UPPER GREEN RIVER OZONE INVESTIGATION
(O3i)

MOBILE MONITORING OF OZONE PRECURSORS

BIG PINEY, LUMAN ROAD, BOULDER SOUTH ROAD, PINEDALE AND OLSON RANCH MONITORING SITES

01/31/2009– 07/31/2009

OPERATIONAL OVERVIEW, DATA SUMMARIES, DATA PLOTS AND DATA REVIEW

Prepared for

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1.0 INTRODUCTION

The University of Wyoming's (UW) Atmospheric Science Department (ATSC) designed and constructed a custom Mobile Air Quality Monitoring Laboratory (MAQML) during the period September 2008 to January 2009. This facility was fully operational and deployed in late January 2009. Monitoring was conducted through a contract with the Wyoming Department of Environmental Quality, Air Quality Division (DEQ-AQD). This report describes work performed at each of the five O3i monitoring sites during the period 01/31/2009 – 07/31/2009.

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1.1 Background

A mobile laboratory provides the opportunity for a series of short monitoring periods at different locations. For the purpose of O3i Objective One, five sites were selected to represent different locations relative to the Pinedale Anticline Development Area (PAPA) and Jonah Field. Figure 1-1 gives the location of each of these monitoring sites. The Big Piney site, located upwind of PAPA and Jonah Field, was placed as the western boundary location. The Luman Road site, located downwind of Jonah Field, was placed as a downwind location. The Boulder South Road site, located downwind of PAPA, was placed as a downwind location. The Pinedale site, located upwind of both PAPA and Jonah Field, was placed as the Northern boundary location. The Olson Ranch site was located at the boundary of the PAPA and Jonah Field.

Table 1-1 gives detailed information regarding the position and monitoring period at each of these sites.

Figure 1-1. All MAQML monitoring locations within Sublette County, Wyoming.

Table 1-1. Geographic specifications of UW Mobile Air Quality Monitoring Laboratory (MAQML) site locations.

University of Wyoming Mobile Air Quality Monitoring Laboratory 01/31/2009 – 07/31/2009	
Big Piney	
Elevation:	6869 ft
Longitude:	W109.86983
Latitude:	N42.60060
Monitoring Period:	January 31, 2009 – February 27, 2009
Luman Road	
Elevation:	7159ft
Longitude:	W109.5763
Latitude:	N42.4655
Monitoring Period:	February 28, 2009 – April 1, 2009
Boulder South Road	
Elevation:	7008 ft
Longitude:	W109.7078
Latitude:	N42.6841
Monitoring Period:	April 1, 2009 – May 19, 2009
Pinedale	
Elevation:	7188 ft
Longitude:	42° 51.866'N
Latitude:	109° 51.869'W
Monitoring Period:	May 19, 2009 – June 24, 2009
Olson Ranch	
Elevation:	6867 ft
Longitude:	42° 5995’N
Latitude:	109° 8695'W
Monitoring Period:	June 24, 2009 – July 31, 2009

The MAQML was equipped with several gaseous pollutant analyzers as well as a meteorological monitoring station. As given in Table 1-2 the following parameters were measured: ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), and oxides of nitrogen (NO_x), methane (CH_4), and non-methane hydrocarbons (NMHC). This report presents data collected at all MAQML sites for the period January 31, 2009 through July 31, 2009. Ambient concentrations of ozone NO, NO_2, and NO_x, CH_4 and NMHC are continuously monitored according to EPA approved methods.

Wind speed, wind direction, temperature, barometric pressure and relative humidity were monitored to understand local meteorological conditions. Project performance goals included adherence to EPA monitoring guidelines. Details of the monitoring design and quality assurance program plan are given in the Quality Assurance Project Plan for the Upper Green River Ozone Investigation (O3i) (rev 0.1, November 2008).

Table 1-2. Mobile Air Quality Monitoring Laboratory monitored parameters.

University of Wyoming Mobile Air Quality Monitoring Laboratory 01/31/2009 – 07/31/2009	
Gaseous Parameters	**Meteorological Parameters**
• Ozone (O_3) • Nitric Oxide (NO) • Nitrogen Dioxide (NO_2) • Oxides of Nitrogen (NO_x) • Methane (CH_4) • Non-Methane Hydrocarbons (NMHC)	• Wind Speed (WS) • Wind Direction (WD) • Barometric Pressure • Temperature • Relative Humidity (RH)

1.2 UW MAQML Site Photographs

Figure 1-2. Big Piney UW Mobile Air Quality Monitoring Laboratory site location.

Figure 1-3. Luman Road UW Mobile Air Quality Monitoring Laboratory site location.

Figure 1-4. View west from Boulder South Road UW Mobile Air Quality Monitoring Laboratory site location.

Figure 1-5. Pinedale UW Mobile Air Quality Monitoring Laboratory site location.

Figure 1-6. Olson Ranch UW Mobile Air Quality Monitoring Laboratory site location.

1.3 Instrumentation and Sampling Protocols

Table 1-3 shows key characteristics of monitoring instrumentation in the MAQML. Measurement frequencies of 1-minute for gaseous parameters were used – rather than the 5-minute average more commonly applied in air quality monitoring. This sampling rate enhanced the potential for obtaining CH_4 measurements above background levels. The other parameters measured the same time frequency for comparative purposes. In the United States background methane concentration are approximately 1.85 ppm. The rationale behind this selection is discussed in more detail in section 5.3.2.1.

Table 1-3. UW MAQML instrumentation and sampling protocols.

University of Wyoming Mobile Air Quality Monitoring Laboratory 01/31/2009 – 07/31/2009				
Component	**Instrumentation**	**Height**	**Frequency**	**Parameter**
Gaseous	Thermo-Fisher 49i	5 meters	1 minute	O_3
	Thermo-Fisher 42i	5 meters	1 minute	NO, NO_2, NO_x
	Thermo-Fisher 55c/55i	5 meters	1 minute	CH_4, NMHC
Meteorology	Vaisala Weather Transmitter WXT510	5 meters	20 seconds	Wind Speed Wind Direction Temperature Barometric Pressure Relative Humidity

1.4 Quality Assurance

Quality assurance procedures are provided in the QAPP for O3i. Of particular importance is the initial set-up of the MAQML, site operating protocols and post processing procedures. Proper site operation includes calibration, instrument maintenance and trouble-shooting. Independent auditing of the gaseous instrumentation was conducted by an independent contractor of the WDEQ-AQD (T&B Systems). All routine operations and data collection activities are systematic and follow written procedures as detailed in instrument-specific manuals.

2.0 DATA COLLECTION AND VALIDATION

2.1 Gaseous and Meteorology

2.1.1 Data Collection

Raw data are uploaded daily via cellular phone service to the ATSC ftp server. Data is also collected during weekly site visits. Latest data values are available via the project website to review operational status and measurement parameters. The purpose of daily uploads is to perform preliminary data quality checks and to concatenate current data to previously collected data.

2.1.2 Data Validation

This project employs a two-level data validation process. These levels, and the validation codes that designate them, are defined in Tables 2-1 and 2-2, respectively.

Table 2-1. Gaseous Validation Process Summary.

Level 0 Validation
These data are obtained directly from the data acquisition system. Averaging times represent the minimum intervals set by the instruments as indicated in Table 1-3. For the meteorological parameters this data does not correspond to the averaging periods specified for the database files. Level 0 data have not been edited for instrument downtime, nor have procedural adjustments for baseline and span changes been applied. Level 0 data are consulted on a regular basis to ascertain instrument functionality and to identify potential episodes prior to receipt of Level 1 data.
Level 1 Validation
These data have passed several validation tests applied by the measurement investigator prior to data submission. The general features of Level 1 are: 1) removal of values when monitoring instruments fail specified validation criteria; 2) flagging measurements when significant deviations from measurement assumptions have occurred; 3) verifying computer file entries against data sheets, where appropriate; 4) replacement of data from a backup data acquisition system in the event of failure of the primary system; and 5) adjustment of measurement values for quantifiable baseline and span or interference biases.

Table 2-2. Gaseous data validation codes.

Code	Meaning
a	Valid ambient data
C	Valid span calibration data for calculation of response factors
C2	Gas phase titration calibration
c	Transition span calibration data
B	Valid zero calibration data for calculation of response factors
b	Transition zero data
Z	Audit
nd	No data
r	Re-location
rw	Warm-up after re-location
w	Warm up after malfunction
m	Maintenance
mq	Maintenance of data acquisition system
mf	Malfunction of flame
mi	Malfunction of integration
mp	Malfunction of external power supply
mv	Malfunction of valve switch
fo	Flame out

3.0 OPERATIONAL SUMMARY

3.1 Gaseous and Meteorological

Table 3-1. Gaseous and meteorological operational timeline.

University of Wyoming
Mobile Air Quality Monitoring Laboratory
01/31/2009 – 07/31/2009

Date	Summary
01/31/09	Initial Big Piney Startup
02/01/09	Site visit. Zero/span operations. Fix WXT520 sporadic reporting. Correct remote transmission problem
02/03/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
02/07/09	FID air supply depleted; 55c failure.
02/08/09	Site visit. Zero/span operations. Restart 55c to repair communication issue. Replace FID air supply. Restart DAS.
02/11/09	Site visit. Zero/span operations. Adjustment of 42i parameters.
02/12/09	Site visit. Zero/span operations. Audit by T&B Systems.
02/16/09	Site visit. Zero/span operations.
02/19/09	Site visit. Zero/span operations.
02/20/09	Site visit. Replace FID air supply. Zero/span 55c.
02/21/09	Site visit. Zero/span operations.
02/25/09	Site visit. Zero/span operations. Relight flame 55c.
02/27/09	Site visit. Shutdown for move to Luman Road monitoring site.
02/28/09	Initial Luman Road Startup
03/02/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
03/03/09	FID air supply depleted; 55c failure.
03/04/09	Site visit. Zero/span operations. Replace FID air supply. Restart DAS. Begin new GPT procedure for 42i. Restart data system after software modifications.
03/07/09	Site visit. Zero/span operations.
03/09/09	55c data transmission issue begins.
03/11/09	Site visit to troubleshoot 55c issues. Remove 55c from lab.
03/12/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
03/13/09	Site visit. Zero/span operations.
03/16/09	Site visit. Zero/span operations.
03/20/09	Site visit. Zero/span operations. Reboot DAS due to non-response.
03/31/09	Site visit. Zero/span operations.
04/01/09	Site visit. Shutdown for move to Boulder South Road monitoring site.
04/01/09	Initial Boulder South Road Startup
04/04/09	Site visit. Installation of 55i.
04/05/09	Site visit. Zero/span operations.
04/10/09	FID air supply depleted; 55i failure.
04/11/09	Site visit. Zero/span operations. Replace FID air supply. Replace 55i span

	gas.
04/13/09	FID air supply depleted; 55i failure.
04/14/09	Site visit. Zero/span operations. Replace FID air supply. Begin using 1160 zero air supply for FID air supply.
04/23/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue. Air conditioning out upon arrival; issue resolved.
04/28/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
05/06/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
05/14/09	Site visit. Zero/span operations. Changeover Ultrapure Nitrogen supply for 55i.
05/18/09	Site visit. Zero/span operations. Relight flame 55c.
05/19/09	Site visit. Shutdown for move to Pinedale monitoring site.
05/19/09	Initial Pinedale site startup
05/20/09	Site visit. Zero/span operations.
05/27/09	Site visit. Zero/span operations.
06/02/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
06/03/09	Site visit. Zero/span operations. Demonstration for Pinedale High School students.
06/04/09	Site visit.
06/12/09	Planned power outage by rocky Mountain Power.
06/09/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
06/14/09	Power outage
06/15/09	Power outage
06/16/09	Power outage
06/17/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
06/23/09	Site visit. Zero/span operations.
06/23/09	Audit with David Yoho, T&B Systems.
06/24/09	Site visit. Shutdown for move to Olson Ranch monitoring site.
06/24/09	Initial Olson Ranch site startup
07/01/09	Site visit. Zero/span operations.
07/10/09	Site visit. Zero/span operations.
07/22/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
07/25/09	Site visit. Zero/span operations. Reboot 49i & 42i to correct display issue.
07/31/09	Site visit. Shutdown.

4.0 GASEOUS STANDARDS SUMMARY

Ambient concentrations of O_3 and NO_2 are regulated by DEQ-AQD and EPA under Wyoming Ambient Air Quality Standards (WAAQS) and EPA National Ambient Air Quality Standards (NAAQS) provisions of the Clean Air Act. Values measured by O3i are presented with corresponding NAAQS/WAAQS in Table 4-1. This table is intended for comparative purposes as the 03i study was conducted at multiple sites over a period of six months. As such any comparison is for context and does not have direct applicability to NAAQS or WAASQ.

The NAAQS for O_3 was updated by EPA in March 2008, and is 0.075 ppm over an 8-hour period. An exceedance of the standard occurs when an 8-hour average O_3 concentration is greater than or equal to 0.075 ppm. A violation of the standard occurs when the three-year average of the fourth highest daily maximum 8-hour average ozone concentration exceeds 0.075 ppm. The NAAQS for NO_2 is an annual arithmetic mean of the one-hour NO_2 values, 0.053 ppm, or 53 ppb.

While a comparison value cannot be calculated for NO_2, Table 4-1 shows that ozone levels did not exceed the standard value for the rolling 8-hour average.

Table 4-1. UW MAQML Standards Summary Report.

University of Wyoming Mobile Air Quality Monitoring Laboratory 01/31/2009 – 07/31/2009					
Parameter	**NAAQS**		**Measured**		
	Averaging Time	**Standard**	**Measured Value**		**Date(s) and locations**
Ozone	Rolling 8-hour	0.075 ppm	Highest Daily Max:	0.070	5/01/2009 Boulder South Rd
			4th Highest Daily Max:	0.070	4/28/2009 Boulder South Rd
Nitrogen Dioxide	Annual	0.053 ppm	Arithmetic Mean	n/a	n/a

5.0 DATA SUMMARY PRODUCTS

The following sections present summary information for O3i monitoring performed during the period of January to June 2009. These sections assess data recovery and each of the parameters considered in O3i.

Section 5.1 considers data recovery for all measured parameters. Section 5.2 considers meteorological parameters with particular attention given to wind speed and wind direction. Section 5.3 assesses gaseous pollutant behavior. This section illustrates behavior through pollution rose diagrams and temporal plots. Latter plots indicate short-term, diurnal, and longer-term behavior at each monitoring site, respectively.

5.1 Data Collection Summaries

Data recovery information presented in Table 5-1 is calculated with one minute time averaged data. This data is considered complete if a minimum of 75% of data are valid. For Table 5-1 the total number of possible data points in relation to the total number of valid ambient data points are shown. The number possible is the period from when data is produced from the instrument, i.e. from switch on until switch off. This period does not include time for re-locating the laboratory between sites. Collected data excludes the time taken for equipment to warm-up after relocation. The percent collected value is equal to number collected divided by the number possible. Valid data is ambient data that has not been excluded through data validation. Table 2-2 lists the codes and associated cause of invalidation. For all instruments, data is removed due to calibration. Other important causes of data removal include instrument malfunction and instrument behavior outside of preferred diagnostic limits. The ultimate indication of completeness criteria is given by the calculation of the percentage of valid data. This value is the number of valid ambient data points divided by the number possible.

Completeness criteria were exceeded for all but two of the eleven measurement parameters. A higher target was set for CH_4 and NMHC as these pollutants were identified as being the unique measurements of O3i. The value of 75% valid data does not reflect poor data handling or instrument performance as data recovery is close to 100%. Data was lost due to instrument failure that could not be repaired. Since the quality and quantity of this data was prioritized, a replacement instrument was installed within a few days of receipt. The period of data loss impacted the Luman Road site and to a lesser extent the Boulder South Road site.

Table 5-1. UW MAQML data collection statistics.

University of Wyoming Mobile Air Quality Monitoring Laboratory Data Collection Statistics Final Validation 01/31/2009 – 07/31/2009							
Parameter	**Interval**	**Par Code**	**Data Recovery**			**Valid Data**	
			No. Possible	No. Collected	% Collected	No. Valid	% Valid
Ozone	**1-minute**	**O3**	259,390	259,165	99.91%	255,741	98.59%
Nitric Oxide	**1-minute**	**NO**	259,351	259,140	99.92%	255,907	98.67%
Oxides of Nitrogen	**1-minute**	**NOx**	259,352	259,127	99.91%	255,912	98.67%
Nitrogen Dioxide	**1-minute**	**NO2**	259,352	259,127	99.91%	255,912	98.67%
Methane	**1-minute**	**CH4**	257,578	257,266	99.88%	192,575	74.76%
Non-Methane Hydrocarbons	**1-minute**	**NMHC**	257,578	257,266	99.88%	192,575	74.76%
Wind Direction	**1-minute**	**WD**	259,443	256,819	99%	256,819	99%
Wind Speed	**1-minute**	**WS**	259,443	256,819	99%	256,819	99%
Temperature	**1-minute**	**TEMP**	259,443	256,819	99%	256,819	99%
Relative Humidity	**1-minute**	**RH**	259,443	256,819	99%	256,819	99%
Pressure	**1-minute**	**PRES**	259,443	256,819	99%	256,819	99%

Performance Goals: Completeness Criteria Listing from QAAP

O_3	75%
NO | NO_x | NO_2	75%
CH_4 | NMHC	85%
Wind Speed	80%
Wind Direction	80%

5.2 Meteorological Parameter Measurement Summaries

Continuous air temperature, barometric pressure, wind speed and wind direction values are measured using the Vaisala WXT510 Weather Transmitter. Summaries of air temperature, barometric pressure, wind speed and wind direction measurements at each monitoring site are presented in this section.

5.2.1 Meteorological Data Summaries

Tables 5-3 through 5-7 present meteorological data summaries for each of the five UW MAQML measurement locations. Data collection commenced at the Big Piney site on January 31, 2009 and concluded July 31, 2009 at the Olson Ranch site. With the exception of the Pinedale site, all sites were located on open ground without significant influence from proximate structures.

Wind speed and direction data are presented in Figures 5-1 through 5-5 in the wind rose format for each site for the period January 31, 2009 – July 31, 2009. These figures indicate wind field behavior of each site. As discussed previously these sites were selected to be representative of different downwind or upwind situations relative to the PAPA and Jonah developments. These figures confirm the anticipated dominant air movement at each site with respect to position relative to oil and gas developments in the local area. The area of investigation exhibits a complex wind field with seasonal and diurnal variations. Each site was positioned as described in Table 5-2. This table, and the subsequent explanation, follows a sequence that reflects the wind pattern for the region, rather than the chronological sequence of monitoring at these sites.

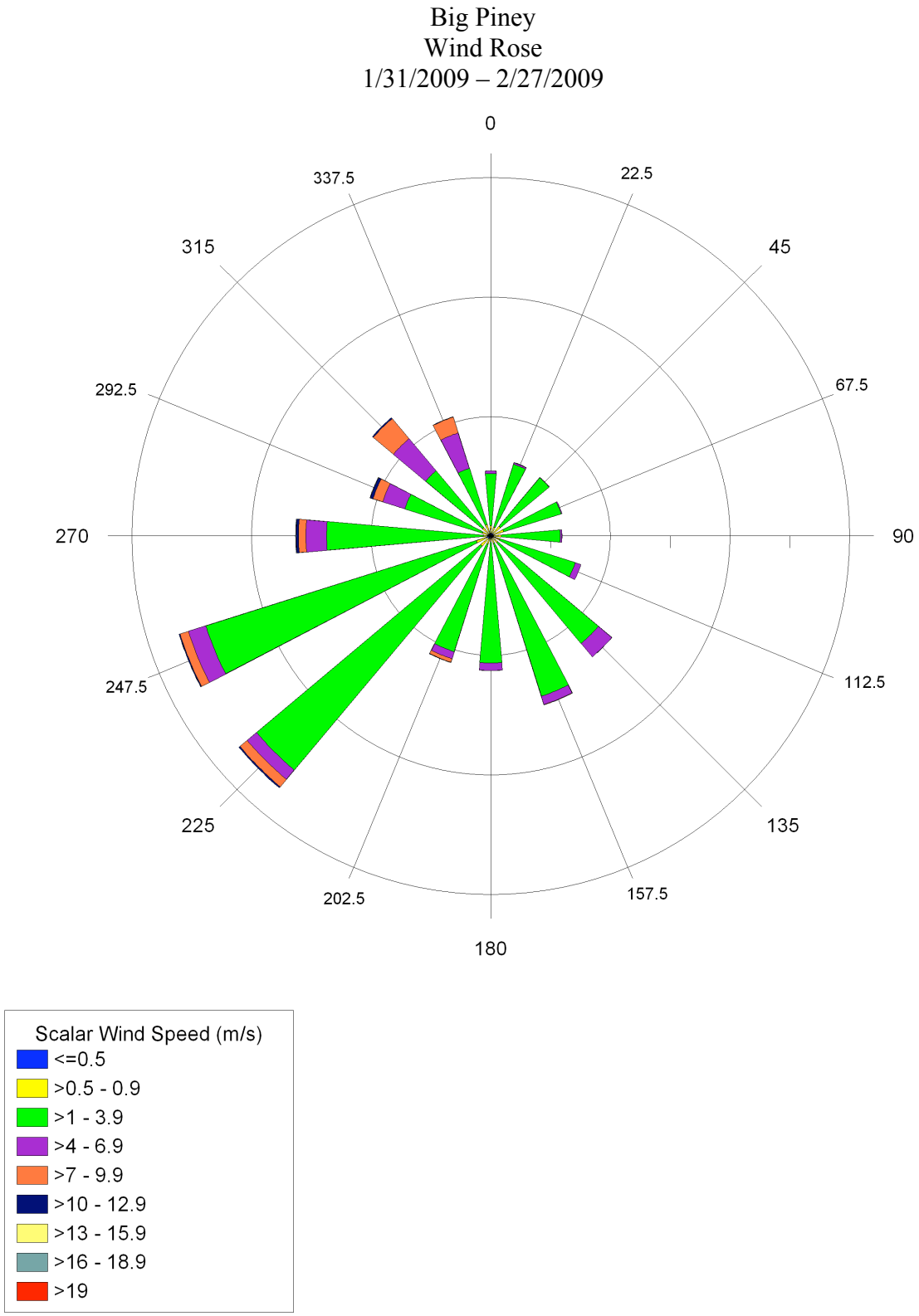
Table 5-2 Initial and final site descriptions relative to local oil and gas development.

Site	Initial Description	Final Description	Period
Big Piney	Upwind of PAPA and Jonah	Same	1/31 – 2/27/2009
Pinedale	Upwind of PAPA and Jonah	Same	5/19 – 6/24/2009
Olson Ranch	Upwind of PAPA and Jonah	Same with qualification*	6/24 – 7/31/2009
Boulder South Road	Downwind of PAPA	Same with qualification*	4/1 –5/19/2009
Luman Road	Downwind of Jonah	Downwind of Jonah and PAPA	2/27 – 4/1/ 2009

*Please note more detailed comments associated with wind roses for this site.

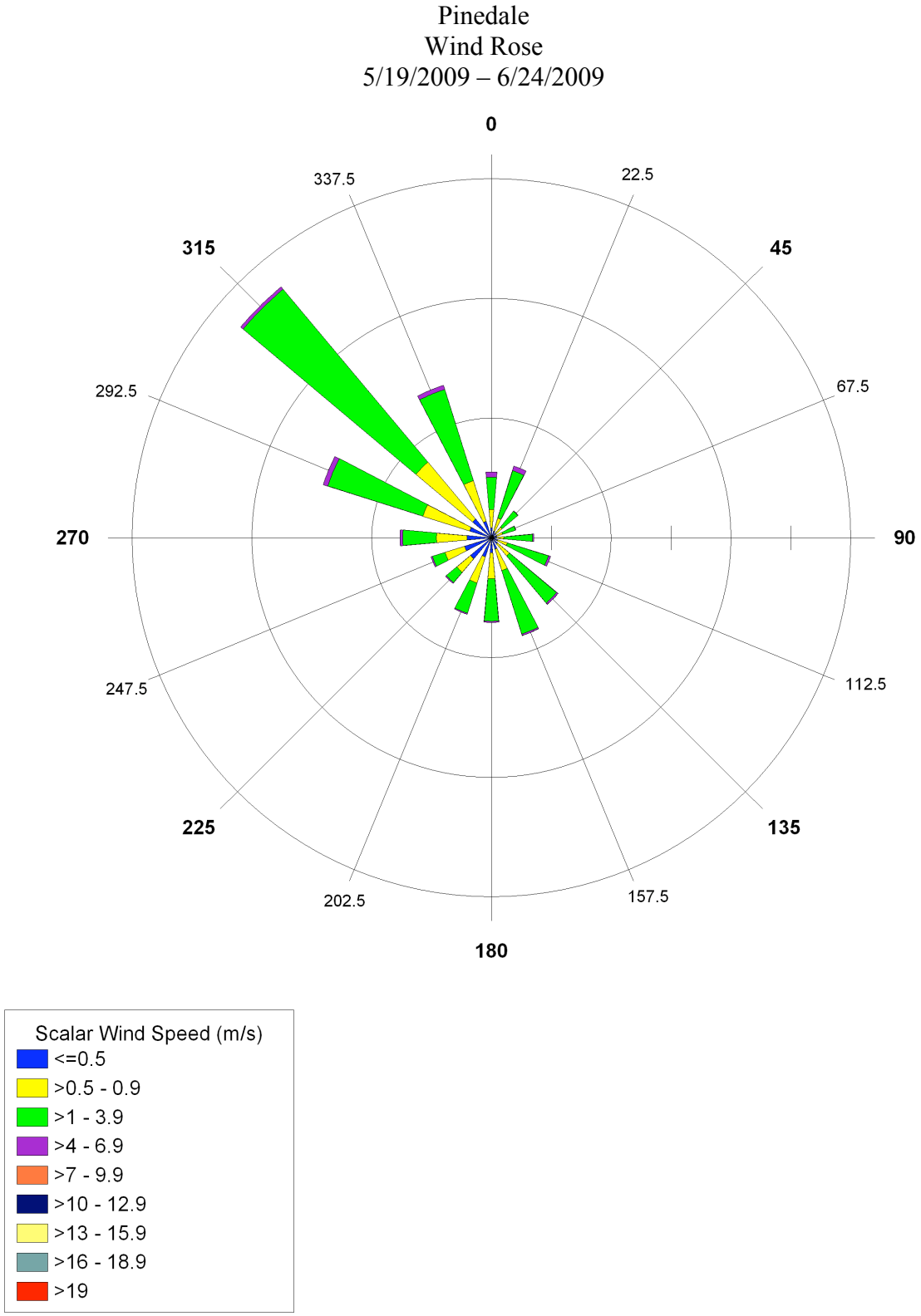
The Big Piney site was located on open ground at the edge of Big Piney High School athletic fields (Figure 1-2). Predominant wind directions as indicated by Figure 5-1 were W/SW and SW with wind speeds between 1 and 3.9 m/s. This direction is associated with airflow from the southern portion of the Wyoming Range. Two other wind direction sectors can be viewed as important secondary patterns, namely S/SE and NW, the latter was associated with higher wind speeds between 4 and 9.9 m/s. Figure 5-1 confirms Big Piney as an upwind site of PAPA and Jonah during the period of monitoring.

Figure 5-1. Big Piney Wind Rose for the period 1/31/2009 – 2/27/2009.



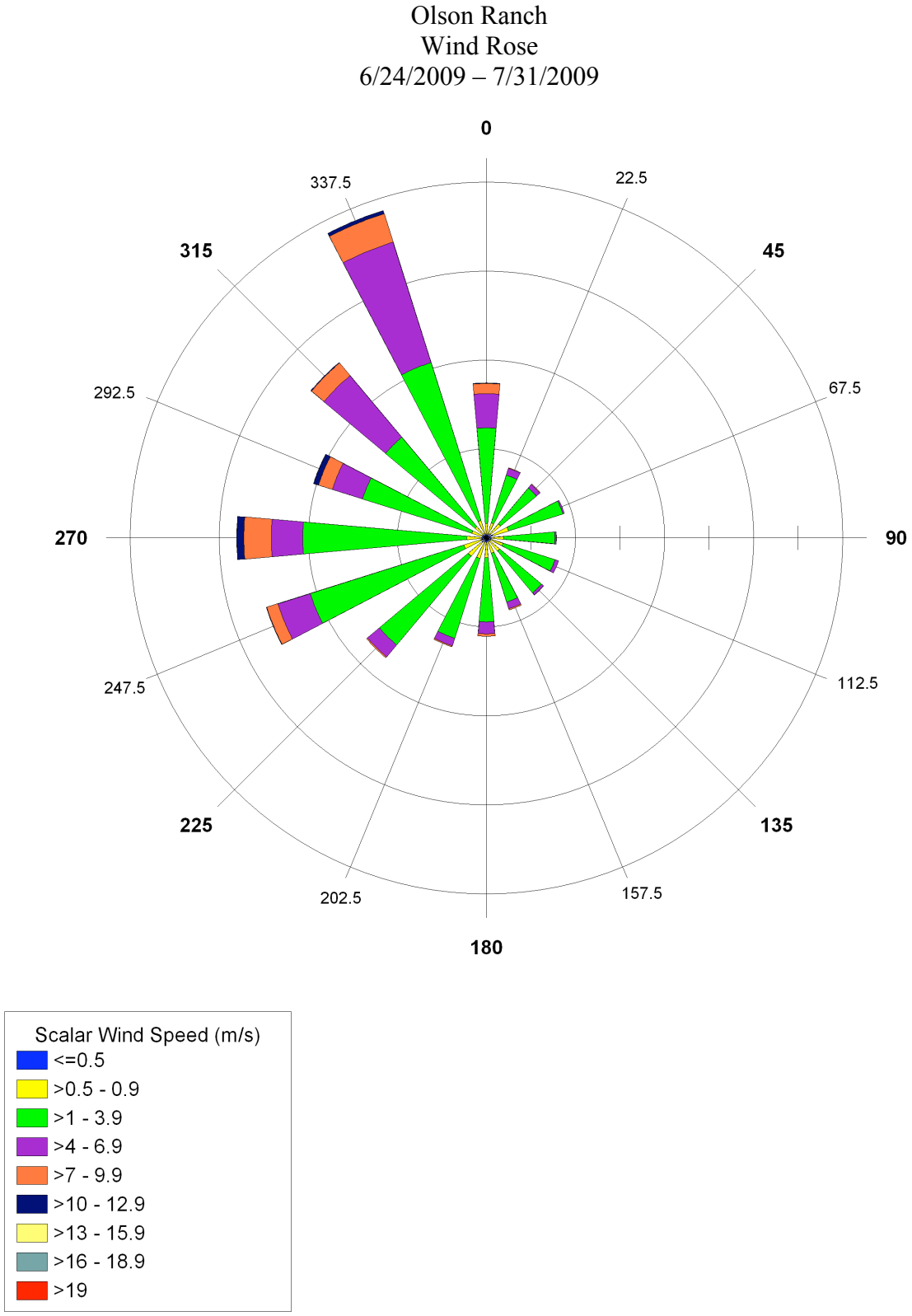
The Pinedale site was located at the edge a recreational park near the center of town (Figure 1-5). The wind profile at this site was likely influenced by surrounding structures. The predominant wind direction, as indicated by Figure 5-4, was NW with wind speeds mainly between 1 and 3.9 m/s. This direction is associated with airflow from the Gros Ventre Range. Figure 5-2 confirms Pinedale as an upwind site of PAPA and Jonah Field during the period of monitoring.

Figure 5-2. Pinedale Wind Rose for the period 5/19/2009 – 6/24/2009.



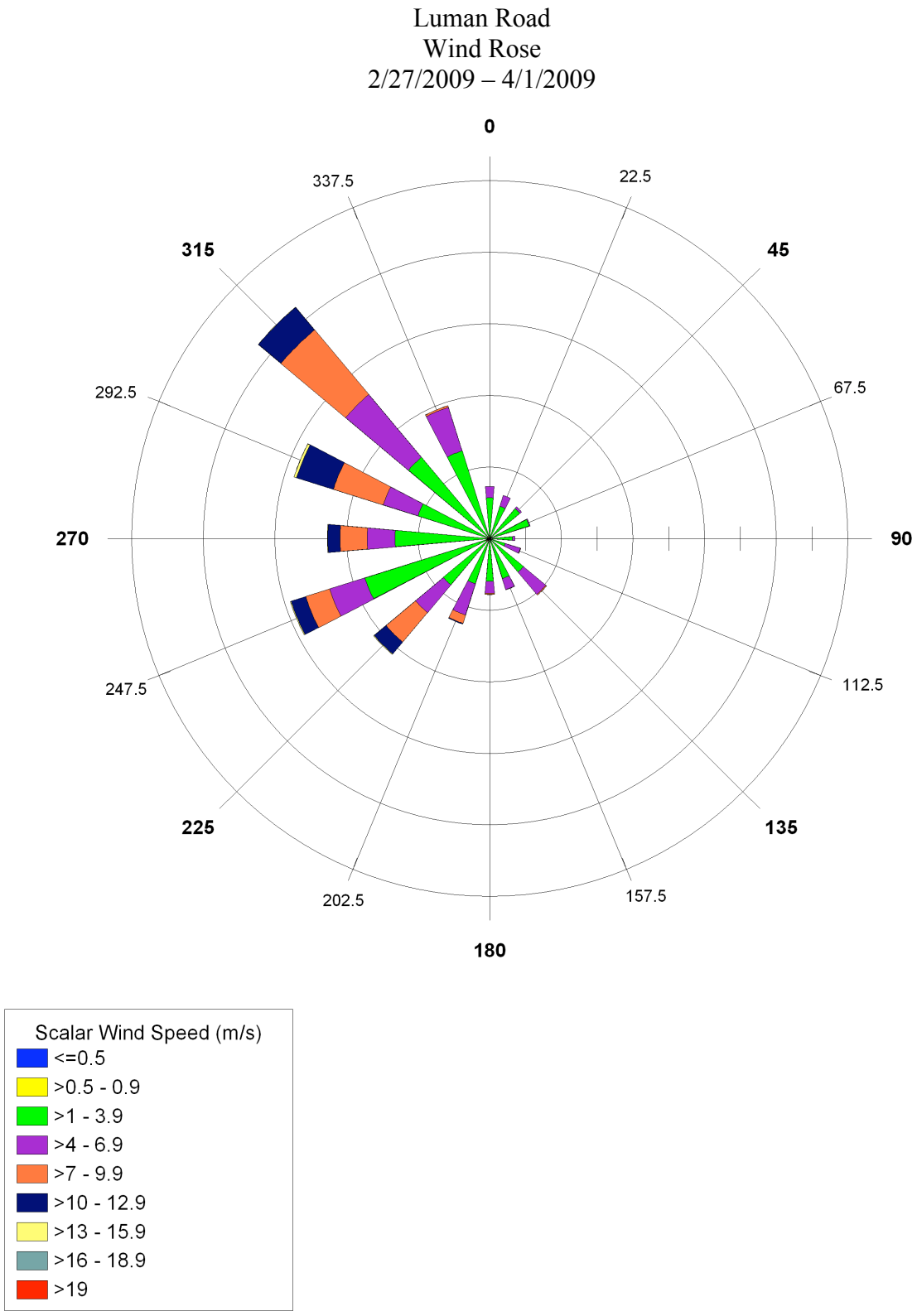
The Olson Ranch site was located on open ground south of US Highway 351 (Figure 1-6). Predominant wind directions, as indicated by Figure 5-5, were N/NW and W with W/SW both with wind speeds ranging from 1 to 12.9 m/s. The former direction, N/NW, is associated with airflow from the Gros Ventre Range. The latter, W with W/SW, is associated with airflow from the southern end of the Wyoming range. This is anticipated given the position of Olson Ranch. This site can be seen as a hybrid of wind fields shown at the Big Piney (Figure 5-1) and Pinedale (Figure 5-2) sites. Faster wind speeds are associated with winds from the Gros Ventre Range. Figure 5-3 confirms Olson Ranch as an upwind site of PAPA and Jonah. However, as indicated in subsequent sections, during low wind speed conditions wind direction may shift and allow for the site to be considered downwind of local oil and gas development. This behavior is accentuated by the relatively close proximity to the PAPA and Jonah Field.

Figure 5-3. Olson Ranch Wind Rose for the period 6/24/2009 – 7/31/2009.



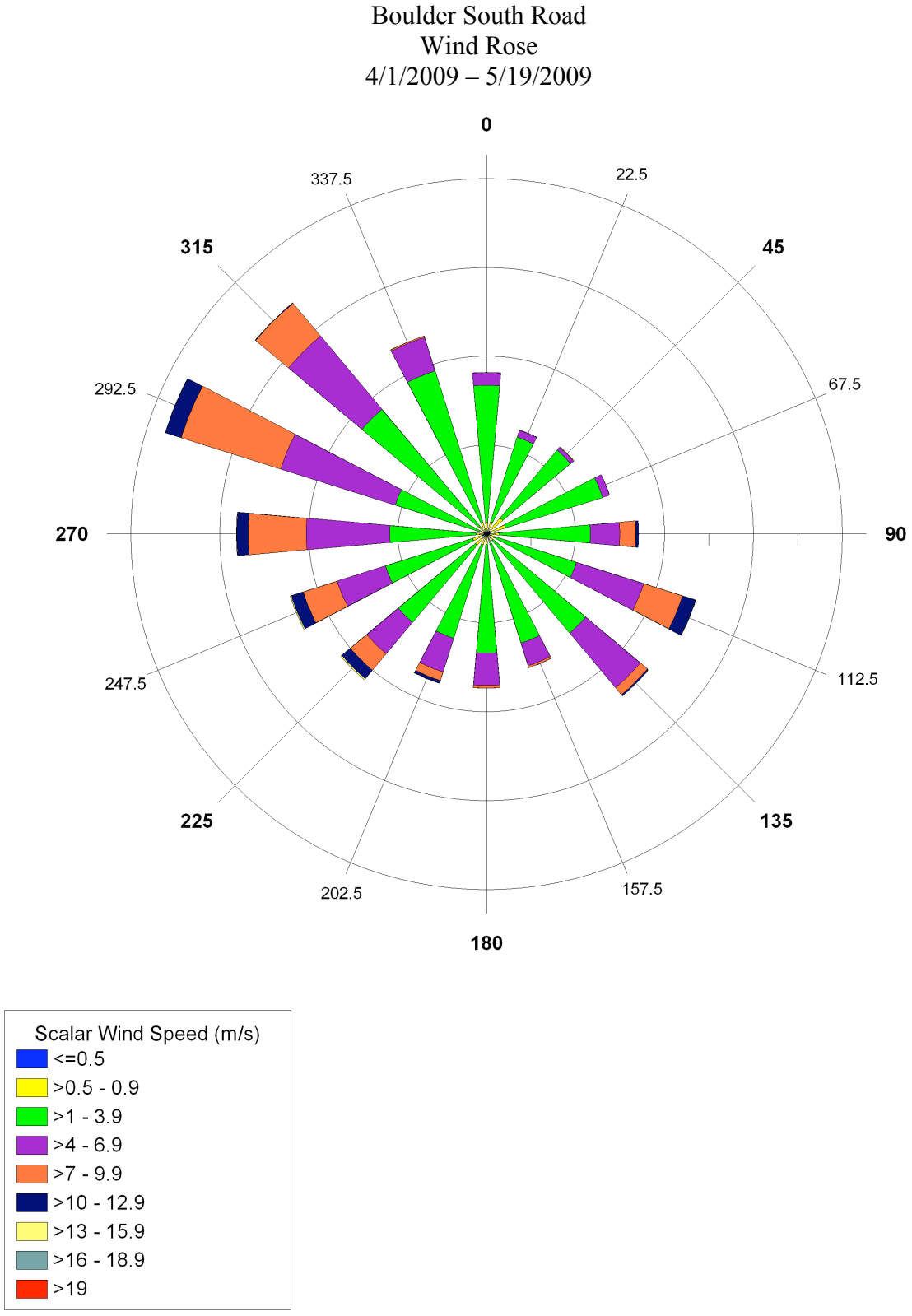
The Luman Road site was located on open ground at the edge of Luman Road (Figure 1-3). Predominant wind directions, as indicated by Figure 5-4, were NW and W/SW with W/SW, with wind speeds ranging from 1 and 12.9 m/s. The NW direction is associated with airflow from the Gros Ventre Range. The latter, W/SW, is associated with airflow from the southern end of the Wyoming range. This is anticipated given the position of Luman Road. This site can be seen as a hybrid of wind fields shown for Big Piney (Figure 5-1) and Pinedale (Figure 5-2). Faster wind speeds are associated with winds from the Gros Ventre Range. Figure 5-4 shows that the Luman Road site should be considered as a site downwind of both Jonah Field and PAPA during the period of monitoring.

Figure 5-4. Luman Road Wind Rose for the period 2/27/2009 – 4/1/2009.



The Boulder South Road site was located on open ground near the junction of US Highway 191 and Boulder South Road (Figure 1-4). While the predominant wind direction is W/NW with NW the wind rose shows a relatively circular distribution. The predominant wind direction, as indicated by Figure 5-5, is dominated by wind speeds ranging from 1 to 12.9 m/s. This site can be seen to be more than a hybrid of the wind fields shown by the Big Piney (Figure 5-1) and Pinedale (Figure 5-2) sites. While Figure 5-5 confirms the Boulder South Road site as downwind of PAPA and Jonah Field. It also shows that all wind directions contribute to the wind field at this site. As such this site can also be upwind of PAPA and Jonah Field.

Figure 5-5. Boulder South Road Wind Rose for the period 4/1/2009 – 5/19/2009.



As indicated by Table 5-3, meteorological conditions are typical for the time of year and geographic position of this site. Big Piney is known for colder temperatures and the average for this period was -8.1°C. Average wind speed, pressure and relative humidity are also typical for this area.

Table 5-3. Big Piney UW MAQML meteorological data summary for the period 01/31/2009 – 02/27/2009.

University of Wyoming Mobile Air Quality Monitoring Laboratory Big Piney *Meteorological Data Summary* Final Validation 01/31/2009 – 02/27/2009				
Parameter	**Value**	**Units**	**Number**	**Standard Deviation**
WIND SPEED				
Average	2.5	m/s	38803	1.7
Maximum	19.4			
TEMPERATURE				
Average	-8.1	°C	38803	6.4
Maximum	5.8			
Minimum	-22.2			
RELATIVE HUMIDITY				
Average	74	%	38803	13
Maximum	96			
Minimum	29			
PRESSURE				
Average	789	mmHg	38803	6
Maximum	801			
Minimum	773			

As indicated by Table 5-4, meteorological conditions are typical for the time of year and geographic position of this site. The Luman road site was located at the edge of a hillside facing the dominant wind direction. Average wind speed, pressure and relative humidity are also typical for this area.

Table 5-4. Luman Road UW MAQML meteorological data summary for the period 02/27/2009 – 04/01/2009.

University of Wyoming Mobile Air Quality Monitoring Laboratory Luman Road *Meteorological Data Summary* Final Validation 02/27/2009 – 04/01/2009				
Parameter	**Value**	**Units**	**Number**	**Standard Deviation**
WIND SPEED				
Average	4.5	m/s	46997	2.9
Maximum	16.3			
TEMPERATURE				
Average	-3.1	°C	46997	6.3
Maximum	14.4			
Minimum	-21.1			
RELATIVE HUMIDITY				
Average	64	%	46997	15
Maximum	95			
Minimum	22			
PRESSURE				
Average	778	mmHg	46997	6
Maximum	792			
Minimum	518			

As indicated by Table 5-5, meteorological conditions at this site reflect a shift from winter to spring, with a relatively large variation in temperature values. Despite atypical average wind speeds, the highest individual wind speed of 48.2 m/s reading was reported at this site. Average relative humidity and pressure is typical for this area.

Table 5-5. Boulder South Road UW MAQML meteorological data summary for the period 04/01/2009 – 05/19/2009.

University of Wyoming Mobile Air Quality Monitoring Laboratory Boulder South Road *Meteorological Data Summary* Final Validation 04/01/2009 – 05/19/2009				
Parameter	**Value**	**Units**	**Number**	**Standard Deviation**
WIND SPEED				
Average	3.7	m/s	68389	2.6
Maximum	48.2			
TEMPERATURE				
Average	4.2	°C	68389	6.0
Maximum	25.5			
Minimum	-10.5			
RELATIVE HUMIDITY				
Average	60	%	68389	23
Maximum	96			
Minimum	12			
PRESSURE				
Average	784	mmHg	68389	6
Maximum	795			
Minimum	768			

As indicated by Table 5-6, meteorological conditions are typical for the time of year and geographic position of this site. The Pinedale site was located near the center of town. This reflects the relatively low wind speeds are at this site. While wind direction reflects anticipated behavior, as the MAQML was situated away from the direct influence of building and trees, wind speed is slowed by the town center situation. Average relative humidity and pressure is typical for this area.

Table 5-6. Pinedale UW MAQML meteorological data summary for the period 05/19/2009 – 06/24/2009.

University of Wyoming Mobile Air Quality Monitoring Laboratory Pinedale *Meteorological Data Summary* Final Validation 05/19/2009 – 06/24/2009				
Parameter	**Value**	**Units**	**Number**	**Standard Deviation**
WIND SPEED				
Average	1.3	m/s	51408	0.9
Maximum	10.4			
TEMPERATURE				
Average	10.2	°C	51408	5.4
Maximum	27.8			
Minimum	-5.6			
RELATIVE HUMIDITY				
Average	67	%	51408	23
Maximum	96			
Minimum	10			
PRESSURE				
Average	781	mmHg	51408	3
Maximum	788			
Minimum	773			

As indicated by Table 5-7, meteorological conditions at this site reflect a shift to spring like regime, with relatively higher temperature values. Average wind speed, relative humidity and pressure are typical for this area.

Table 5-7. Olson Ranch UW MAQML meteorological data summary for the period 06/24/2009 – 07/31/2009.

