T&B Systems
environmental research associates

859 2nd St, Santa Rosa, CA 95404
(707) 526-2775  fax (707) 579-5954

# CLARK COUNTY REGIONAL OZONE & PRECURSOR STUDY FINAL REPORT (P.O. 225900)

## Prepared for:

**Mr. William Cates**
**Clark County**
Air Quality
Protecting the air we share
**Department of Air Quality & Environmental Management**
**500 South Grand Central Parkway**
**Las Vegas, NV 89106**

## Prepared by:

**David Bush**
**Robert Baxter**
**William Knuth**
**Don Lehrman**
**Paul Fransioli**
**David Yoho**
T&B Systems
environmental research associates

**Dr. Wendy Goliff**
**Desert Research Institute**
**Reno, NV**

**Dr. Mark Green**
**Dr. David Dubois**
**Desert Research Institute**
**Las Vegas, NV**

**Dr. Dennis Fitz**
**CE-CERT**
**University of California, Riverside**
**Riverside, CA**

**September 18, 2006**

T&B Systems
environmental research associates

859 2nd St, Santa Rosa, CA 95404
(707) 526-2775 fax (707) 579-5954

# CLARK COUNTY REGIONAL OZONE & PRECURSOR STUDY

# FINAL REPORT (P.O. 225900)

## Prepared for:

**Mr. William Cates**
**Clark County**
Protecting the air we share
Air Quality
**Department of Air Quality & Environmental Management**
**500 South Grand Central Parkway**
**Las Vegas, NV 89106**

## Prepared by:

**David Bush**
**Robert Baxter**
**William Knuth**
**Don Lehrman**
**Paul Fransioli**
**David Yoho**
T&B Systems
environmental research associates

**Dr. Wendy Goliff**
**Desert Research Institute**
**2215 Parkway**
**Reno, NV 89512**

**Dr. Mark Green**
**Dr. David Dubois**
**Desert Research Institute**
**755 E. Flamingo Rd.**
**Las Vegas, NV 89110**

**Dr. Dennis Fitz**
**CE-CERT**
**University of California, Riverside**
**1084 Columbia Ave.**
**Riverside, CA 92507**

**September 18, 2006**

# ACKNOWLEDGEMENTS

This work was performed for the Clark County Department of Air Quality & Environmental Management under Purchase Order No. 225900. Messrs. William Cates and John Koswan provided overall project management. A large field program such as CCROPS is successful only when all the participants share the hard work necessary and coordinate their activities. Therefore, we would like to express our gratitude to the DAQEM staff members who participated in planning and operational meetings, and those who contributed to the field monitoring effort. In particular, Mr. Phil Wiker, who participated in daily forecasts; and Messrs. Mick Turner and Al Lesksys who were instrumental in obtaining project-specific monitoring sites.

Dr. Krys Stave of the University of Nevada, Las Vegas is commended for coordinating the aircraft measurements and piloting the glider while tending to the monitors. Drs. David DuBois and Mark Green of DRI, Dr. Daryl Randerson and Ray Dennis of NOAA/SORD must be acknowledged for coordinating their remote wind sensing measurements and balloon-borne measurements, respectively, with the CCROPS field measurements.

Recognition is due to Ms. Elizabeth Niccum of T&B Systems who assembled all the project-specific measurements and integrated them into a consistent relational database. Many thanks to Ms. Susan Hynek who was central in compiling all the text, figures, and tables from the various authors into a consistent document.

# EXECUTIVE SUMMARY

During the last two and a half decades, the Las Vegas Valley has emerged as one of the fastest growing metropolitan areas in the nation, leading to increased emissions into the atmosphere that are precursors to ozone production. In recent years, concentrations of ozone in Clark County have approached, and on occasion exceeded, the new 8-hr ambient air quality standard as defined by the recently adopted Federal Ozone Standard. These exceedances increase the potential for a violation of the federally mandated Clean Air Act, and the necessity for developing control strategies. Planning realistic, cost-effective control strategy requires a comprehensive understanding of the origin and fate of ozone and ozone precursors. Characterizing ozone in Clark County and the Las Vegas Valley is a challenging process. Local airflow is a complex diurnal cycle resulting from mountain and valley dynamic influences when the area is under high-pressure weather systems that suppress regional airflow. Regional transport from nearby metropolitan areas, primarily in southern and central California, occurs in an even more complex structure of airflow in both the horizontal and vertical directions. Adding to this complexity is the limited amount of air quality and meteorological data available along transport pathways.

The Clark County Department of Air Quality and Environmental Management (DAQEM) contracted T&B Systems, Inc. to design and conduct a program to collect data necessary for the characterization and understanding of tropospheric ozone in Clark County. The program is now referred to as the Clark County Regional Ozone and Precursor Study (CCROPS.) The field-monitoring portion of the study was conducted during the 2005 ozone season from May through August.

The program was designed to meet the following objectives:

- Obtain a set of meteorological and air quality measurements that will increase our understanding of the origin of high ambient ozone and precursor levels in Clark County.
- Determine if the current Clark County air quality and meteorological network is adequate to define the regional peak ozone concentrations.
- Obtain a set of ambient measurements of a known quality that can be used to validate meteorological and air quality numerical models.
- Generate a database that can support current and future SIP development.
- On the basis of what is learned from this ozone study, provide specific recommendations for future research programs to support air quality modeling for ozone.

## Overview of the Field Study

Much of the design of the network for the 2005 ozone study was based on analysis of ozone data collected for the period 2000 through 2003, including detailed analysis of ten case studies. This information was summarized during the Clark County Ozone Characterization Study conducted as a prelude to CCROPS.

The establishment and operation of the following measurements enhanced the surface air-quality network:

- Supplemental ozone monitoring stations. Ten sites were established and operated by T&B Systems that consisted of EPA-designated equivalent ozone analyzers and meteorological sensors that operated continuously over the CCROPS study period.
- Saturation ozone monitoring stations. Thirteen sites, also operated by T&B Systems, consisted of portable battery operated samplers with the data recorded on self-contained data loggers. Because of their unique design, the instruments could be cost-effectively operated in virtually any location. The siting of the saturation ozone network concentrated on locations where ozone was suspected to be high.
- CE-CERT equipped two DAQEM measurement sites with analyzers that specifically measured the ozone precursors $NO_y$, nitric acid, $NO_2$, and peroxyacetyl nitrate (PAN). One site was located near primary emissions (JD Smith), and the other was located generally downwind of primary emissions (Joe Neal).
- Ozone precursors of VOC were measured by DRI Reno. Canisters were exposed at three sites, Jean, Joe Neal, and JD Smith during select periods. Timing of the samples was coordinated with general diurnal activities relating to emissions and chemical reactivity. The Jean site was intended to characterize rural/upwind conditions where as the two urban sites characterized the smog during likely different ozone chemistry phases.

Another major gap in the understanding of the atmospheric processes associated with Las Vegas air quality was due to the absence of measurements of both meteorology and ozone aloft. Filling this gap became a major element in the 2005 field study**.** Measurements of meteorology and air quality aloft were made using a variety of methods and participants. These included:

- A radar wind profiler and mini-SODAR located at the North Las Vegas airport and operated by DRI continuously during the field study.
- Three standard SODARs, capable of measuring winds up to 600 m, located at Jean, Floyd Lamb State Park, and the Las Vegas Speedway and operated by DRI continuously during the field study.
- Balloon-borne measurements of temperature, RH, and winds (rawinsonde) and ozone (ozonesonde) from the North Las Vegas airport obtained by T&B Systems,
- Aircraft measurements of temperature and ozone during select periods made by T&B Systems.
- Rawinsondes at Jean during select periods made by NOAA/SORD.
- Winds aloft (pibal) measurements in the foothills of the Las Vegas Valley during select periods made by NOAA/SORD.

The following three-tiered field monitoring effort was developed to maximize the effectiveness of study resources.

- Supplemental air quality and meteorological monitoring, including ten surface ozone and meteorological monitoring sites, two $NO_y$ monitoring sites, and four upper-air monitoring SODARs and a radar wind profiler. This monitoring occurred continuously from May 15 through August 31, 2005.

- Intensive Operational Period (IOP) monitoring, consisting of continuous saturation ozone measurements at up to 13 locations and rawinsonde measurements at one location. These measurements were conducted during six “windows of opportunity” when conditions for ozone concentrations were predicted to be good for an extended period of time.
- Episodic monitoring, consisting of ozonesondes at one location, VOC sampling at three locations, and some additional balloon meteorological measurements at various locations. These were two to three day periods that were imbedded within the IOP monitoring effort, when ozone concentrations were predicted to be near or above the Federal 8-hour standard of 85 ppb.

**Table E-1** summarizes the three-tier and the CCROPS measurements.

Table E-1. Three-Tier and CCROPS Measurements

| Period of Operation | Measurables |
|---|---|
| Entire study period (May 15 – August 31) | • Continuous ozone and meteorology at 10 additional sites<br>• Continuous upper-air meteorology at 4 sites (3 SODAR, 1 radar profiler/SODAR)<br>• Continuous $NO_y$, PAN, Nitric Acid measurements at 2 sites |
| Intensive Operational Periods (four 1- to 2-week periods of potential high ozone conditions) | • Upper-air meteorology using rawinsondes at 1 site<br>• Continuous ozone using portable samplers at 13 saturation sites |
| Episodic Operations (1- to 3-day periods of forecasted high ozone imbedded within IOPs). | • VOC samples at 3 sites (up to 4 samples per day)<br>• Upper-air ozone measurements using ozonesondes at 1 site (6 AM, 10 AM, 4 PM)<br>• Upper-air ozone measurements using aircraft/glider (typically 6 AM and 10 AM)<br>• Pibal and rawinsonde measurements at various sites throughout western Clark County |

## Results and Recommendations

The field-monitoring phase of the program was conducted during May through August 2005. The complete surface monitoring network and balloon-borne upper-air measurements were completely functional by May 15. The SODARs and radar wind profiler were phased in as the equipment was installed and became operational.

The IOP and episodic levels of monitoring efforts were distributed throughout the ozone season as originally intended. The plan was to include a representative set of meteorological conditions during which high ozone levels are experienced in Clark County. Episodic-mode field activity was thereby based on high ozone levels being forecast while the IOPs were ongoing, and the field crews were already deployed in the field. As it turned out, IOP operations occurred on 38 days over the following 6 periods. The late August IOPs were an attempt to capture a solid "interbasin transport" high ozone case.

- May 15-16 (intended as a "shakedown period" as well)
- May 23-29
- June 20-July 2
- July 11- 21 July
- August 21-22
- August 27-29

Embedded in these IOPs were a total of 15 episodic days. Nine of these days occurred during June and July, consistent with historical observations indicating that peak ozone activity in Clark County occurred during June and July.

Consistent with the Characterization Study, maximum ozone levels in Clark County during the 2005 field study generally occurred in the northwest quadrant of the Las Vegas Valley. However, on nine of the twelve exceedance-days, the maximum occurred outside the area covered by the DAQEM network. The Paiute Reservation site and Indian Springs, both Supplemental sites and further upvalley from Lone Mountain and Joe Neal, usually measured the highest ozone.

A descriptive analysis of each of the exceedance periods is provided in the main body of this report with the principal goal of determining whether they were transport or locally driven. **Table E-2** summarizes the 2005 exceedances and the results from the analysis. The number of exceedances of the 8-hr ozone standard, if any, and the maximum ozone level is given for the routine DAQEM network, the supplemental network, the saturation network, and for all sites in the CCROPS network. The location of the CCROPS network maximum is given as well. Based on the preliminary analyses and the CART model classification, each exceedance day was classified as primarily due to local sources or interbasin transport. The designation of "transport" versus "local" is, of course, one of relative distinction. All days will likely have some transport component and some local contribution component.

The exceedances on July 2 and July 18 are discussed in more detail, as they are classic examples of a transport scenario and local contribution scenario, respectively. On July 2, Jean was the only DAQEM site to report an exceedance. With southwest winds dominating during the exceedance, Jean was upwind of Las Vegas and thus the background levels were not associated with the Las Vegas urban plume. The California deserts had experienced high ozone levels the previous day. On July 18, air-mass trajectories indicated an extremely stagnant air mass precluding interbasin transport as an important contribution to the large number of exceedances that were experienced (13 sites). The peak ozone level at Jean was only 67 ppb. Analysis of the VOC data showed that the air at Jean was relatively clean and the site was not greatly affected by fresh emissions as shown by the toluene to propane ratio. Emissions of anthropogenic VOCs at Jean showed no correlation with wind direction thus providing no evidence to support transport being a significant source of VOCs in the Clark County area. Also, concentrations of biogenic compounds were lower at Jean compared to the Joe Neal and JD Smith sites.

Table E-2. Summary of 2005 Ozone Exceedances

| | DAQEM Network | | Supplemental Network | | Saturation Network | | CCROPS Network | | Location of Maximum Ozone | Local or Transport Driven Consensus* |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Max 8-hr Avg ppb | Number Sites Exceeded | Max 8-hr Avg ppb | Number Sites Exceeded | Max 8-hr Avg ppb | Number Sites Exceeded | Max 8-hr Avg ppb | Number Sites Exceeded | | |
| **12-Jun** | 90 | 3 | 89 | 1 | | | 90 | 4 | Lone Mtn | Local |
| **29-Jun** | 101 | 12 | 102 | 7 | 122 | 9 | 122 | 28 | Paiute Res | Local |
| **30-Jun** | 105 | 11 | 108 | 8 | 129 | 10 | 129 | 29 | Paiute Res | Local |
| **1-Jul** | 81 | 0 | 88 | 1 | 99 | 3 | 99 | 4 | Indian Sprgs | Both |
| **2-Jul** | 85 | 1 | 91 | 2 | 90 | 4 | 91 | 7 | Indian Sprgs | Transport |
| **3-Jul** | 87 | 1 | 88 | 2 | 80 | 0 | 88 | 3 | Paiute Res | Transport |
| **6-Jul** | 82 | 0 | 85 | 1 | | | 85 | 1 | Black Mtn | Both |
| **8-Jul** | 86 | 1 | 87 | 2 | | | 87 | 3 | Paiute Res | Both |
| **15-Jul** | 87 | 4 | 90 | 1 | 94 | 3 | 94 | 8 | Paiute Res | Local |
| **18-Jul** | 95 | 5 | 90 | 2 | 105 | 6 | 105 | 13 | Lone Mtn | Local |
| **6-Aug** | 87 | 2 | 84 | 0 | | | 87 | 2 | Lone Mtn | Local |
| **10-Aug** | 78 | 0 | 88 | 1 | | | 88 | 1 | Paiute Res | Local |

* Consensus of preliminary analyses and CART model

The JD Smith and Joe Neal sites were most often in the VOC limited regime during the summer of 2005. For most (but not all) instances when the regime was $NO_x$ limited, ozone concentrations were low, suggesting deposition as the cause of low $NO_x$ concentrations. This suggests that VOC emission controls in Clark County should be considered first to reduce urban ozone mixing ratios. For the majority of the summer the difference between the Joe Neal VOC/$NO_x$ ratios and the JD Smith VOC/$NO_x$ ratios lies in the negative, meaning the ratios at the JD Smith site are higher than for the Joe Neal site. This implies that Joe Neal was not an appropriate downwind location for canister sampling. Rather, the Joe Neal site was too close to local sources. This suggests that in future ozone studies in Clark County, the “downwind location” should be established farther downwind from the urban center.

Cluster analysis of upper-air wind data collected during the study revealed the following groupings:

- Strong Southwesterly Flow: Regional to synoptic scale forcing- early summer indicative of transport from San Joaquin Valley and South Coast Air Basin. Associated with highest ozone concentrations at county background sites (Jean and Black Mountain), with average 8-hour maximums of 65 and 68 ppb, respectively). One exceedance day (at Jean) in this group.
- Light Northerly Flow: Highest concentrations at Boulder City. About 11 ppb increment from urban Las Vegas area, but no exceedances.
- San Joaquin Valley + Las Vegas increment: Suggestive of transport aloft from San Joaquin Valley coupled with low-level transport in urban area to northwestern Las Vegas Valley. Occurred mainly in July. Highest concentration pattern due to high background and 8 ppb urban increment. Three exceedance days in this group.
- Local Terrain Dominated Flow: Weak synoptic forcing resulting in low-level flow dominated by local terrain features. Regional transport noted from north, South Coast area, and the south with little apparent San Joaquin Valley transport. Highest ozone concentrations in northwestern Las Vegas Valley. Four exceedance days, 2 of which are believed to be largely fire-related (June 29-30). About 9 ppb increment due to urban area.

Based on initial analyses of the CCROPS data, recommended monitoring network changes and enhancements are the following:

- The Ozone Characterization Study revealed that ozone data from City Center was being impacted by emissions from an adjacent major highway. This was supported by the 2005 field study measurements. Indeed, the site does not currently meet EPA siting criteria for ozone due to its proximity to the highway. Moreover, the analysis indicated it is not representative of regional ozone concentrations, with low daytime readings due to titration by NO from vehicles on the nearby freeway. For these reasons, it is recommended that ozone monitoring be terminated at City Center as it does not provide useful information regarding community health impacts. Data from the nearby JD Smith site appear to adequately represent this area.
- A permanent site at Paiute should be installed to ensure that peak ozone exposure in Clark County is measured.
- A permanent site at Indian Springs should be installed to further define the northwest extent of high ozone levels. Moreover, as growth and development continues to expand in the Valley, the ozone peak could conceivably shift further northwest.
- Temporary monitoring sites near McCarran Airport in the Sunset Park area were originally recommended based on the 2005 study results. This was accomplished during the 2006 ozone season to further investigate the possibility of high ozone concentrations in that area. That study showed that the Orr School and Henderson routine sites are representative of ozone at Sunset Park. The high ozone levels measured there in 2005 were an artifact of the monitoring used there.

In addition, the following monitoring should be considered:

- An additional ozone site in the foothills to the northwest of Las Vegas. The saturation network showed the urban ozone plume extending well into the foothill region. While the Lone Mountain site does a fairly good job of representing the area, an additional site may be warranted, especially as the area demographics changes. For example, housing developments are already extending to the Red Rock Canyon boundary. Kyle Canyon development and regions in between will likely follow.
- Additional monitoring in the Craig Ranch area for similar reasons noted above. Temporary monitoring should initially be considered to confirm the results obtained by the saturation network.
- To determine the importance of ozone aloft at night and early morning, and to aid in the daily ozone forecasts, monitoring could be conducted at one of the two CCROPS ridgetop sites. Based on preliminary analyses, both the Black Mountain and Lower Potosi sites did a good job of producing measurements representative of ozone concentrations aloft. However, the Black Mountain site is considerably closer to the DAQEM offices, and would therefore be easier to service.

To further enhance the understanding of the ozone issues we recommend the following additional analyses of the data collected during the 2005 study:

- Select periods from the 2005 field study for detailed analyses and as candidates for DAQEM's numerical modeling based on 1) the quality and extent of measured data, 2) initial indications of the contributions from interbasin transport and/or local sources, and 3) representativeness. Detailed descriptive analyses should be performed of the 3-dimensional wind field using all sonde, SODAR, and profiler measurements. The growth and decay of the surface boundary layer evaluated, and the characteristics of ozone and precursors both at the surface and aloft should be determined.

- From the periods selected for detailed analyses and modeling, determine what features are critical to ozone processes. Compare these features with MM5 and ozone model outputs.
- Examine the hourly timing of peak ozone within the extended network. Characterize with respect to the ‘conceptual model’ developed from the detailed episode analysis.
- Using the entire data set, including aircraft measurements, quantify the contribution by the Las Vegas urban area to ozone concentrations under different meteorological scenarios.
- Integrate the ozone, VOC and $NO_y$ data to determine extent of reaction and what information can be extracted regarding major sources.
- Examine the meteorological and air quality measurements at locations such as Moapa, Meadview, Mesquite, and western Utah for downwind impacts.
- Examine in more detail interbasin transport routes (e.g., Coachella Valley in the south and Antelope Valley in the north of the SoCAB, and Tehachapi Pass for San Joaquin Valley).
- Investigate in greater detail the effect that wildfires have on ozone formation. Determine the extent of the smoke plume using existing PM and $NO_y$ data.
- Update and refine the existing CART model and forecasting protocol.

## TABLE OF CONTENTS

**Section** **Page**

# TABLE OF CONTENTS

**Section** **Page**

*7. SUMMARY OF THE OBSERVATIONS (DESCRIPTIVE ANALYSIS) continued*

# LIST OF FIGURES

## LIST OF FIGURES

# LIST OF FIGURES

## LIST OF TABLES

# 1. INTRODUCTION

During the last two and a half decades, the Las Vegas Valley has emerged as one of the fastest growing metropolitan areas in the nation, leading to increased emissions into the atmosphere that are precursors to ozone production. In recent years, concentrations of ozone in Clark County have approached, and on occasion exceeded, the new 8-hr ambient air quality standard as defined by the recently adopted Federal Ozone Standard. These exceedances increase the potential for a violation of the federally mandated Clean Air Act, and the necessity for developing control strategies. Planning realistic, cost effective control strategies requires a comprehensive understanding of the origin and fate of ozone and ozone precursors. Characterizing ozone in Clark County and the Las Vegas Valley is a challenging process. Local airflow is a complex diurnal cycle resulting from mountain and valley dynamic influences when the area is under high-pressure weather systems that suppress regional airflow. Regional transport from nearby metropolitan areas, primarily in southern and central California, occurs in an even more complex structure of airflow in both the horizontal and vertical directions. Adding to this complexity is the limited amount of air quality and meteorological data available along transport pathways.

The Clark County Department of Air Quality Management (DAQEM) contracted T&B Systems, Inc. to design and conduct a program to collect data necessary for the characterization and understanding of tropospheric ozone in Clark County. The program is now referred to as the Clark County Regional Ozone and Precursor Study or CCROPS. The field-monitoring portion of the study was conducted during the 2005 ozone season from May through August.

The program was designed to meet the following objectives:

- Obtain a set of meteorological and air quality measurements that will increase our understanding of the origin of high ambient ozone and precursor levels in Clark County.
- Determine if the current Clark County air quality and meteorological network is adequate to define the regional peak ozone concentrations.
- Obtain a set of ambient measurements of a known quality that can be used to validate meteorological and air quality numerical models.
- Generate a database that can support current and future SIP development.
- On the basis of what is learned from this ozone study, provide specific recommendations on future research programs to support air quality modeling for ozone.

## 1.1 Overview of the Study Design

Much of the design of the network for the 2005 ozone study is based on analysis of ozone data collected for the period 2000 through 2003, including detailed analysis of ten case studies. This information was summarized during the Clark County Ozone Characterization Study[1] (Lehrman et al, 2005) conducted as a prelude to CCROPS. Generally, on the days examined, the afternoon surface winds in the Las Vegas Valley (Valley) supported transport of the Las Vegas urban plume to the northwest. The prevailing-winds trajectory initially moved early morning

---

[1] Lehrman D, D Bush, W Knuth, C Blanchard; Ozone Characterization Study; Final Report to Clark County Department of Air Quality & Environmental Management; by T&B Systems, Santa Rosa, CA; January, 2006.

urban emissions to the southeast under a terrain-induced drainage flow but reversed as the drainage winds diminished and were replaced by an upvalley flow. This provided a recirculation back through the center of the city; possibly adding to the ozone precursors and ultimately increased the urban plume ozone. Superimposed on the locally generated ambient ozone are potentially high background ozone levels due to interbasin transport from the population centers in southern and central California. Instances of overwhelming transport were observed in the analyses of prior events.

The prevailing peak ozone levels in the northwest portion of the Valley are demonstrated by reviewing the spatial distribution of 8-hr exceedances over the last few years. **Figure 1-1** is a map showing the location of the DAQEM ozone monitoring sites and the number of ozone exceedances recorded at each of the sites for the period 2000 through 2003. The dominance of exceedances in the northwest and western sections of the Valley is clearly demonstrated. The only other site that shows a significant number of exceedances is Jean, located southwest of the Las Vegas urban area.

On the basis of the data analyzed, a monitoring network was designed for 2005 to fill in gaps between existing monitors and make measurements in regions that are suspected of having high ozone concentrations, as well as to measure boundary-layer air quality and meteorology above the ground surface.

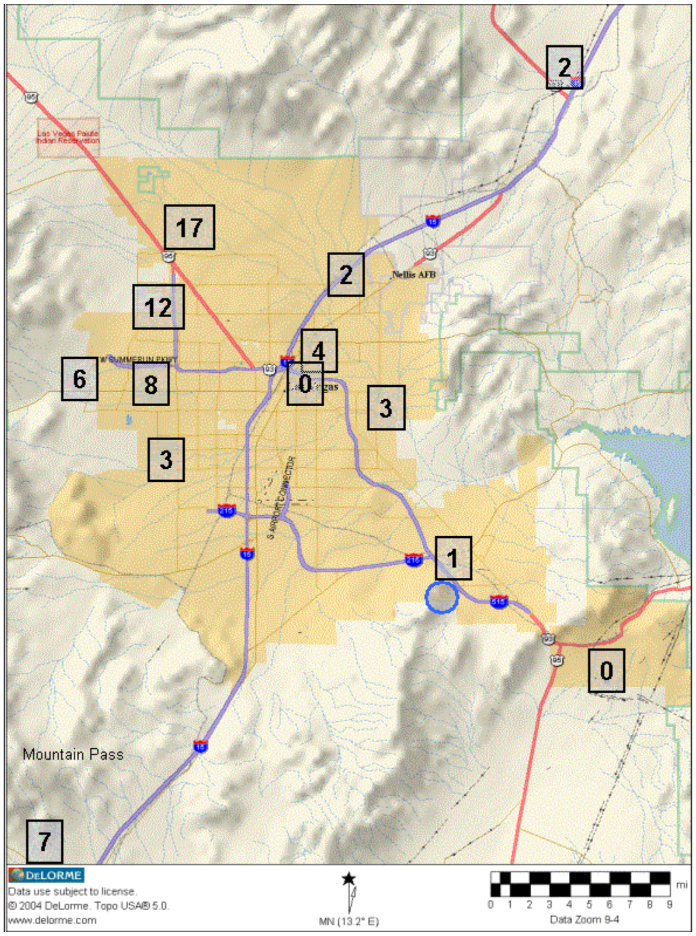


Figure 1-1. Existing DAQEM Monitoring Network, Showing Number of Exceedances 2000 – 2003

## 1.2 Overview of the Field Activities

The CCROPS 2005 monitoring program was conducted during May through August, and consisted of the following new and existing elements:

- DAQEM Monitoring – Ozone, NOx, and meteorology at existing sites operated by Clark County. .
- Saturation Ozone -- Sites to collect ozone data during select periods ranging over the ozone season. These employed portable, battery operated samplers (12 sites)
- Supplemental Ozone -- Continuous FRM monitors operated for the duration of the ozone season (10 sites May through August). This network of sites extended from Indian Springs in the north to Searchlight in the south, with collocated meteorological measurements. Two sites were located on top of prominent peaks to measure ozone aloft.
- Upper Air – Aircraft measurements (2 airborne platforms), remote sensing of winds at 4 sites, 2 rawinsonde sites, 1 ozonesonde site and 1 pibal site.
- Nitrogen Species ($NO_y$, PAN, etc.) -- Measurements added to existing DAQEM sites at J.D. Smith and Joe Neal
- Volatile Organic Compounds (VOC) -- Measurements added to existing DAQEM sites at Jean, J.D. Smith and Joe Neal
- Enhanced $NO_x$ -- Added to the Joe Neal site

In addition to the DAQEM monitoring, continuous supplemental ozone, nitrogen species, and remote wind sensing measurements were conducted throughout the entire study period. The remaining measurements were conducted using an established protocol during periods of anticipated high ozone concentrations in order to best utilize project resources.

## 1.3 Content of This Report

This report consists of seven main sections in addition to this introduction. In Section 2, the study design and subsequent CCROPS monitoring network are discussed, including detailed maps of the locations of all of the study-specific measurements. The overall organization of the study is also discussed. Details regarding the monitoring methodologies used during the study are presented in Section 3. Section 4 presents a discussion of the field activities during the CCROPS monitoring conducted in the summer of 2005. This includes a summary of weather conditions during the study, and specifics regarding monitoring for each day of the study. A discussion of the quality assurance employed for the study is contained in Section 5. Section 6 discusses the CCROPS database development, and presents specifics regarding the structure of the delivered database. Section 7 contains results from initial analyses of the CCROPS data. These analyses address such questions as the adequacy of the existing DAQEM ozone monitoring network, the role of both transport and local contributions in producing exceedances of the ozone standard, the role ozone concentration aloft play in the Las Vega Valley, and the role that wildfires had on ozone in Clark County. Finally, recommendations for enhancing the DAQEM monitoring network and for additional analyses are provided in Section 8.

# 2. SAMPLING NETWORK

## 2.1 Overview of Network Components

Because of its extensive nature, the CCROPS field monitoring effort involved a coordinated and cooperative effort from a number of participants. **Figure 2-1** shows the project organization for CCROPS, and the role that each participant had in the overall monitoring effort. This section describes each of these monitoring efforts in more detail.

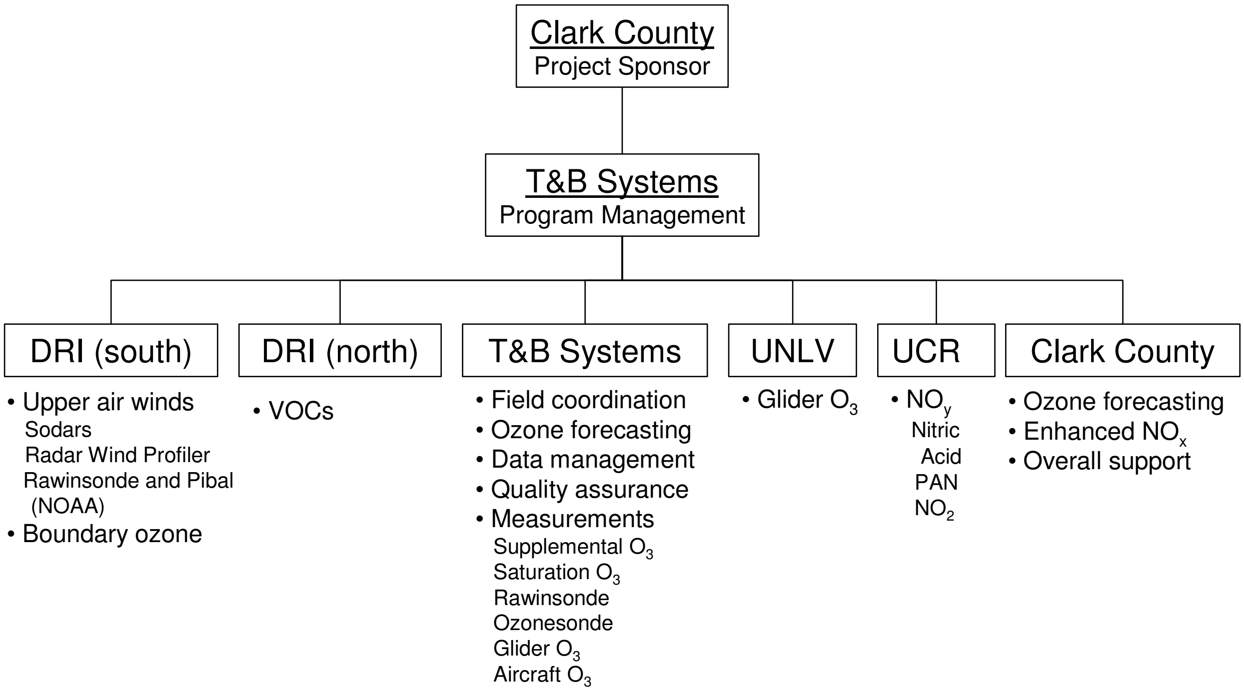


Figure 2-1. Project Organization and Responsibilities

Surface-based measurements established and operated <u>specifically for this project</u> consisted of ozone, oxides of nitrogen ($NO_y$), Volatile Organic Compounds (VOC), and meteorology (winds). The charts on **Figures 2-2, 2-3, and 2-4** show the locations of surface observations.

A major gap in the understanding of the atmospheric processes associated with Las Vegas air quality was due to the absence of measurements both meteorology and ozone aloft. Filling this gap became a major element in the 2005 field study**.** Measurements of meteorology and air quality aloft were made using a variety of methods and participants. These include:

- A radar wind profiler and mini-SODAR located at the North Las Vegas Airport and operated by DRI continuously during the field study,
- Three standard SODARs, capable of measuring winds up to 600 m, located at Jean, Floyd Lamb State Park, and the Speedway and operated by DRI continuously during the field study,

- Balloon-borne measurements of temperature, RH, and winds (rawinsonde) and ozone (ozonesonde) from the North Las Vegas Airport during intensive operation- and episode-mode operations by T&B Systems,
- Aircraft measurements of temperature and ozone during select periods by T&B Systems,
- Rawinsondes at Jean during episode-mode operations by NOAA/SORD, and
- Winds aloft (pibal) measurements in the foothills of the Las Vegas Valley during episode-mode operations by NOAA/SORD.

**Figure 2-5** shows the locations of the upper-air measurements including the special pibals conducted by NOAA/SORD. Aircraft sampling routes and patterns are discussed in detail in Section 7.

## 2.2 DAQEM

In addition to providing the overall project oversight, the DAQEM meteorologist collaborated with T&B Systems meteorologists in daily operational forecasting for project activities. The Monitoring section of the Clark County Department of Air Quality and Environmental Management (DAQEM) operates air quality monitoring instruments to continuously measure ambient concentrations of pollutants. This includes an existing network of 15 ozone monitors and corresponding surface (10 m) winds. The station locations are based on such factors as population exposure and highest likely air pollution concentrations. The locations of the established DAQEM ozone measurements are shown in Figures 2-2 and 2-3. Specific details regarding their location are provided in **Table 2-1**.

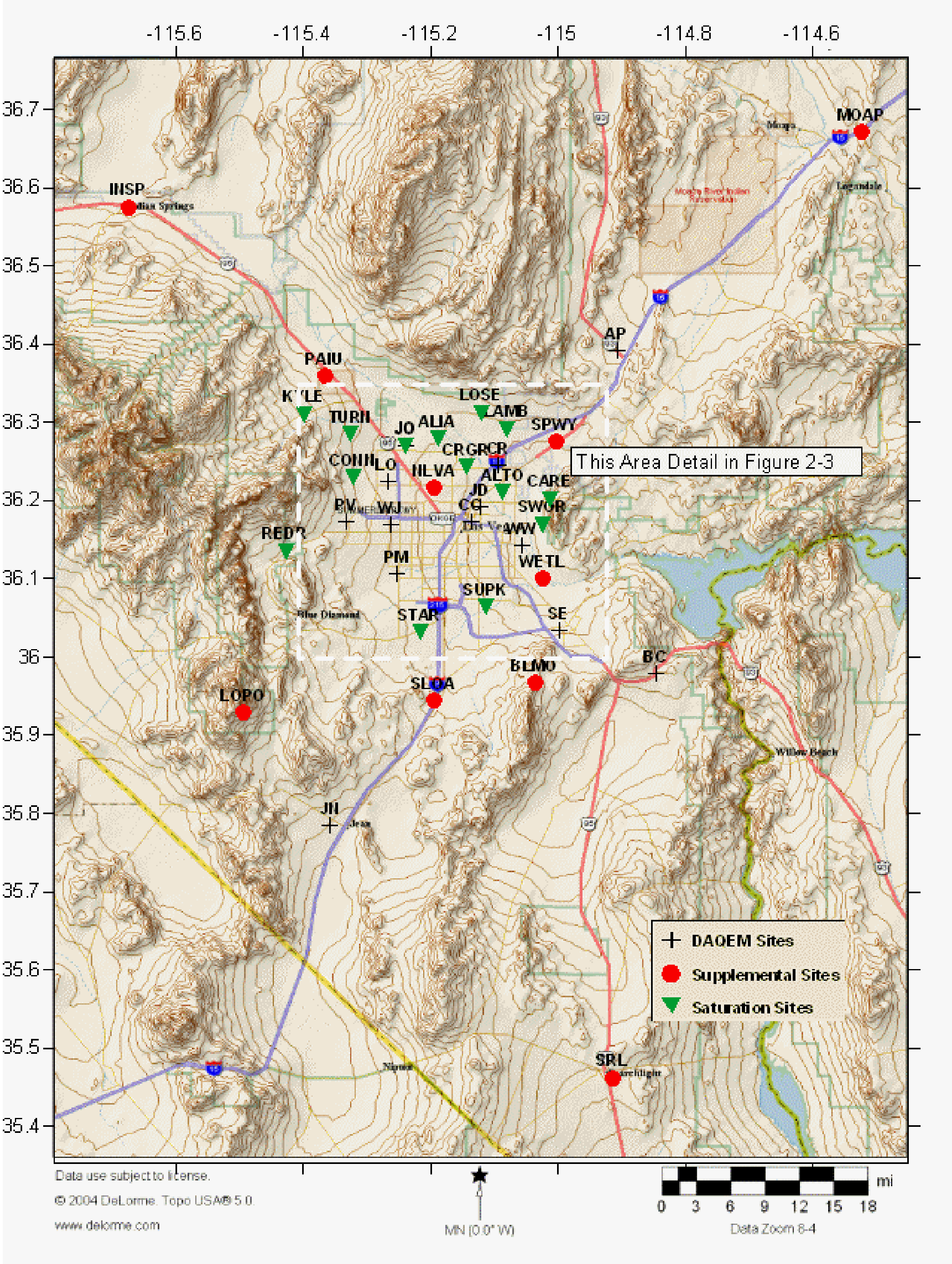


Figure 2-2. CCROPS Surface Ozone Monitoring Network Coverage in Clark County

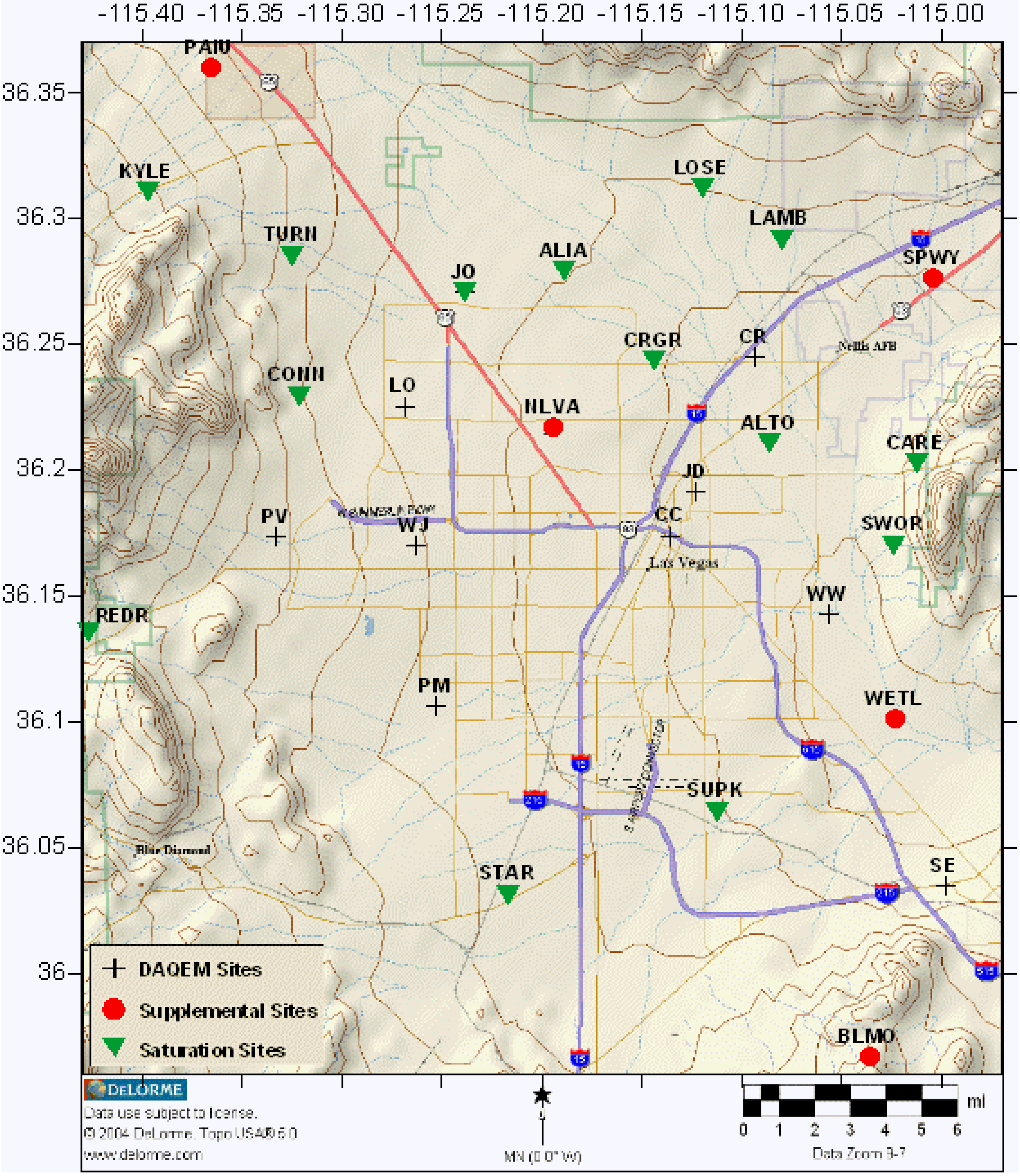


Figure 2-3. CCROPS Surface Ozone Monitoring Network Coverage in Las Vegas Valley

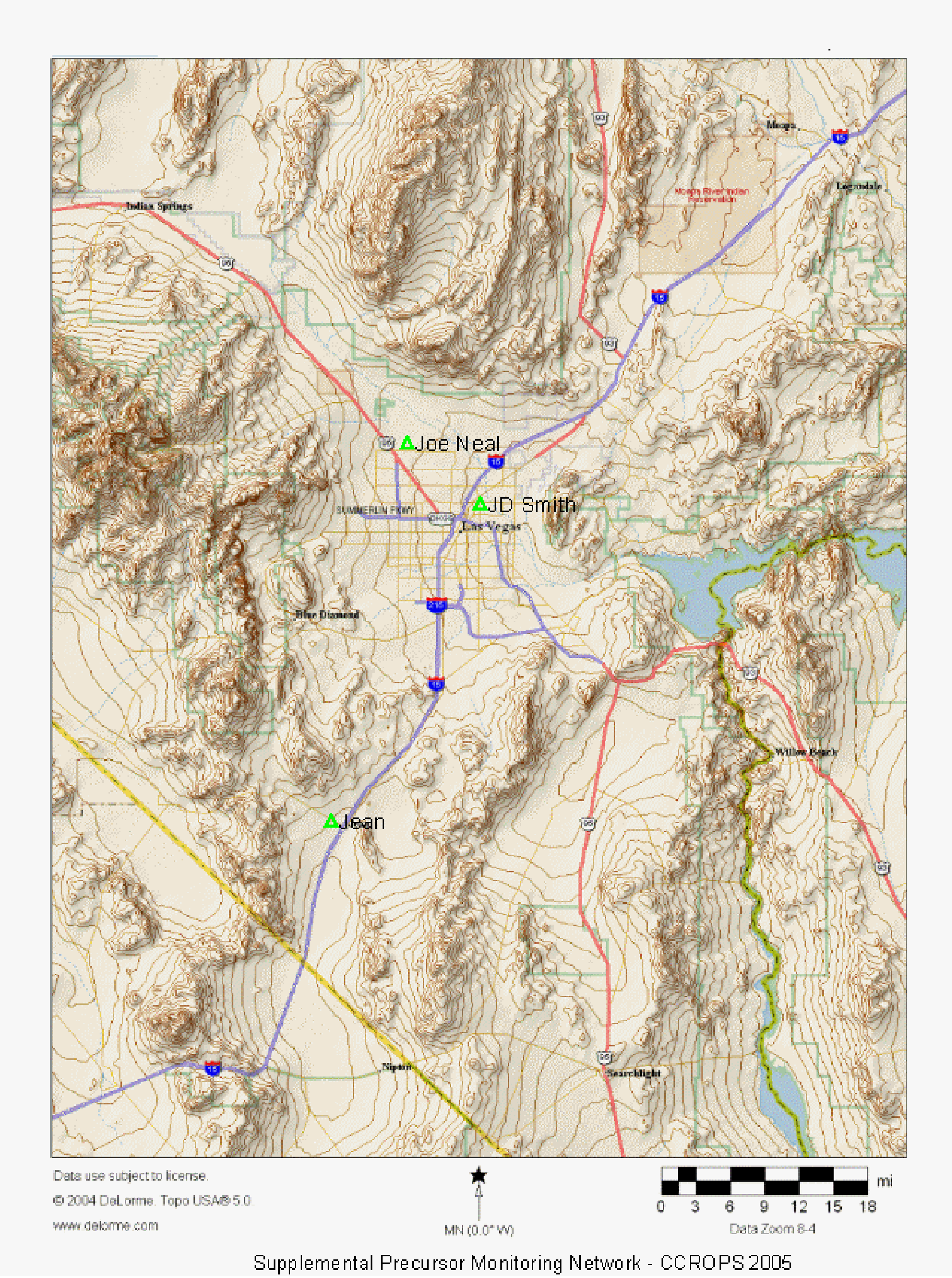


Figure 2-4. CCROPS Precursor Monitoring Network

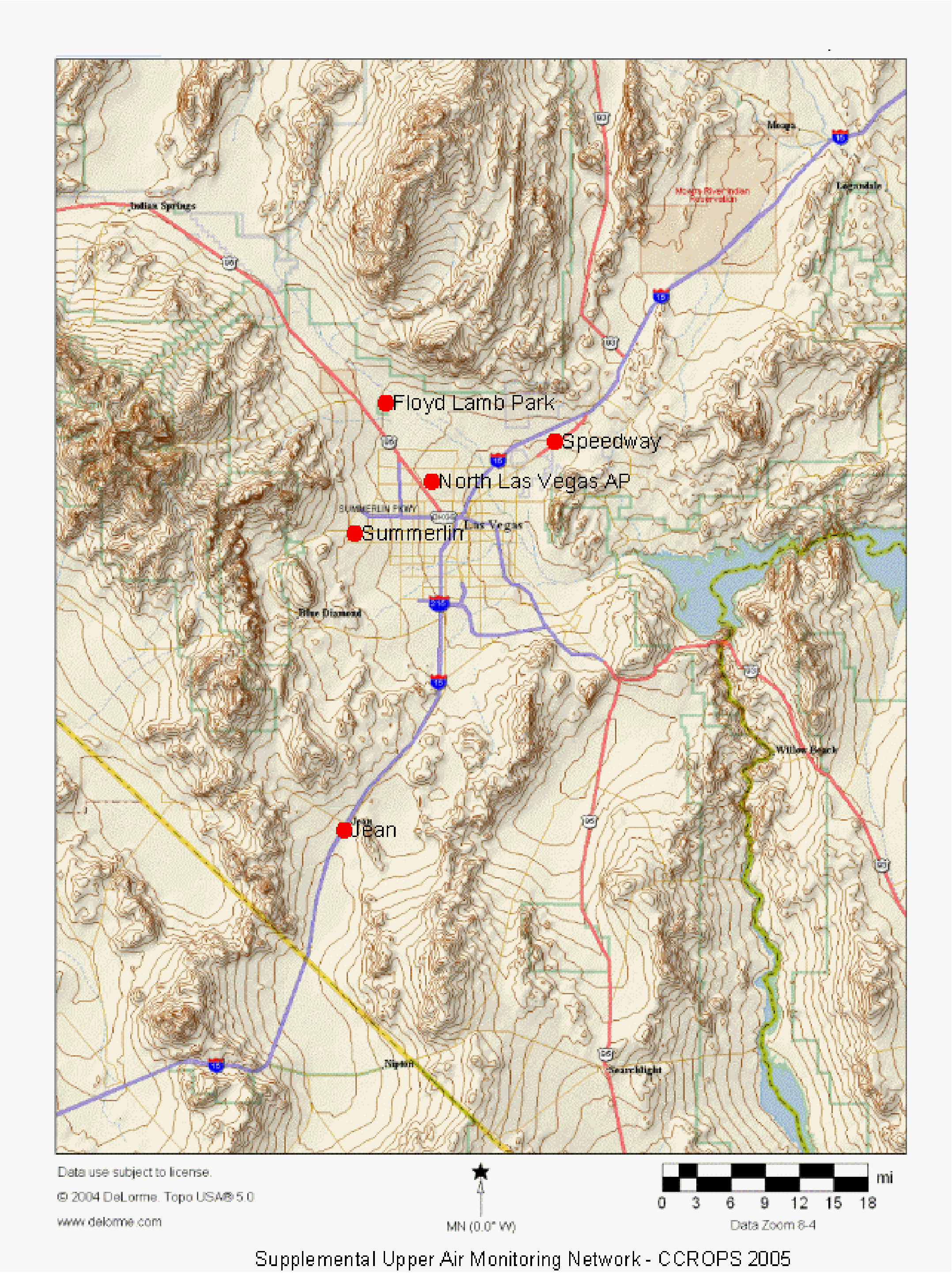


Figure 2-5. CCROPS Upper-Air Monitoring Network

## Table 2-1. Summary of DAQEM Site Locations

| Site Designation | Location |
|---|---|
| AP - Apex<br>Lat: 36.3910<br>Lon: -114.9075<br>Alt: 659 m | I-15 and US93 |
| BC – Boulder City<br>Lat: 35.9781<br>Lon: -114.8463<br>Alt: 758 m | Industrial and US93 |
| CC – City Center<br>Lat: 36.1738<br>Lon: -115.1358<br>Alt: 607 m | Bonanza Road and 7th St. |
| CR – E. Craig Road (Bemis)<br>Lat: 36.2452<br>Lon: -115.0932<br>Alt: 583 m | Craig Rd. and I-15 |
| JD – JD Smith<br>Lat: 36.1912<br>Lon: -115.1229<br>Alt: 568 m | Bruce St. and Tonapah Ave. |
| JN – Jean<br>Lat: 35.7857<br>Lon: -115.3572<br>Alt: 921 m | Jean, NV |
| JO – Joe Neal<br>Lat: 36.2706<br>Lon: -115.2382<br>Alt: 710 m | Tropical Pkwy and Rebecca Rd. |
| LO – Loan Mountain<br>Lat: 36.2252<br>Lon: -115.2680<br>Alt: 725 m | W. Gowan Rd. and Buffalo Dr. |
| MQ – Mesquite<br>Lat: 36.8079<br>Lon: -114.0609<br>Alt: 488 m | Old Mill Rd. and Mimosa Way |
| PL – Henderson (SE Valley)<br>Lat: 36.0289<br>Lon: -114.9889<br>Alt: 795 m | W. Lake Mead Dr. and Van Wagenen |
| PM – Paul Meyer<br>Lat: 36.1064<br>Lon: -115.2532<br>Alt: 731 m | W. Flamingo Rd. and Tenaya Way |
| PV – Palo Verde<br>Lat: 36.1734<br>Lon: -115.3327<br>Alt: 930 m | W. Alta Dr. and Pavillion Center Dr. |
| WJ – Walter Johnson<br>Lat: 36.1698<br>Lon: -115.2630<br>Alt: 769 m | W. Alta Dr. and Buffalo Dr. |
| WW – Winterwood<br>Lat: 36.1429<br>Lon: -115.0563<br>Alt: 523 m | E. Sahara Ave. and Winterwood Blvd. |

## 2.3 T&B Systems

### 2.3.1 Surface Ozone Measurements

Much of the design of the surface ozone measurement network for the CCROPS is based on analysis of ozone data collected for the period 2000 through 2003 during the Clark County Ozone Characterization Study[1], including a detailed analysis of ten case studies. Generally the afternoon surface winds in the Valley supported transport of the Las Vegas urban plume to the northwest on study days. The prevailing-winds trajectory initially moves to the southeast under drainage flow but reverses as drainage winds diminish. This provides a recirculation back through the center of the city, possibly adding to the ozone precursors and ultimately increasing the urban plume ozone as it moves to the northwest.

