9
Sept 14 2002	11:30	35	30.5
Sept 14 2002	11:45	34	29.3
Sept 14 2002	12:00	34	29.3
Sept 14 2002	12:15	35	30.5
Sept 14 2002	12:30	30	26.4
Sept 14 2002	12:45	30	26.4
Sept 14 2002	13:00	28	24.1
Sept 14 2002	13:15	29	25.5
Sept 14 2002	13:30	32	27.6
Sept 14 2002	13:45	35	30.2
Sept 14 2002	14:00	35	30.2
Sept 14 2002	14:15	34	29.6
Sept 14 2002	14:30	34	29.6
Sept 14 2002	14:45	33	28.4
Sept 14 2002	15:00	33	28.4
Sept 14 2002	15:15	34	29.3
Sept 14 2002	15:30	34	29.9
Sept 14 2002	15:45	36	31.3

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.16. OZONE CONCENTRATIONS ON THE TRAIL 9/17/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 17 2002	9:00	31	27.3
Sept 17 2002	9:15	38	33.4
Sept 17 2002	9:30	40	34.5
Sept 17 2002	9:45	41	36.0
Sept 17 2002	10:00	42	36.3
Sept 17 2002	10:15	40	35.1
Sept 17 2002	10:30	52	45.2
Sept 17 2002	10:45	51	44.4
Sept 17 2002	11:00	57	49.9
Sept 17 2002	11:15	54	47.0
Sept 17 2002	11:30	48	41.5
Sept 17 2002	11:45	52	45.0
Sept 17 2002	12:00	61	53.1
Sept 17 2002	12:15	51	44.4
Sept 17 2002	12:30	47	41.2
Sept 17 2002	12:45	45	38.9
Sept 17 2002	13:00	42	36.8
Sept 17 2002	13:15	48	41.8
Sept 17 2002	13:30	44	38.6
Sept 17 2002	13:45	45	38.9
Sept 17 2002	14:00	45	39.2
Sept 17 2002	14:15	45	39.2
Sept 17 2002	14:30	41	35.4
Sept 17 2002	14:45	41	36.0
Sept 17 2002	15:00	38	33.1
Sept 17 2002	15:15	37	32.2
Sept 17 2002	15:30	39	33.9
Sept 17 2002	15:45	45	38.9
Sept 17 2002	16:00	41	36.0
Sept 17 2002	16:15	39	33.9

* 9:00 represents 9:00 – 9:15 local time.

Table B.17. OZONE CONCENTRATIONS ON THE TRAIL 9/20/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Sept 20 2002	9:00	41.9	36.3
Sept 20 2002	9:15	41.9	36.3
Sept 20 2002	9:30	41.9	36.3
Sept 20 2002	9:45	41.9	36.3
Sept 20 2002	10:00	41.9	36.3
Sept 20 2002	10:15	41.9	36.3
Sept 20 2002	10:30	41.9	36.3
Sept 20 2002	10:45	41.9	36.3
Sept 20 2002	11:00	41.9	36.3
Sept 20 2002	11:15	41.9	36.3
Sept 20 2002	11:30	41.9	36.3
Sept 20 2002	11:45	50	43.2
Sept 20 2002	12:00	49	42.6
Sept 20 2002	12:15	49	42.6
Sept 20 2002	12:30	46	40.3
Sept 20 2002	12:45	45	39.2
Sept 20 2002	13:00	44	38.6
Sept 20 2002	13:15	44	38.6
Sept 20 2002	13:30	41	36.0
Sept 20 2002	13:45	42	36.5
Sept 20 2002	14:00	42	36.5
Sept 20 2002	14:15	43	37.4
Sept 20 2002	14:30	41.0	35.6
Sept 20 2002	14:45	41.0	35.6
Sept 20 2002	15:00	40.0	34.8
Sept 20 2002	15:15	40.0	34.8
Sept 20 2002	15:30	40.0	34.8
Sept 20 2002	15:45	40.0	34.8

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.