University of Wyoming Mobile Air Quality Monitoring Laboratory Olson Ranch *Meteorological Data Summary* Final Validation 06/24/2009 – 07/31/2009				
Parameter	**Value**	**Units**	**Number**	**Standard Deviation**
WIND SPEED				
Average	2.8	m/s	51222	2.1
Maximum	15.3			
TEMPERATURE				
Average	16.7	°C	51222	6.6
Maximum	30.6			
Minimum	2.4			
RELATIVE HUMIDITY				
Average	47	%	51222	22
Maximum	96			
Minimum	10			
PRESSURE				
Average	795	mmHg	51222	3
Maximum	801			
Minimum	528			

5.3 Gaseous Pollutant Measurement Summaries

Continuous CH_4 and NMHC values were measured using Thermo-Fisher 55c and 55i Direct Methane, Non-Methane Hydrocarbon Analyzer. Summaries of CH_4 and NMHC measurements are presented in sections 5.3.2 and 5.3.3.

Continuous NO_x, NO_2 and NO values are measured using a Thermo-Fisher 42i Chemiluminescence NO_x-NO_2-NO Analyzer. Summaries of NO_x, NO_2 and NO measurements are presented in sections 5.3.4, 5.3.5 and 5.3.6, respectively. NO_2 is a regulated pollutant with an annual average standard value.

Continuous O_3 values are measured using a Thermo-Fisher 49i UV Photometric O_3 Analyzer. A summary of ozone measurements is presented in section 5.3.7. Ozone is a regulated air pollutant with a rolling 8-hour standard value.

Summaries of gaseous pollutant measurements for each monitoring site are presented. Section 5.3.1 explores pollutant roses by site to illustrate spatial differences related to location. Pollutant measurements are displayed on a temporal basis in sections 5.3.2 to 5.3.7 by pollutant rather than by site.

5.3.1 Spatial Gaseous Pollutant Roses

In light of the mobile monitoring approach of O3i, a brief overview of pollution roses at each site provides context for considering the temporal behavior shown by diurnal and longer-term temporal data plots in the sub-sections given below.

5.3.1.1 Spatial Gaseous Pollutant Roses – Big Piney

Figure 5-6 illustrates the pollution rose for CH_4 at Big Piney. Wind directions of WSW and SW were associated with the greatest proportion of CH_4 levels equal to or greater than 2.6 ppm. Ranges from SSW to SE show elevated CH_4 levels, for the mid concentration range. By contrast, wind directions from the NW and NNW showed the greatest proportion of CH_4 concentrations equal to or below 2 ppm. Figure 5-7 shows that the pollution rose for NMHC at Big Piney mirrors that of CH_4. As indicated by Figures 5-8, 5-9 and 5-10 oxides of nitrogen, nitric oxide and nitrogen dioxide pollution roses all exhibit similar behavior. Concentrations are relatively low with levels rarely exceeding 30 ppb. In relative terms the wind direction SSE and SE has the greatest proportion of higher concentrations. Figure 5-11, for ozone, contrasts with the other pollution roses, with the greatest proportion of ozone concentrations above 50 ppb, in the region NE clockwise to SSE. The highest values were associated with the wind direction NNE. The greatest proportion of lower ozone concentrations, below 25 ppb, is from wind directions of WSW and SW.

Figure 5-6. Big Piney CH_4 pollutant rose for the period 1/31/2009 – 2/27/2009.

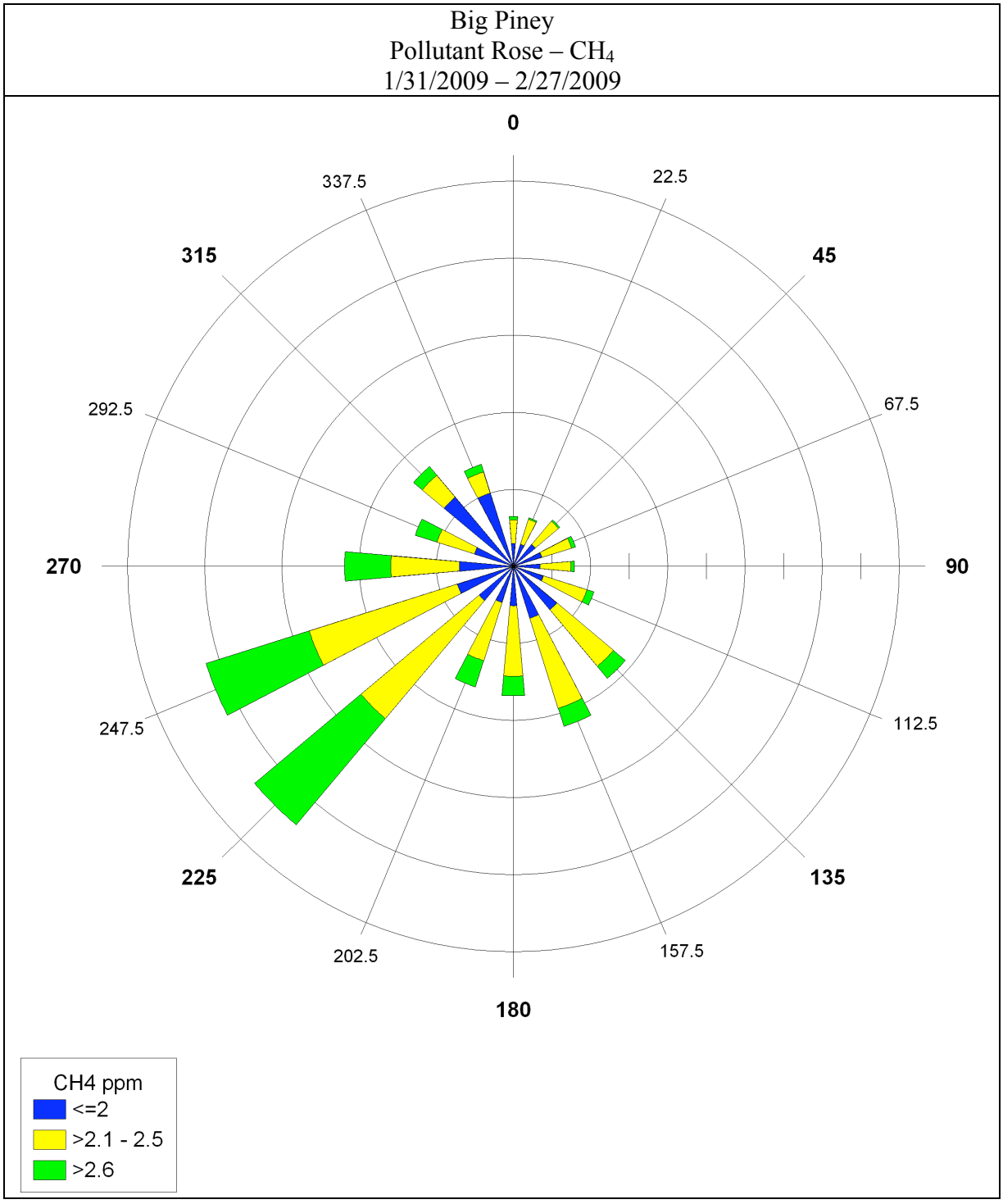


Figure 5-7. Big Piney NMHC pollutant rose for the period 1/31/2009 – 2/27/2009.

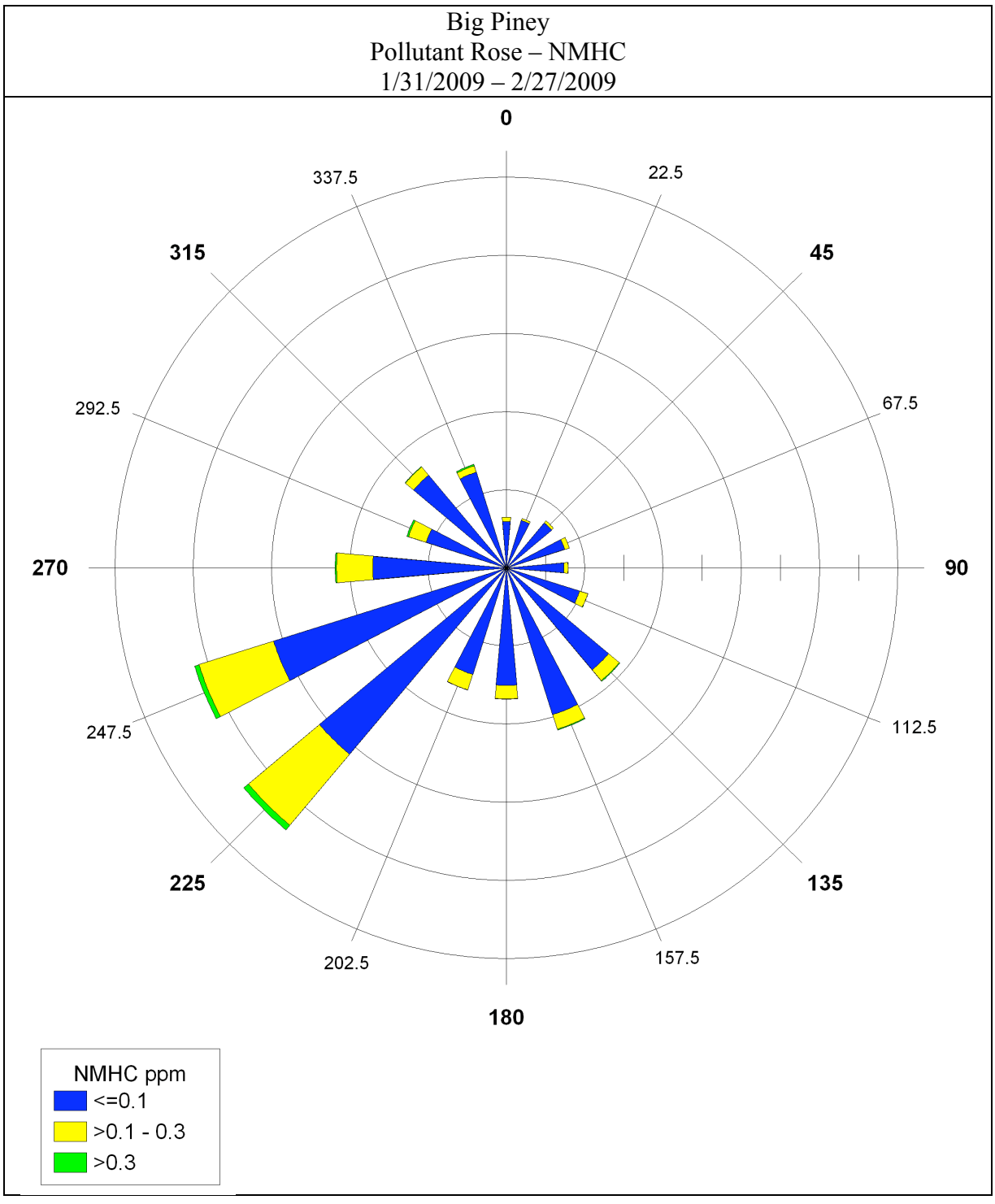


Figure 5-8. Big Piney NO_x pollutant rose for the period 1/31/2009 – 2/27/2009.

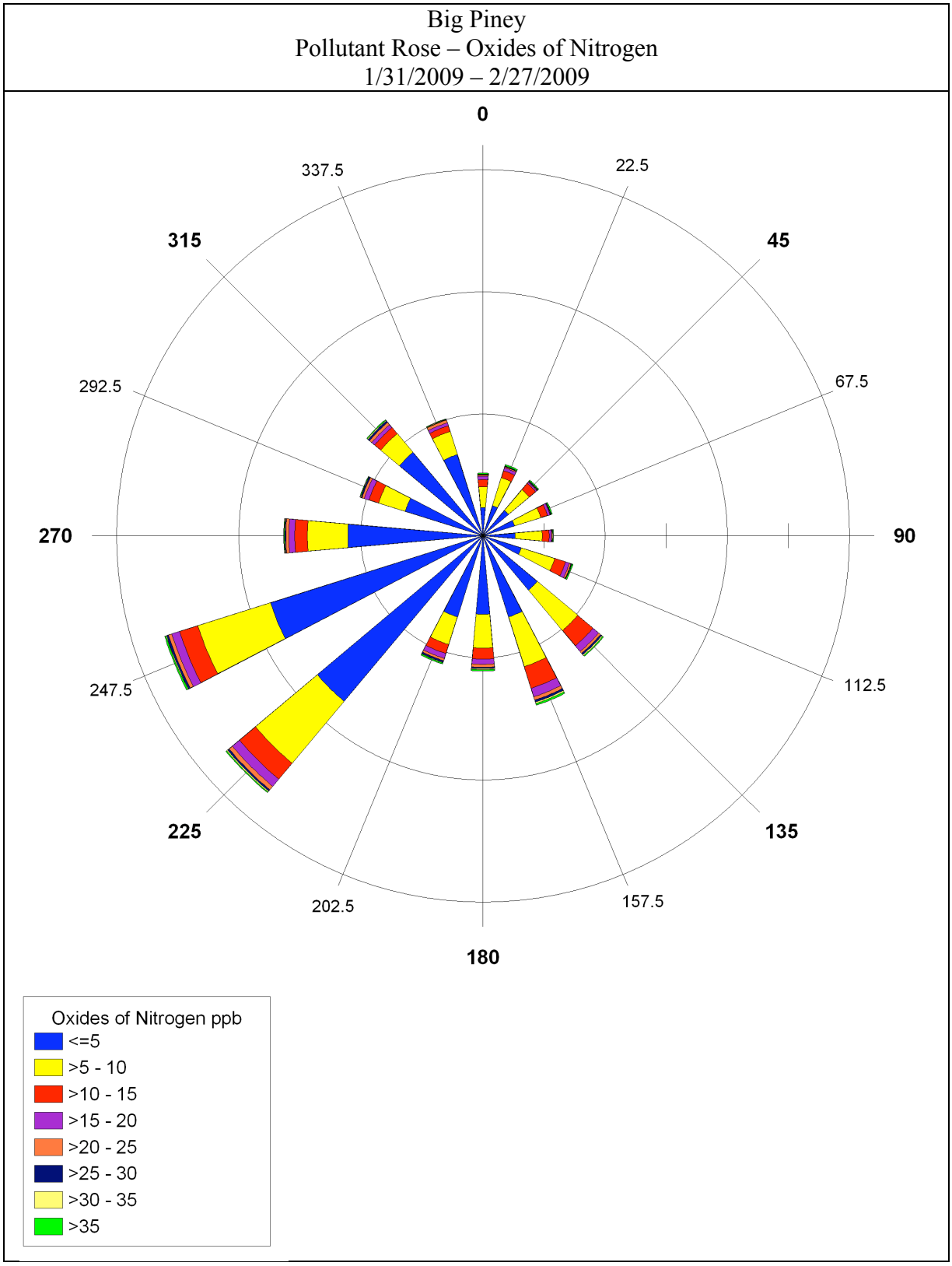


Figure 5-9. Big Piney NO pollutant rose for the period 1/31/2009 – 2/27/2009.

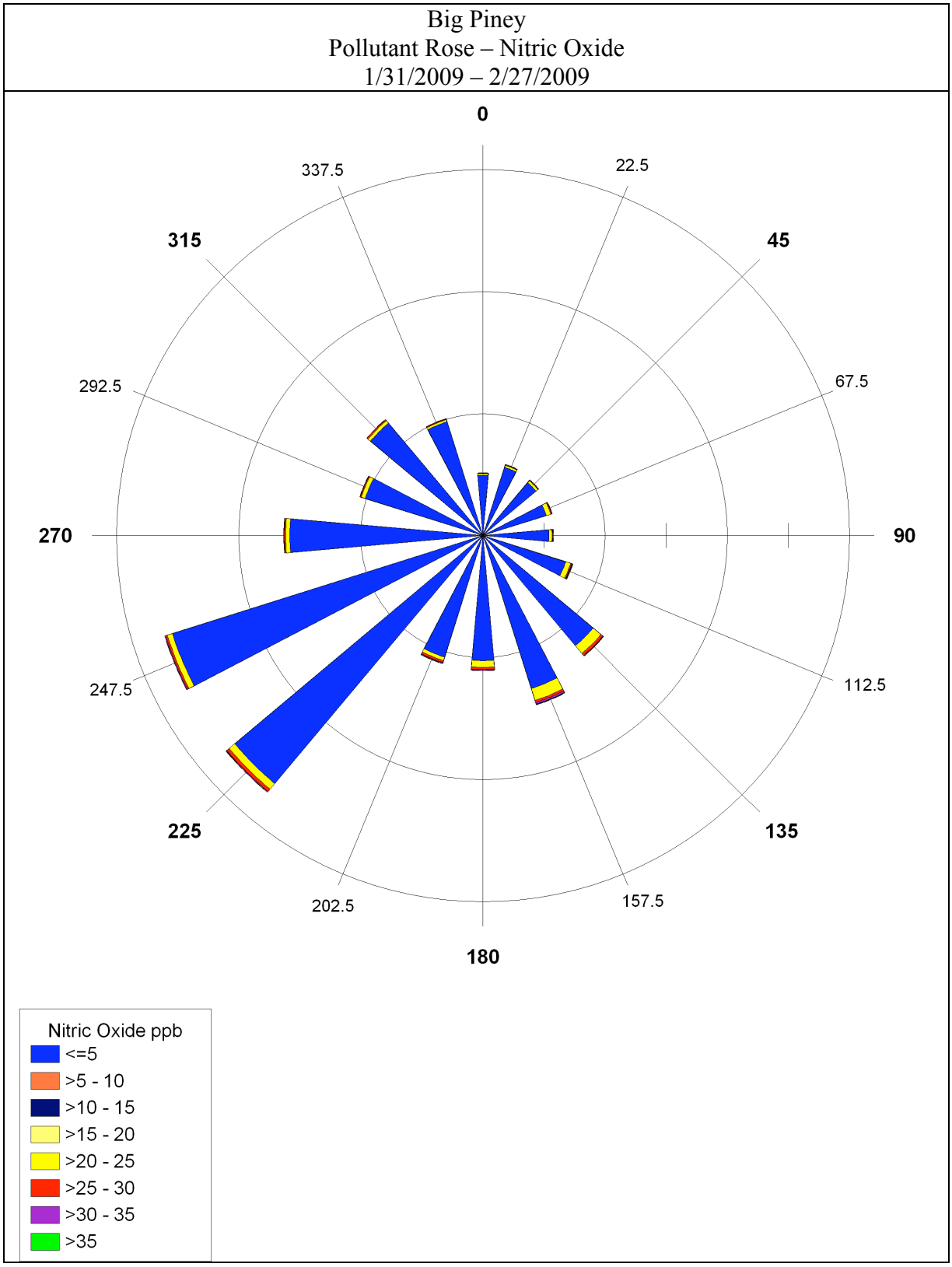


Figure 5-10. Big Piney NO_2 pollutant rose for the period 1/31/2009 – 2/27/2009.

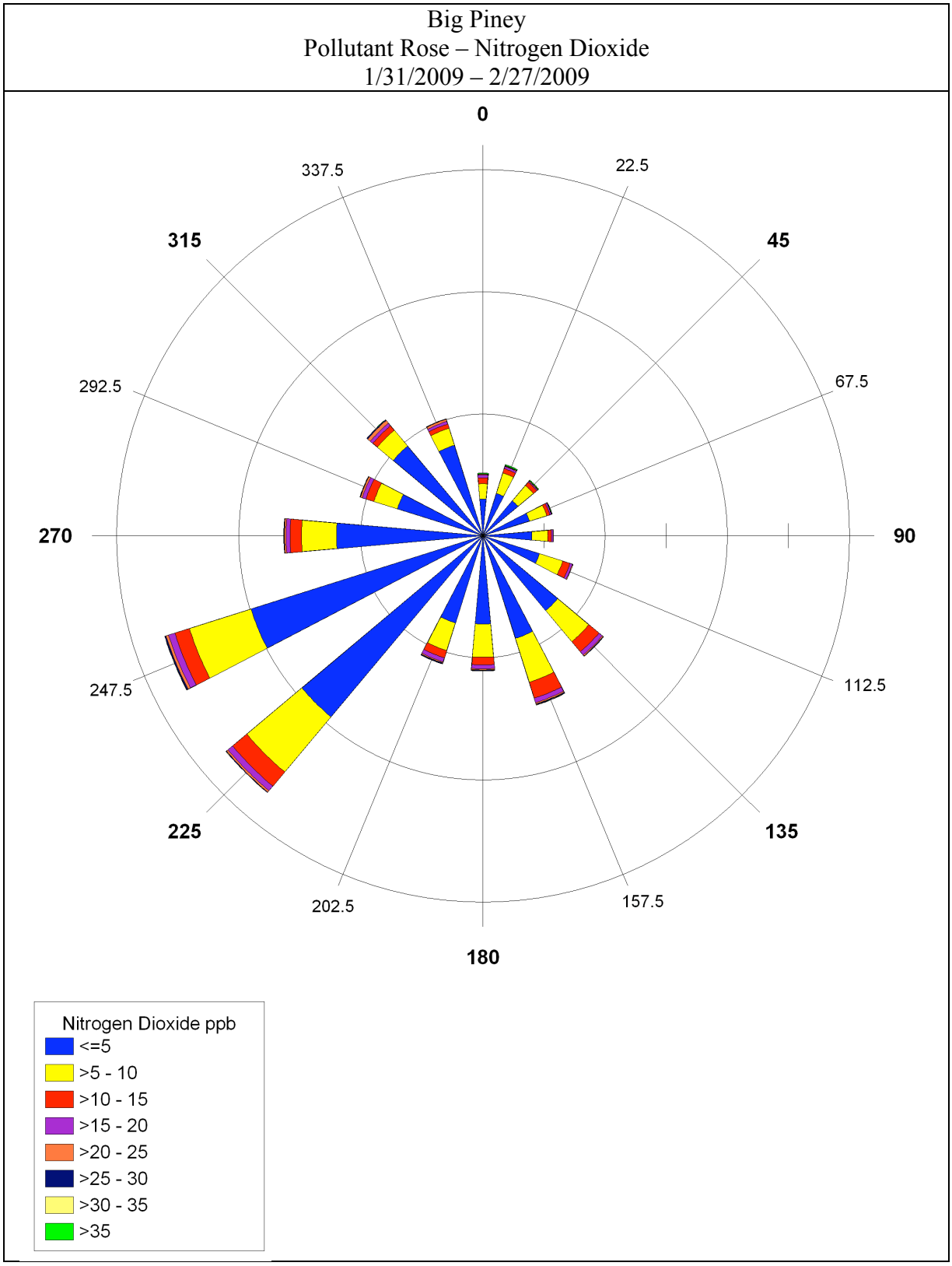
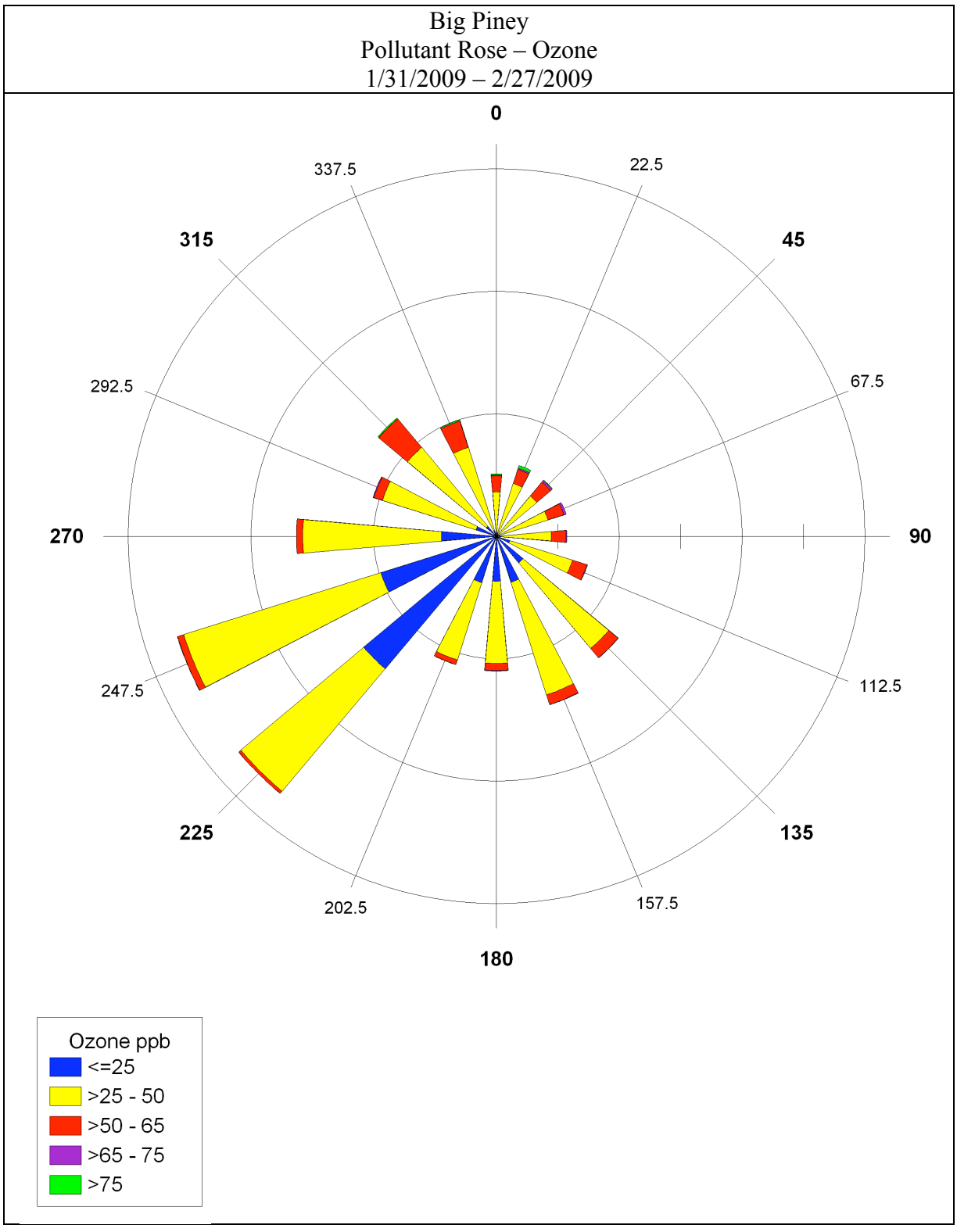


Figure 5-11. Big Piney O_3 pollutant Rose for the period 1/31/2009 – 2/27/2009.



5.3.1.2 Spatial Gaseous Pollutant Roses – Luman Road

Figure 5-12 illustrates the pollution rose for CH_4 at Luman Road. Wind directions from WSW clockwise to NNW were associated with the greatest proportion of CH_4 levels above 2.6 ppm. North-by-northwest wind directions provided a relatively low contribution of CH_4 concentrations below 2 ppm. Figure 5-13 shows that the pollution rose for NMHC at Luman Road mirrors that of CH_4. The wind direction WNW has the greatest proportion of NMHC concentrations above 0.3 ppm. As indicated by Figures 5-14, 5-15 and 5-16 oxides of nitrogen, nitric oxide and nitrogen dioxide pollution roses all exhibit similar behavior. Concentrations are relatively low with levels rarely exceeding 30 ppb. In relative terms the wind direction range WSW clockwise to NNW was associated with the greatest proportion of higher concentration levels. The ozone pollution rose given by Figure 5-17 is similar to the other pollution roses, with the greatest proportion of ozone concentrations above 50 ppb, in the region WSW clockwise to NNW. The greatest contribution of concentrations greater than 50 ppb was from the NW wind direction.

Figure 5-12. Luman Road CH_4 pollutant rose for the period 2/27/2009 – 4/1/2009.

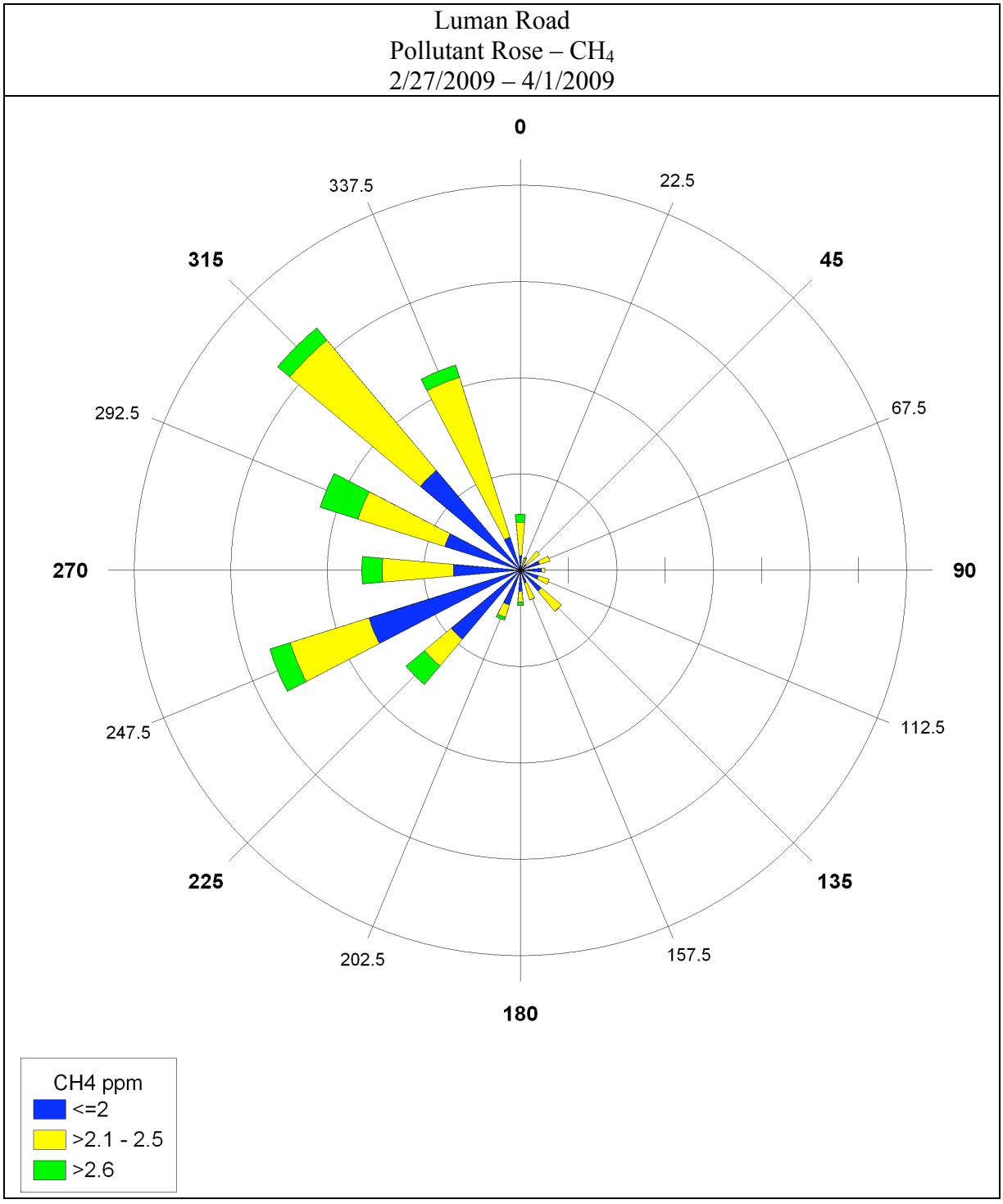


Figure 5-13. Luman Road NMHC pollutant rose for the period 2/27/2009 – 4/1/2009.

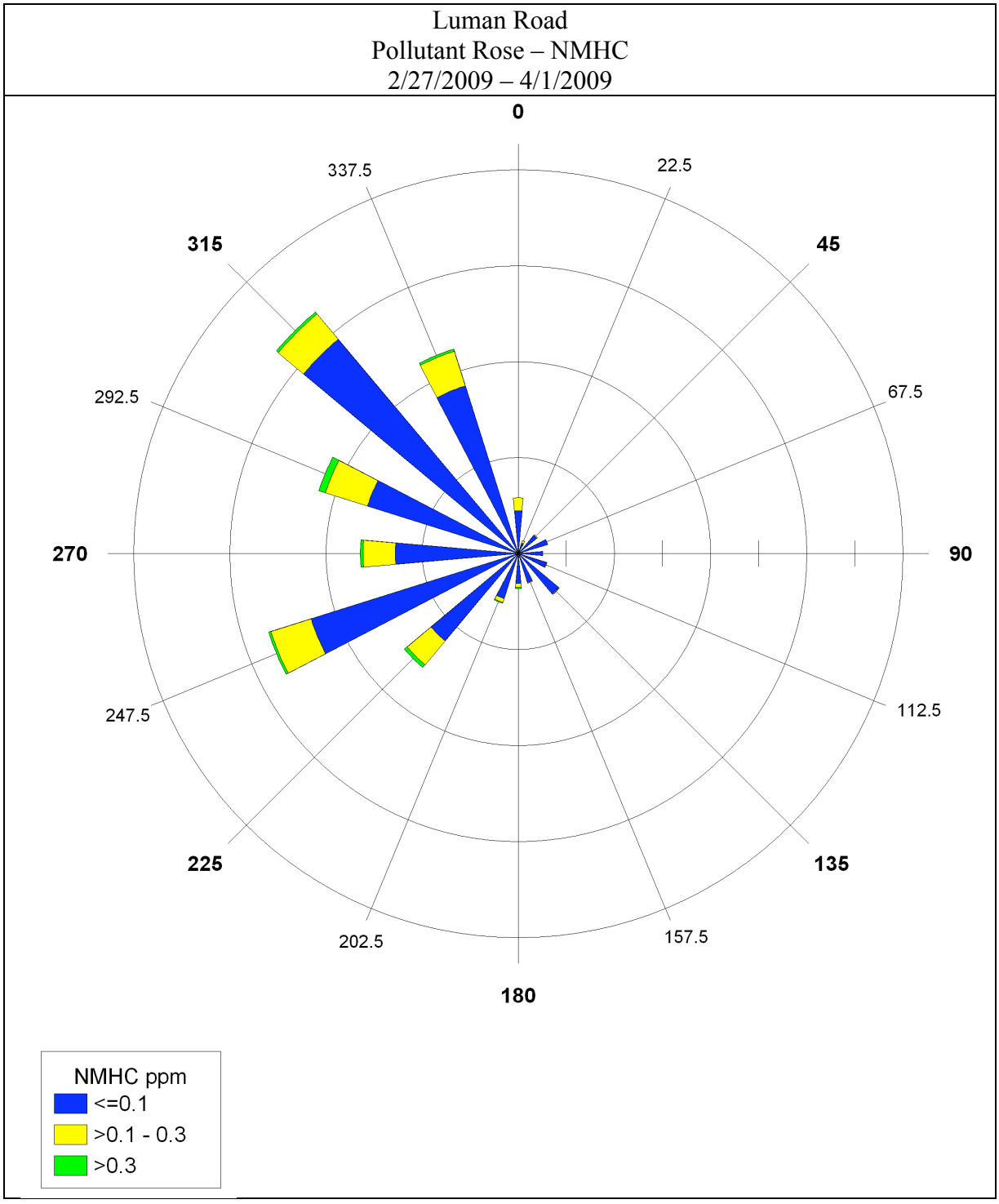


Figure 5-14. Luman Road NO_x pollutant rose for the period 2/27/2009 – 4/1/2009.

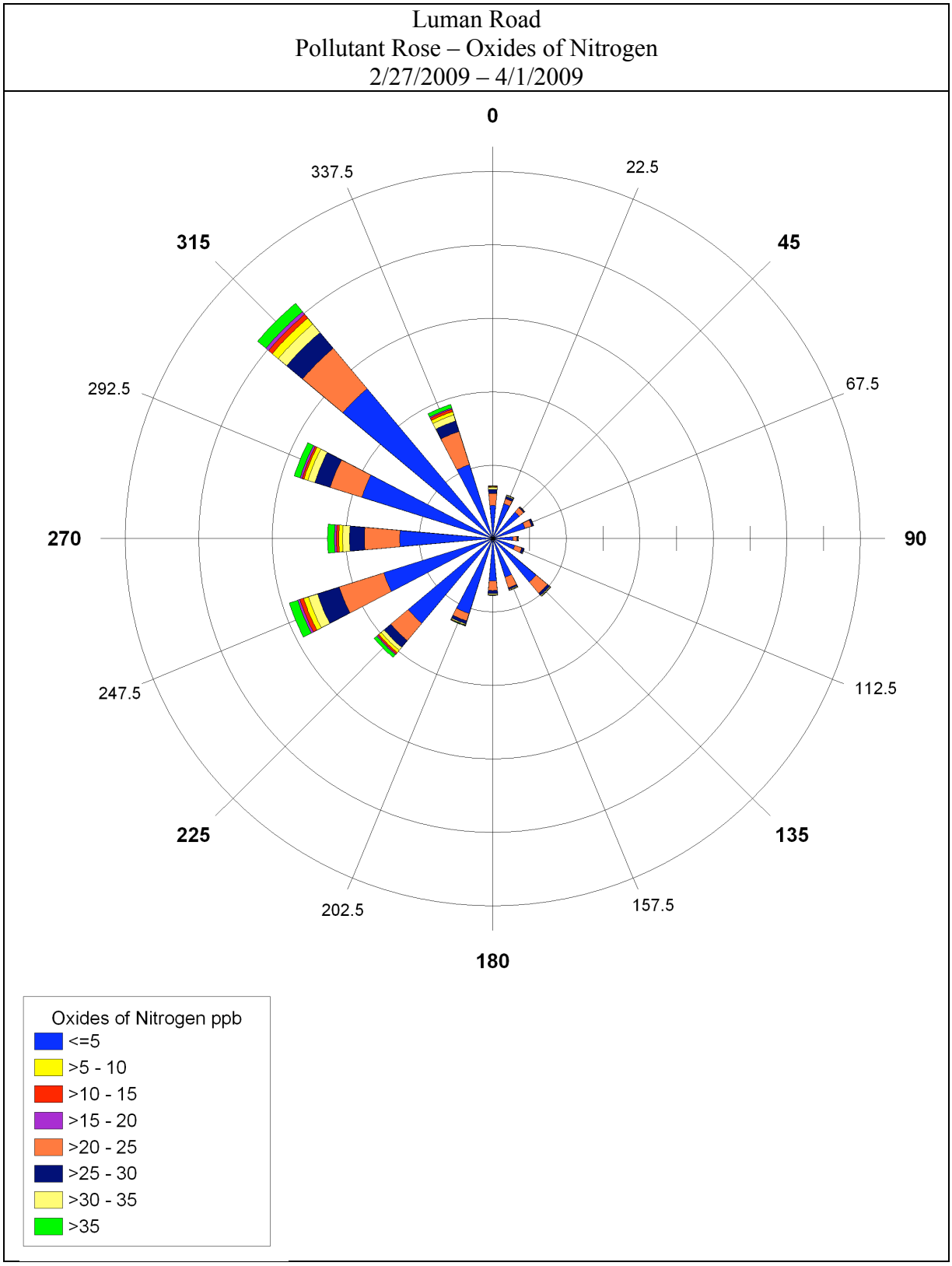


Figure 5-15. Luman Road NO time series for the period 2/27/2009 – 4/1/2009.

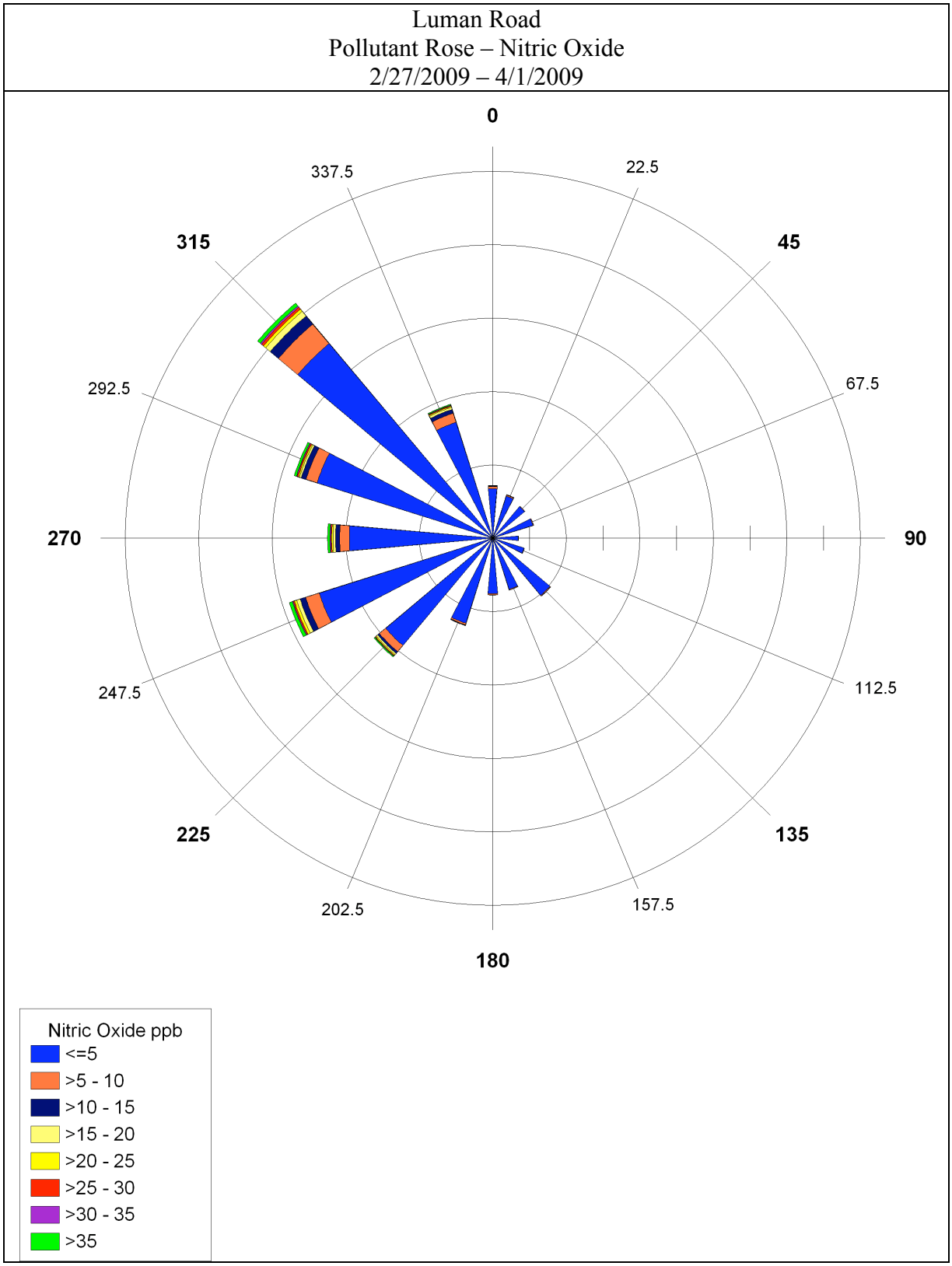


Figure 5-16. Luman Road NO_2 pollutant rose for the period 2/27/2009 – 4/1/2009.