On the basis of the data analyzed, a monitoring network was designed to fill in regions between existing DAQEM monitors and make measurements in regions that may be suspected of having elevated ozone levels. Additional surface ozone measurements conducted by T&B Systems consisted of the following types:

- Supplemental ozone monitoring stations. These sites consisted of EPA-designated equivalent ozone analyzers located at available facilities for the CCROPS study period. Wind speed / wind direction was also collected at each site, typically at about 2 meters above rooftop (2 to 10 meters agl). The supplemental sites were placed at locations that addressed specific issues regarding ozone in Clark County. These included better defining boundary conditions of the region and obtaining more information about background concentrations and nocturnal concentrations above and outside of the urban area.
- Saturation ozone monitoring stations. These sites consisted of portable samplers operated from batteries with the data recorded on self-contained data loggers. Because of the unique design, the samplers could be hung on utility poles or placed at ground level with a sample line extending to a 3-meter sample height. The instruments required no environmental controls so they could be cost-effectively operated in virtually any location. The siting of the saturation ozone network concentrated on locations where ozone was suspected to be high based on a review of the existing data, flow patterns, and the distribution of the major source regions. In addition, samplers were placed in areas currently underrepresented relative to their population. Samplers thus were located primarily in the urbanized area of Las Vegas.

Figures 2-2 and 2-3 show the enhanced CCROPS ozone monitoring network. **Tables 2-2 and 2-3** present additional information regarding the locations of the supplemental and saturation measurements, respectively.

Table 2-2. Summary of Supplemental Site Locations

| Site Designation | Location | Purpose |
|---|---|---|
| BLMO – Black Mountain<br>Lat: 35.9477<br>Lon: -115.0512<br>Alt: 1221 m | Located at transmission tower complex in the foothills south of Henderson, south of the end of Eastern Ave | Upwind background concentrations from south, nighttime elevated plume concentrations |
| INSP – Indian Springs<br>Lat: 36.5693<br>Lon: -115.6766<br>Alt: 975 m | Located at the Indian Springs community center off of US-95, approximately 65 km northwest of Las Vegas | Defining extent of ozone plume northwest of Las Vegas |
| LOPO – Lower Potosi<br>Lat: 35.8927<br>Lon: -115.4951<br>Alt: 1884 m | Located at transmission tower complex on Lower Potosi, approximately 35 km southwest of Las Vegas | Upwind background concentrations from southwest, nighttime elevated plume concentrations |
| MOAP – Moapa<br>Lat: 36.6718<br>Lon: -114.5253<br>Alt: 540 m | Located at BLM fire station off of I-15 approximately 75 km northeast of Las Vegas | Defining extent of ozone plume northeast of Las Vegas |
| NLVA – North Las Vegas<br>Lat: 36.2170<br>Lon: -115.1942<br>Alt: 669 m | Located at the North Las Vegas airport, 4107 W. Cheyenne Ave. | Urban site, area of high concentrations, ozonesonde ground truth |
| PAIU – Paiute<br>Lat: 36.3577<br>Lon: -115.3614<br>Alt: 930 m | Located at a pump house on the Paiute Reservation off of US-95 approximately 25 km northwest of Las Vegas | Potential area of peak concentrations to the northwest of Las Vegas |
| SLOA – Sloan<br>Lat: 35.9512<br>Lon: -115.1920<br>Alt: 991 m | Located at transmission tower complex on a ridge above Sloan, off of I-15 approximately 25 km south of Las Vegas | Placed between Jean and Las Vegas, and located above influence of I-15 |
| SPWY – Speedway<br>Lat: 36.2759<br>Lon: -115.0032<br>Alt: 607 m | Located at the Las Vegas Speedway, off of I-15 approximately 15 km northeast of Las Vegas | Possible high concentration to the north-east of Las Vegas |
| SRLT – Searchlight<br>Lat: 35.4683<br>Lon: -114.9066<br>Alt: 1088 m | Located at the Searchlight community center, off of US-95 approximately 80 km south-southeast of Las Vegas | Upwind background concentrations and study boundary site southeast of Las Vegas |
| WETL – Wetlands<br>Lat: 36.1014<br>Lon: -115.0230<br>Alt: 490 m | Located at the Wetlands Park Visitor's Center near the eastern end of Tropicana Ave | Drainage flow along Las Vegas Wash between Las Vegas and Lake Mead |
| DRAP – Desert Rock Airport<br>Lat: 36.6167<br>Lon: -116.0017<br>Alt: m | Located at the Desert Rock Airport | Study boundary site northwest of Las Vegas |
| MOPR – Mojave Preserve<br>Lat: 35.4169<br>Lon: -115.6502<br>Alt: m | Located on the Mojave Wilderness Preserve, CA, off I-15 approximately 80 km southwest of Las Vegas | Study boundary site southwest of Las Vegas |

## Table 2-3. Summary of Saturation Site Locations

| Site Designation | Location | Purpose |
|---|---|---|
| ALIA - Aliante<br>Lat: 36.2793<br>Lon: -115.1885<br>Alt: 688 m | Aliante Deer Springs Park, in the irrigation pump enclosure at the intersection of Aviary and Deer Springs Rds., Aliante. | Measure possible ozone impact within a suburban setting in the far north-central area of the L.V. Valley, just south of CC215. |
| ALTO – Alto<br>Lat: 36.2097<br>Lon: -115.0861<br>Alt: 557 m | Backyard of a private residence near the intersection of Alto Ave., and Walnut Rd. | Measure possible ozone impact in a residential area in the east-central region of the L.V. Valley, southwest of Nellis AFB. |
| CARE – Carey<br>Lat: 36.2024<br>Lon: -115.0122<br>Alt: 624 m | A Power pole on the south side of Carey Ave., approximately 100 meters east of the Sunrise Terrace sub-division. | Measure possible afternoon upslope ozone transport toward the Sunrise Mountains. |
| CONN – Conner<br>Lat: 36.2293<br>Lon: -115.3215<br>Alt: 839 m | At the south boundary of the Eileen Connors Elementary School, 3810 Shadow Peak Dr., 150 meters south of Alexander. | Measure possible upslope ozone transport south of Lone Mountain, just east of CC215. |
| CRGR – Craig Ranch<br>Lat: 36.2433<br>Lon: -115.1433<br>Alt: 612 m | A Power pole on the east side of Commerce St. across from the Craig Ranch Golf Course, about 200 meters north of Craig Rd. | Measure possible ozone impact in the northeastern area in the gap between the DAQEM Craig site and the N.L.V. airport. |
| KYLE – Kyle Canyon<br>Lat: 36.3105<br>Lon: -115.3957<br>Alt: 1129 m | East edge of private residences at Reymore and Racel Rds., approximately 150 meters north of Kyle Canyon Rd. (Nv-157). | Measure possible upslope ozone transport in the far northwest quadrant of the L.V. Valley. |
| LAMB – Lamb<br>Lat: 36.2918<br>Lon: -115.0828<br>Alt: 648 m | Near the southwest corner of the Nevada Power - Lamb Power Station, 100 meters north of the end of Lamb Bl. at CC215. | Measure possible ozone impact in an open area of future expansion in the north-central portion of the L.V. Valley. |
| LOSE – Losee<br>Lat: 36.3122<br>Lon: -115.1195<br>Alt: 691 m | In a remote undeveloped area about 1.5 km northwest of the end of Losee Rd., north of CC215. | Measure possible ozone impact in an open area of future expansion in the far north-central portion of the L.V. Valley |
| REDR – Red Rock<br>Lat: 36.1356<br>Lon: -115.4371<br>Alt: 1150 m | At the southeast corner of the roof of the two story Visitor Center at the Red Rock Canyon National Conservation Area. | Measure possible upslope or inter/intra-basin ozone transport near the far west edge of the L.V. Valley. |
| STAR – Star Nursery<br>Lat: 36.0312<br>Lon: -115.2165<br>Alt: 737 m | On the perimeter wall at the northwest corner of the Star Nursery, Blue Diamond Rd. and Mohawk St. | Measure possible inter/intra-basin ozone transport in the southwest quadrant of the L.V. Valley. |
| SUPK – Sunset Park<br>Lat: 36.0640<br>Lon: -115.1120<br>Alt: 611 m | A power pole about 100 meters south of the pond and 100 meters east of the Eastern Ave. parking area, Sunset Park. | Measure possible inter/intra-basin ozone transport in the southeast quadrant of the L.V. Valley, SE of McCarran Field. |
| SWOR – Sword<br>Lat: 36.1699<br>Lon: -115.0235<br>Alt: 565 m | Backyard of a private residence SSE of Hollywood Bl., and Bonanza RD. | Measure possible afternoon upslope ozone transport toward the Sunrise Mountains. |
| TURN – Turner<br>Lat: 36.2734<br>Lon: -115.3262<br>Alt: 871 m | Backyard of a private residence, about 0.5 km south of Centennial Pkwy, and 100 meters east of CC215 | Measure possible upslope ozone transport north of Lone Mountain, just east of CC215. |

### 2.3.2 Rawinsondes and Ozonesondes

Balloon-borne measurements of temperature, humidity, and winds were made from the T&B Systems facilities at the North Las Vegas airport (Figure 2-3) during IOP-mode operations. Twice-daily soundings were made using GPS wind finding technology that provided one-second data resolution to 6km or more. During so-called episode-mode sampling, operations were ramped to up to include three soundings daily; two of which measured ozone (and associated parameters) as well. Sounding times were coordinated closely to the NOAA Desert Rock routine schedule so they could be compared. On a routine basis, the Desert Rock sounding is the only upper-air measurements available in Clark County. An element of this study was to examine how representative the Desert Rock sounding was of conditions in the Las Vegas Valley.

### 2.3.3 Aircraft Measurements

Characterization of ozone episodes is important in devising effective control strategies to ensure that those strategies work in a variety of conditions corresponding with high measured ozone levels. The transport of ozone/precursors into an area is an important distinguishing characteristic of these episodes. Goals of the CCROPS included obtaining a set of meteorological and air quality measurements that will increase the understanding of the origin of high ambient ozone and precursor levels in Clark County and the determination if the current Clark County measurement network was adequate to define the regional peak ozone concentrations. The reservoir of available ozone upwind of the Las Vegas Valley provides a potentially significant source of both background ozone and precursors that could be transported from upwind locations. A key location in understanding what is being transported into the Las Vegas Valley is the Jean Valley, just upwind. This valley is in the major transport route from areas of the desert southwest that frequently experience elevated ozone levels from air masses passing through the South Coast and San Joaquin Valley Air Basins. The Jean Valley is about a third of the way between the California/Nevada border and Las Vegas and has experienced exceedances of the 8-hr ozone NAAQS, even when the regions within and downwind of the Las Vegas urban area were less than the standard. This makes the Jean region key to the understanding of the drivers causing exceedances in Clark County.

Early in the performance of the CCROPS field study, the potential to use gliders or sailplanes based at the Jean airport was recognized as a sampling platform of opportunity. Through a key connection with the Department of Environmental Studies at University of Nevada, Las Vegas (Dr. Krystyna Stave) and a local soaring association, a research grant and contract support were obtained to add a simple instrument for measuring temperature and ozone profiles from sailplanes. This platform was used to provide ozone and temperature soundings in the Jean Valley during key episode periods of the CCROPS. After initial data were collected and analyzed from the glider platform it became clear that additional valuable information on the spatial distribution of ozone throughout the Las Vegas Valley could be obtained using the glider's tow plane as a cost-effective additional platform for data collection. Thus, an additional instrument was assembled and used in this second aircraft.

## 2.4 DRI South (Las Vegas) /NOAA

DRI operated four SODARs and one radar wind profiler to measure winds aloft. SODAR and profiler sites were chosen based on conceptual models of surface wind patterns and historical locations of high ozone. DRI also processed level II NEXRAD radar data to provide VAD vertical wind profiles from three sites in the region.

Table 2-4. DRI SODAR and Wind Profiler Site Specifics

| Site ID | Location | Elev. (m MSL) | Instrumentation | Site Purpose |
|---|---|---|---|---|
| NLVA | Northern boundary just outside of North Las Vegas Airport | 669 | Vaisala LAP-3000 profiler and AeroVironment Model 4000 Mini-SODAR | Central valley transport; close proximity to North Las Vegas Airport (KVGT) |
| JNAP | Jean Airport | 862 | AeroVironment Model 2000 SODAR | Upwind transport |
| SPWY | Las Vegas Motor Speedway at northeast corner of property | 607 | AeroVironment Model 2000 SODAR | Northeast valley flow and flow exiting valley toward Apex Valley |
| FLSP | Floyd Lamb State Park | 753 | AeroVironment Model 2000 SODAR | Northwest valley flow near high ozone concentrations |
| SUMM | Summerlin | 917 | Pibal and Rawinsonde | West valley flows, investigate slope flows and return flows aloft from the Spring Mountains |

NOAA ARL/SORD conducted episodic upper-air measurements in support of the SODAR audits as well as filling in gaps in the upper-air monitoring network during the CCROPS field study. The NOAA measurements were made using pilot balloons (pibals) and radiosondes. Balloons were released from 05:00 through 23:00, with radiosondes released at 05:00, 09:00, 18:00, and 22:00 PDT, and pibals released on the remaining hours.

Additional details regarding the DRI/NOAA upper-air measurements can be found in the DRI report included in **Appendix A.**

The combination of these measurements and the North Las Vegas and Desert Rock rawinsondes provided more information into the three-dimensional regional wind fields than has ever been available and provide the information to initialize and validate MM5 model output during the SIP process.

In addition, DRI operated two surface ozone monitors to measure boundary conditions. Sites were in the Mojave Wildlife Preserve and at Desert Rock.

## 2.5 UCR/CE-CERT

In order to characterize the ozone chemistry a comprehensive knowledge of nitrogenous species is necessary. Reactive nitrogenous species ($NO_y$) consists primarily of nitric oxide (NO), nitrogen dioxide ($NO_2$), peroxyacyl nitrates (PAcNs), nitric acid ($HNO_3$), particulate nitrate, and nitrous acid (HONO) roughly in that order of concentration in ambient photochemical air pollution. Commercial chemiluminescent NO analyzers, such as those currently in use by the DAQEM, are equipped with converters that reduce these $NO_2$ to NO in order to measure $NO_2$

concentrations by difference. These converters also reduce other $NO_y$ components thus giving a high bias for the $NO_2$ concentrations. Because the air stream is filtered, particulate nitrate is not measured. Since the converter (which is integral with the analyzer) resides in a temperature-controlled environment nitric acid is unlikely to penetrate the sampling line effectively. While these lower the $NO_2$ bias, there is uncertainty in the concentration of $NO_y$. CE-CERT equipped two DAQEM measurement sites with analyzers that specifically measured $NO_y$, nitric acid, $NO_2$, and peroxyacetyl nitrate (PAN, the most abundant PAcN). One site was near primary emissions (JD Smith), and the other is generally downwind of primary emissions (Joe Neal).

## 2.6 DRI North (Reno)

The DRI Reno staff was responsible for VOC sampling that was conducted concurrent with episode-mode monitoring to provide additional information on ozone precursors. Canisters were exposed at three sites, Jean, Joe Neal, and JD Smith. Two 6-hr integrated samples daily were taken at Jean (beginning at 00 and 06 PDT), and four 3-hr integrated samples daily taken at the latter two sites (beginning at 00, 06, 11, 17 PDT). Timing of the samples was coordinated to general diurnal activities relating to emissions and chemical reactivity. The Jean site was intended to characterize rural/upwind conditions where as the two urban sites characterized the air mass during likely different ozone chemistry phases.

## 3. MEASUREMENT METHODS

Descriptions of the instrumentation and methods employed in the study specific measurements are provided in this section. The meteorological measurements are discussed first and include both surface and upper-air equipment. Upper-air measurements were made using a variety of methods ranging from remote sensing instruments to balloon-borne, GPS wind finding systems. The air quality measurements include ozone and ozone precursor monitoring equipment.

### 3.1 Meteorological Measurements

Surface-based and aloft meteorological measurements comprise the supplemental measurements made for CCROPS. The only project-specific surface measurements were winds. Aloft measurements were made using both remote-sensing wind finding equipment and balloon-borne measurements of temperature, humidity and winds.

### 3.1.1 Surface Wind Speed and Direction

An RM Young 5103 Wind Monitor or 5305 Wind Monitor-AQ wind speed and direction sensor was used at all T&B supplemental sites. These sensors employ a propeller anemometer. The sensors were mounted on 2-meter tripods, typically on the roof of the saturation site shelter, resulting in measurement heights ranging form 2 to 10 meters. Continuous data were recorded using a Campbell Scientific CR10 data logger.

| | |
|---|---|
| Accuracy (instrument specifications) | |
| Horizontal Wind Speed | ±(0.2 m/s + 5% of observed) |
| Horizontal Wind Direction | ±5 degrees |
| Precision (performance checks) | |
| Horizontal Wind Speed | ±0.1 m/s |
| Horizontal Wind Direction | ±2 degrees |
| Output Resolution | |
| Horizontal Wind Speed | 0.1 m/s |
| Horizontal Wind Direction | 1 deg. |
| Starting Threshold | 1.0 m/s |

### 3.1.2 Radar Wind Profiler

The Vaisala LAP® -3000 Lower Atmosphere Wind Profiler was utilized in this study without the associated RASS. This instrument is a Doppler radar that provides vertical profiles of horizontal wind speed and direction, and vertical wind velocity to an altitude of 3 km above ground level. The wind profiler operated at the North Las Vegas airport.

Performance specifications were not provided.

### 3.1.3 SODARs

Two models of SODARS were utilized in the project: AeroVironment Model 2000 and Model 4000.

## Model 2000 SODAR System

At Jean, the Speedway, and Floyd Lamb Park, AeroVironment Model 2000 SODAR systems were installed and operated continuously for the duration of the field study.

The Model 2000 includes the following components: (1) the antenna array and pre-amplification electronics, (2) the acoustic signal processor (ASP) and (3) Pentium based computer user interface. The antenna array consists of three heated parabolic dishes enclosed with 1-2 meter high acoustic enclosures. Thnadners™ are mounted at the top of each enclosure. Thnadners™ are saw-tooth (patented) acoustic devices that optimize the directional performance.

Three-dimensional wind profiles are determined using the data from all three antennae. One antenna is pointed vertically and the other two antennae are orthogonally oriented and positioned at variable zenith angles of up to 30° (nominally). In normal situations the non-vertical antennae are set to a zenith angle of 20°. For precise horizontal wind measurements in complex terrain locations the horizontal wind components are corrected for the actual vertical velocity on a pulse-by-pulse basis. Depending upon the physical characteristics of the site, other operating zenith angles may be used.

The heart of the system is the acoustic signal processor (ASP) unit. It generates the acoustic pulses, tapers (to lengthen the diaphragm lifetime) the pulse, samples the received atmospheric echo at preselected height intervals, transforms these range gated data into the spectral domain, detects the mean frequency shift and translates these data into useful meteorological information.

The ASP is connected to a Pentium microcomputer via a serial communications link that normally operates at 19.2 Kb. The ASP produces three types of data: (1) the wind and wind turbulence information, (2) the time series of the echo intensity from the vertical antenna (called the facsimile data) and (3) troubleshooting information based on the real time examination of the Doppler spectra.

| Accuracy (instrument specifications) | |
|---|---|
| Horizontal Wind Speed Components | 0.20 m/s for 2 m/s < WS < 5 m/s<br>(5% for WS > 5 m/s) |
| Horizontal Wind Speed | 0.30 m/s for 2 m/s < WS < 5 m/s<br>(7% for WS > 5 m/s) |
| Vertical Wind Speed Component | 0.10 m/s for W > 0.5 m/s<br>(5% for W > 3 m/s) |
| Horizontal Wind Direction | 3 deg. for WS > 2 m/s |
| Output Resolution | |
| Horizontal Wind Speed Components | 0.01 m/s |
| Horizontal Wind Speed Vector | 0.01 m/s |
| Vertical Wind Speed Component | 0.01 m/s |
| Horizontal Wind Direction | 1 deg. |
| Sampling Heights | 20 |
| Sampling Height Increment | 30 meters |
| Minimum Sampling Height | 20 meters |
| Transmit Frequency | 500 to 6000 Hz. |
| Averaging and Reporting Interval | Single pulses to 1440 minutes |

**Model 4000 Mini-SODAR System**

To complement the radar wind profiler at the North Las Vegas airport, An AeroVironment Model 4000 high-frequency Doppler SODAR system, or Mini-SODAR was utilized. This system consists of a compact 32-element phased array antenna to form the three orthogonal beams needed to measure a complete three-dimensional wind profile. In addition to its compact size and minimal power requirements, winds are measured at 5-meter increments and are typically used as a wind tower replacement system —measuring up to 200 meters.

| Accuracy (instrument specifications) | |
|---|---|
| Horizontal Wind Speed | 0.5 m/s |
| Horizontal Wind Direction | ±5° |
| Maximum Altitude | 200 meters |
| Sampling Height Increment | 5 meters |
| Minimum Sampling Height | 15 meters |
| Transmit Frequency | 4500 Hz. |
| Averaging and Reporting Interval | 1 to 60 minutes |

### 3.1.4 Rawinsonde Systems

**Sippican W-9000 (T&B Systems)**

The Sippican W-9000 system consists of a SIPPICAN ZEEMET W-9000 GPS based navaid receiver/data system for measuring winds and the SIPPICAN Mark II Microsondes radiosonde packages.

The SIPPICAN ZEEMET W-9000 receiving station interfaces with a personal computer and printer. This is a state-of-the-art wind finding system employing GPS technology. The UHF receiver operates in the 400 MHZ range. SIPPICAN software enables the interface with the SIPPICAN W-9000 receiver and reduces the thermodynamic pressure, temperature and humidity (PTU) and navaid/wind data. During each flight, the technician is able to monitor both raw and reduced data in near real time. The software also includes graphics and plotting capabilities that allow the technician to review results during and at the end of each flight. Both raw and reduced data were stored on the hard disk in subdirectories identified by the flight name. All data files were copied to both primary and backup diskettes immediately after each flight.

**SIPPICAN Mark II Microsondes (T&B Systems)**

The SIPPICAN Mark II Microsondes are 10 x 19 x 15 cm and weigh 250 grams with a water-activated 18V battery. The radiosonde UHF transmitter sends its modulated signals in the 400 MHZ range. The Microsondes are calibrated at the factory in a computer-controlled environmental chamber. Calibration coefficients are stored in read-only-memory (ROM) within each sonde and are automatically transmitted to the receiver in 1.5 sec intervals. Temperature is measured using a bead thermistor and relative humidity using a carbon hygristor. The SIPPICAN W-9000 is an automatic wind finding system that is based on tracking the sonde using the GPS satellite network. The Microsonde incorporates a low-noise integrated circuit GPS receiver. Winds aloft are calculated from the change in balloon position (determined from navaid) with time. Height is obtained directly from GPS positioning and, unlike older systems, pressure is now a derived parameter, calculated from the hydrostatic equation, using measured height, temperature, and humidity.

| Accuracy (instrument specifications) | |
|---|---|
| Horizontal Wind Speed | ± 0.5 $ms^{-1}$ |
| Horizontal Wind Direction | unknown |
| Temperature | ± 0.2° C |
| Relative Humidity | ± 2.0% |
| Output Resolution | |
| Horizontal Wind Speed | 0.1 m/s |
| Horizontal Wind Direction | 1.0° |
| Temperature | 0.1° C |
| Relative Humidity | 1.0% |

It should be noted here that the EN-SCI Corporation KZ-ECC ozonesonde system was used in conjunction with the SIPPICAN W-9000 Mark II Microsondes radiosonde package at the North Las Vegas airport. This instrument is discussion in Section 3.2.1.3.

## 3.2 Air Quality Measurements

### 3.2.1 Ozone

**Dasibi Model 1000 series**

The supplemental sites were equipped with either Dasibi Model 1003 or Model 1008 UV photometric ozone analyzers (EPA equivalent numbers EQOA-0577-019 and EQOA-0383-056, respectively). Sampling was made through Teflon lines, which, with the exception of the site at the Speedway, were of sufficiently short length to meet EPA requirements for sample residence time. Analyzers were routinely checked using a certified transfer standard, following operating procedures consistent with EPA guidelines. Continuous data were recorded using a Campbell Scientific CR10 data logger. Continuous internal shelter temperature was also recorded at all sites.

| Accuracy (performance checks) | ±5% |
|---|---|
| Precision (performance checks) | ±5% |
| Resolution | 0.001 ppm |
| Lower Quantifiable Limit | 0.002 ppm |

**2B Model 202 Ozone Analyzer**

The 2B Ozone Monitor was utilized at the Lower Potosi site after a nearby wildfire disrupted commercial power for an extended period. In addition, 2B monitors were used at the boundary sites at Mountain Pass and Desert Rock. This monitor has a low power consumption (12v DC, 0.33 amp, 4.0 Watt) relative to conventional instruments allowing operation with solar-panel charged batteries. Additionally, it does not require a temperature-controlled environment.

The 2B Technologies Model 202 Ozone Monitor™ is designed to enable accurate and precise measurements of ozone ranging from low ppb (precison of ~1 ppbv) up to 100,000 ppb (0-100 ppm) based on the well established technique of absorption of light at 254 nm. "Absorption spectroscopy" is a chemical analysis technique made possible by the phenomenon that a given molecule absorbs light at selected wavelengths. The wavelengths absorbed are characteristic of each molecule's atomic features. The amount of light radiation absorbed by a substance depends on two factors: the number of molecules in the path of the light, and the characteristics of the molecule (e.g., absorption cross-section). Measurement of changes in the light intensity as it passes through the molecules, and the use of calibration and reference data, enable the determination of the number of molecules encountered.

| | |
|---|---|
| Accuracy (performance checks) | ±5% |
| Precision (performance checks) | ±5% |
| Resolution | 0.001 ppm |
| Lower Quantifiable Limit | 0.002 ppm |

## EN-SCI Ozone Analyzer (ozonesondes)

The EN-SCI Corporation Model KZ-ECC atmospheric ozone sounding system is designed for ozone measurements from balloon platforms, but for this project was used both from balloon platforms and, in a modified package, for continuous surface sampling at fixed locations (see Section 3.2.1.4). Ozone is measured with an electrochemical concentration cell (ECC) ozonesonde coupled through an electronic interface to a SIPPICAN W-9000 Mark II radiosonde.

The ECC ozonesonde is of a simple design consisting of a rigid mainframe on which is mounted a motor-driven Teflon/glass air sampling pump, a thermistor for measuring pump temperature, an ozone sensing ECC, and an electronics box containing interface circuitry which couple the ozone sensor to the radiosonde. The mainframe is mounted in a lightweight weatherproof polystyrene flight box that is taped and wired to the radiosonde during flight.

The ozone-sensing cell is made of two bright platinum electrodes immersed in potassium iodide (KI) solutions of different concentrations contained in separate cathode and anode chambers. The chambers are linked with an ion bridge that, in addition to providing an ion pathway, retards mixing of the cathode and anode electrolytes thereby preserving their concentrations. The electrolytes also contain potassium bromide (KBr) and a buffer whose concentrations in each half-cell are the same. The driving electromotive force for the cell, of approximately 0.13 V, is provided by the difference in potassium iodide concentrations in the two half cells. Sample air is forced through the ECC sensor by means of a non-reactive pump fabricated from TFE Teflon impregnated with glass fibers. The pump is designed to operate without ozone-destroying lubricants. Pumping efficiency for each pump varies from pump to pump and is also dependent on ambient air pressure. The sampling flow rate is calibrated at the factory and checked in the field before launch. The ECC ozone concentration calibration is also determined prior to launch.

When ozone in air enters the sensor, iodine is formed in the cathode half cell according to the relation

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2. \qquad (1)$$

The cell converts the iodine to iodide according to

$$I_2 + 2e \rightarrow 2I^- \qquad (2)$$

during which time two electrons flow in the cell's external circuit. Measurement of the electron flow (i.e., the cell current), together with the rate at which ozone enters the cell per unit time, enables ozone concentrations in the sampled air to be derived from

$$p_3 = 4.307 \times 10^{-3}(i_m - i_b)T_p t \qquad (3)$$

where $p_3$ is the ozone partial pressure in nanobars, $i_m$ is the measured sensor output current in microamperes, $i_b$ is the sensor background current (i.e., the residual current emanating from the cell in the absence of ozone in the air) in microamperes, $T_p$ is the pump temperature in kelvins, and t is the time in seconds taken by the sonde gas sampling pump to force 100 ml of air through the sensor.

| | |
|---|---|
| Sensitivity | 2-3 ppb by volume ozone in air |
| Response Time | 15 seconds for 67% of change; 60 seconds for 85% of change |
| Noise | less than 1% of full scale |
| Estimated Measurement Uncertainty | less than ± 10% of indicated value |

## Saturation Samplers

The saturation sampler used for CCROPS is based on the potassium iodide (KI) bubbler detection principle described above. As initial design criteria required the sampler to run for at least two to four days between servicing, early designs looked to use the existing ozonesonde type systems for tropospheric and stratospheric soundings with a modified and enlarged cathode cell. The primary reason for enlarging the cathode cell was to provide enough cathode solution to allow evaporation to take place during operation without significantly depleting the amount of the cathode solution. However, while successful in testing, the size and placement of the additional cathode cell, as well as the power requirements needed for continuous operation of the pump over a number of days, suggested an alternative approach. This alternate approach involved using the same cells that are used in the commercial ozonesonde system, and cycling the pump at appropriate intervals to both conserve power and cathode solution. A prototype system was developed in 2003, and tested at the South Coast Air Quality Management District monitoring site in Santa Clarita. This demonstration documented the cycling technique with successful results during a high ozone event. **Figure 3-1** shows the collected data with 5-minute average values at 30-minute intervals, along with the hourly average data from the local ozone monitor.

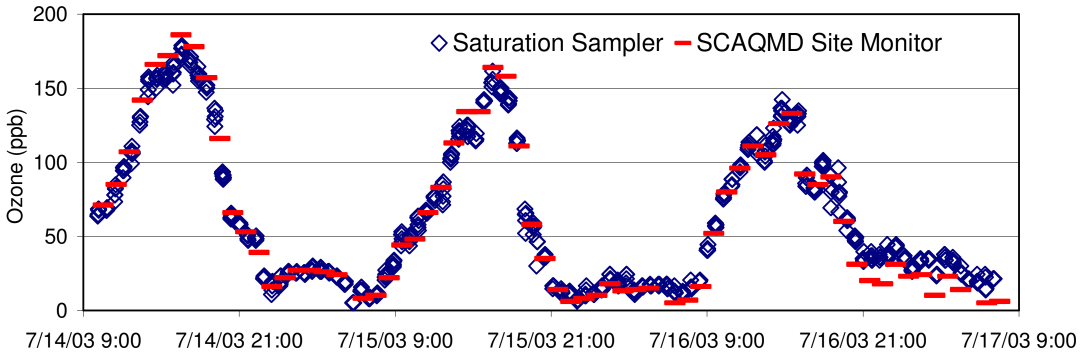


Figure 3-1. Comparison of Saturation Sampler Versus SCAQMD Ozone Data at the Santa Clarita Site in 2003

On the basis of the test results at Santa Clarita, the design was finalized with the system fully self-contained and programmable for continuous running or on and off cycle times. “AA” batteries provided power for the entire system with the ability to operate for up to 5 days without servicing. Data were recorded by a simple multi-channel 8-bit data logger that recorded the cell temperature and current over a nominal range of equivalent ozone concentrations from 0 to 250 ppb, with 1 ppb resolution. This design formed the basis for the samplers built and deployed during the 2005 CCROPS.

During the 2005 ozone season there were four intensive operating periods (IOPs) ranging from one to two weeks in duration during which the saturation sampler operated. Approximately 36 hours prior to the start of an IOP-mode operation, the sample cells and samplers were prepared for deployment. The samplers were then deployed the day prior to the start of the IOP with the original intent of servicing the samplers every three to four days. During the first IOP a more frequent schedule of servicing was used to ensure that the newly designed systems would function properly in the harsh desert environment. It was quickly learned that a service interval of two days was needed to exchange the sample cells as the high ambient temperatures and low humidity evaporated the cathode solutions rapidly. This actually turned out to be advantageous because the data were available sooner for analysis to watch the evolution of the ozone episodes and identify any potential instrument problems.

The design of the samplers allowed a number of deployment options. For some sites, a 3-meter sample line was used to place the sampler at ground level and mount the inlet on an elevated pole. At other sites, the physical sampler was attached to a utility pole. **Figures 3-2** and **3-3** show examples of the sampler mounting. The Styrofoam enclosure was used at each installation and provided both protection for the sampler and insulation for the internal system to regulate, to some degree, the internal temperature.

Figure 3-2. Sampler Mounting at Ground Level with the Sample Inlet at the Top of the Pole

Figure 3-3. Sampler Mounting on a Utility Pole

| | |
|---|---|
| Accuracy (performance checks) | ±10% |
| Precision (performance checks) | ±10% |
| Resolution | 0.001 ppm |
| Lower Quantifiable Limit | 0.002 ppm |

## Aircraft Measurements

The ozone sampling instrumentation for the aircraft was based on the wet cell KI technique implemented by EN-SCI Corporation for tropospheric and stratospheric ozone profiling, as described above. The sample pump/cell system was housed in a small case with the output signal from the sampler recorded on a Campbell CR1000 data logger. This data logger allowed the recording and parsing of a serial data stream from a Global Positioning System receiver as well as recording analog signals of pressure, ambient temperature, detection cell temperature and the calculated values of ozone based on the sampled parameters. Data were sampled and recorded at 4-second intervals. A set of AA batteries provided power and the capability for the entire system to measure ozone continuously for over 8 hours. The sample inlet was through a length of FEP Teflon tubing to a region of the respective aircraft in free airflow. For the glider it was through the nose of the aircraft and for the tow plane, it was half way out the wing, on a support strut. The temperature probe in the glider was placed in the fresh air vent, close to the inlet, but away from any region that could cause solar heating. The probe on the tow aircraft was placed near the sample inlet on the wing strut. For each of the sampling platforms, the installation time prior to a flight required approximately 20 to 30 minutes to install, pre-flight and assure that the systems were operational. The system was also used in another of the sailplanes in the soaring association when the primary plane was unavailable. The mounting, GPS and temperature and sample line runs were essentially the same in each of the installations. **Figure 3-4** shows both the primary sailplane and the tow aircraft prepared for launch. **Figure 3-5** shows the basic sampler installed behind the pilot seat in the glider. **Figure 3-6** shows the installation of the package behind the pilot seat in the tow aircraft. The sample line was run out the open window to the mounting on the strut.

Figure 3-4. Sailplane with Tow Aircraft Readied for Launch

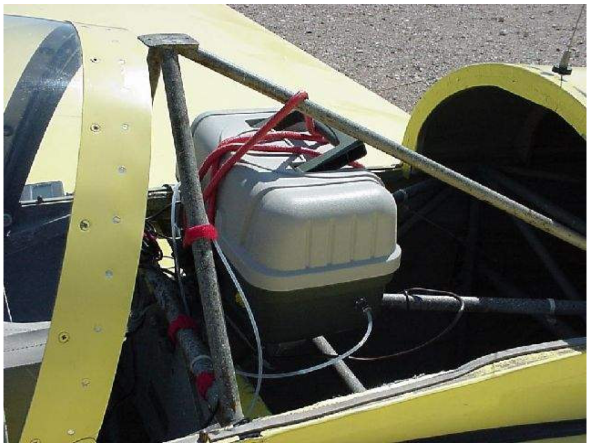


Figure 3-5. Sampler Mounting in Glider with Cowling Removed

Figure 3-6. Sampler Mounting in Back Seat of Tow Aircraft

### 3.2.2 $NO_y$ / PAN Measurements

Two of the DAQEM network sites were supplemented with analyzers that specifically measured $NO_y$, nitric acid, $NO_2$, and peroxyacetyl nitrate (PAN, the most abundant PAcN). The $NO_y$ and $NO_y$- analyzer was a ThermoEnvironmental model 42CY. The performance of this analyzer has been described previously[2]. **Figure 3-7** is a schematic drawing of how the analyzer was configured. The external converter housing was a stainless steel box with fiberglass insulation. The box was, therefore, slightly warmer than ambient air due to the heat released by the two converters. A minimum amount of ¼ inch outside diameter PFA tubing (15 cm) was used to direct the ambient air into the converters. A sodium chloride fabric denuder[3] was used to selectively remove nitric acid from one channel. Nitric acid is therefore measure by subtracting the concentration from the channel scrubbed of nitric acid from the $NO_y$ concentrations. Each channel was sampled twice per minute for ten seconds. Multi-point calibrations were performed at the beginning and end of the study period using a commercial calibrator to dilute NO in nitrogen from a certified compressed gas cylinder. The gas phase titration of NO with $O_3$ by the calibrator was used to verify converter efficiency. Daily span and converter checks were automatically performed with the calibrator.

$NO_2$ and PAN were measured using a gas chromatograph with luminol detection. **Figure 3-8** shows a schematic diagram of the $NO_2$/PAN gas chromatograph. Sample is drawn through a

---

[2] Fitz, D.R., Pankratz, D.V., Bumiller, K., Smith M.K. Measurement of $NO_2$ and PAN by gas chromatography with luminol detection. Air and Waste Management Association Symposium on Air Quality Measurement Methods and Technology, 2002. San Francisco, CA November 13-15, 2002.

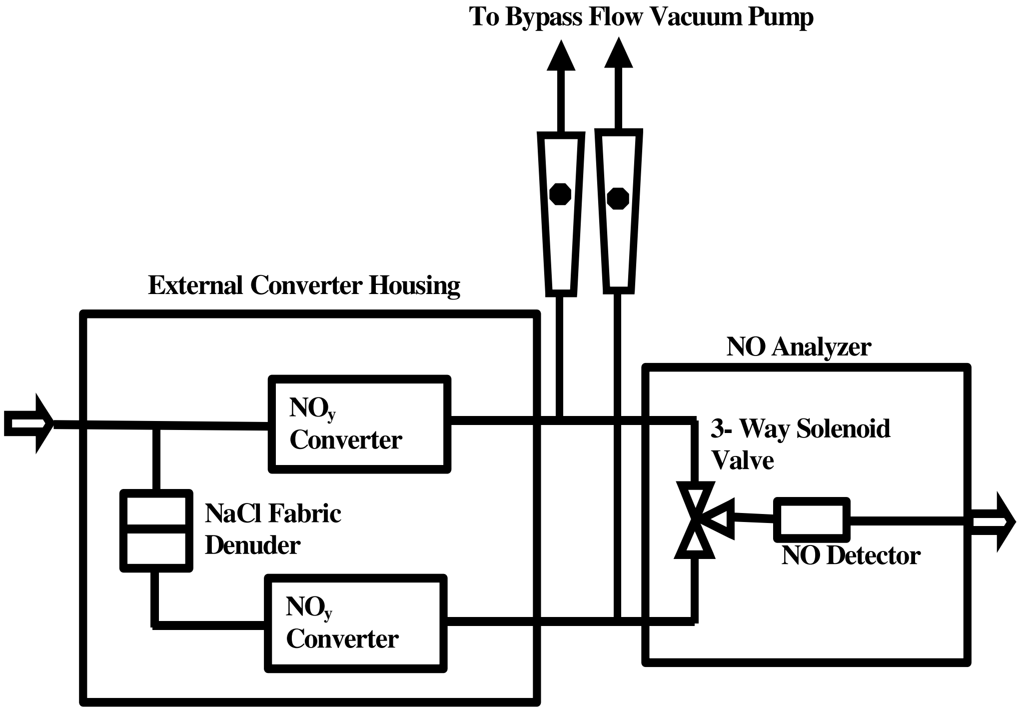


Figure 3-7. Schematic Diagram of $NO_y$ Analyzer Configuration

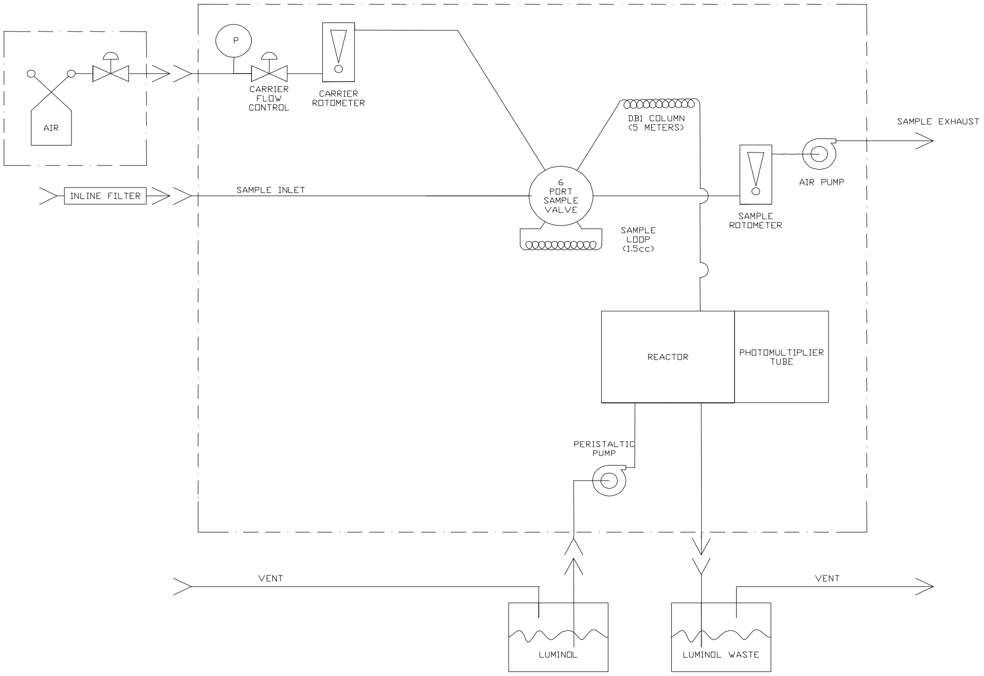


Figure 3-8. Schematic Diagram of $NO_2$/PAN Gas Chromatograph

1 ml PFA Teflon® sample loop connected to a six-port GC injection valve (Valco Instruments model 000-0106L). The sample is injected at 2-minute intervals (i.e. the sample switched briefly into the carrier stream) into a chromatographic column (J&W Scientific DB1, 0.53 mm bore, 3 µm coating) maintained at room temperature. Dry, purified air is used as a carrier gas. PAN elutes from the column several seconds after $NO_2$. In the detector, a luminol solution on a wick reacts with $NO_2$ and with PAN, generating light that is detected by a photomultiplier tube (Hamamatsu Corporation model H5920-01). A buffered solution containing luminol[6] (0.05M NaOH, 0.1 M $Na_2SO_3$, $2x10^{-4}$ M luminol and 0.05 percent (v/v) *tert*-butyl alcohol in deionized water) is supplied to the wick with a piston pump (Fluid Metering Inc. model QG6), and used luminol solution exits the detector with the carrier gas. The intensity of the light is proportional to the amount of $NO_2$ or PAN reactant present in the detector. The output of the PMT is amplified and directed to the $NO_2$/PAN GC computer data acquisition and control system, which stores and analyzes one complete chromatogram every two minutes. The software used is based on Labview®. The total area of the $NO_2$ and PAN peaks in the chromatogram are calculated as well as the area within an equivalent time of baseline. Calibration factors are applied to the net area, and the resulting ambient $NO_2$ and PAN concentrations in ppb are stored on the $NO_2$/PAN GC computer along with the original chromatogram. Carrier gas flows were adjusted to clearly separate the $NO_2$ and PAN and allow the tail of the PAN peak to return to baseline before the background was determined. Carrier flow rates of 20-40 ml were generally found to be optimum. The response to $NO_2$ and PAN was found to be similar on a molar basis and $NO_2$ generated from calibrator from gas phase titration of NO with $O_3$ was used to calibrate the response. Daily zero span checks were performed automatically and simultaneously with the $NO_y$-$NO_{y-}$ analyzer.

| | |
|---|---|
| Accuracy | |
| $NO_y$, $NO_y$-, and Nitric Acid | ±15% |
| $NO_2$ and PAN | ±15% |
| Precision | |
| $NO_y$, $NO_y$-, and Nitric Acid | ±10% |
| $NO_2$ and PAN | ±10% |
| Output Resolution | |
| $NO_y$, $NO_y$-, and Nitric Acid | 0.5 ppb |
| $NO_2$ and PAN | 1 ppb |
| Lower Quantifiable Limit | |
| $NO_y$, $NO_y$-, and Nitric Acid | 1 ppb |
| $NO_2$ and PAN | 2 ppb |

### 3.2.3 VOC Measurements

The DRI Canister Sampler takes air from the sample inlet and injects it into a canister or bag at a constant flow rate for a preset time. The excess air is released through the bypass exhaust. The constant flow rate and elapsed time allow the operator to compute the volume of the integrated air sample. The sample is pumped through a 12 V.D.C. pump which develops sufficient pressure to control the flow with a Variflo regulator. The pump also samples the air at a flow rate sufficient to keep any long sampling lines flushed. A small, constant flow of sampled air is pumped into the sample container. The sampler is automatically purged for five minutes at the beginning of each run. The timer turns on the pump for five minutes before the canister solenoid is turned on. Following sampling, the solenoid is shut off to seal the canister until an operator can shut off the canister valve. The canister is also be sealed with a Swagelok cap.