Table B.18. OZONE CONCENTRATIONS ON THE TRAIL 9/21/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Sept 21 2002	9:00	30.0	26.1
Sept 21 2002	9:15	30.0	26.1
Sept 21 2002	9:30	30.0	26.1
Sept 21 2002	9:45	30.0	26.1
Sept 21 2002	10:00	30.0	26.1
Sept 21 2002	10:15	30.0	26.1
Sept 21 2002	10:30	30.0	26.1
Sept 21 2002	10:45	30.0	26.1
Sept 21 2002	11:00	27.3	23.7
Sept 21 2002	11:15	27.3	23.7
Sept 21 2002	11:30	27.3	23.7
Sept 21 2002	11:45	27.3	23.7
Sept 21 2002	12:00	28.2	24.5
Sept 21 2002	12:15	28.2	24.5
Sept 21 2002	12:30	28.2	24.5
Sept 21 2002	12:45	28.2	24.5
Sept 21 2002	13:00	27.3	23.7
Sept 21 2002	13:15	27.3	23.7
Sept 21 2002	13:30	27.3	23.7
Sept 21 2002	13:45	27.3	23.7
Sept 21 2002	14:00	27.3	23.7
Sept 21 2002	14:15	27.3	23.7
Sept 21 2002	14:30	27.3	23.7
Sept 21 2002	14:45	27.3	23.7
Sept 21 2002	15:00	24.6	21.3
Sept 21 2002	15:15	24.6	21.3
Sept 21 2002	15:30	24.6	21.3
Sept 21 2002	15:45	24.6	21.3

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.

Table B.19. OZONE CONCENTRATIONS ON THE TRAIL 9/23/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Sept 23 2002	9:00	49.1	42.7
Sept 23 2002	9:15	49.1	42.7
Sept 23 2002	9:30	49.1	42.7
Sept 23 2002	9:45	49.1	42.7
Sept 23 2002	10:00	46.4	40.3
Sept 23 2002	10:15	46.4	40.3
Sept 23 2002	10:30	46.4	40.3
Sept 23 2002	10:45	46.4	40.3
Sept 23 2002	11:00	41.9	36.3
Sept 23 2002	11:15	41.9	36.3
Sept 23 2002	11:30	41.9	36.3
Sept 23 2002	11:45	41.9	36.3
Sept 23 2002	12:00	40.0	34.8
Sept 23 2002	12:15	40.0	34.8
Sept 23 2002	12:30	40.0	34.8
Sept 23 2002	12:45	40.0	34.8
Sept 23 2002	13:00	N/A***	
Sept 23 2002	13:15	N/A***	
Sept 23 2002	13:30	N/A***	
Sept 23 2002	13:45	N/A***	
Sept 23 2002	14:00	37.3	32.4
Sept 23 2002	14:15	37.3	32.4
Sept 23 2002	14:30	37.3	32.4
Sept 23 2002	14:45	37.3	32.4
Sept 23 2002	15:00	37.3	32.4
Sept 23 2002	15:15	37.3	32.4
Sept 23 2002	15:30	37.3	32.4
Sept 23 2002	15:45	37.3	32.4

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.
*** N/A – portable and CD not available

Table B.20. OZONE CONCENTRATIONS ON THE TRAIL 9/29/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Sept 29 2002	9:00	38	33.0
Sept 29 2002	9:15	34	29.3
Sept 29 2002	9:30	34	29.2
Sept 29 2002	9:45	34	29.6
Sept 29 2002	10:00	33	29.0
Sept 29 2002	10:15	34	29.2
Sept 29 2002	10:30	32	28.0
Sept 29 2002	10:45	38	33.2
Sept 29 2002	11:00	39	33.6
Sept 29 2002	11:15	42	36.8
Sept 29 2002	11:30	41	35.6
Sept 29 2002	11:45	42	36.9
Sept 29 2002	12:00	43	37.8
Sept 29 2002	12:15	43	37.8
Sept 29 2002	12:30	42	36.5
Sept 29 2002	12:45	40	34.9
Sept 29 2002	13:00	40	34.7
Sept 29 2002	13:15	43	37.4
Sept 29 2002	13:30	47	40.7
Sept 29 2002	13:45	44	38.7
Sept 29 2002	14:00	42	36.4
Sept 29 2002	14:15	43	37.8
Sept 29 2002	14:30	40	34.7
Sept 29 2002	14:45	40	34.6
Sept 29 2002	15:00	41	35.7
Sept 29 2002	15:15	41	36.1
Sept 29 2002	15:30	44	37.9

* 9:00 represents 9:00 – 9:15 local time.