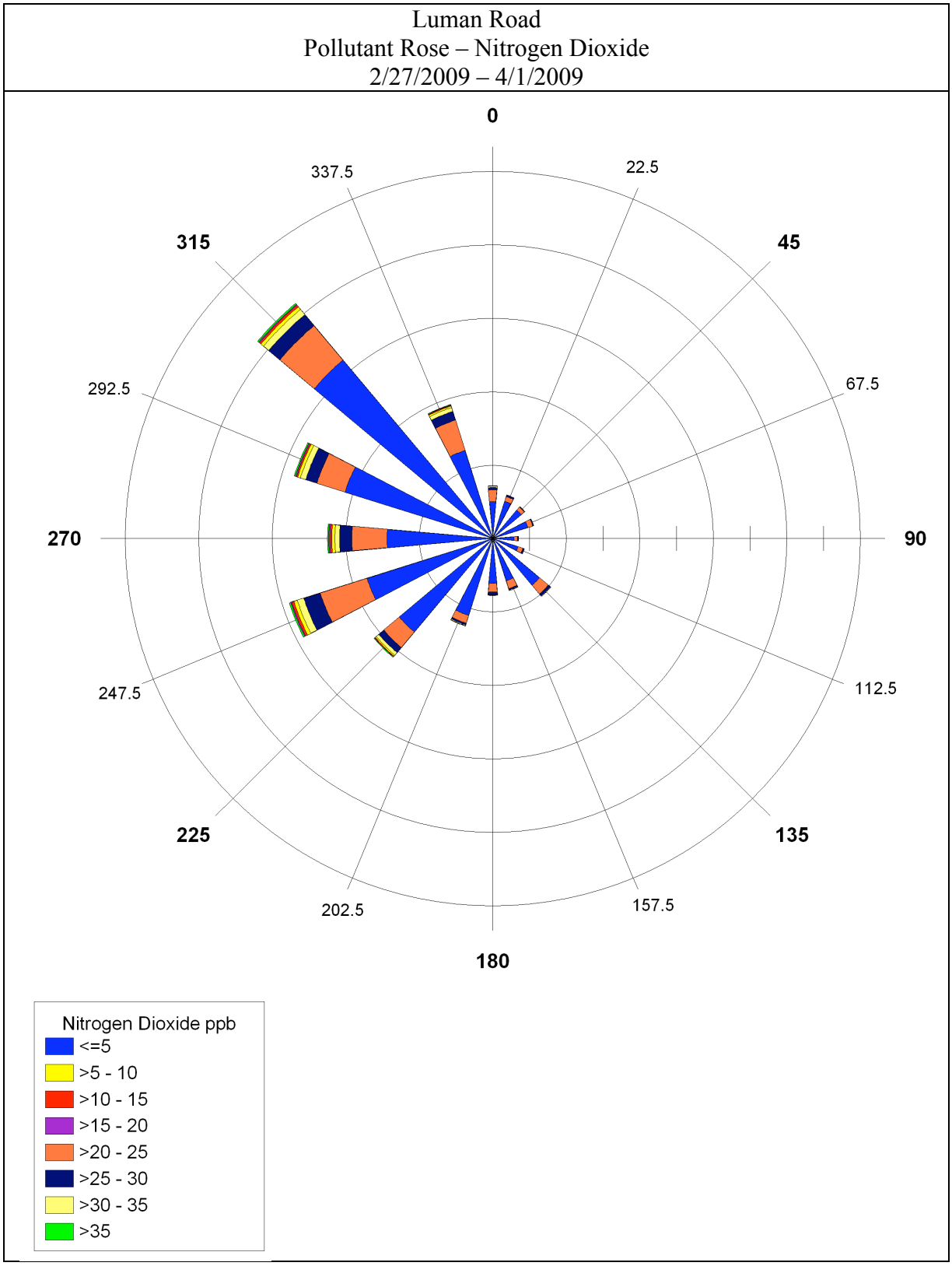
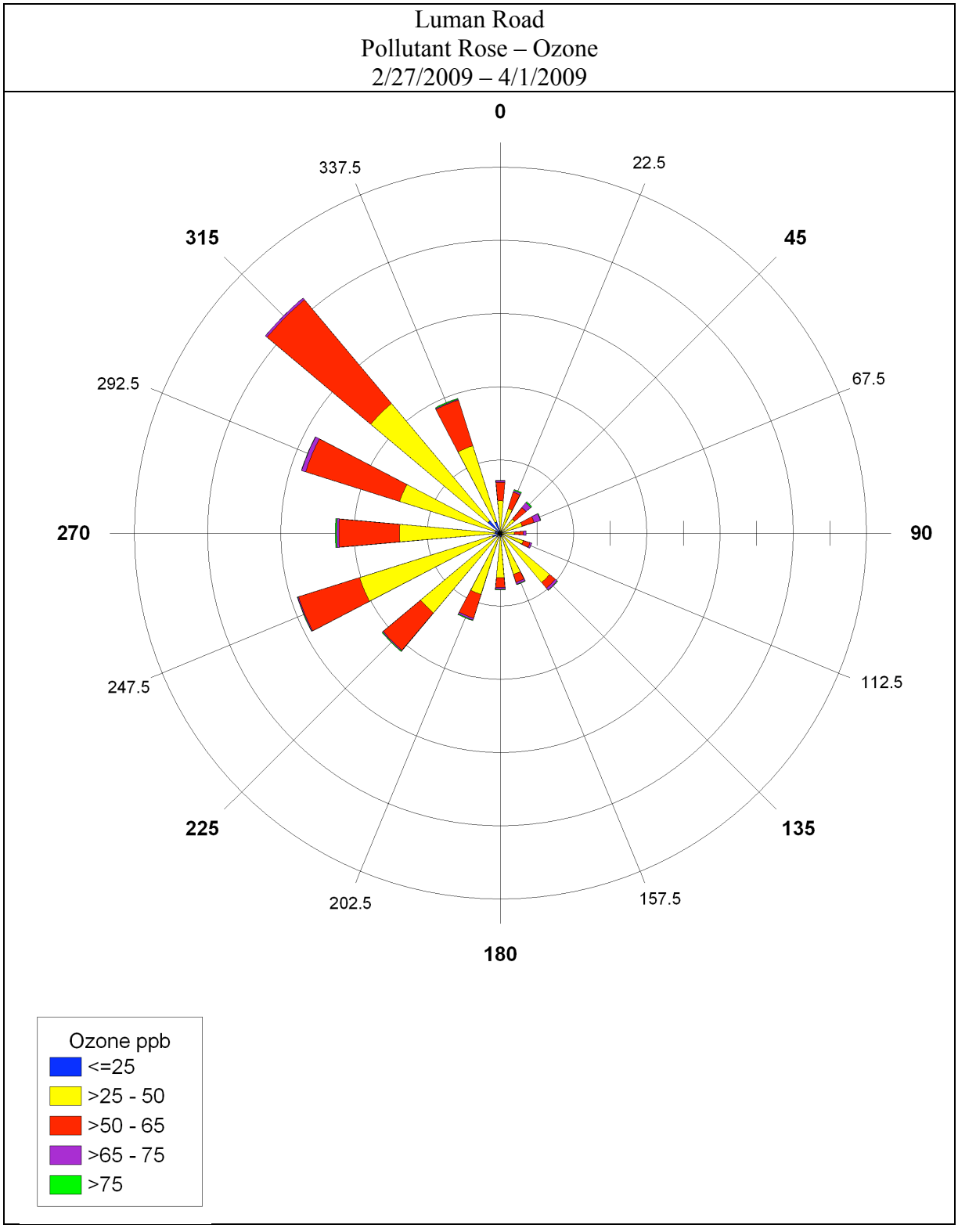


Figure 5-17. Luman Road O_3 pollutant rose for the period 2/27/2009 – 4/1/2009.



5.3.1.3 Spatial Gaseous Pollutant Roses – Boulder South Road

Figure 5-18 illustrates the pollution rose for CH_4 at Boulder South Road. To a first approximation, there is no wind direction range for methane that is overwhelmingly predominant. This is somewhat unexpected, and reflects the unique geographic position of this site in an area associated with a dual wind flow regime. Figure 5-19 shows that the pollution rose for NMHC at Boulder South Road mirrors that of CH_4. As indicated by Figures 5-20, 5-21 and 5-22 oxides of nitrogen, nitric oxide and nitrogen dioxide pollution roses all exhibit similar behavior. Ambient concentrations are relatively low with levels rarely exceeding 30 ppb. There is no wind direction range that is clearly associated with elevated mixing ratios for these species. While Figure 5-23 shows this behavioral pattern also applies to ozone, another behavior appears to be superimposed. Ozone concentrations show the greatest number of highest concentrations between 65 and 75 ppb in the region SW clockwise to NW. In relative terms the highest values were associated with the wind direction NNE.

Figure 5-18. Boulder South Road CH_4 pollutant rose for the period 4/1/2009 – 5/19/2009.

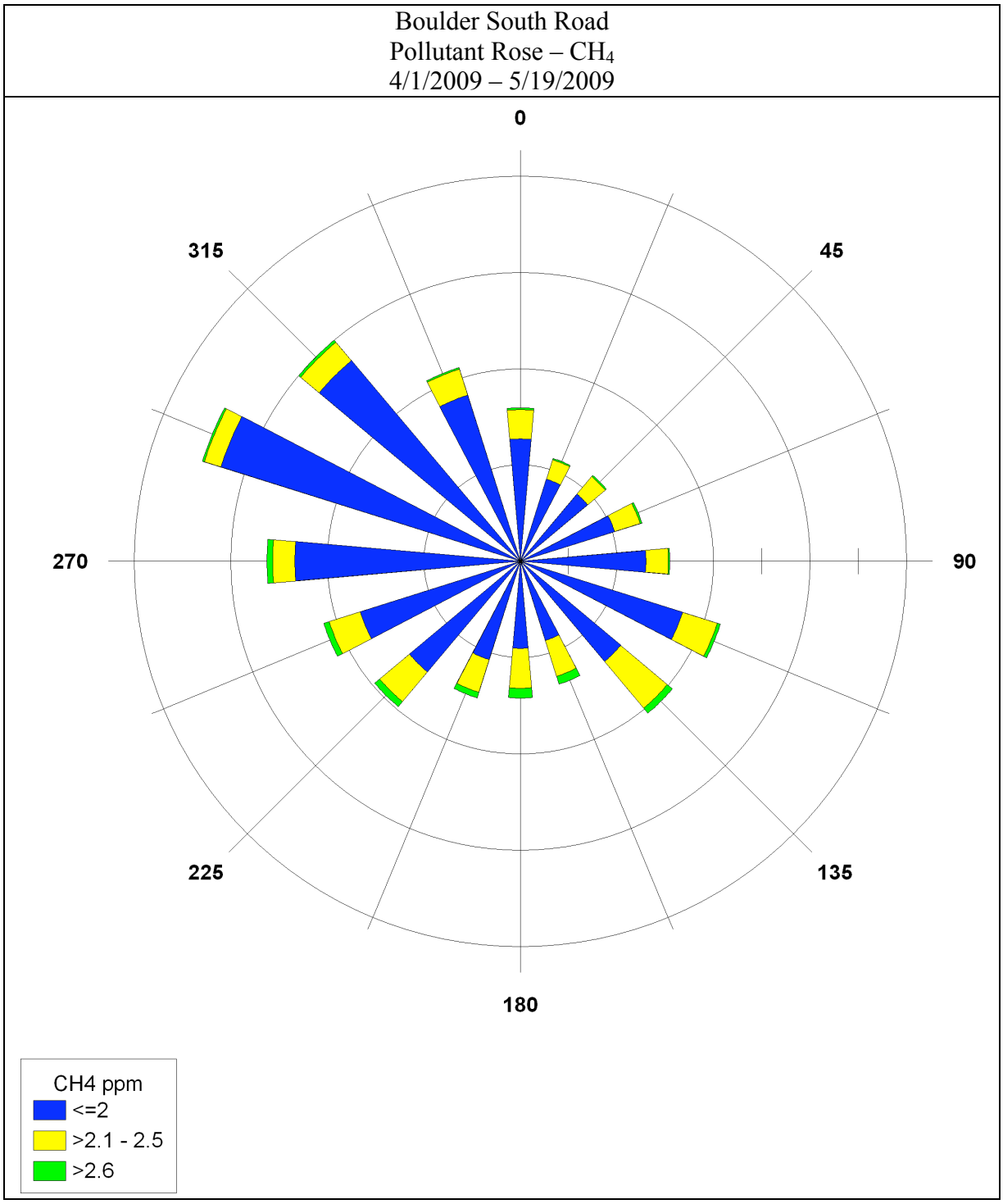


Figure 5-19. Boulder South Road NMHC pollutant rose for the period 4/1/2009 – 5/19/2009.

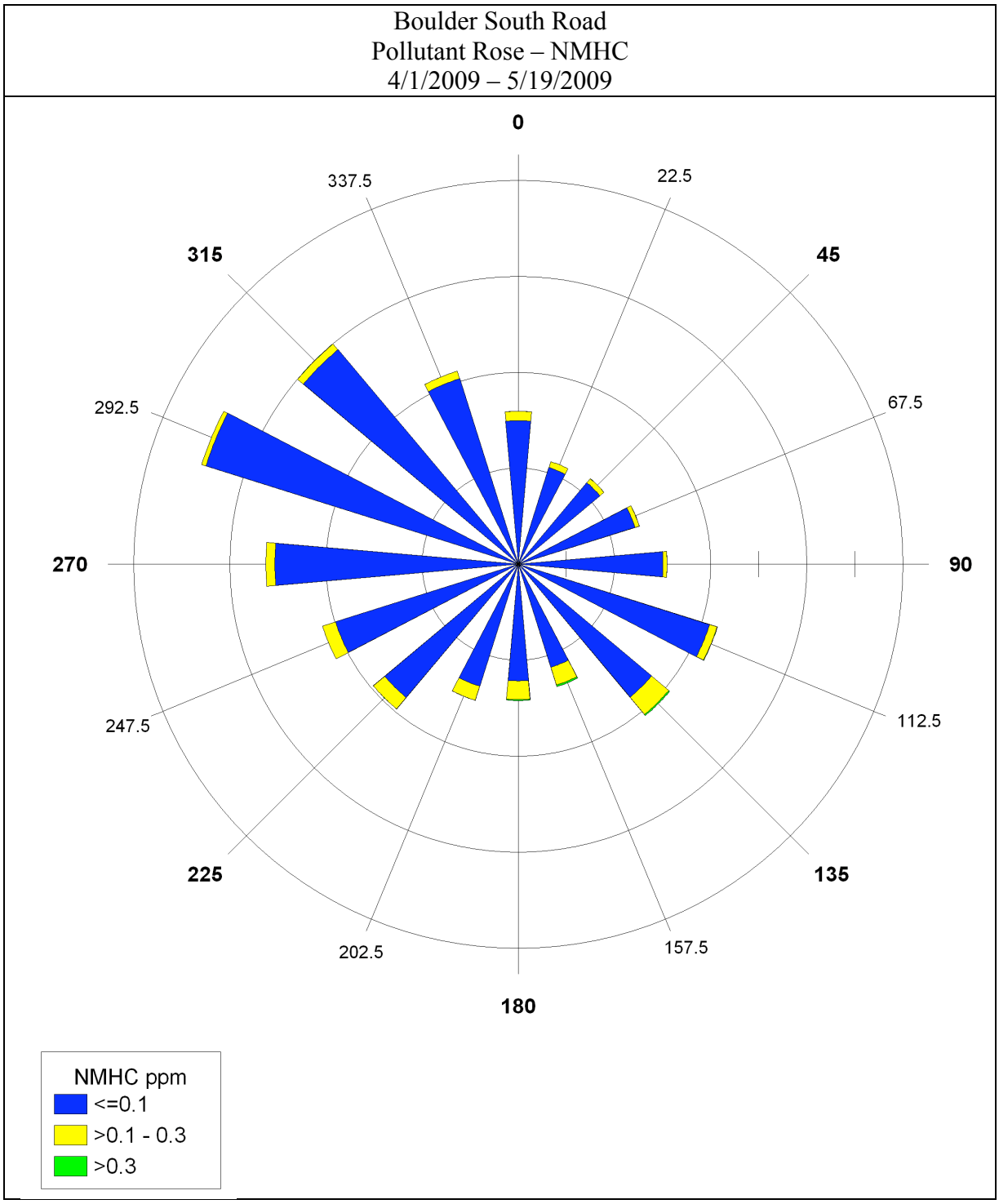


Figure 5-20. Boulder South Road NO_x pollutant rose for the period 4/1/2009 – 5/19/2009.

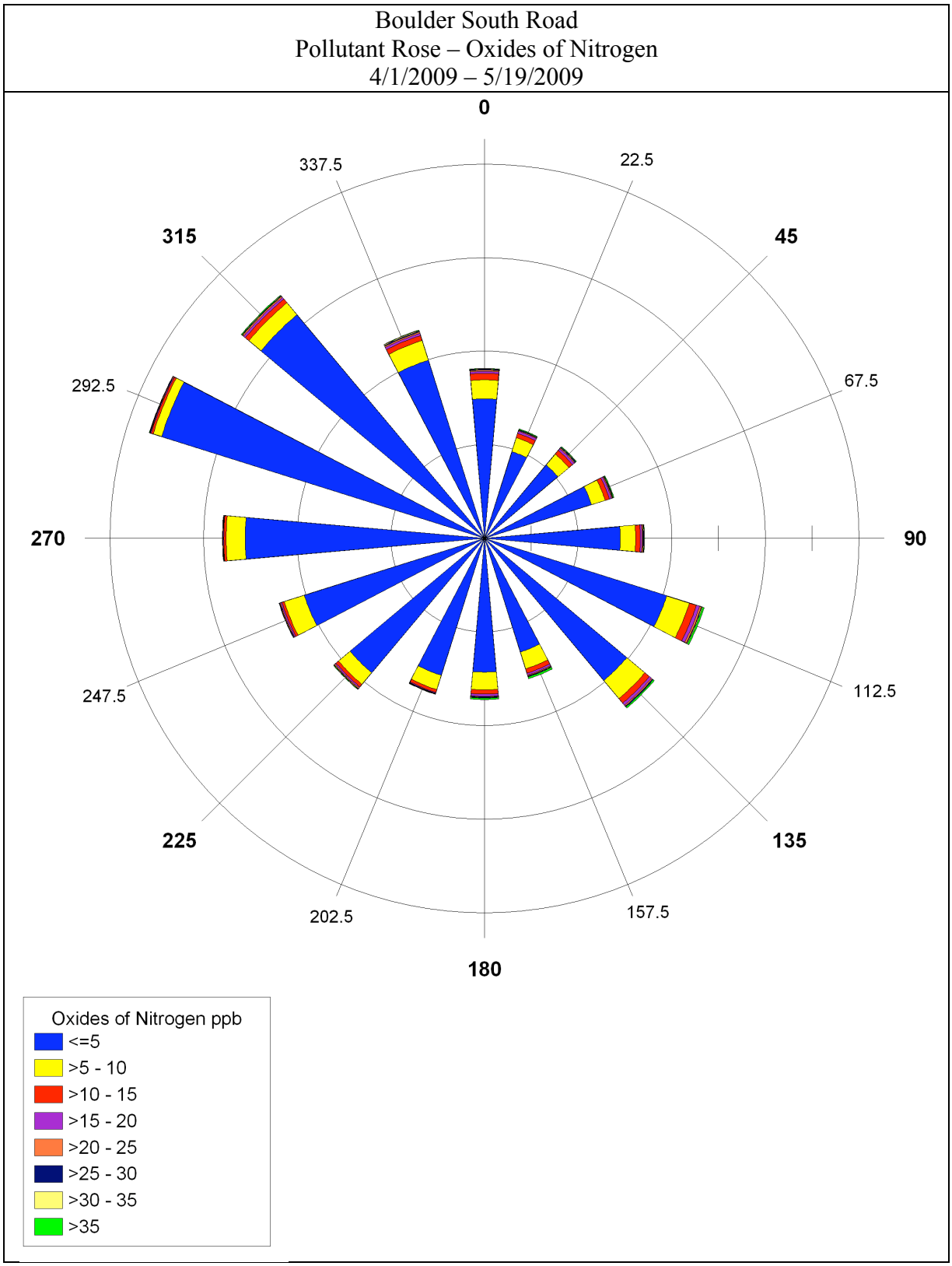


Figure 5-21. Boulder South Road NO time series for the period 4/1/2009 – 5/19/2009.

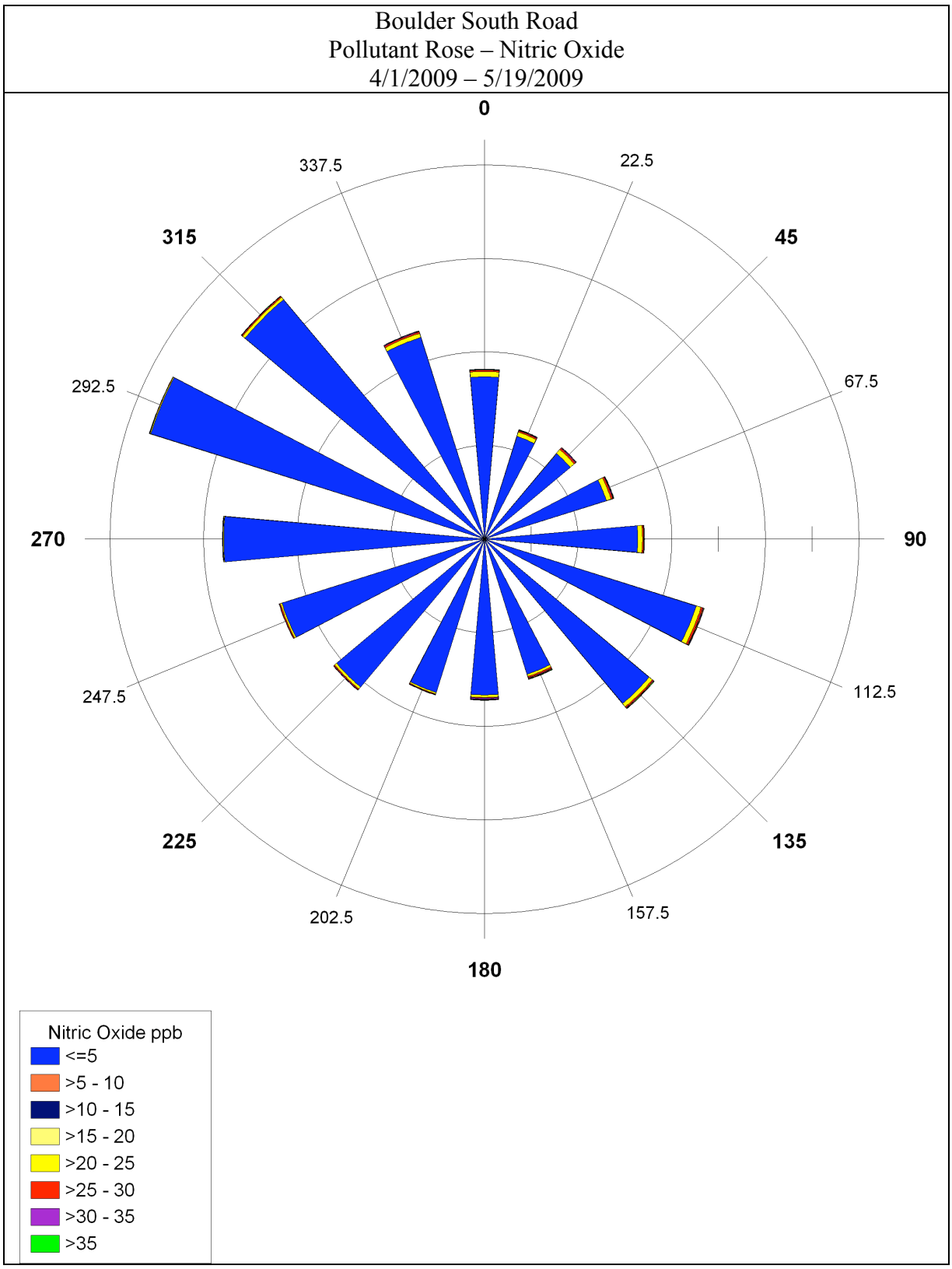


Figure 5-22. Boulder South Road NO_2 pollutant rose for the period 4/1/2009 – 5/19/2009.

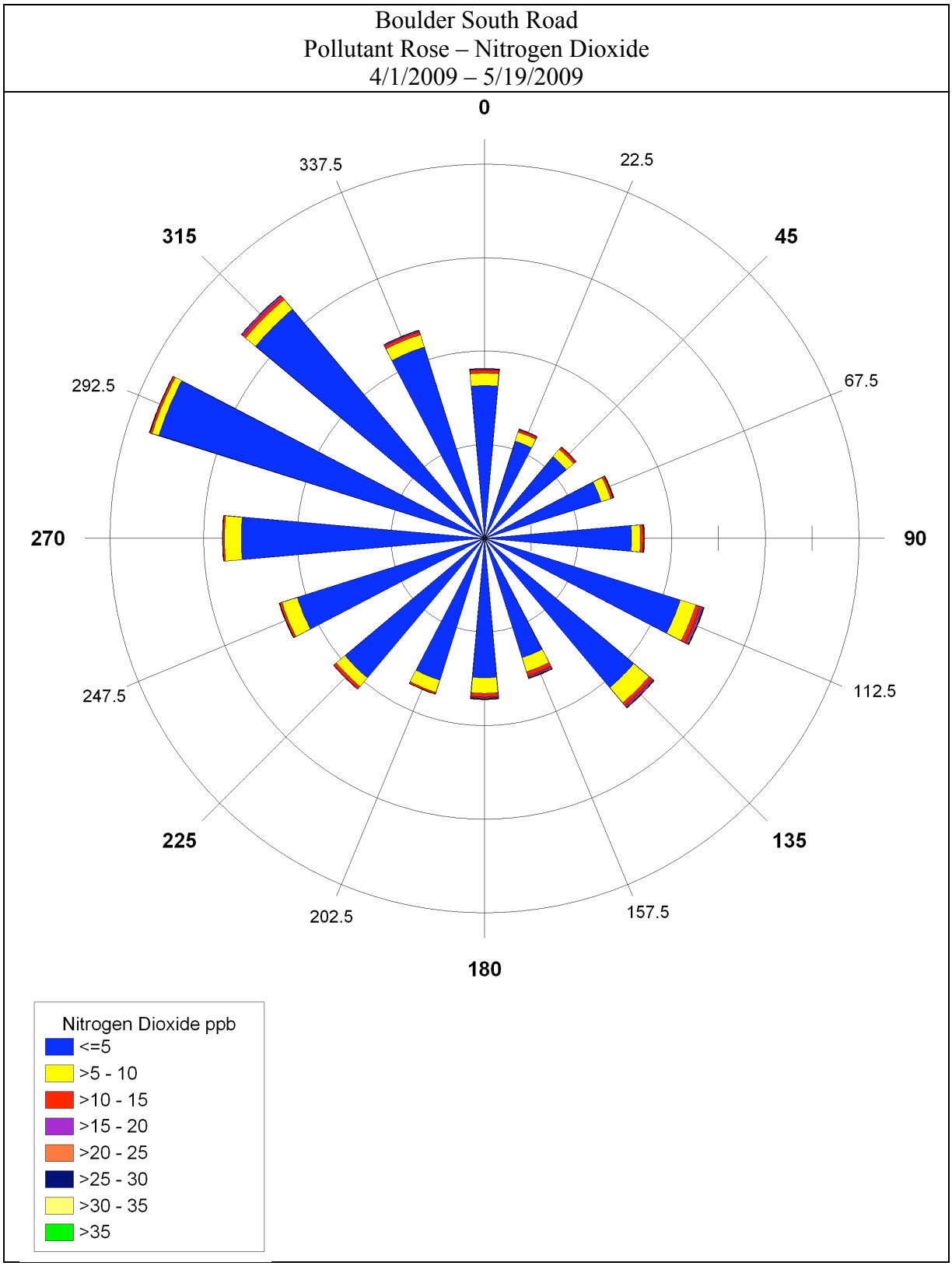
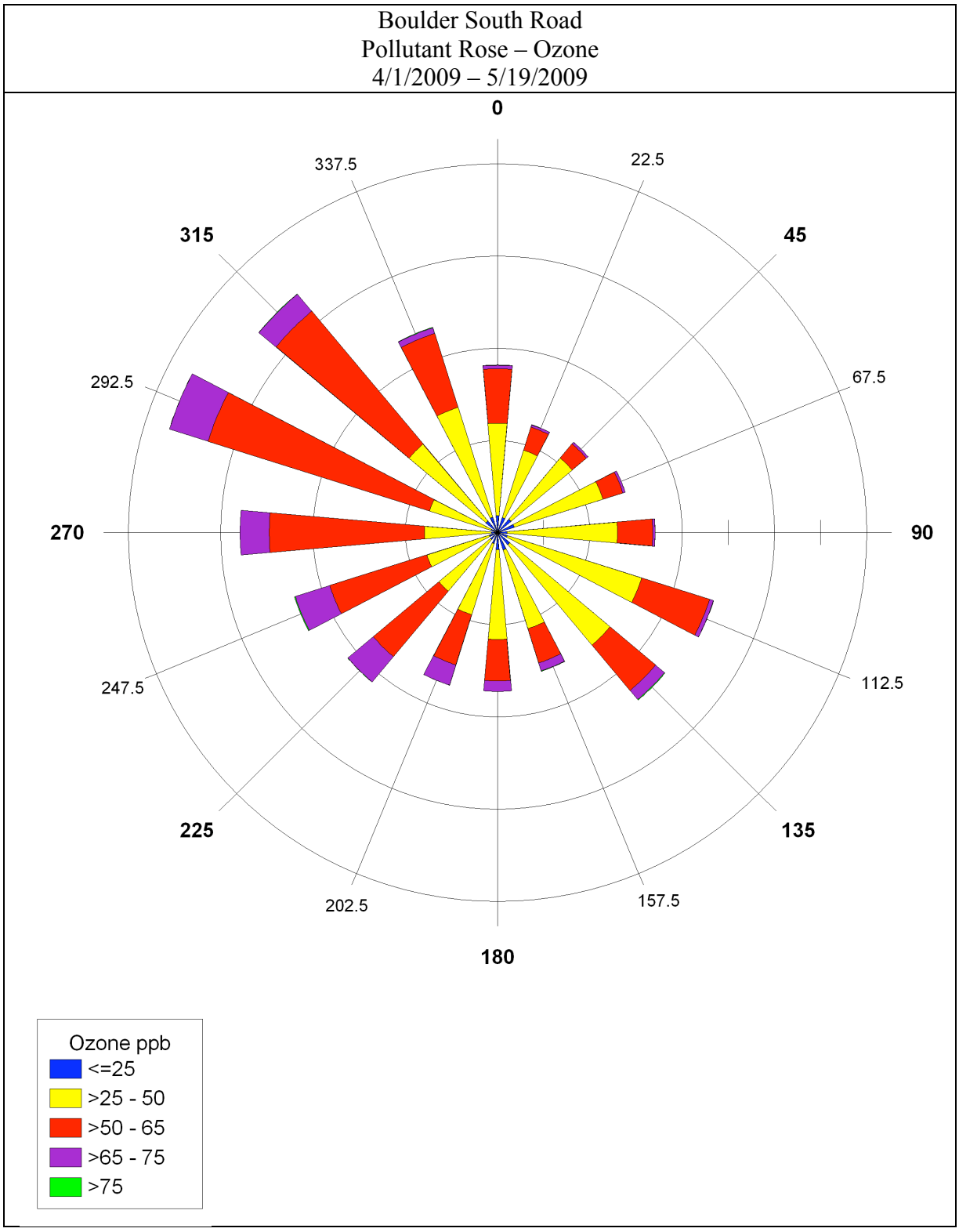


Figure 5-23. Boulder South Road O_3 pollutant rose for the period 4/1/2009 – 5/19/2009.



5.3.1.4 Spatial Gaseous Pollutant Roses – Pinedale

Figure 5-24 illustrates the pollution rose for CH_4 at Pinedale. There is no wind direction range that is preferentially associated with high methane mixing ratios, as for most of the time, CH_4 levels are at or below 2 ppm. Figure 5-25 shows the pollution rose for NMHC at Pinedale mirrors CH_4 with levels usually less than 0.1 ppm. As indicated by Figures 5-26, 5-27 and 5-28 oxides of nitrogen, nitric oxide and nitrogen dioxide pollution roses all exhibit similar behavior. Mixing ratios are relatively low with levels rarely exceeding 20 ppb. Again there is no wind direction range that is associated with elevated levels of these species. Similar behavior is also observed for ozone, as shown in Figure 5-29. Given the predominance of NW winds, it is interesting to note that this direction is associated with the greatest number of both higher and lower ozone concentrations.

Figure 5-24. Pinedale CH_4 pollutant rose for the period 5/19/2009 – 6/24/2009.

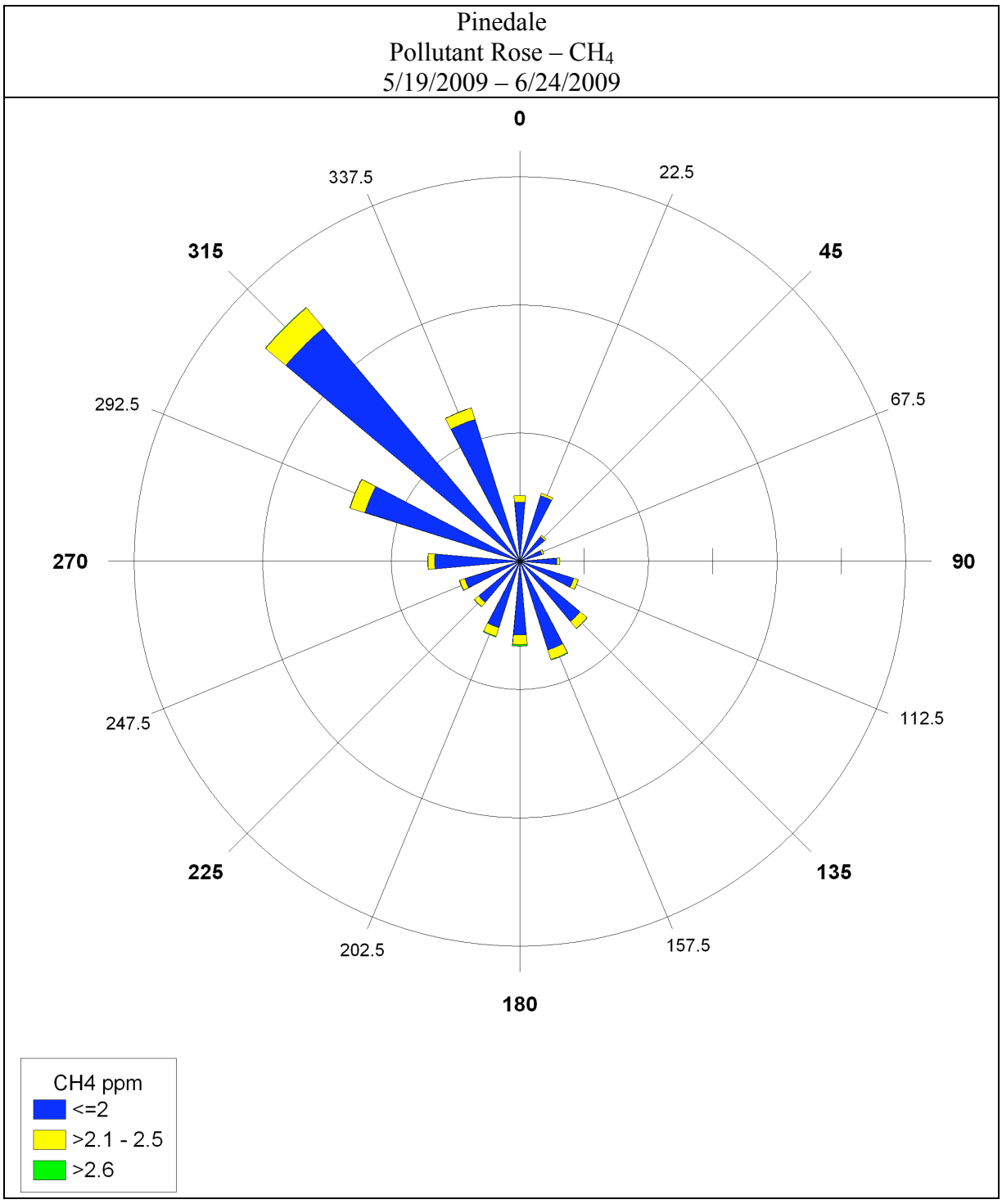


Figure 5-25. Pinedale NMHC pollutant rose for the period 5/19/2009 – 6/24/2009.

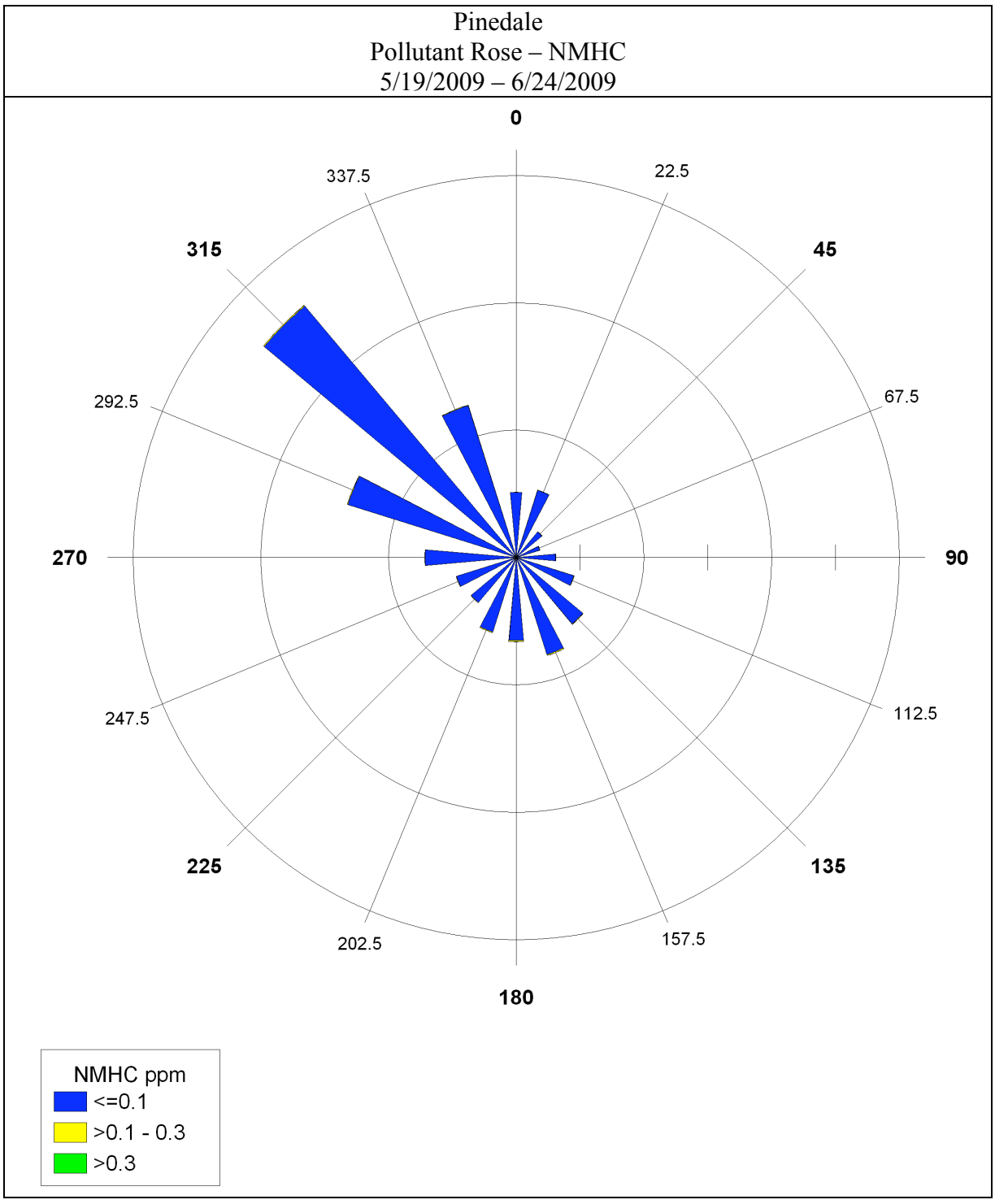


Figure 5-26. Pinedale NO_x pollutant rose for the period 5/19/2009 – 6/24/2009.

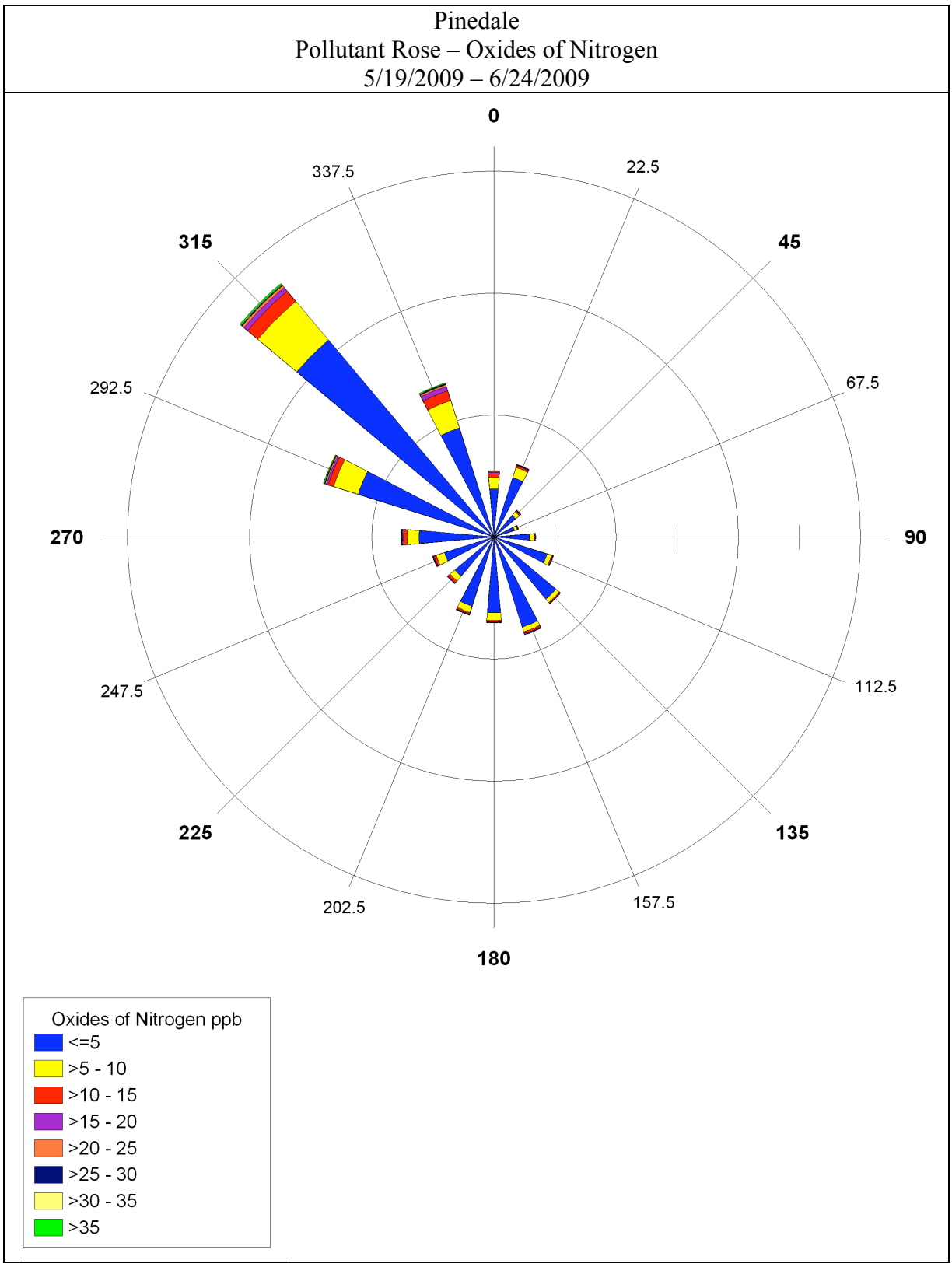


Figure 5-27. Pinedale NO time series for the period 5/19/2009 – 6/24/2009.

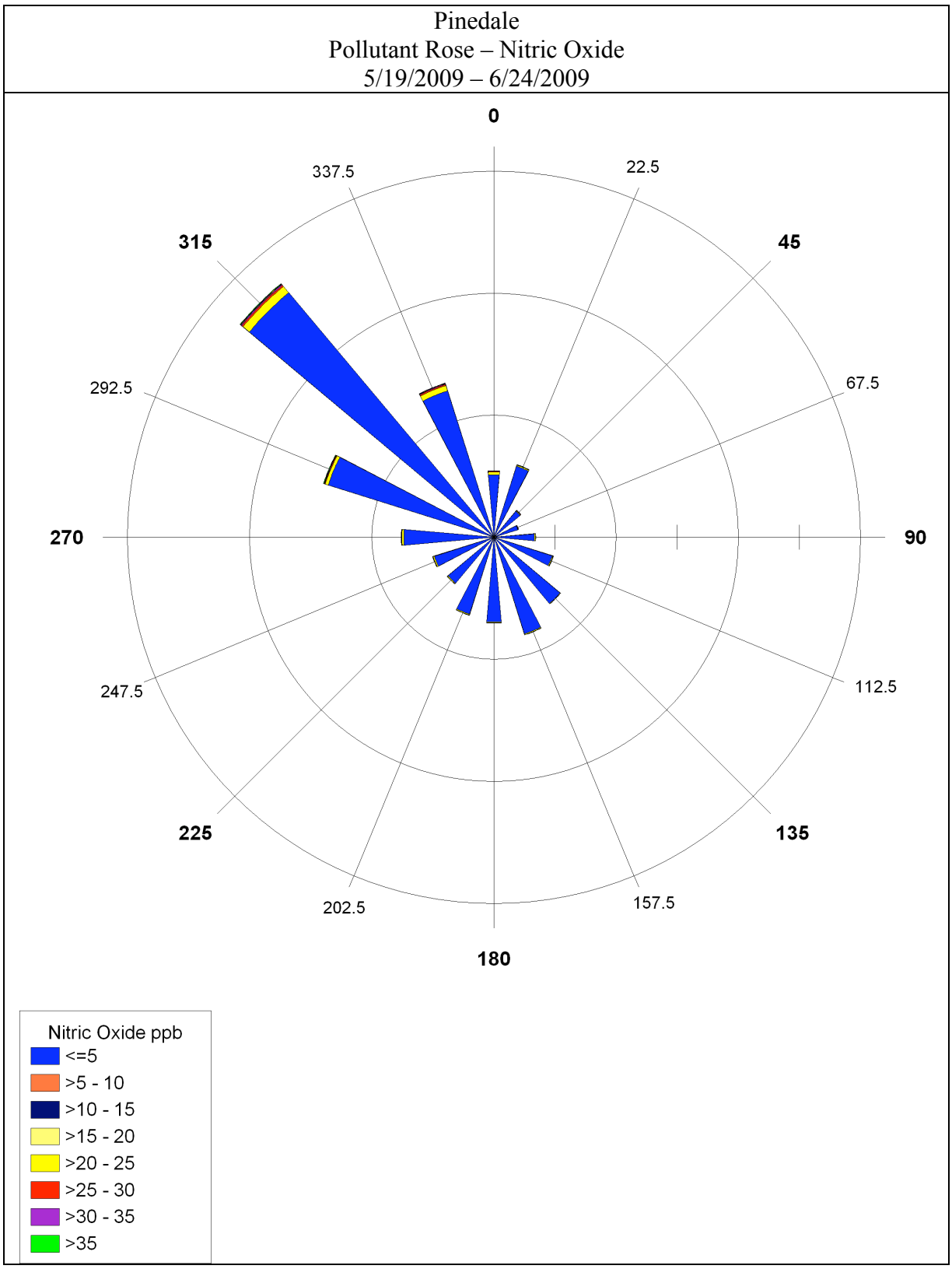


Figure 5-28. Pinedale NO_2 pollutant rose for the period 5/19/2009 – 6/24/2009.