Canister samples were analyzed upon receipt of samples from the field operators method TO-15 for volatile organic compounds (PAMs), and with gas chromatography with flame ionization detection (GC/FID) for $C_2$-$C_4$ compounds.

For this project, samples collected before 8/8/05 were analyzed on a GC/FID/MS. An Entech 7100 preconcentrator was used for sample collection and concentration, and a Varian 3800 gas chromatograph with FID and column switching valve, interfaced to a Varian Saturn 2000 ion trap mass spectrometer was used for sample analysis. For samples analyzed on and after 8/8/05, the light hydrocarbons were analyzed on a separate gas chromatograph with flame ionization detection (Hewlett Packard) while the heavy hydrocarbons were analyzed on the GC/MS, bypassing the GS-GasPro column and the FID. This was done to optimize the performance of the GC/MS.

The trapping and focusing process of the Entech 7100 consisted of a first trap of 50 percent glass beads/50 percent Tenax, which was trapped at –100 °C. The sample was then desorbed from this trap at 10 °C and transferred to a trap of 100 percent Tenax held at –40 °C. This trap was desorbed at 200 °C and transferred to a final focusing trap at –180 °C. This trap was desorbed at approximately 70 °C to a transfer line heated to 110 °C and connected to the head of the first column. The objective of the three-stage trapping process was first to manage water and limit the amount of water entering the column by the relatively low desorption temperature. The second trap was to eliminate $CO_2$ since it will not trap on Tenax and stays gaseous even at –40 °C. And the third trap was to focus the sample so that the injection was made as small as possible to limited band broadening.

For the GC/FID/MS configuration, the GC was configured so that the sample was injected at the head of a 60 m x 0.32 mm polymethylsiloxane column (CPSil-5, Varian, Inc.). This column led into the switching valve that was set so the effluent went into a 30 m x 0.53 mm GS-GasPro column (J&W Scientific). After approximately 7 min the column switched so that the effluent from the first column eluted on to a second 15 m x 0.32 mm polymethylsiloxane column into the mass spectrometer. The column switch was timed so that the $C_2$ and $C_3$ compounds eluted on the FID and all $C_4$ and higher compounds eluted on the mass spectrometer.

An oven program of -65 to 223°C with a 2-min. hold and a 6°C/min. program adequately resolved most compounds in this range. On and after 8/8/05 the light hydrocarbons ($C_2$ - $C_5$ compounds) were separated on a 30 m x 0.53 mm GS-GasPro column (J&W Scientific). N-butane was separated on both columns and was used as an internal quality control check.

The GC/FID response was calibrated in ppbC, using primary calibration standards traceable to the NIST Standard Reference Materials (SRM). 1 ppm propane in a nitrogen standard (Scott Specialty Gases), periodically traced to SRM 1805, was used for calibrating the light hydrocarbon analytical system. Based on the uniform carbon response of the FID to hydrocarbons, the response factors determined from these calibration standards were used to convert area counts into concentration units (ppbC) for every peak in the chromatogram. Identification of individual compounds in an air sample was based on the comparison of linear retention indices (RI) with those RI values of authentic standard compounds.

Calibration of the GC/MS system was conducted with a 112 component mixture that contained the most commonly found hydrocarbons (75 compounds from ethane to n-undecane), halocarbons (23 compounds from F12 to the dichlorobenzenes) and oxygenated compounds (14 compounds from acetaldehyde to nonanal, including MTBE).

The minimum detection limit for all hydrocarbons was 0.1 ppbC. All of the gas chromatographs were connected to a data acquisition system (Saturn GCMS Workstation Star Version 5.5.1.). Acquired data were automatically stored on a hard disk. A custom-designed database management system was used to confirm all peak identifications. Table 3-1 contains the hydrocarbons identified and quantified by DRI.

Blanks were performed once daily, while a two-point calibration check was performed every day on the GC/MS/FID and GC/MS. Our analysis plan and data processing standards called for the replicate analysis of approximately 10 percent of the samples. For canisters the replicate analysis was conducted at least 24 hours after the initial analysis to allow re-equilibration of the compounds within the canister. Replicate analysis was important because it provided a continuous check on all aspects of each analysis, and indicated problems with the analysis before they became significant.

| | |
|---|---|
| Accuracy (performance checks) | ±10% |
| Precision (performance checks) | ±10% |
| Background Carryover | <10 ppbC |
| Lower Quantifiable Limit | 0.01-0.05 ppbC |

Table 3-1. Hydrocarbons Identified and Quantified for This Study

| | |
|---|---|
| ethane | 2-methylhexane |
| ethene | 2,3-dimethylpentane |
| acetylene | 3-methylhexane |
| propane | cyclohexene |
| propene | 1,3-dimethylcyclopentane (cis) |
| iso-butane | 1-heptene |
| 1-butene + isobutene | 2,2,4-trimethylpentane |
| 1,3-butadiene | n-heptane |
| n-butane | 2,3-dimethyl-2-pentene |
| t-2-butene | methylcyclohexane |
| c-2-butene | 2,3,4-trimethylpentane |
| 1,2-butadiene | toluene |
| iso-pentane | 2-methylheptane |
| 1-pentene | 4-methylheptane |
| 2-methyl-1-butene | 3-methylheptane |
| n-pentane | n-octane |
| isoprene | ethylbenzene |
| t-2-pentene | m/p-xylene |
| c-2-pentene | styrene |
| 2-methyl-2-butene | o-xylene |
| 2,2-dimethylbutane | n-nonane |
| cyclopentene | i-propylbenzene |
| cyclopentane | alpha-pinene |
| 2,3-dimethylbutane | propylbenzene |
| 2-methylpentane | 3-ethyltoluene |
| methyl-t-butylether | 4-ethyltoluene |
| 3-methylpentane | 1,3,5-trimethylbenzene |
| 2-methyl-1-pentene | 2-ethyltoluene |
| n-hexane | 1,2,4-trimethylbenzene+t-butylbenzene |
| t-2-hexene | n-decane |
| c-2-hexene | 1,2,3-trimethylbenzene |
| 1,3-hexadiene (trans) | indan |
| methylcyclopentane | 1,3-diethylbenzene |
| 2,4-dimethylpentane | 1,4-diethylbenzene |
| benzene | butylbenzene |
| cyclohexane | n-undecane |

# 4. FIELD PROGRAM

## 4.1 Basic Elements

The following three-tiered field monitoring effort was developed to maximize the effectiveness of study resources.

- Supplemental air quality and meteorological monitoring, including ten surface ozone and meteorological monitoring sites, two $NO_y$ monitoring sites, and four upper-air monitoring SODARs and a radar wind profiler. This monitoring occurred continuously from May 15 through August 31, 2005.
- IOP monitoring, consisting of continuous saturation ozone measurements at up to 13 locations and rawinsonde measurements at one location. These measurements were conducted during six “windows of opportunity” when conditions for ozone concentrations were predicted to be good for an extended period of time.
- Episode-mode monitoring, consisting of ozonesondes at one location, VOC sampling at three locations, and some additional balloon meteorological measurements at various locations. These were two to three day periods that were imbedded within the IOP monitoring effort, when ozone concentrations were predicted to be near or above the Federal 8-hr standard of 85 ppb.

Te three-tier and the CCROPS measurements are summarized in **Table 4-1.**

Table 4-1. CCROPS Measurements

| Period of Operation | Measureables |
|---|---|
| Entire study period (May 15 – August 31) | • Continuous ozone and meteorology at 10 additional sites<br>• Continuous upper-air meteorology at 4 sites (4 SODAR, 1 radar profiler)<br>• Continuous $NO_y$, PAN, Nitric Acid measurements at 2 sites |
| Intensive Operational Periods (four 1- to 2-week periods of potential high ozone conditions) | • Upper-air meteorology using rawinsondes at 1 site<br>• Continuous ozone using portable samplers at up to 13 saturation sites |
| Episode-Mode Operations (1- to 3-day periods of forecasted high ozone imbedded within IOPs. | • VOC samples at 3 sites (up to 4 samples per day)<br>• Upper-air ozone measurements using ozonesondes at 1 site (6 AM, 10 AM, 4 PM)<br>• Upper-air ozone measurements using aircraft/glider (typically 6 AM and 10 AM)<br>• Pibal and rawinsonde measurements at various sites throughout western Clark County |

## 4.2 Operations Summary

The field-monitoring phase of the program was conducted during May through August 2005. The complete surface monitoring network and balloon-borne upper-air measurements were completely functional by May 15. The SODARs and radar wind profiler were phased in as the equipment was installed and became operational. The effective ozone season in Clark County is May through August. Historically the first ozone episode has not occurred before May 15 (the only exception in the prior 9-year record is May 9, 2004). The 2005 ozone season was no exception. The first exceedance of the 8-hr ozone standard occurred on June 12.

The IOP and episode-mode levels of monitoring efforts were distributed throughout the ozone season as originally intended. The plan was to include a representative set of meteorological conditions during which high ozone levels are experienced in Clark County. For planning purposes, it was supposed that IOP periods would occur over three 2-week periods occurring near the start, in the middle, and towards the end of the ozone season. Episode-mode field activity was thereby based on high ozone levels being forecast while the IOPs were ongoing, and the field crews were already deployed in the field. As it turned out, IOPs operations occurred on 38 days over the following 6 periods. The late August IOPs were an attempt to capture a solid “interbasin transport” high ozone case.

- May 15-16 (intended as a “shakedown period” as well)
- May 23-29
- June 20-July 2
- July 11- 21 July
- August 21-22
- August 27-29

Embedded in these IOPs were a total of 15 episode-mode days. Nine of these days occurred during June and July, consistent with historical observations indicating that peak ozone activity in Clark County occurred during June and July.

A complete summary of daily activities from May 15 through August 31 is given in **Table 4-2**. A lot of information is contained in this table. In addition to the project operational status, the peak 8-hr ozone levels from Jean and Joe Neal sites and number of exceedances are noted, if any, as well as the number and types of special measurements made. Jean and Joe Neal ozone levels are generally indicative of background (upwind) levels and peak levels in the Las Vegas Valley, respectively.

IOPs consisted of deploying a network of *saturation* ozone monitors and twice-daily rawinsonde measurements from the North Las Vegas airport. Rawinsondes were taken near sunrise (~ 6 DT) to measure the lower atmosphere during the most stable period of the diurnal cycle, and in the afternoon (~ 16 PDT) to measure the lower atmosphere when the boundary layer is the most unstable and vertical mixing has peaked.

Variations in operations occurred with the balloon-borne ozonesonde/rawinsondes depending on how forecasted ozone levels evolved during the day. On some “episode-mode” days, the full complement of ozonesondes was not made if high ozone levels did not materialize as forecast. On other days, the field crew made ozonesonde measurements when none were scheduled but ozone levels were greater than forecast. The operations were kept dynamic in an attempt to monitor the real-time conditions and respond accordingly.

A weather forecasting protocol was developed for the CCROPS that combined the data information resources and expertise of both the DAQEM and the CCROPS operators in order to issue daily, specialized weather updates and advisories. These forecasts provided project management with the information required to call for the IOP and episode-mode monitoring efforts. The forecast discussion and specific forecasts were posted daily to the project web site. The general meteorological conditions encountered during the field study are described in the following section.

## 4.3 Meteorological Conditions

A synopsis of the general meteorological conditions affecting ozone development during the 2005 CCROPS field monitoring study can be accomplished by examining the daily synoptic scale weather characteristics over the Southwestern U.S. during the project period (May 15 to August 31). It was determined during the Ozone Characterization Study[1] that the 500 mb constant pressure patterns provide the most representative prospective of the synoptic influence on regional dispersion characteristics. Daily 500 mb charts were examined for three ozone seasons resulting in the identification of a number of patterns and parameter values that appeared to correspond to ozone or non-ozone days in southern Nevada. The same process was carried out for the 2005 project period, resulting in the following summary.

### May 15 - 19

The synoptic pattern during the 15th featured a short-wave high-pressure ridge that drifted across the study area bringing warmer stable conditions and light flow. By the 16th, a short-wave trough was approaching the area from the west coast. This feature turned flow to the southwest, but also brought in cooler air and better mixing conditions to southern Nevada. The pattern of short-wave ridges and troughs continued through May 19th, resulting in a fairly unsettled dispersion scenario that did not allow much build up of pollutants.

### May 20 – 29

The main synoptic feature that dominated the regional pattern during this period was a strong high pressure ridge that remained located over the Southwest U.S. for more than a week. Initially, a weak short-wave trough passed over the top of the ridge in the northern Great Basin, but the strong ridge kept this type of feature from affecting the warming and stabilizing conditions in the study area. The ridge produced near record high temperatures around the 22nd and 23rd, and also relatively poor dispersion conditions. Wind flow generally was light during most of the period, with intra-basin flow apparently predominating. By the 28th, the ridge weakened considerably as low pressure to the north and south eroded its strength. At the same time, a subtropical low in the southern Baja became a more dominant synoptic feature as it started injecting moisture and less stability into the Southwest. Late on the 28th, a short-wave trough to the north started influencing the wind flow in southern Nevada as it approached the great Basin from the West Coast. The trough also transported the additional moisture from the Baja low into the study area causing a broken cloud cover after dark. Wind flow late on the 28th and early on the 29th increased considerably from the southwest, enhancing inter-basin transport during the overnight hours. The cloud cover did prevent nocturnal radiation cooling and helped maintain a neutral stability condition overnight, thus allowing pollutants aloft to mix to the surface. During the daylight hours on the 29th, the strong southwesterly flow continued, but the cloud cover dissipated, and good thermodynamic and turbulent mixing predominated during the remainder of the day.

## May 30 – June11

The short-wave frontal passage that occurred during the day on the 29th was followed by a short-wave ridge on the 30th. Brisk wind flow and good mixing continued in the study area during both days. By June 1st, a general long-wave troughing pattern became the dominant synoptic weather feature for the next ten days. During that time, temperatures were somewhat cooler than average and mixing was generally good. A short ridge embedded in the general pattern migrated through the area around June 4th and 5th, temporarily increasing temperatures aloft and decreasing dispersion efficiency.

## June 12 – 16

A nicely defined ridge moved into the Great Basin from the West Coast on the 12th, quickly displacing the long-wave trough that had been so dominate since the beginning of the month. The ridge, however, was migratory, and drifted off to the east by the 16th. Wind flow tended to be light during the 12th to the 15th, apparently favoring intra-basin transport during that time. A developing West Coast trough turned flow in the study area around to the southwest by the 15th, thus indicating a greater opportunity for inter-basin flow.

## June 17 – 21

West Coast troughing developed into a strong closed low just off the Oregon Coast during this period. Significant on-shore flow predominated throughout the Southwest as a result. Although the southwesterly wind flow was indicated strong inter-basin transport potential, the air mass was cooler and well mixed because of the cyclonic synoptic pattern.

## June 22 – 25

The strong West Coast low had weakened and broadened into a trough off the coast by the 22nd. At the same time, a very larger high-pressure ridge centered in the western Plains expanded to the west. The interface zone between the influence of the trough and ridge was generally situated over the Great Basin during this period. As a result, regional flow remained southwesterly while the air mass stabilized somewhat due to the ridging influence to the east. Unfortunately, the interface zone also contained a stronger pressure gradient, which manifested itself with breezy afternoon local winds and also some local cumulus development over higher terrain. Flow during the period was mostly inter-basin.

## June 26 – 28

The West Coast low/trough finally progressed from west to east as a short-wave trough during this period. As this system moved across the Great Basin, it kicked off considerable thunderstorm activity, particularly in Utah and northern Arizona. The storms were based, and therefore many areas experienced “dry” lightning strikes, including around the study area. An outbreak of wildfires in southern Nevada, Arizona and Utah resulted.

## June 29 – July 3

A flat high-pressure ridge built into the southern Great Basin by the 29th as the short-wave trough exited to the east. The ridge brought an end to the thunderstorm activity with increased air mass stability and a lack of moisture. The stable air mass brought capping subsidence layers to the study area and very light flow below the cap. Boundary layer flow (below ~12,000 ft) in the study area was initially from the east on the on the 29th, and then became light intra-basin by the 30th. The flat ridging scenario continued through July 1st with stagnant conditions prevailing in the southern Great Basin. By July 2nd, a weak west to east zonal flow pattern developed in the boundary layer, which was reflective of the conditions higher aloft during the period. A series of weak short-wave troughs also migrated across the northern Great basin within the zonal flow pattern. During the 2nd and 3rd, boundary layer flow became light southwesterly as a result of the synoptic pattern. The zonal flow pattern was not strong enough to destabilize the air mass and the capping subsidence layer persisted over the boundary layer. This scenario resulted in the best inter-basin transport conditions of the summer.

## July 4 – 8

Weak zonal flow associated with a persistent flat ridge over the extreme southern Great Basin and northern Mexico continued through July 8th. Several migrating short-wave troughs moved across the Great Basin north of the study area. Air mass stability remained fairy consistent, varying slightly from day to day depending on the location of the current short-wave troughs. Wind flow also remained light during the period, with trajectories favoring inter-basin transport from the west to the east during several periods, depending on the short-wave locations. The overall synoptic pattern was rather flat and poorly defined over the southern half of the western U.S., which is rather typical for mid summer.

## July 9 – 11

A West Coast trough located initially off Washington and Oregon dug its way southeastward during this period. The trough was actually induced by a Pacific high pressure area to its west that was slowly building during previous days. The trough brought increased on-shore flow to the west, extending well into the Great Basin by the 10th. The result was a break up of the stable air mass over the study area and an increase in thermodynamic and turbulent mixing.

## July 12 – 21

This entire period can be characterized by a persistent strong long-wave high-pressure ridge that remained centered over the interior west for more than ten days. This large synoptic feature spread in from the Pacific to combine with the flat ridging that had been over northern Mexico and the southern plain for many days previously. The center of the ridge wobbled around the southern Great Basin, sometimes west of the study area, but more often to the east in the general vicinity of the Four Corners area. The ridge was responsible for producing an extended period of record high temperatures in the Las Vegas area, and throughout the Southwest U.S. The air mass associated with the ridge was stable and rather stagnant, featuring light flow and high-level subsidence capping. The intense surface heating during the afternoons likely increased the depth of the boundary layer in the study area and induced local flow regimes. Synoptic scale flow during the period was quite light and mostly from east to west during the period. There was very little indication of large-scale inter-basin transport, at least not from west to east.

By late on July 20th, the center of the ridge had shifted to east of the Four Corners area, and flow in the study area shifted to the south to southeast. The shift opened the door for possible inter-basin transport from the south along the Colorado Valley. The flow trajectory also started a monsoonal fetch in that brought mid-level cloudiness to the study area. Besides inhibiting new ozone production, the clouds also began to change the thermodynamic configuration of the air mass.

**July 22 – August 3**

A large long-wave high pressure ridge remained centered east of the Four Corners area, often all the way back to the southern Plains during this entire period. The resulting south to southeast fetch around the western flank of the ridge brought day after day of monsoonal flow to the southern Great Basin. The flow taped into a rich moister source in northern and central Mexico that was constantly replenished by a series of tropical disturbances migrating in the subtropical easterlies. There was no flow in the study area with a westerly component, thus precluding inter-basin transport from the west, and early day local ozone development was broken by convective thunderstorm activity (sometimes severe) in the afternoons.

**August 4 – 13**

The long protracted monsoonal activity that was established by July 22nd continued during this period as well. However, several short breaks occurred in the cycle that enabled localized ozone development in the study area. These occurred on the 6th and 10th. A short-wave trough moved through the northern Great Basin on the 4th, leading in a fresh short-wave ridge from the west. When the axis of the ridge approached the study area, it temporarily cut off the monsoonal fetch and as a result, ozone development was curtailed by afternoon thunderstorms on the 6th. However, there was no inter-basin flow from the west during this day.

No thunderstorm activity took place in the study area on August 10th. The monsoonal moisture was temporarily cut off that day by the influx of drier air from California. The dry line quickly slipped back to the west of the area by the 11th. Flow in the drier air mass was more southerly with a possible westerly component, but the event was too short-lived to allow the establishment of consistent inter-basin transport from the west.

**August 14 – 26**

Afternoon monsoonal thunderstorm activity was continuing in southern Nevada by August 14th. However, troughing off the southern California coast, and also off southern Baja, was beginning to combine with the monsoon pattern. During subsequent days, the West Coast troughing developed into a rather vigorous closed low off Point Conception California. Rotation around the low brought cooler air into the study area, but the unstable nature of the air mass triggered more thunderstorm activity in the southern Great Basin. Good mixing and variable cloudiness curtailed pollution development in the study area. Another low off the California Coast around the 18th produced much less cloudiness, but the well-mixed nature of the air mass kept the boundary layer clean of pollutants. During most of this period, flow trajectories had turned far enough from the southeasterly monsoonal direction to set up inter-basin transport flow. However, the well-ventilated composition of the air mass precluded the formation of any pollutants to transport.

**August 27 –31**

The influence of the West Coast troughing in the study area was curtailed during the final five days of the project by a ridge of high pressure building into the region from the southern Plains. Circulation around the ridge did not bring a monsoonal fetch with, as was the case for so many days earlier during the project. Instead, the southerly flow generated by the ridging to the east and troughing to west resulted in inter-basin type flow with a westerly component. The influx of the ridge was enough to stabilize air mass, but pollution levels up wind in California never materialized enough to provide a significant source. The closer proximity of the trough and the lateness of the season probably were probably responsible for the poor development in California.

# Table 4-2. Network Operational Status and Daily Summaries

| Date | IOP | Episode | Max Jean 8-hr Ozone (ppb) | Max Joe Neal 8-hr Ozone (ppb) | Supplemental Sites Operational | Saturation Sites Operational | Rawinsondes Launched | Ozonesondes Launched | Pibals Launched | SODARS Operational | Radar Profilers Operational | VOC Samples Collected | NOy Sites Operational | Glider/Tow Aircraft Flights | Ozone Exceedance Day | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15-May | X | | 73 | 68 | 9 | 9 | 0 | | | 0 | 0 | 0 | 2 | | | |
| 16-May | X | | 54 | 55 | 9 | 9 | 2 | | | 0 | 0 | 0 | 2 | | | |
| 17-May | | | 60 | 60 | 9 | | | | | 0 | 0 | | 2 | | | |
| 18-May | | | 49 | 54 | 9 | | | | | 0 | 0 | | 2 | | | |
| 19-May | | | 47 | 49 | 9 | | | | | 0 | 0 | | 2 | | | |
| 20-May | | | 46 | 40 | 9 | | | | | 0 | 0 | | 2 | | | |
| 21-May | | | 67 | 71 | 9 | | | | | 0 | 0 | | 2 | | | |
| 22-May | | | 72 | 76 | 9 | | | | | 0 | 0 | | 2 | | | |
| 23-May | X | | 56 | 61 | 9 | 9 | 2 | | | 1 | 0 | | 2 | | | |
| 24-May | X | X | 62 | 59 | 10 | 11 | 3 | 3 | | 1 | 0 | 6 | 2 | | | |
| 25-May | X | | 82 | 74 | 10 | 10 | 2 | | | 1 | 0 | | 2 | | | |
| 26-May | X | | 71 | 75 | 10 | 10 | 2 | | | 1 | 0 | | 2 | | | |
| 27-May | X | X | 70 | 75 | 9 | 12 | 3 | 3 | | 1 | 0 | 6 | 2 | | | |
| 28-May | X | X | 77 | 69 | 9 | 11 | 3 | 3 | | 1 | 0 | 6 | 2 | | | |
| 29-May | X | | 73 | 68 | 9 | 11 | 2 | | | 2 | 0 | | 2 | | | |
| 30-May | | | 63 | 61 | 9 | | | | | 3 | 0 | | 2 | | | |
| 31-May | | | 64 | 76 | 10 | | | | | 3 | 0 | | 2 | | | |
| 1-Jun | | | 81 | 70 | 10 | | | | | 3 | 0 | | 2 | | | |
| 2-Jun | | | 76 | 71 | 10 | | | | | 3 | 0 | | 2 | | | |
| 3-Jun | | | 71 | 61 | 10 | | | | | 3 | 0 | | 2 | | | |
| 4-Jun | | | 74 | 71 | 10 | | | | | 3 | 0 | | 2 | | | |
| 5-Jun | | | 77 | 76 | 10 | | | | | 3 | 0 | | 2 | | | |
| 6-Jun | | | 70 | 67 | 10 | | | | | 3 | 0 | | 2 | | | |
| 7-Jun | | | 64 | 62 | 10 | | | | | 3 | 0 | | 2 | | | |
| 8-Jun | | | 65 | 67 | 9 | | | | | 3 | 0 | | 2 | | | |
| 9-Jun | | | 44 | 35 | 9 | | | | | 3 | 0 | | 2 | | | |
| 10-Jun | | | 52 | 59 | 9 | | | | | 3 | 0 | | 2 | | | |
| 11-Jun | | | 66 | 61 | 9 | | | | | 3 | 0 | | 2 | | | |
| 12-Jun | | | 79 | 42 | 9 | | | | | 3 | 0 | | 2 | | 3 | "Surprise Sunday" |
| 13-Jun | | | 72 | 67 | 9 | | | | | 3 | 0 | | 2 | | | |
| 14-Jun | | | 66 | 66 | 9 | | | | | 3 | 0 | | 2 | | | |
| 15-Jun | | | 72 | 67 | 9 | | | | | 3 | 0 | | 2 | | | |
| 16-Jun | | | 79 | 70 | 10 | | | | | 3 | 1 | | 2 | | | |
| 17-Jun | | | 62 | 61 | 10 | | | | | 3 | 1 | | 2 | | | |
| 18-Jun | | | 66 | 58 | 10 | | | | | 3 | 1 | | 2 | | | |
| 19-Jun | | | 57 | 59 | 10 | | | | | 3 | 1 | | 2 | | | |
| 20-Jun | X | | 58 | 58 | 10 | 12 | 2 | | | 3 | 1 | | 2 | | | |
| 21-Jun | X | | 56 | 61 | 10 | 12 | 2 | | | 3 | 1 | | 2 | | | |
| 22-Jun | X | X | 62 | 54 | 10 | 12 | 6 | 3 | 8 | 3 | 1 | 13 | 2 | | | |
| 23-Jun | X | X | 66 | 68 | 9 | 12 | 6 | 3 | 8 | 3 | 1 | 13 | 2 | 2 | | |
| 24-Jun | X | X | 69 | 66 | 9 | 13 | 6 | 2 | 8 | 3 | 1 | 13 | 2 | 1 | | |
| 25-Jun | X | | 66 | 60 | 9 | 13 | 2 | | | 3 | 1 | | 2 | | | |
| 26-Jun | X | | 75 | 76 | 9 | 12 | 2 | | | 3 | 1 | | 2 | | | |
| 27-Jun | X | | 65 | 57 | 9 | 13 | 2 | | | 3 | 1 | | 2 | | | |
| 28-Jun | X | | 69 | 67 | 9 | 13 | 2 | | | 3 | 1 | | 2 | | | |
| 29-Jun | X | | 88 | 99 | 9 | 12 | 2 | 1 | | 3 | 1 | | 2 | | 12 | Fires |
| 30-Jun | X | | 92 | 105 | 9 | 12 | 2 | | | 3 | 1 | | 2 | | 12 | Fires |

# Table 4-2. Network Operational Status and Daily Summaries (Continued)

| Date | IOP | Episode | Max Jean 8-hr Ozone (ppb) | Max Joe Neal 8-hr Ozone (ppb) | Supplemental Sites Operational | Saturation Sites Operational | Rawinsondes Launched | Ozonesondes Launched | Pibals Launched | SODARS Operational | Radar Profilers Operational | VOC Samples Collected | NOy Sites Operational | Glider/Tow Aircraft Flights | Ozone Exceedance Day | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-Jul | X | X | 81 | 79 | 9 | 13 | 6 | 3 | 8 | 3 | 1 | 13 | 2 | 2 | | |
| 2-Jul | X | X | 85 | 81 | 9 | 13 | 6 | 3 | 8 | 3 | 1 | 13 | 2 | 4 | 1 | |
| 3-Jul | | | 76 | 87 | 9 | | | | | 3 | 1 | | 2 | | 1 | Ended IOP due to non-typical holiday |
| 4-Jul | | | 70 | 75 | 9 | | | | | 3 | 1 | | 2 | | | |
| 5-Jul | | | 73 | 76 | 9 | | | | | 3 | 1 | | 2 | | | |
| 6-Jul | | | 81 | 77 | 9 | | | | | 3 | 1 | | 2 | | | |
| 7-Jul | | | 77 | 78 | 9 | | | | | 4 | 1 | | 2 | | | |
| 8-Jul | | | 83 | 86 | 9 | | | | | 4 | 1 | | 2 | | 1 | Pauite also showed exceedance |
| 9-Jul | | | 65 | 67 | 9 | | | | | 4 | 1 | | 2 | | | |
| 10-Jul | | | 56 | 63 | 9 | | | | | 4 | 1 | | 2 | | | |
| 11-Jul | X | | 53 | 64 | 9 | 11-13 | 2 | | | 4 | 1 | | 2 | | | |
| 12-Jul | X | | 57 | 69 | 9 | 11-13 | 2 | | | 4 | 1 | | 2 | | | |
| 13-Jul | X | | 56 | 74 | 9 | 11-13 | 2 | | | 4 | 1 | | 2 | | | |
| 14-Jul | X | X | 70 | 84 | 9 | 11-13 | 6 | 3 | 7 | 4 | 1 | 13 | 2 | 1 | | Near exceedance at County site |
| 15-Jul | X | X | 67 | 85 | 10 | 11-13 | 6 | 3 | 8 | 4 | 1 | 13 | 2 | 1 | 3 | |
| 16-Jul | X | | 72 | 81 | 10 | 11-13 | 2 | | | 4 | 1 | | 2 | | | |
| 17-Jul | X | X | 70 | 68 | 10 | 11-13 | 6 | 3 | 8 | 4 | 1 | 13 | 2 | 1 | | Sunday event sampling |
| 18-Jul | X | | 72 | 91 | 10 | 11-13 | 5 | | 9 | 4 | 1 | | 2 | | 5 | Local "sloshing" |
| 19-Jul | X | | 70 | 74 | 10 | 11-13 | 5 | | 8 | 4 | 1 | | 2 | | | |
| 20-Jul | X | X | 68 | 76 | 10 | 11-13 | 6 | 4 | 8 | 4 | 1 | 13 | 2 | 1 | | Transport, but cloudy |
| 21-Jul | X | | 62 | 70 | 10 | 11-13 | 5 | | | 4 | 1 | | 2 | | | |
| 22-Jul | | | 57 | 68 | 10 | | | | | 4 | 1 | | 2 | | | |
| 23-Jul | | | 50 | 62 | 10 | | | | | 4 | 1 | | 2 | | | |
| 24-Jul | | | 46 | 61 | 10 | | | | | 4 | 1 | | 2 | | | |
| 25-Jul | | | 62 | 74 | 10 | | | | | 4 | 1 | | 2 | | | |
| 26-Jul | | | 67 | 74 | 10 | | | | | 4 | 1 | | 2 | | | |
| 27-Jul | | | 62 | 72 | 10 | | | | | 4 | 1 | | 2 | | | |
| 28-Jul | | | 53 | 59 | 10 | | | | | 4 | 1 | | 2 | | | |
| 29-Jul | | | 53 | 65 | 10 | | | | | 4 | 1 | | 2 | | | |
| 30-Jul | | | 62 | 78 | 10 | | | | | 4 | 1 | | 2 | | | |
| 31-Jul | | | 58 | 71 | 10 | | | | | 4 | 1 | | 2 | | | |
| 1-Aug | | | 57 | 71 | 10 | | | | | 4 | 1 | | 2 | | | |
| 2-Aug | | | 59 | 63 | 10 | | | | | 4 | 1 | | 2 | | | |
| 3-Aug | | | 50 | 71 | 10 | | | | | 4 | 1 | | 2 | | | |
| 4-Aug | | | 69 | 72 | 10 | | | | | 4 | 1 | | 2 | | | |
| 5-Aug | | | 64 | NA | 10 | | | | | 4 | 1 | | 2 | | | |
| 6-Aug | | | 67 | NA | 10 | | | | | 4 | 1 | | 2 | | | |
| 7-Aug | | | 66 | NA | 10 | | | | | 4 | 1 | | 2 | | | |
| 8-Aug | | | 72 | 65 | 10 | | | | | 4 | 1 | | 2 | | | |
| 9-Aug | | | 51 | 48 | 10 | | | | | 4 | 1 | | 2 | | | |
| 10-Aug | | | 64 | 79 | 10 | | | | | 4 | 1 | | 2 | | | |
| 11-Aug | | | 62 | 73 | 10 | | | | | 4 | 1 | | 2 | | | |
| 12-Aug | | | 82 | 84 | 10 | | | | | 4 | 1 | | 2 | | | Near exceedance, but no transport |
| 13-Aug | | | 67 | 73 | 10 | | | | | 4 | 1 | | 2 | | | |
| 14-Aug | | | 43 | 53 | 10 | | | | | 4 | 1 | | 2 | | | |
| 15-Aug | | | 52 | 53 | 10 | | | | | 4 | 1 | | 2 | | | |
| 16-Aug | | | 47 | 53 | 10 | | | | | 4 | 1 | | 2 | | | |
| 17-Aug | | | 42 | 49 | 10 | | | | | 4 | 1 | | 2 | | | |
| 18-Aug | | | 49 | 49 | 10 | | | | | 4 | 1 | | 2 | | | |
| 19-Aug | | | 49 | 54 | 10 | | | | | 4 | 1 | | 2 | | | |
| 20-Aug | | | 47 | 59 | 10 | | | | | 4 | 1 | | 2 | | | |
| 21-Aug | X | | 52 | 62 | 10 | 11-12 | 2 | | | 4 | 1 | | 2 | | | |
| 22-Aug | X | X | 52 | 56 | 10 | 11-12 | 7 | 2 | 8 | 4 | 1 | 13 | 2 | 2 | | |
| 23-Aug | | | 60 | 62 | 10 | | | | | 4 | 1 | | 2 | | | |
| 24-Aug | | | 50 | 54 | 10 | | | | | 4 | 1 | | 2 | | | |
| 25-Aug | | | 42 | 45 | 10 | | | | | 4 | 1 | | 2 | | | |
| 26-Aug | | | 39 | 44 | 10 | | | | | 4 | 1 | | 2 | | | |
| 27-Aug | X | X | 51 | 66 | 10 | NA | 1 | 1 | | 4 | 1 | 13 | 2 | 2 | | |
| 28-Aug | X | X | 58 | 72 | 10 | NA | 1 | 2 | | 4 | 1 | 13 | 2 | 2 | | |
| 29-Aug | X | | 58 | 54 | 10 | NA | 1 | 2 | | 4 | 1 | | 2 | 2 | | Transport flow, but good mixing |
| 30-Aug | | | 62 | 48 | 10 | | | | | 4 | 1 | | 2 | | | |
| 31-Aug | | | 56 | 56 | 10 | | | | | 4 | 1 | | 2 | | | |

# 5. QUALITY ASSURANCE AND DATA VALIDATION

Quality assurance (QA) for CCROPS was achieved through a number of specific efforts, which are summarized below.

## 5.1 Project Plan

The CCROPS project plan was created in the form of a frequently updated, project-specific web site accessible through the Internet. The web site contained the following web pages:

- Study Overview - This page presented a brief overview of the study, the study objectives, and study schedule.
- What's New? – This page served as "document control" for the web site, providing a complete history of all modifications to the web site. Anytime the web pages were expanded or modified, a brief summary and the date of the modification were posted.
- Project Status – This page provided information regarding the readiness of participants' monitoring efforts. The page was particularly important during the early stages of the study period for helping to maintain the study schedule.
- Study Forecast – This page provided for the communication of study-specific information regarding forecasted ozone conditions, and served as the alert for IOPs and episode-mode monitoring efforts.
- Monitoring Sites – This page provided a description of the CCROPS measurements and a map of the measurement locations.
- Project Participants – This page provided a list of the CCROPS participants, a summary of each participant's study responsibilities, and contact information for key individuals.
- Planning Documents – This page requested and posted measurement quality assurance documentation. This is discussed in more detail below.
- Preliminary Analysis – This page provided participants with a means to present preliminary analysis of collected data. This in turn provided study management with feedback regarding collected data versus study goals, and the means of refining the monitoring effort, if needed.

## 5.2 Quality Assurance/Quality Control Documentation

The following two sets of tables were initially requested from participants regarding the Quality Assurance program implemented by each for the measurements that they conducted:

- Measurement Quality Objectives (MQOs): MQOs were requested for each of the study measurements. In defining these objectives, participants were in essence describing their quality assurance program. One table was filled out for each parameter that the participant was measuring. Examples and a recommended format were provided in order to provide consistency in submitted information.
- Standard Operating Procedures (SOPs): A list of SOPs used by each of the participants was also requested. This list demonstrate that procedures had been developed and documented for each of the measurement activities, and provided those interested with

a mechanism for obtaining more information regarding quality assurance and quality control procedures in place for each of the measurements.

At the end of the study, a standardized metafile format was developed for submission of collected data. Information from MQOs and SOPs were combined and included in the metafiles. The metafiles contained additional descriptions of QA/QC activities, as well as pictures of all of the monitoring locations. Metafiles for all of the CCROPS measurements are contained in **Appendix B.**

## 5.3 Data Validation

All data collected for CCROPS were validated to Level 1 validation (see section 6). As part of the validation effort, participants were requested to evaluate whether data collected met the stated MQOs. If data clearly did not meet MQOs, they were removed from the database as invalid data. If, however, data missed meeting the primary MQOs in a definable way to the point where the data were still considered useful, participants had the ability of assigning secondary MQOs to the data in question. This use of secondary MQOs had to be specifically documented in the metafiles.

In reviewing the validity of the data submitted for CCROPS, it should be noted that the data submitted by DRI for the Desert Rock and Mountain Pass sites are of a different validity than that for the rest of the CCROPS network. Measurements at these sites were not initially planned, but were provided by DRI as an additional, though non-funded, effort. With no funding, QA for these sites was not provided, and calibrations conducted at each site by T&B personnel revealed significant issues, both in siting and operations. Initial attempts to use the data in analysis were problematic. Before use, data from these sites should be closely evaluated.

For the VOC validation effort, correlation plots were created to more easily identify canister samples that were contaminated due to leaking sampling lines or valves damaged by field operators (all canisters were leak-checked before they leave DRI for sampling). A number of canisters were determined to be either invalid or suspect, and the data flagged as such. These samples are identified in the full report provided in **Appendix C.**

# 6. DATABASE DESIGN

A primary study objective was to produce an adequately validated data set from the field measurements that is well defined and documented within the desired completion time. The overall goal of the data management effort was to create a system that is straightforward and easy for users to obtain data and provide updates.

Each organization was responsible for reviewing and validating their collected data. The raw data was validated to level 1 as described in "The Measurement Process: Precision, Accuracy, and Validity"[3] before being submitted to the database. This included flagging values for instrument downtime and performance tests, applying any adjustments for calibration deviation, investigating extreme values and applying appropriate flags. Flags used for CCROPS are presented in **Table 6-1**. Each contractor was responsible for documenting the validation process so that it could be provided to the data manager and other analysts if needed.

In addition, each data provider was responsible for furnishing information regarding the monitoring equipment used in the field study and any additional site information to the data manager as requested to enhance the overall documentation of the study. In particular, participants provided the Monitoring Quality Objective (MQOs) define the quality of all data submitted as "valid." These MQOs contain the following:

- Accuracy
- Precision
- Lower quantifiable limit
- Resolution
- Completeness

If cases exist where data did not meet the primary MQOs but is still deemed useable and can be defined with a secondary set of MQOs, these additional MQOs and the dates to which they apply were also submitted.

Table 6-1. Data Flags

| Flag | Description |
|---|---|
| V | Valid. Data meets primary MQOs. |
| S | Valid, but does not meet primary MQOs. Secondary MQOs in effect. |
| I | Data invalid. |
| M | Missing. Measurement not taken. |

Once the data were validated to level 1, the data were prepared for submittal to the database in a form that clearly defined the time reference, averaging period, parameter names and units. The time reference for the database is local standard time (Pacific Standard Time) and the

---

[3] Watson, J.G., B.J. Turpin, and J.C. Chow (2001). The measurement process: Precision, accuracy, and validity. In *Air Sampling Instruments for Evaluation of Atmospheric Contaminants,* 9th ed., B. Cohen, Ed. American Conference of Governmental Industrial Hygienists, Cincinnati, OH, in press.

averaging period reference was standardized to hour beginning (0 – 23). The data were submitted as ASCII comma delimited text files or excel spreadsheet files, with data columns well defined to clarify site identification, parameters, instrumentation, units, and time reference.

Participant's also submitted a metadata file for each measurable. This metadata file includes all pertinent information regarding the measurement process, including the information described in Section 3. This metadata file was received prior to inclusion of the data in question into the final dataset.

Data were submitted in a format similar to that of the final database structure, as outlined below. This basically has a second column for each measured value for an accompanying QC code. Data flagged as invalid or missing was given a value of -9999. In the event that data for a given measurable is either valid (meeting primary MQOs) or missing, participants need not supply the flag column, this was specifically stated in the metafile.

### Preliminary Database Management Design

T&B Systems assimilated the submitted data into an integrated relational Microsoft ACCESS database and is managing the data for subsequent distribution and analysis. The database consists of both information and data files. The goal was to make the database very usable by data analysts and all participants.

The following describes the preliminary design for the database. The database includes an inventory spreadsheet file to help users track and ensure all of the data was submitted and processed in a timely and consistent manner. All data files submitted were examined to verify unique names for all sites, instruments, and parameters so that no orphan or duplicate records exist in any of the tables. A system was also designed for identifying the version and or modification date of all data files.

The main metadata file is a site file that contains all site information as specified above. Data were organized and grouped together by platform, averaging period and data type.

Surface hourly meteorological data have the following flat format:

Surface Hourly Meteorological Data

**SITE, DATE, HOUR, WS, WS_QC, WD, WD_QC, TP, TP_QC,** and any additional met parameters and QC codes, if collected.

There are three file types for surface air quality with the following formats:

Ozone 8-hr Averaged:

**SITE, DATE, HOUR, O3_8HR, O38HR_QC**

Hourly Surface Air Quality:

**SITE, DATE, HOUR, OZONE, O3_QC, NO, NO_QC, NOx, NOx_QC, NOy, NOy_QC, PAN, PAN_QC** and any additional air quality parameters if collected and QC codes.