Table B.21. OZONE CONCENTRATIONS ON THE TRAIL 10/02/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Oct 02 2002	9:00	35.5	30.8
Oct 02 2002	9:15	35.5	30.8
Oct 02 2002	9:30	35.5	30.8
Oct 02 2002	9:45	35.5	30.8
Oct 02 2002	10:00	36.4	31.6
Oct 02 2002	10:15	36.4	31.6
Oct 02 2002	10:30	36.4	31.6
Oct 02 2002	10:45	36.4	31.6
Oct 02 2002	11:00	40.0	34.8
Oct 02 2002	11:15	40.0	34.8
Oct 02 2002	11:30	40.0	34.8
Oct 02 2002	11:45	40.0	34.8
Oct 02 2002	12:00	40.0	34.8
Oct 02 2002	12:15	40.0	34.8
Oct 02 2002	12:30	40.0	34.8
Oct 02 2002	12:45	40.0	34.8
Oct 02 2002	13:00	30.0	26.1
Oct 02 2002	13:15	30.0	26.1
Oct 02 2002	13:30	30.0	26.1
Oct 02 2002	13:45	30.0	26.1
Oct 02 2002	14:00	30.9	26.9
Oct 02 2002	14:15	30.9	26.9
Oct 02 2002	14:30	30.9	26.9
Oct 02 2002	14:45	30.9	26.9
Oct 02 2002	15:00	30.9	26.9
Oct 02 2002	15:15	30.9	26.9
Oct 02 2002	15:30	30.9	26.9
Oct 02 2002	15:45	30.9	26.9

* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.

Table B.22. OZONE CONCENTRATIONS ON THE TRAIL 10/08/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 8 2002	9:00	42	36.2
Oct 8 2002	9:15	38	32.9
Oct 8 2002	9:30	39	34.0
Oct 8 2002	9:45	37	32.1
Oct 8 2002	10:00	37	32.2
Oct 8 2002	10:15	36	31.0
Oct 8 2002	10:30	38	32.8
Oct 8 2002	10:45	40	34.5
Oct 8 2002	11:00	39	33.8
Oct 8 2002	11:15	40	34.5
Oct 8 2002	11:30	41	35.4
Oct 8 2002	11:45	40	34.4
Oct 8 2002	12:00	39	34.2
Oct 8 2002	12:15	38	33.0
Oct 8 2002	12:30	38	32.8
Oct 8 2002	12:45	38	33.1
Oct 8 2002	13:00	36	31.1
Oct 8 2002	13:15	36	31.0
Oct 8 2002	13:30	40	34.5
Oct 8 2002	13:45	37	31.8
Oct 8 2002	14:00	36	31.5
Oct 8 2002	14:15	39	34.0
Oct 8 2002	14:30	36	31.7
Oct 8 2002	14:45	36	31.4
Oct 8 2002	15:00	45	38.7
Oct 8 2002	15:15	39	34.0
Oct 8 2002	15:30	42	36.1
Oct 8 2002	15:45	45	38.7

* 9:00 represents 9:00 – 9:15 local time.

Table B.23. OZONE CONCENTRATIONS ON THE TRAIL 10/12/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 12 2002	9:00	45	35.6
Oct 12 2002	9:15	45	35.6
Oct 12 2002	9:30	45	35.6
Oct 12 2002	9:45	45	35.6
Oct 12 2002	10:00	41	32.4
Oct 12 2002	10:15	41	32.4
Oct 12 2002	10:30	41	32.4
Oct 12 2002	10:45	41	32.4
Oct 12 2002	11:00	39	30.8
Oct 12 2002	11:15	39	30.8
Oct 12 2002	11:30	39	30.8
Oct 12 2002	11:45	39	30.8
Oct 12 2002	12:00	39	30.8
Oct 12 2002	12:15	39	30.8
Oct 12 2002	12:30	39	30.8
Oct 12 2002	12:45	39	30.8
Oct 12 2002	13:00	39	30.8
Oct 12 2002	13:15	39	30.8
Oct 12 2002	13:30	39	30.8
Oct 12 2002	13:45	39	30.8
Oct 12 2002	14:00	40	31.6
Oct 12 2002	14:15	40	31.6
Oct 12 2002	14:30	40	31.6
Oct 12 2002	14:45	40	31.6
Oct 12 2002	15:00	42	33.2
Oct 12 2002	15:15	42	33.2
Oct 12 2002	15:30	42	33.2
Oct 12 2002	15:45	42	33.2
Oct 12 2002	16:00	40	31.6
Oct 12 2002	16:15	40	31.6
Oct 12 2002	16:30	40	31.6
Oct 12 2002	16:45	40	31.6

* 9:00 represents 9:00 – 9:15 local time.