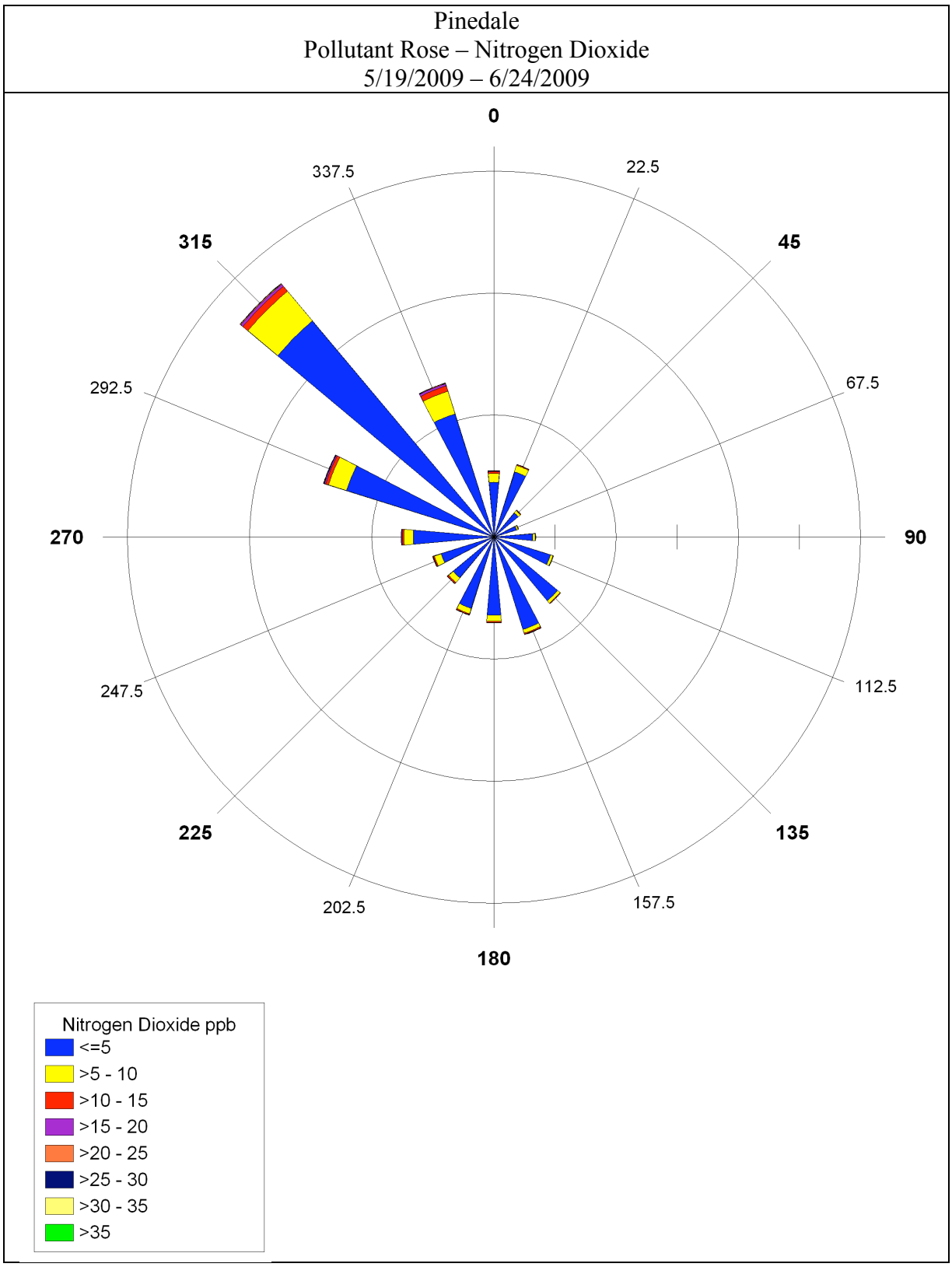
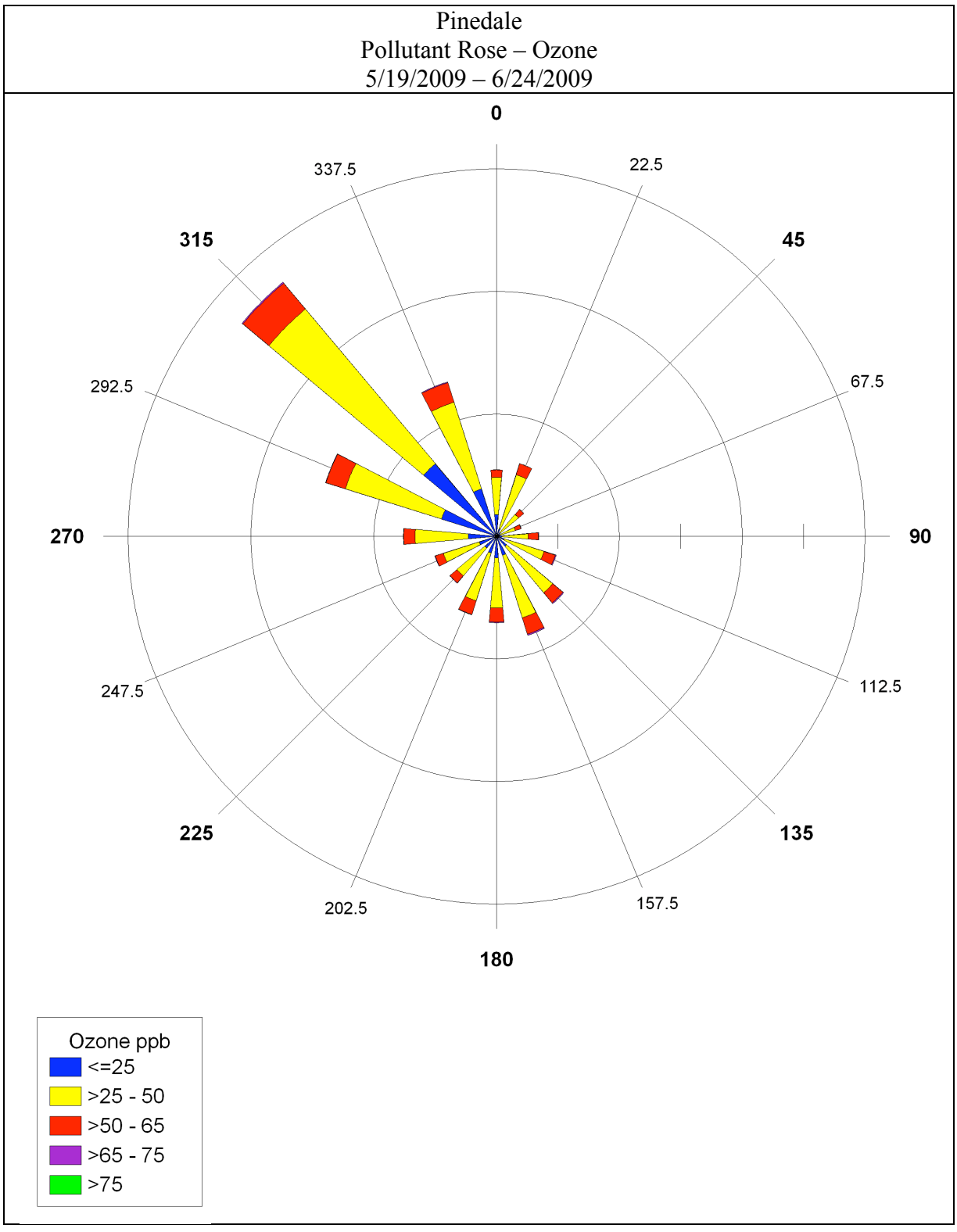


Figure 5-29. Pinedale O_3 pollutant rose for the period 5/19/2009 – 6/24/2009.



5.3.1.5 Spatial Gaseous Pollutant Roses – Olson Ranch

Figure 5-30 illustrates the pollution rose for CH_4 at Olson Ranch. While all wind directions report contributions from all concentration ranges, the wind direction range from N clockwise to E and perhaps to S appears to be associated with a disproportionately large number of episodes of highest CH_4 mixing ratio. However, these wind directions were observed infrequently during this monitoring period. Figure 5-31 shows the pollution rose for NMHC at Olson Ranch mirrors that of CH_4. As indicated by Figures 5-32, 5-33 and 5-34 the oxides of nitrogen, nitric oxide and nitrogen dioxide pollution roses all exhibit similar behavior. Concentrations are relatively low with levels rarely exceeding 20 ppb. Again there is no wind direction range that is clearly associated with the highest mixing ratios for these species. As shown in Figure 5-35 the highest ozone mixing ratios are associated with wind directions NW and NNW.

Figure 5-30. Olson Ranch CH_4 pollutant rose for the period 6/24/2009 – 7/31/2009.

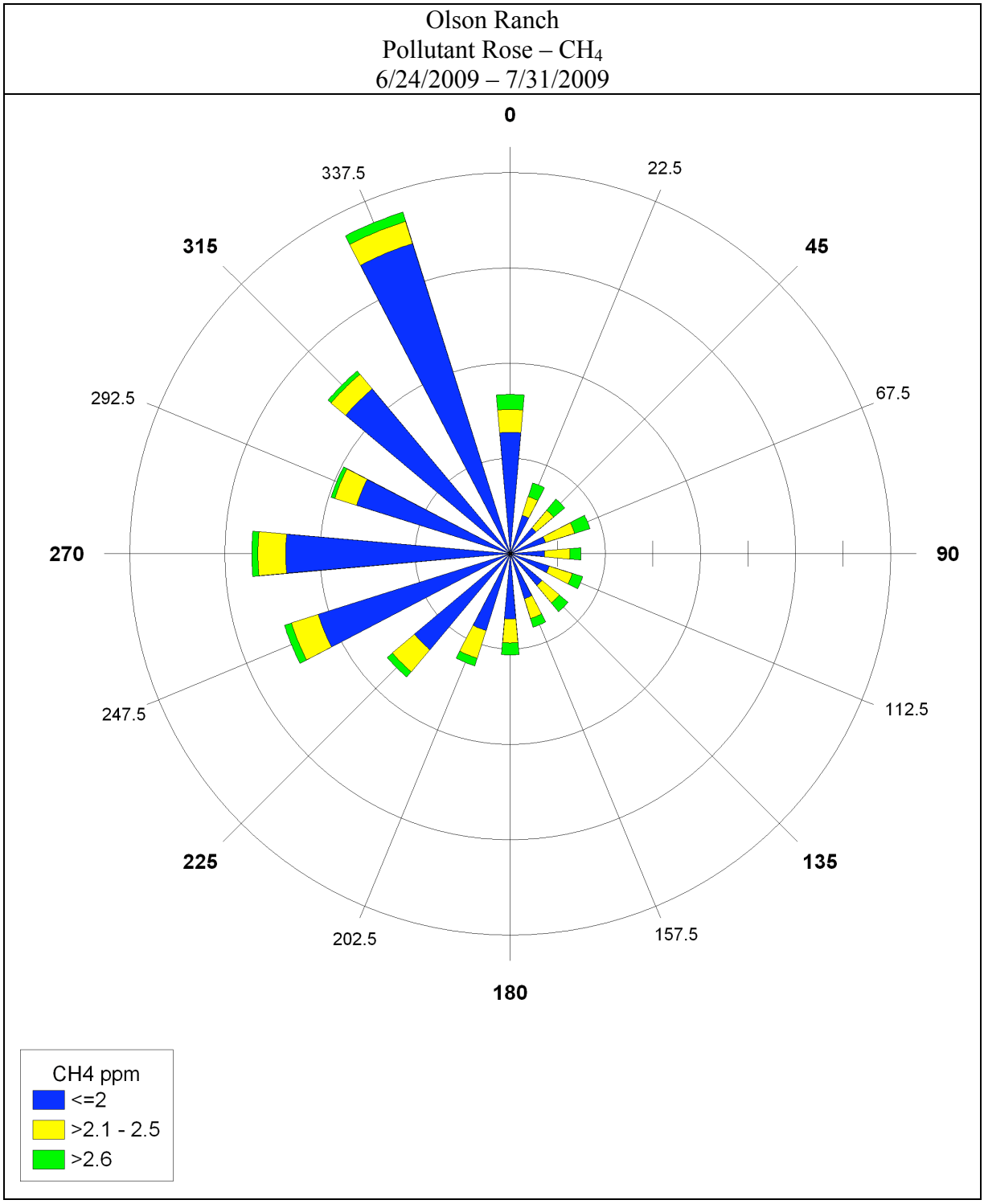


Figure 5-31. Olson Ranch NMHC pollutant rose for the period 6/24/2009 – 7/31/2009.

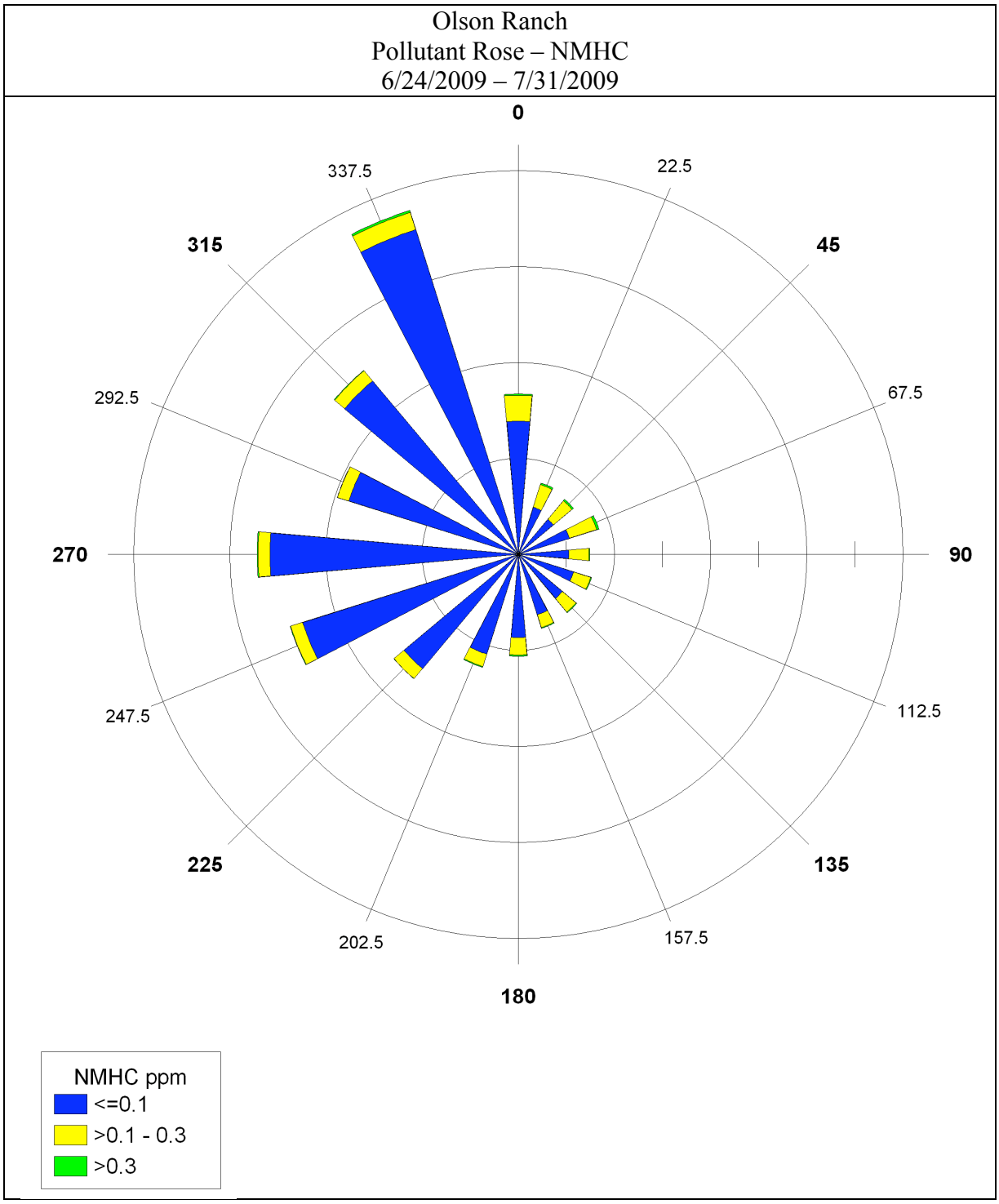


Figure 5-32. Olson Ranch NO_x pollutant rose for the period 6/24/2009 – 7/31/2009.

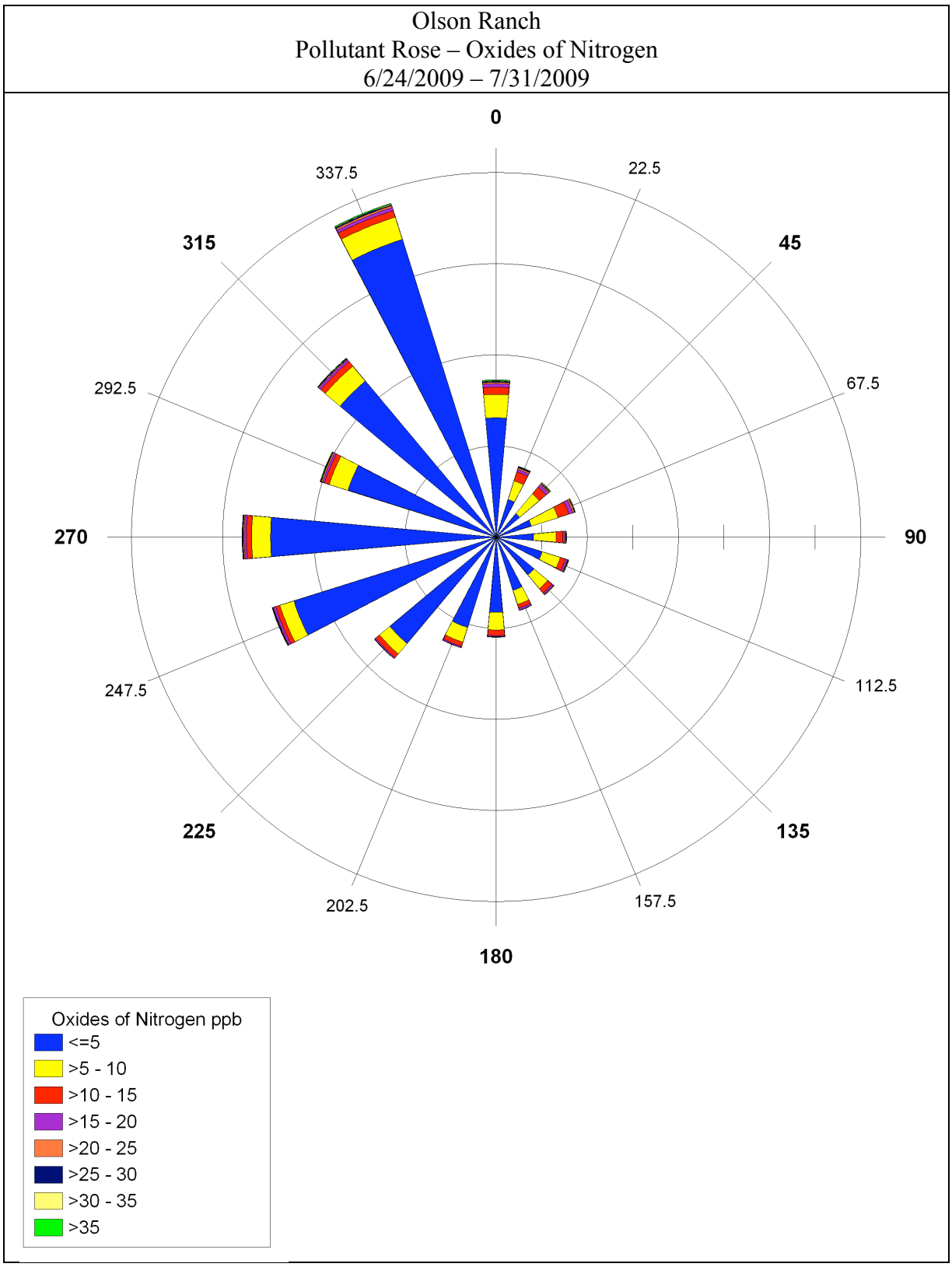


Figure 5-33. Olson Ranch NO time series for the period 6/24/2009 – 7/31/2009.

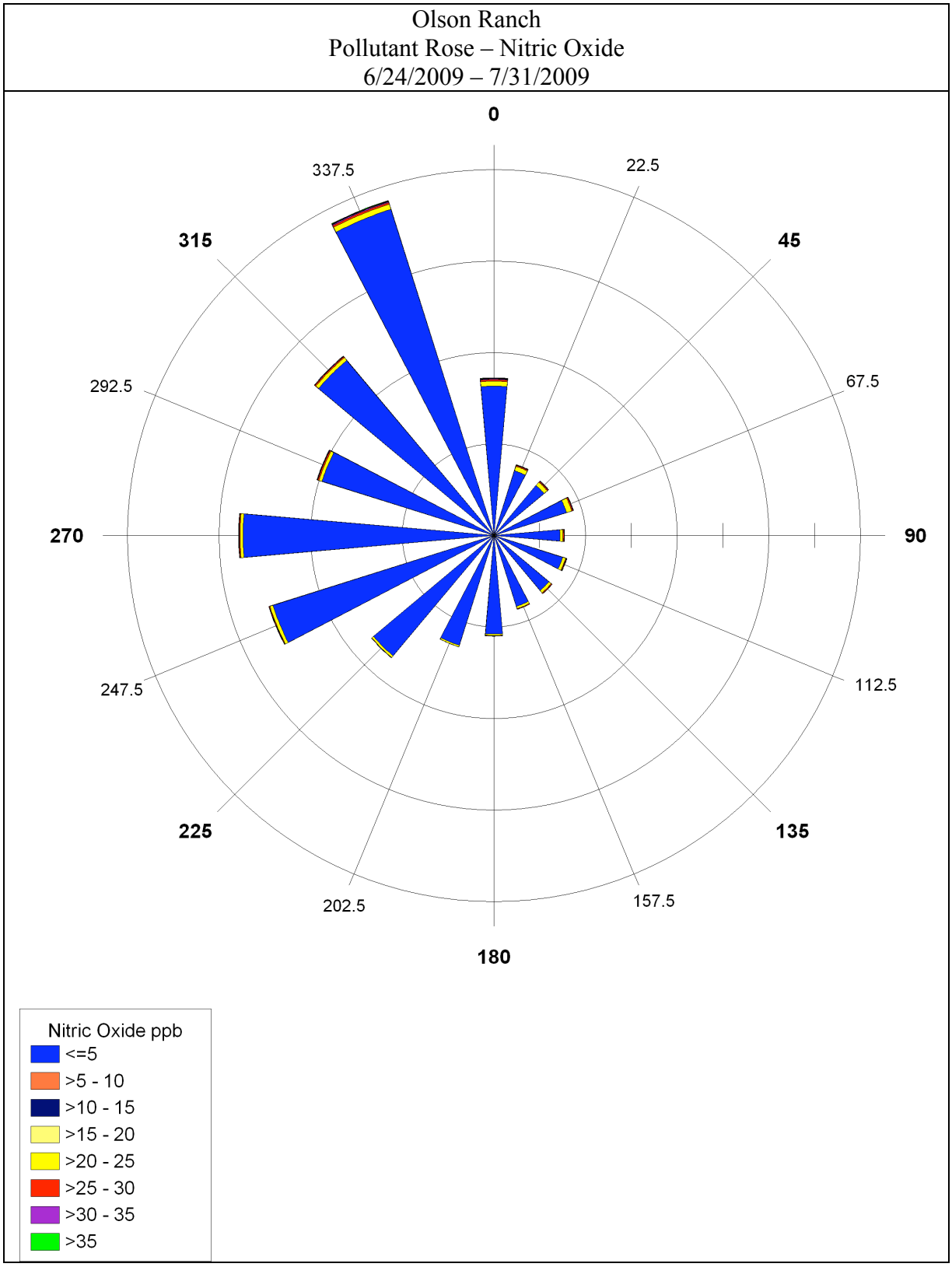


Figure 5-34. Olson Ranch NO_2 pollutant rose for the period 6/24/2009 – 7/31/2009.

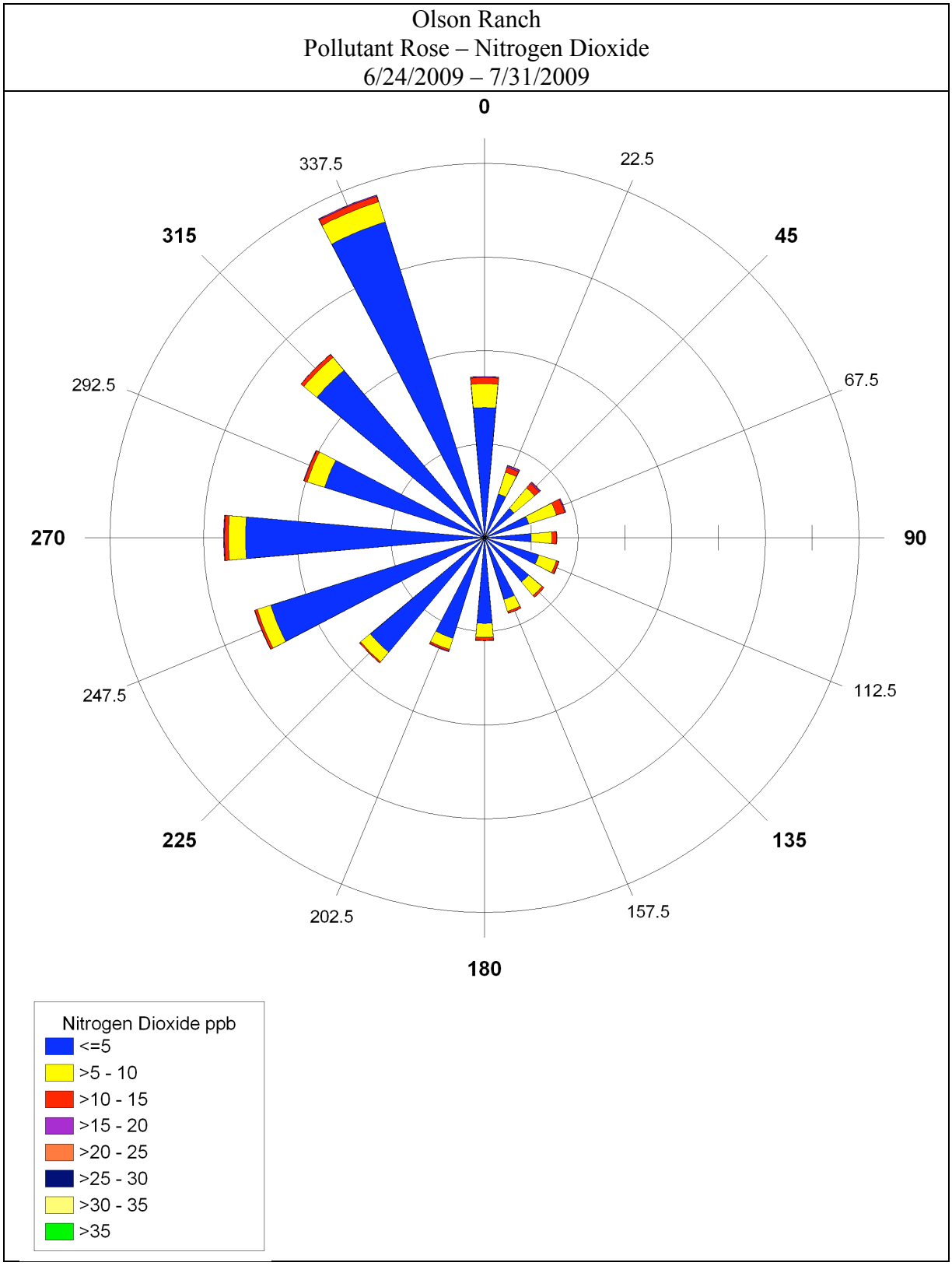
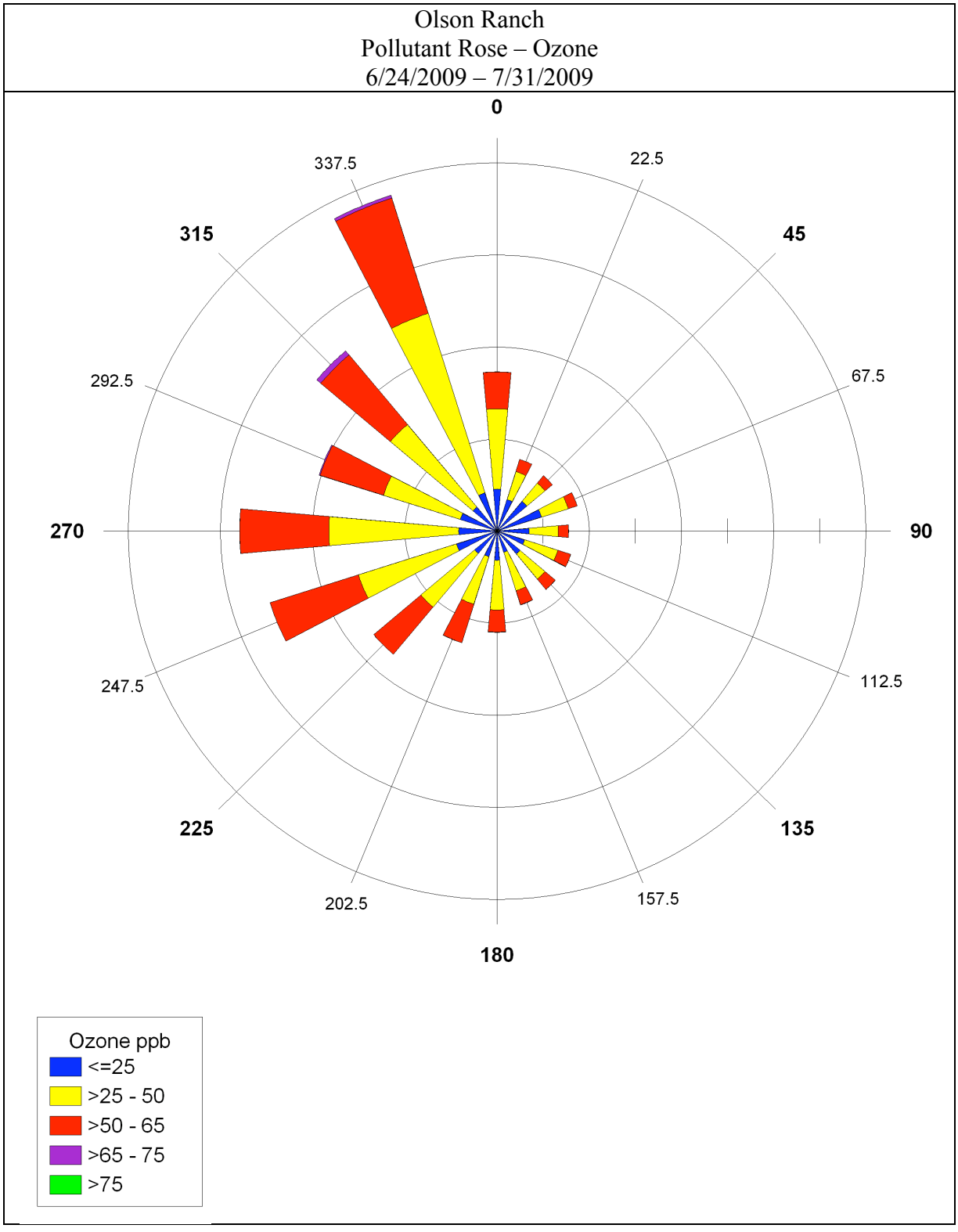


Figure 5-35. Olson Ranch O_3 pollutant rose for the period 6/24/2009 – 7/31/2009.



5.3.2 Gaseous Pollutant Time Series Plots

The following subsections describe data generated for each pollutant collectively and by monitoring site. Data are displayed in table form and graphically. While monitoring data for each site are collected under different conditions, comparisons are useful as long as the influence of geographic position and time of the year are taken into account.

Diurnal plots, influenced by changing dispersion conditions throughout the day, are useful for gaining an insight into the contributions of various emission sources. This section includes diurnal behavior plots constructed from hourly averaged values, an approach that enables hourly variations to be visualized. This section also displays time series plots of 1-minute time averaged data. Longer time series plots that display sequential data are more useful to illustrate trends and deviations from normal conditions during the given monitoring period.

5.3.2.1 Methane

Table 5-8 presents highest and second highest daily 1-hour average CH_4 concentrations, and highest daily twenty-four hour averages that occurred during the period beginning January 31, 2009 and ending July 31, 2009. As indicated by the pollution rose diagrams for CH_4, elevated concentrations were reported at all sites with the exception of Pinedale. Table 5-8 shows that elevated hourly averages were present at Big Piney, Luman Road, Boulder South Road and Olson Ranch. Dispersion conditions are generally poorest during colder conditions. Consequently, ambient concentrations at Luman Road and Big Piney (the locations monitored earliest in the study) can be expected to more influenced by stable meteorological conditions than at Boulder South Road or Olson Ranch. As shown by Table 5-8, the highest values are observed at times expected to have greater atmospheric stability and less vertical mixing and dilution. When considering the highest 24-hour CH_4 averages, Big Piney, by far the coldest site, shows the most consistent elevation above background levels, as previously defined. All of the five highest 24-hour values are at this site.

Figures 5-36 through 5-45 show the diurnal plots and time series plots of ambient CH_4 concentrations at each monitoring site over the whole of the operational period.

A noticeable feature of the diurnal plots is that the lowest mixing ratios are consistently observed in the early afternoon. At most sites the highest ambient concentrations are found early in the morning and late at night. Such behavior is consistent with the expected impact of mixing upon measured ambient concentrations. However given the reported level of CH_4, local emission sources are also anticipated to contribute to the measured values. At Big Piney (Figure 5-36) notwithstanding expected ranching contributions from cattle, many of the higher CH_4 mixing ratios are observed during periods with SW winds with speeds greater than 5 m/s. For this wind direction, numerous upwind large-scale emission source areas and facilities could also contribute to the observed high methane values. Figures 5-38 and 5-40 for Luman Road and Boulder South Road show a similar behavioral pattern to those at Big Piney but the curve is less well-defined, indicating less consistency with respect to contributing emission sources. While a similar curve is found for Pinedale (Figure 5-42) the mixing ratio levels reflect background conditions without significant additional contributions. In contrast to the

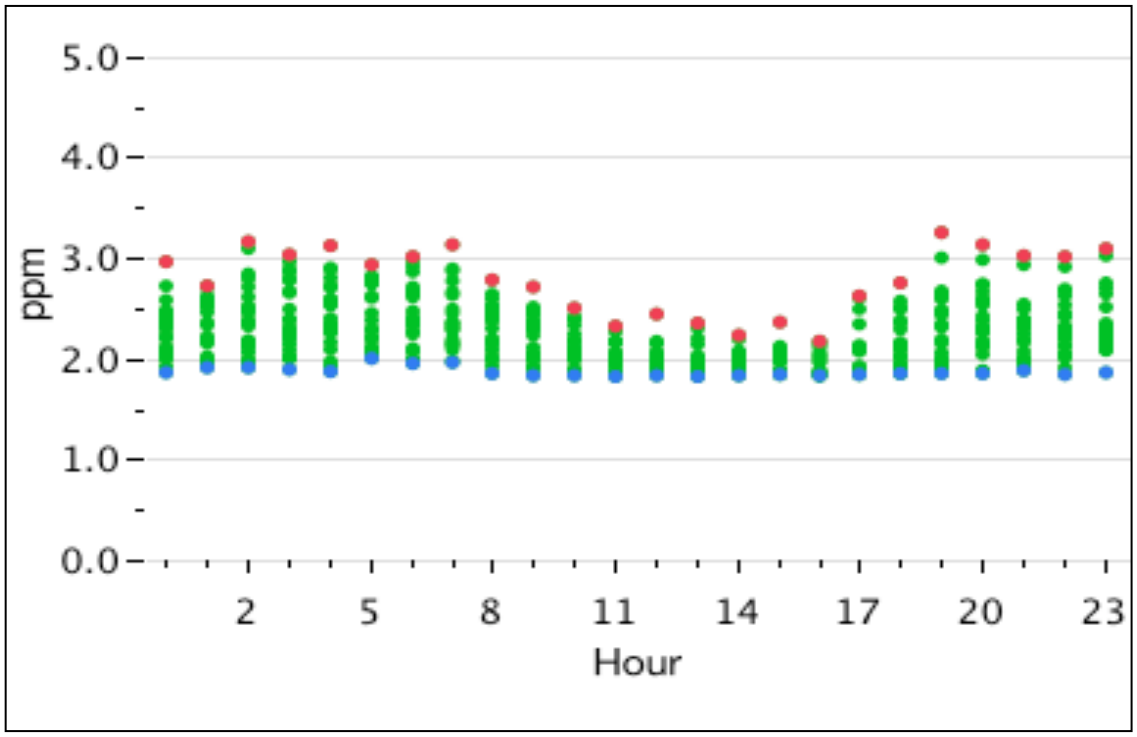
other sites, Olson Ranch (Figure 5-44) shows a significant difference between early morning and late evening peaks. Early morning has elevated concentrations.

Time series plots for CH_4 expand the diurnal behavior and allow longer-term trends and intermittent episodes unrelated to diurnal patterns to be viewed. This possibility is enhanced by the use of minute, as opposed to hourly averaged, data for the time series plots. Figure 5-37 shows considerable variation on the daily cycle at Big Piney. While data capture for CH_4 is limited at Luman Road as shown by Figure 5-39, a similar variation is apparent. Figure 5-41 for Boulder South Road shows a different behavior. Some periods exhibit variation and others display relatively stable concentrations. The time series for Pinedale, Figure 5-43, shows relatively stable and low concentrations throughout the monitoring period. The Olson Ranch site, Figure 5-45, has a unique behavior pattern with longer-lived episodes of somewhat elevated concentrations upon a relatively stable background level.

Table 5-8. UW MAQML five highest daily 1-hour averages, 2nd highest daily 1-hour averages, and 24-hour averages for CH_4.

University of Wyoming Mobile Air Quality Monitoring Laboratory *5 Highest Daily 1-Hour Averages, 2nd Highest Daily 1-Hour Averages, and 24-Hour Averages for CH_4* Final Validation 01/31/2009 – 07/31/2009				
Highest Daily 1-Hour Averages				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	3/01/09	3	4.77	Luman Rd
2	5/04/09	21	3.62	Boulder South Rd
3	2/22/09	19	3.25	Big Piney
4	7/30/09	6	3.18	Olson Ranch
5	7/13/09	6	3.18	Olson Ranch
2nd Highest Daily 1-Hour Averages				
1	6/27/09	4	3.17	Olson Ranch
2	2/21/09	2	3.16	Big Piney
3	5/16/09	20	3.14	Boulder South Rd
4	6/27/09	5	3.13	Olson Ranch
5	2/16/09	7	3.13	Big Piney
Highest Daily 24-Hour Averages				
1	2/22/09	0-23:00	2.52	Big Piney
2	2/21/09	0-23:00	2.52	Big Piney
3	2/04/09	0-23:00	2.46	Big Piney
4	2/05/09	0-23:00	2.41	Big Piney
5	2/16/09	0-23:00	2.38	Big Piney

Figure 5-36. Big Piney CH_4 diurnal plot for the period 01/31/2009 – 02/27/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-37. Big Piney CH_4 time series for the period 01/31/2009 – 02/27/2009.

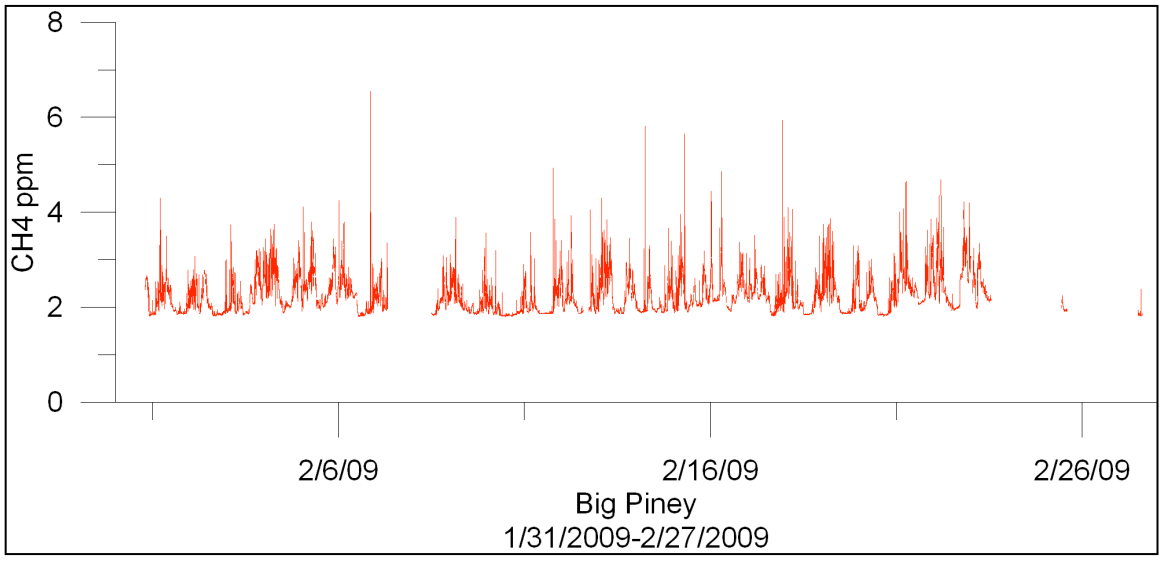


Figure 5-38. Luman Road CH_4 diurnal plot for the period 02/27/2009 – 04/01/2009.

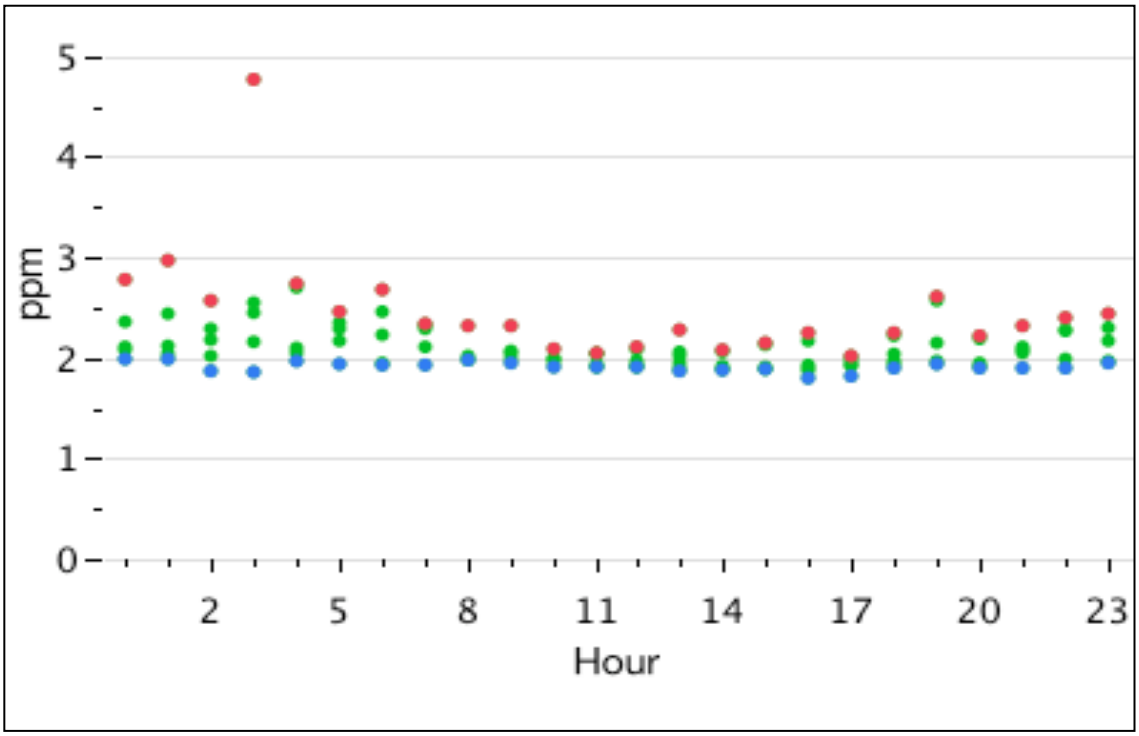


Figure 5-39. Luman Road CH_4 time series for the period 02/27/2009 – 04/01/2009.

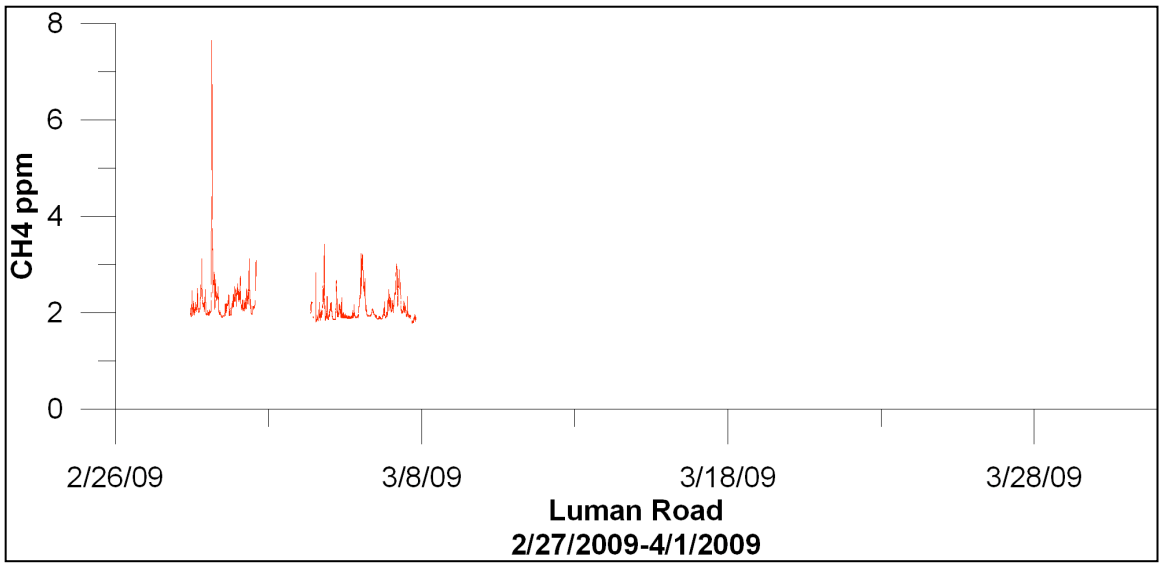


Figure 5-40. Boulder South Road CH_4 diurnal plot for the period 04/01/2009 – 05/19/2009.