NMHC VOC:

**SITE, DATE, HOUR, START_TIME, END_TIME, CANNISTER_ID, QC_CODE, PARAMETER1, PARAMETER2, PARAMETER3,..PARAMETERn, notes**

Upper-Level Meteorological and Air Quality Data

The rawinsonde, ozonesonde, pibal, and glider data measured during episode-mode operations are stored together in a file with the following format:

**SITE, DATE, TIME, HEIGHT, PRESSURE, PRESSURE_QC,**
**O3, O3_QC, WS, WS_QC, WD, WD_QC, TP, TP_QC, RH, RH_QC**

The data are formatted into the final database with the following unit configurations and naming conventions:

Parts per million for $O_3$, $NO_x$, $NO_y$
Meters per second for wind speed (as a general rule, metric units will be used)
Degrees Celsius for ambient temperature
Percent for relative humidity
Parts per Billion Carbon for non-methanated hydrocarbon species

SITE = Alpha-numeric site code identifier
DATE = (MM/DD/YY)
HOUR= Nearest whole begin hour (HH) (PST)
TIME, START_TIME or END_TIME = Time stamp of data (HH:MM:SS) (PST)
HEIGHT = Elevation in meters above MSL
QC_CODE (for NMHC-VOC), WS_QC, WD_QC, O3_QC, etc =
“V” (valid), “M” (missing), “I” (invalid), “S” (secondary MQOs)
NOTES = any additional information

The level 1 data files along with the documentation files are available for download on an FTP server.

# 7. SUMMARY OF THE OBSERVATIONS (DESCRIPTIVE ANALYSIS)

The Ozone Characterization Study (Lehrman et al, 2005) pointed out major gaps in our knowledge of the relationships between air quality and both regional and local meteorological features. The 2005 field study was designed to address a number of these shortcomings. In this section, preliminary analyses of the field measurements are provided which speak to the following questions:

- How well does the existing DAQEM monitoring network measure the maximum ozone exposure in Clark County?
- How well does the existing DAQEM monitoring station at Jean represent ozone background levels in Southern Nevada and the Las Vegas Valley?
- What are ozone levels aloft; and is day-to-day carryover an important feature?
- Is the three-dimensional wind field in the Las Vegas Valley uniform or dominated by local terrain features?
- How representative is the NOAA sounding at Desert Rock of the boundary layer in the Las Vegas Valley?
- How well does the CART ozone forecast model perform in an operational mode?
- Can we distinguish the relative contributions from transport and local emissions to the total ozone burden in Clark County?

In addition, a descriptive analysis of the air quality and meteorology during high ozone periods, which occurred over the duration of the 2005 field study, is given. Each day on which an exceedance of the 8-hr ozone standard occurred is discussed to some extent. **Appendix C** presents graphics of ozone concentration contours using various combinations of the CCROPS monitoring network as well as the 24-hr Hysplit back-trajectory and rawinsonde/ozonesonde plots for each day. In addition to exceedance days, plots for the July IOP are also included in the appendix, as this period was particularly representative of conditions for high ozone in the Las Vegas area. Key examples are included in the discussions below.

## 7.1 High Ozone Events – 2005

Historically, high ozone levels are most frequent in Clark County during June and July. The 2005 ozone season was no exception. **Table 7-1** contains the number of days the 8-hr. ozone standard was exceeded by month as reported by Lehrman, et al and for the 2005 ozone season. The 2005 totals are shown for 1) just the DAQEM network, 2) just the Supplemental network, and 3) both the DAQEM and Supplemental sites combined. There were not any exceedances of the 85 ppb criteria during May in either network. During June, exceedances were measured on the same three days in both networks. In July, DAQEM's network measured exceedances on five days whereas the Supplemental network experienced exceedances on those same five days and on two additional days. August was interesting in that each network caught an exceedance on one day but on different dates. Therefore had the routine network consisted of the set of sites used in both the DAQEM and Supplemental networks, exceedances of the 8-hr ozone standard would have been reported for three additional days.

**Figure 7-1** shows daily peak 8-hr ozone levels over the field operations period for the DAQEM network and Supplemental network on separate plots. As can be seen from the figure, there were four periods during which ozone levels exceeded the 85 ppb standard; June 12, June 29-July 3, July 15-18, and August 6-10. In general, maximum ozone exposure was well represented by the existing DAQEM but there were some notable exceptions.

Table 7-1. Number of Days When Peak 8-hr Ozone was Greater Than or Equal to 85 ppb

| #Sites | Season | May* | June | July | Aug | Totals |
|---|---|---|---|---|---|---|
| 5 | **1996** | 1 | 2 | 1 | 1 | 5 |
| 6 | **1997** | 1 | 0 | 0 | 0 | 1 |
| 6 | **1998** | 0 | 2 | 6 | 0 | 8 |
| 13 | **1999** | 1 | 3 | 2 | 0 | 6 |
| 15 | **2000** | 0 | 0 | 1 | 2 | 3 |
| 15 | **2001** | 0 | 0 | 0 | 3 | 3 |
| 15 | **2002** | 0 | 3 | 1 | 2 | 6 |
| 15 | **2003** | 2 | 6 | 2 | 1 | 11 |
| 15 | **2004** | 2 | 0 | 1 | 0 | 3 |
| 14 | **2005 DAQEM Sites** | 0 | 3 | 5 | 1 | 9 |
| 24 | **2005 with Supplemental Sites** | 0 | 3 | 7 | 1 | 11 |
| 34 | **2005 including both networks** | 0 | 3 | 7 | 2 | 12 |

*Supplemental Sites fully operational May 15

Consistent with the Characterization Study, maximum ozone levels in Clark County during the 2005 field study generally occurred in the northwest quadrant of the Las Vegas Valley. However, on nine of the twelve exceedance days, the maximum occurred outside of the area covered by the DAQEM network. The Paiute Reservation site and Indian Springs, both Supplemental sites and further upvalley from Lone Mountain and Joe Neal, usually measured the highest ozone. The following discussion provides a descriptive analysis of and additional details on each of the exceedance periods.

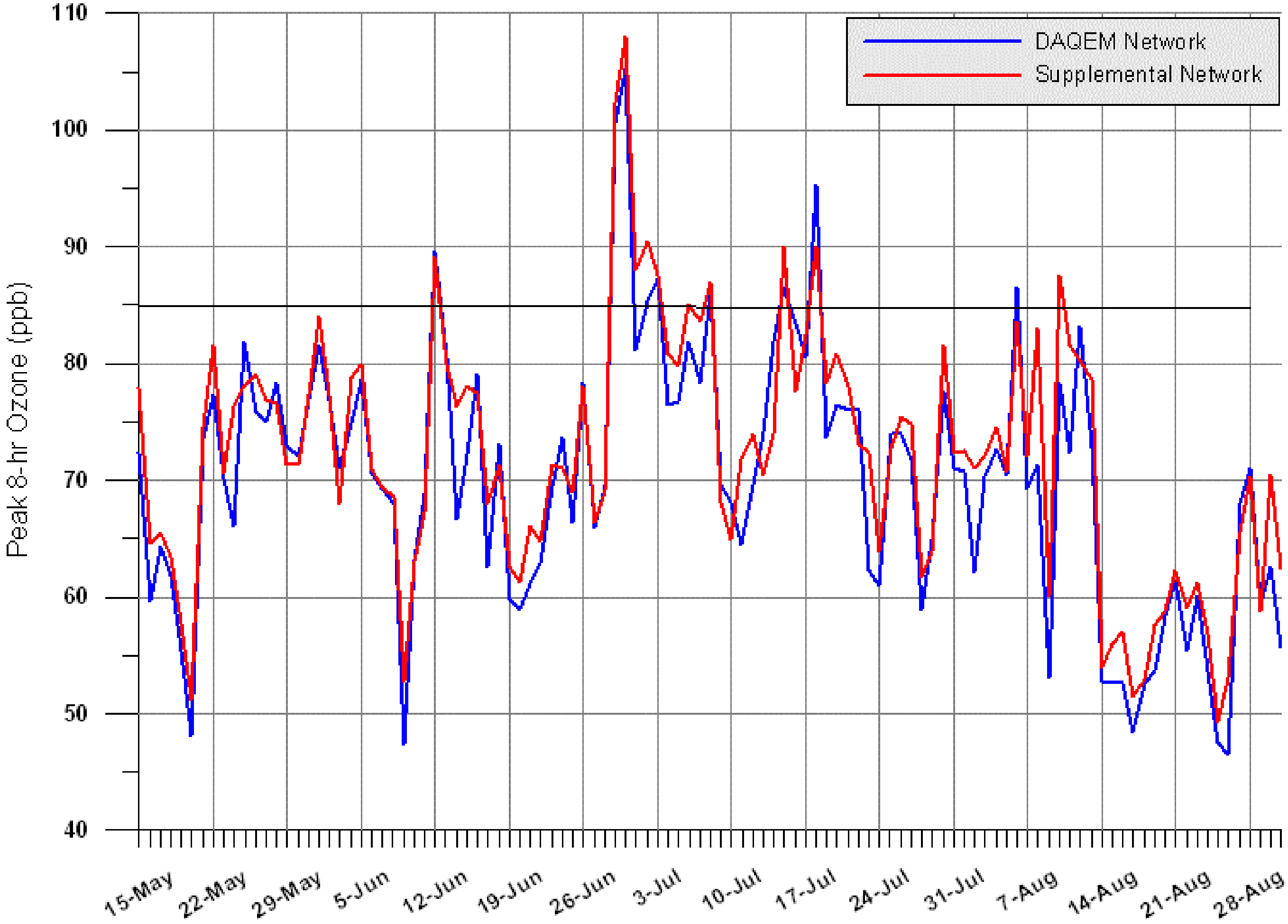


Figure 7-1. DAQEM and Supplemental Networks Daily Peak 8-hr Ozone Concentration

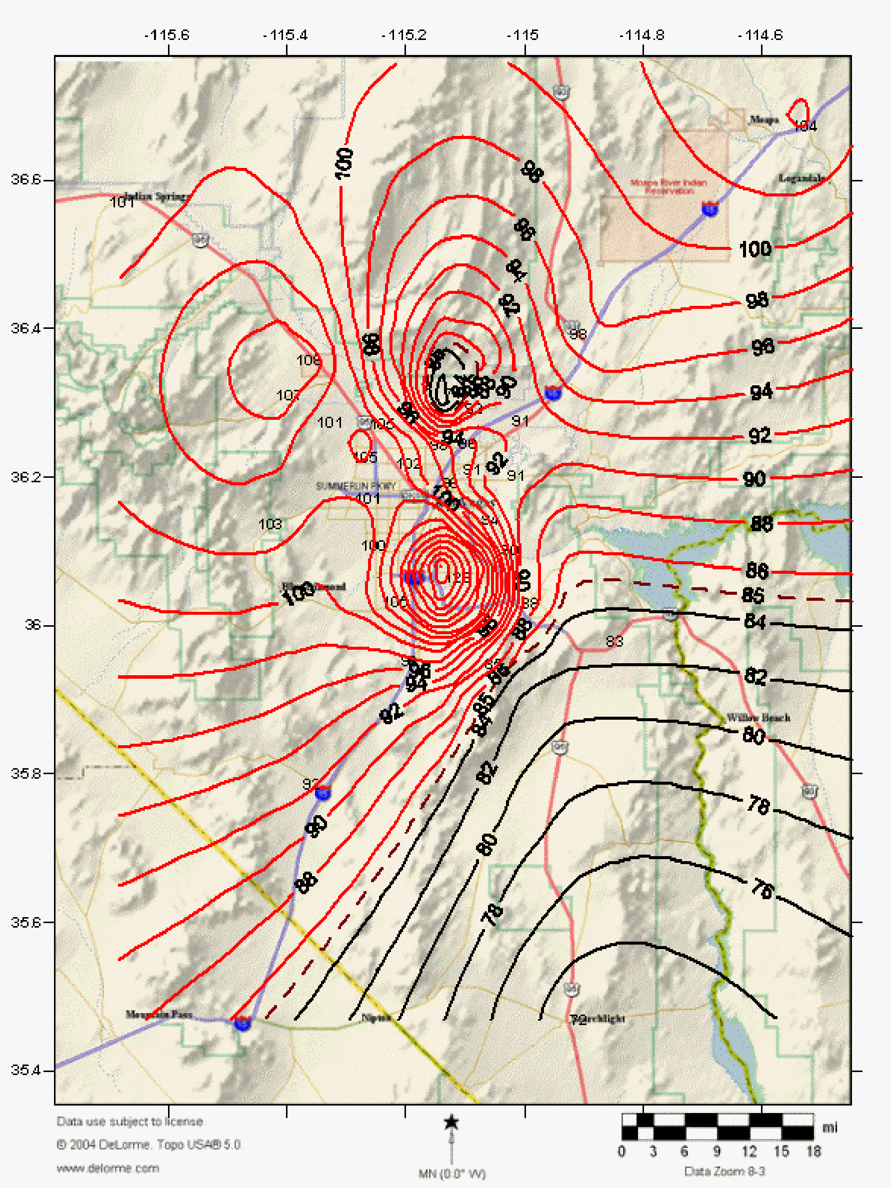
## 7.2 Saturation Network

Prior to discussing exceedances measured by the CCROPS ozone monitoring network, it is first necessary to discuss in some detail the ozone saturation network developed for CCROPS. The 12-sampler saturation network was operated during four IOP events. When combined with the data obtained from the 13 DAQEM and 10 Supplemental sites, the information enhances the base of information and understanding of the distribution of ozone. While the data from each of the saturation samplers is internally consistent, there are some results that must be explored further to determine if occasional network anomalies may be related to the sampling technique, or are real events that were captured by the additional detail provided by the Saturation network and would be potentially missed by the routine measurements.

The saturation site Sunset Park fell into this category. From the peak 8-hr average contour plots, it can be seen that on several occasions ozone at Sunset Park was notably higher than at surrounding sites and frequently recorded the network maximum, producing a singular point on regional ozone contour maps. **Figure 7-2** shows a particularly striking example of this. **Figure 7-3** shows the same data set with the Sunset Park data removed, producing contours more consistent with the regional behavior usually associated with ozone plumes. It should be noted that the low readings at the Losee site (another Saturation site) apparent in both figures cannot immediately be explained, though low values can be the result of scavenging by local sources and thus are more easily explained than high point values.

### 7.2.1 The Sunset Park Anomaly

This ozone behavior necessitated a reexamination of the site calibrations and equipment performance to ensure the validity of the measurement. All aspects of the sensor performance were examined, since the ozone-measuring method used is not a FRM and interferences from other oxidants are known to exist. This also entailed activating the specific instrument used at Sunset Park well after the end of the field program and subjecting it to performance checks against a standard, as well as to possible interferences such as $SO_2$ and $NO_2$. The results of this initial reevaluation of the Sunset Park sampler showed that the calibration factors used during data reduction were valid and did not shift significantly over time, and no significant interference effects were noted. Ozone at Sunset Park, Star Nursery, and Paul Meyer are compared in **Table 7-2**. Statistics are given in the table for 8-hr averaged ozone levels for all days that the saturation network was operational. The “daytime” values consist of ozone occurring from 10-18 PST when photochemistry is most active. The “nighttime” values include the hours from 22 to 07 PST when photochemistry is inactive. If other oxidants are interfering with the saturation sampler, unless they are also photochemical, they should interfere at nighttime as well as during the day. From the table, it can be seen that night readings at Sunset Park are skewed lower than those at Star Nursery, and their averages are within 1 ppb. Lower nighttime levels are observed at the Sunset Park site that would be consistent with greater concentrations of nocturnal ozone reducing emissions. However, the nighttime readings at Paul Meyer are even lower, and are more typical for the urban ozone sites. This would tend to imply that artificially high readings due to some sort of an instrument artifact might be affecting the Sunset Park sampler. The higher nighttime concentrations at Star Nursery could simply be due to location in a less urban area.



Data use subject to license
© 2004 DeLorme. Topo USA® 5.0
www.delorme.com

June 30, 2005 Peak 8-hour Ozone Levels
All Sites

Figure 7-2. Maximum 8-hr Ozone Contours for June 30 at All Sites

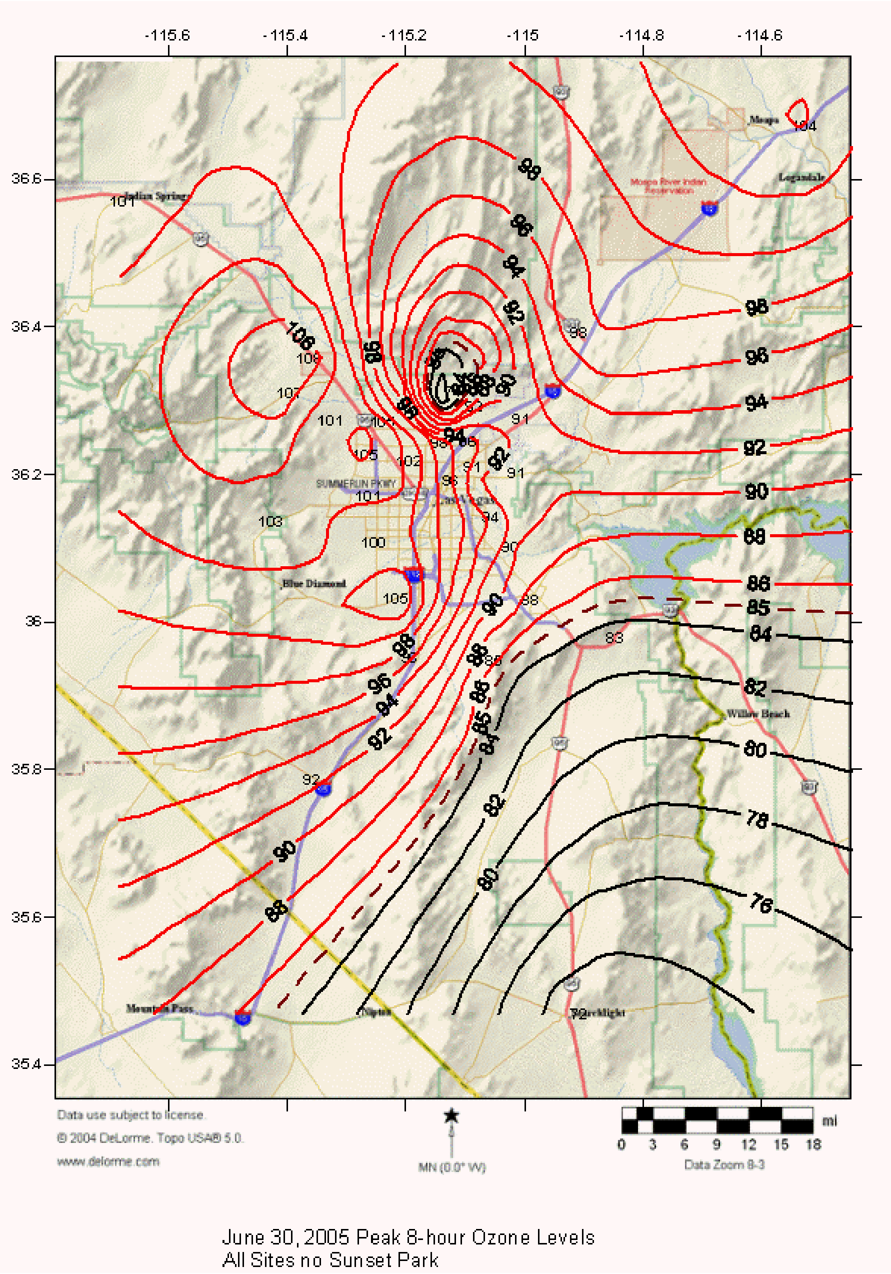


Figure 7-3. Maximum 8-hr Ozone Contours-Without Sunset Park on June 30, 2005

Table 7-2. Comparison of Concentrations Versus Sunset Park

| | Sunset Daytime | Sunset Nighttime | Star Daytime | Star Nighttime | Pmeyer Daytime | Pmeyer Nighttime |
|---|---|---|---|---|---|---|
| Average | 83 | 47 | 76 | 48 | 65 | 23 |
| Maximum | 129 | 82 | 108 | 73 | 100 | 55 |
| Minimum | 60 | 5 | 55 | 11 | 37 | 5 |
| 1stQuartile | 73 | 35 | 68 | 42 | 55 | 14 |
| Median | 80 | 45 | 75 | 49 | 63 | 18 |

units are ppb

### 7.2.2 The Sunset Park 2006 Study

To further investigate the Sunset Park results, a special study was conducted in June, July, and August 2006. The following measurements were made during the study period:

- Four monitoring sites in and around Sunset Park were established for measurement of ozone using the EPA designated equivalent UV photometric method for ozone detection. Ozone data were recorded in both 5-minute and 1-hour averages. Site locations are shown in **Figure 7-4**.
- Saturation measurements at the same location as the 2005 CCROPS study were made as well as additional locations to investigate the reasons for the high readings in 2005.
- Periodic surveys for ozone of the Sunset Park region were made with a mobile monitoring van using both the UV photometric and the KI detection methods. The aircraft sampler developed in 2005 was used for this effort, which employed the same KI method used in the saturation sampler. The 2B ozone analyzer owned by the DAQEM was used for the UV photometric method measurements.
- One surface measurement site was established for wind speed and wind direction with scalar wind speed and unit vector wind direction, with data recorded in both 5-minute and 1-hour averages.
- Upper-air meteorological measurements were made using a Doppler SODAR with data collected in 10-minute averages. The data documented the transport layer into and out of the Sunset Park region. The SODAR was operated by the Clark County DAQEM monitoring staff. The intent of the data was to better understand the depth of the layer that contained the higher ozone concentrations, if those concentrations were from a local source.

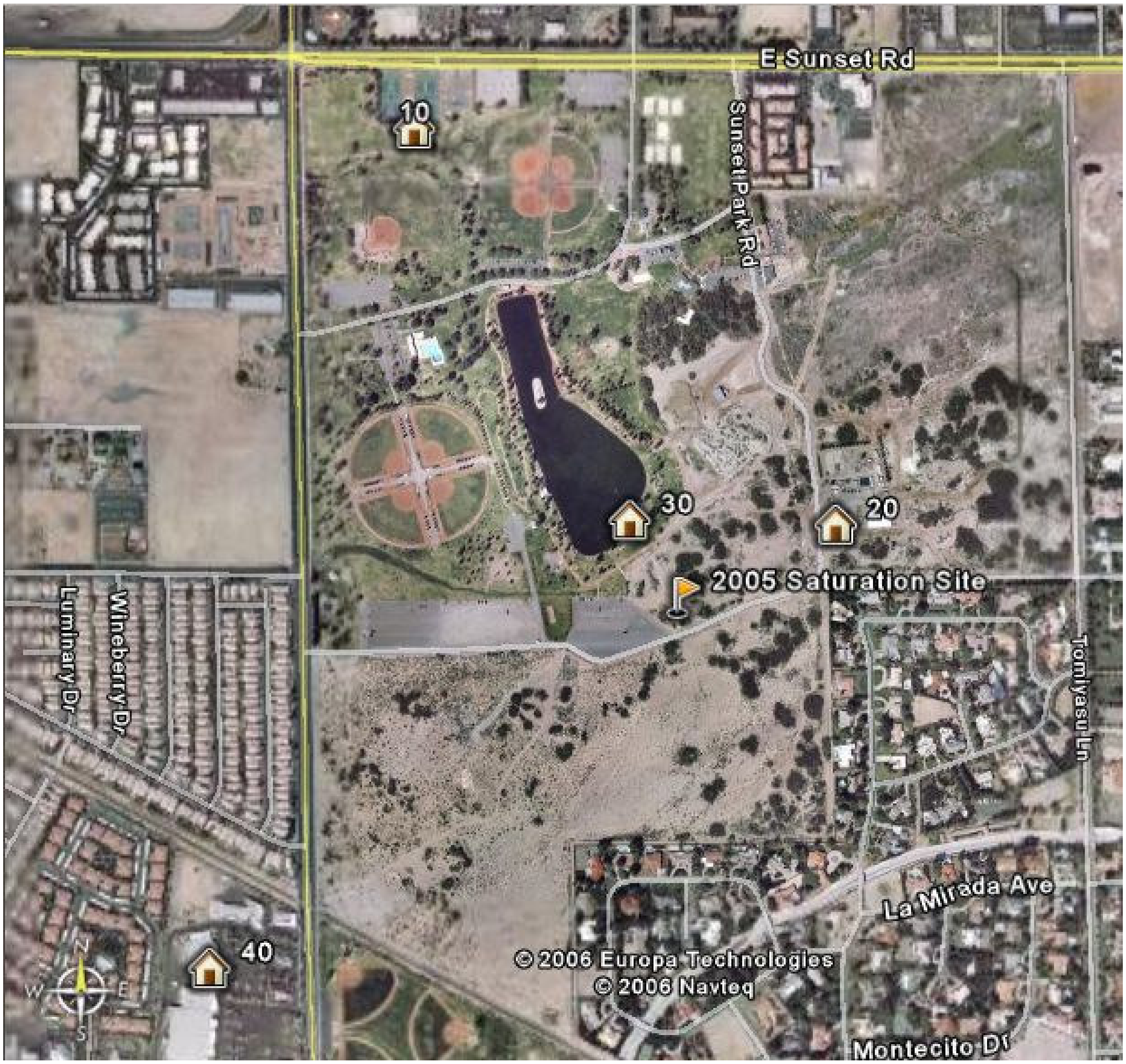


Figure 7-4. Location of the 2006 Sunset Park Monitoring Sites. The location of the saturation monitor relative to the network is also shown. Site 20 is the primary Maintenance Yard site where the SODAR was located.

During biweekly servicing of the monitoring network, an ozone saturation sampler was prepared using the same procedures that were used during the 2005 CCROPS. The sample cell was prepared the night before deployment and the sampler was then placed in the field during the period that the four monitoring stations were being serviced. An additional cell was prepared and placed in the aircraft sampler that was used during the 2005 CCROPS. This system had a 3-meter sample inlet attached to a mount on the top of the service vehicle. The DAQEM-owned 2B UV photometric ozone analyzer was also operated in parallel with the aircraft sampler, with the data recorded along with the GPS position on the same data logger as the aircraft sampler. The 2B analyzer used its own sample inlet line mounted adjacent to the aircraft sampler line. The intent of the two samplers was two-fold; first to identify any potential ozone hot spots, and second to compare the two methods (UV and KI) for any systematic differences. These systems were operated during each of the four servicing periods.

The saturation sampler was operated during four periods over the course of the Sunset Park Study. The first two periods had the operation on the same utility pole that was used during the 2005 CCROPS. The third period had the operation collocated with the sample inlet for the Maintenance Yard photometric sampler (site 20). The fourth period moved the sampler to the Lone Mountain site, a general region where we had operated the saturation samplers during the 2005 CCROPS where there was no noticeable bias in the ozone readings. The sampler was mounted to be collocated with the sample inlet for the DAQEM ozone monitoring being conducted at this site.

**Figure 7-5** through **Figure 7-9** shows the results of the data comparisons. From each of the three comparisons for data collected at Sunset Park, there was a noticeable bias in the concentrations. When the sampler was moved to the Lone Mountain site, there was no bias observed. These results suggest that there is an interferent to the KI method in the Sunset Park area. The magnitude of the bias is similar to what was observed during the 2005 CCROPS and was seen to a lesser degree at the Joe Neal quality control site. The primary issue in common with these two sites is the adjacent regions with landscaping and grass. Maybe there are some fertilizers or other compounds that are common and affect the KI detection principle?

Also shown in the figures are the data collected by the mobile sampling vehicle from both the KI and UV-photometric methods. It should be noted that the mobile data shown is from 4 seconds scans, so it will naturally be noisier than the 5-minute average or hourly data. However, it appears from the data set that the comparisons of the network data to the KI aircraft sampler are better than to the 2B UV photometric instrument. It is suspected that the temperature compensation that is inherent to the KI method is likely handling the excessively high instrument temperature in the vehicle better than the 2B compensation, as there appears to be a divergence of the measured values when the sampler temperatures exceeds about 40℃. While the original intent of the mobile sampling was to map higher concentrations of ozone and identify potential sources, the fact that no “hot spots” were identified with the four site network (sites 10, 20, 30 and 40) made further analysis of this data set less important. Nevertheless, the data are available for any future analyses, if that is so desired.

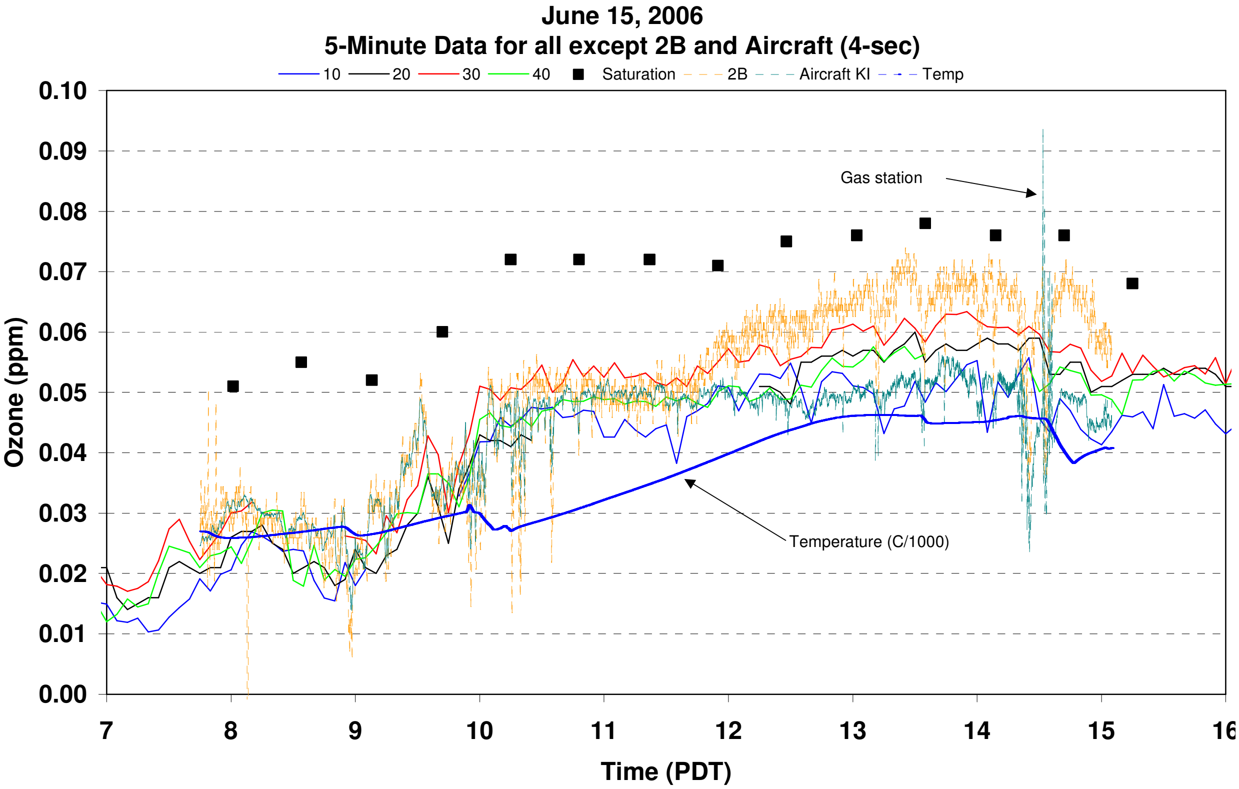


Figure 7-5. Saturation Sampler, Mobile Sampler and Fixed Site Ozone Data from the June 15, 2006 Sampler Servicing Period. (Note the positive bias in the saturation sampler data and the divergence of the 2B ozone data from the mobile KI sampler data when the temperature in the vehicle rose above 40°C. The noted period at the gas station did show an interferent with the KI sampling technique.)

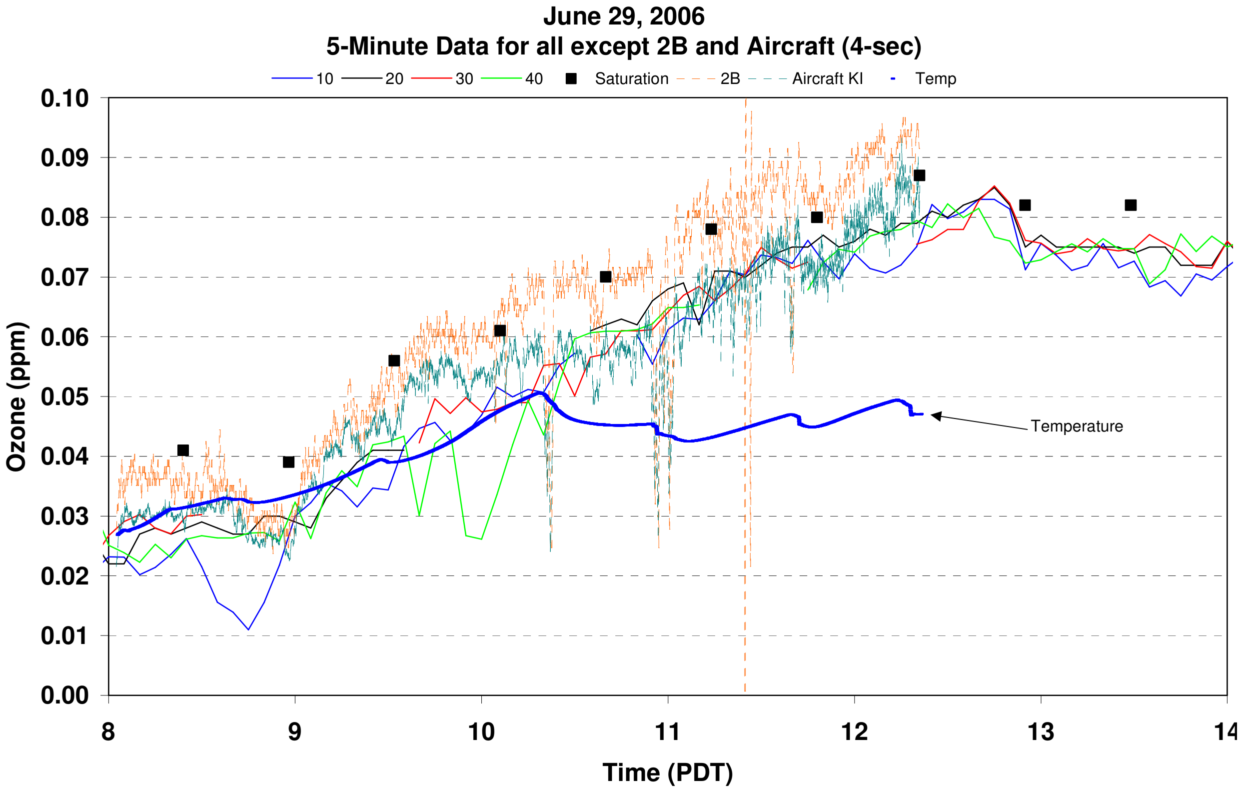


Figure 7-6. Saturation Sampler, Mobile Sampler and Fixed Site Ozone Data from the June 29, 2006 Sampler Servicing Period. (Note again the positive bias in the saturation sampler data, but not to the same degree as the prior period. Also the divergence of the 2B ozone data from the mobile KI sampler data is present when the temperature in the vehicle rose above 40°C. While the 2B and saturation sampler data sets agree reasonably well, the 2B data is biased high relative to the Sunset Park network stations.)

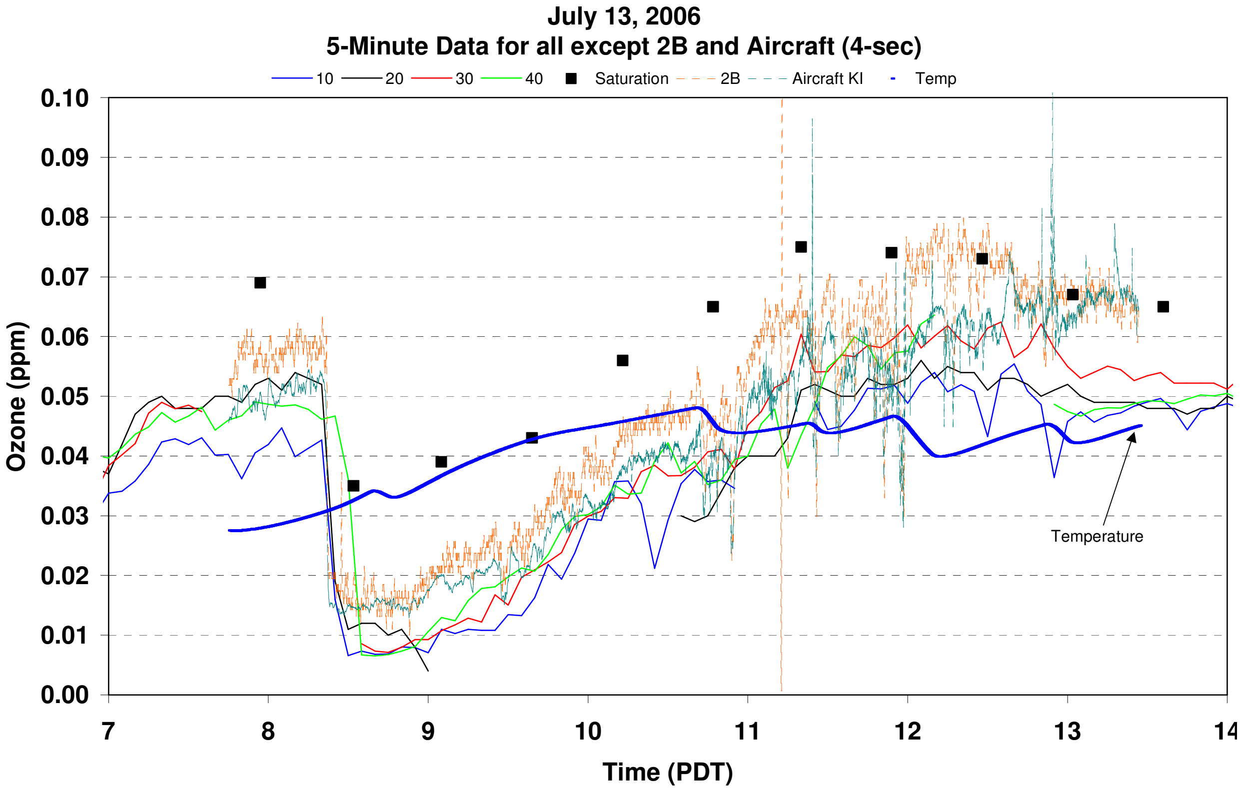


Figure 7-7. Saturation Sampler, Mobile Sampler and Fixed Site Ozone Data from the July 13, 2006 Sampler Servicing Period. (Note again the positive bias in the saturation sampler data. Also the divergence of the 2B ozone data from the mobile KI sampler data is present when the temperature in the vehicle rose above 40°C, but those differences decreased at the end of the period with the KI sampler values increasing. It is suspected that there was an interferent present following the refueling, as can be seen in the KI data just before 1300.)

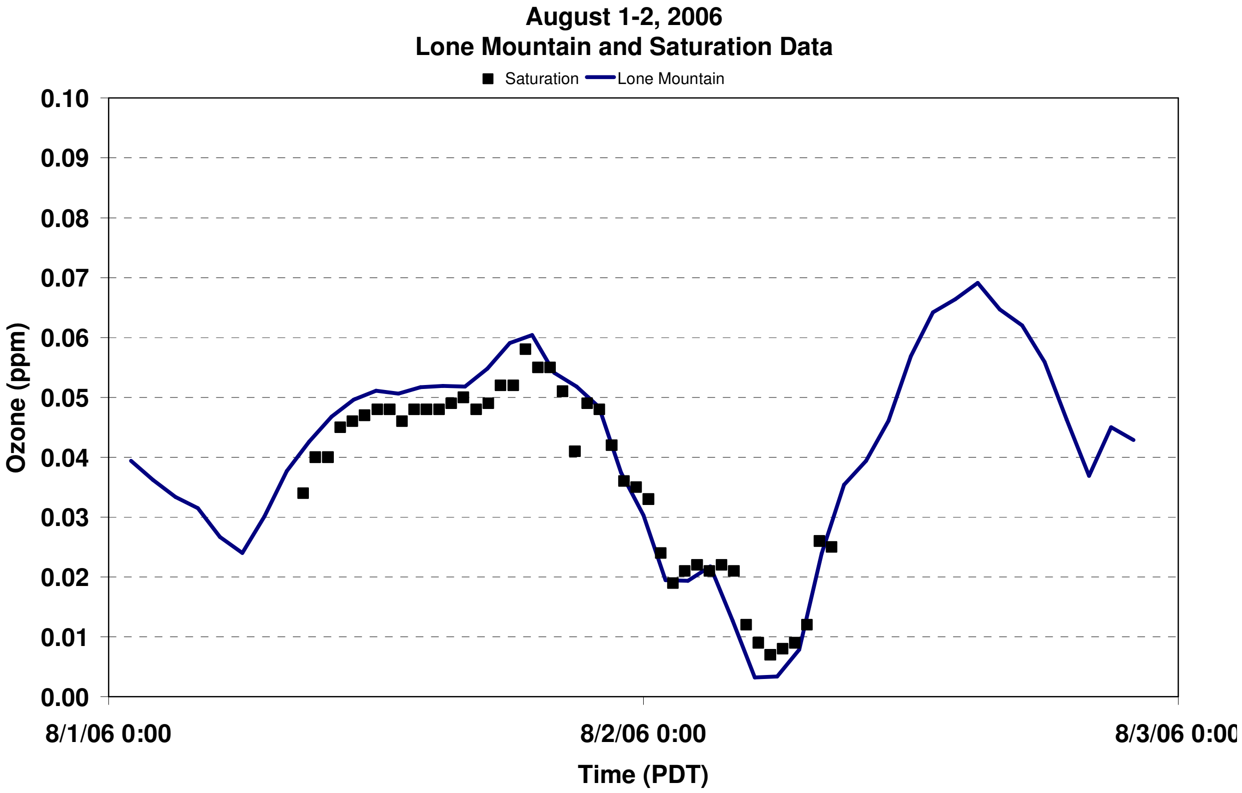


Figure 7-8. Saturation Sampler Data Collected at the Lone Mountain DAQEM Station Showing Good Agreement with the Site UV Photometric Analyzer. (The results of this comparison suggest an interferent is responsible for the differences observed at the Sunset Park location.)

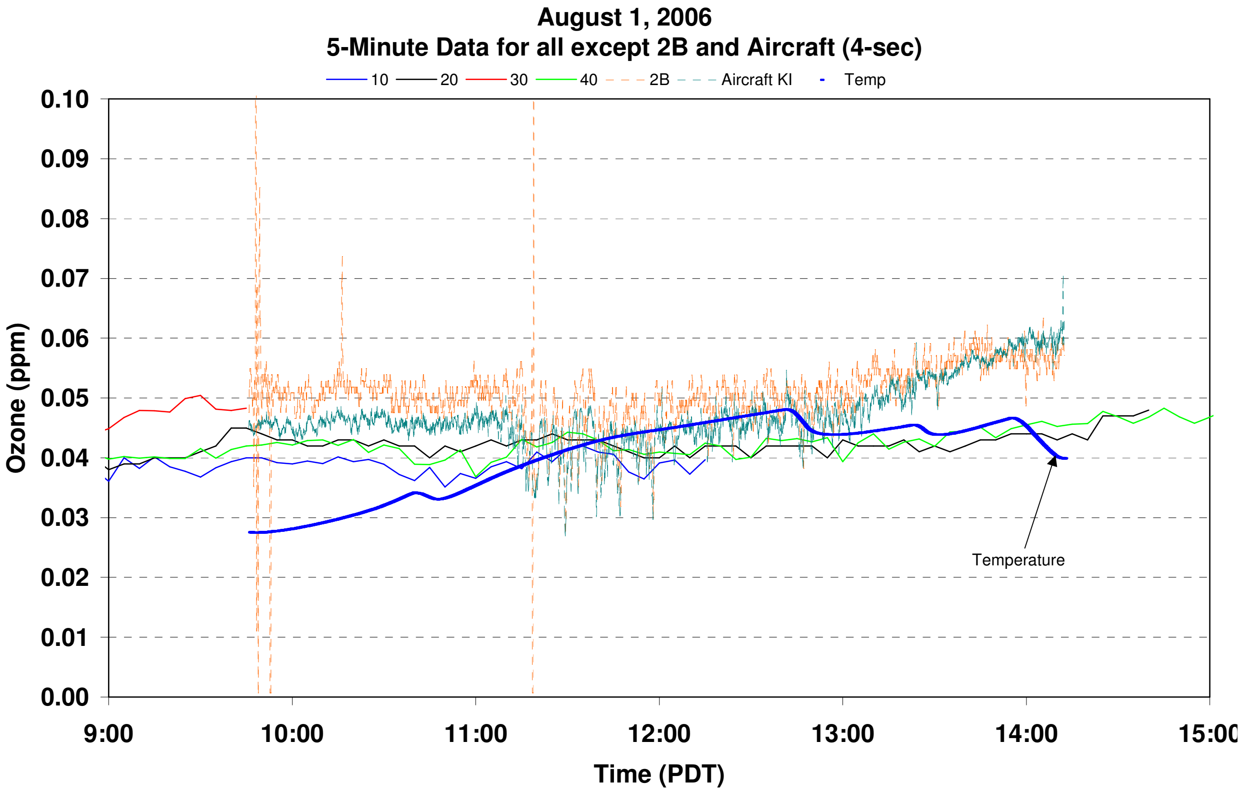


Figure 7-9. Mobile Sampler and Fixed Site Ozone Data From the August 1, 2006 Sampler Servicing Period. With the exception of the very end of the run, the UV photometric method data from the 2B read consistently higher than the KI method. The increase in the response of the KI system at the end of the run may be due to the evaporation of the cathode solution, which is known to increase the system response.

From the observed differences between the saturation sampler and the four network site readings we further analyzed the data set to see if the bias in the saturation sampler is wind speed dependent, and is maybe related to a residence time of any potential interferent in the local area. **Figure 7-10** plots the difference between the saturation sampler data and the closest Sunset Park station as a function of wind speed. For the first two saturation sampler runs, the closest site was the Pump House (site 30). For the third run the comparison site was the Maintenance Yard (site 20), as the sampler was placed coincident with the Maintenance Yard sample inlet. The indicated trend line does show a downward trend in the differences as the wind speed increases, however, the magnitude of the decrease is not sufficient to provide a definitive conclusion. All that can be said is that there appears to be correlation between increased mixing associated with high wind speeds and a decreased difference between the saturation sampler and the network samplers. This wind speed relationship is consistent with the observations from the 2005 CCROPS data set where higher differences were noted during the lower wind speeds from the Wetlands site.