Table B.24. OZONE CONCENTRATIONS ON THE TRAIL 10/13/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 13 2002	9:00	N/A**	
Oct 13 2002	9:15	N/A**	
Oct 13 2002	9:30	N/A**	
Oct 13 2002	9:45	N/A**	
Oct 13 2002	10:00	42	36.5
Oct 13 2002	10:15	32	28.1
Oct 13 2002	10:30	29	25.2
Oct 13 2002	10:45	22	18.9
Oct 13 2002	11:00	27	23.8
Oct 13 2002	11:15	28	24.3
Oct 13 2002	11:30	30	26.0
Oct 13 2002	11:45	34	29.5
Oct 13 2002	12:00	31	27.4
Oct 13 2002	12:15	39	34.3
Oct 13 2002	12:30	45	39.0
Oct 13 2002	12:45	52	45.5
Oct 13 2002	13:00	42	36.4
Oct 13 2002	13:15	45	38.9
Oct 13 2002	13:30	57	49.8
Oct 13 2002	13:45	46	40.1
Oct 13 2002	14:00	56	48.7
Oct 13 2002	14:15	66	57.7
Oct 13 2002	14:30	49	42.8
Oct 13 2002	14:45	42	36.7
Oct 13 2002	15:00	53	46.3
Oct 13 2002	15:15	54	47.3
Oct 13 2002	15:30	58	50.8
Oct 13 2002	15:45	57	49.2
Oct 13 2002	16:00	54	46.7
Oct 13 2002	16:15	51	44.6
Oct 13 2002	16:30	52	45.0
Oct 13 2002	16:45	47	40.9

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.25. OZONE CONCENTRATIONS ON THE TRAIL 10/14/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 14 2002	9:00	N/A**	
Oct 14 2002	9:15	N/A**	
Oct 14 2002	9:30	N/A**	
Oct 14 2002	9:45	N/A**	
Oct 14 2002	10:00	38	32.8
Oct 14 2002	10:15	37	32.0
Oct 14 2002	10:30	40	34.5
Oct 14 2002	10:45	39	34.1
Oct 14 2002	11:00	37	32.0
Oct 14 2002	11:15	37	32.4
Oct 14 2002	11:30	40	34.9
Oct 14 2002	11:45	36	31.1
Oct 14 2002	12:00	30	26.5
Oct 14 2002	12:15	33	28.8
Oct 14 2002	12:30	39	33.8
Oct 14 2002	12:45	35	30.0
Oct 14 2002	13:00	35	30.9
Oct 14 2002	13:15	35	30.6
Oct 14 2002	13:30	38	33.0
Oct 14 2002	13:45	36	30.9
Oct 14 2002	14:00	33	28.7
Oct 14 2002	14:15	35	30.5
Oct 14 2002	14:30	34	29.5
Oct 14 2002	14:45	38	33.4
Oct 14 2002	15:00	38	33.1
Oct 14 2002	15:15	37	32.5
Oct 14 2002	15:30	37	32.1
Oct 14 2002	15:45	39	33.5
Oct 14 2002	16:00	37	32.1
Oct 14 2002	16:15	38	33.1
Oct 14 2002	16:30	37	32.5

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.26. OZONE CONCENTRATIONS ON THE TRAIL 10/17/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 17 2002	9:00	43	37.0
Oct 17 2002	9:15	42	36.9
Oct 17 2002	9:30	43	37.5
Oct 17 2002	9:45	41	36.1
Oct 17 2002	10:00	38	33.5
Oct 17 2002	10:15	35	30.2
Oct 17 2002	10:30	32	28.0
Oct 17 2002	10:45	33	28.8
Oct 17 2002	11:00	33	28.4
Oct 17 2002	11:15	35	30.1
Oct 17 2002	11:30	35	30.6
Oct 17 2002	11:45	36	30.9
Oct 17 2002	12:00	35	30.4
Oct 17 2002	12:15	35	30.4
Oct 17 2002	12:30	37	32.6
Oct 17 2002	12:45	38	32.7
Oct 17 2002	13:00	39	33.9
Oct 17 2002	13:15	39	33.7
Oct 17 2002	13:30	43	37.4
Oct 17 2002	13:45	40	35.0
Oct 17 2002	14:00	42	36.5
Oct 17 2002	14:15	44	38.4
Oct 17 2002	14:30	43	37.4
Oct 17 2002	14:45	44	38.7
Oct 17 2002	15:00	46	40.1
Oct 17 2002	15:15	44	38.0
Oct 17 2002	15:30	43	37.5
Oct 17 2002	15:45	44	38.2
Oct 17 2002	16:00	41	35.4
Oct 17 2002	16:15	40	35.2
Oct 17 2002	16:30	37	32.5

* 9:00 represents 9:00 – 9:15 local time.