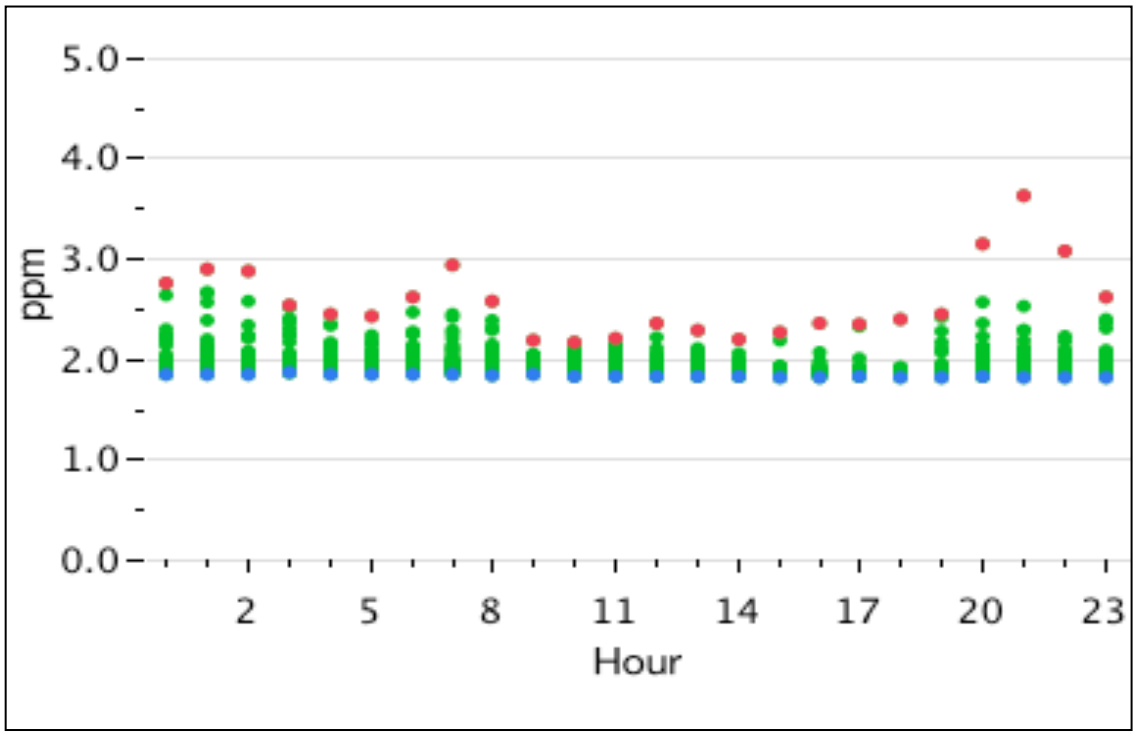


Figure 5-41. Boulder South Road CH_4 time series for the period 04/01/2009 – 05/19/2009.

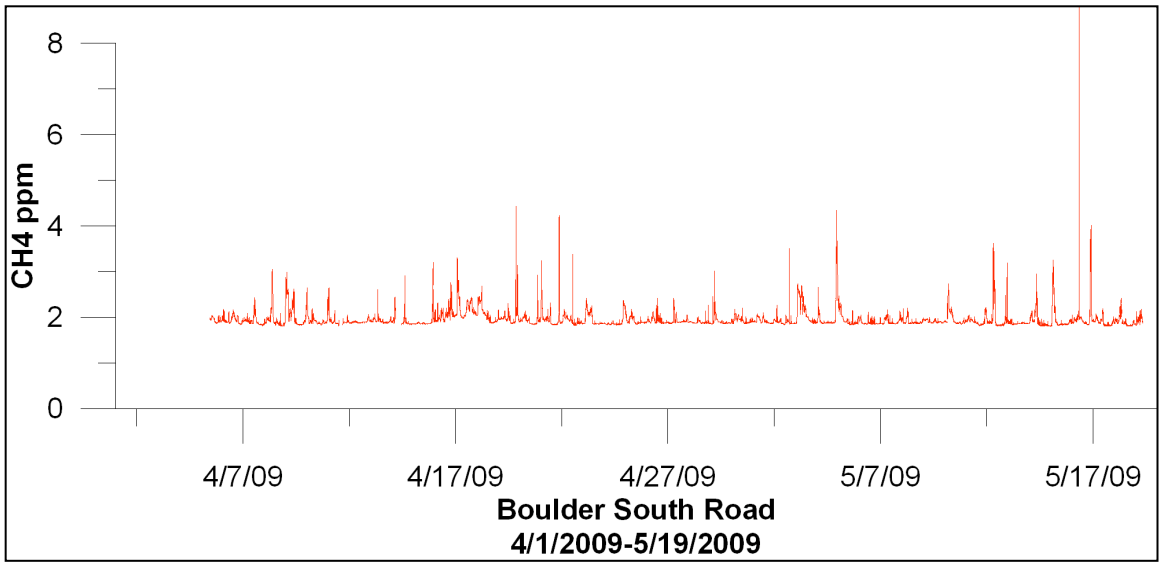
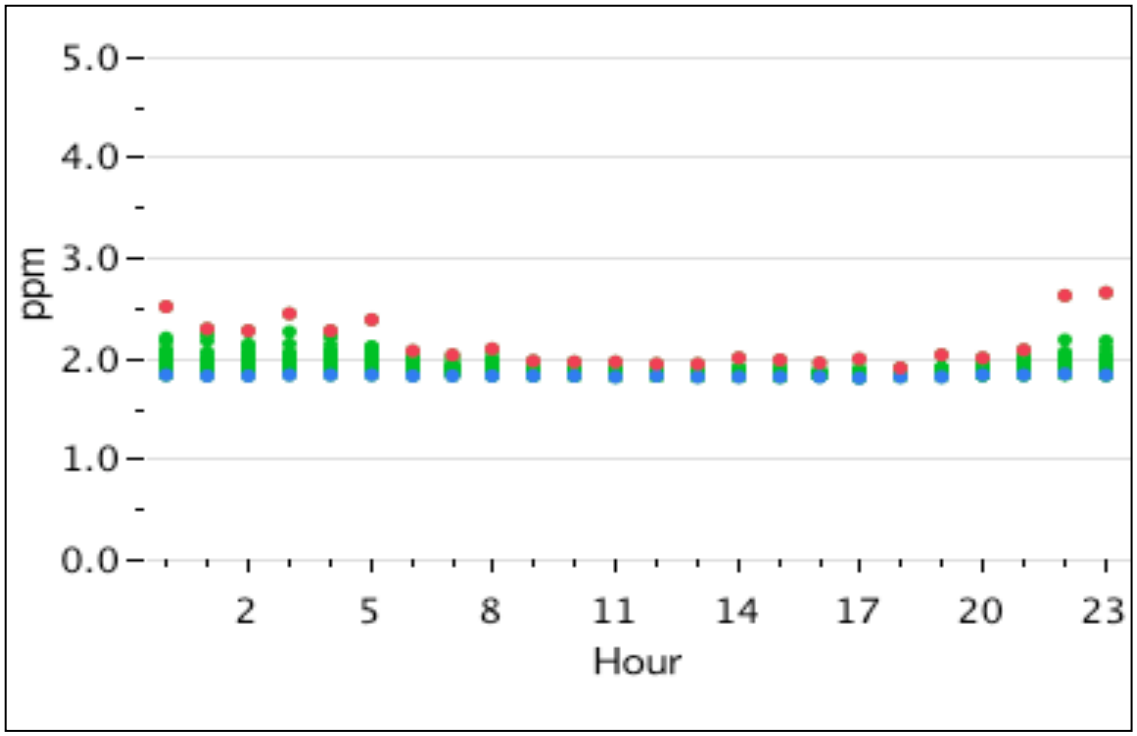


Figure 5-42. Pinedale CH_4 diurnal plot for the period 05/19/2009 – 06/24/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-43. Pinedale CH_4 time series for the period 05/19/2009 – 06/24/2009.

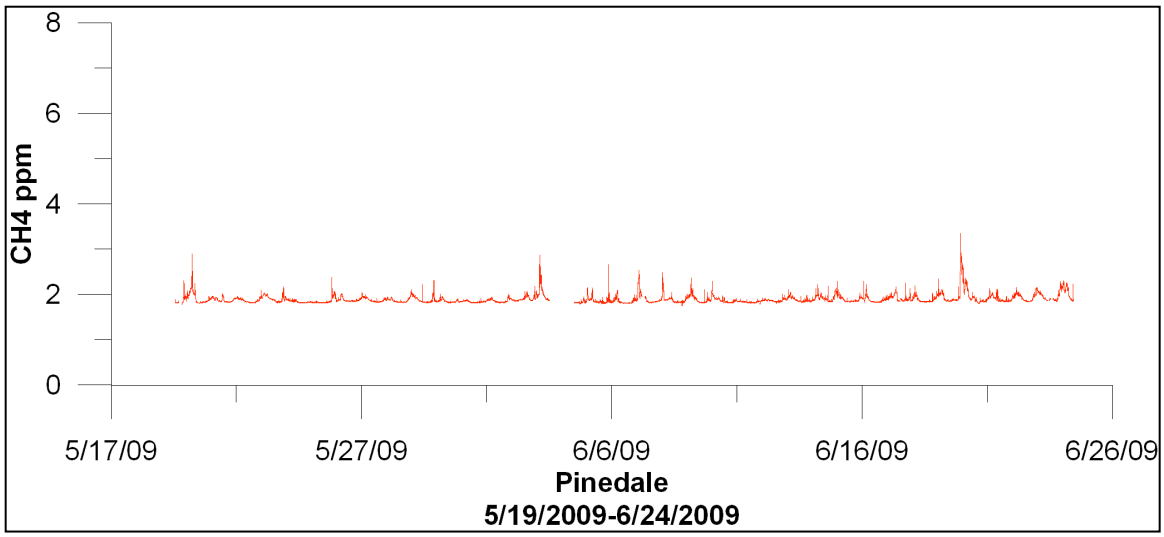


Figure 5-44. Olson Ranch CH_4 diurnal plot for the period 06/24/2009– 07/31/2009.

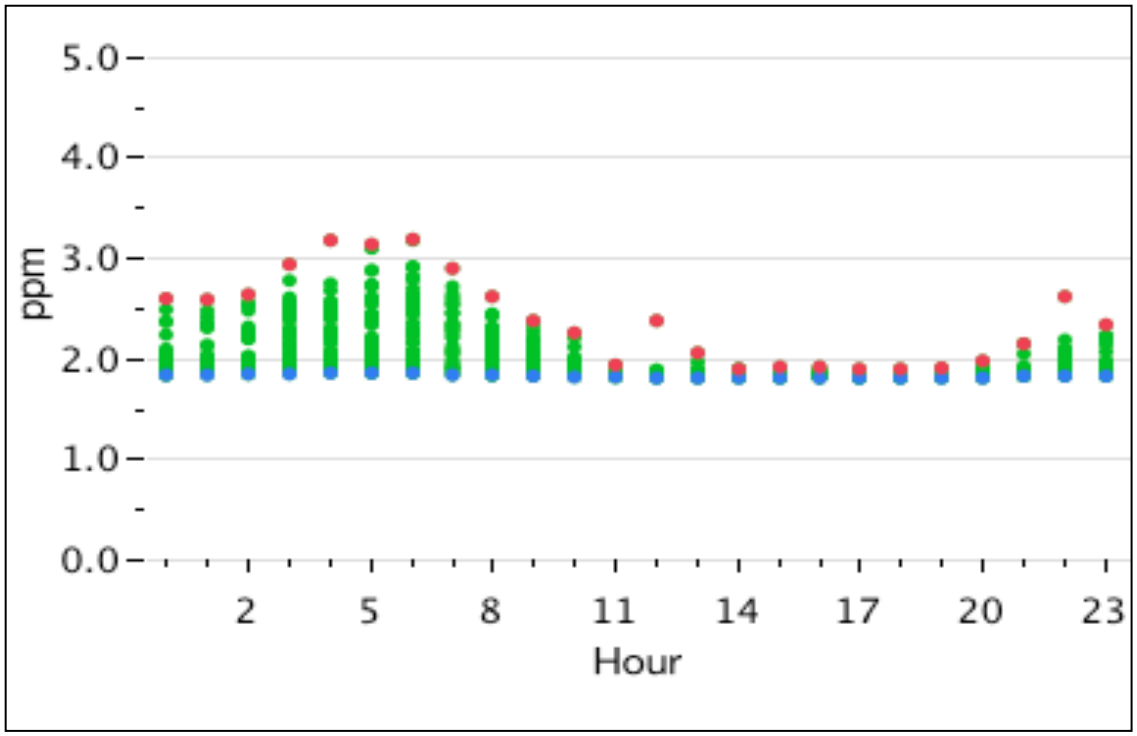
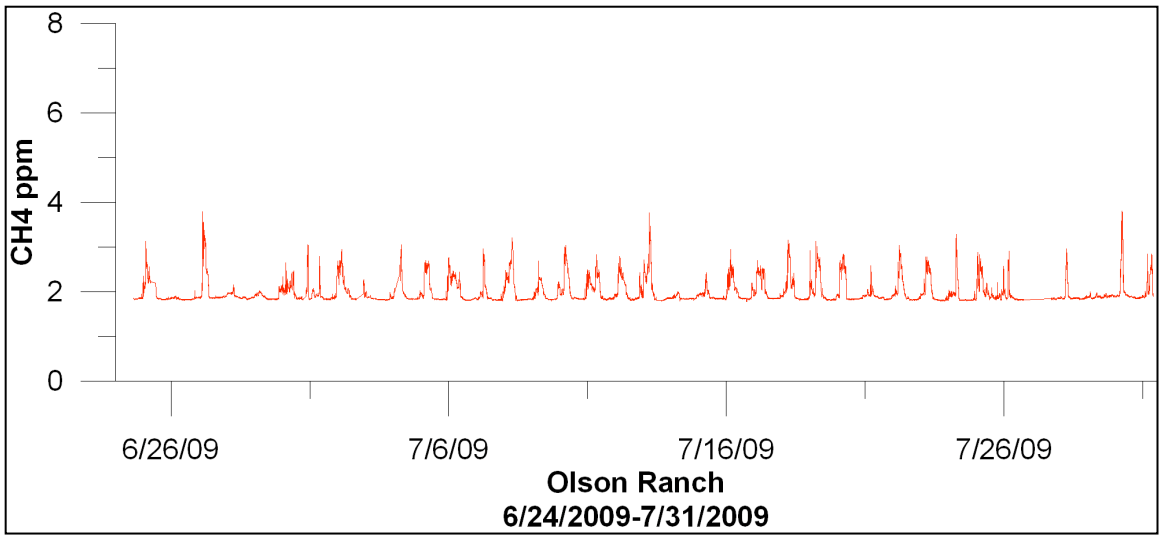


Figure 5-45. Olson Ranch CH_4 time series for the period 06/24/2009– 07/31/2009.



5.3.2.2 Non-Methane Hydrocarbons

Table 5-9 presents highest and second highest daily 1-hour average NMHC concentrations, and highest daily twenty-four hour averages that occurred during the period beginning January 31, 2009 and ending July 31, 2009. Four of the five highest 1-hour average values for NMHC on Table 5-9 are the exact same hour as for CH_4. There are also some differences. The daily average values show a more divergent site representation. This could be explained by a different CH_4 to NMHC ratio at Big Piney compared to the other sites with elevated hydrocarbon concentrations. Figures 5-46 through 5-55 represent the diurnal plot and time series plot of ambient NMHC concentrations at each of the monitoring sites over the whole of the operational period.

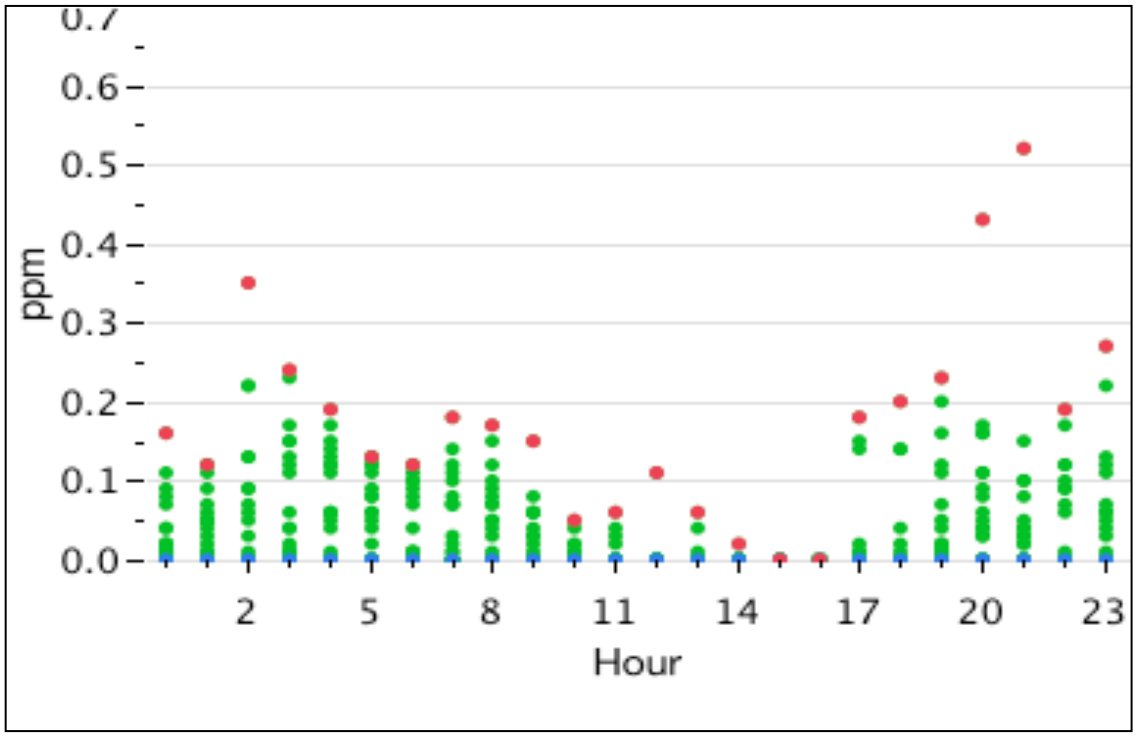
With respect to the diurnal plots, again a similarity to CH_4 is evident. There is one dominant pattern, lowest concentrations in the early afternoon hour. At most monitoring sites the highest concentrations are early in the morning and late at night. In addition to emission source variation, the influence of the relatively low concentrations of NMHC is of importance. Levels are often not measurable with values of 0.00 ppb frequently reported.

Time series plots for NMHC expand the diurnal behavior and allow for longer-term trends and intermittent episodes unrelated to diurnal patterns to be viewed. This possibility is enhanced by the use of minute, as opposed to hourly averaged data for the time series plots. The figures for NMHC mirror the behavior evident for CH_4. Figure 5-47 shows that considerable variation is apparent on the daily cycle at Big Piney. While the data capture for NMHC is limited at Luman Road, as shown by Figure 5-49, a similar variation is apparent. Figure 5-51 for Boulder South Road shows a different behavior; some periods exhibit a high level of variation as per Figures 5-47 and 5-49, others showed relatively stable concentrations with intermittent shorter-lived period of elevated concentrations. The time series for Pinedale, Figure 5-53, reinforces previous figures for CH_4 at this site by showing relatively stable and low concentrations throughout this monitoring period. The Olson Ranch site, Figure 5-55, has a unique behavior pattern with longer-lived episodes of elevated concentrations upon a relatively stable background level.

Table 5-9. UW MAQML five highest daily 1-hour averages, 2nd highest daily 1-hour averages, and 24-hour averages for NMHC.

University of Wyoming Mobile Air Quality Monitoring Laboratory *5 Highest Daily 1-Hour Averages, 2nd Highest Daily 1-Hour Averages, and 24-Hour Averages for NMHC* Final Validation 01/31/2009 – 07/31/2009				
Highest Daily 1-Hour Averages				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	3/01/09	3	0.58	Luman Rd
2	2/22/09	21	0.52	Big Piney
3	7/30/09	6	0.42	Olson Ranch
4	2/21/09	2	0.35	Big Piney
5	5/04/09	21	0.32	Boulder South Rd
2nd Highest Daily 1-Hour Averages				
1	2/22/09	20	0.43	Big Piney
2	7/30/09	5	0.36	Olson Ranch
3	7/13/09	6	0.30	Olson Ranch
4	6/27/09	5	0.30	Olson Ranch
5	4/21/09	0	0.30	Boulder South Rd
Highest Daily 24-Hour Averages				
1	2/22/09	0-23:00	0.12	Big Piney
2	2/21/09	0-23:00	0.09	Big Piney
3	7/13/09	0-23:00	0.07	Olson Ranch
4	2/13/09	0-23:00	0.07	Big Piney
5	3/01/09	0-23:00	0.07	Luman Rd

Figure 5-46. Big Piney NMHC diurnal plot for the period 01/31/2009 – 02/27/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-47. Big Piney NMHC time series for the period 01/31/2009 – 02/27/2009.

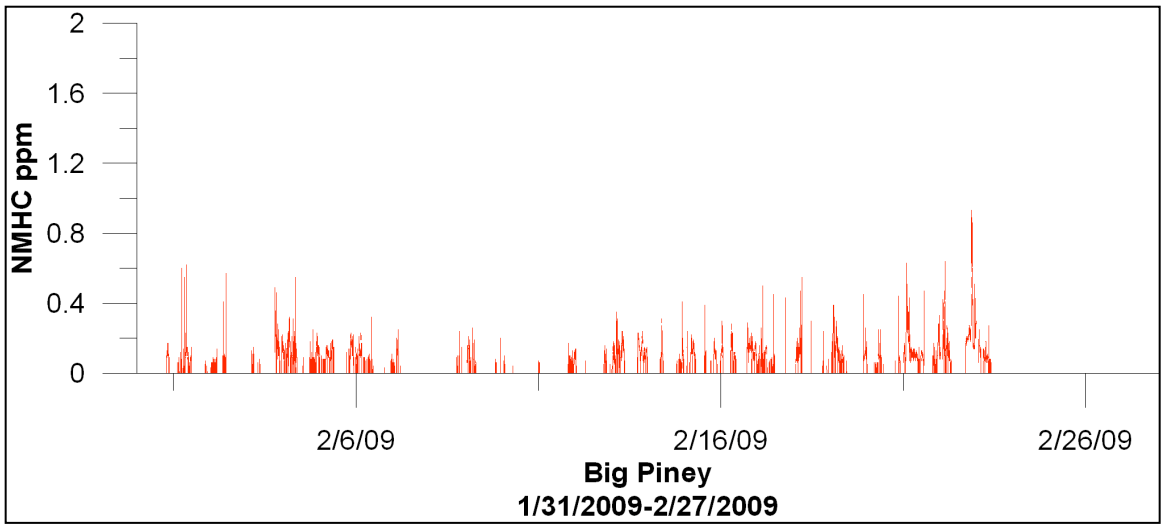


Figure 5-48. Luman Road NMHC diurnal plot for the period 02/27/2009 – 04/01/2009.

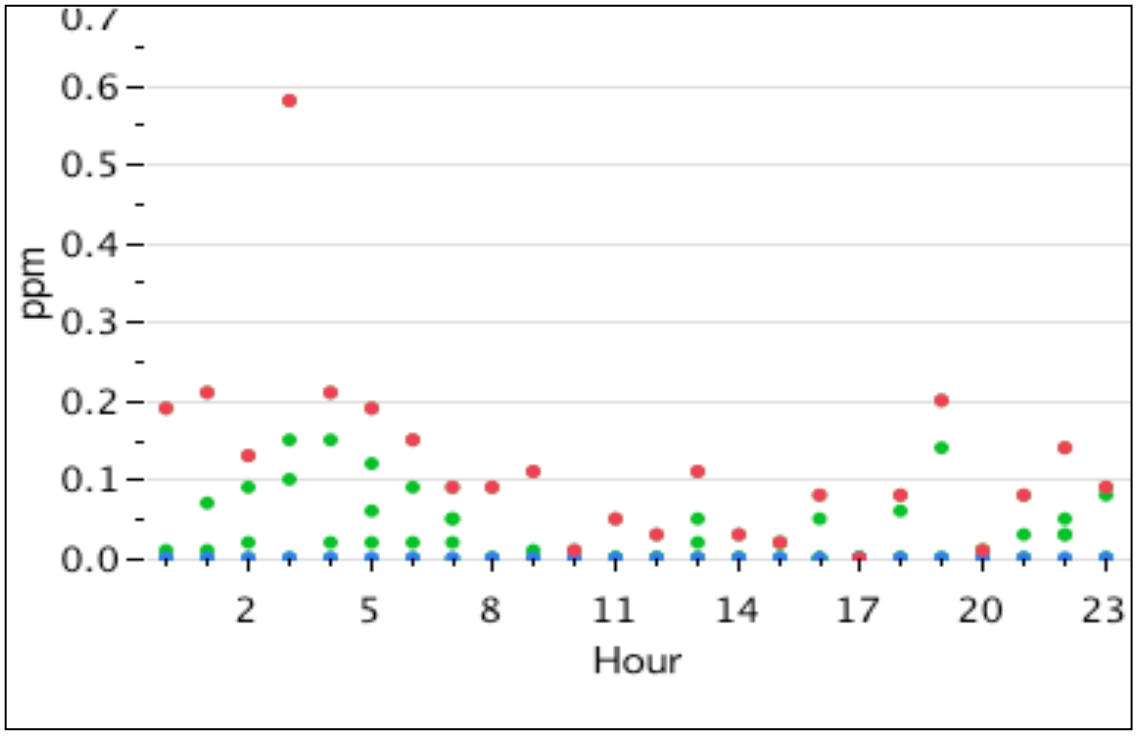


Figure 5-49. Luman Road NMHC time series for the period 02/27/2009 – 04/01/2009.

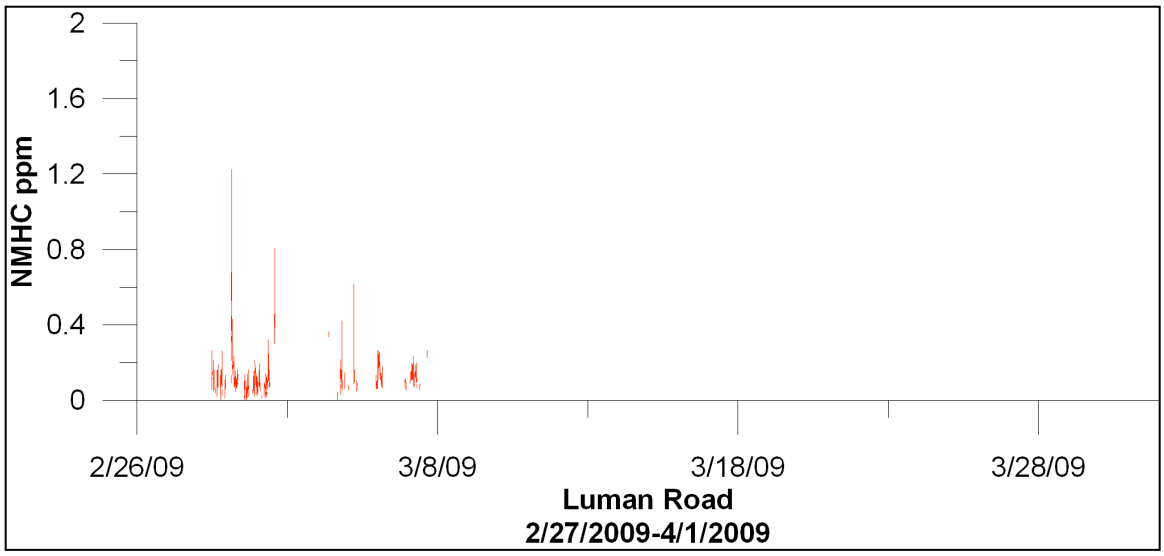
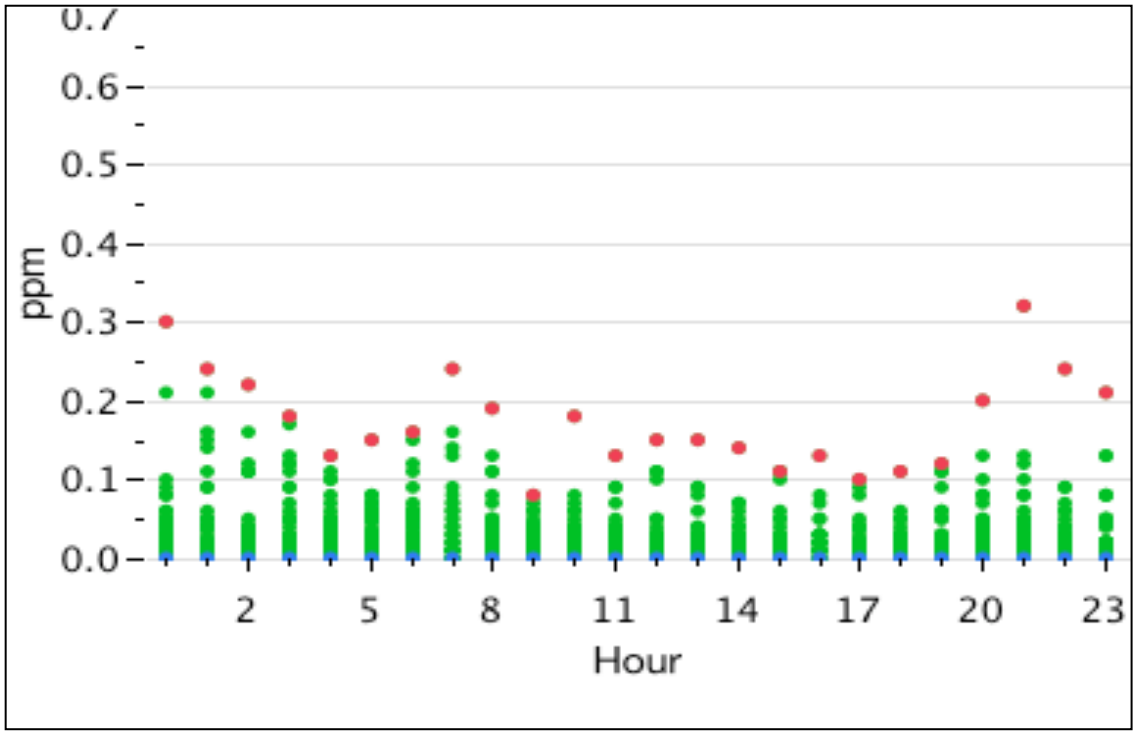


Figure 5-50. Boulder South Road NMHC diurnal plot for the period 04/01/2009 – 05/19/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-51. Boulder South Road NMHC time series for the period 04/01/2009 – 05/19/2009.

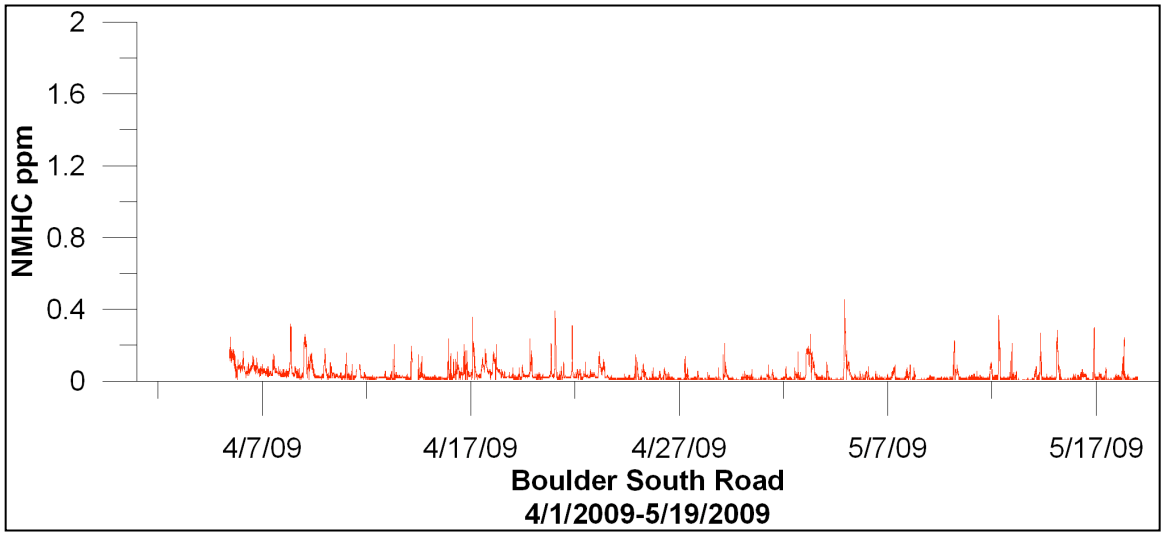
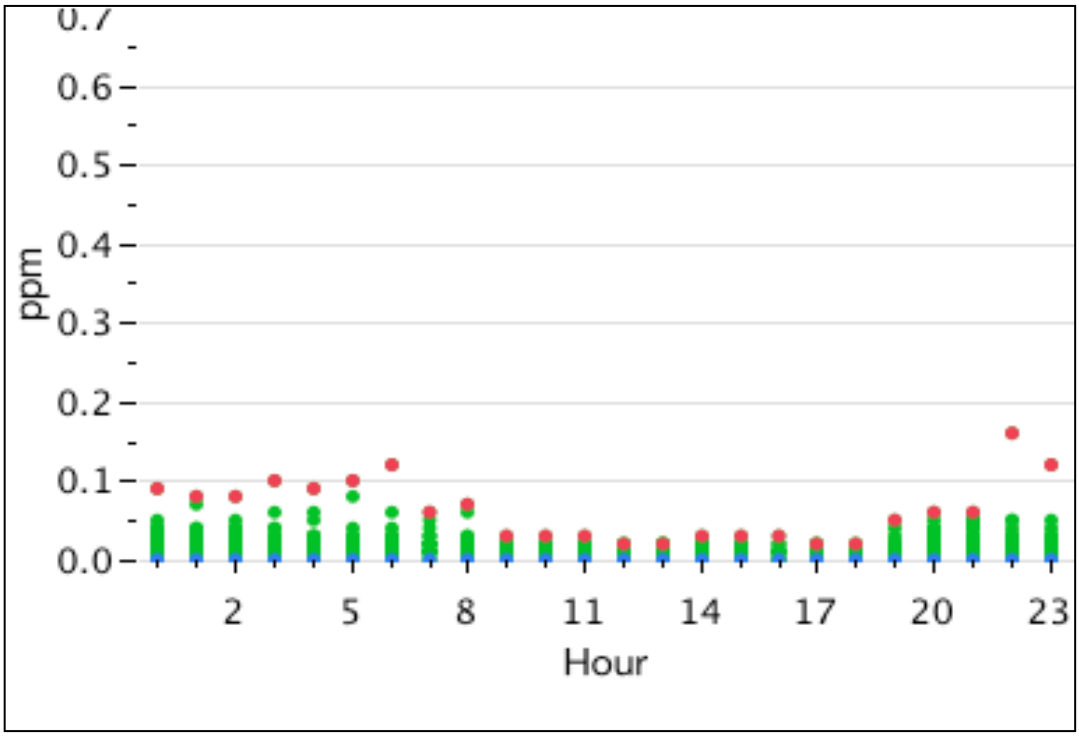


Figure 5-52. Pinedale NMHC diurnal plot for the period 05/19/2009 – 06/24/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-53. Pinedale NMHC time series for the period 05/19/2009 – 06/24/2009.

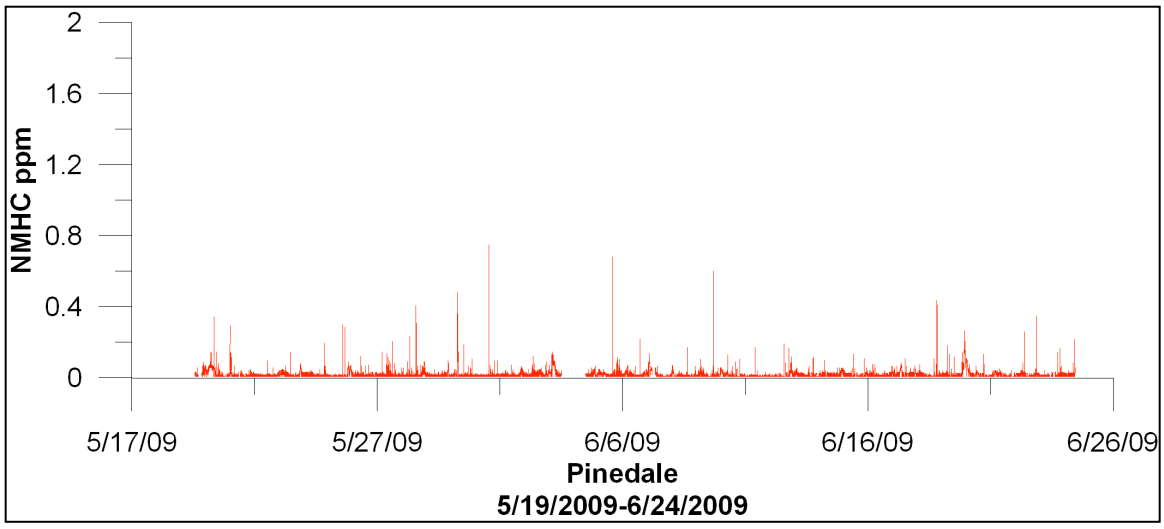


Figure 5-54. Olson Ranch NMHC diurnal plot for the period 06/24/2009– 07/31/2009.

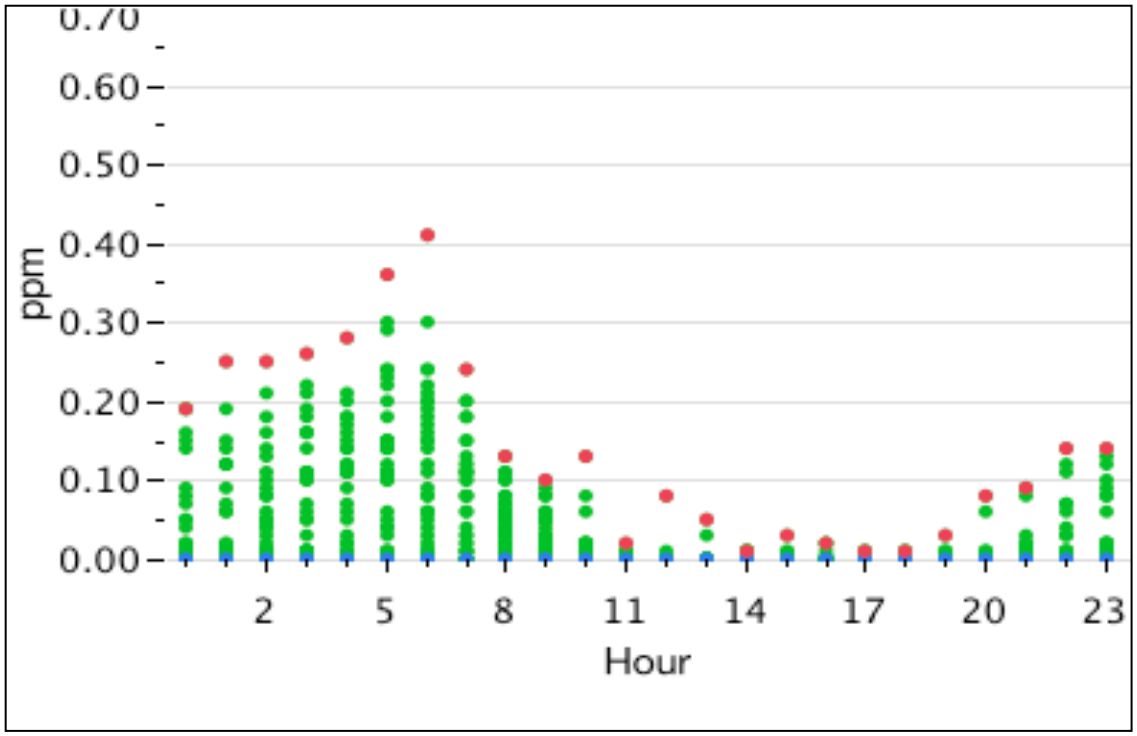
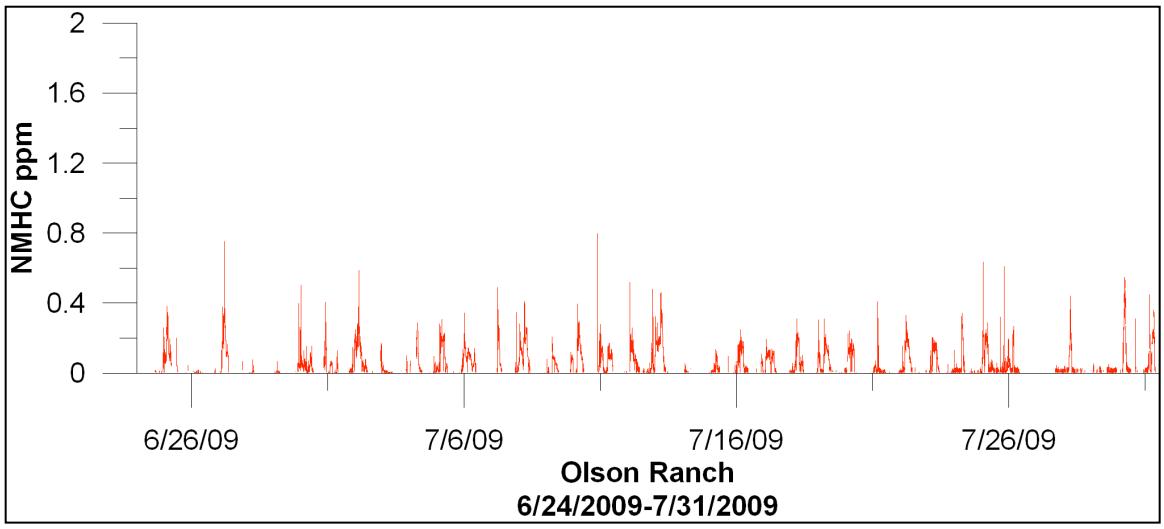


Figure 5-55. Olson Ranch NMHC time series for the period 06/24/2009– 07/31/2009.



5.3.3 Oxides of Nitrogen

Table 5-10 presents highest and second highest daily 1-hour average NO_x concentrations, and highest daily twenty-four hour averages that occurred during the period beginning January 31, 2009 and ending July 31, 2009. Times represented in this table are different than those given in Tables 5-8 and 5-9. Since the measurements are simultaneous this behavior could be due to having a different balance of contributing emission sources for NO_x than for methane and NMHC. NO_x measurements, as the combination of NO and NO_2, can be considered a hybrid of a primary and a secondary pollutant. NO is considered a primary pollutant of combustion systems. While some combustion systems can directly produce NO_2, more often this pollutant is formed from the reaction of NO to form NO_2. NO_2 is classed as a secondary pollutant. This reaction may occur during the emission process or at a position downwind. Measured NO_x concentrations can indicate the influence of both emission sources and reaction chemistry, therefore the position of sampling relative to emission sources is an important consideration. Ignoring of seasonal influences upon emissions and atmospheric chemistry, locations close to direct emission sources will tend to have relatively high NO compared to those at sites downwind of emission sources. Three of the five highest 1-hour average values for NO_x are reported from Luman Road. Elevated 1-hour average values are also reported for Pinedale, Big Piney and Olson Ranch. When considering the highest daily average values; Luman Road has the three highest values with Big Piney having the fourth and fifth. Figures 5-56 through 5-65 represent the diurnal plot and time series plot of ambient NOx concentrations at each of the monitoring sites over the whole of the O3i operational period.

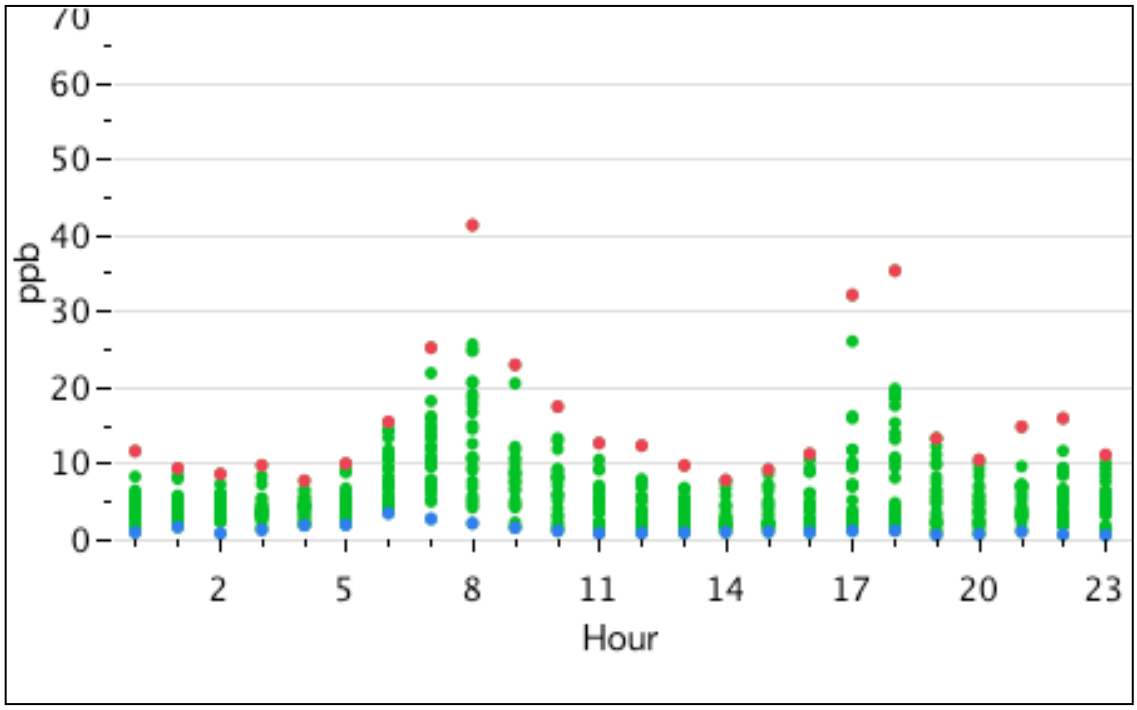
With respect to the diurnal plots the typical behavior is a morning peak followed by a mid day trough and a late afternoon peak. However, the balance of this pattern is divergent. At Big Piney, Figure 5-56, the morning peak is broader and more pronounced than the afternoon peak. At Luman Road, Figure 5-58, a similar pattern is evident, with the morning peak earlier in the day. At Boulder South Road, Figure 5-60, an afternoon peak is nearly indiscernible. At Pinedale, Figure 5-62, while peaks are apparent, magnitude is diminished. Again as a somewhat analogous pattern the Olson Ranch site, Figure 5-64, shows similarity to the behavior of hydrocarbons at that site. At most, sites the highest concentrations are early in the morning and late at night. The NO_x concentration during morning peak hours at all monitoring sites is generally not more than 20 ppb.