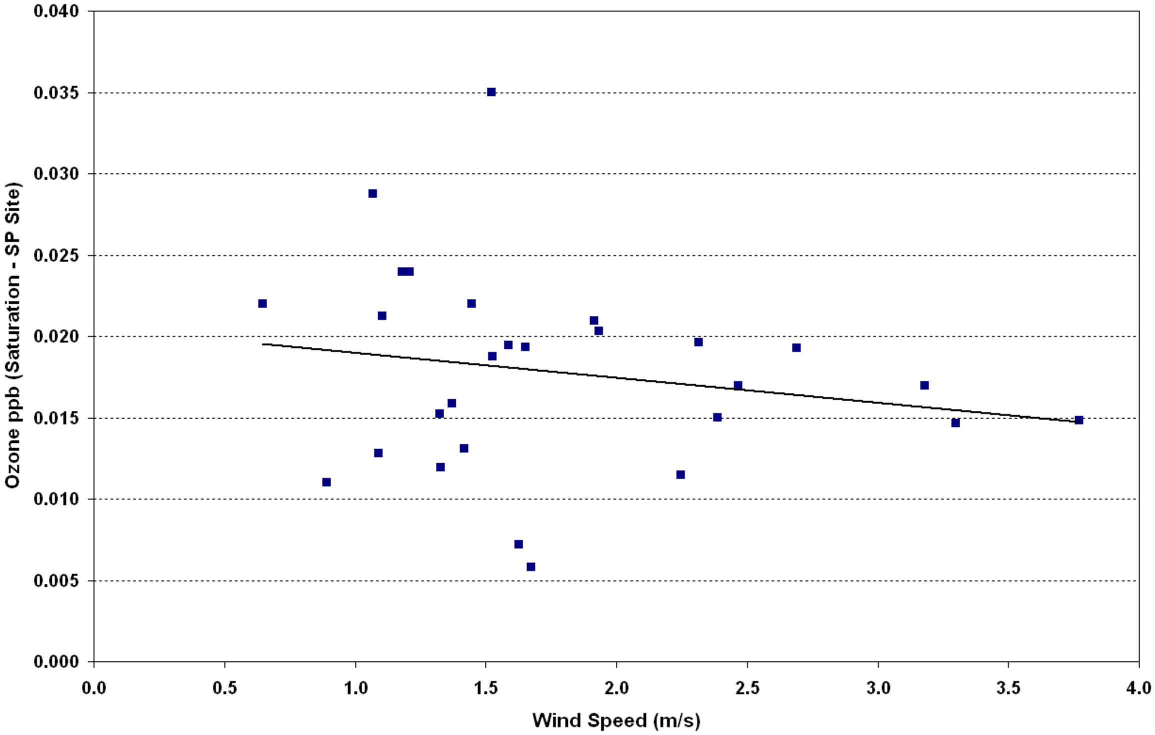


Figure 7-10. Plot Showing Decreasing Difference Between Saturation Sampler and Adjacent UV-Photometric Site in Sunset Park

As the data collected by the four-station network does not support any hot spot ozone measurements, and the higher readings, or apparent biases, are similar to what was seen in 2005, it could be concluded that the Sunset Park saturation sampler readings are biased high and that there are no ozone hot spots in the Sunset Park region.

The following summarizes the results of the 2006 study:

1. Using the network of four UV-photometric sampling sites deployed for the study no unusually high readings of ozone were found in the Sunset Park region.
2. Measurements made with the saturation sampler during the 2006 Sunset Park Ozone Study at the same location as was used in the 2005 CCROPS showed a similar high bias as was noted in the 2005 CCROPS data set. These high readings were measured during each of the saturation sampling periods.
3. Movement of the saturation sampler to the Lone Mountain site for the final sampling period showed no bias in the readings, with a good comparison to the DAQEM ozone monitored values. This leads us to believe that there is either a natural or anthropogenic interfering source to the KI method in the Sunset Park region. This may be related to either vegetation or land use related compound(s), as this bias was seen to a limited extent in 2005 at other sites that were close to park-like regions, such as Joe Neal. At this time we are unsure of what the source may be, but feel confident that the observations made do not show an ozone hot spot in the region of Sunset Park.
4. As a result of the analysis that compared the values measured in the Sunset Park ozone network to the nearby DAQEM sites at Henderson and Orr, we can conclude that

measurements at the two DAQEM sites are very similar to the values seen at Sunset Park and there is probably no benefit in adding a fixed site for ozone measurements at Sunset Park.

## 7.3 Summary of Exceedances

As noted above, exceedances of the 8-hr ozone standard were recorded on nine days by the DAQEM monitoring network. The CCROPS Supplemental monitoring network recorded exceedance levels on an additional three days. Finally, the saturation monitoring network recorded concentrations above the 8-hr standard on 11 additional days. However, due to the experimental nature of the saturation monitoring methodology, the absolute accuracy of the measurements is still under review.

A primary goal of the 2005 study was to provide a data set that provides additional insight into the relationship between meteorology and air quality in Clark County. More specifically, can the relative contributions of interbasin transport and local emission sources be determined, and, if so, do we understand the critical atmospheric processes involved.(i.e. transport and dispersion). It is beyond the scope of the current project to completely analyze the copious amount of data collected. However, as an initial attempt at answering this question, the data were examined using the following five approaches:

- Meteorological conditions and ozone concentrations on and around the days of the exceedances were input to the CART model generated as part of the Clark County Ozone Characterization Study. The CART model separates the exceedances into categories that can basically be distinguished as favoring transport or favoring local contributions.
- The Ozone Characterization Study demonstrated that the timing of the ozone peak could provide information as to the cause of the exceedance. High concentrations due to transport can occur any time of the day and ozone levels can rise very rapidly within a brief period. Often a peak in surface ozone is observed during the night or before noon, due to mechanical or convective mixing entraining ozone aloft, either transported or carried over from the prior day reach the surface. Locally generated ozone reacts from accumulated precursors and insolation over the course of the day and will peak in the afternoon exhibiting a gradual buildup. One-hour data from the DAQEM and Supplemental network were reviewed and the median time of the concentration peak was determined at each site for each of the exceedance days. Ozone peaks at noon or earlier were considered indicative of transport. Afternoon ozone peaks could be owing to local sources exclusively or could be a combination of local sources and transported pollutants.
- Conditions at the Jean site (DAQEM) were reviewed for each exceedance day. If the peak 8-hr ozone concentrations at Jean was nominally high (greater than 75 ppb) and the winds recorded at the Sloan Supplemental site had a predominate westerly component, it was concluded that the high Jean concentration could not have been influenced by the greater Las Vegas urban area, and the high concentration was therefore due to interbasin transport from California.
- 24-hr back-trajectories were generated for each exceedance day using the Hysplit model, nominally based on a 10-meter ending height at the North Las Vegas airport at 14 PST. Ozone data around the apparent source-area of the trajectory were reviewed for the occurrence or not of high levels of ozone. If concentrations greater than about 80

ppb were noted at these source areas on the day-before the Clark County exceedance, transport was considered to be a likely possibility.

- Data from two of the Supplemental network sites were reviewed as an initial effort to estimate the contribution of the greater Las Vegas urban area to the ozone concentrations in Clark County. Data for 05 PST from the Black Mountain site, which was on a mountaintop and above the Valley nocturnal boundary layer, was considered representative of the ozone pool aloft and available for adding to the current day's ozone burden. This site is located well above the valley floor and away from ozone scavenging mechanisms. Data from the Paiute site was selected as most representative of the regional ozone maximum concentrations. This site exceeded the 85 ppb standard on nearly all the exceedance days and most often had the highest concentrations (see Table 7-2). Comparing the data from the two sites, the 8-hr peak concentration at Paiute is on average 10.6 ppb higher than the 05 PST 1-hr average at Black Mountain, with a standard deviation of 11.7. Using of limit of 22 ppb derived from the average difference plus one standard deviation, it was assumed that differences greater than 22 ppb are indicative of an above average local contribution to the ozone burden at Paiute, whereas lower values reveal that relatively high ozone concentrations were already present, either from transport or from the previous day.

In addition to the above, meteorological data were reviewed and compared with results and conclusions from the Ozone Characterization Study. CCROPS forecast notes were also reviewed.

**Table 7-3** summarizes the 2005 exceedances and the results from the above analysis. Each of the exceedance days are briefly discussed below, with the principal goal of determining whether they were transport or locally driven. The designation of "transport" versus "local" is, of course, one of relative distinction. All days will likely have some transport component and some local contribution component. The exceedances on July 2 and July 18 are discussed in more detail, as they are classic examples of a transport scenario and local contribution scenario, respectively. These two days also were episode-mode days, when additional data were available.

# Table 7-3. Summary of 2005 Ozone 8-hr Exceedances

| | 12-Jun | 29-Jun | 30-Jun | 1-Jul | 2-Jul | 3-Jul | 6-Jul | 8-Jul | 15-Jul | 18-Jul | 6-Aug | 10-Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Max 8-hr avg (ppb)- DAQEM network** | 90 | 101 | 105 | 81 | 85 | 87 | 82 | 86 | 87 | 95 | 87 | 78 |
| **# Exceedances - DAQEM network** | 3 | 12 | 11 | 0 | 1 | 1 | 0 | 1 | 4 | 5 | 2 | 0 |
| **Max 8-hr avg (ppb) - supplemental network** | 89 | 102 | 108 | 88 | 91 | 88 | 85 | 87 | 90 | 90 | 84 | 88 |
| **# Exceedances - supplemental network** | 1 | 7 | 8 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 0 | 1 |
| **Max 8-hr avg (ppb) - saturation network** | | 122 | 129 | 99 | 90 | 80 | | | 94 | 105 | | |
| **#Exceedances - saturation network** | | 9 | 10 | 3 | 4 | 0 | | | 3 | 6 | | |
| **Max 8-hr avg (ppb) - entire network** | 90 | 122 | 129 | 99 | 91 | 88 | 85 | 87 | 94 | 105 | 87 | 88 |
| **#Exceedances - entire network** | 4 | 28 | 29 | 4 | 7 | 3 | 1 | 3 | 8 | 13 | 2 | 1 |
| **Maximum Ozone Location** | Lone Mtn | Paiute Res | Paiute Res | Indian Sprgs | Indian Sprgs | Paiute Res | Black Mtn | Paiute Res | Paiute Res | Lone Mtn | Lone Mtn | Paiute Res |
| | | | | | | | | | | | | |
| **CART model** | Transport? | Local | Local | Transport? | Transport | Transport? | ? | Transport? | Local? | Local | ? | ? |
| **Peak hr < 1300 = transport** | Local | Local | Tansport | Local | Local | Tansport | Local | Local | Local | Local | Local | Local |
| **Jean conditions** | Local | Local | Local | Local | Transport | Transport | ? | Local | Local | Local | Local | Local |
| **Back trajectories** | Local | Local | Local | Transport | Transport | Transport | Both | Transport | Local | Local | Local | Local |
| **Paiute/Black Mountain difference (ppb)** | 13 | 32 | 32 | 10 | -4 | 15 | 3 | 16 | 35 | 23 | 37 | 43 |
| | Both | Local | Local | Tansport | Tansport | Both | Tansport | Both | Local | Local | Local | Local |
| | | | | | | | | | | | | |
| **Concensus** | Local | Local | Local | Both | Transport | Transport | Both | Both | Local | Local | Local | Local |

Note: For CART model, "?" indicates that not all CART criteria were specifically satisfied, but results leaned towards this conclusion.

**June 12**

While the CART models pointed toward this exceedance being likely due to interbasin transport, primarily because of higher regional mid-day wind speeds, the back-trajectory does not really support this. Concentrations in Jean were reasonably high (79 ppb), but winds at Sloan were from the northwest during much of the day, indicating that the high concentrations at Jean were more likely due to the Las Vegas urban plume.

**June 29 and 30**

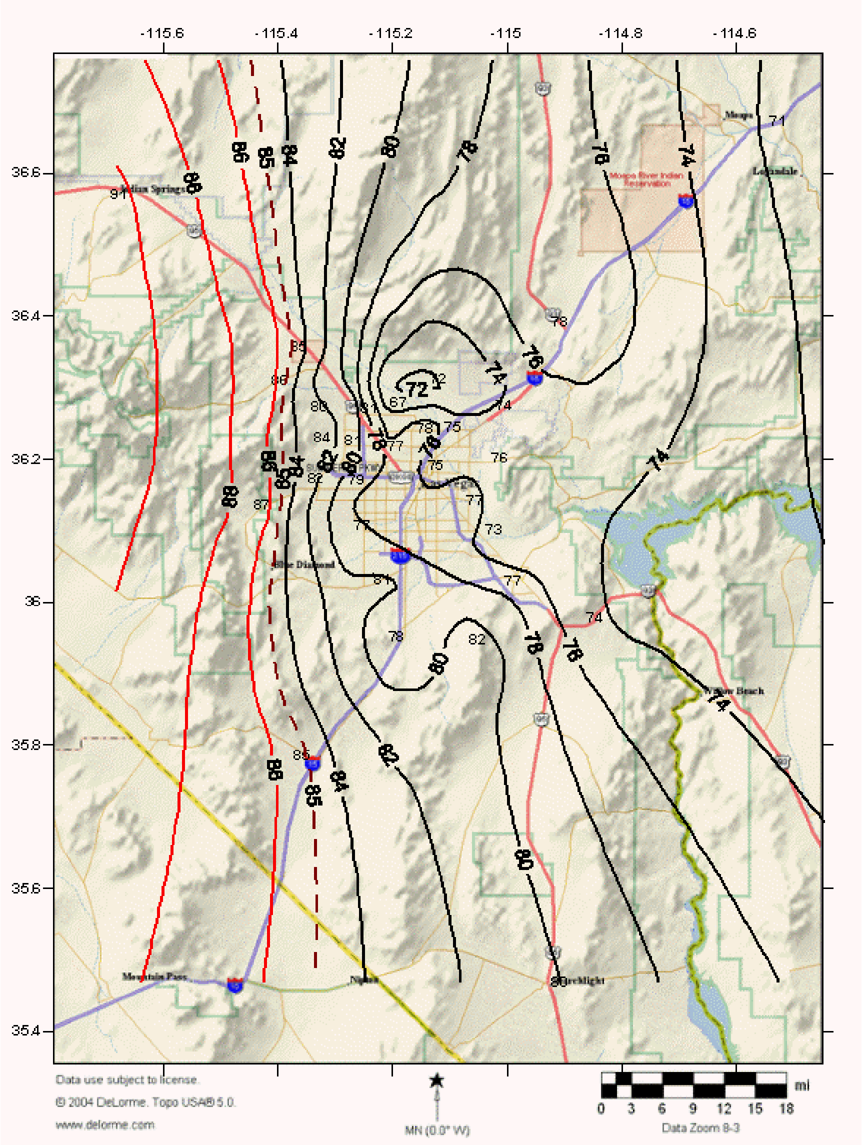
It is unfortunate that wildfires were burning in and around the area on these two days, as they both have the earmarks of being classic, significant local contribution driven days - high pressure, light regional winds, the classic nighttime downslope winds/ daytime upvalley winds directing the urban plume to the northwest, and low RH both at the surface and aloft. Furthermore, June 29 shows hourly ozone peaking in the afternoon with peaks at downwind sites occurring a couple of hours later, consistent with a “local” scenario. The early peak hour on June 30 is almost certainly due to morning entrainment of carryover from the previous day, rather than to transport from elsewhere. As shown in Table 7-3, this period essentially met all of the criteria for the “local” scenario, and would likely have experienced exceedances without the smoke impact. As it stands, these days will have to live with an asterisk, due to the likely but probably unquantifiable contribution by the smoke. These two days are discussed in more detail in Section 7.4.

**July 1**

The one exceedance experienced this day was measured at the Paiute site, and was not seen by any DAQEM sites. Overwhelming transport indicators are mixed for this site, with the possibility of both significant transport and local contributions. The back-trajectory appears consistent with a transport scenario. Although Jean concentrations were high (81 ppb), the winds at Sloan were light and variable. Under those conditions, transport into the Valley from the southwest is not certain.

**July 2**

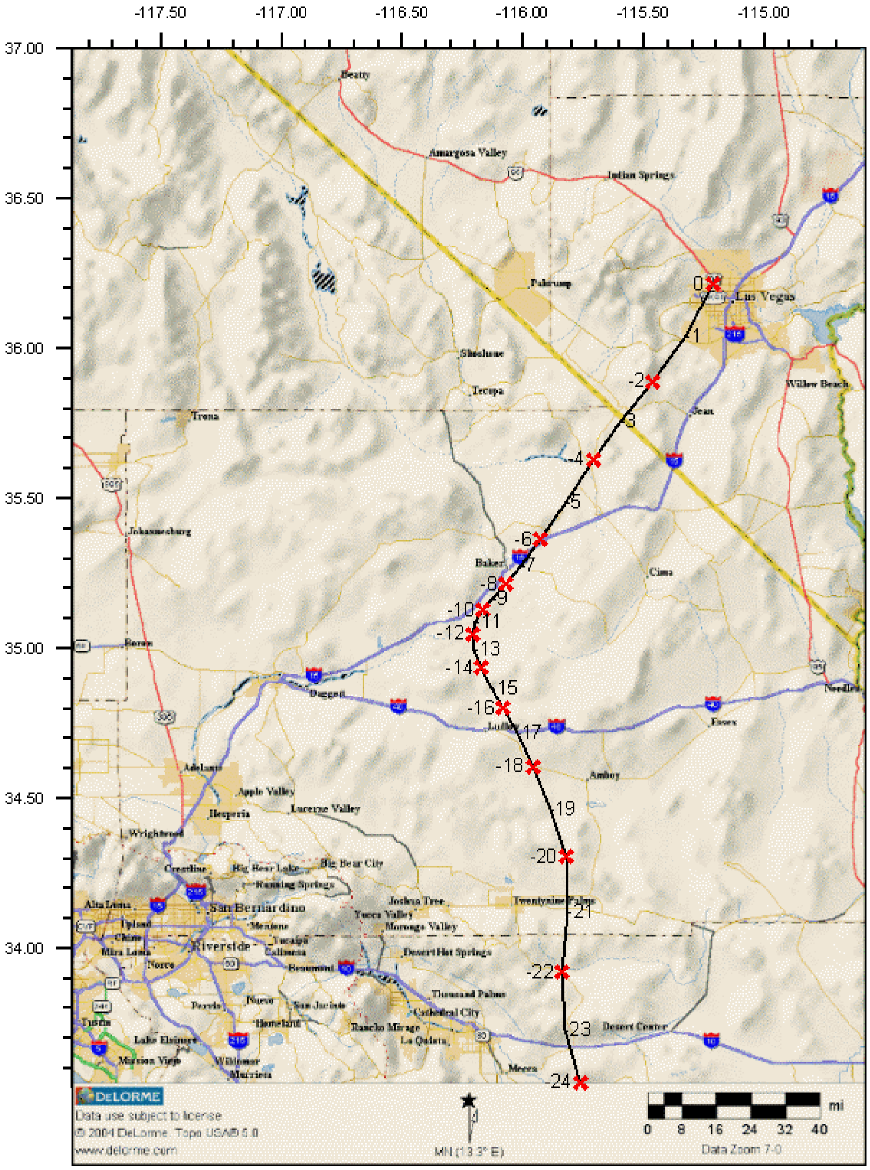
Conditions on this day were classic for a transport scenario, as demonstrated by the back-trajectory. The peak 8-hr concentration at Jean was 85 ppb, and indeed, Jean was the only DAQEM site to report an exceedance. With southwest winds dominating during the exceedance, the source of the exceedance is quite obviously not the Las Vegas urban plume. As can be seen in **Figure 7-11**, exceedances in the CCROPS monitoring network occurred solely on the very western edge of the study area, well away from the urban area. **Figure 7-12** shows the back-trajectory analysis for the day, further inferring that the strong southwesterly flow had transported high ozone concentrations from the California desert region, which had high ozone concentrations the previous day. **Figures 7-13 and 7-14** are ozonesonde profiles from the CCROPS site at the North Las Vegas airport for 6 AM and 10 AM on July 2, respectively. At 6 AM a reservoir of ozone and near-exceedance concentrations was poised above North Las Vegas, separated from the surface by a notable inversion. By 10 AM, the inversion had eroded, providing a mechanism to mix the reservoir of ozone down to the surface. However, low-level winds at this time were already pushing the plume to the northwest, impacting the Indian Springs site as well as the Red Rock and Kyle Canyon saturation sites. This exceedance is further discussed in Section 7.9, which presents results from the aircraft measurements, which further supported transport on this day.



Data use subject to license.
© 2004 DeLorme. Topo USA® 5.0.
www.delorme.com

July 2, 2005 Peak 8-hour Ozone Levels
All Sites no Sunset Park

Figure 7-11. Maximum 8-hr Ozone Levels for July 2



Backward Trajectory Ending at 14 PST July 02, 2005
Hours prior to end point shown

Figure 7-12. Back-Trajectory Analysis for July 2

## **July 3**

July 3, another apparent transport day, was similar in most ways to July 2. However, the back-trajectory originated more from the west than from the south inferring the southern San Joaquin Valley as the possible source.

## **July 6**

The Black Mountain site was the only site in the network to record an exceedance this day, demonstrating the unique information gained from monitoring aloft when the atmosphere is stable. The 8-hr exceedance, while technically occurring during July 6, actually consisted of the last hour on July 6 and the first seven hours on July 7. This nighttime occurrence therefore was due entirely to an elevated reservoir of ozone separated from the surface by the nocturnal inversion. This elevated plume apparently passed the Las Vegas Valley while decoupled from the surface boundary layer. As such, no populated areas of Las Vegas were impacted, and the fact that the DAQEM network did not detect this “exceedance” is for the most part inconsequential.

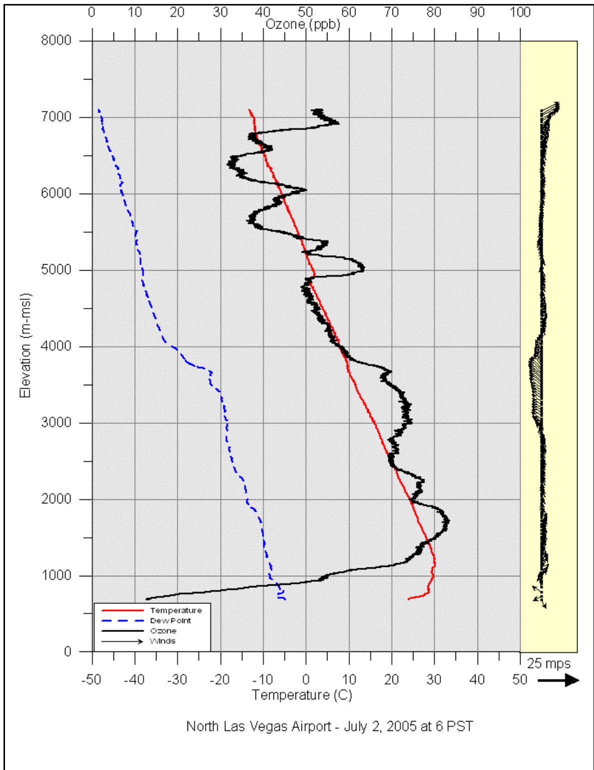


Figure 7-13. July 2, 6 AM Ozonesonde

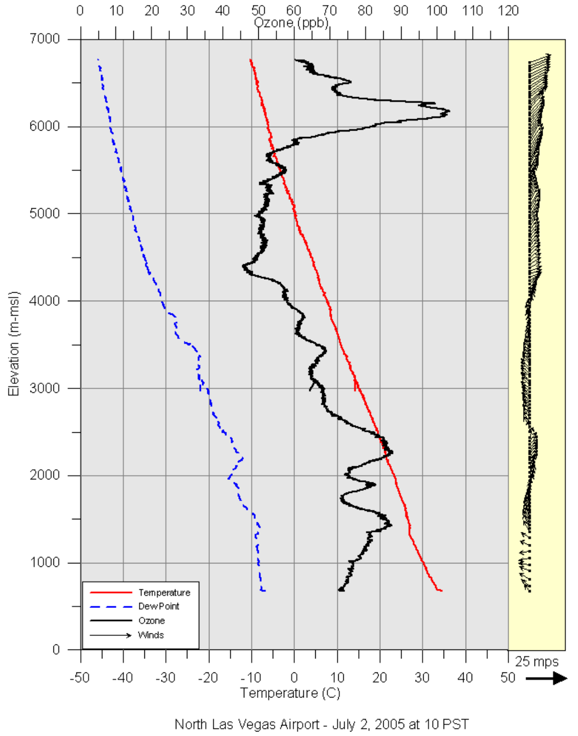


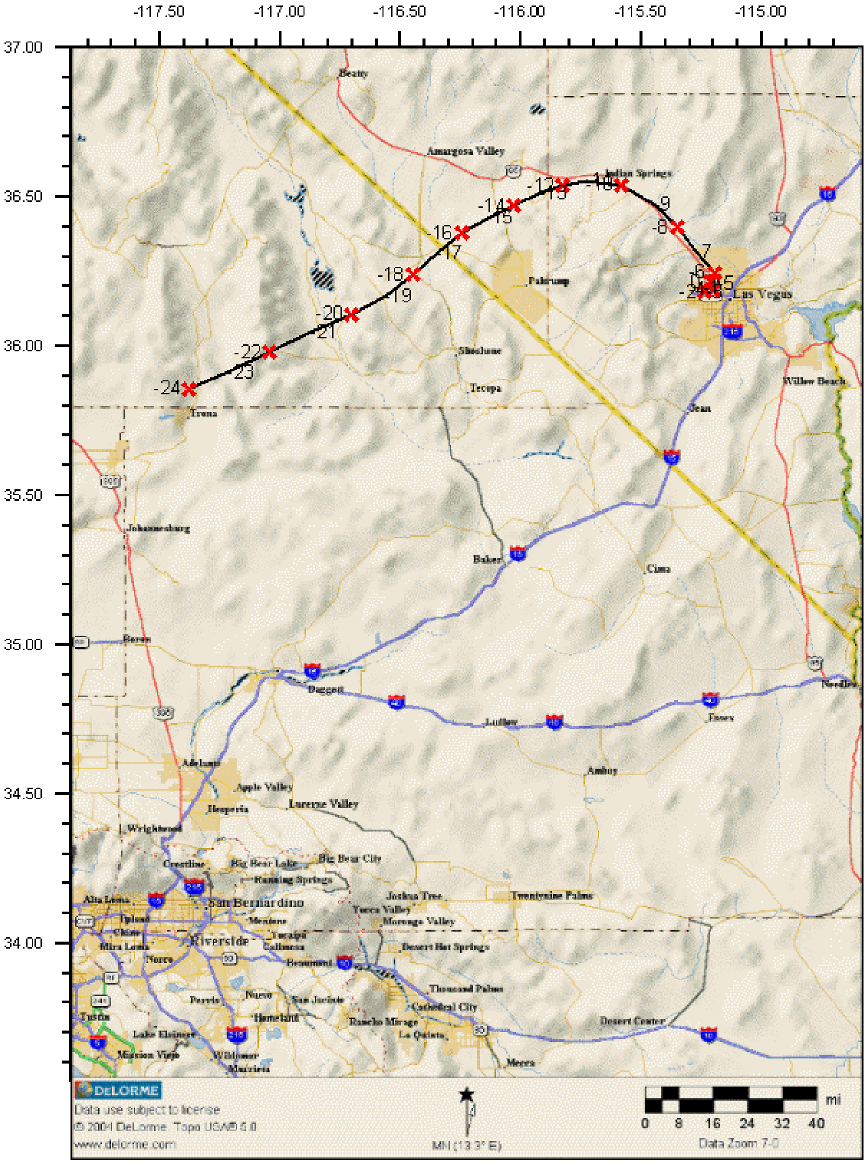
Figure 7-14. July 2, 10 AM Ozonesonde

## July 8

Both transport and local contributions appeared to play a significant role in the July 8 exceedance. Both the CART model and the back-trajectory analysis imply contribution from transport. However, the late peaking of concentrations and a significant increase in concentrations differences between Black Mountain and Paiute imply that local contributions were also important.

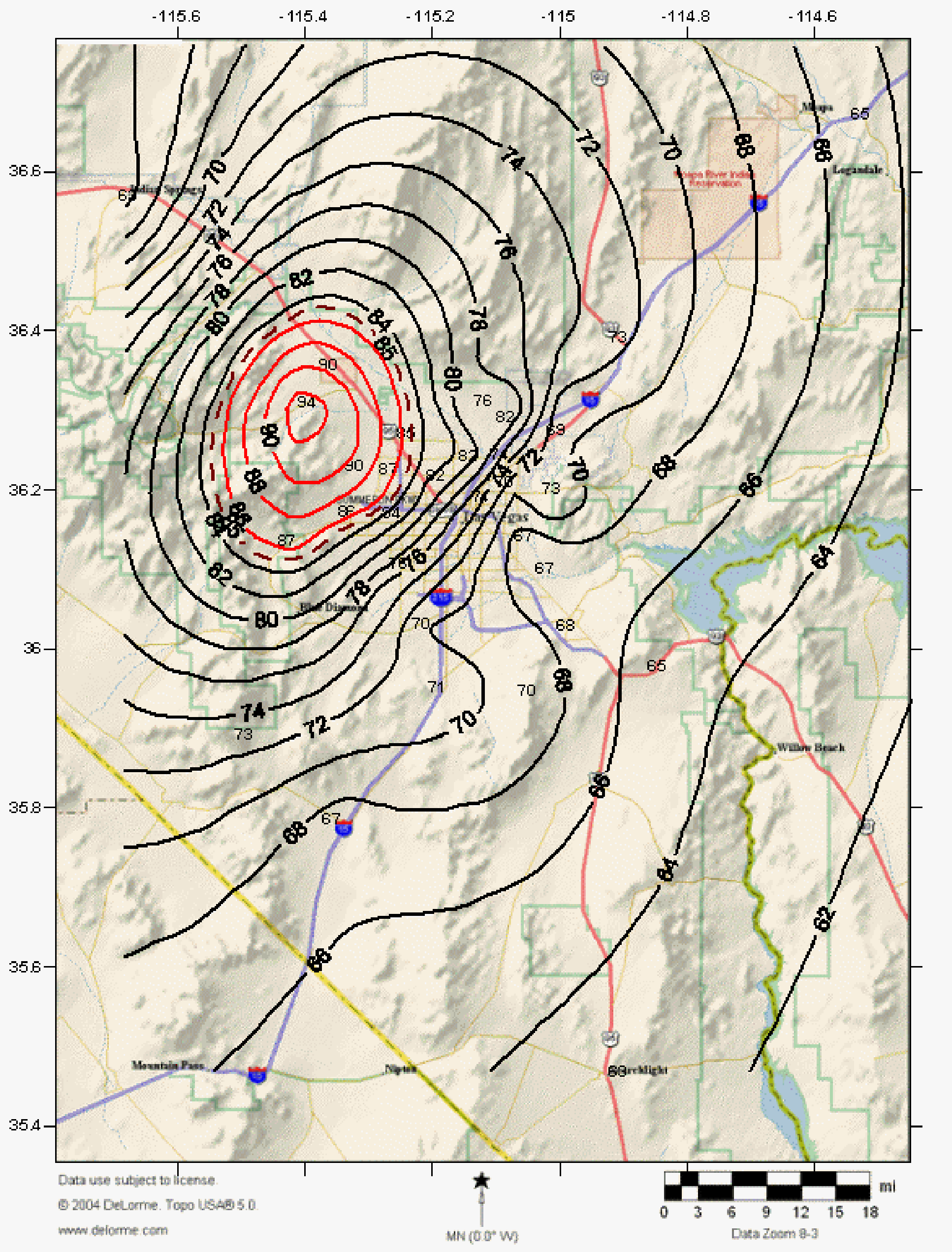
## July 15 and July 18

These periods were dominated by light and variable winds - classic conditions for an exceedance that includes significant local contributions. This is demonstrated by the air mass trajectory for the seven hours immediately preceding the July 18 exceedance, which can be seen in **Figure 7-15**. **Figure 7-16** shows the maximum 8-hr ozone contours for the July 18, which is characterized by a plume of higher concentrations pushed to the northwest by daytime upvalley winds. Again, this is a classic local-contribution scenario as described in the Ozone Characterization Study.



Backward Trajectory Ending at 14 PST July 18, 2005
Hours prior to end point shown

Figure 7-15. Back-Trajectory Analysis for July 18



July 15, 2005 Peak 8-hour Ozone Levels
All Sites, no Sunset Park

Figure 7-16. Maximum 8-hr Ozone Levels for July 15

**August 6 and 10**

These two exceedance days were similar in almost all respects. The 8-hr ozone standard was barely exceeded on both days, and only at one site. While the CART model did not provide any hint towards the principal source of the exceedances, all other criteria indicate that local emissions were significant to causing the exceedance. Trajectories for both days show only light winds and meandering plume within the Las Vegas Valley. The difference between Black Mountain and Paiute readings is particularly large.

## 7.4 Wild Fire Events

CCROPS forecasters had predicted that the last part of June would be conducive for high ozone potential in Clark County. Consequently, Intensive Operation Period monitoring was in effect when two major smoke events occurred; the first beginning June 23 as a result of the Goodsprings fire located approximately 20 km southeast of Las Vegas, and the second on June 29 and 30 due to wildfires in southern California and southern Utah that inundated the area with smoke (**Figure 7-17**). The latter was associated with widespread exceedances of the 8-hr ozone standard throughout Clark County, with 8-hr concentrations reaching 108 ppb, among the highest ever recorded in this region (**Figure 7-18**).

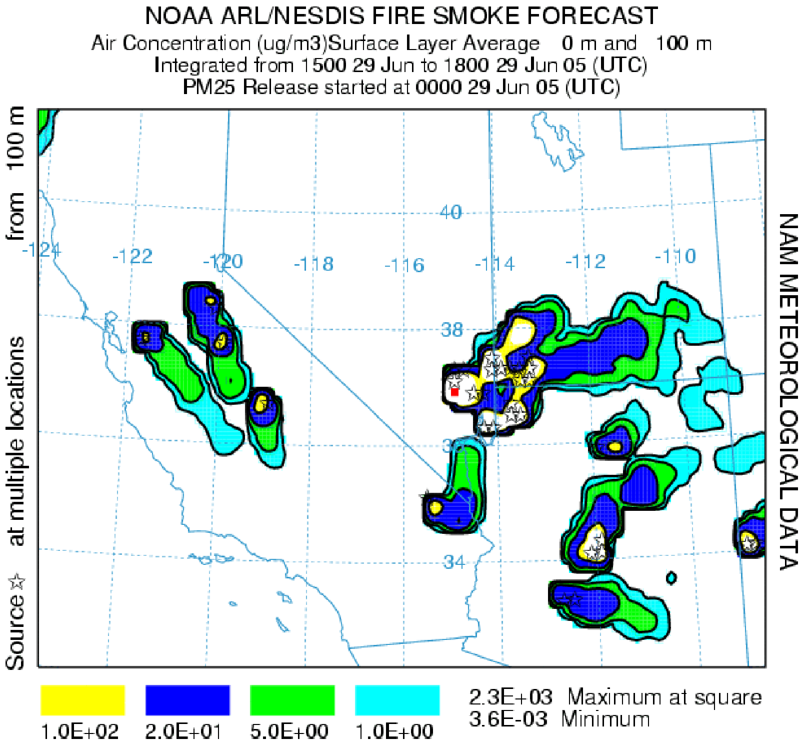


Figure 7-17. NOAA Smoke Forecast for Afternoon of June 29
(Star's designate active fires)

Preliminary analysis of the CCROPS data has shown apparent relationships between ozone concentrations and wildfire smoke. This relationship appears to be dependent on the age of the constituents that comprised the smoke plume. As in an urban plume, reactants in the fire plume titrate ambient ozone. Thus near the wild fire ozone may be less than regional background levels. Conversely, as the fire plume ages in which ozone production has been active, ozone levels increase to above background.

The Goodsprings fire on June 23 produced a plume that, when in the greater Las Vegas area, was still in its infancy with regard to precursor conversion to ozone.

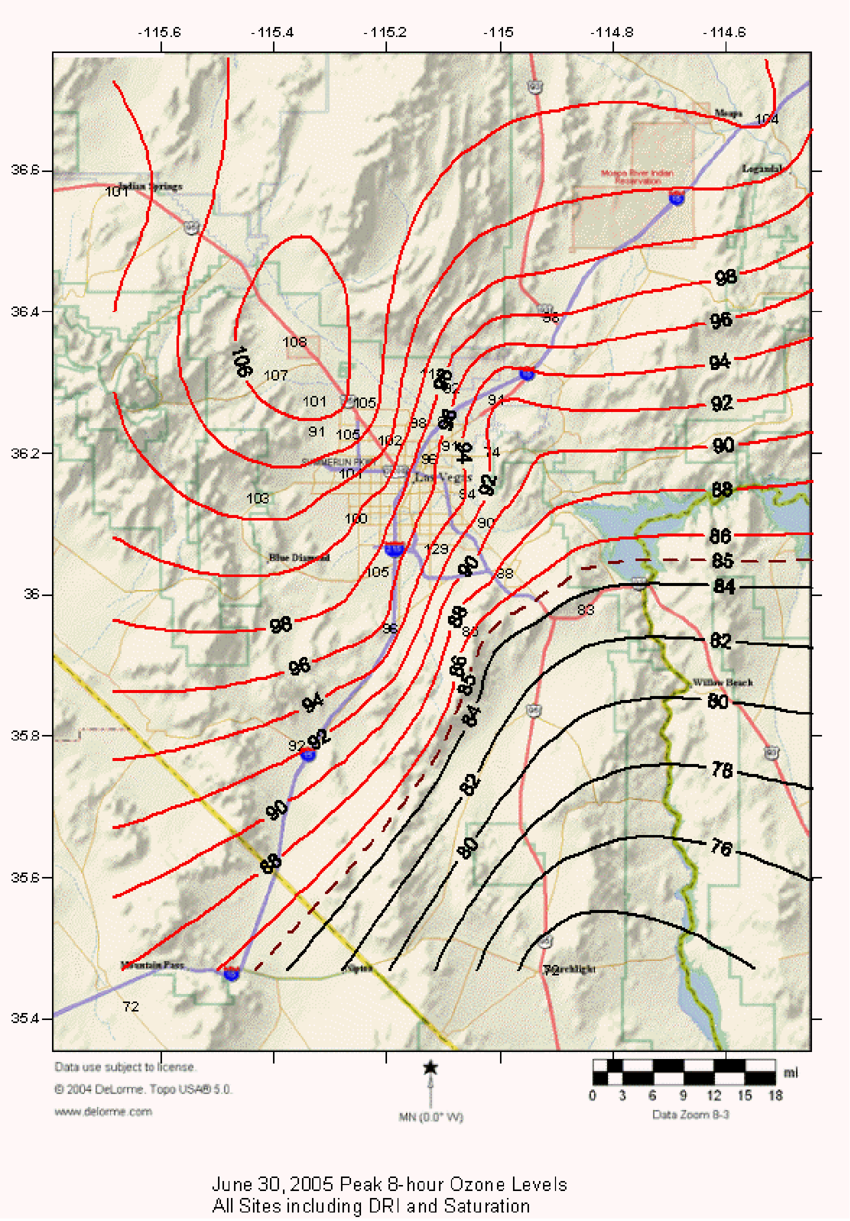


Figure 7-18. Maximum 8-hr Ozone Levels on June 30

A glider equipped with an ozone monitor conducted soundings during this period. The glider operated out of the Jean airport, only a few kilometers from the Goodsprings fire. **Figure 7-19** shows a plot of the glider ozone profile taken during the fire. Based on observations from the glider pilot, entering the plume from the Goodsprings fire was accompanied by a significant decrease in ozone concentrations by titration. In contrast, when the glider was above the Goodsprings plume in air that back-trajectory analysis indicates came from fires near Joshua Tree in southern California, ozone concentrations were clearly greater above those near the surface.

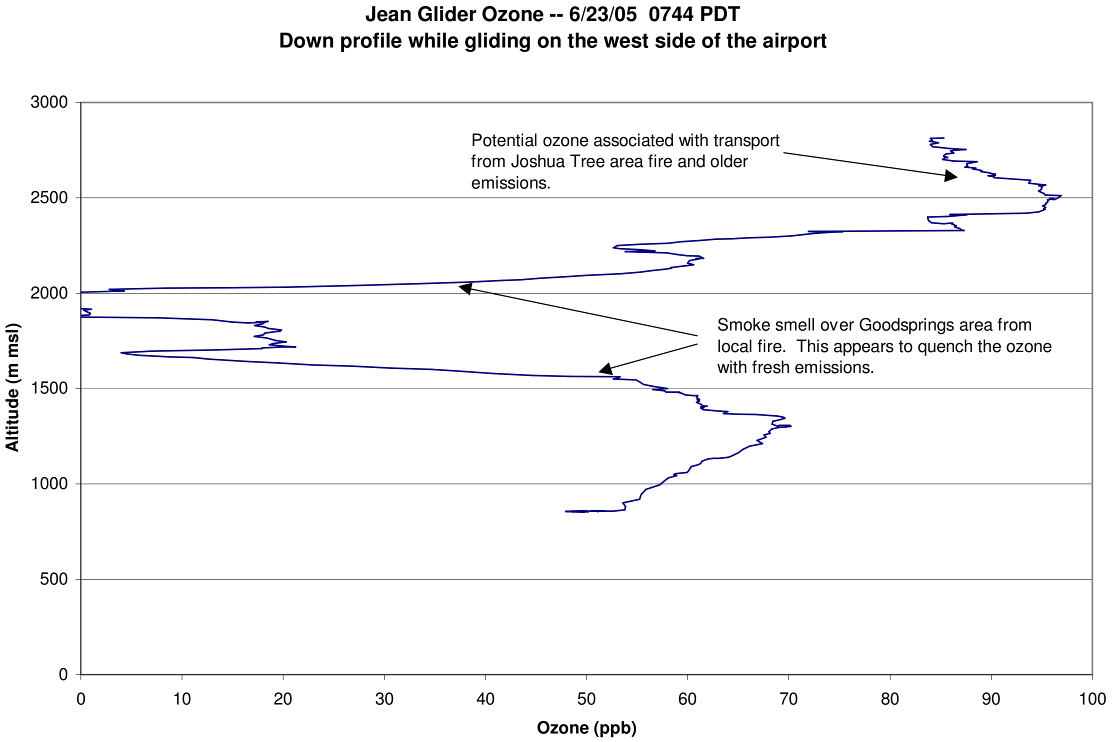


Figure 7-19. Ozone Profile for Morning of June 23 Near Goodsprings Fire

This association of higher ozone concentrations with wildfire smoke plumes was further demonstrated during another aircraft sounding on July 1 as the smoke was beginning to clear after the June 29 and 30 fire event (**Figure 7-20**). For this sounding, the tow aircraft was equipped with a portable light-scattering $PM_{10}$ analyzer as well as ozone monitor. The sounding clearly shows an increase in measured ozone concentrations as the aircraft encounters the remnants of the smoke plume, indicated by a corresponding increase in $PM_{10}$ concentrations.

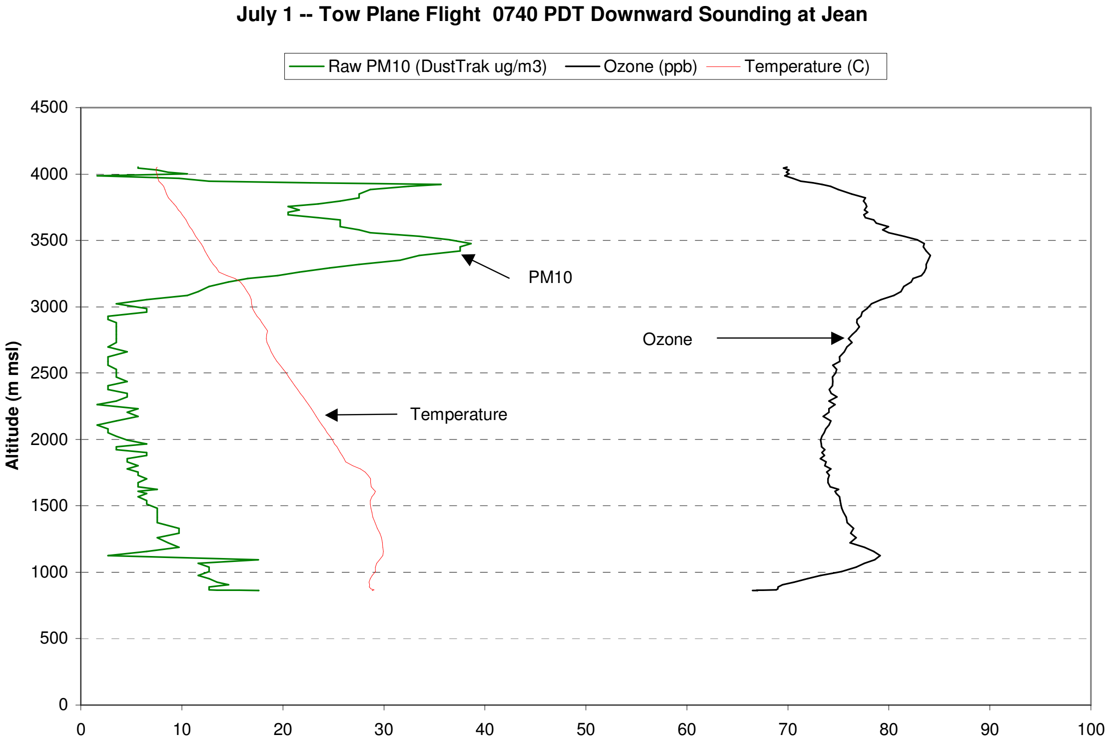


Figure 7-20. Ozone and $PM_{10}$ Profile for Morning of July 1

The above is just a cursory analysis of the CCROPS data during these wildfire events, using only one of the many measurement platforms available during these periods. Additional analysis of surface $PM_{10}$, $PM_{2.5}$, VOC and $NO_y$ concentrations may better define the extent of the smoke events and their correlation with ozone concentrations. Investigation into the source and age of the events through review of fire data and meteorology is also needed. Furthermore, based on conclusions from the Ozone Characterization Study, initial analysis of the June 29 and 30 event has indicated that these days had all of the characteristics of high ozone concentration potential, even without the smoke. Determining the extent that the smoke played in causing the record exceedances remains a critical goal in understanding ozone in Clark County.

## 7.5 Forecasting Ozone in Clark County

The forecasting protocol used during CCROPS was described in Section 4. The following summarizes our observations relating to the forecasting effort.