Table B.27. OZONE CONCENTRATIONS ON THE TRAIL 10/19/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 19 2002	9:00	45	38.9
Oct 19 2002	9:15	42	36.4
Oct 19 2002	9:30	40	34.8
Oct 19 2002	9:45	38	32.8
Oct 19 2002	10:00	41	35.8
Oct 19 2002	10:15	39	33.7
Oct 19 2002	10:30	37	32.0
Oct 19 2002	10:45	45	39.2
Oct 19 2002	11:00	40	34.9
Oct 19 2002	11:15	38	33.5
Oct 19 2002	11:30	41	35.6
Oct 19 2002	11:45	39	33.9
Oct 19 2002	12:00	41	35.4
Oct 19 2002	12:15	39	34.2
Oct 19 2002	12:30	41	35.3
Oct 19 2002	12:45	41	35.7
Oct 19 2002	13:00	43	37.8
Oct 19 2002	13:15	45	38.9
Oct 19 2002	13:30	49	42.6
Oct 19 2002	13:45	44	37.9
Oct 19 2002	14:00	49	42.3
Oct 19 2002	14:15	51	44.1
Oct 19 2002	14:30	49	42.5
Oct 19 2002	14:45	48	41.6
Oct 19 2002	15:00	53	45.8
Oct 19 2002	15:15	46	40.3
Oct 19 2002	15:30	45	39.5
Oct 19 2002	15:45	46	40.2
Oct 19 2002	16:00	46	39.8
Oct 19 2002	16:15	47	41.1

* 9:00 represents 9:00 – 9:15 local time.

Table B.28. OZONE CONCENTRATIONS ON THE TRAIL 10/20/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 20 2002	9:00	N/A**	
Oct 20 2002	9:15	46	39.7
Oct 20 2002	9:30	49	42.5
Oct 20 2002	9:45	48	42.2
Oct 20 2002	10:00	44	38.5
Oct 20 2002	10:15	41	36.0
Oct 20 2002	10:30	44	38.5
Oct 20 2002	10:45	45	38.9
Oct 20 2002	11:00	44	38.2
Oct 20 2002	11:15	42	36.7
Oct 20 2002	11:30	43	37.5
Oct 20 2002	11:45	41	35.7
Oct 20 2002	12:00	41	35.4
Oct 20 2002	12:15	38	32.9
Oct 20 2002	12:30	31	26.9
Oct 20 2002	12:45	28	24.4
Oct 20 2002	13:00	29	25.5
Oct 20 2002	13:15	30	26.2
Oct 20 2002	13:30	34	29.5
Oct 20 2002	13:45	34	29.8
Oct 20 2002	14:00	34	29.3
Oct 20 2002	14:15	35	30.4
Oct 20 2002	14:30	36	30.9
Oct 20 2002	14:45	35	30.7
Oct 20 2002	15:00	39	34.0
Oct 20 2002	15:15	36	31.2
Oct 20 2002	15:30	39	34.0
Oct 20 2002	15:45	45	38.9
Oct 20 2002	16:00	46	39.8
Oct 20 2002	16:15	47	41.1

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

Table B.29. OZONE CONCENTRATIONS ON THE TRAIL 10/23/02

Date	Time*	O_3 NFG (ppbv)	O_3 on trail (ppbv)
Oct 23 2002	9:00	N/A**	
Oct 23 2002	9:15	44	38.3
Oct 23 2002	9:30	37	32.4
Oct 23 2002	9:45	36	31.7
Oct 23 2002	10:00	36	31.7
Oct 23 2002	10:15	36	31.3
Oct 23 2002	10:30	38	32.9
Oct 23 2002	10:45	35	30.2
Oct 23 2002	11:00	41	36.0
Oct 23 2002	11:15	42	36.7
Oct 23 2002	11:30	43	37.5
Oct 23 2002	11:45	41	35.7
Oct 23 2002	12:00	41	35.4
Oct 23 2002	12:15	38	32.9
Oct 23 2002	12:30	31	26.9
Oct 23 2002	12:45	28	24.4
Oct 23 2002	13:00	29	25.5
Oct 23 2002	13:15	30	26.2
Oct 23 2002	13:30	34	29.5
Oct 23 2002	13:45	34	29.8
Oct 23 2002	14:00	34	29.3
Oct 23 2002	14:15	35	30.4
Oct 23 2002	14:30	36	30.9
Oct 23 2002	14:45	35	30.7
Oct 23 2002	15:00	39	34.0
Oct 23 2002	15:15	36	31.2
Oct 23 2002	15:30	39	34.0
Oct 23 2002	15:45	37	32.2