The time series plots for NO_x reinforce the benefits indicated earlier of viewing short time averaged data over relatively long times. Variation is apparent for all of the time series figures for NO_x. At Big Piney, Figure 5-57, the diurnal variation is visible along with some higher concentration spikes. At the Luman Road site, Figure 5-59, there are far more concentration spikes although the magnitude rarely exceeds 50 ppb. At the Boulder South Road site, Figure 5-61, while higher concentration spikes are less frequent, the concentration level often exceeds 50 ppb. The Pinedale site, Figure 5-63 show a similar behavior as that at Boulder South Road however concentrations spikes exceed 100 ppb on a number of occasions. The Olson Ranch site behavior, Figure 5-65, is similar to that shown for Big Piney in Figure 5-57.

Table 5-10. UW MAQML 5 highest daily 1-hour averages, 2nd highest daily 1-hour averages, and 24-hour averages for NO_x.

University of Wyoming Mobile Air Quality Monitoring Laboratory *5 Highest Daily 1-Hour Averages, 2nd Highest Daily 1-Hour Averages, and 24-Hour Averages for NO_x* Final Validation 01/31/2009 – 07/31/2009				
Highest Daily 1-Hour Averages				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	3/10/09	6	68.26	Luman Rd
2	3/14/09	5	55.22	Luman Rd
3	3/13/09	23	51.23	Luman Rd
4	5/20/09	13	48.46	Pinedale
5	2/19/09	9	44.24	Big Piney
2nd Highest Daily 1-Hour Averages				
1	3/13/09	22	45.92	Luman Rd
2	2/18/09	8	41.22	Big Piney
3	7/16/09	5	40.58	Olson Ranch
4	3/02/09	7	35.83	Luman Rd
5	2/04/09	18	35.24	Big Piney
Highest Daily 24-Hour Averages				
1	3/14/09	0-23:00	12.40	Luman Rd
2	3/10/09	0-23:00	12.35	Luman Rd
3	3/02/09	0-23:00	11.86	Luman Rd
4	2/05/09	0-23:00	11.79	Big Piney
5	3/11/09	0-23:00	11.77	Big Piney

Figure 5-56. Big Piney NO_x diurnal plot for the period 01/31/2009 – 02/27/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-57. Big Piney NO_x time series for the period 01/31/2009 – 02/27/2009.

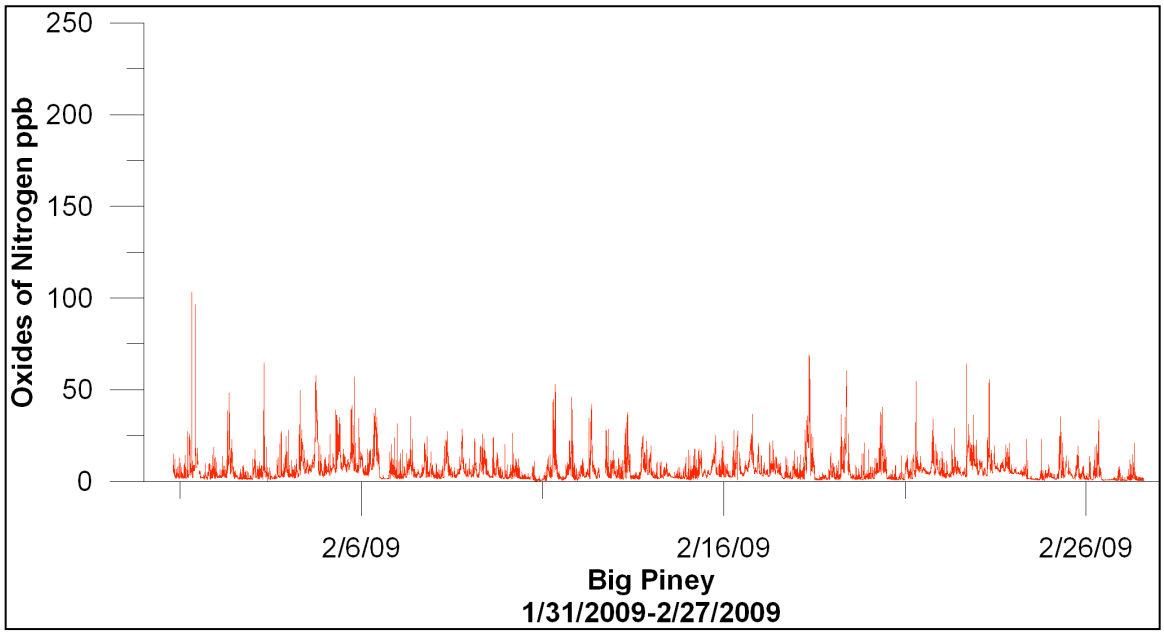


Figure 5-58. Luman NO_x diurnal plot for the period 02/27/2009 – 04/01/2009.

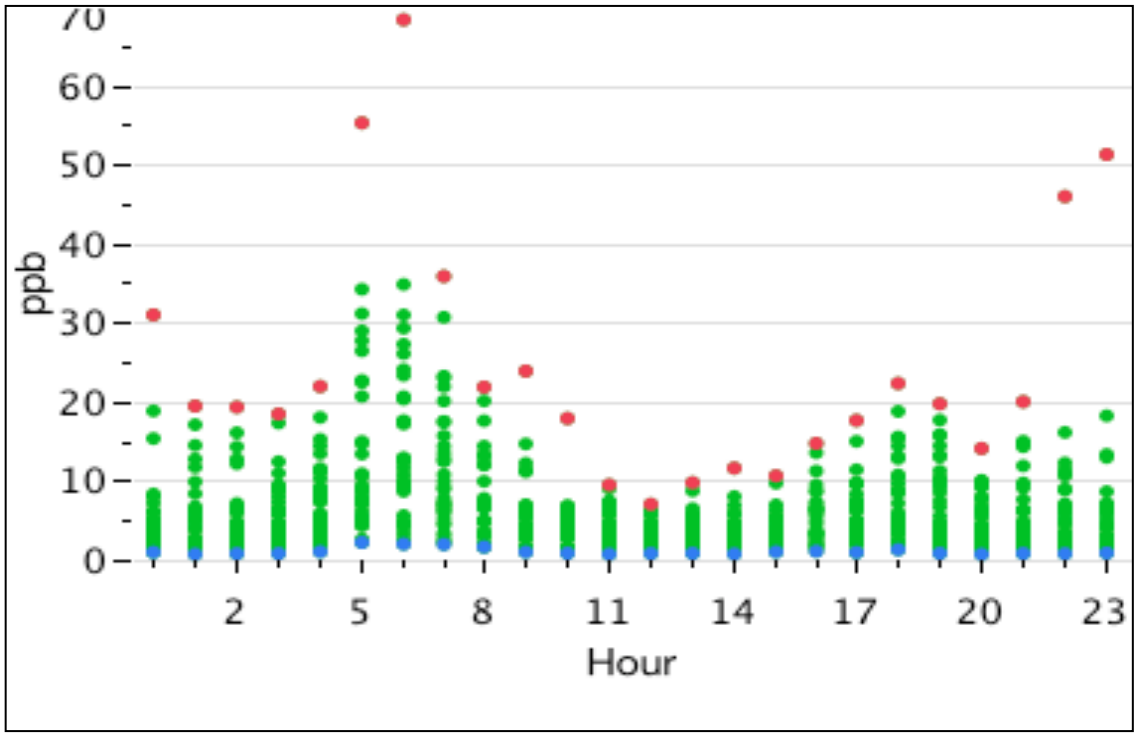


Figure 5-59. Luman NO_x time series for the period 02/27/2009 – 04/01/2009.

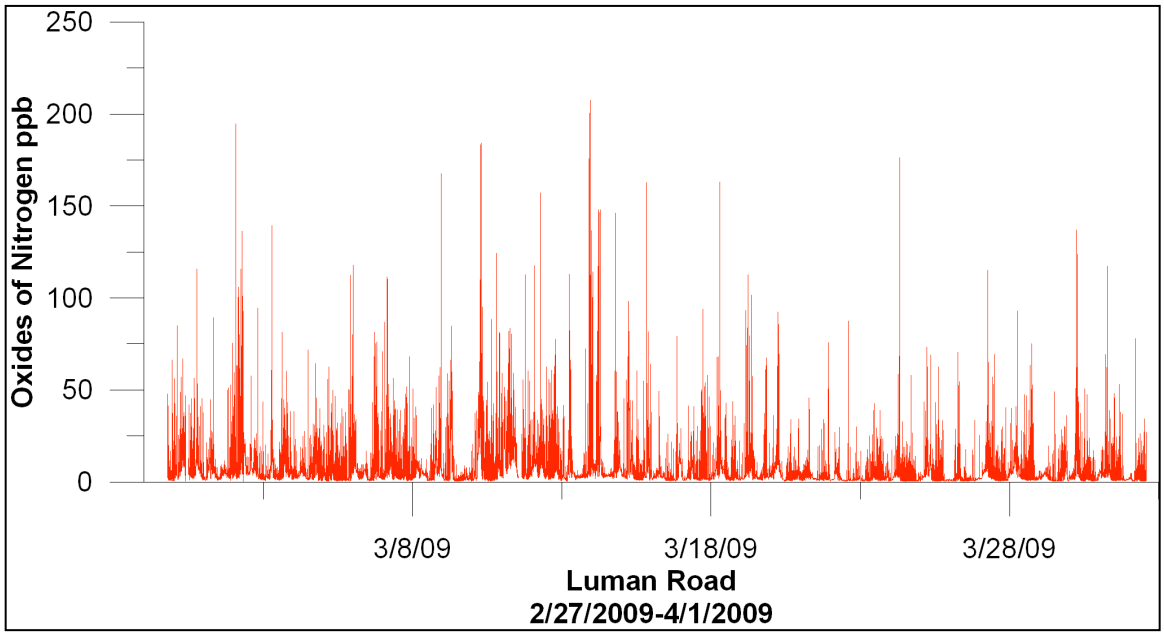


Figure 5-60. Boulder South Road NO_x diurnal plot for the period 04/01/2009 – 05/19/2009.

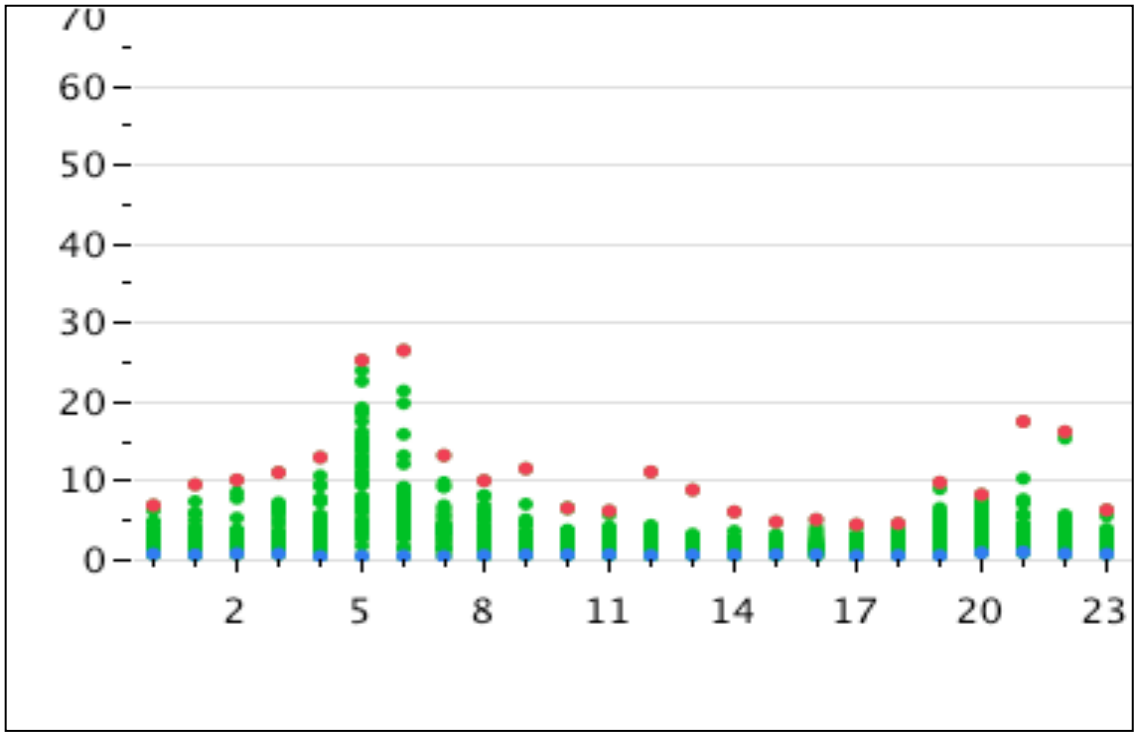


Figure 5-61. Boulder South Road NO_x time series for the period 04/01/2009 – 05/19/2009.

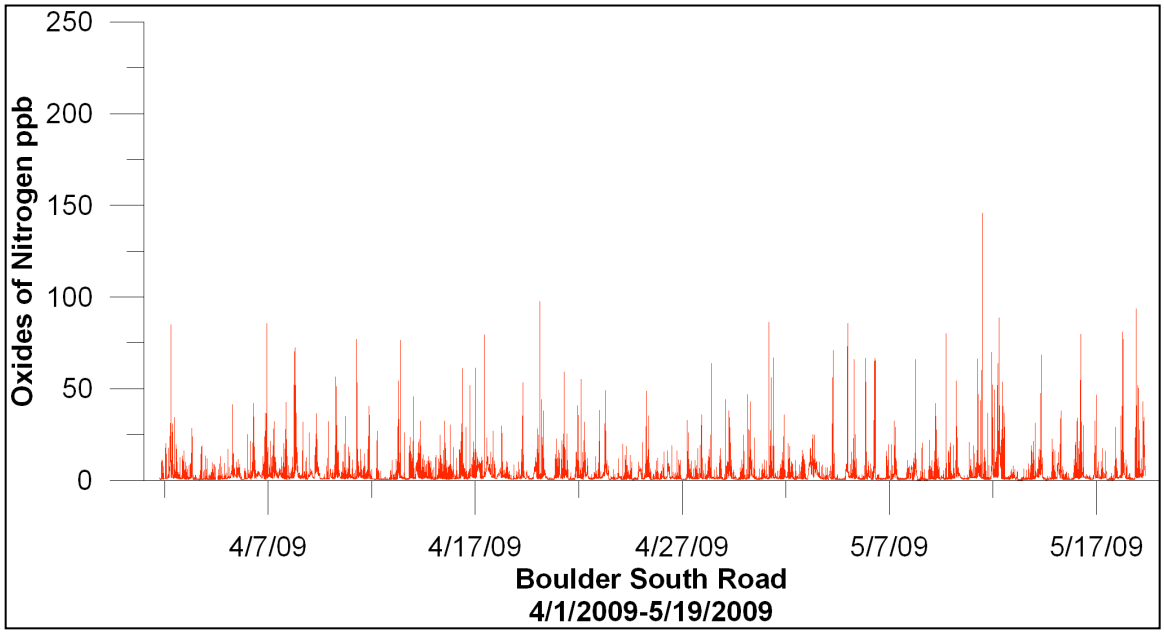


Figure 5-62. Pinedale NO_x diurnal plot for the period 05/19/2009 – 06/24/2009.

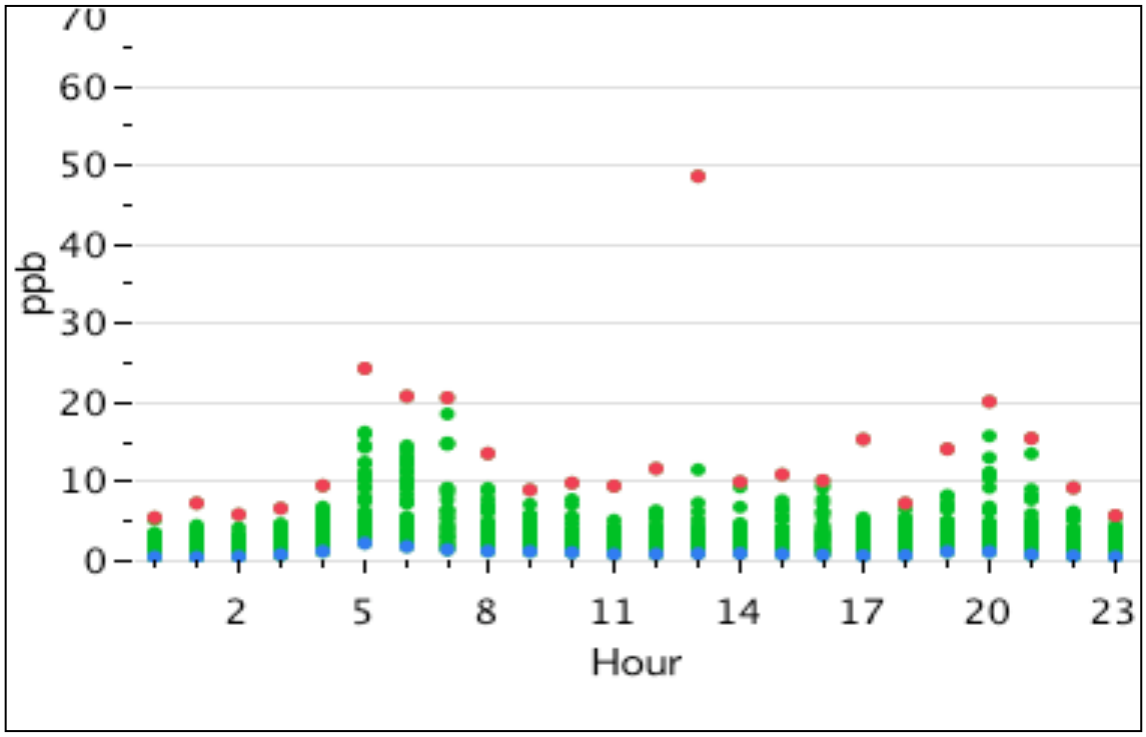


Figure 5-63. Pinedale NO_x time series for the period 05/19/2009 – 06/24/2009.

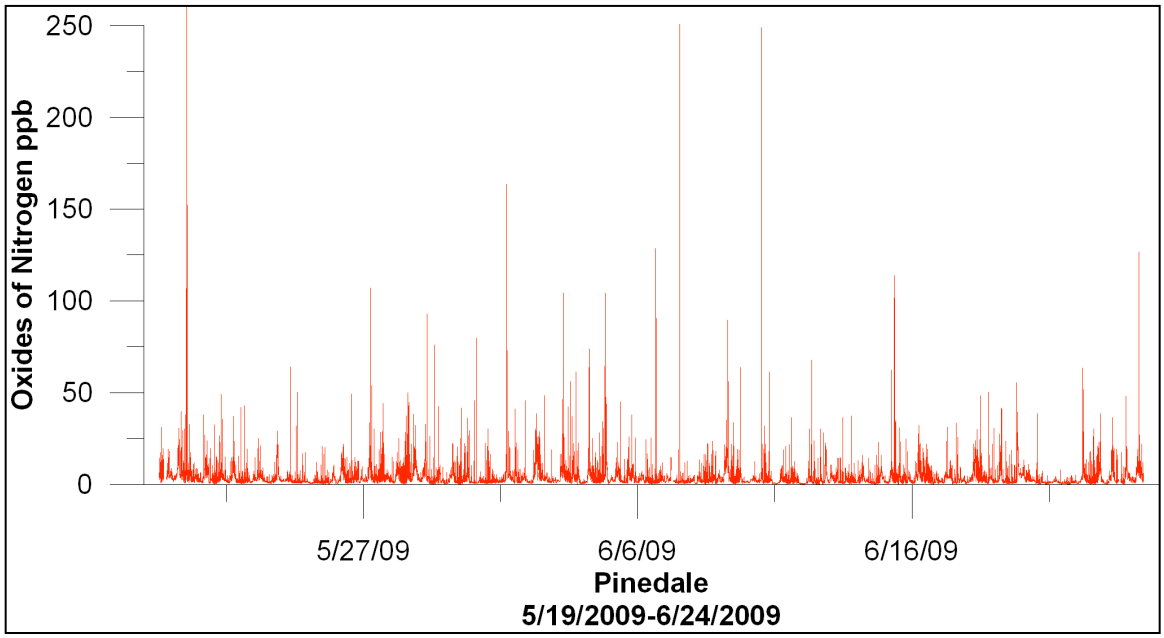
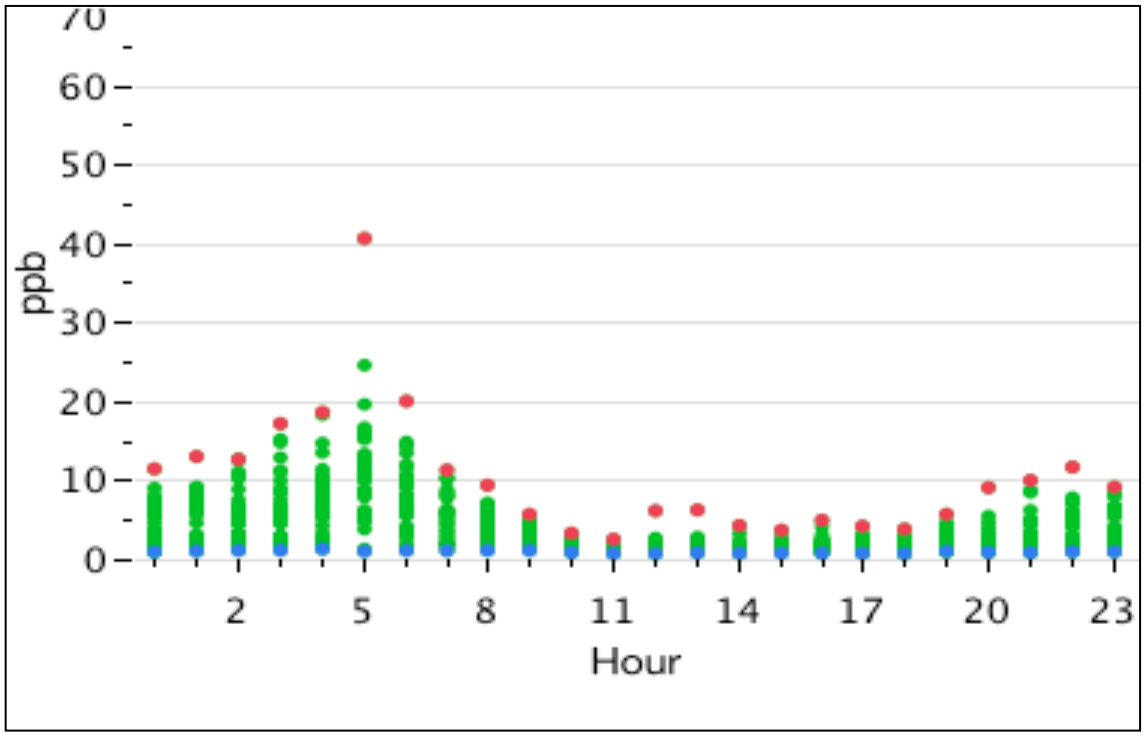
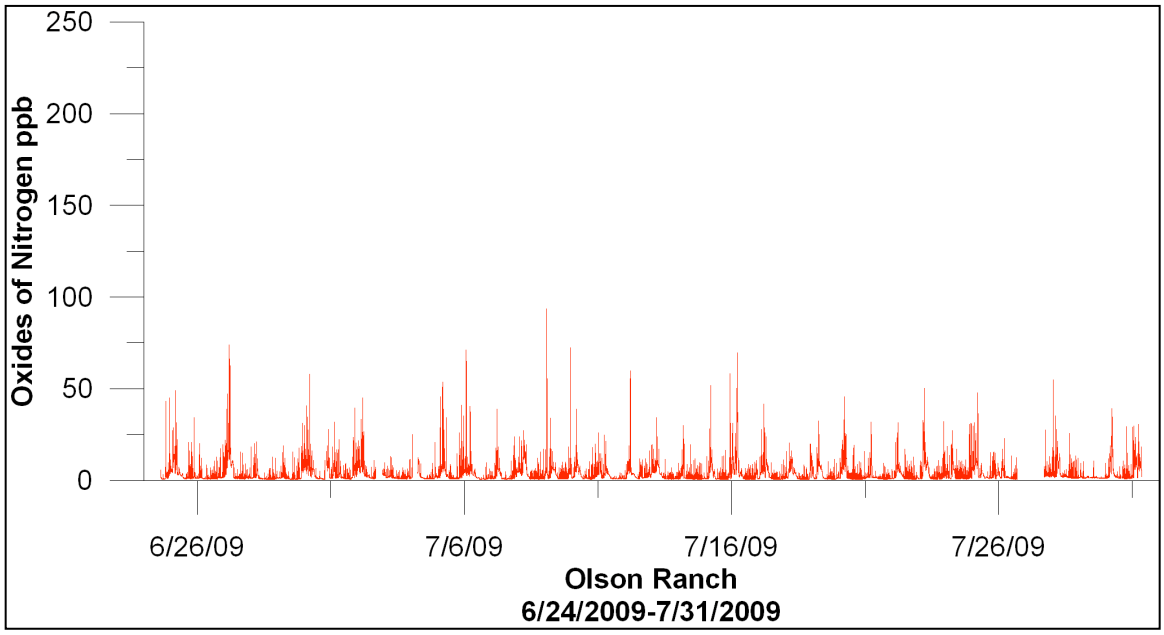


Figure 5-64. Olson Ranch NO_x diurnal plot for the period 06/24/2009– 07/31/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-65. Olson Ranch NO_x time series for the period 06/24/2009– 07/31/2009.



5.3.4 Nitric Oxide

Table 5-11 presents highest and second highest daily 1-hour average NO concentrations, and highest daily twenty-four hour averages that occurred during the period beginning January 31, 2009 and ending July 31, 2009. The times that are represented in this table are similar to those given in Table 5-10, in particular for 1-hour maximum values. This is no surprise given that NO is a one of the two components of the NO_x measurement. Four of the five highest 1-hour average values for NO on Table 5-11 are the exact same hour as for NO_x. Three of the five highest 1-hour average values for NO_x are again reported at Luman Road. High 1-hour average values are also reported for Pinedale, Big Piney and Olson Ranch. By Contrast to Table 5-10, Luman Road has all of the five highest daily average values. This site was situated downwind of oil and gas development and is also next to one of the main entry roads into the Jonah development. Figures 5-66 through 5-75 represent the diurnal plot and time series plot of ambient NO concentrations at each of the monitoring sites over the whole of the O3i operational period.

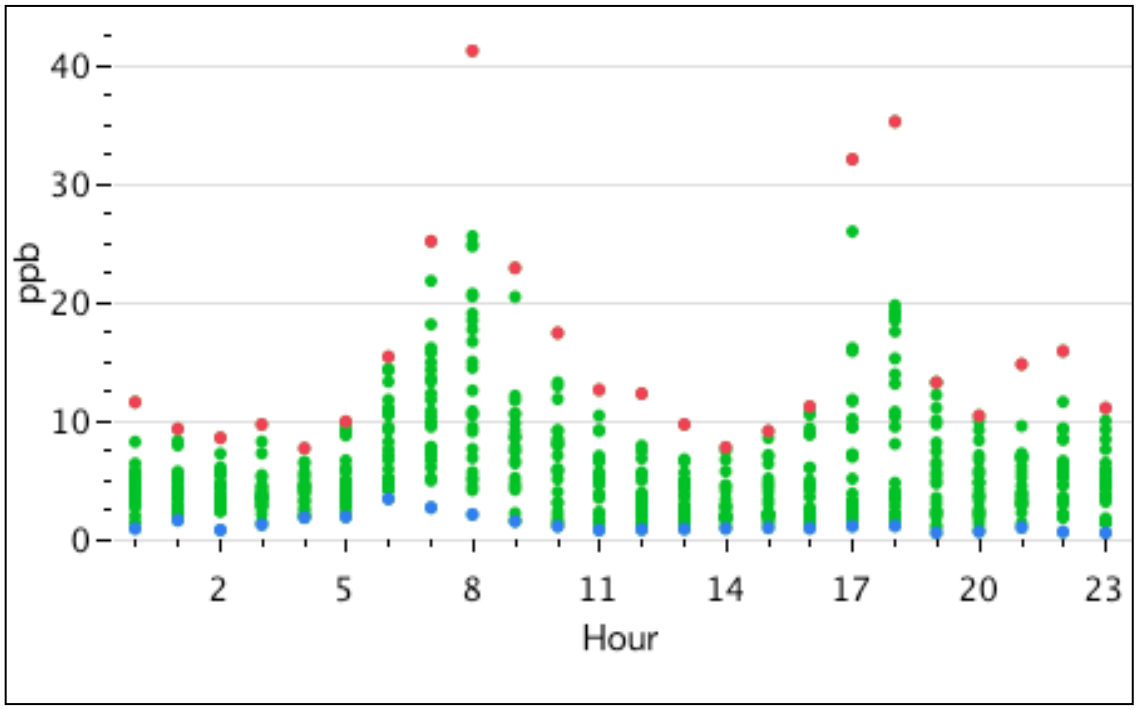
With respect to the diurnal plots, the typical behavior is a morning peak followed by a mid day trough and a late afternoon rise in concentrations. The afternoon pattern shows divergence from that for NO_x. However the balance of this pattern is also divergent between sites. At Big Piney, Figure 5-66, the morning peak is more pronounced with a discernable afternoon peak. At Luman Road, Figure 5-68, a similar, though less pronounced, pattern is evident, with the morning peak earlier in the day. At Boulder South Road, Pinedale and Olson Ranch, Figures 5-70, 5-72 and 5-74, an afternoon peak is practically indiscernible.

Time series plots for NO indicate a behavior similar to that of NO_x, albeit with a lower magnitude. Site to site differences are also evident. At Big Piney, Figure 5-67, high concentration spikes are less frequent and rarely exceed 50 ppb. By contrast, at Luman Road, Figure 5-69, there are far more concentration spikes that often exceed 50 ppb. The Boulder South Road site, Pinedale site and Olson Ranch site (Figure 5-71, Figure 7-73 and Figure 5-75) exhibit a similar behavior to each other. These sites all show far less concentration spiking than at Luman Road. Of these three sites Pinedale, Figure 5-73, shows the most concentration spikes above 50 ppb.

Table 5-11. UW MAQML five highest daily 1-hour averages, 2nd highest daily 1-hour averages, and 24-hour averages for NO.

University of Wyoming Mobile Air Quality Monitoring Laboratory *5 Highest Daily 1-Hour Averages, 2nd Highest Daily 1-Hour Averages, and 24-Hour Averages for NO* Final Validation 01/31/2009 – 07/31/2009				
Highest Daily 1-Hour Averages				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	3/10/09	6	43.37	Luman Rd
2	3/14/09	5	35.05	Luman Rd
3	3/13/09	23	33.21	Luman Rd
4	7/16/09	5	32.43	Olson Ranch
5	5/20/09	13	31.59	Pinedale
2nd Highest Daily 1-Hour Averages				
1	2/19/09	9	29.79	Big Piney
2	3/13/09	22	28.54	Luman Rd
3	2/18/09	8	26.5	Big Piney
4	3/09/09	6	17.92	Luman Rd
5	3/02/09	7	16.59	Luman Rd
Highest Daily 24-Hour Averages				
1	3/10/09	0-23:00	5.48	Luman Rd
2	3/13/09	0-23:00	4.56	Luman Rd
3	3/14/09	0-23:00	4.45	Luman Rd
4	3/11/09	0-23:00	4.19	Luman Rd
5	3/12/09	0-23:00	3.64	Luman Rd

Figure 5-66. Big Piney NO diurnal plot for the period 01/31/2009 – 02/27/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-67. Big Piney NO time series for the period 01/31/2009 – 02/27/2009.

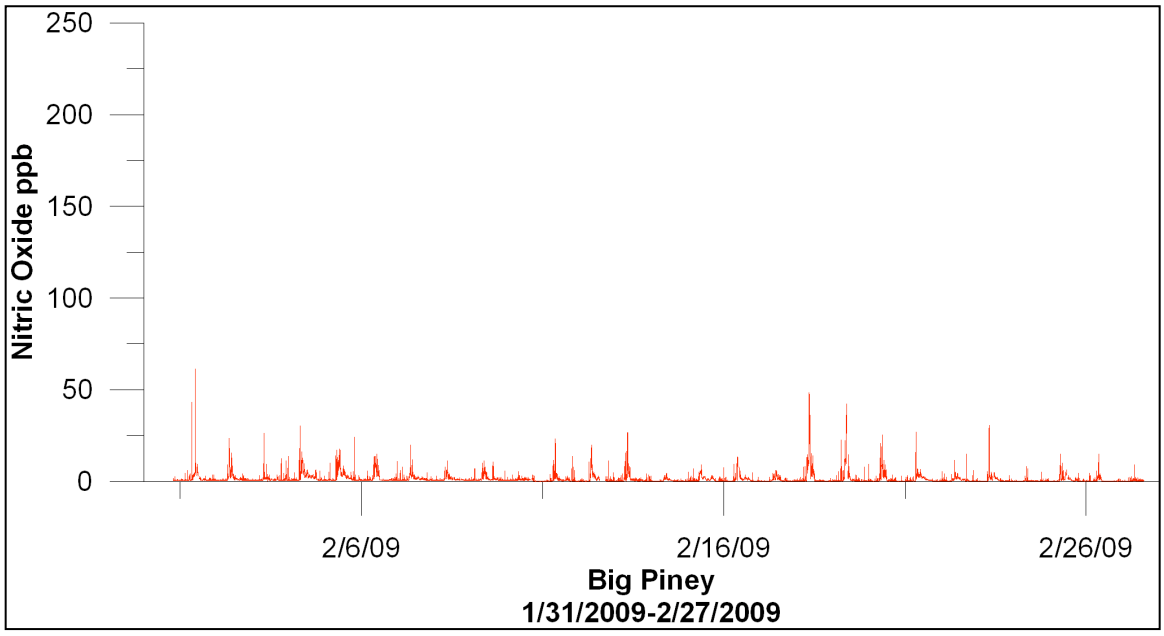


Figure 5-68. Luman Road NO diurnal plot for the period 2/27/2009 – 4/1/2009.

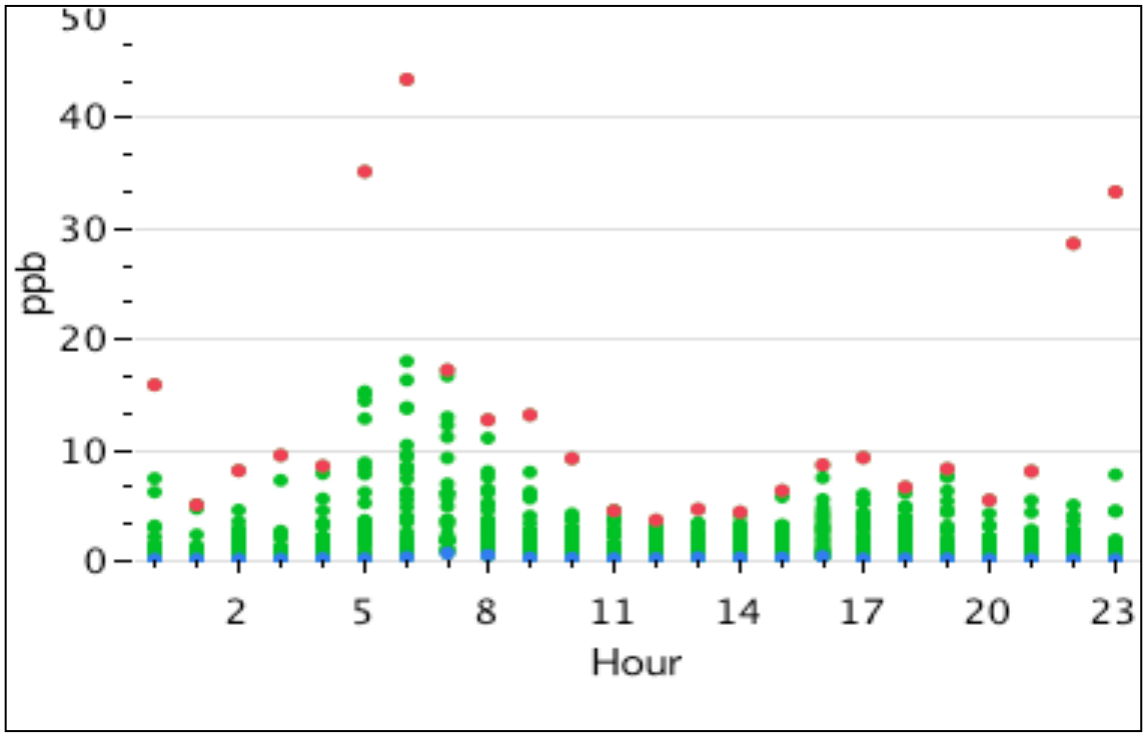


Figure 5-69. Luman Road NO time series for the period 2/27/2009 – 4/1/2009.

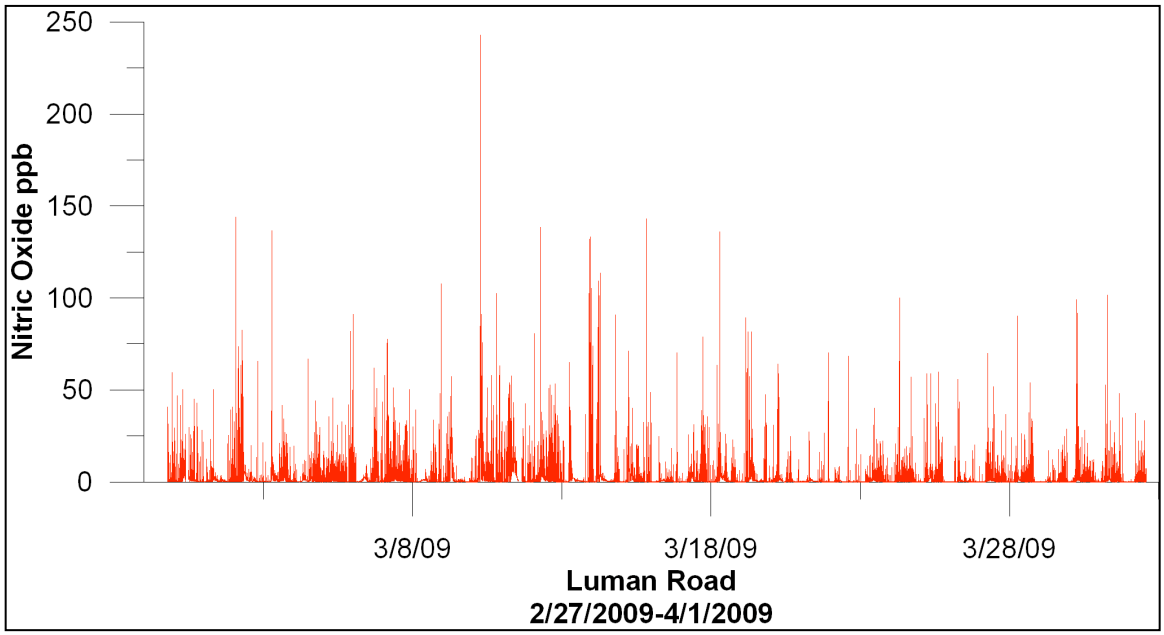


Figure 5-70. Boulder South Road NO diurnal plot for the period 04/01/2009 – 05/19/2009.

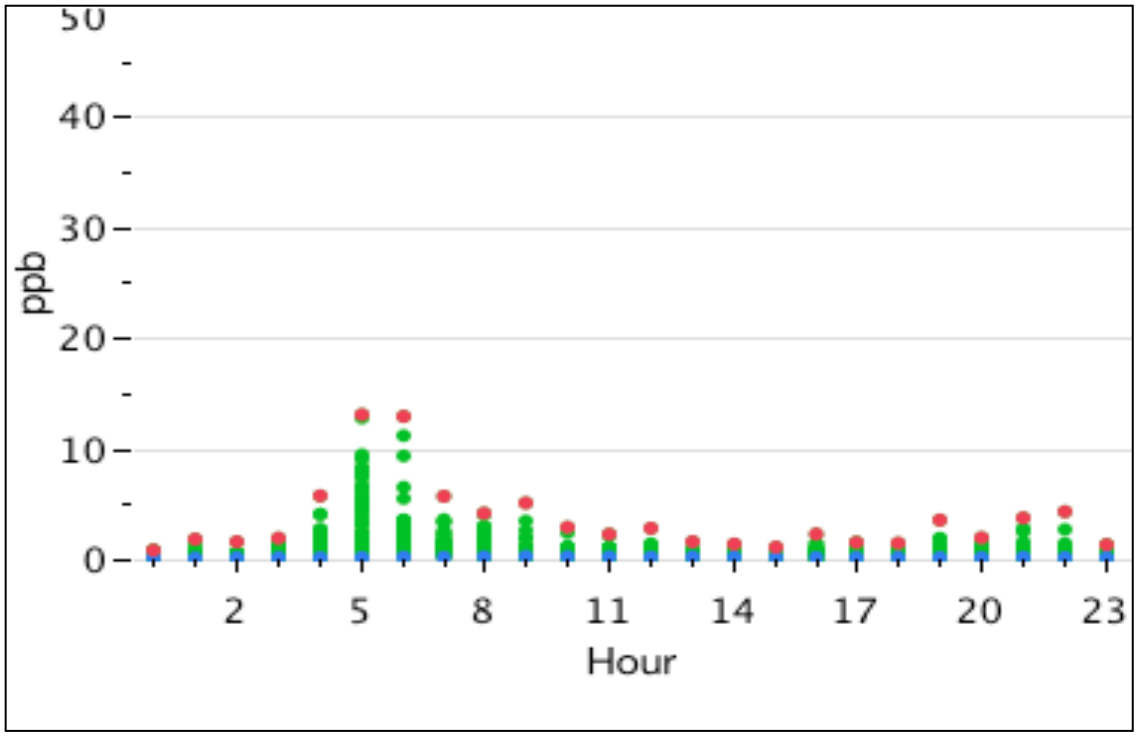


Figure 5-71. Boulder South Road NO time series for the period 04/01/2009 – 05/19/2009.