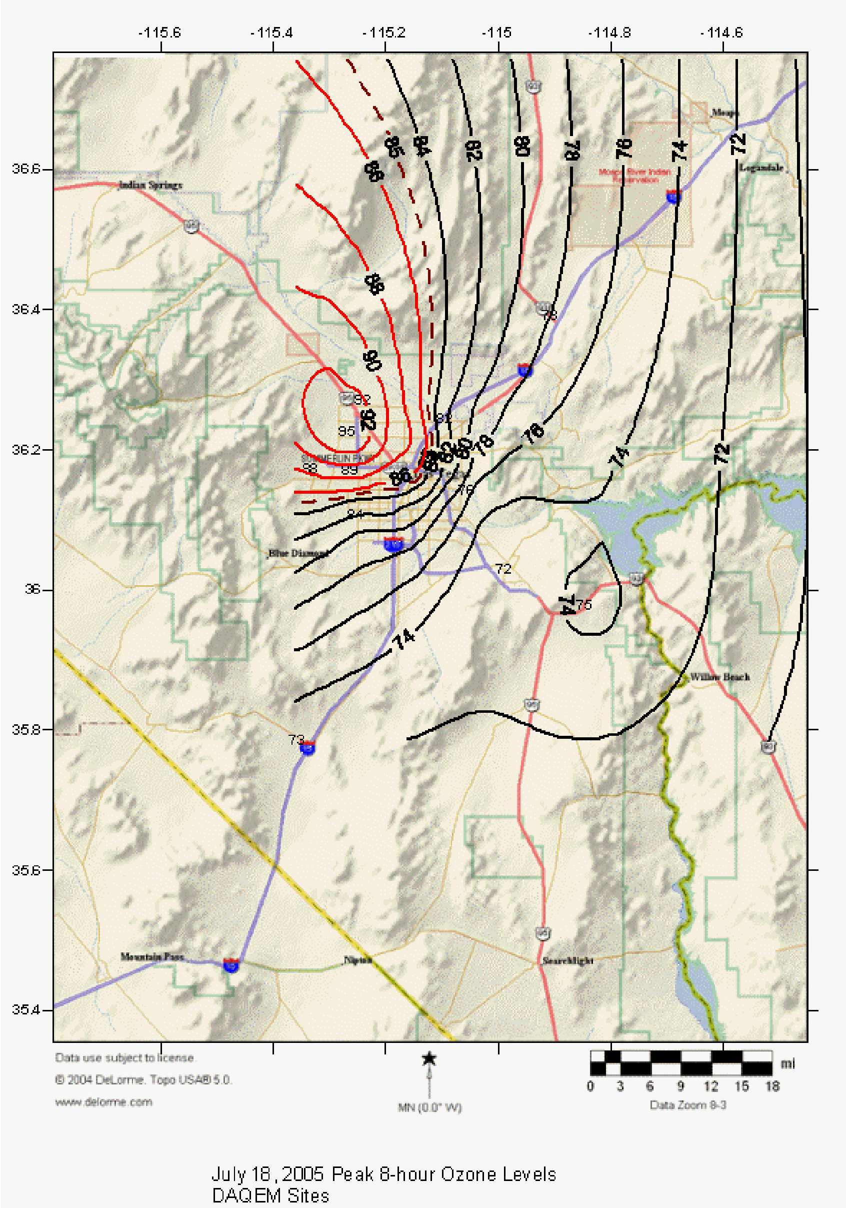
- In general, the daily operational forecast was issued in a timely fashion everyday of the project, and proved to be a critical in the determination of each day's operational monitoring strategy. Inevitable professional disagreements between forecasters were discussed until a consensus forecast was decided.
- The 2005 ozone season in southern Nevada appears to have been one of anomalies. Very few clear-cut interbasin transport events took place in the manner reported in the Ozone Characterization Study. There were also at least two unusually long "clean" periods resulting from troughing or monsoonal activity that precluded intensive

monitoring activities for extended periods. Conversely, an ozone episode took place in late June that was characterized by some of the highest concentrations ever recorded in Clark County. This event was associated with a severe wildfire smoke event that also produced high PM concentrations. Another “surprise” single day ozone event took place on a Sunday in early June that appears to be associated with weekend tourist traffic leaving of Clark County during meteorological conditions particularly conducive to the development of high ozone.

- Overall, the forecast accuracy for the project met project expectations. Intensive monitoring operations were initiated prior to the severe smoke event in late June. Only the “Sunday Surprise” on June 12 was totally missed, resulting in only routine monitoring data coverage (both the DAQEM network and the CCROPS supplemental network). In addition, the long periods when good air quality was present and even when marginally poor low ozone events occurred was recognized early enough to minimize non-productive monitoring effort.
- The general success of the specialized operational forecasting for this project indicates that the number of meteorological factors associated with ozone and non-ozone events have been sufficiently identified. Hopefully, after detailed analyses of the data collected during the field study is complete more improved forecasts will result. The short and medium range NWS forecast products for the most part proved to be accurate and reliable tools for use in generating the specialized pollution forecasts. The main problems were the result of unknown or unforeseen precursor and ozone sources (e.g. smoke events), and not having a clear understanding of the daily variations of local emissions, and their impacts on regional ozone.
- The CART models developed during the Ozone Characterization Study did a mixed job of predicting ozone exceedances. Of the eight exceedance days recorded by the DAQEM monitoring network, four of the exceedances fit the developed CART criteria. However, in most failed cases, conditions failed the criteria only by a slight amount, and refinement of the CART models will likely improve forecasting accuracy. There was also good agreement between the CART models and the forecaster regarding whether the ozone burden would be dominated by interbasin transport or local sources.

## 7.6 Adequacy of the DAQEM Ozone Measurement Network

As noted at the beginning of this section, a major goal of the study was to determine the adequacy of the DAQEM’s ozone monitoring network. There was concern regarding the current networks ability to measure the peak ozone levels occurring in the northern sectors of the study area. The CCROPS network proved worthy to address this issue as demonstrated by **Figure 7-21**. Contours on this figure were based on the DAQEM network exclusively and shows the high ozone concentration contours remaining open in the northwest portion of the Valley as there are no measurements beyond Lone Mountain-Joe Neal sites. CCROPS Supplemental sites were placed at Paiute and Indian Springs in the northwest, and at Speedway and Moapa in the northeast. **Figure 7-22** shows how these additions altered the areal ozone distribution analysis. Contours are now closed in the northwest, clearly defining the extent of the high ozone. The Paiute site repeatedly recorded some of the highest, if not the highest, readings on a given day. In addition, saturation samplers in the northern areas of North Las Vegas and the foothills along the west and northwest regions of the study area further defined the extent of the plume on several days, as shown in **Figures 7-23 and 7-24.**



July 18, 2005 Peak 8-hour Ozone Levels
DAQEM Sites

Figure 7-21. Maximum 8-hr Ozone Levels-Only DAQEM Sites

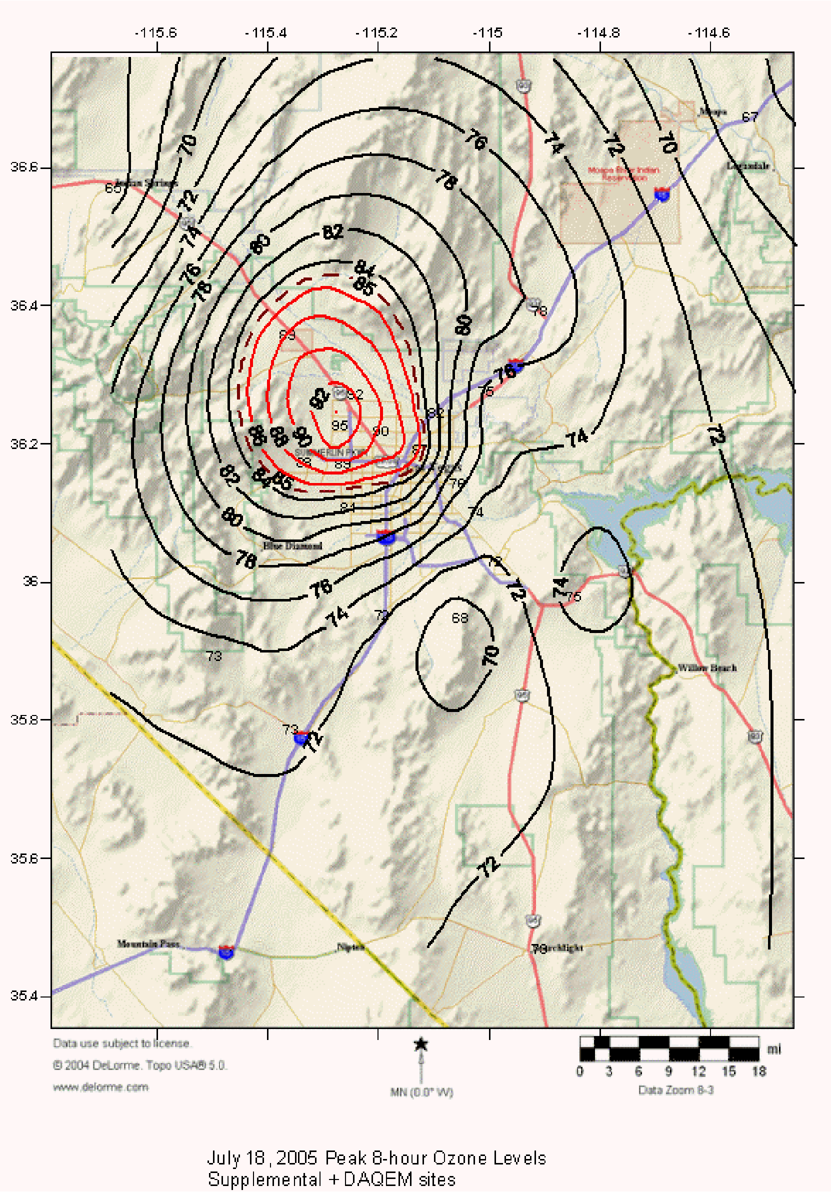
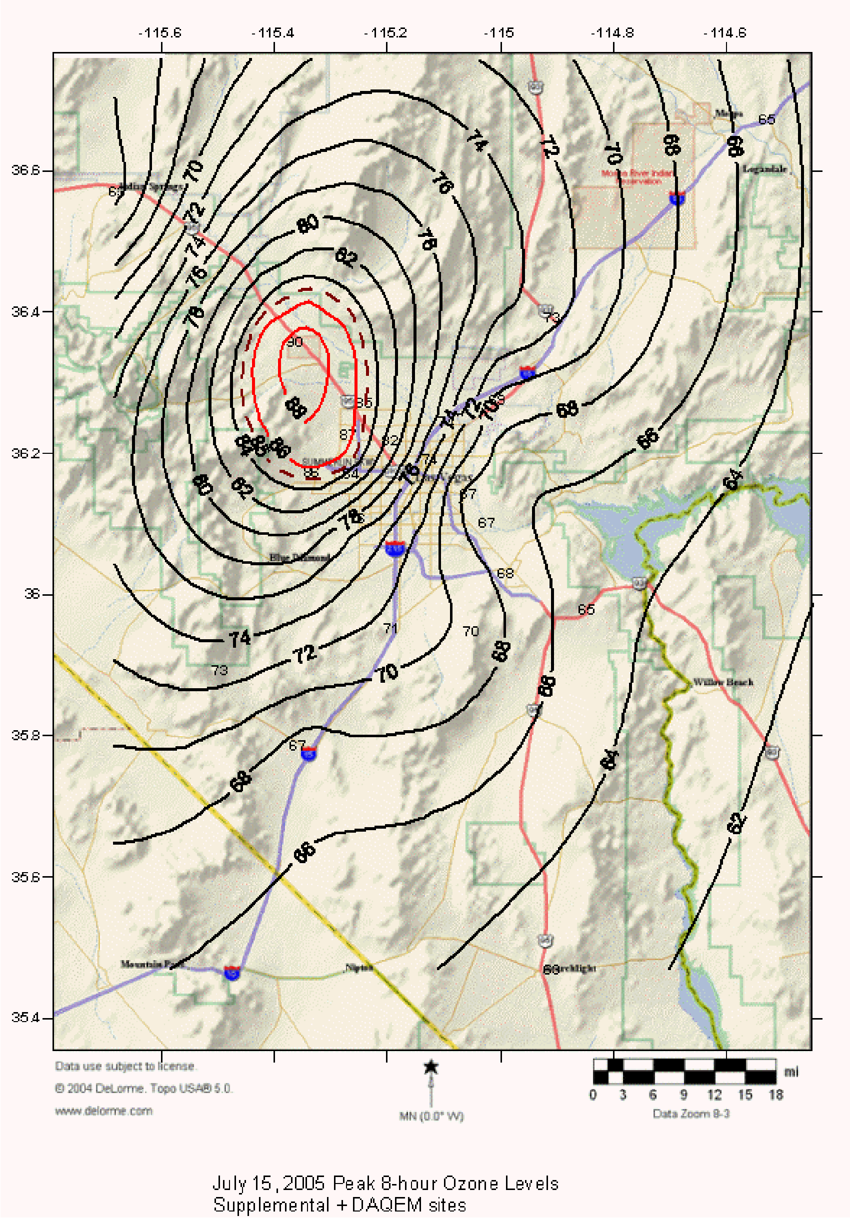


Figure 7-22. Maximum 8-hr Ozone Levels for July 18 at Both DAQEM and Supplemental Sites

**Figure 7-25** is a composite representation of all high ozone days (greater than 70 ppb) during the IOPs, when the complete CCROPS ozone network was operating, including the saturation samplers. This figure shows daily data for each site compared against the regional average of all sites. Daily differences between the peak ozone and regional average were then averaged, producing the values presented on Figure 7-25. In this manner, positive values depict areas where concentrations were typically above the regional average, and negative values depict areas of lower concentrations.

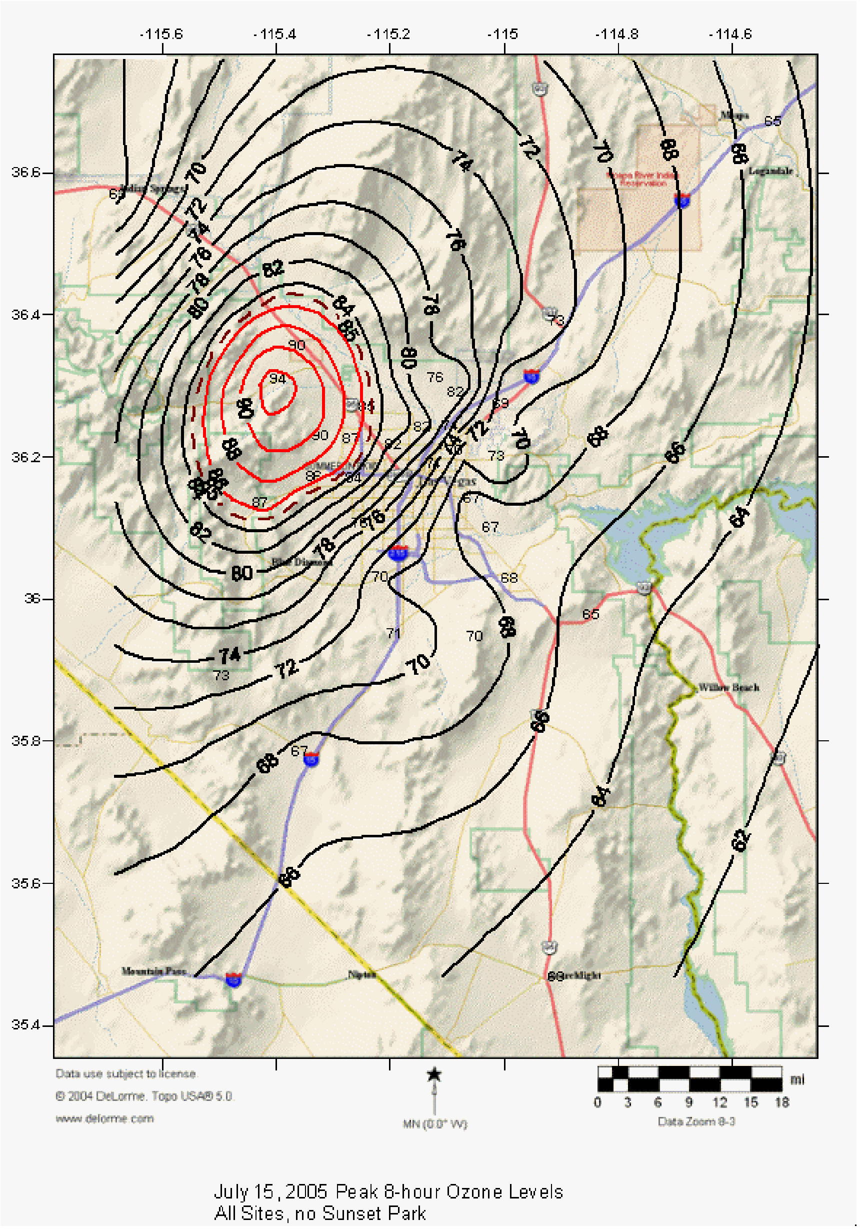
The resulting contours are consistent with much of what has been presented above. This figure once again shows the greatest ozone exposure to the northwest of Las Vegas, driven primarily by daytime upvalley and upslope winds. This plot however emphasizes to a greater extent the impact on the foothill locations in this area. In contrast, areas to the northeast of Las Vegas show only average concentrations, and the area around Searchlight is clearly upwind of the urban plume. Even without the Sunset Park data, the contours suggest the possibility of higher concentrations in the southwest portion of Las Vegas near McCarran airport. Finally, there is also some evidence of consistently higher concentrations in the area around Craig Ranch.



Data use subject to license.
© 2004 DeLorme. Topo USA® 5.0.
www.delorme.com

July 15, 2005 Peak 8-hour Ozone Levels
Supplemental + DAQEM sites

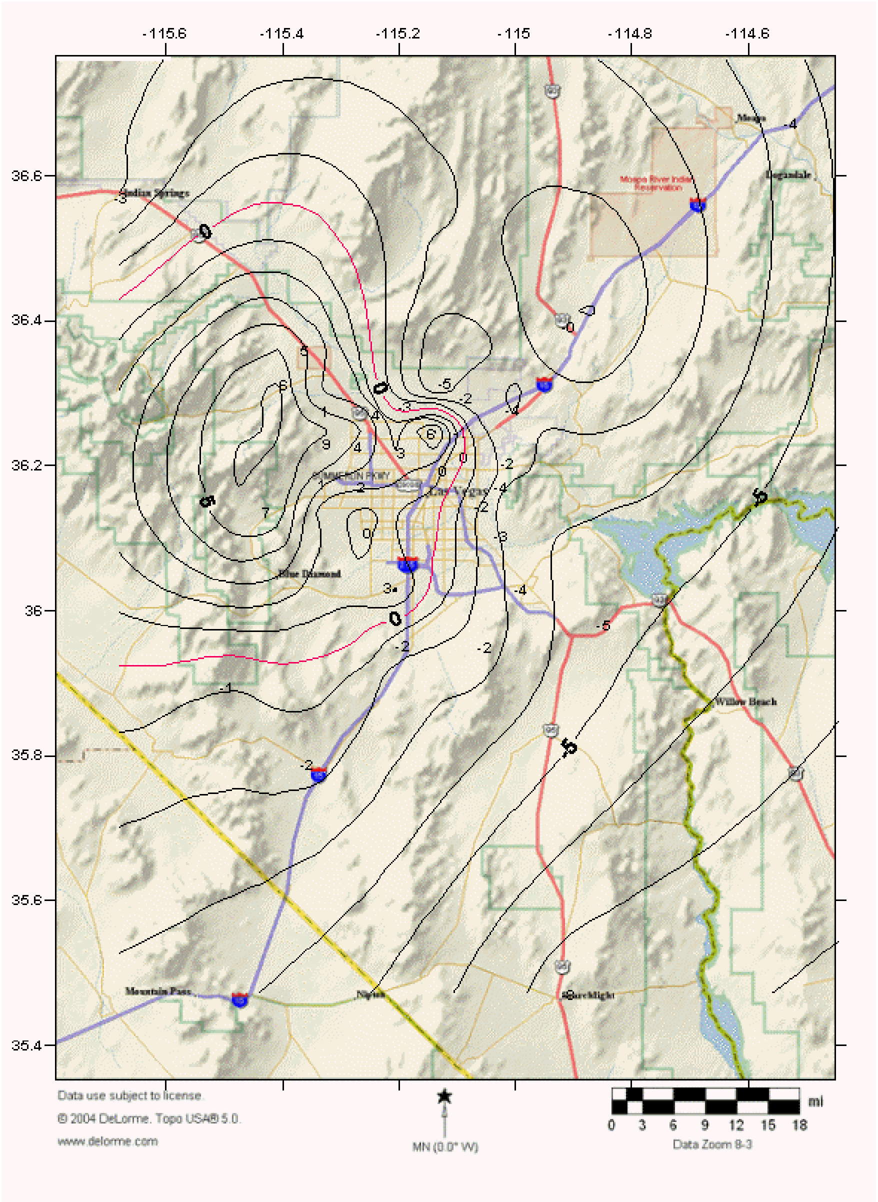
Figure 7-23. Maximum 8-hr Ozone Levels for July 15 at Both DAQEM and Supplemental Sites



Data use subject to license
© 2004 DeLorme. Topo USA® 5.0
www.delorme.com

July 15, 2005 Peak 8-hour Ozone Levels
All Sites, no Sunset Park

Figure 7-24. Maximum 8-hr Ozone Levels for July 15 at All CCROPS Sites ncluding Saturation Sites



Average difference from network 8-hr average
for days when network average >= 70 ppb, w/o Sunset Park

Figure 7-25. Composite Representation of Relative Ozone Concentration During IOPs

## Jean Site

Another objective of the network evaluation was to determine if Jean is representative of the Las Vegas Valley upwind ozone levels. Air transported between the highly urbanized southern California and southern San Joaquin Valley would have a trajectory roughly over the Goodsprings Valley where Jean is located. Our approach was to site one of the supplemental ozone and meteorological stations at Sloan, a small rural community adjacent to I-15 at the southwest edge of the Las Vegas Valley. Sloan is between both valleys, approximately 15 miles northeast from the DAQEM site at Jean. Since the prevailing winds in west Clark County are southwest and Sloan is situated in the lowest gap in the terrain that defines the west side of the Valley, it was logical that the air quality there would often be representative of the air flowing into the Valley. The site was situated on a hilltop approximately 200 m above the surrounding terrain to reduce the impact of I-15 traffic and nighttime surface deposition. As supposed, Sloan proved to be located directly in the gap where there is a major influx of air to the Las Vegas Valley. The observed winds at Sloan are depicted in the wind-rose diagram in **Figure 7-26**. As can be seen, winds are remarkably persistent from the southwest and very strong.

All indications from the 2005 measurements are that the site at Jean is situated well for measuring upwind/background under most meteorological circumstances. This is illustrated by the plot in **Figure 7-27** comparing the daily peak 8-hr ozone at Jean and Sloan. Ozone at the two sites compare as well as many collocated measurements and are within 2 percent of each other. Since there appears to be a well-defined pathway between Jean and Sloan, and ozone levels at the two sites are comparable, it follows that the ozone burden at Jean is representative of the inflow to the Las Vegas Valley.

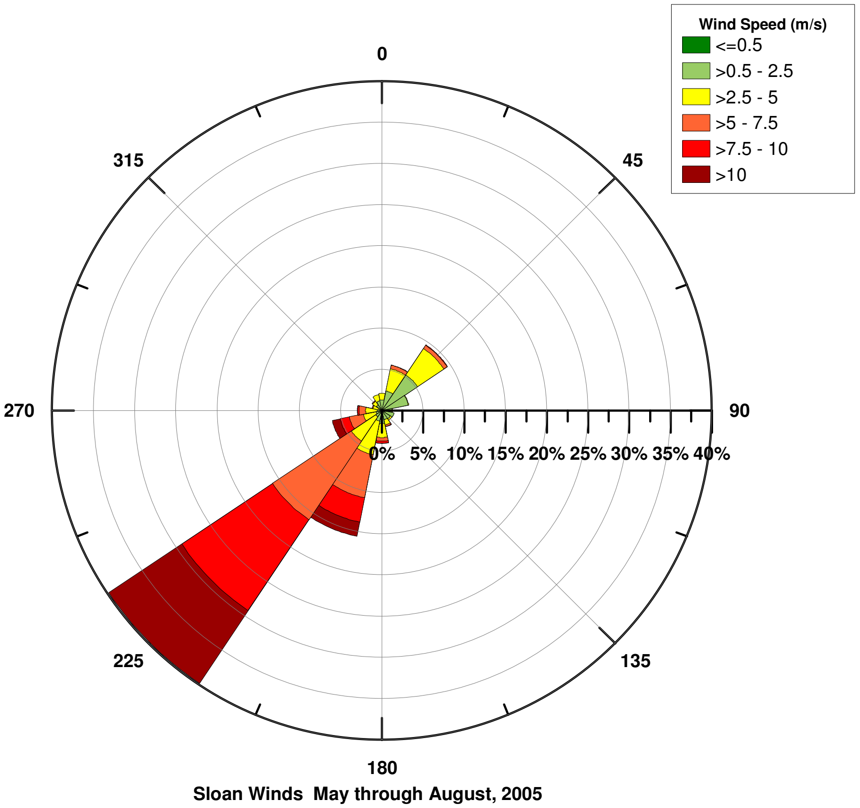


Figure 7-26. Wind Rose Diagram for Sloan

## Ridgetop Sites

One of the questions addressed during CCROPS was the usefulness of ridgetop sampling in the Las Vegas area, with the specific goal of measuring ozone aloft, particularly during the night and morning hours. **Figure 7-28** demonstrates how the differences in siting influences the diurnal variations in ozone at five sites in the Las Vegas area:

- North Las Vegas (airport). This is a typical urban site, located in the middle of the Las Vegas Valley. Temporal patterns are classic for this type of site – a strong diurnal variation consisting of high afternoon peaks and the nearly total titration of ozone at night by urban emissions, particularly NO.
- Jean. As discussed above, this is a good example of a rural background site. Lacking are the afternoon peaks associated with a downwind urban site such as North Las Vegas. Nighttime ozone concentrations remain relatively high in this rural, upwind site, though the region is likely still influence by nocturnal inversions, which typically affect the lower 1000 m or so (see **Figure 7-29** for an example).
- Paiute. This site is representative of conditions downwind of urban activities and their associated emissions and subject to the aged urban plume. This site shows the same afternoon peaks as North Las Vegas. However, the nighttime concentrations are not nearly as low as those at North Las Vegas, due to the site’s rural location, which is not impacted greatly by local emissions.

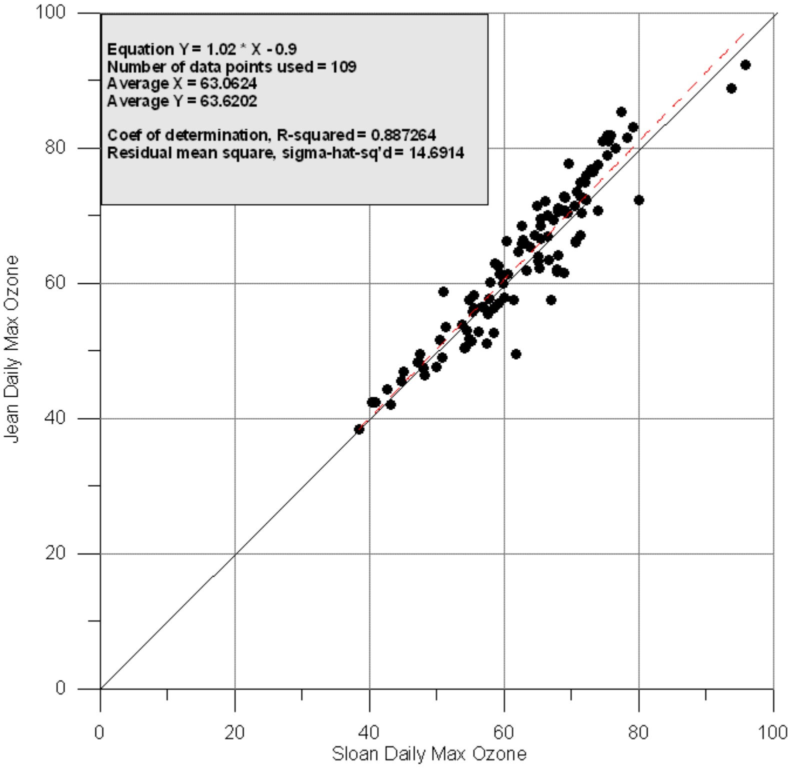


Figure 7-27. Comparison of Daily Maximum Ozone at Jean and Sloan

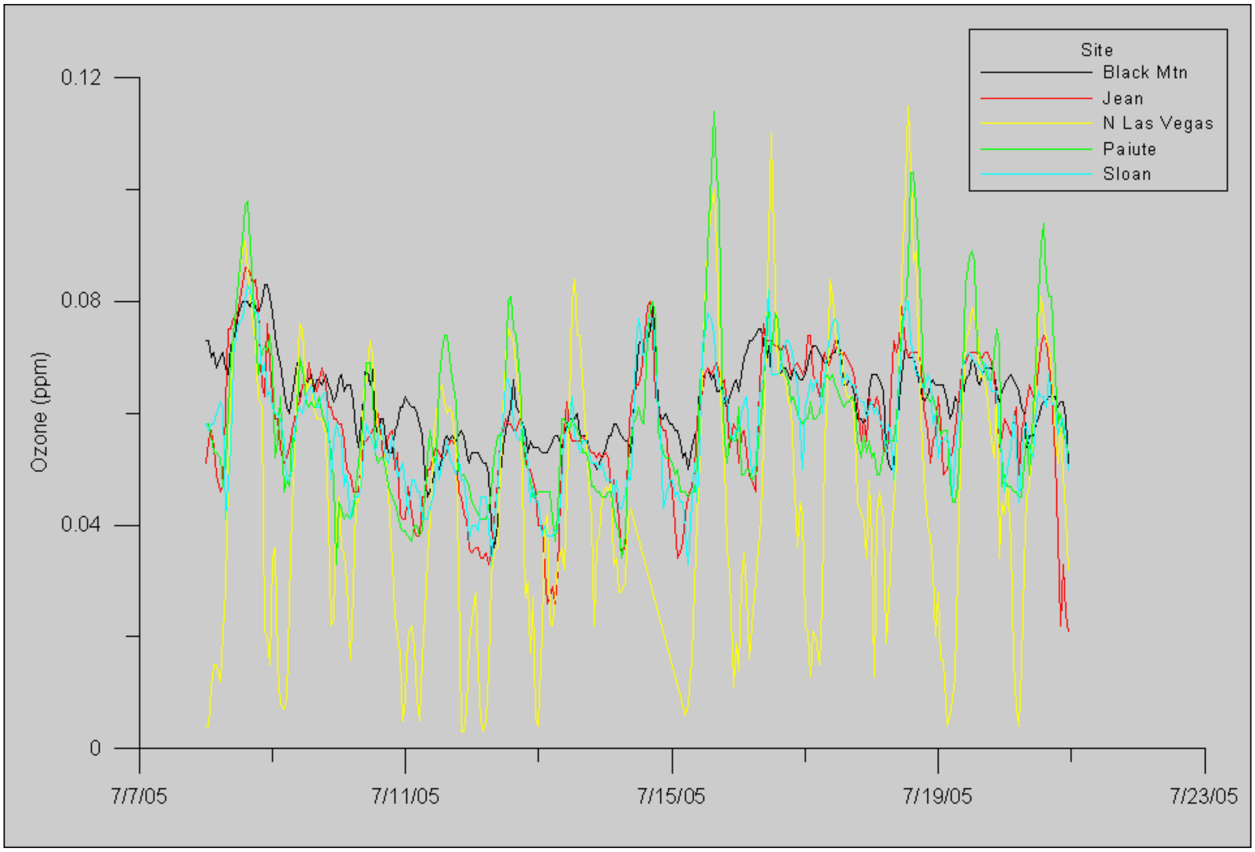


Figure 7-28.  Time-Series Plot Showing Relationship Between Ridgetop and Valley Sites

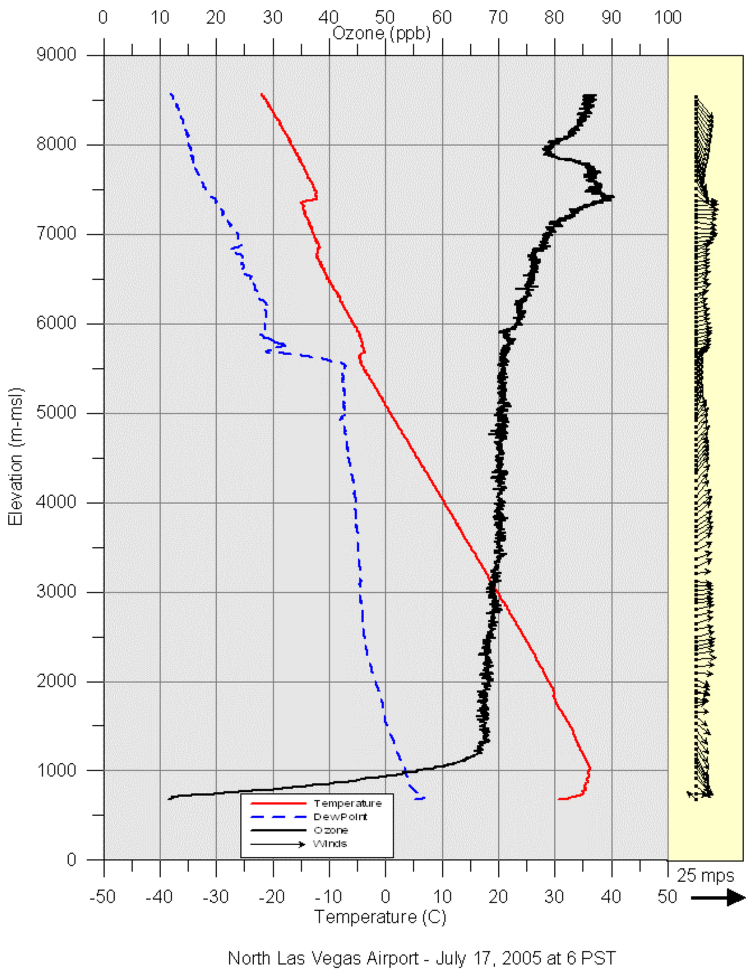


Figure 7-29. Example of Ozonesonde Data Showing Morning Inversion at 1000 m

- Sloan. The Sloan site was chosen as a location that would possibly experience relatively high nighttime concentrations due to elevated ozone layers not being subject to as much deposition and titration from surface effects. Moreover, Sloan is upwind of the Las Vegas Valley based on prevailing winds. The site is located about 200 meters above the general terrain at about 1000 meters-msl. Thus the site was likely still below the top of the nocturnal inversion, and some scavenging of ozone still occurred, similar to Jean. As noted above and in viewing Figures 7-27 and 7-28, ozone concentrations at Sloan and Jean are virtually the same.
- Black Mountain. Located above the typical top of the inversion layer at 1221 meters-msl and in a rural area, basically upwind of Las Vegas. Ozone at Black Mountain exhibits virtually no diurnal variation. Readings from this site may accurately provide a continuous record of regional background concentrations, and for the most part are unaffected by nocturnal inversions. Figure 7-28 shows several instances during the night when readings from Black Mountain are significantly higher than those from the valley floor sites under the inversion. These readings represent potential ozone that can be entrained to the surface during daytime convective mixing.

Ozonesondes were employed during the episode-mode monitoring periods of CCROPS. A possible alternative to expensive ozonesondes for determining ozone concentrations aloft is to maintain a ridgetop monitor such as the one at Black Mountain. **Figure 7-30** is a time series plot covering the period of the July IOP, during which several ozonesondes were released. Time-series plots of surface ozone concentrations from North Las Vegas, Black Mountain, and Lower Potosi are shown. Superimposed on these plots are readings from the ozonesonde measurements corresponding to each site's elevation. Note that North Las Vegas Airport was situated at 681 m-mls, Black Mountain at 1221 m-msl and Lower Potosi at 1885m-msl. The figure shows in general very good agreement between the ozonesonde data and the continuous analyzers, and is particularly good at representing ozone concentrations aloft during the morning hours.

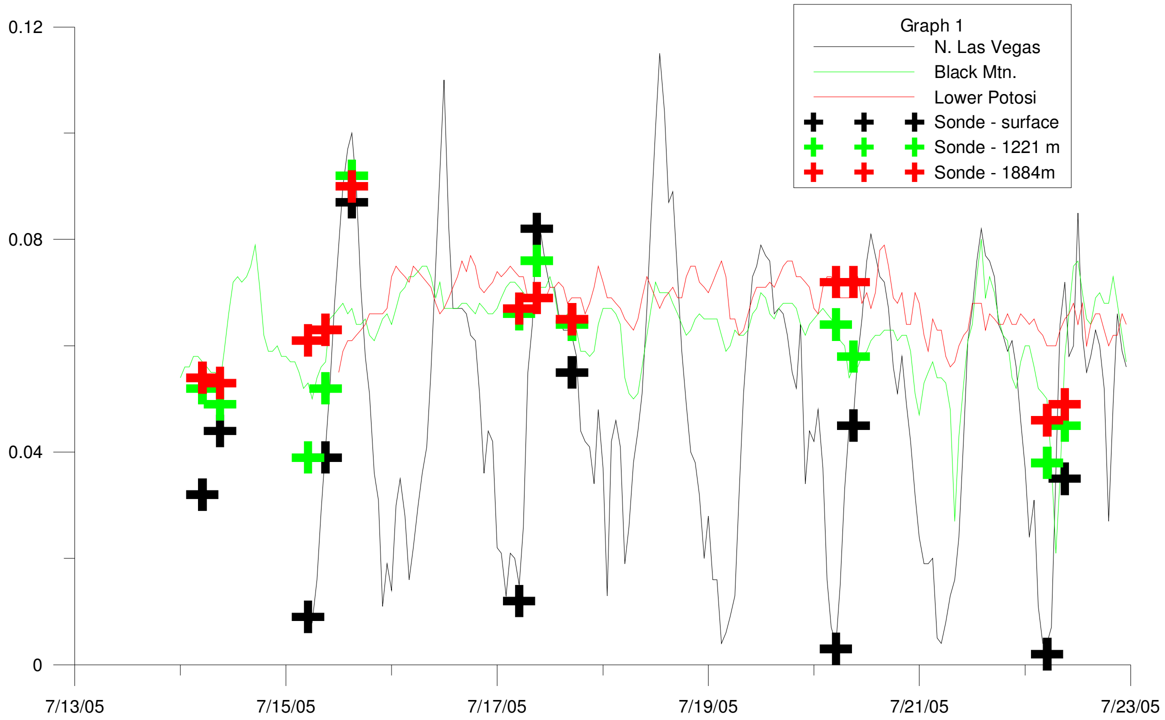


Figure 7-30. Ozone at Ridgetop Sites Compared with NLV Ozonesonde

## Conclusions

Based on the above, the following changes are recommended to the monitoring network:

- The Ozone Characterization Study revealed that ozone data from City Center was being impacted by emissions from a major freeway. This was supported by the 2005 field study measurements. Indeed, the site does not currently meet EPA siting criteria for ozone due to its proximity to the freeway. No data from City Center were used for any of the above analysis, as they appears to be not representative of regional ozone concentrations, with unrepresentatively low daytime readings due to titration by NO from vehicles on the freeway. For these reasons, it is recommended that ozone monitoring be terminated at City Center. Data from the nearby JD Smith site appear to adequately represent this area.

- A permanent site at Paiute should be installed to ensure that peak ozone exposure in Clark County is measured.
- A permanent site at Indian Springs should be installed to further define the northwest extent of high ozone levels. Moreover, as growth and development continues to expand in the Valley, the ozone peak could conceivably shift further northwest.
- A temporary monitoring site at Sunset Park should be operated during the upcoming ozone season to further investigate the possibility of high ozone concentrations in that area.

In addition, the following monitoring should be considered:

- An additional ozone site in the foothills to the northwest of Las Vegas. The saturation network showed the urban ozone plume extending well into the foothill region. While the Lone Mountain site does a fairly good job of representing the area, an additional site may be warranted, especially as the area demographics changes. For example, housing developments are already extending to the Red Rock Canyon boundary. Kyle Canyon development and regions between will likely follow.
- Additional monitoring in the Craig Ranch area for similar reasons. Temporary monitoring should initially be considered to confirm the results obtained by the saturation network.
- To determine the importance of ozone aloft at night and early morning, for daily ozone forecasts, monitoring could be conducted at one of the two CCROPS ridgetop sites. Based on preliminary analyses, both the Black Mountain and Lower Potosi sites did a good job of producing measurements representative of ozone concentrations aloft. However, the Black Mountain site is considerably closer to the DAQEM office, and therefore easier to service.

## 7.7 Ozone Precursor Measurements

An integral part of the 2005 study was to measure ambient concentrations ozone precursors including volatile organic compounds (VOC) and oxides of nitrogen ($NO_y$). CE-CERT installed and operated $NO_y$ measurements at two of the existing DAQEM sites for the duration of the 2005 field study. DRI established three VOC automated canister sampling sites that operated during episode-mode operations. Descriptions of the resulting measurements are given in this section.

### 7.7.1 $NO_y$

$NO_y$ monitoring was conducted at two DAQEM sites. One was the JD Smith site in North Las Vegas. This site is impacted by emissions from the downtown portions of Las Vegas. The other site was Joe Neal which is generally downwind of the majority of pollution sources. Peak ozone levels in the Las Vegas Valley are often at or near the Joe Neal site.

Some general observations regarding the measurements follow:

## Joe Neal Site

**Table 7-4** shows the average concentrations for the nitrogenous species that were measured. PAN was not included since most of the values were below the 1 ppb detection limit. Nitric acid was also not included since it may be calculated from the differences between $NO_y$ and $NO_y$- and since nitric acid was observed above the detection limit typically for a few hours in the afternoon, its contribution averaged over the day was small, typically a ppb, in comparison to the $NO_y$. At this site, which is not near local sources, the majority of the $NO_y$ consists of $NO_2$.

**Figure 7-31** shows the concentrations of nitric acid plotted as two-minute averages for the month of August. Peak concentrations of 1-6 ppb are clearly observed each day in the afternoon. The plot shows some scatter because nitric acid is measured as a difference in concentration from samples that are slightly different in time; rapidly changing concentrations can therefore lead to sporadically high or low values. **Figure 7-32** shows the diurnal concentrations of nitric acid and ozone during the highest episode on August 12th. Both the nitric acid and ozone concentrations reach peak values near 13:00 hours PDT and a second higher peak at 16:00 hours. This is indicative of transport of these secondary pollutants from a source area.

**Figure 7-33** is a graph of the $NO_2$ determined by the gas chromatograph (GC) compared with the $NO_2$ measured by the NO-$NO_x$ chemiluminescent (CL) analyzer operated in the standard configuration by the Clark County Department of Air Quality and Environmental Management for the month of August. The overall trend line gives a slope of 0.86 indicating that the CL values are lower than GC, an unexpected result since the CL method should include other nitrogenous species as interferents. The plot shows, however, a divergence into two distinct lines at higher concentrations. The one with the higher slope is likely more indicative of aged photochemical nitrogenous species resulting in higher values for CL compared to GC.

## JD Smith Site

Table 7-4 shows that the mean concentrations of nitrogenous species at the JD Smith site are significantly higher than those at the Joe Neal Site. The $NO_y$ and $NO_y$- are nearly identical. On average, approximately half of the $NO_y$ is $NO_2$, a much smaller ratio than that found at the Joe Neal Site. This behavior is typical of a source-dominated site.

**Figure 7-34** shows the concentrations of nitric acid plotted as two-minute averages for the month of August. Peak concentrations of nitric acid of 1-3 ppb are clearly observed each day in the afternoon. These are about half of that observed at the Joe Neal site, although, like at Joe Neal, the peak for the month is also on August 12th. **Figure 7-35** shows the diurnal concentrations of nitric acid and ozone during the highest episode on August 12th. Both the nitric acid and ozone concentrations reach peak values near 13 PDT and a second higher peak just before 16 PDT. This plot is very similar to that of the Joe Neal site, but the concentrations are approximately half as high. Although this is a source dominated site, this behavior is indicative of transport of these secondary pollutants from a source area.

**Figure 7-36** is a graph of the $NO_2$ determined by the gas chromatograph (GC) compared with the $NO_2$ measured by the NO-$NO_x$ chemiluminescent (CL) analyzer operated in the standard configuration by the Clark County Department of Air Quality and Environmental Management for the month of August. The overall trend line gives a slope of 0.97 indicating little difference between the two measurement methods at this site. The plot does not show the divergence observed at the Joe Neal site.