* 9:00 represents 9:00 – 9:15 local time.
** N/A – portable and CD not available

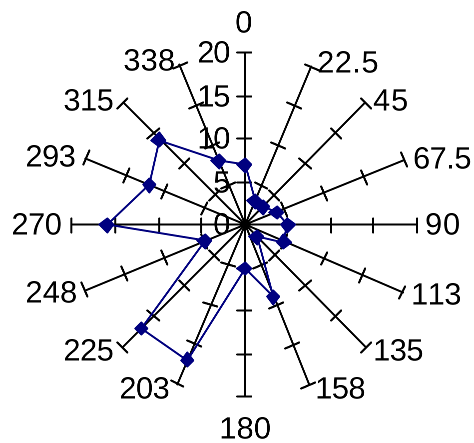
Table B.30. OZONE CONCENTRATIONS ON THE TRAIL 10/26/02

Date	Time*	O_3 NFG (ppbv)**	O_3 on trail (ppbv)**
Oct 26 2002	9:00	29.1	25.3
Oct 26 2002	9:15	29.1	25.3
Oct 26 2002	9:30	29.1	25.3
Oct 26 2002	9:45	29.1	25.3
Oct 26 2002	10:00	26.4	22.9
Oct 26 2002	10:15	26.4	22.9
Oct 26 2002	10:30	26.4	22.9
Oct 26 2002	10:45	26.4	22.9
Oct 26 2002	11:00	24.6	21.3
Oct 26 2002	11:15	24.6	21.3
Oct 26 2002	11:30	24.6	21.3
Oct 26 2002	11:45	24.6	21.3
Oct 26 2002	12:00	29.1	25.3
Oct 26 2002	12:15	29.1	25.3
Oct 26 2002	12:30	29.1	25.3
Oct 26 2002	12:45	29.1	25.3
Oct 26 2002	13:00	31.9	27.7
Oct 26 2002	13:15	31.9	27.7
Oct 26 2002	13:30	31.9	27.7
Oct 26 2002	13:45	31.9	27.7
Oct 26 2002	14:00	32.8	28.4
Oct 26 2002	14:15	32.8	28.4
Oct 26 2002	14:30	32.8	28.4
Oct 26 2002	14:45	32.8	28.4
Oct 26 2002	15:00	32.8	28.4
Oct 26 2002	15:15	32.8	28.4
Oct 26 2002	15:30	32.8	28.4
Oct 26 2002	15:45	32.8	28.4

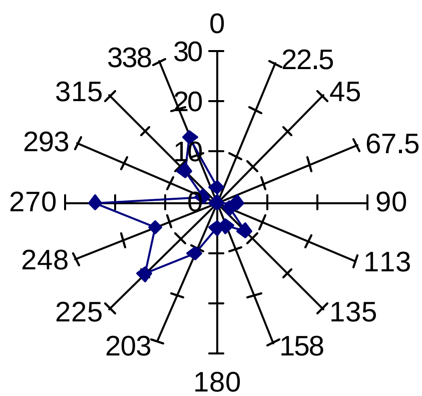
* 9:00 represents 9:00 – 9:15 local time.
** Shaded areas indicate portable ozone monitor not available. Clingmans Dome hourly data were used instead. CD data were corrected by 0.91*CD to obtain NFG data. CD data were corrected by 0.87*.91=0.79 to obtain on the trail, canopy effect data.