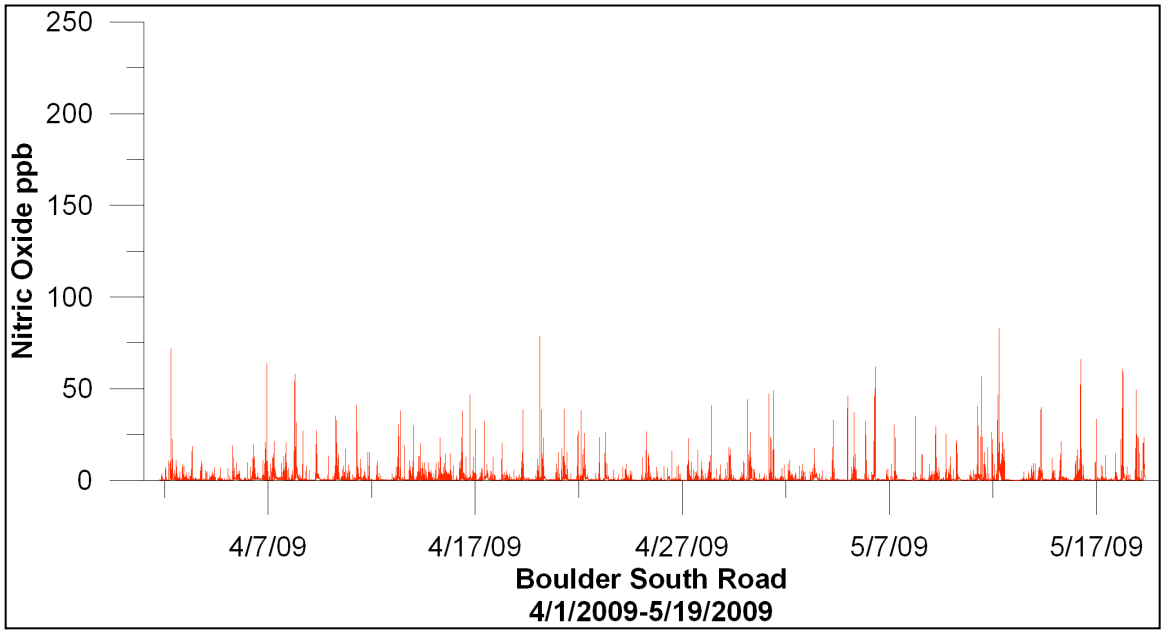
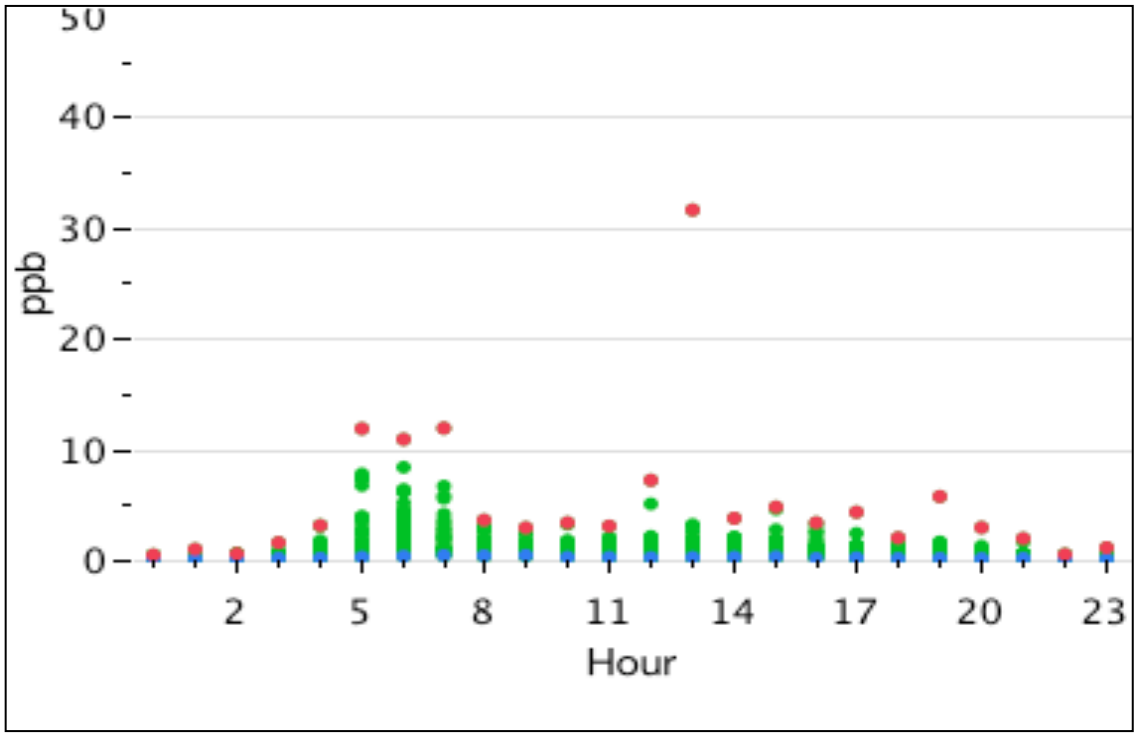


Figure 5-72. Pinedale NO diurnal plot for the period 05/19/2009 – 06/24/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-73. Pinedale NO time series for the period 05/19/2009 – 06/24/2009.

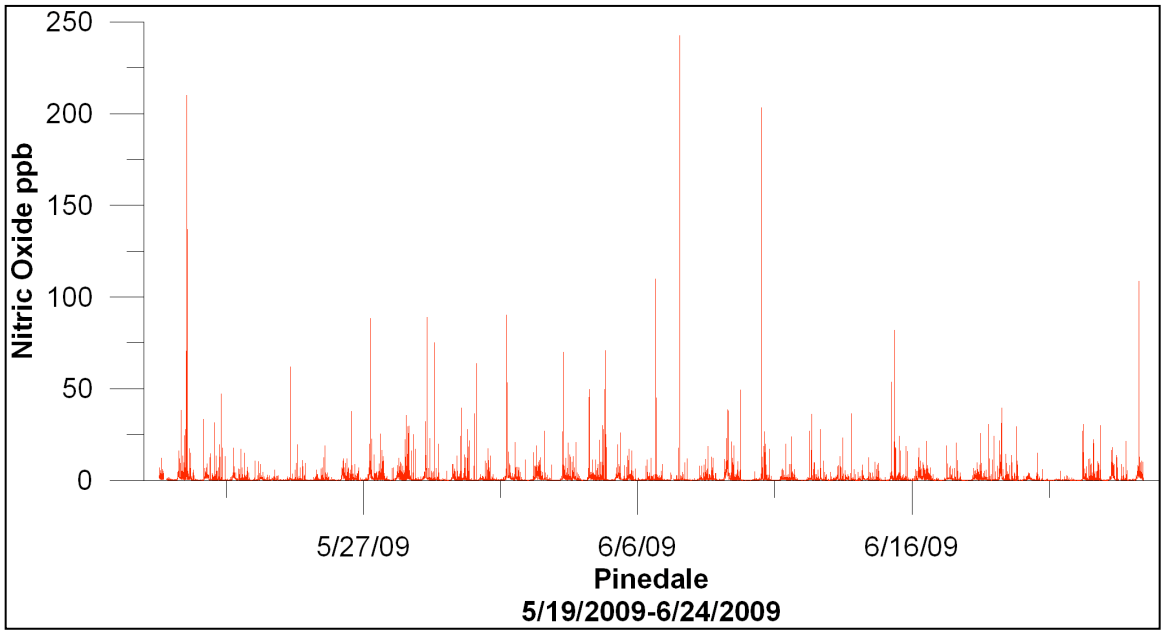
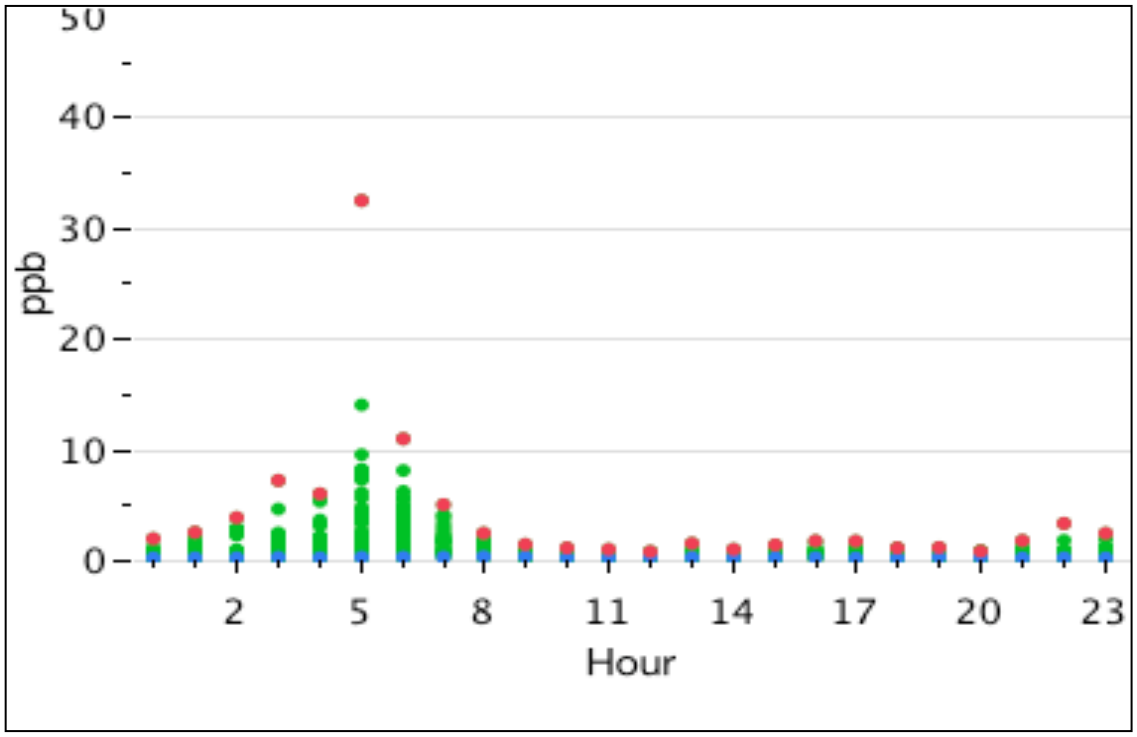
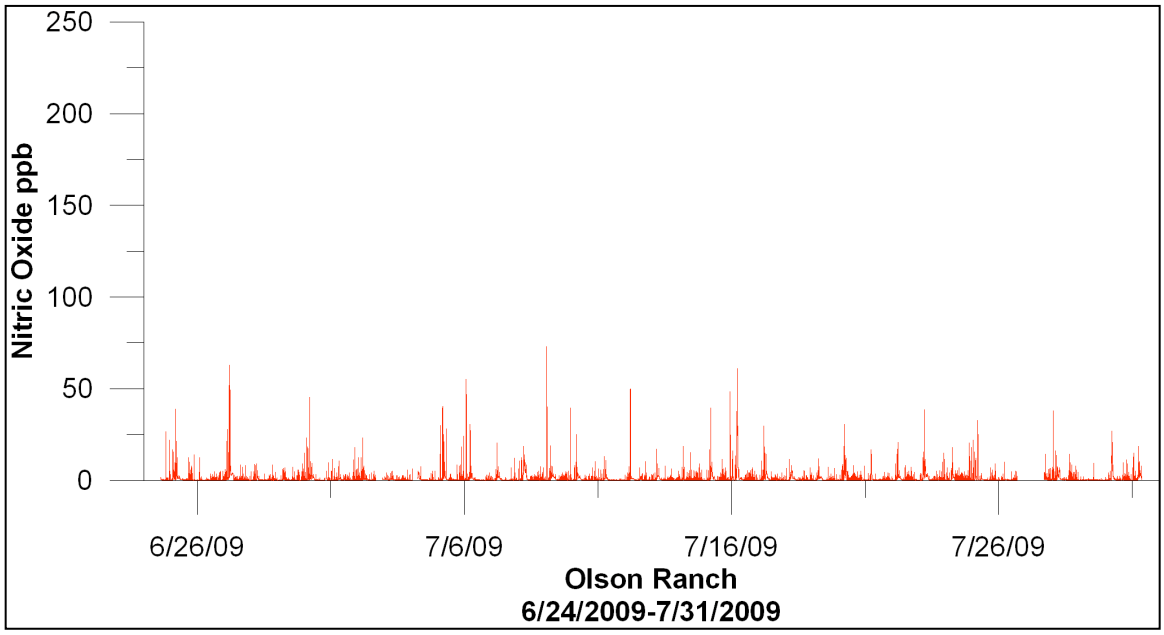


Figure 5-74. Olson Ranch NO diurnal plot for the period 06/24/2009– 07/31/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-75. Olson Ranch NO time series for the period 06/24/2009– 07/31/2009.



5.3.5 Nitrogen Dioxide

Table 5-12 presents highest and second highest daily 1-hour average NO_2 concentrations, and highest daily twenty-four hour averages that occurred during the period beginning January 31, 2009 and ending July 31, 2009. The times that are represented in this table show that NO_2 1-hour maximum values occur at different times to those of NO_x and NO. The highest 1-hour average values for NO_2 reported in Table 5-12 are from the Big Piney and Luman Road sites. However when considering daily maximum four of the highest five values are common with those given in Tables 5-11 for NO_x. While this may be expected given that NO_2 is one of the two components of NO_x measurement it contrasts with the behavior evident for NO. Figures 5-76 through 5-85 represent the diurnal plot and time series plot of ambient NO_2 concentrations at each of the monitoring sites over the whole of the O3i operational period.

With respect to the diurnal plots for NO_2, the typical behavior at each site (Big Piney Figure 5-76, Luman Road Figure 5-78, Boulder South Road Figure 5-80, Pinedale Figure 5-82 and Olson Ranch Figure 5-84) is a morning peak followed by a mid day trough and a late afternoon peak of concentrations. The afternoon pattern shows divergence from that shown for NO_x and NO. This can be expected for a secondary pollutant whose main production route is through daytime photochemical reaction. NO_2 is a product from the reaction:

$NO + O_3 \rightarrow NO_2 + O_2$.

This reaction consumes O_3. NO_2 is produced via a photochemical production during which it may serve as an ozone precursor.

NO_2 + sunlight $\rightarrow$ NO + O, then O + $O_2 \rightarrow O_3$

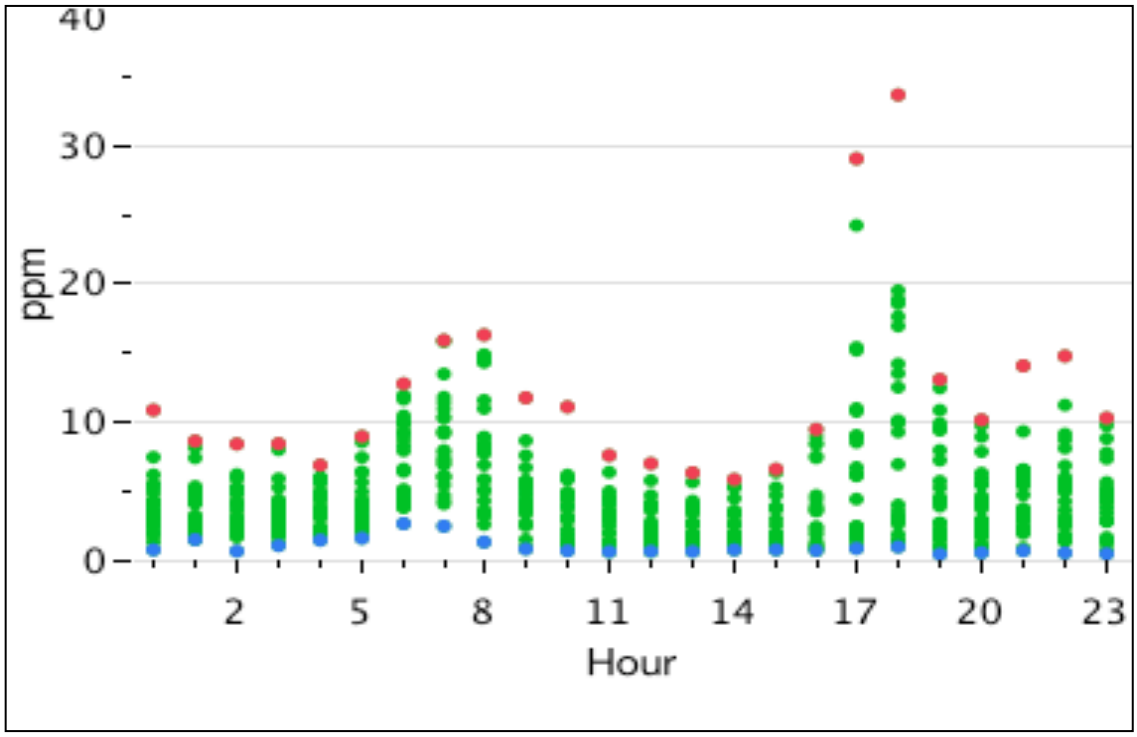
When peroxy and hydro-peroxy radical chemistry is considered, there is net production of NO_2 which does not consume O_3. During this time NO_2 may also serve as a precursor to O_3 based on this reaction.

The time series plots of NO_2 indicate a similar behavior as that of NO_x, albeit with a lower magnitude. Site to site differences are also evident. At Big Piney, Figure 5-77, high concentration spikes for NO_2 are more frequent than for NO. At Luman Road, Figure 5-79, the reverse is shown. The Boulder South Road site, Pinedale site and Olson Ranch site (Figure 5-81, Figure 5-83 and Figure 5-85) exhibit a similar behavior to each other. These sites all show far less concentration spiking than at Luman Road. Of these three sites Pinedale, Figure 5-73, shows the most concentration spikes above 50 ppb.

Table 5-12. UW MAQML five highest daily 1-hour averages, 2nd highest daily 1-hour averages, and 24-hour averages for NO_2.

University of Wyoming Mobile Air Quality Monitoring Laboratory *5 Highest Daily 1-Hour Averages, 2nd Highest Daily 1-Hour Averages, and 24-Hour Averages for NO_2* Final Validation 01/31/2009 – 07/31/2009				
Highest Daily 1-Hour Averages				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	2/04/09	18	33.58	Big Piney
2	3/10/09	5	28.11	Luman Rd
3	2/05/09	17	24.15	Big Piney
4	3/14/09	5	20.18	Luman Rd
5	2/22/09	18	19.44	Big Piney
2nd Highest Daily 1-Hour Averages				
1	2/04/09	17	28.97	Big Piney
2	3/10/09	6	24.89	Luman Rd
3	3/02/09	7	19.24	Luman Rd
4	2/16/09	18	18.81	Big Piney
5	6/19/09	20	18.75	Pinedale
Highest Daily 24-Hour Averages				
1	2/05/09	0-23:00	9.02	Big Piney
2	3/02/09	0-23:00	8.24	Luman Rd
3	3/14/09	0-23:00	7.95	Luman Rd
4	3/11/09	0-23:00	7.58	Luman Rd
5	2/23/09	0-23:00	7.18	Big Piney

Figure 5-76. Big Piney NO_2 diurnal plot for the period 01/31/2009 – 02/27/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-77. Big Piney NO_2 time series for the period 01/31/2009 – 02/27/2009.

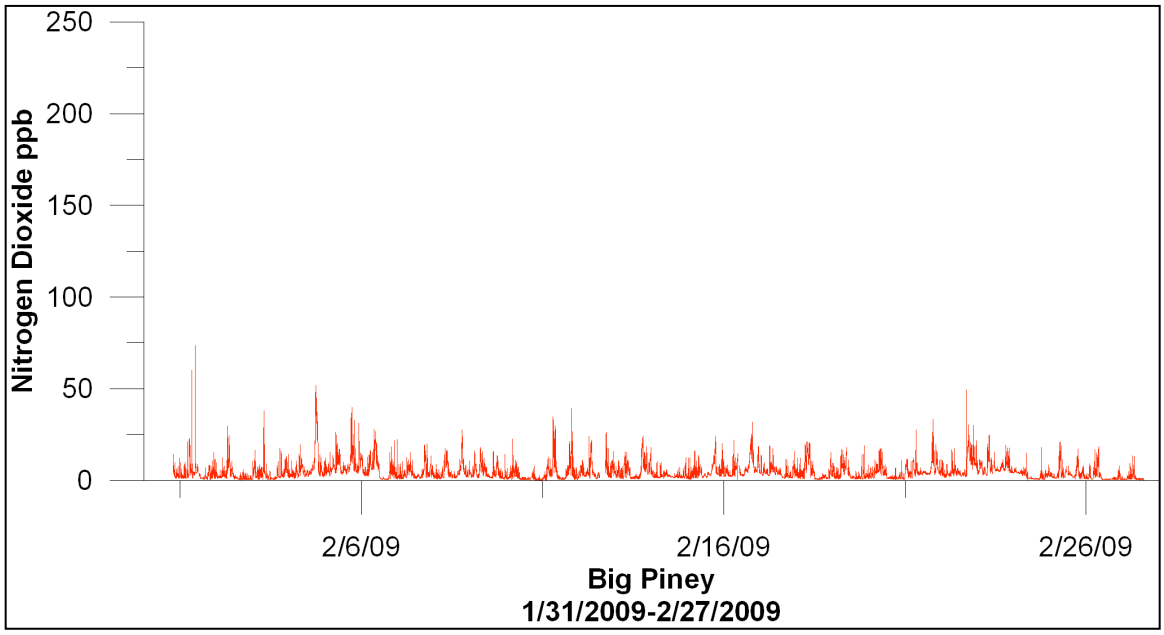


Figure 5-78. Luman Road NO_2 diurnal plot for the period 2/27/2009 – 4/1/2009.

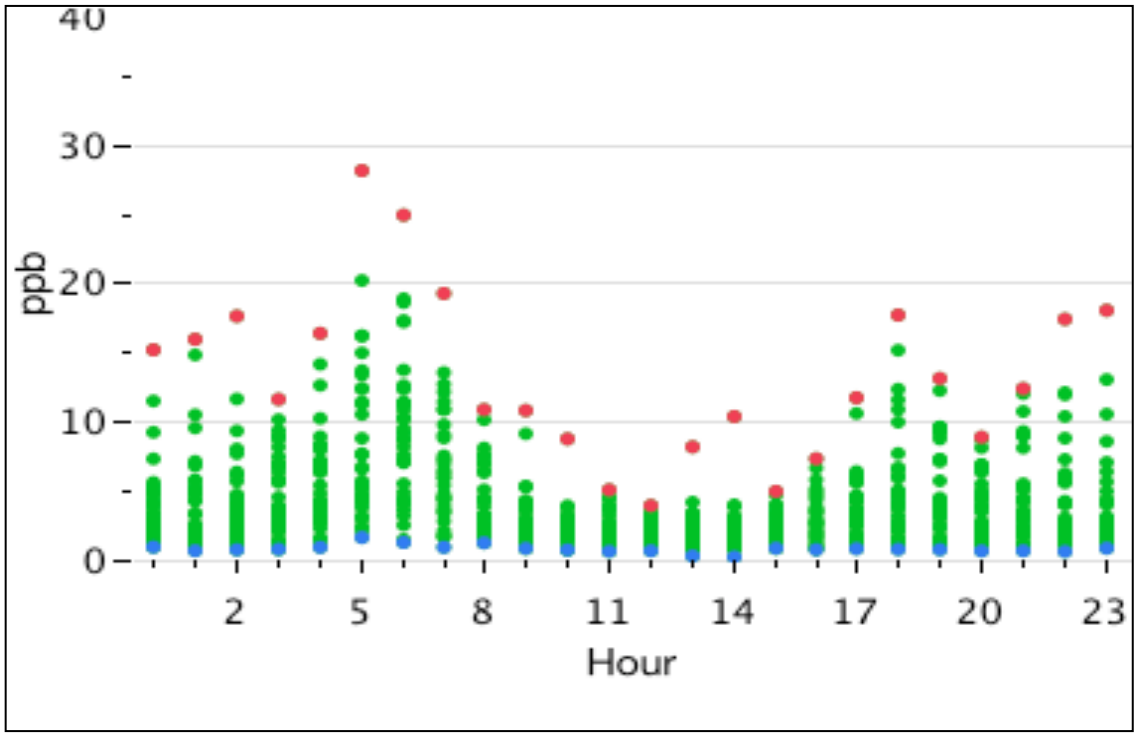


Figure 5-79. Luman Road NO_2 time series for the period 2/27/2009 – 4/1/2009.

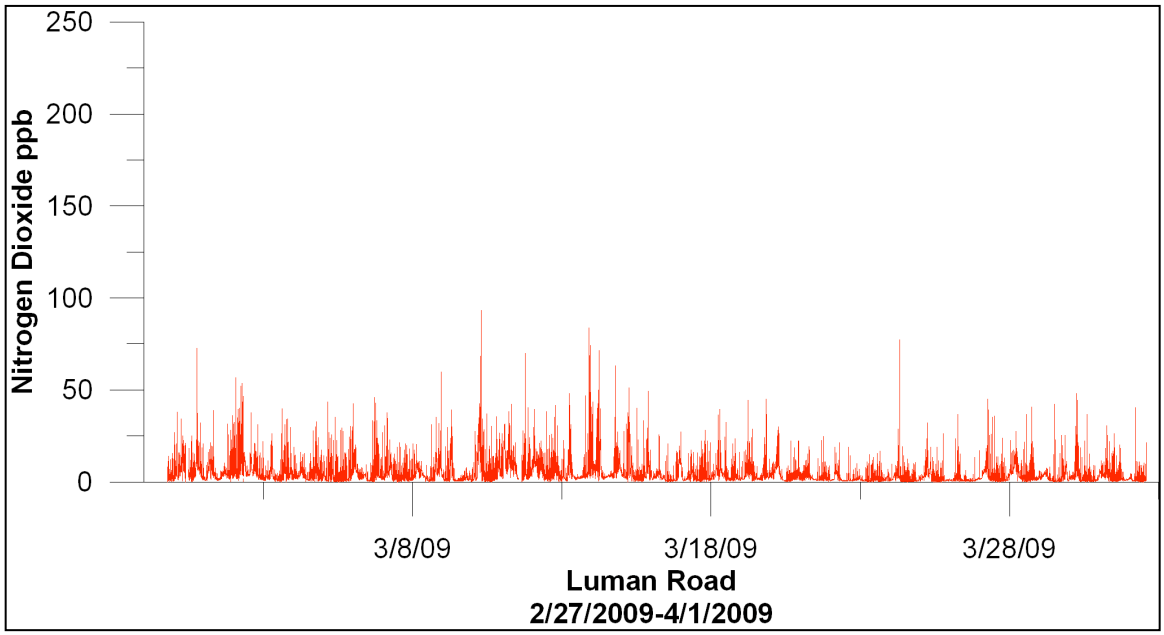
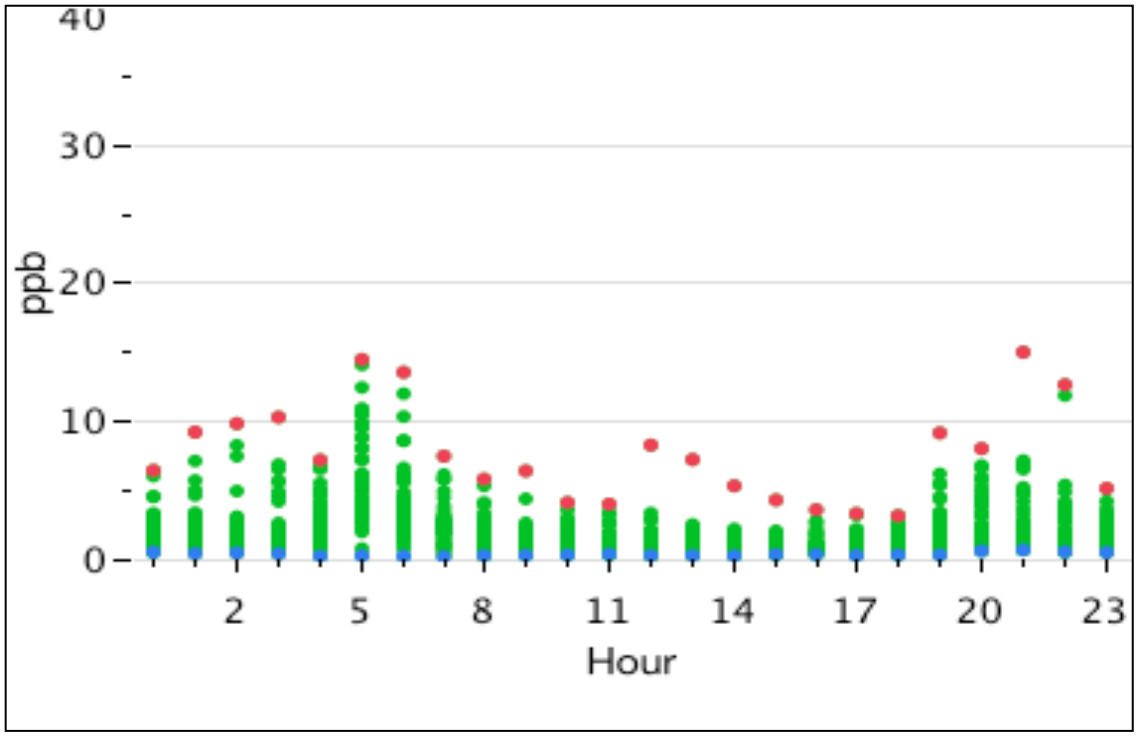


Figure 5-80. Boulder South Road NO_2 diurnal plot for the period 04/01/2009 – 05/19/2009.



• Hourly Maximum • Hourly Average • Hourly Minimum

Figure 5-81. Boulder South Road NO_2 time series for the period 04/01/2009 – 05/19/2009.

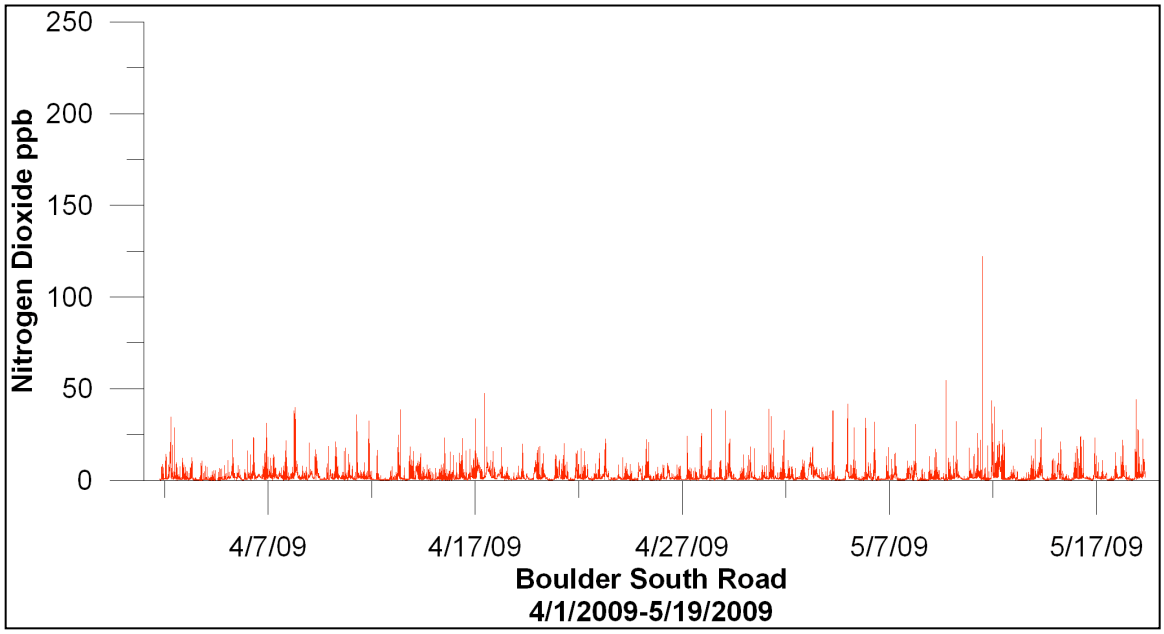


Figure 5-82. Pinedale NO_2 diurnal plot for the period 05/19/2009 – 06/24/2009.

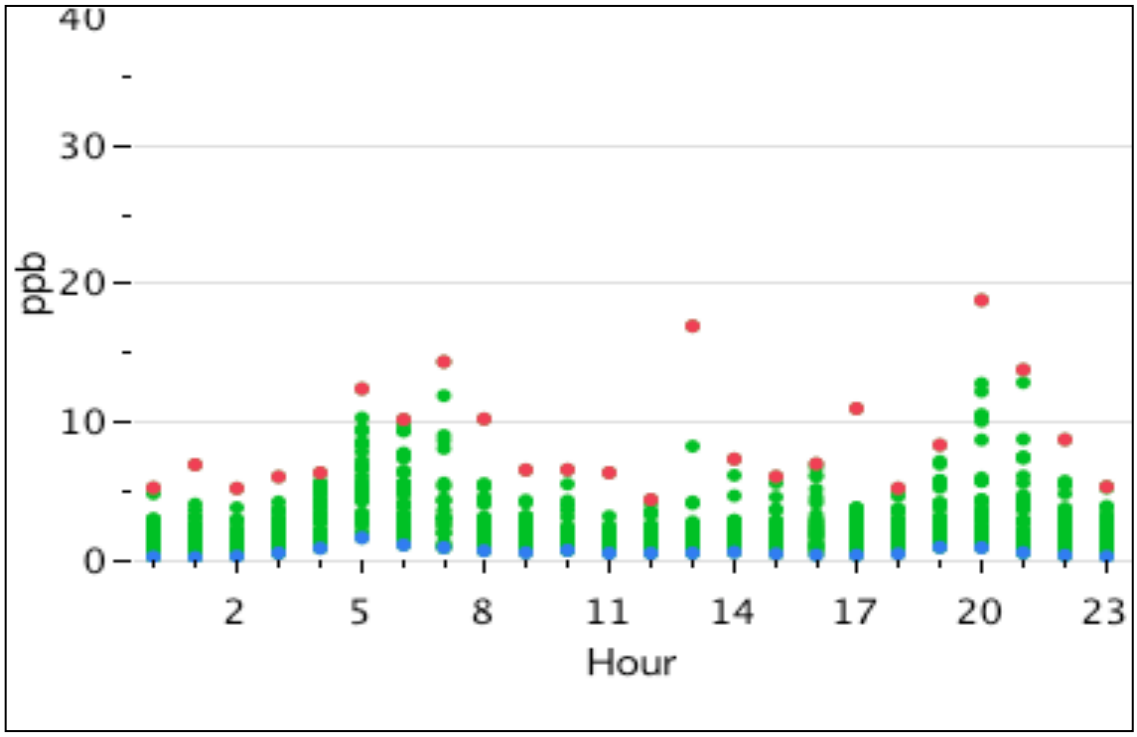


Figure 5-83. Pinedale NO_2 time series for the period 05/19/2009 – 06/24/2009.

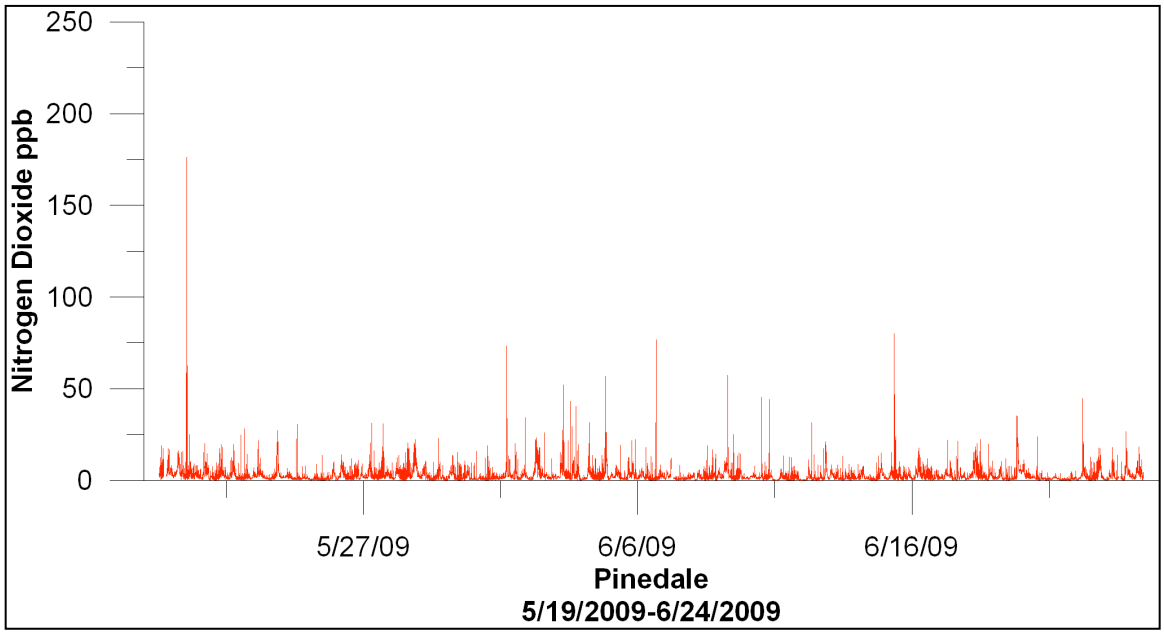


Figure 5-84. Olson Ranch NO_2 diurnal plot for the period 06/24/2009– 07/31/2009.

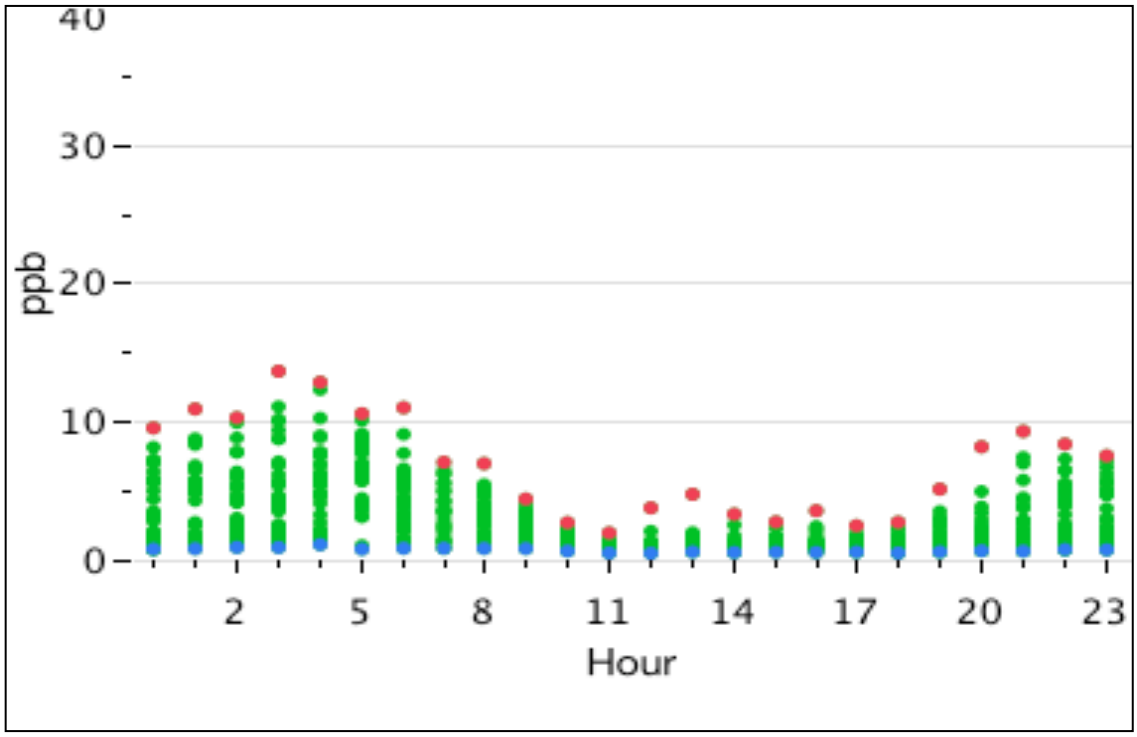
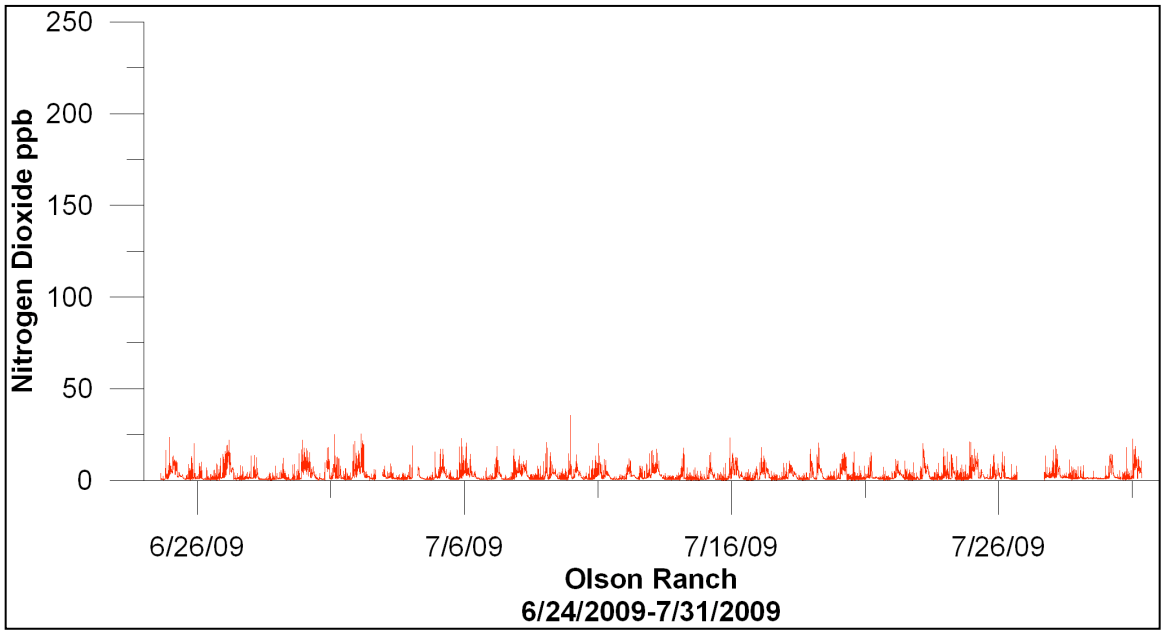


Figure 5-85. Olson Ranch NO_2 time series for the period 06/24/2009– 07/31/2009.



5.3.6 Ozone Data Summaries

Table 5-13 presents the ten highest daily 1-hour average O_3 concentrations that occurred during the period beginning January 31, 2009 and ending July 31, 2009. This table is intended for comparative purposes as the O3i study was conducted at multiple sites. The ten highest hourly values occurred at the three sites monitored during the colder winter months, namely Big Piney, Luman Road and Boulder South Road. Three days each had 3 hourly values of levels over 70 ppb: 02/23/2009 at Big Piney; 03/29/2009 at Luman road and 04/08/2009 at Boulder South Road. Table 5-14 presents the ten highest daily 8-hour average O_3 concentrations. Again all of these values are below the standard value of 0.075 ppm. By contrast to Table 5-2 all of these values are at one site, Boulder South Road. Three days are represented by this table; 04/08/2008, 04/28/2009 and 05/01/2009. The reason for the relative difference in representation between these two tables is explained by viewing the figures given in the remainder of this section. While there can be anticipated to be a seasonal variation in behavior at each given sites combined with the influence of meteorology, the ozone behavior at Boulder South Road is different to that at Big Piney and Luman Road. At the latter two sites ozone levels exhibit a more defined peak in late afternoon, whereas levels at Boulder South Road are less variable. As such, when levels are relatively high at this site 8-hour rolling averages are higher than those at sites with higher peak levels set within declining concentrations before and after peak levels are reached.

Figures 5-86 through 5-95 represent the diurnal plot and time series plot of ambient O_3 concentrations for each of the monitoring sites over the whole of the O3i operational period. With respect to the diurnal plots the typical behavior for each of the monitoring sites is a rise from an early morning trough to an afternoon peak followed by a decline. This behavior was marked for Big Piney, Figure 5-86, and Luman Road, Figure 5-88. For Boulder South Road, Figure 5-90, Pinedale, Figure 5-92 and Olson Ranch, Figure 5-94, while a similar curve is evident the afternoon peak is less clearly defined. Boulder South Road exhibits the widest variation on an hour-by-hour basis.

The time series plots for O_3 once again reinforce the benefits indicated earlier of viewing short time averaged data over relatively long time periods. At Big Piney, Figure 5-87, the diurnal variation is visible with the highest values occurring on the day indicated previously. A similar pattern is visible at all the sites. As indicated by this figure, short-term levels exceeding 75 ppb occurred only one day at this site. At Luman Road, Figure 5-89, that threshold was exceeded on five occasions. Again Boulder South Road, Figure 5-91, shows the potential for high ozone levels, with seven days exceeding a short-term level of 75 ppb. While short-term ozone levels at Pinedale only exceeded 75 ppb on one occasion, the levels at Olson Ranch did not exceed 75 ppb.

Table 5-13. UW MAQML ten highest daily 1-hour average concentrations for O_3.

University of Wyoming Mobile Air Quality Monitoring Laboratory 10 Highest Daily 1-Hour Average Maximum Concentrations 01/31/2009 – 07/31/2009				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	2/23/09	16	82.51	Big Piney
2	4/08/09	20	78.44	Boulder South Rd
3	2/23/09	17	76.18	Big Piney
4	2/23/09	15	74.37	Big Piney
5	3/29/09	12	74.25	Luman Rd
6	4/08/09	19	73.85	Boulder South Rd
7	3/29/09	13	73.76	Luman Rd
8	3/14/09	16	73.68	Luman Rd
9	4/17/09	14	73.41	Boulder South Rd
10	4/08/09	18	73.36	Boulder South Rd

Table 5-14. UW MAQML summary of the ten highest daily maximum 8-hour averages.

University of Wyoming Mobile Air Quality Monitoring Laboratory Summary of the 10 Highest Daily Maximum 8-Hour Averages 01/31/2009 – 07/31/2009				
Value	**Date**	**Hour**	**Concentration ppb**	**Site**
1	5/01/09	11-18	70.16	Boulder South Rd
2	4/28/09	10-17	69.86	Boulder South Rd
3	5/01/09	10-17	69.83	Boulder South Rd
4	4/28/09	11-18	69.70	Boulder South Rd
5	4/28/09	12-19	68.78	Boulder South Rd
6	4/08/09	16-23	68.70	Boulder South Rd
7	4/08/09	14-21	68.53	Boulder South Rd
8	5/01/09	9-16	68.52	Boulder South Rd
9	4/08/09	15-22	68.44	Boulder South Rd
10	5/01/09	12-19	68.33	Boulder South Rd

Figure 5-86. Big Piney O_3 diurnal chart for the period 01/31/2009 – 02/27/2009.

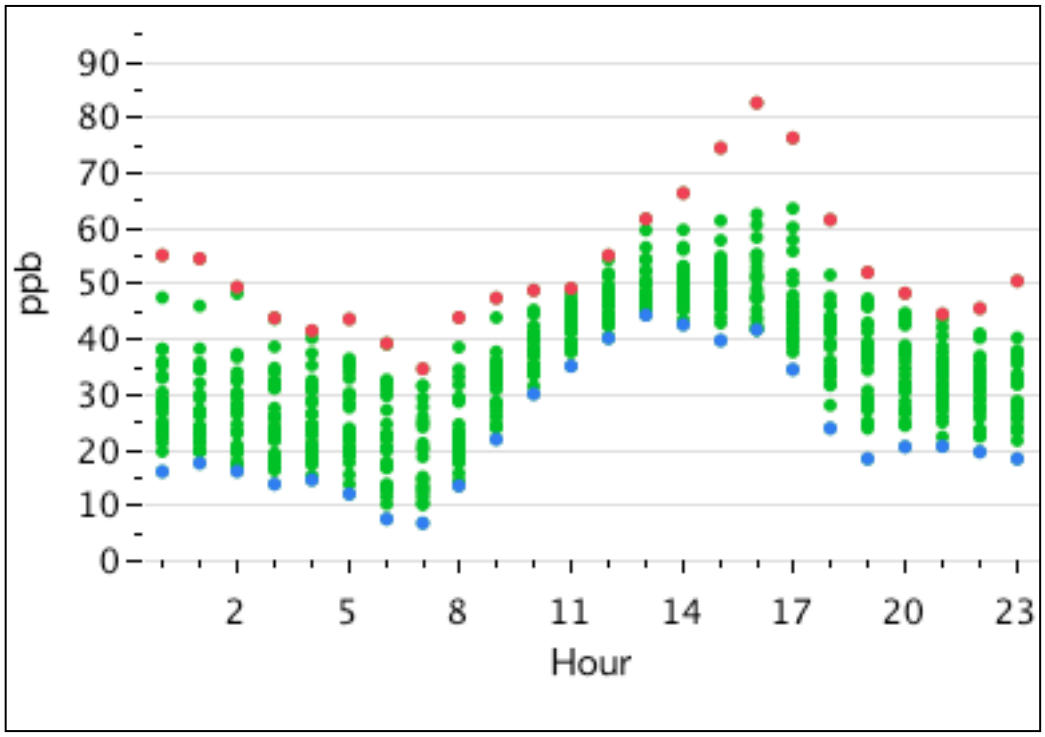


Figure 5-87. Big Piney O_3 time series for the period 01/31/2009 – 02/27/2009.