Table 7-4. Mean Concentrations of Nitrogenous Species in 2005 at Joe Neal and JD Smith Air Quality Monitoring Sites

| | NOy | NOy- | GCNO2 |
|---|---|---|---|
| **Joe Neal** | | | |
| June | 12.6 | 11.6 | 10.5 |
| July | 12.7 | 11.1 | 13.7 |
| August | 10.8 | 9.7 | 9.3 |
| | | | |
| **JD Smith** | | | |
| June | 33.3 | 33.1 | 13.3 |
| July | 38.9 | 38.8 | 19.9 |
| August | 33.5 | 33.5 | 16.5 |

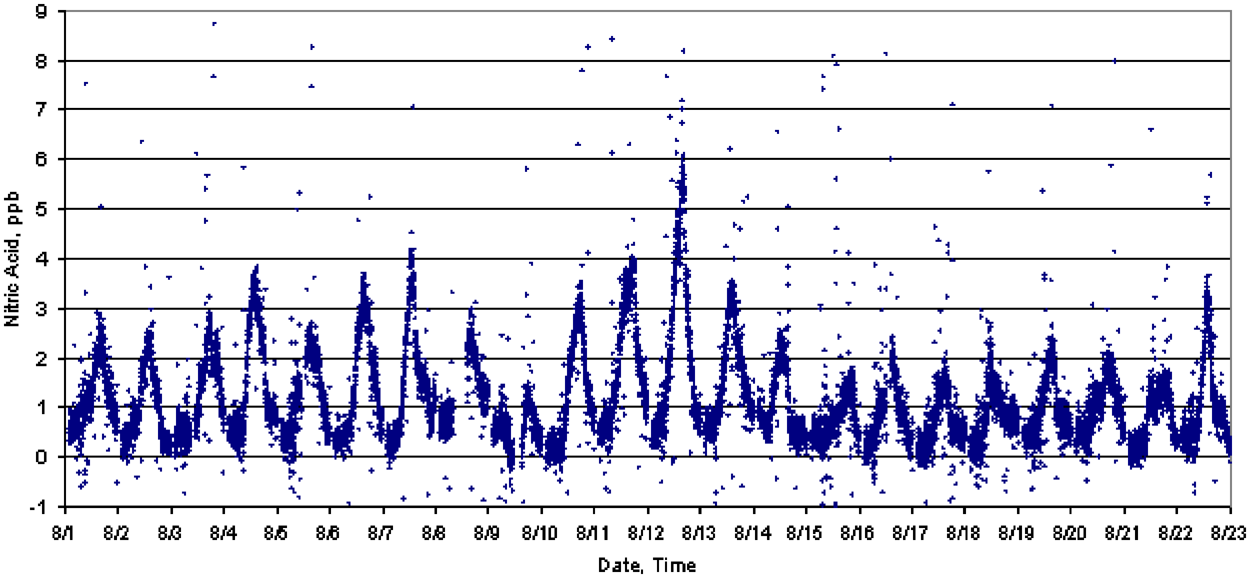


Figure 7-31. Plot of Nitric Acid for August 2005 at Joe Neal Site

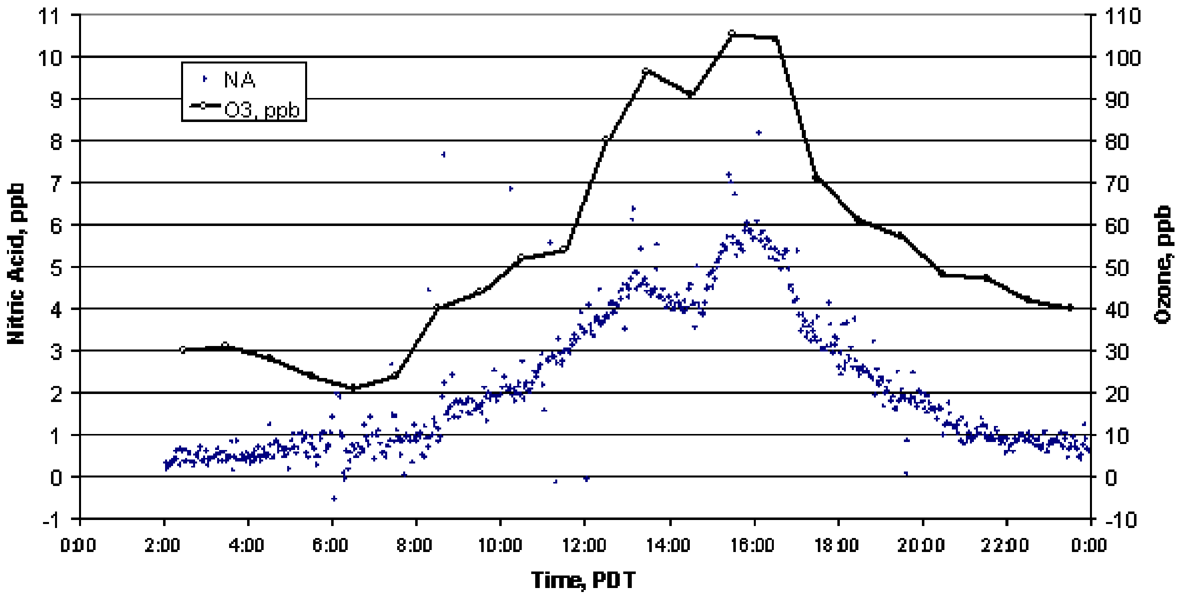


Figure 7-32. Plot of Nitric Acid and Ozone for August 12, 2005 at Joe Neal Site

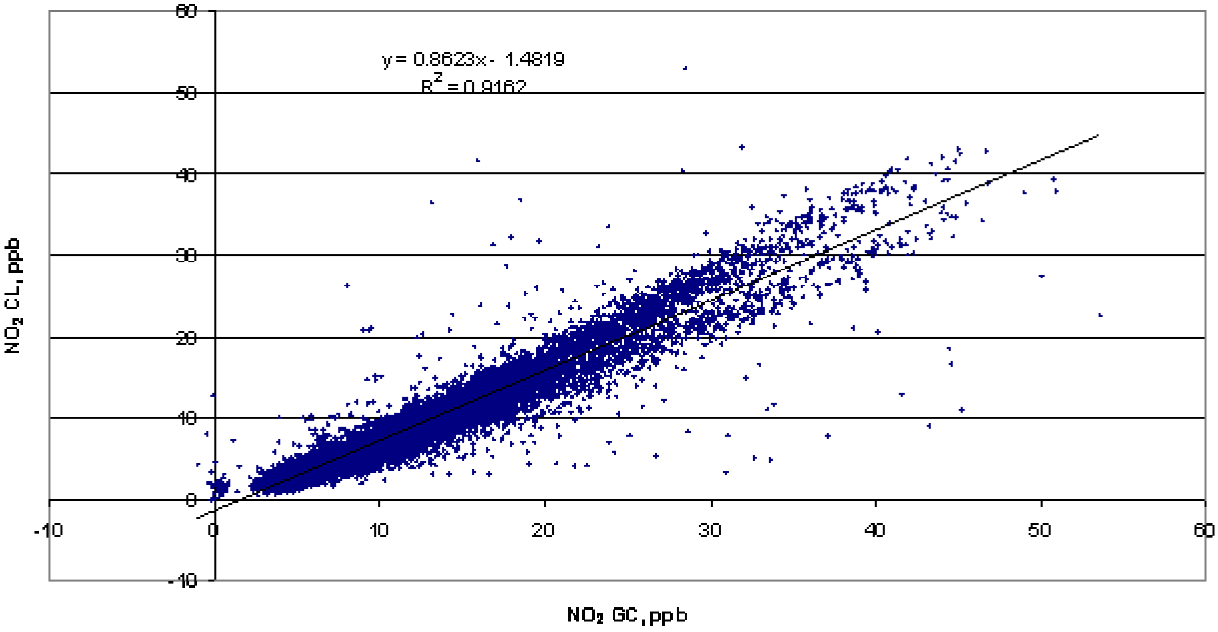


Figure 7-33. Comparison of $NO_2$ Determined by Chemiluminescence (CL) and Gas Chromatography (GC) at Joe Neal Site in August 2005

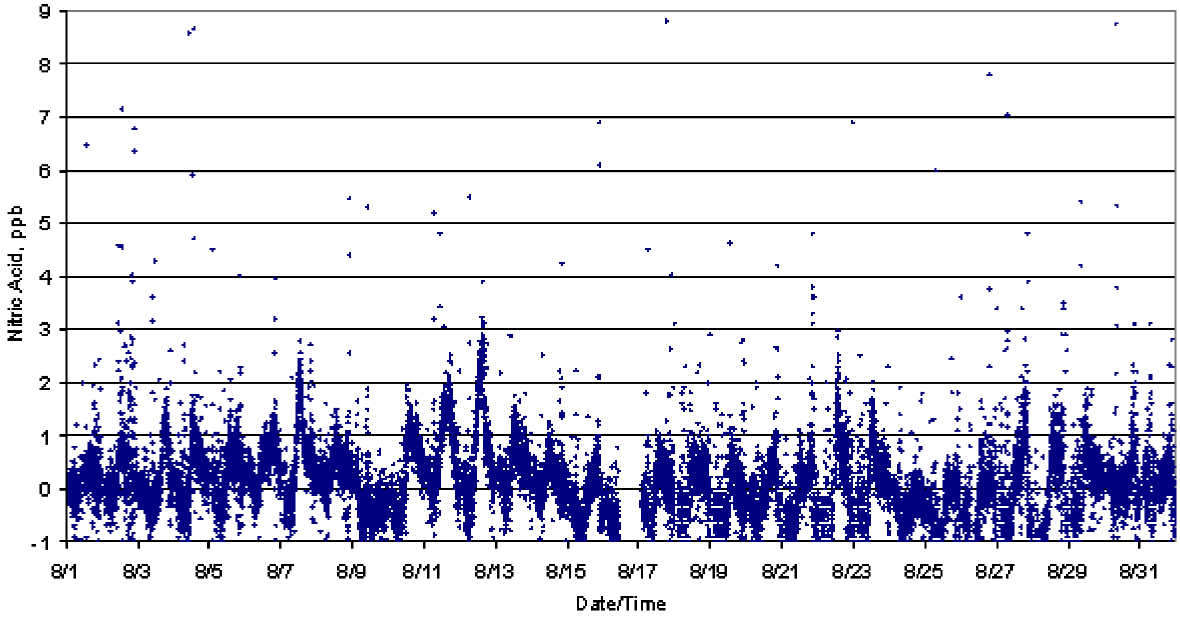


Figure 7-34. Plot of Nitric Acid for August 2005 at JD Smith Site

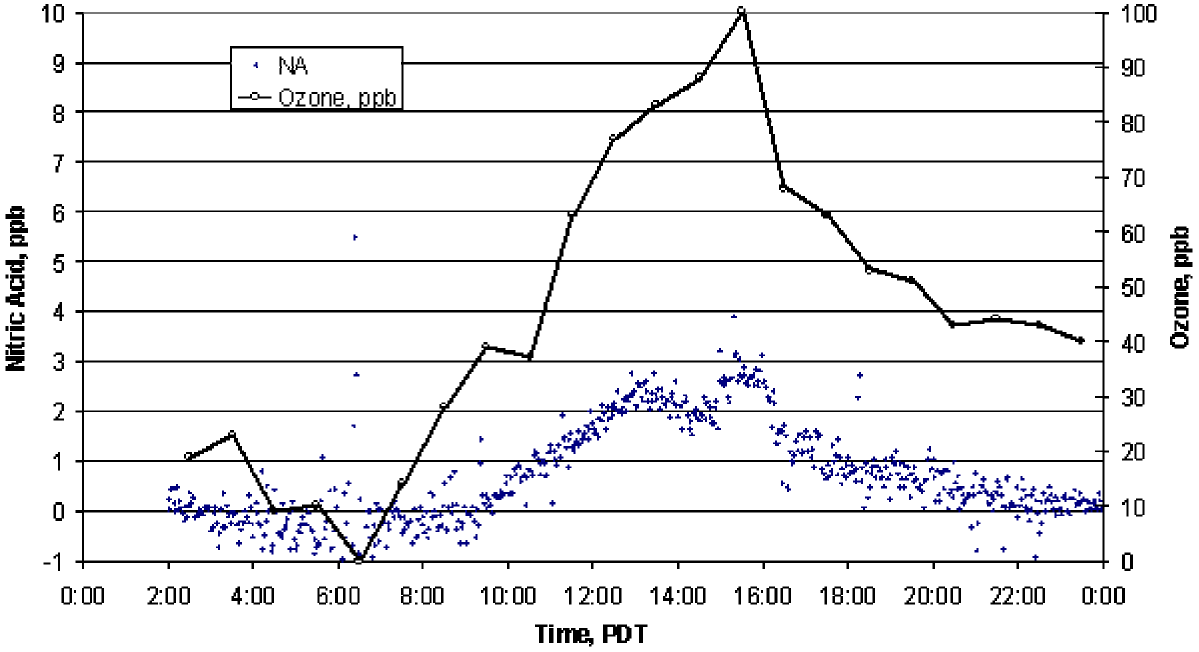


Figure 7-35. Plot of Nitric Acid and Ozone for August 12, 2005 at JD Smith Site

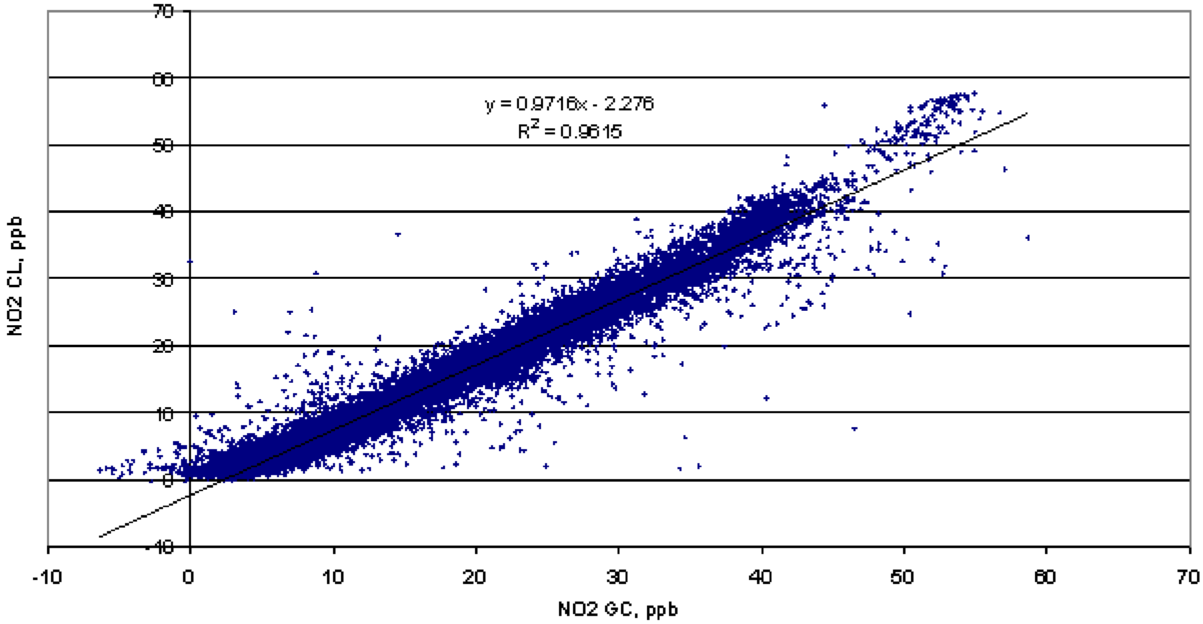


Figure 7-36. Comparison of $NO_2$ Determined by Chemiluminescence (CL) and Gas Chromatography (GC) at JD Smith Site in August 2005

The results show that nitric acid can be measured at both source and receptor sites in the Clark County metropolitan area. Typical concentrations are a few ppb in the afternoon, peaking concurrently with the ozone concentrations. Concentrations of nitric acid at the receptor site were typically twice those of the source-dominated site despite higher $NO_y$ concentrations at the latter. At both site the contribution to the monthly mean $NO_y$ was a ppb or less. Despite the potential positive interference of measuring $NO_2$ with chemiluminescent analyzers, there was little difference between measurements made using this technique and those made with high specificity using a gas chromatograph with luminol detection. During the entire study period PAN concentrations were all below the 1 ppb detection limit of the luminol-based gas chromatograph.

### 7.7.2 VOC Measurements

The Desert Research Institute (DRI) provided ambient VOC sampling and associated laboratory analytical support for the Clark County Department of Air Quality Management as part of their Clark County Regional Ozone and Precursor Study. The specific objective was to provide ambient concentrations for speciated non-methane organic compounds (in the $C_2$-$C_{11}$ range).

Ozone is produced by the photolysis of nitrogen dioxide ($NO_2$). The oxidation of volatile organic compounds is important for ozone production because peroxy radicals ($RO_2$) are produced that react with nitric oxide (NO) to convert it to $NO_2$. The photolysis of $NO_2$ also replenishes NO.

$$NO + RO_2 \rightarrow NO_2 + \text{prod} \qquad (1)$$
$$NO_2 + h\nu \rightarrow O_3 + NO \qquad (2)$$

Each organic compound makes a different contribution to the formation of ozone is because each compound has its own oxidation mechanism. One measure of an organic compound's ozone forming potential of is incremental reactivity (IR).

$$IR = \Delta[O_3] / \Delta[VOC] \qquad (3)$$

Incremental reactivates are somewhat scenario dependent and they are reported at specific $VOC/NO_x$ ratios. Incremental reactivity is typically reported as Maximum Incremental Reactivity (MIR) or Maximum Ozone Incremental Reactivity (MOIR). MIR is the incremental reactivity of a specific VOC at the $VOC/NO_x$ ratio that maximizes the aggregate incremental reactivity for a particular scenario. MOIR is the VOC reactivity of a specific at a $VOC/NO_x$ ratio that maximizes ozone formation for a particular scenario.

It is very possible that high mixing ratios of ozone are transported to Clark County from southern California. The level of VOC precursors that may also be transported are unknown and these concentrations are required to set boundary conditions for air quality modeling.

The sampling schedules for each of the three sites targeted for VOC monitoring are listed in **Table 7-5.**

Table 7-5. Sampling Schedule for Canisters at JD Smith, Joe Neal and Jean, NV

| Date | Time (PDT) | Site | | |
|---|---|---|---|---|
| | | Jean | JD Smith | Joe Neal |
| 5/24/2005 | 0000-0300 | 1 | 2 | 2 |
| | 0600-0900 | 1 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 5/27/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 1 | 2 | 2 |
| | 1300-1600 | | 1 | |
| | 1700-2000 | | 1 | 1 |
| 5/28/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 0 | 1 | 1 |
| | 1300-1600 | | 2 | 2 |
| | 1700-2000 | | 1 | 1 |
| 6/22/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 1 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 2 | 2 |
| 6/23/2005 | 0000-0300 | 2 | 1 | 1 |
| | 0600-0900 | 1 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 6/24/2005 | 0000-0300 | 1 | 2 | 2 |
| | 0600-0900 | 2 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 7/1/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 1 | 2 | 2 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 7/2/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 1 | 1 | 1 |
| | 1300-1600 | | 2 | 2 |
| | 1700-2000 | | 0 | 1 |
| 7/14/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 2 | 2 | 2 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 7/15/2005 | 0000-0300 | 2 | 1 | 1 |
| | 0600-0900 | 1 | 1 | 1 |
| | 1300-1600 | | 2 | 2 |
| | 1700-2000 | | 1 | 1 |
| 7/17/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 2 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 2 | 2 |
| 7/20/2005 | 0000-0300 | 2 | 1 | 2 |
| | 0600-0900 | 1 | 2 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 8/22/2005 | 0000-0300 | 1 | 1 | 2 |
| | 0600-0900 | 2 | 2 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |
| 8/27/2005 | 0000-0300 | 1 | 1 | 1 |
| | 0600-0900 | 2 | 1 | 2 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 2 | 1 |
| 8/28/2005 | 0000-0300 | 1 | 2 | 1 |
| | 0600-0900 | 2 | 1 | 1 |
| | 1300-1600 | | 1 | 1 |
| | 1700-2000 | | 1 | 1 |

At the JD Smith site, the canister for 7/2/2005 at 1700 hours was a void sample due to equipment failure. Collocated samples were not collected at Joe Neal on 6/23/2005, at JD Smith on 6/23/2005, and at Jean for 5/24-6/23/2005 and at Jean for 7/1-2/2005 due to equipment failures. The canister for Jean on 5/28/2005 at 0600-0900 hours was returned to DRI in Reno unopened. A collocated sample for Joe Neal on 8/28/2005 at 0600 hours was not collected because the canister remained unopened during the sampling period.

### Data trends and analysis – anthropogenic emissions

One method of determining an air parcel's relative age is to look at the toluene to propane ratio. Toluene has a lifetime (with respect to oxidation by hydroxyl radical) of 1.9 days, while propane has a lifetime of 10 days. Therefore, the ratio of toluene to propane will decrease as the age of the air parcel increases. For this study, Jean, Nevada was used for an upwind site to determine the relative importance of transport of ozone precursors to Clark County area, while JD Smith was the urban site and Joe Neal the downwind location for measurement of volatile organic compounds. **Figure 7-37** shows the toluene to propane ratio versus the date and time of sample collection for the duration of the project. In this figure, the ratio at the Jean, Nevada site are generally lower than the other two sites, indicating that Jean is exposed to few fresh emissions of VOCs as compared to the other two sites, indicating that Jean, Nevada was an appropriate site for upwind sampling.

### Data trends and analysis – biogenic emissions

**Figures 7-38 through 7-40** show the concentrations of isoprene and alpha-pinene at all three sites, JD Smith, Joe Neal and Jean, respectively, during the entire sampling period. Concentrations of alpha-pinene did not exceed 0.35 ppbC at the Jean, Nevada site, while they reached as high as 4.83 ppbC at JD Smith and 1.77 ppbC at Joe Neal. Concentrations of isoprene at Jean, Nevada peaked at 0.49 ppbC, which concentrations reached as high as 2.01 ppbC at JD Smith and 2.60 ppbC at Joe Neal. With a lifetime with respect to oxidation by reaction hydroxyl radical of 3.4 hours for alpha-pinene and 1.8 hours for isoprene, Jean, Nevada is a suitable background site biogenic emissions.

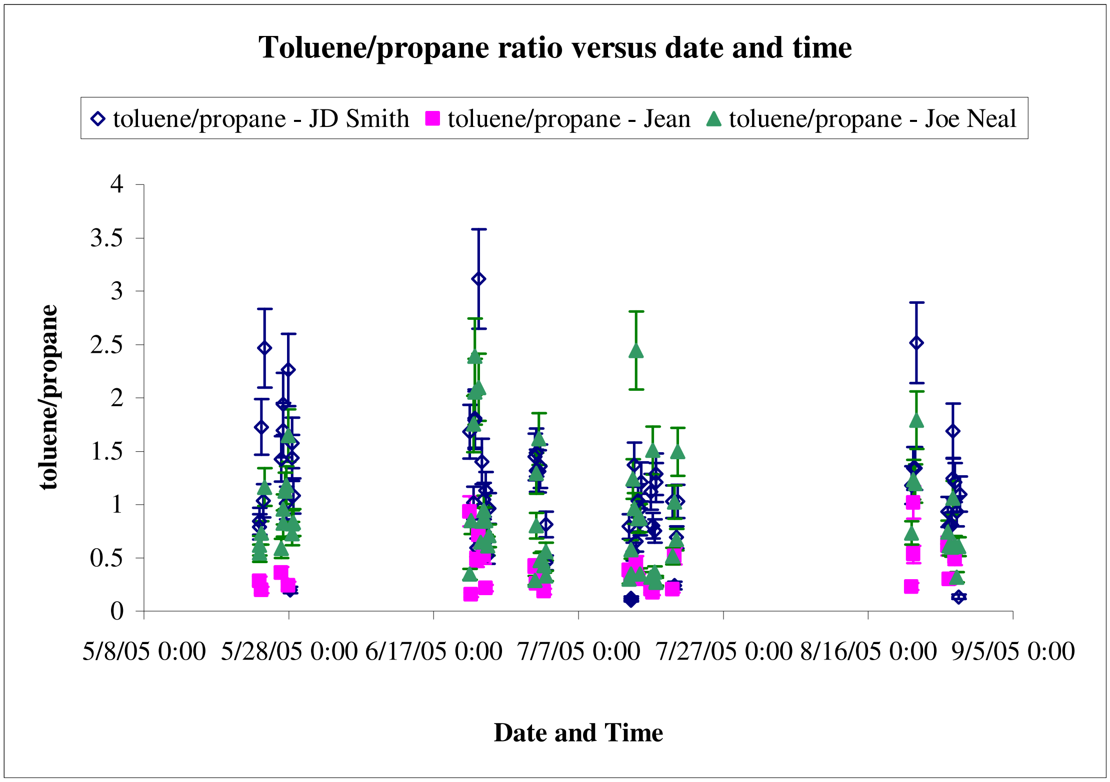


Figure 7-37. Toluene to Propane Ratios Versus Data and Time of Sample Collection

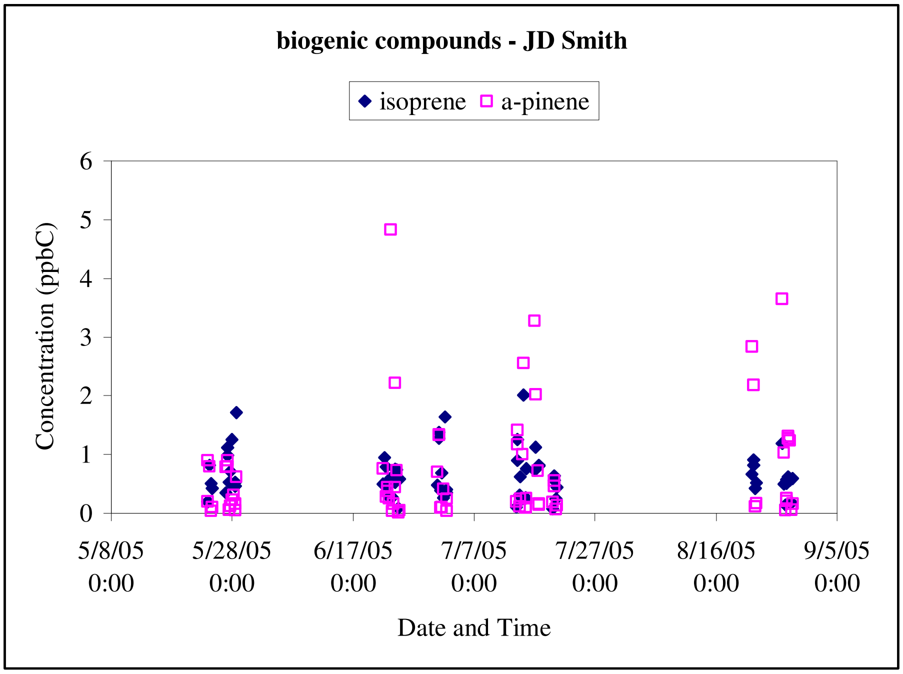


Figure 38. Concentrations of Isoprene and Alpha-Pinene at JD Smith

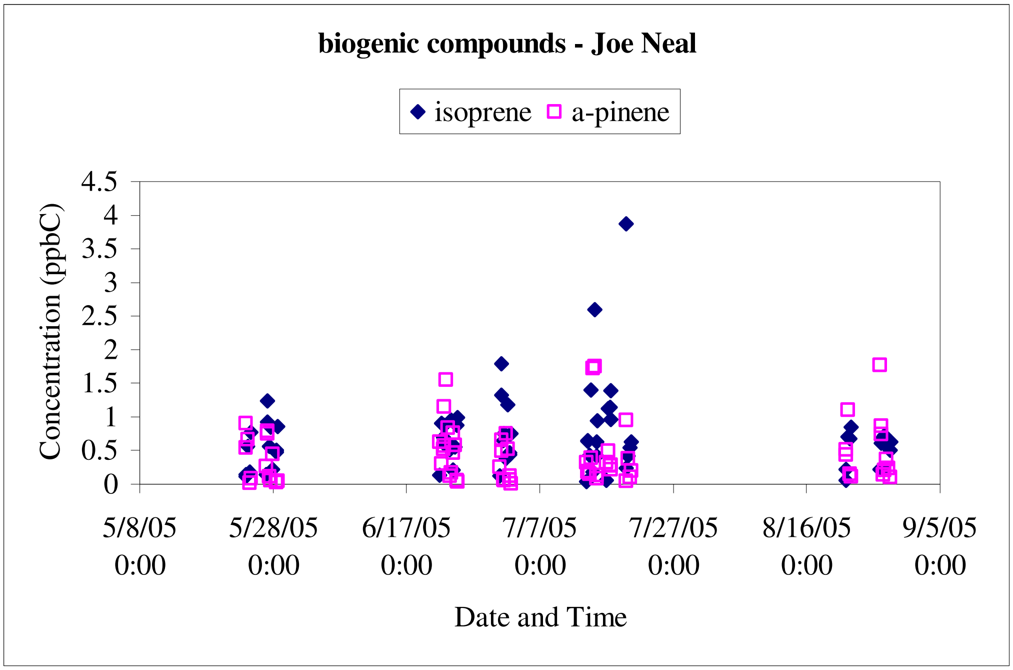


Figure 39. Concentrations of Isoprene and Alpha-Pinene at Joe Neal

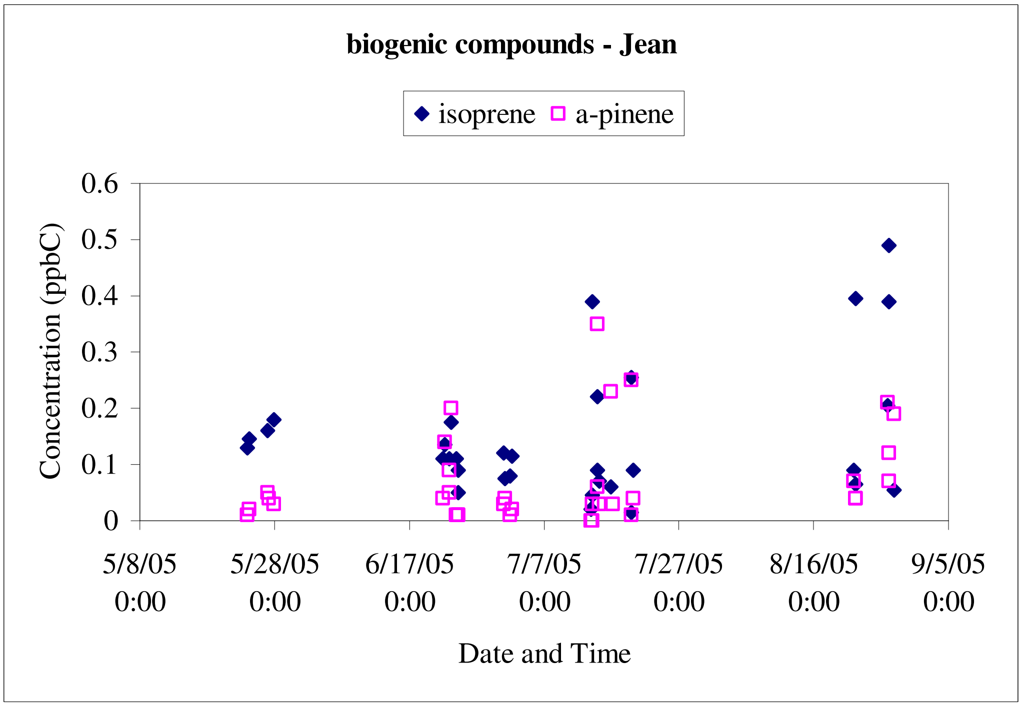


Figure 40. Concentrations of Isoprene and Alpha-Pinene at Jean

## VOC-LIMITED AND $NO_X$-LIMITED REGIMES

The optimum ratio of VOC to $NO_x$ ($NO_x = NO + NO_2$) for the formation of ozone is between 6:1 and 9:1. At ratios higher than 9:1, less ozone will be formed because less $NO_x$ is available for the reaction (ozone formation is $NO_x$-limited). Similarly, conditions where VOC to $NO_x$ ratios are less than 6:1 are characterized as VOC-limited (http://www.bayareamonitor.org/may00/air3.html). This use of the VOC to $NO_x$ ratio as an indicator of the ozone formation potential does not necessarily reflect observed ozone mixing ratios because it does not take transport into account, so caution must be used. Also, because VOCs were measured by mass spectrometry, one must assume that the species measured for this project constitute the majority of the VOCs present in the atmosphere and therefore it is possible that the VOC/$NO_x$ ratios are underestimated.

At the Jean, NV site $NO_x$ concentrations were at the detection limit of the instrument, so a meaningful analysis of the VOC/$NO_x$ ratio is not possible.

### JD Smith

NO and $NO_2$ concentrations were monitored at this site by Clark County DAQEM. While the instrument measuring $NO_2$ included $HNO_3$, giving the data a positive bias, the contribution of $HNO_3$ is deemed insignificant as it was determined that $HNO_3$ concentrations to be no more than 1 ppb during the entire field study period. **Figure 7-41** illustrates the VOC to $NO_x$ ratio for the month of May 2005, for which the majority of data points lie in the VOC-limited regime.

**Figure 7-42** shows the same data for the month of June 2005. For this month, three points lie in the $NO_x$ limited regime. For all of these points, 6/22/2005 11:00:00 PM, 6/23/2005 5:00:00 AM and 6/23/2005 11:00:00 PM, ozone is low (21 ppb, 13 ppb and 6ppb, respectively), so one must assume that deposition played a role in lowering $NO_x$ concentrations, thereby increasing the VOC to $NO_x$ ratio.

**Figure 7-43** shows the VOC to $NO_x$ ratio for the month of July 2005. Only one of the data points in the $NO_x$ limited regime is associated with low ozone: 7/13/2005 11:00:00 PM with an ozone concentration of 33 ppb. The data for 7/1/2005 12:00:00 PM, 7/2/2005 12:00:00 PM and 7/17/2005 12:00:00 PM are not included in this figure because the $NO_x$ data for these times were reported as 0 ppm.

**Figure 7-44** illustrates the VOC to $NO_x$ ratio for the month of August 2005. There is low ozone (37 ppb) for one instance when the data lies in the $NO_x$ limited regime: 8/22/2005 4:00:00 PM.

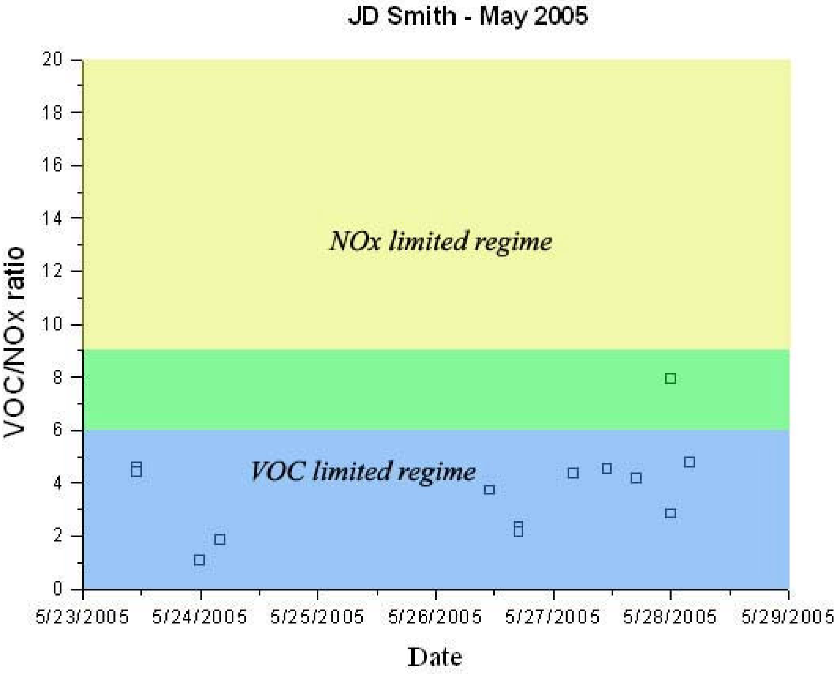


Figure 7-41. Total VOC to $NO_x$ ratio for JD Smith for May 2005

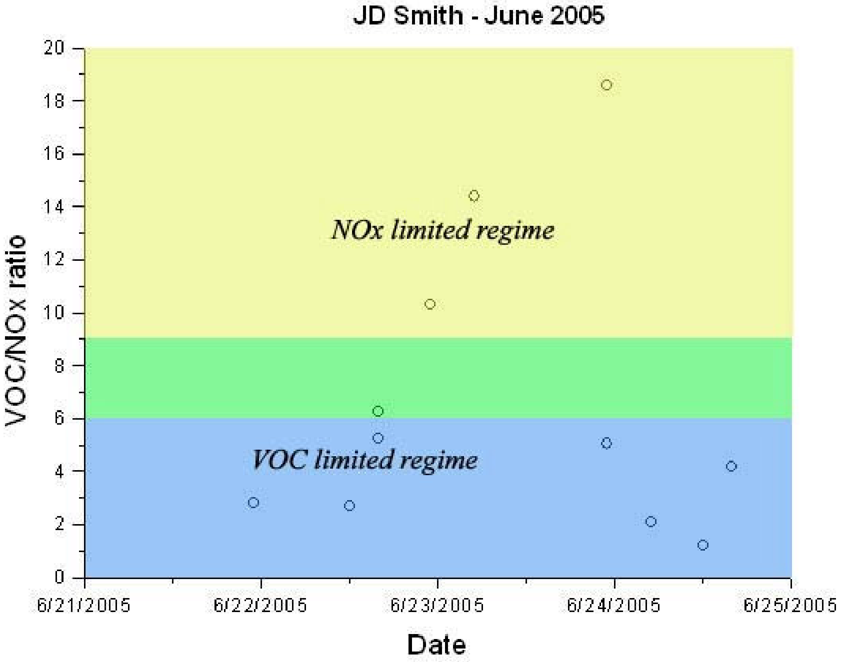


Figure 7-42. Total VOC to $NO_x$ Ratio for JD Smith for June 2005

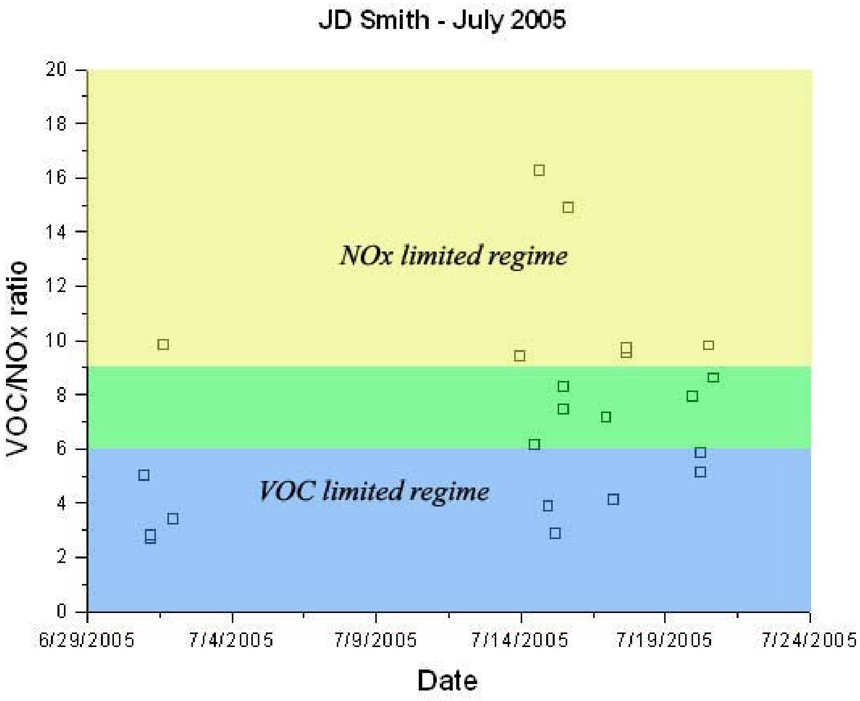


Figure 7-43. Total VOC to $NO_x$ Ratio for JD Smith for July 2005

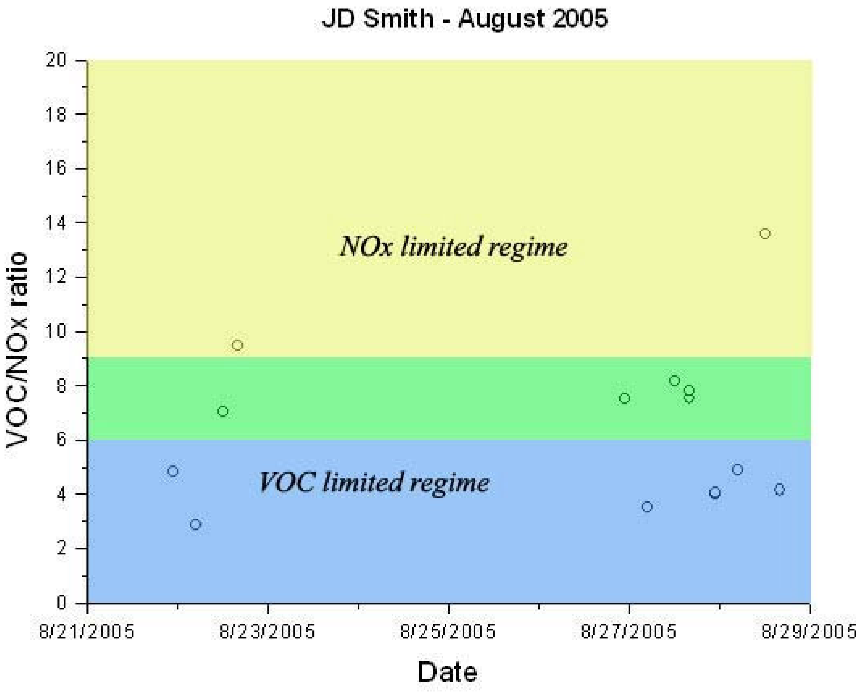


Figure 7-44. Total VOC to $NO_x$ Ratio for JD Smith for August 2005

**Joe Neal**

This site was chosen as the downwind location for canister sampling. **Figures 7-45 through 7-48** show the VOC/NO$_x$ ratio as a function of time for the months of May, June, July and August 2005, respectively. For the majority of the summer of 2005, the VOC/NO$_x$ ratios at the Joe Neal site were in the VOC-limited regime.

**Figure 7-49** illustrates the difference between the Joe Neal VOC/NO$_x$ ratios and the JD Smith VOC/NO$_x$ ratios for the entire summer of 2005. As seen in this graph, for the majority of the summer the difference lies in the negative, meaning the ratios at the JD Smith site are higher than for the Joe Neal site. This implies that Joe Neal was not an appropriate downwind location for canister sampling.

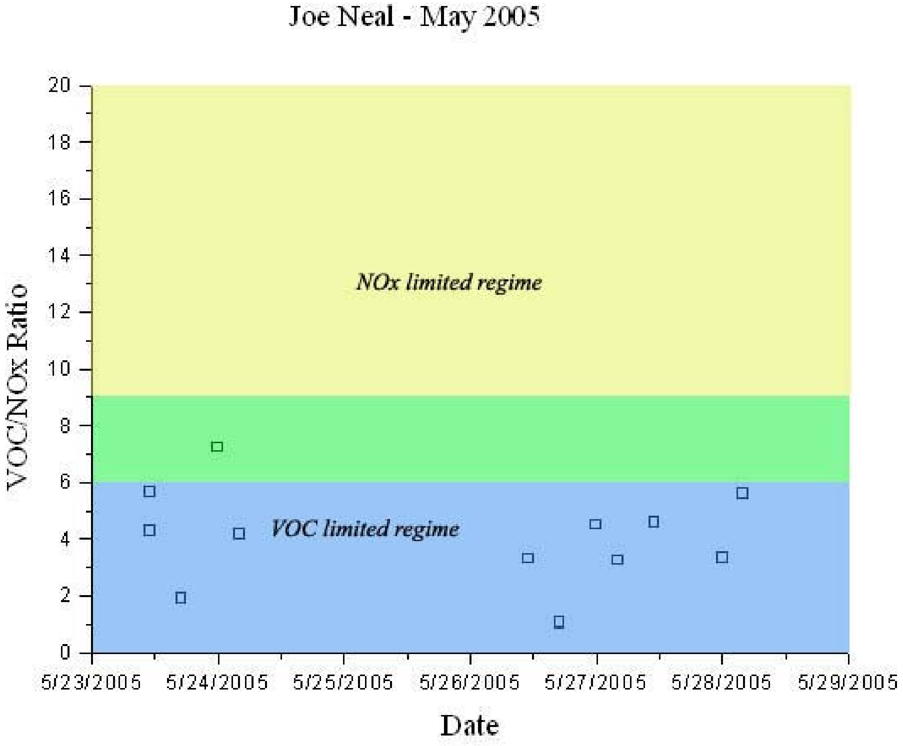


Figure 7-45. Total VOC to NO$_x$ Ratio for Joe Neal for May 2005

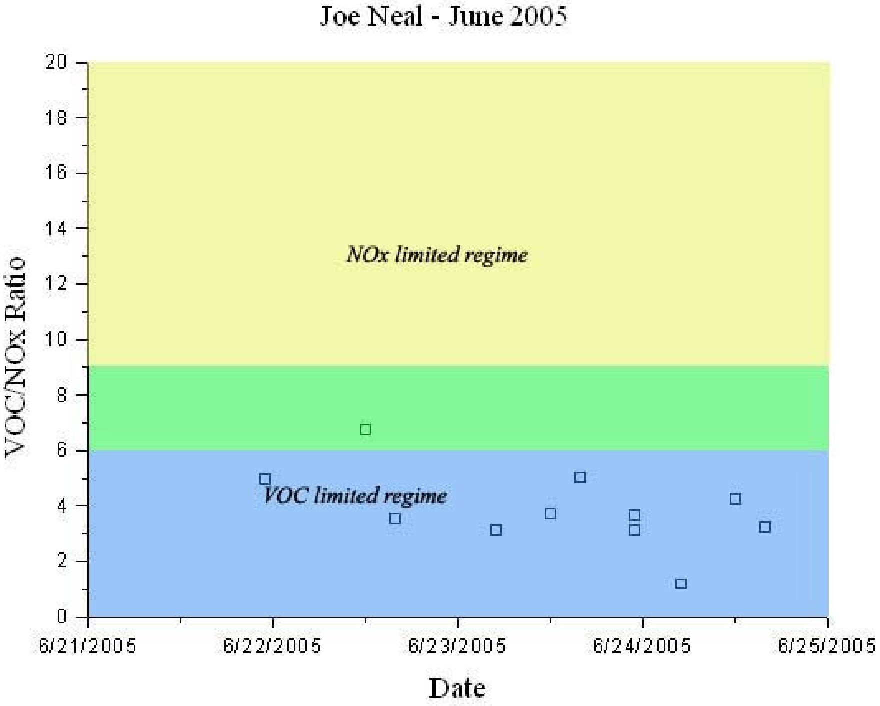


Figure 7-46. Total VOC to $NO_x$ Ratio for Joe Neal for June 2005

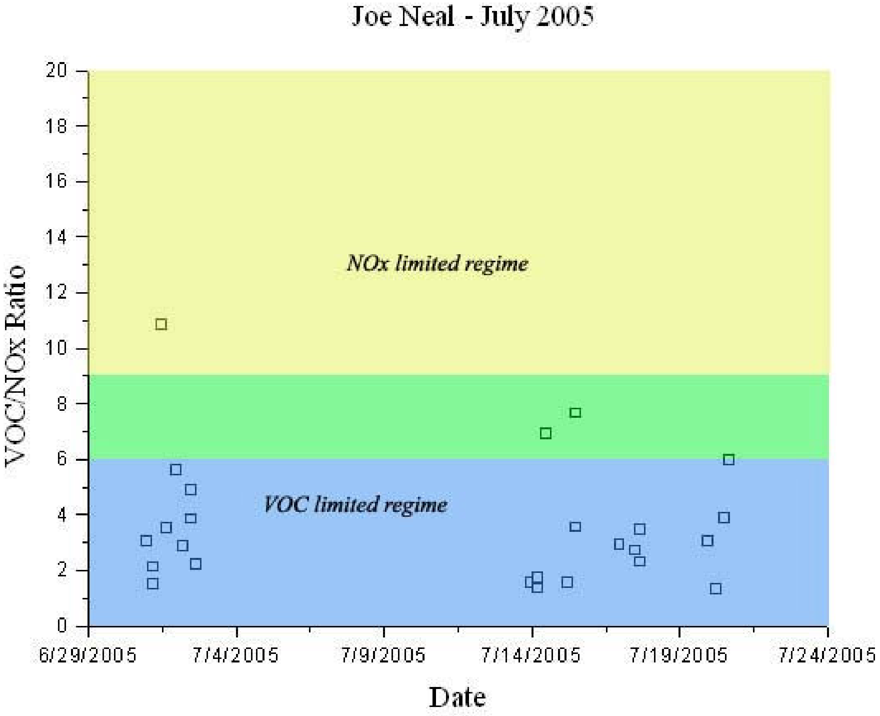


Figure 7-47. Total VOC to $NO_x$ ratio for Joe Neal for July 2005

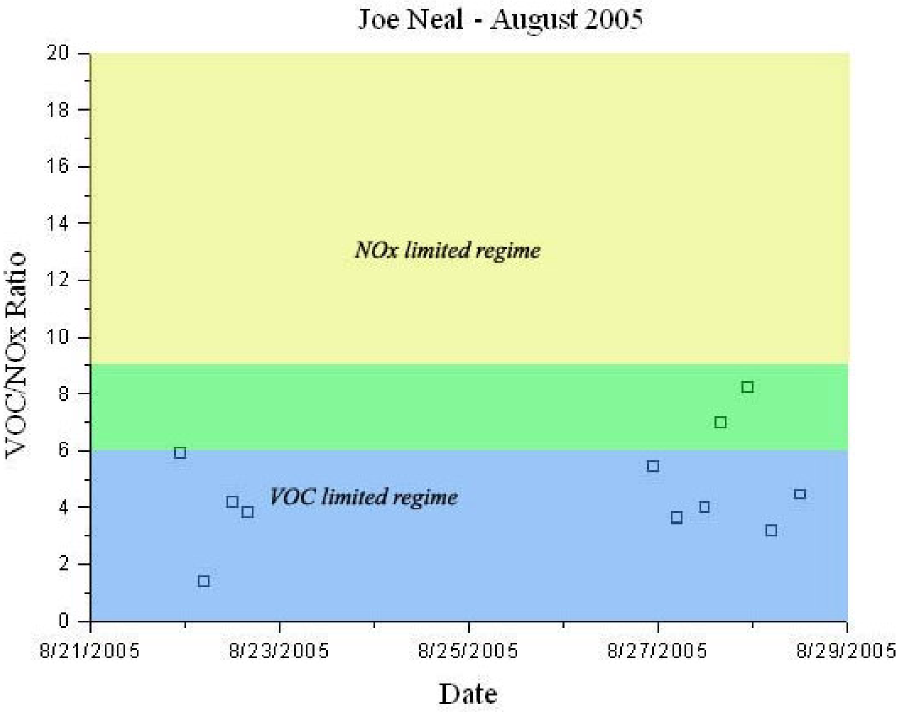


Figure 7-48. Total VOC to $NO_x$ ratio for Joe Neal for August 2005

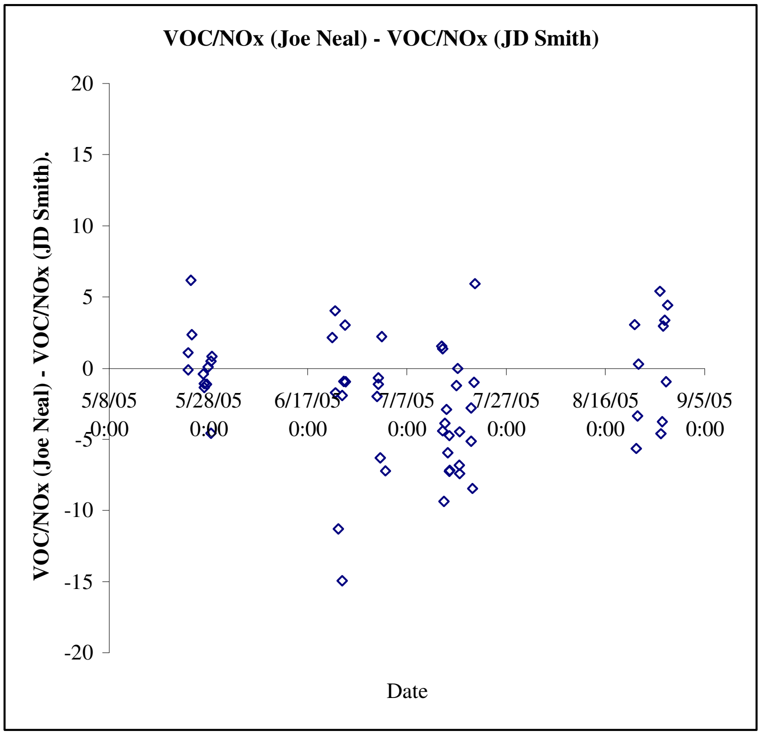


Figure 7-49. Differences of VOC/NO$_x$ Ratios Between Joe Neal and JD Smith During the Summer of 2005

Jean was chosen as the background site, and indeed analysis of the data showed that its air was relatively clean and the site was not greatly affected by fresh emissions as shown by the toluene to propane ratio. Emissions of anthropogenic VOCs at Jean showed no correlation with wind direction thus providing no evidence to support transport being a significant source of VOCs in the Clark County area. Also, concentrations of biogenic compounds were lower at Jean compared to the Joe Neal and JD Smith sites.