APPEDNDIX C

WIND DATA



C.1. Daylight Wind Direction Frequency at Clingman's Dome



C.2. Nighttime Wind Direction Frequency at Clingman's Dome

APPENDIX D

CANOPY EFFECT DATA

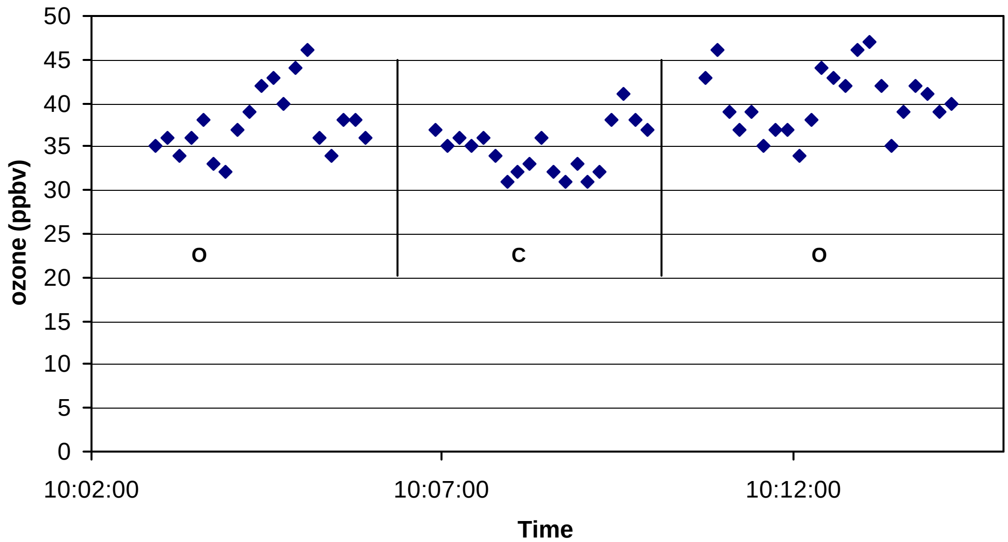


Figure D.1. Canopy Effect AM 7-30-02

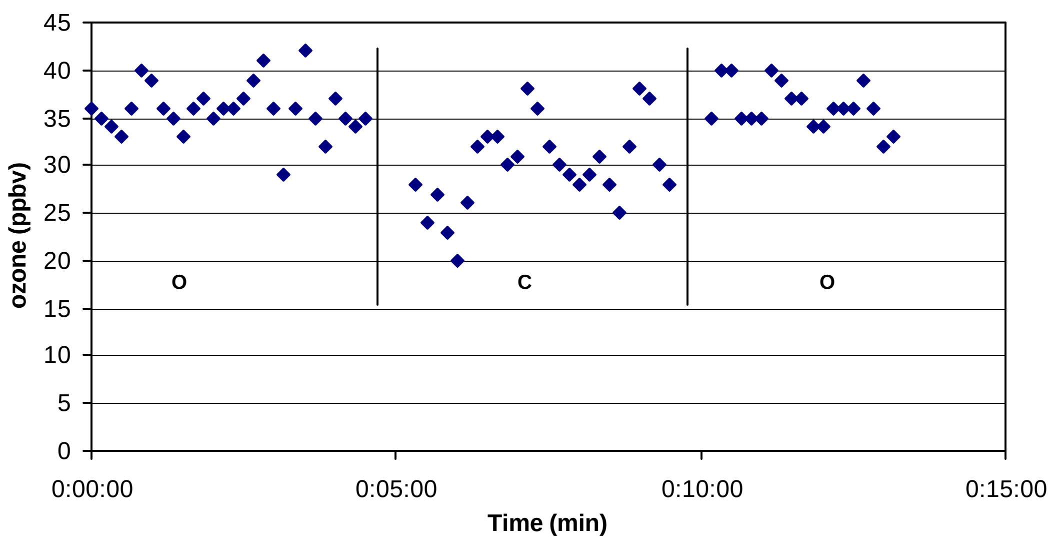


Figure D.2. Canopy Effect PM 7/30/02

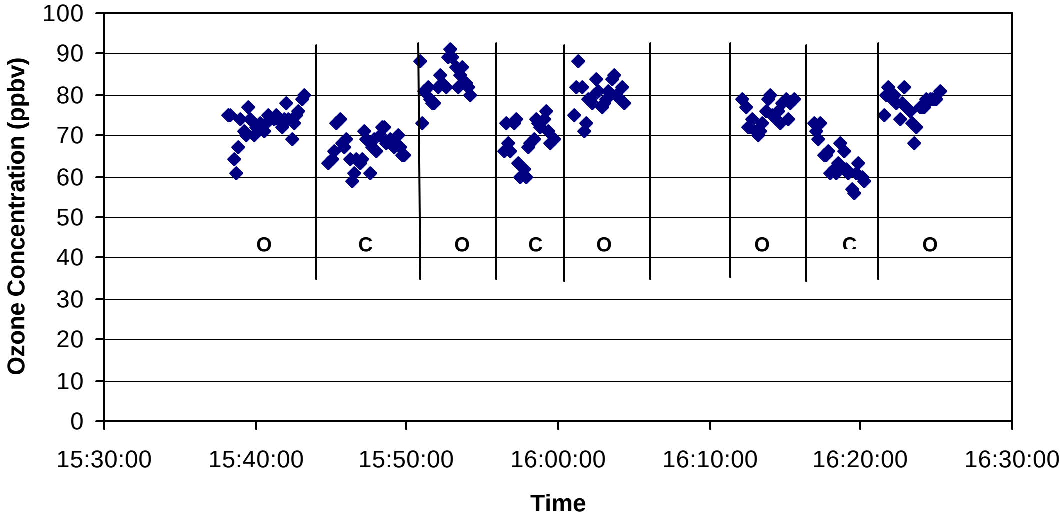


Figure D.3. Canopy Effect at NFG 8/22/02

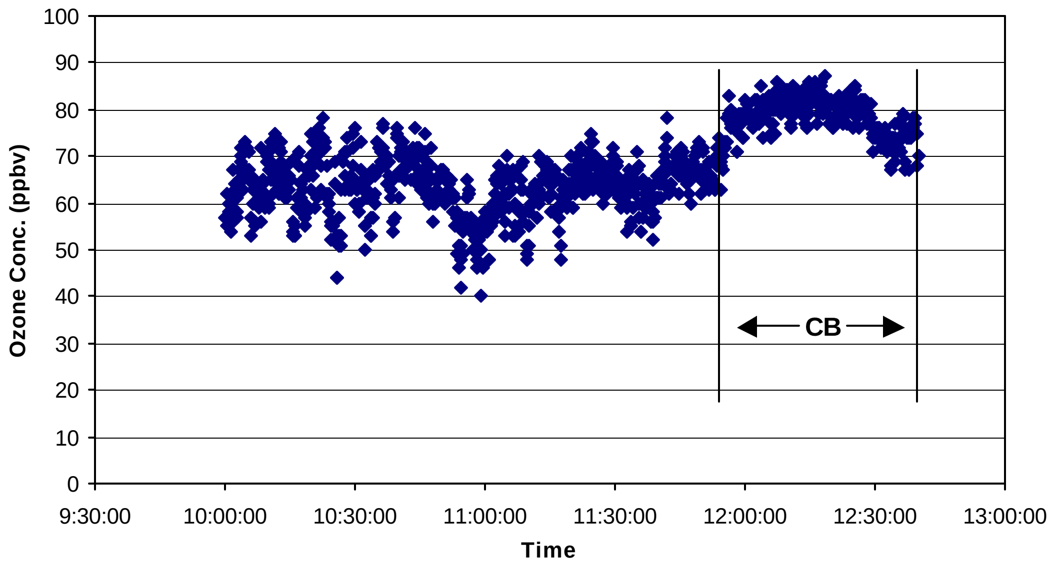


Figure D.4. Hike from NFG to CB 6/11/02

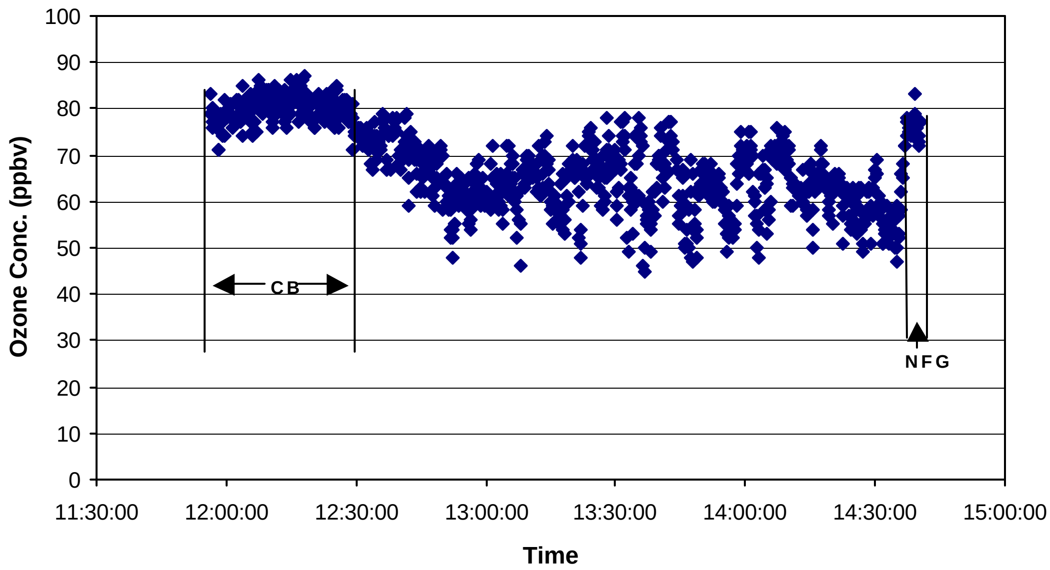


Figure D.5. Hike from CB to NFG 6/11/02

VITA

Ryan William Maloney was born in Murfreesboro, TN on October 25, 1977. He was raised there and graduated from Riverdale High School in 1996. From there, he went to the University of Tennessee-Knoxville and received a B.S. in civil engineering with a minor in environmental engineering in 2000. After graduation, he was accepted to the environmental engineering graduate school at the University of Tennessee-Knoxville. Mr. Maloney shall receive a M.S. in the spring of 2003 in environmental engineering with concentrations in air quality and solid/hazardous waste management.