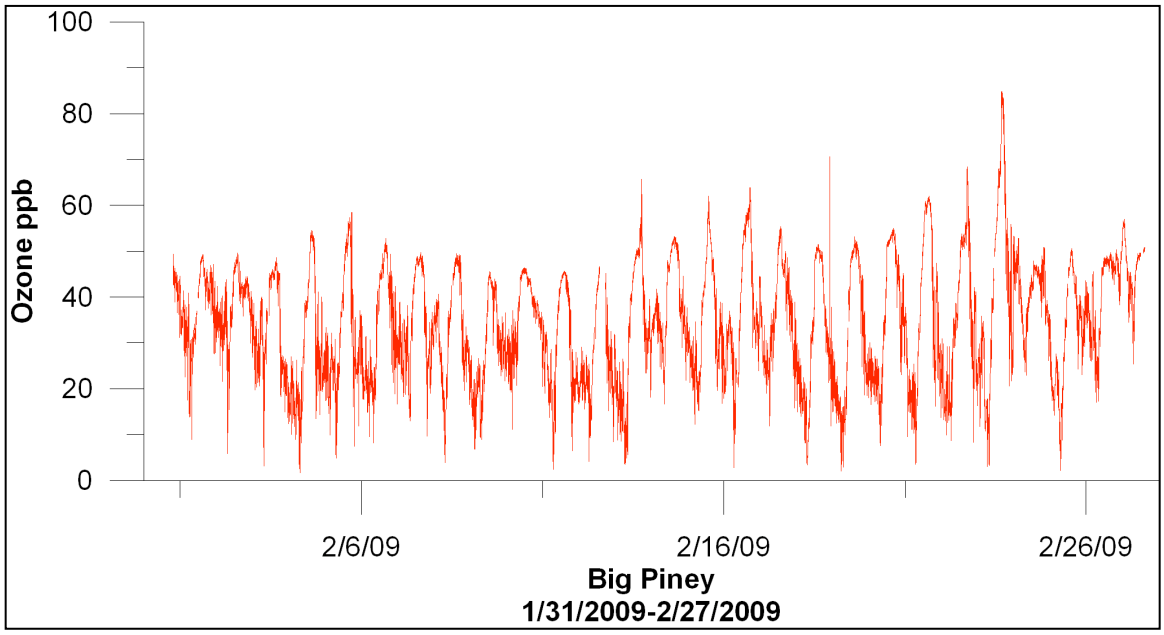


Figure 5-88. Luman Road O_3 diurnal chart for the period 2/27/2009 – 4/1/2009.

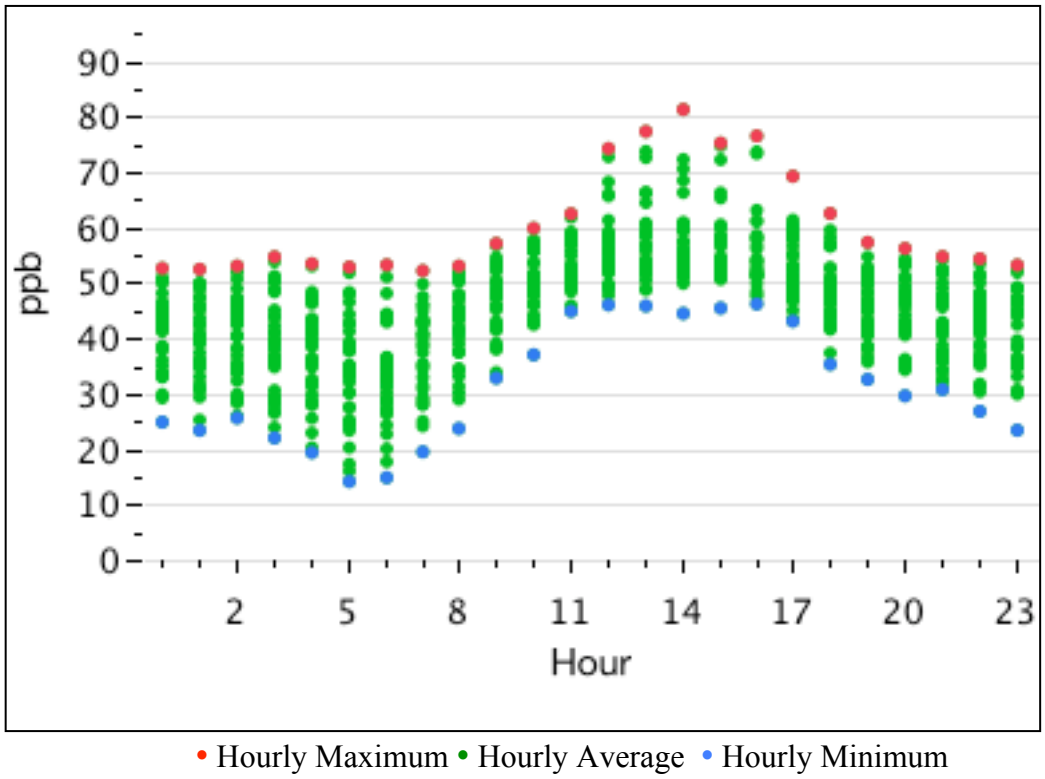


Figure 5-89. Luman Road O_3 time series for the period 2/27/2009 – 4/1/2009.

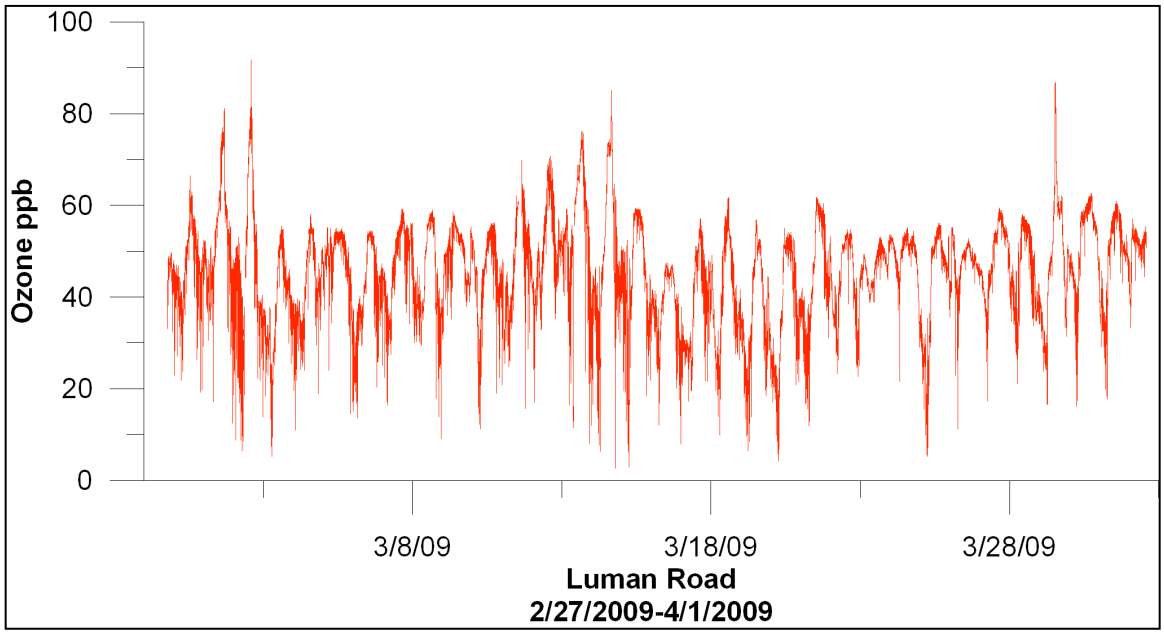


Figure 5-90. Boulder South Road O_3 diurnal chart for the period 04/1/2009 – 05/19/2009.

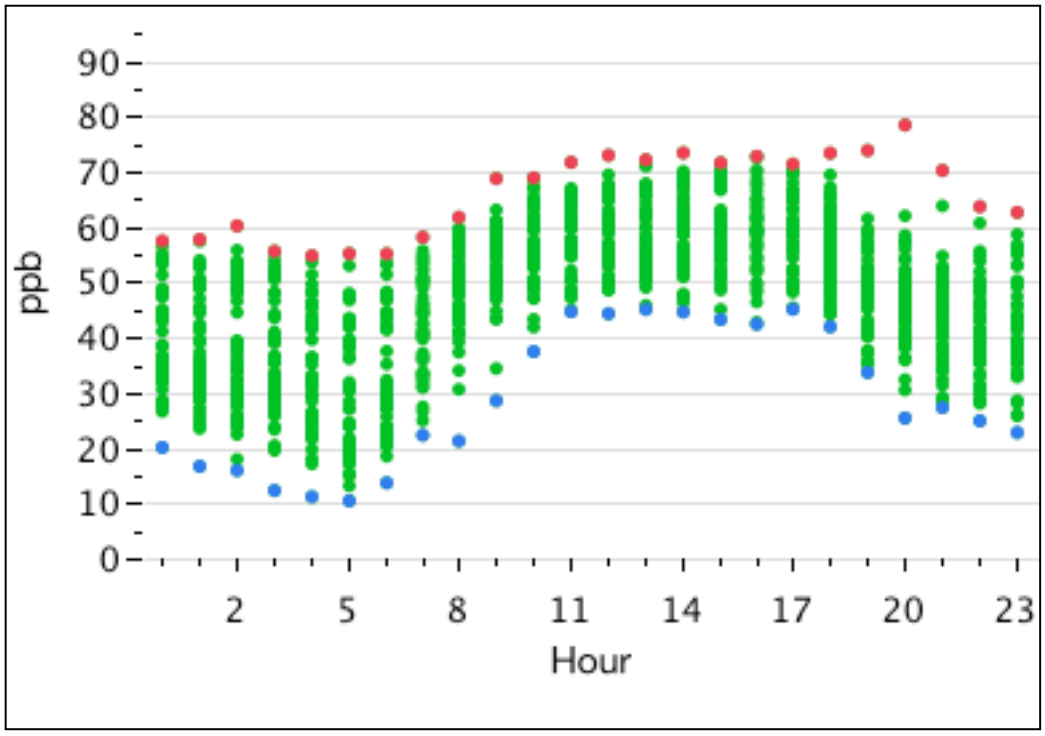


Figure 5-91. Boulder South Road O_3 time series for the period 04/1/2009 – 05/19/2009.

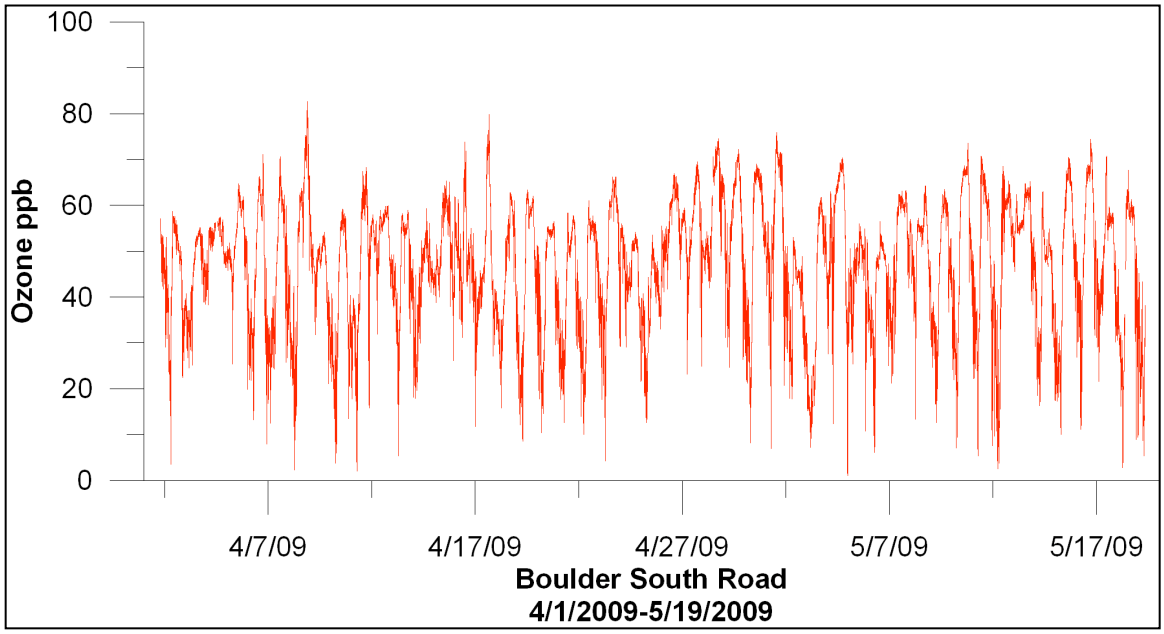


Figure 5-92. Pinedale O_3 diurnal chart for the period 05/19/2009 – 06/24/2009.

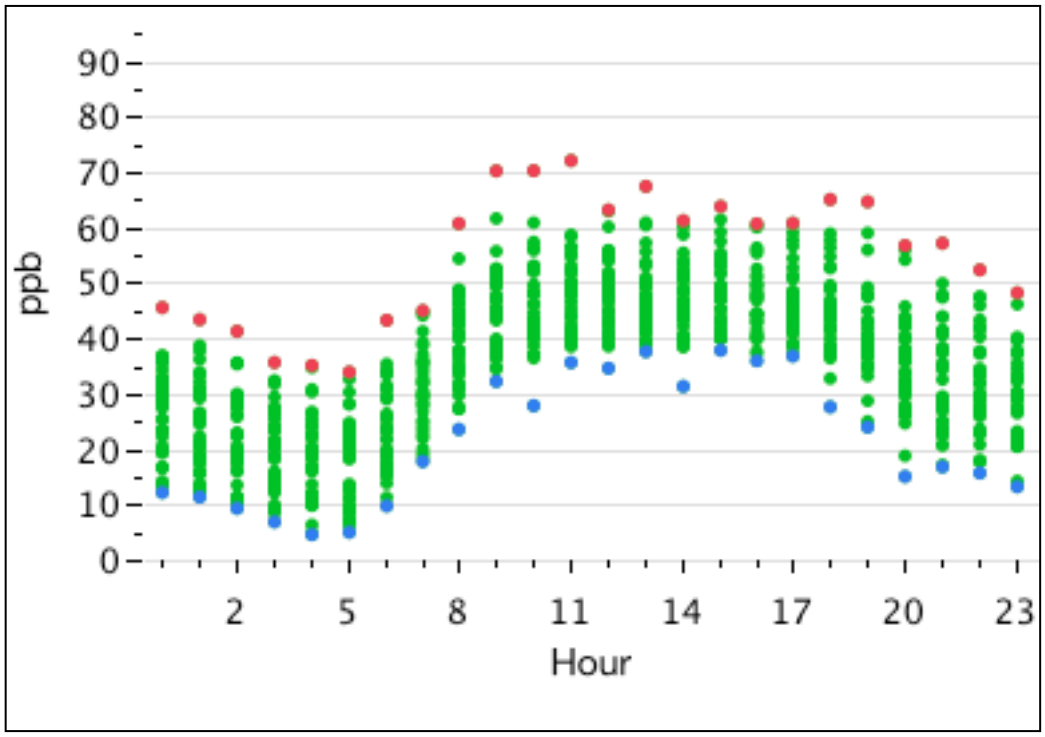


Figure 5-93. Pinedale O_3 time series for the period 05/19/2009 – 06/24/2009.

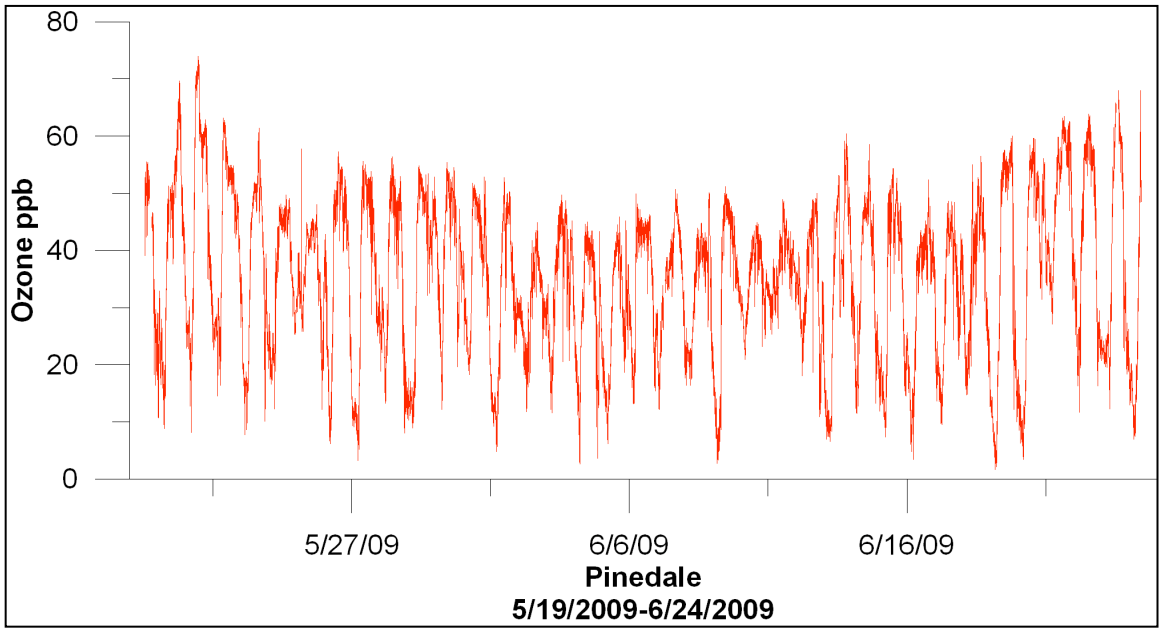


Figure 5-94. Olson Ranch O_3 diurnal chart for the period 06/24/2009– 07/31/2009.

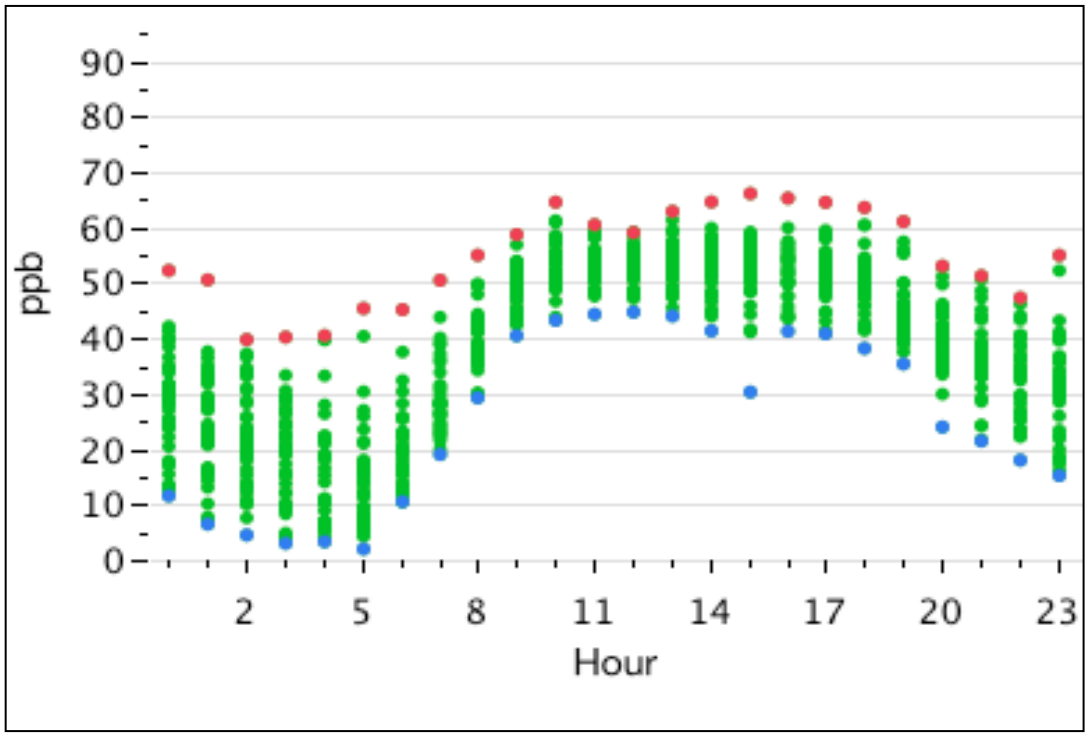
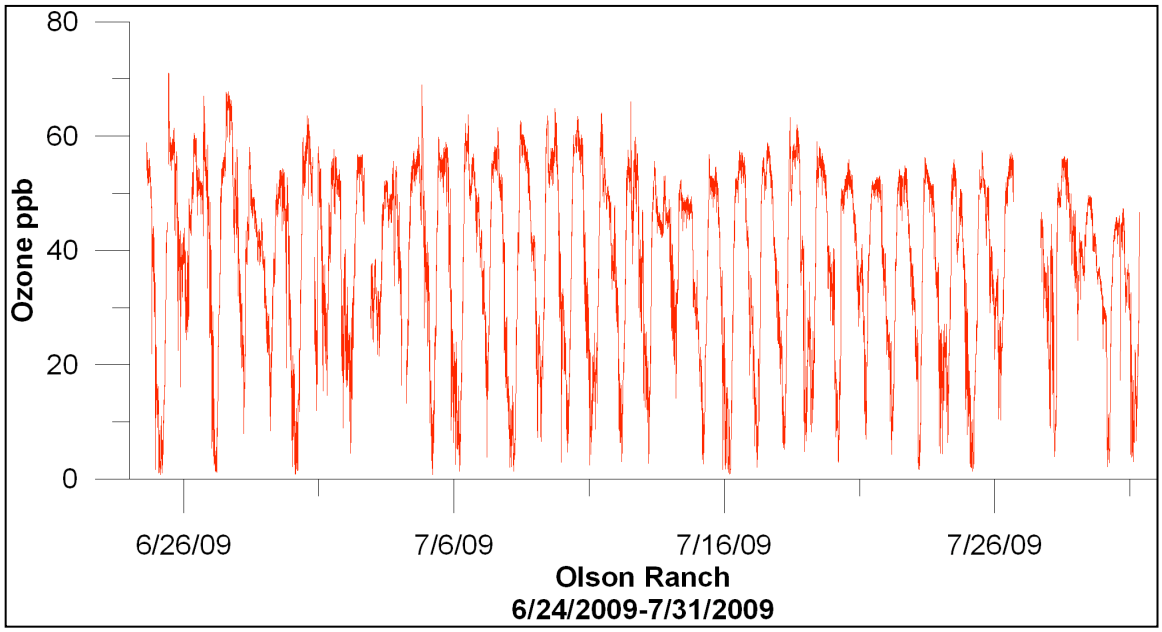


Figure 5-95. Olson Ranch O_3 time series for the period 06/24/2009– 07/31/2009.



6.0 DISCUSSION

The purpose of this report is to present the main outcomes of the monitoring for the O3i. As such, analysis presented in this section is intended to further elaborate the behavior of the air pollutants measured through the operation of the MAQML for O3i. Particular attention is given to CH_4 and NMHC since these measurements are unique for the region considered with the O3i monitoring sites.

6.1 Methane and Non Methane Hydrocarbons

Tropospheric background concentrations of CH_4, while slowly increasing, are relatively stable, albeit when taking into account global seasonal variations. The background level for the US can be considered to be between 1.75 ppm and 1.85 ppm. As such we consider that a level of equal to or less than 2.0 ppm is a background concentration with some local influence. Concentrations of CH_4 greater than 2.5 ppm can be anticipated to have additional contributions from local emission sources. Given the proximity of oil and gas development to the study area, this activity is the prime candidate for an explanation of the elevated CH_4 concentrations. Often the subtleties of the variation of ambient concentrations are smoothed out through averaging. While this is necessary when hourly values are used for air quality standards it can hide from view important shorter term variations. One of the considerations of the monitoring approach using one-minute averages was to view the elevation of CH_4 and NHMC concentrations with two main questions in mind:

1. Could elevated levels of CH_4 be detected and explained by geographic position?
2. If CH_4 ambient concentrations were elevated did NMHC follow suit?

Table 6-1 shows the behavior of CH_4 and NMHC at each of the O3i monitoring sites. The number of measurements is considerable with a total of approximately two hundred thousand values. The sites are presented in chronological order with the corresponding season indicated. In broad terms dispersion improves from winter to summer months. There are considerable differences between sites with respect to the amount of time that background levels (< 2.00 ppm) were measured compared to elevated levels (>2.5 ppm). At Big Piney a background level for 30% of the time compares to an elevated level for 20% of the time. At the opposite extreme at Pinedale a background level for 90% of the time compares to an elevated level for 0.5% of the time. Luman Road reports a background level for 40% of the time with an elevated level for 10% of the time. Olson ranch also has a relatively high frequency of elevated methane for 7% of the time combined with relatively high background frequency at 75% of the time. The Boulder South Road site has a background frequency of 80% of the time compared to an elevated frequency of 2.5% of the time. These values indicate that while Pinedale can be considered a background site this designation is far less appropriate for Big Piney. While it is a boundary site in geographic terms by being situated upwind of the PAPA and Jonah developments, the reported CH_4 levels indicate other influences. The Luman Road and Boulder South Road sites indicate that while background levels are common, elevated levels of CH_4 are often reported. While the Olson Ranch often measured background

levels of methane, it also had unanticipated frequent periods of elevated CH_4 concentrations.

Table 6-1. The behaviors of methane and non-methane hydrocarbons at O3i monitoring sites.

Location	Season	CH_4 Level ppm	n	CH_4:NMHC
Big Piney (n = 27,000)	Winter	<2.00 2.50 to 2.99 >3.00	9,106 (~35%) 4,574 1,178	1.90 : 0.00 2.69 : 0.11 3.28 : 0.21
Luman Rd (n = 7,000)	Winter	<2.00 2.50 to 2.99 >3.00	3008 (~45%) 550 114	1.92 : 0.00 2.67 : 0.18 3.92 : 0.44
Boulder South (n = 61,000)	Spring	<2.00 2.50 to 2.99 >3.00	48,677 (~80%) 1,099 344	1.89 : 0.02 2.65 : 0.18 3.33 : 0.27
Pinedale (n = 48,000)	Spring	<2.00 2.50 to 2.99 >3.00	43,987 (~90%) 181 15	1.87 : 0.01 2.65 : 0.12 3.15 : 0.23
Olson Ranch (n = 50,000)	Summer	<2.00 2.50 to 2.99 >3.00	38,536 (~75%) 2,991 466	1.86 : 0.00 2.66 : 0.19 3.20 : 0.31

Table 6-1 also presents the actual averaged concentration values for CH_4 and NMHC for each of the reported ranges. While some degree of similarity may be anticipated due to the pooling approach there is an encouraging degree of comparability with respect to the "background pool" with values for CH_4 ranging from 1.86 to 1.92. The consistency of background indicates that elevated levels are quantifiable. The importance of CH_4 for local photochemical production of ozone is far less important than the role of NMHC. While NMHC is a bulk measurement that includes both reactive and relatively inert volatile organic compounds, it is important to consider whether it varies closely with CH_4 or not. Table 6-2 considers the concentration of both CH_4 and NMHC when elevated by simply subtracting the background level. A ratio is also presented in this table. At each of the O3i sites the ratios are similar for both CH_4 ranges.

Table 6-2. Methane to non-methane hydrocarbons ratios at O3i monitoring sites.

Location	Level	CH_4:NMHC (ppm)	Ratio
Big Piney	2.50 to 2.99 >3.00	0.79: 0.11 1.38 : 0.21	7.18 6.57
Luman Road	2.50 to 2.99 >3.00	0.75 : 0.18 2.00 : 0.44	4.17 4.54
Boulder South Rd	2.50 to 2.99 >3.00	0.76: 0.16 1.44 : 0.25	4.75 5.76
Pinedale	2.50 to 2.99 >3.00	0.76 : 0.11 1.28 : 0.22	6.91 5.82
Olson Ranch	2.50 to 2.99 >3.00	0.80 : 0.19 1.34 : 0.31	4.21 4.32

There is greater inter-site than intra-site difference. This may be related to a number of possible contributing factors. Table 6-3 compares the ambient concentration ratios with that reported for wet gas by WDEQ-AQD. The lowest ambient ratios of CH_4 to NMHC are calculated for the three sites most likely to be influenced by the PAPA and Jonah developments. The higher ratios are reported at the boundary sites. So while Big Piney has a high level of CH_4 the associated NMHC are relatively low. This is also true for Pinedale, although a different explanation may apply. While elevated CH_4 as indicated in previous sections for Big Piney is related to winds from the south west region, for Pinedale the rarer higher values may be more related to unusual conditions given the small number of samples.

The ratios given for the O3i monitoring site in Table 6-3 are approximately half to a third of that reported for wet gas. If it can be assumed that elevated CH_4 ambient concentrations are predominately the result of emissions from natural gas development, then consideration of this difference is important. One clear factor could be additional emissions sources of NMHC, for example traffic. Another could be the use of propane as a calibration standard for the NMHC measurements. However it should be noted that the average carbon number of natural gas when balanced by compound contribution is C_3. However, if ambient concentrations have a relatively high level of higher molecular weight species VOC, then the ambient measurement reported from the instrument would be biased too high. However, this is unlikely to be the only factor and is not enough to account for this difference alone. Unfortunately, without simultaneous speciated ambient data the exact nature of this influence toward the calculated difference is impossible to determine. Another linked explanation could be greater ambient contributions from BTEX. This is a possibility given the removal of condensate from wet gas. Condensate consists of heavier VOC constituents of wet natural gas, in particular BTEX (Benzene, Toluene, Ethyl-Benzene and m-p-x-Xylene). A combination of factors is most likely to explain the differences shown in Table 6-3.

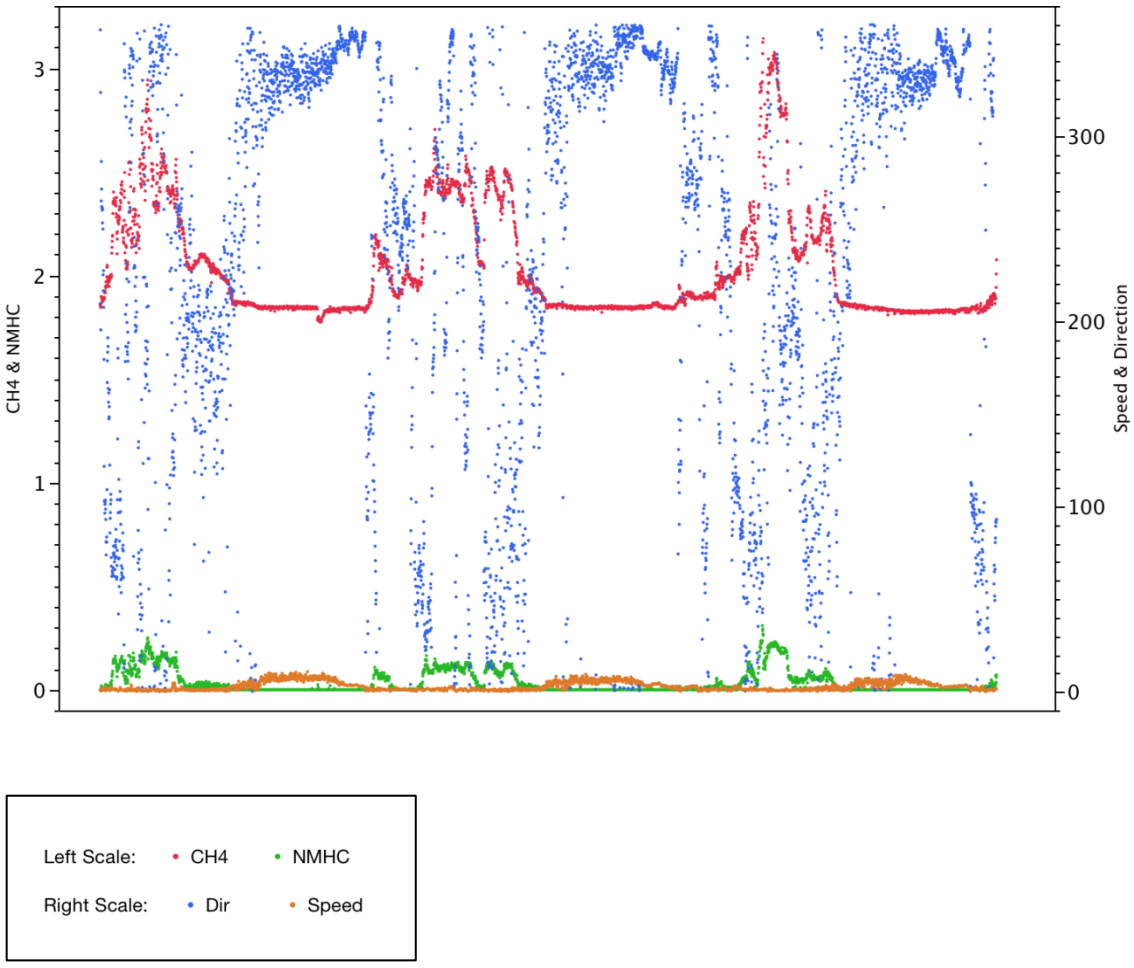
Table 6-3. Methane to non-methane hydrocarbon ratio for O3i sites and wet natural gas.

Location	CH_4:NHMC Ratio (ppm)	Approx. Range of Ratio
Boulder South Rd	4.75 to 5.76	from 4:1 to 5:1
Olson Ranch	4.21 to 4.32	
Luman Road	4.17 to 4.54	
Big Piney	7.18 to 6.57	from 6:1 to 7:1
Pinedale	6.91 to 5.82	
Typical line	CH_4:NHMC Ratio (mol %)	
PAPA wet gas	11.76	Approx 12:1
Jonah Field wet gas	11.80	

It has been recognized that specific meteorological conditions are of particular significance for the formation of secondary pollutants such as ozone. When considering primary pollutants, while some physical parameters become less significant others

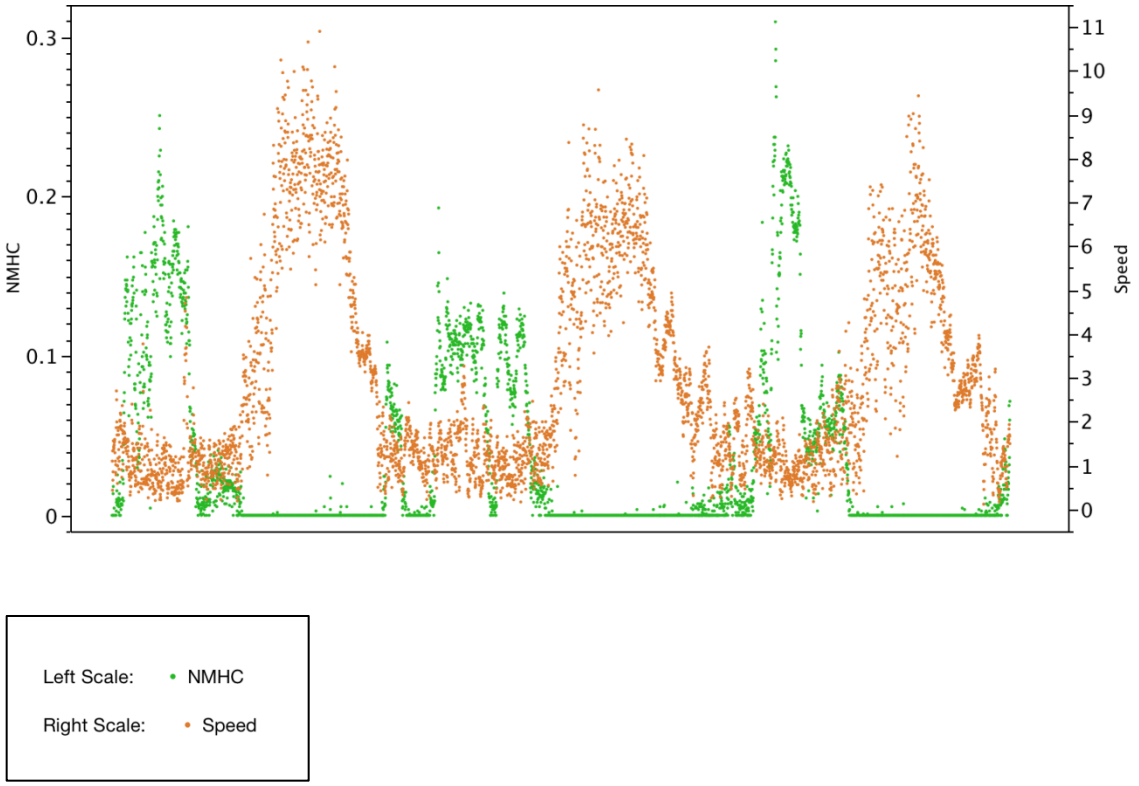
become more important. For example, elevation of CH_4 or NMHC ,at a site near to emissions sources is likely to report higher levels with poorer dispersion conditions and when directly downwind. Such behavior was evident, even in summer months. Figure 6-1 shows the influence of location with wind direction associated with elevated CH_4 concentrations.

Figure 6-1. Methane, non-methane hydrocarbons, wind speed and wind direction at Olson Ranch July 17th to July 18th 2009 in ppm.



It is clear that CH_4 and NMHC trends are similar and that while wind directions of around 300 degrees are associated with background air, winds with a more scattered direction are associated with higher concentrations. Figure 6-2 expands the scale of the parameters that are scaled less effectively in Figure 6-1. Higher wind speeds are associated with NMHC concentrations less than 0.1 ppb, whereas wind speeds of less than 1 m/s are associated with higher NMHC concentrations. When wind speeds drop to low values the influence of the terrain upon air drainage can be become important.

Figure 6-2. Non-methane hydrocarbons and wind speed and wind direction at Olson Ranch July 17th to July 18th 2009 in ppm.



6.2 Oxides of nitrogen, nitric oxide and nitrogen dioxide

The behavior of NO_x, NO and NO_2 is as anticipated. These parameters are primarily associated with combustion systems. The monitoring sites were located in positions likely to be influenced by emissions from traffic sources and other forms of combustion systems for a variety of uses including flaring, compression, heating and power generation. In urban environments, there can be a significant seasonal variation of NOx concentrations, related to the combined impact of the level of heating sources and the effect of dispersion conditions. For the O3i sites, while dispersion conditions are known to vary, the balance of contributing combustion sources is different. As such, it is difficult to make more than basic comparisons between the sites. Table 6-4 compares the average values for NO_x, NO and NO_2 at each site.

Table 6-4. The behaviors of oxides of nitrogen, nitric oxide and nitrogen dioxide at O3i monitoring sites.

Location	Season	NO	NO_x	NO_2
Big Piney (n = 38085)	Winter	1.33	5.99	4.66
Luman Rd (n = 46582)	Winter	2.23	6.48	4.25
Boulder South (n = 68090)	Spring	0.81	2.84	2.04
Pinedale (n = 51037)	Spring	0.98	3.59	2.61
Olson Ranch (n = 51949)	Summer	0.94	3.51	2.57

6.1 Ozone

The behavior of ozone was interesting. Winter ozone episodes are defined to a large extent by the appropriate meteorological conditions. Conditions could be considered as winter-like for Big Piney and Luman Road, and to a lesser extent Boulder South Road. Pinedale and Olson Ranch monitoring had zero snow cover and occurred during spring-like conditions. Table 6-5 compares the average values for ozone at each site along with the number of minute values above 70 ppb as well as the maximum 8-hour rolling average.

Table 6-5. The behavior of ozone at O3i monitoring sites.

Location	Season	Average	Values above 70 ppb	Highest 8-hr
Big Piney (n = 38020)	Winter	34.6	147	66.1
Luman Rd (n = 46672)	Winter	45.4	839	67.5
Boulder South (n = 68002)	Spring	47.3	1258	70.2
Pinedale (n =)	Spring	35.7	134	64.4
Olson Ranch (n = 51945)	Summer	38.2	8	62.3

6.0 CONCLUSIONS

Note:

- The initial contracted deployment date of January 1st was delayed by 1 month due to late finalization of the contract and subsequent late ordering and delivery of instruments and trailer.

- The monitoring campaign was extended by 1 month to compensate for lost sampling time.

- Measurement campaigns were completed on schedule for the required time period at all five O3i monitoring sites.

For the six-month duration of the study, we draw the following conclusions:

- Use of a mobile laboratory to monitor pollutants in different locations around the study area enabled the opportunity to demonstrate the variability of pollutant behavior in the study area in relation to meteorology and emission sources.

- Site locations met project design criteria of being at boundary locations and at sites downwind of local oil and gas development.

- Time invested in choosing appropriate site locations was valuable, as these different sites were positioned in such a way that they demonstrated pollutant behavior variability in the study area.

- Audits proved to be invaluable, especially in terms of providing confidence in the parameters measured by the mobile laboratory.

- Coupled with meeting other O3i objectives and associated aims the intensive use of site visits was valuable, in particular for building a foundation for future mobile monitoring campaigns.

- The target data capture criteria of 75% was exceeded for nine out of eleven measurement parameters with data recovery over 95%.

- The lowest data capture of 74% was for CH_4 and NMHC. This was caused by an instrument failure that necessitated obtaining replacement equipment.

- Wind rose diagrams indicated two wind fields of importance to the normal conditions in study area namely; NW Gros-Ventre pattern and SW Wyoming Range pattern.

- Wind roses demonstrate variability of wind behavior in and around the study area. This is important in terms of demonstrating the potential variability of pollutant behavior throughout the study area.

- The wind rose diagram for the Boulder South Road site revealed that this site had the most evenly spread wind field of the O3i monitoring sites during the study period.

- The presence of katabatic (down-slope) air flows near the Boulder South Road site may, along with temperature inversions, facilitate the trapping and mixing of ozone precursors.

- The ozone NAAQS was not exceeded at any sites during the O3i monitoring period.

- Data for CH_4 and NMHC revealed the incidence of concentrations above normal background levels at all O3i sites with the exception of Pinedale.

- While CH_4 levels at what is considered normal background are common at Pinedale, there is a wide variation of the relative amounts of time that other sites have background versus elevated levels of methane.

- Methane and NMHC concentrations appear to be elevated based on 1) proximity to production emissions; 2) meteorology; and 3) seasonality. Some NMHC may be highly reactive ozone precursors, whereas methane is a long-lived and far less reactive precursor.

- Pollution rose diagrams for Big Piney indicate wind flows from the SW have elevated levels of CH_4.

- Pollution rose diagrams for Luman Road indicate elevated pollution levels from westerly winds from the PAPA and Jonah developments.

- Pollutant roses from Boulder South Road show the wind field of this site with pollutant inflow from all directions. This effect is most pronounced for ambient ozone concentrations.

- Monitoring data at Pinedale indicate that the MAQML was not directly influenced by oil and gas emissions. We believe elevated levels of nitrogen species are produced locally from traffic emissions related to Town Park activity.

- Gaseous roses created from Olson Ranch monitoring data indicate elevated levels of CH_4 and NMHC are present during low mixing regimes, and are most likely produced locally.

- The importance of atmospheric mixing and air pollutant concentration was shown by the diurnal curves for methane, as afternoon mixing tended to show the closest approximation to tropospheric background levels.

- Diurnal curves for CH_4 and NMHC showed that local sources are most likely to influence measured concentration during times associated with the highest atmospheric stability.

- Behavior of measured nitrogen species indicates additional influence from local sources. Nitric Oxide concentrations from traffic sources are important at three sites, and for NO_2 concentrations the influence of daytime photochemical production is evident in late afternoon hours.

- The O3i monitoring sites diurnal curves for ozone showed a similar shape at all the monitoring sites, albeit with some variation related to afternoon peaks and duration of highest levels. This curve represents the pattern of production and destruction of ozone.

- Elevated levels of nitrogen species at Big Piney and Luman Road highlight the role that local traffic can play in creating ozone precursors, as both areas had frequent periods of vehicle idling. Luman Road, a primary arterial access point to Jonah Field, is subject to heavy truck traffic and is located in an area of acceleration and deceleration.

- One-minute data allows a perspective upon the variability of pollutant concentrations that is lost through averaging. One-minute data can show the influence of short-term variations related to emission sources and meteorology.

- One-minute data for CH_4 and NMHC indicate commonality of emission sources.

- The ratios of CH_4 to NMHC at sites with elevated concentrations showed similarity between Luman Road, Boulder South and Olson Ranch. At the Big Piney site high CH_4 had relatively low associated NHMC concentrations.

- Time series data for nitrogen species shows the high level of variability associated with these compared to hydrocarbon species. Nitrogen species had frequent periods of low concentrations followed by pollution spikes. This spiking behavior was particularly evident at sites influenced by emissions from traffic.

- Ozone time series show more stability with diurnal variations clearly visible.

- Geography appears to be important at Boulder South Road site. This location had more O_3 values over 70 ppb than the other sites combined.