The JD Smith and Joe Neal sites were most often in the VOC limited regime during the summer of 2005. For most (but not all) instances when the regime was NO$_x$ limited, ozone concentrations were low, suggesting deposition as the cause of low NO$_x$ concentrations. This suggests that VOC emission controls in Clark County should be considered first to reduce urban ozone mixing ratios. For the majority of the summer the difference between the Joe Neal VOC/NO$_x$ ratios and the JD Smith VOC/NO$_x$ ratios lies in the negative, meaning the ratios at the JD Smith site are higher than for the Joe Neal site. This implies that Joe Neal was not an appropriate downwind location for canister sampling. Rather, the Joe Neal site was too close to local sources. This suggests that in future ozone studies in Clark County, the "downwind location" should be established farther downwind from the urban center.

## 7.8 Balloon-Borne Measurements

Rawinsondes measure the vertical profiles of temperature, humidity and winds. When interfaced with the En-Sci monitors they measure ozone as well, hereafter referred to as an ozonesonde. During the CCROPS field study a total of 85 rawinsonde/ozonesonde observations were made from the North Las Vegas airport. Of those, 43 were ozonesondes. A complete list of the soundings taken at the North Las Vegas airport (NLV) is provided in **Table 7-6**. Plots of soundings are presented in **Appendix D**. Table information includes the sounding day and time of balloon release, type of soundings (standard rawinsondes or Ozonesonde), and the range of data.

## Table 7-6. Rawinsonde/Ozonesonde Schedule at NLV

| Release |  |  | Sonde | Data Range |  |
|---|---|---|---|---|---|
| Date | Time | Sounding ID | Type (S or O) | Bottom Ht (m-agl) | Top Ht (m-agl) |
| 23-May | 530 | NLV52306 | S | 590 | 6717 |
| 23-May | 1650 | NLV52316 | S | 786 | 6033 |
| 24-May | 633 | NLV52406 | O | 677 | 6228 |
| 24-May | 1050 | NLV52411 | O | 677 | 5993 |
| 24-May | 1600 | NLV52416 | O | 677 | 6674 |
| 25-May | 530 | NLV52506 | S | 677 | 6999 |
| 25-May | 1600 | NLV52516 | S | 677 | 6369 |
| 26-May | 530 | NLV52606 | S | 677 | 6518 |
| 26-May | 1600 | NLV52616 | S | 677 | 6189 |
| 27-May | 610 | NLV52706 | O | 677 | 7648 |
| 27-May | 1030 | NLV52711 | O | 677 | 6308 |
| 27-May | 1735 | NLV52716 | O | 677 | 3643 |
| 28-May | 530 | NLV52806 | O | 677 | 7128 |
| 28-May | 1017 | NLV52810 | O | 677 | 6848 |
| 28-May | 1600 | NLV52816 | O | 677 | 6972 |
| 29-May | 542 | NLV52906 | S | 677 | 6502 |
| 29-May | 1721 | NLV52917 | S | 677 | 6243 |
| 20-Jun | 502 | NLV62005 | S | 964 | 6509 |
| 20-Jun | 1604 | NLV62016 | S | 677 | 6091 |
| 21-Jun | 504 | NLV62105 | S | 677 | 6622 |
| 21-Jun | 1613 | NLV62116 | S | 677 | 6093 |
| 22-Jun | 603 | NLV62206 | S | 677 | 6881 |
| 22-Jun | 1630 | NLV62216 | O | 677 | 3721 |
| 23-Jun | 600 | NLV62306 | O | 677 | 6764 |
| 23-Jun | 1015 | NLV62310 | O | 677 | 6515 |
| 23-Jun | 1608 | NLV62316 | O | 677 | 6378 |
| 24-Jun | 630 | NLV62406 | O | 677 | 6955 |
| 24-Jun | 1013 | NLV62410 | O | 677 | 6773 |
| 24-Jun | 1603 | NLV62416 | O | 842 | 5916 |
| 25-Jun | 555 | NLV62506 | O | 677 | 6769 |
| 25-Jun | 1554 | NLV62516 | S | 677 | 6684 |
| 26-Jun | 536 | NLV62606 | S | 677 | 6597 |
| 26-Jun | 1557 | NLV62616 | S | 677 | 6416 |
| 27-Jun | 530 | NLV62706 | S | 677 | 6505 |
| 27-Jun | 1558 | NLV62716 | S | 677 | 6022 |
| 28-Jun | 539 | NLV62806 | S | 677 | 6603 |
| 28-Jun | 1554 | NLV62816 | S | 677 | 5995 |
| 29-Jun | 525 | NLV62906 | S | 677 | 6791 |
| 29-Jun | 1624 | NLV62916 | O | 677 | 7582 |
| 30-Jun | 529 | NLV63006 | S | 677 | 6726 |
| 30-Jun | 1557 | NLV63016 | S | 677 | 6069 |

Table 7-6. Rawinsonde/Ozonesonde Schedule at NLV (continued)

| Release | | | Sonde | Data Range | |
|---|---|---|---|---|---|
| Date | Time | Sounding ID | Type (S or O) | Bottom Ht(m-agl) | Top Ht(m-agl) |
| 1-Jul | 618 | NLV70106 | O | 677 | 7262 |
| 1-Jul | 1011 | NLV70110 | O | 677 | 7434 |
| 1-Jul | 1622 | NLV70116 | O | 677 | 7111 |
| 2-Jul | 603 | NLV70206 | O | 677 | 7103 |
| 2-Jul | 957 | NLV70210 | O | 677 | 6765 |
| 2-Jul | 1608 | NLV70216 | O | 677 | 8218 |
| 12-Jul | 529 | NLV71206 | S | 677 | 7375 |
| 12-Jul | 1555 | NLV71216 | S | 677 | 1139 |
| 12-Jul | 1630 | NLV71217 | S | 677 | 8004 |
| 13-Jul | 528 | NLV71306 | S | 677 | 8044 |
| 13-Jul | 1603 | NLV71316 | S | 1326 | 7458 |
| 14-Jul | 620 | NLV71406 | O | 677 | 8150 |
| 14-Jul | 1017 | NLV71410 | O | 677 | 7339 |
| 14-Jul | 1605 | NLV71416 | O | 677 | 6696 |
| 15-Jul | 627 | NLV71506 | O | 677 | 9185 |
| 15-Jul | 1024 | NLV71510 | O | 677 | 7805 |
| 15-Jul | 1701 | NLV71516 | O | 677 | 7427 |
| 16-Jul | 525 | NLV71606 | S | 677 | 7909 |
| 16-Jul | 1600 | NLV71616 | S | 677 | 7007 |
| 17-Jul | 558 | NLV71706 | O | 677 | 8555 |
| 17-Jul | 1010 | NLV71710 | O | 677 | 8169 |
| 17-Jul | 1854 | NLV71718 | O | 677 | 8228 |
| 18-Jul | 556 | NLV71806 | S | 677 | 7932 |
| 18-Jul | 1618 | NLV71816 | S | 677 | 7198 |
| 19-Jul | 543 | NLV71906 | S | 677 | 7837 |
| 19-Jul | 1618 | NLV71916 | S | 677 | 8876 |
| 20-Jul | 558 | NLV72006 | O | 677 | 8241 |
| 20-Jul | 1000 | NLV72010 | O | 677 | 10333 |
| 20-Jul | 1607 | NLV72016 | O | 677 | 8008 |
| 21-Jul | 530 | NLV72106 | S | 677 | 8764 |
| 21-Jul | 1559 | NLV72116 | S | 677 | 7841 |
| 21-Aug | 542 | NLV82105 | S | 677 | 6207 |
| 21-Aug | 1600 | NLV82116 | S | 677 | 7035 |
| 22-Aug | 634 | NLV82206 | O | 677 | 8426 |
| 22-Aug | 1002 | NLV82210 | O | 677 | 6014 |
| 22-Aug | 1633 | NLV82216 | S | 677 | 6763 |
| 27-Aug | 557 | NLV82706 | S | 677 | 7169 |
| 27-Aug | 1712 | NLV82716 | O | 677 | 8043 |
| 28-Aug | 648 | NLV82806 | S | 677 | 7749 |
| 28-Aug | 1007 | NLV82810 | O | 677 | 6812 |
| 28-Aug | 1659 | NLV82816 | O | 677 | 7820 |
| 29-Aug | 629 | NLV82906 | O | 677 | 7703 |
| 29-Aug | 1030 | NLV82910 | O | 677 | 7689 |
| 29-Aug | 1638 | NLV82916 | S | 677 | 6144 |

Beginning in the early evening, as the ground surface cools, a surface based inversion develops. Typically this nocturnal boundary layer is decoupled from the air aloft which can cause complex ozone layering in the vertical and associated wind shears. An example of a well-developed boundary layer with both ozone concentration and wind shears is shown on **Figure 7-50**. Temperature, dew point temperature, ozone, and winds with height are shown. On July 1 at 06 PDT, a surface-based temperature inversion extended to about 1200 m or about 500 m above the ground. At the surface, ozone concentrations were about 25 ppb, which were the lowest concentrations measured on this sounding. A layer of 70-75 ppb ozone resides above the nocturnal inversion to ~ 4200 m, capped by a stable layer characterized by an inversion associated with lower humidity and ozone.

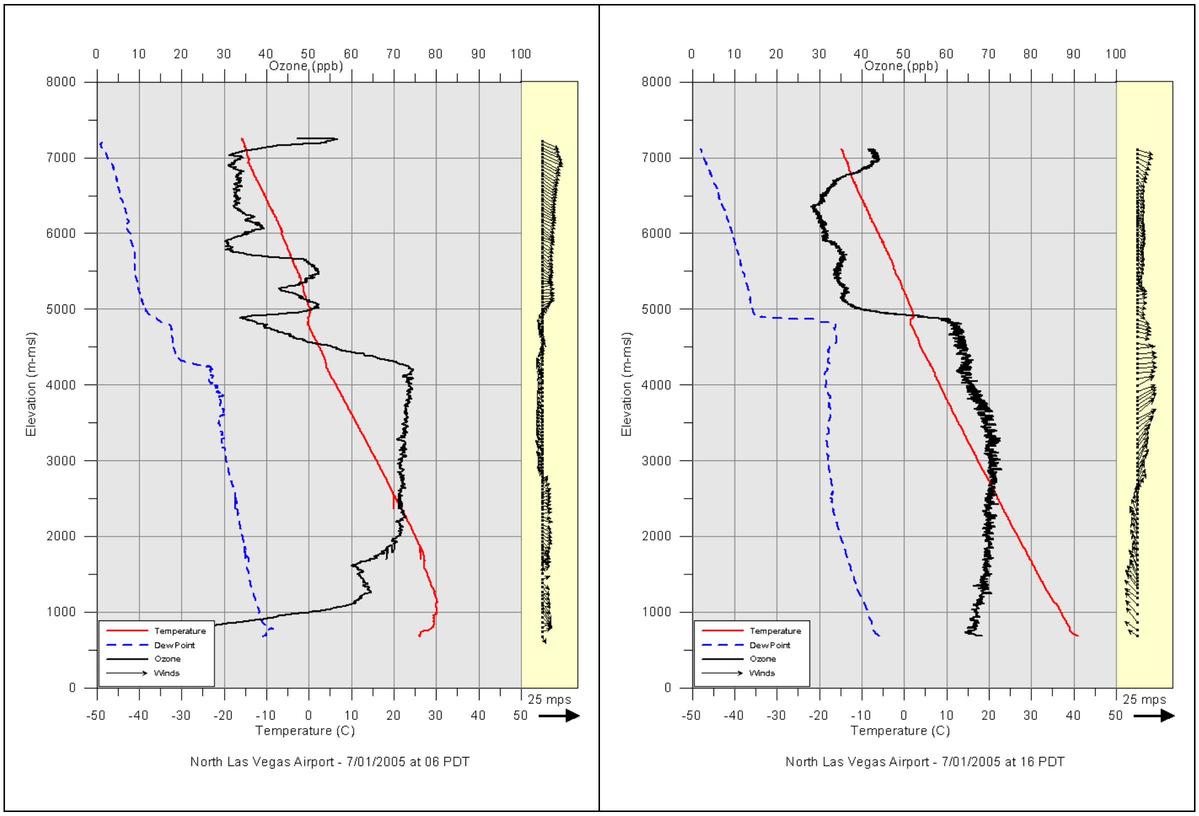


Figure 7-50. Ozonesonde Soundings at NLV on July 1, 2005

During the day, as the ground surface warms due to insolation, the boundary layer deepens and surface-emitted pollutants readily mix vertically. The afternoon sounding on July 1 is shown on right panel in Figure 7-50. Ozone is well-mixed and uniform in a layer from the ground to about 4900 m, at which point a temperature inversion occurs. This scenario was repeated throughout the study. Mixing during the night and early morning hours was limited by a nocturnal inversion. Daytime mixing intensified throughout the late morning, peaking in the afternoon typically to more than 4000 m above the ground.

With the exception of wildfire impacts, there has been initially little evidence of major interbasin transport during 2005. When atmospheric conditions were conducive to long-range transport from major source regions in California, heavily polluted air either had not accumulated in those basins or wildfires were present, which in themselves produced high ozone levels aloft. However, the data should be examined more closely to determine the sources of ozone aloft that were observed.

The combination of vertical mixing and horizontal movement due local winds is commonly referred to as dispersion. Surface concentrations of pollutants are highly dependent upon dispersion conditions. Thus, from a modeling standpoint, mixing height and low-level winds are all-important. One objective of the study was to determine if the routinely taken sounding at Desert Rock (DRA), approximately 40 miles north of (downtown) Las Vegas, adequately measures dispersion conditions over the Las Vegas Valley. NOAA takes the DRA sounding twice daily on weekdays but not on weekends, which is a major shortcoming. The DRA site is located at 1009 m-msl, which is substantially higher than the Valley floor.

Comparisons of the data from the project site at NLV with those from the NOAA site at DRA reveal that the latter are of only limited value in determining low-level dispersion conditions critical for characterizing ozone. The sounding plots on **Figure 7-51** provide an example of critical differences. The soundings were made at approximately the same time on the afternoon of June 29, 2005. These data are very important as some of the highest ozone levels measured in the network occurred on this date.

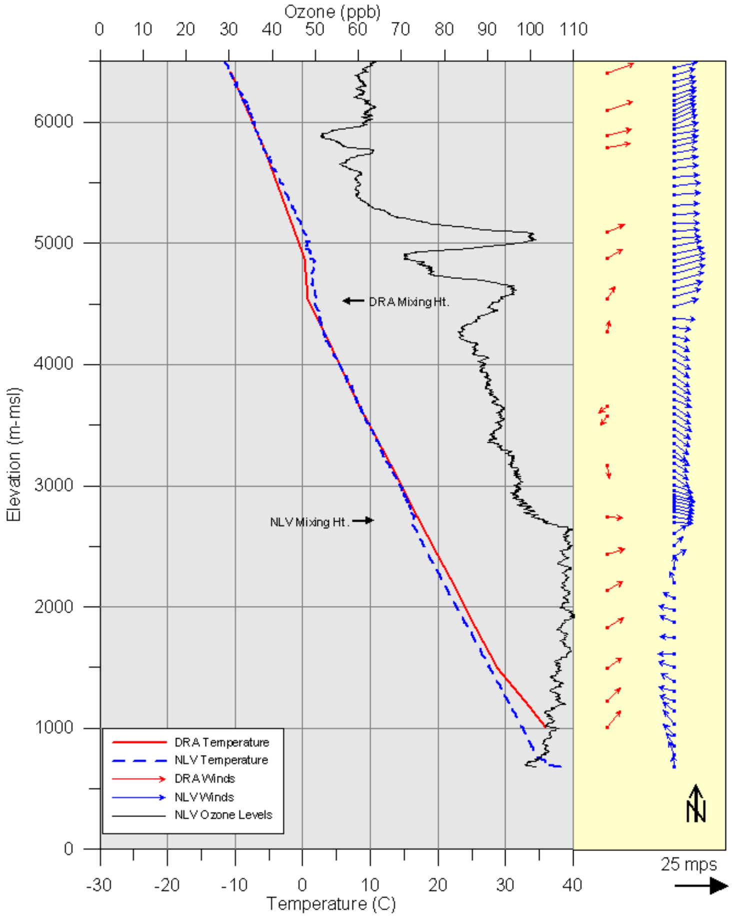


Figure 7-X Comparison of North Las Vegas Airport with Desert Rock
6/29/ 2005 at 16 PDT

Figure 7-51. Comparison of NLV and Desert Rock Soundings

The plot shows vertical temperature and wind structure from the two sites, as well as the ozone profile at NLV. A number of critical differences between soundings are evident. Note that ozone is well-mixed (uniform) in the 100-110 ppb range from the surface to 2700 m-msl. This ozone layer is capped by a small but effective temperature inversion (dashed blue line) measured by the NLV sounding. The DRA temperature profile does not show this lower inversion. It would normally be inferred from the DRA temperature lapse-rate that pollutant mixing was active to the temperature inversion shown at 4500 m on both soundings. The reason the lower inversion was not captured in the DRA data may be from NOAA's standard procedure for minimizing the number of data points in a sounding for ease of transmitting. Soundings are summarized as 'significant levels" which reproduce the sounding within a stated accuracy that is not adequate for many air quality applications.

There are major differences in the winds as well. Wind directions within the boundary layer are almost 180 degrees different. Southeasterly to easterly winds were measured at NLV whereas southwesterly winds were measured at DRA. Its noteworthy that both soundings show decoupling based on wind shears at about 2700 m-msl that corresponds to the boundary-layer depth indicated by temperature and ozone profiles at NLV. Winds at NLV are generally westerly above the boundary layer. The DRA soundings measured light and variable winds from about 3000 m to 4300 m-msl before becoming comparable to NLV (westerly) above.

In summary, the DRA sounding does not capture the critical lower-level winds and stability over the Las Vegas Valley, particularly at night and in the late morning, due to being situated on higher terrain. On occasions, such as the example on June 29, the critical features that influence dispersion are not characterized at all by the DRA observations.

## 7.9 Aircraft Measurements

Aircraft measurements were made using two airborne platforms. The primary platform was the glider with an additional instrument package added later in the program to the aircraft used to tow the glider to altitude. The glider was used to document the profile of ozone upwind of the Las Vegas Valley and identify any transported ozone from air basins upwind of the Clark County region. The tow aircraft was then used to document the profiles of ozone around the boundaries of the Valley and assess the contribution of ozone from the Las Vegas urban area.

Key to understanding and interpreting the data is assuring the quality of the data collected is understood. As the application of this sampling technique is relatively new, there were several quality control measures implemented and evaluations performed to assure the quality of the data. **Figure 7-52** shows the results of a parallel flight with both the glider and tow aircraft sampling systems. The purpose of the comparison was to determine the equivalency of the two sampling packages in measuring the same air mass. Additionally the tow package was audited using a certified ozone transfer standard with the results of the audit showing excellent agreement with the transfer standard. **Figure 7-53** shows the results.

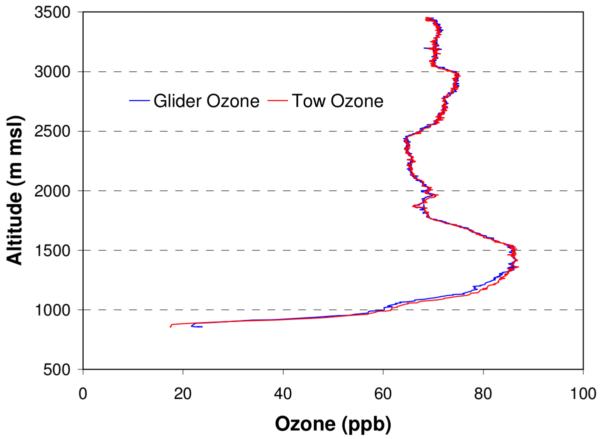


Figure 7-52. Results of Comparison Flight Between Glider and Tow Ozone Samplers

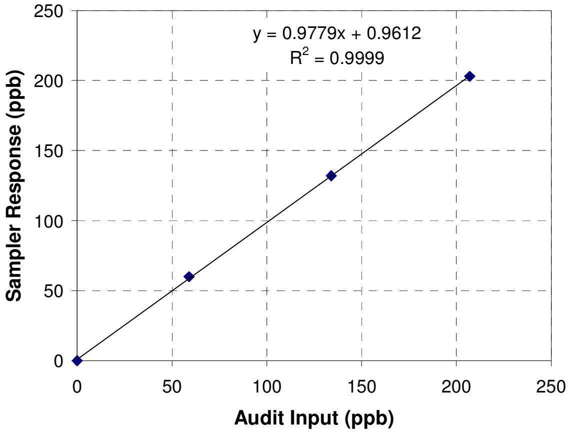


Figure 7-53. Results of Audit of Tow Aircraft Sampler

Some notable events were documented by both the glider and tow aircraft. These events are described below.

On July 2, 2005 the meteorology of the region was set for a transport event from the southwest with the synoptic flow providing the needed transport. Fires that were upwind of the region on previous days that had affected the air quality of the Clark County area, had been extinguished. On July 1 there were exceedances observed in both the San Joaquin Valley and South Coast Air Basins, as shown in **Figures 7-54** and **7-55**. Figure 7-54 shows the peak 24-hr AQI for July 1 and Figure 7-36 shows the peak hourly average ozone concentration. It should be noted that there is a gap in the measurement network in California, upwind of the Clark County region and this probably accounts for why lower values immediately upwind of Nevada are shown. **Figures 7-56** and **7-57** show the July 2nd values for the maximum AQI and 1-hr ozone concentrations, respectively with the exceedance noted in the vicinity of the Jean site on the AQI map.

Further supporting the transport scenario are the data from the glider soundings on the morning of July 2. **Figure 7-58** shows a time series of four soundings performed on July 2, with the glider documenting the presence of ozone aloft in the early morning and the subsequent mixing of the ozone to the surface by as early as 0730 PDT. By the time of the 1040 PDT sounding, a layer of ozone over 80 ppb was observed from the surface to over 2000 meters, the height of the mixed layer. Subsequently, exceedances of the 8-hr ozone standard were observed at the Jean site and at two of the project supplemental ozone stations.

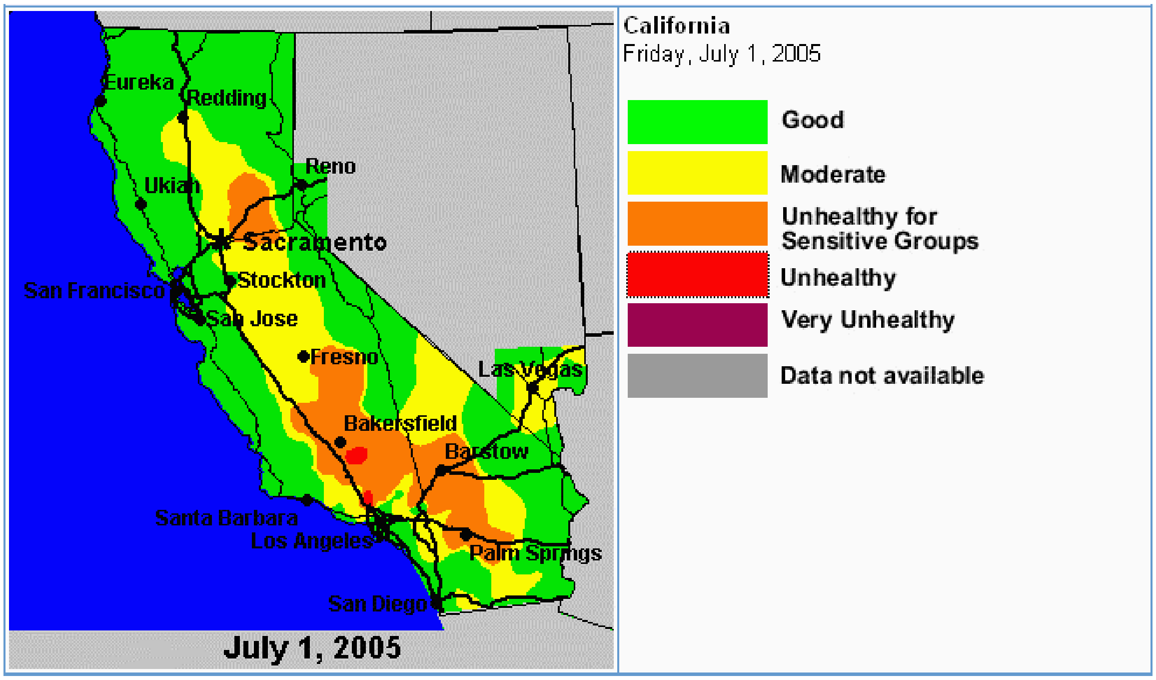


Figure 7-54. Maximum AQI for July 1, 2005

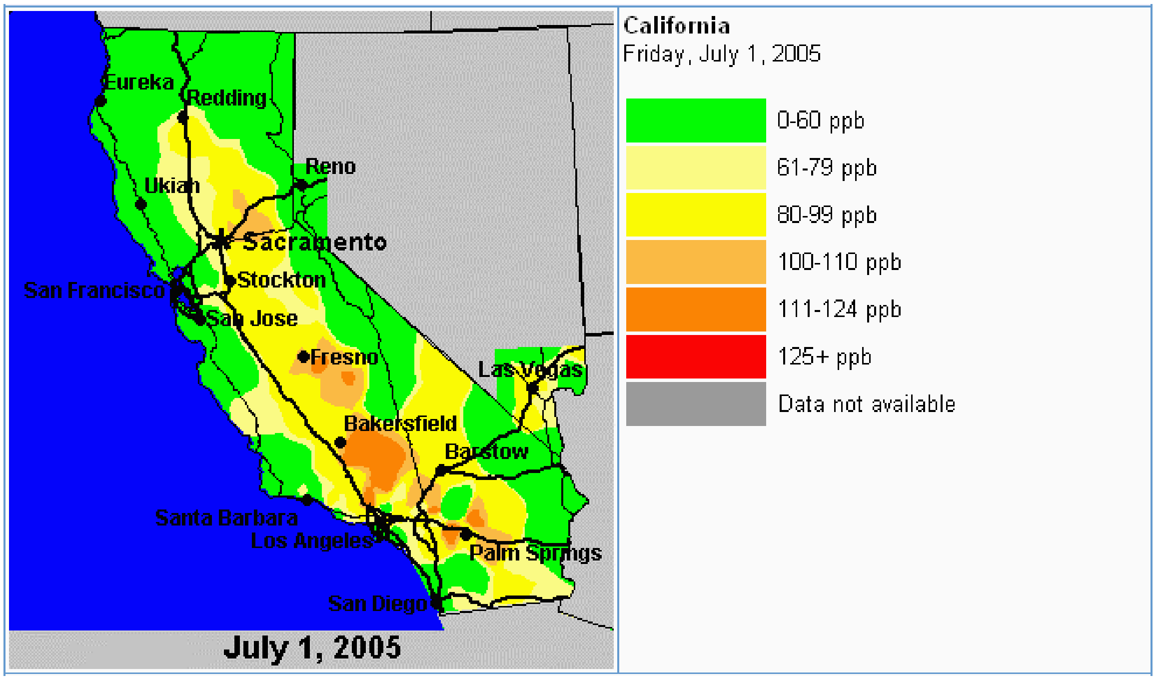


Figure 7-55. Maximum 1-Hr Ozone Concentrations for July 1, 2005

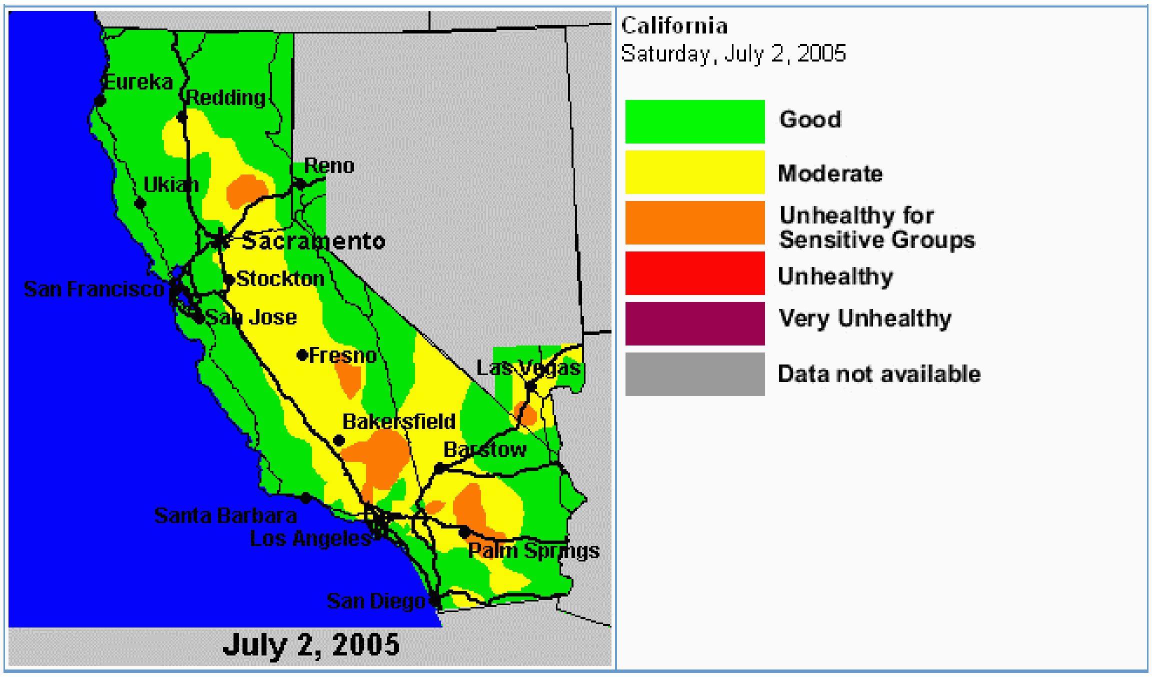


Figure 7-56. Maximum AQI for July 2, 2005, the Day of the Exceedance at Jean

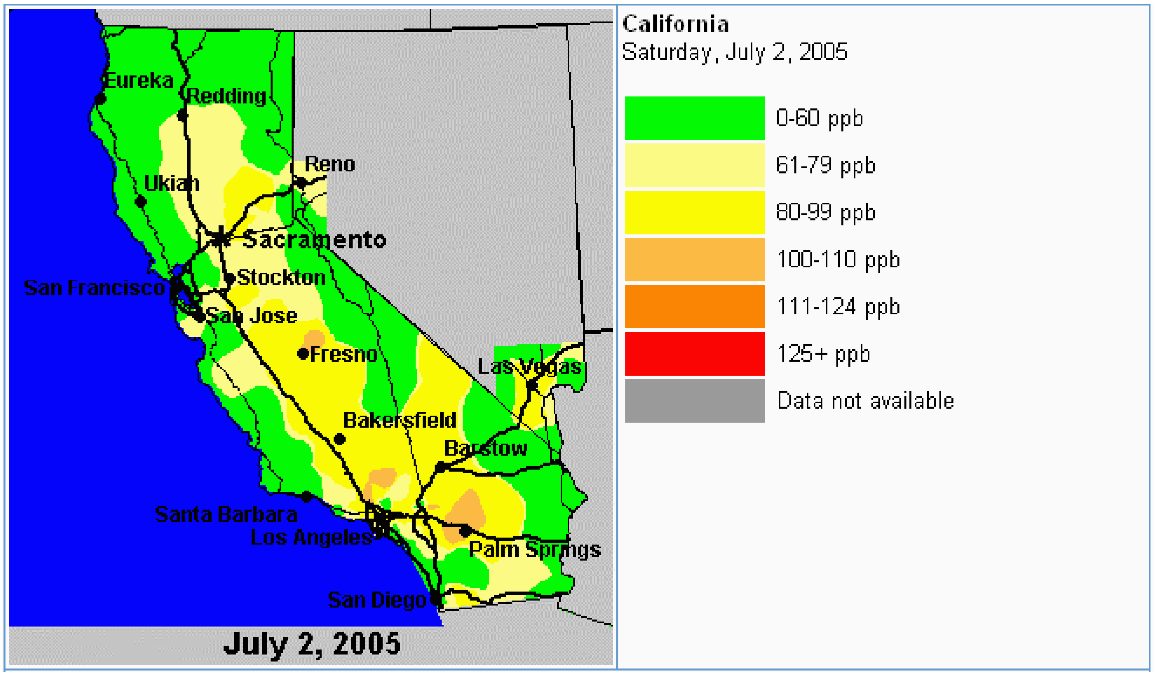
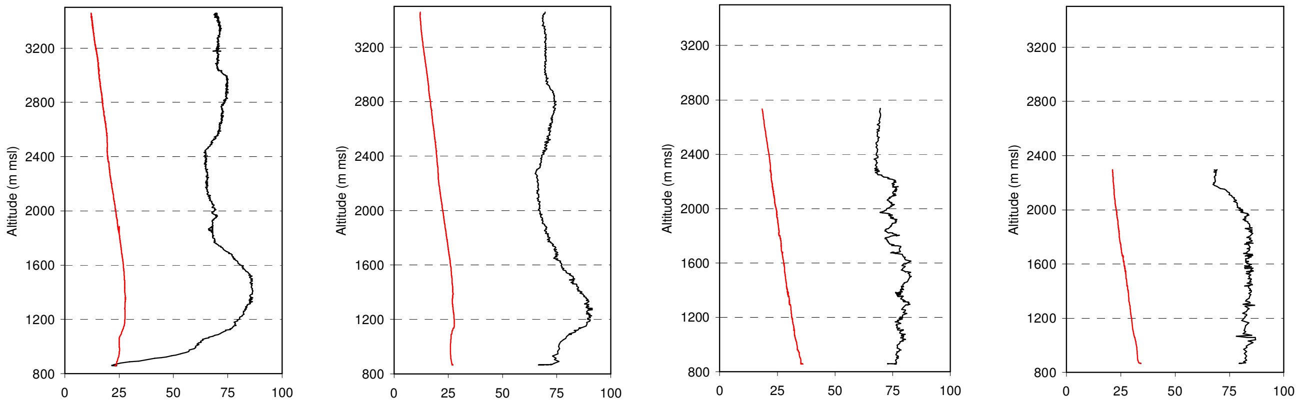


Figure 7-57. Maximum 1-Hr Ozone Concentrations for July 2, 2005



0641 PDT 0732 PDT 1014 PDT 1040 PDT

Figure 7-58. Four Soundings Showing the Progression of the Mixing of Ozone to the Surface. The red line is the temperature and black is ozone.

The primary goal of the sampling missions from the tow aircraft was to gain a better understanding of the spatial distribution of ozone throughout the Las Vegas Valley during transport scenarios and to assess the contribution of the urban area to the observed downwind ozone concentrations. To this end, the flight paths typically originated in the southwest, around the Jean airport and a box pattern was flown to the east, north, west and finally back to the south. This provided a traverse through the upwind and downwind regions from the urban center in Las Vegas. **Figures 7-59** through **7-63** show the afternoon traverse patterns from each of the flights. These patterns were flown from about 15 to 17 PDT, the period of the anticipated maximum 1-hour ozone concentrations, on each of the days. From the five flights that were conducted, and the differences observed between the upwind and downwind regions, the contribution of the urban area to the downwind concentrations during these flight days was estimated to be about 20 to 30 ppb. While none of the flight days occurred on exceedance days, the fact that ozone concentrations upwind of the Las Vegas Valley during transport events can be upwards of 80 ppb or more, indicates that this urban contribution to the air mass could provide the needed additional ozone to create exceedances of the NAAQS.

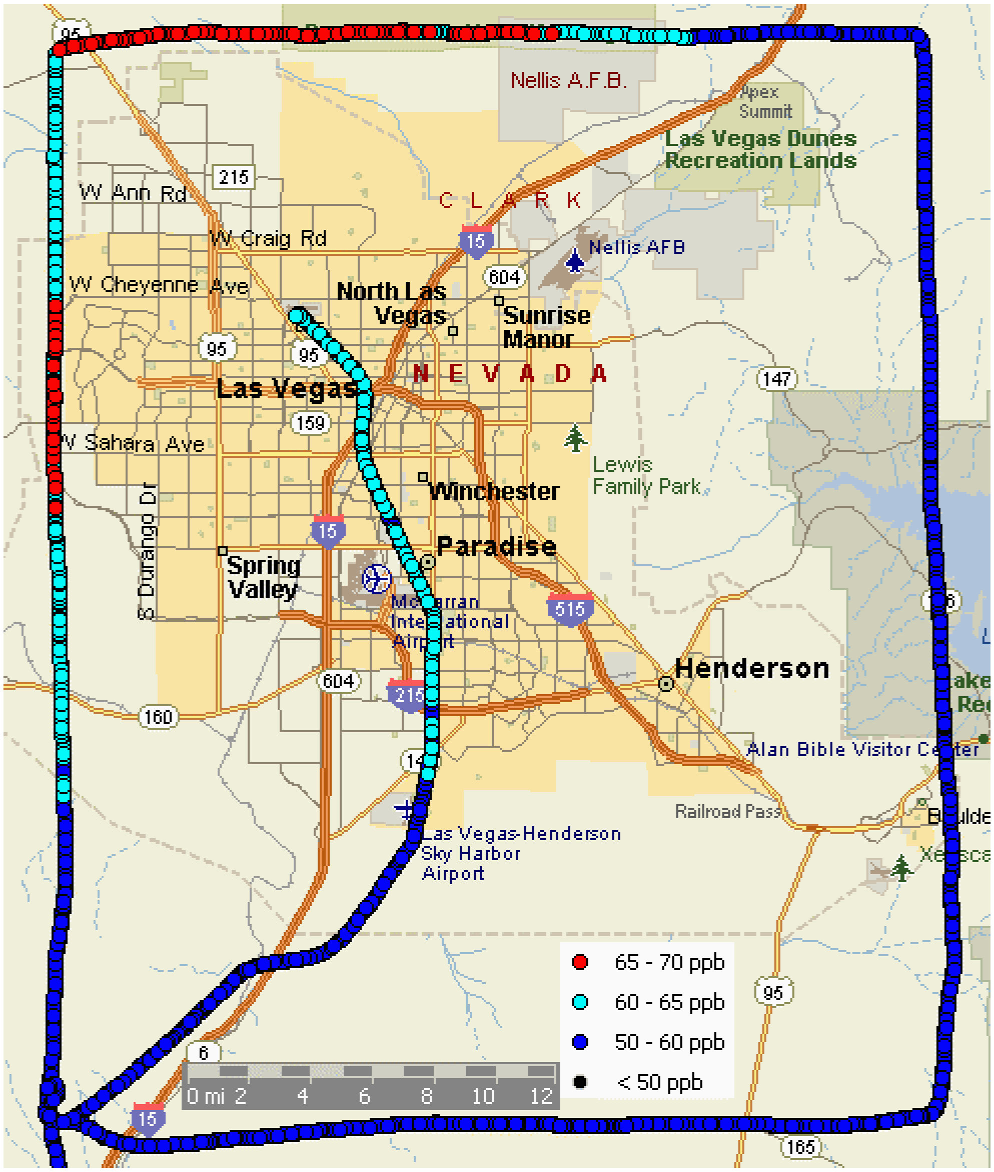


Figure 7-59. Aircraft Flight Observations of Ozone on August 21

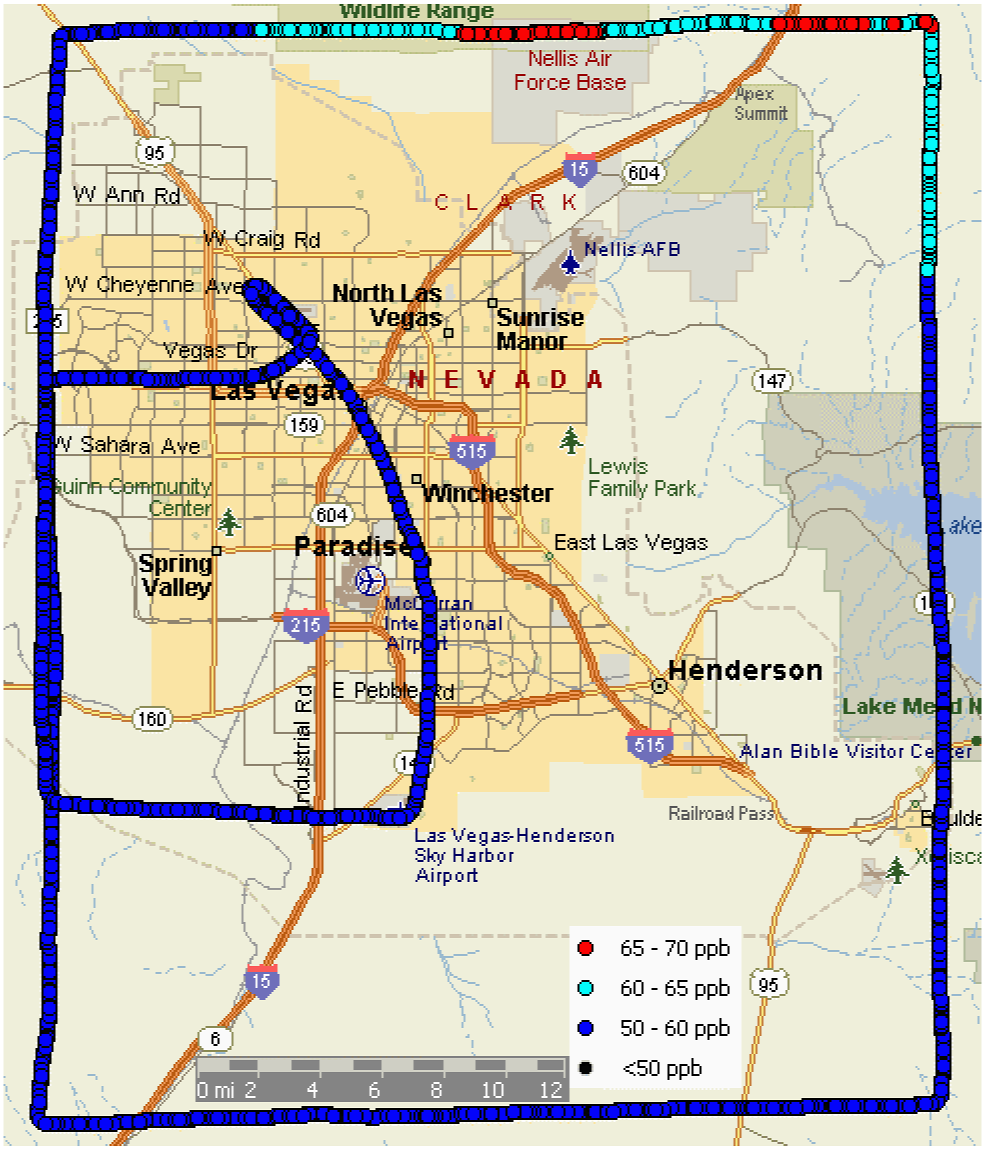


Figure 7-60. Aircraft Flight Observations of Ozone on August 22

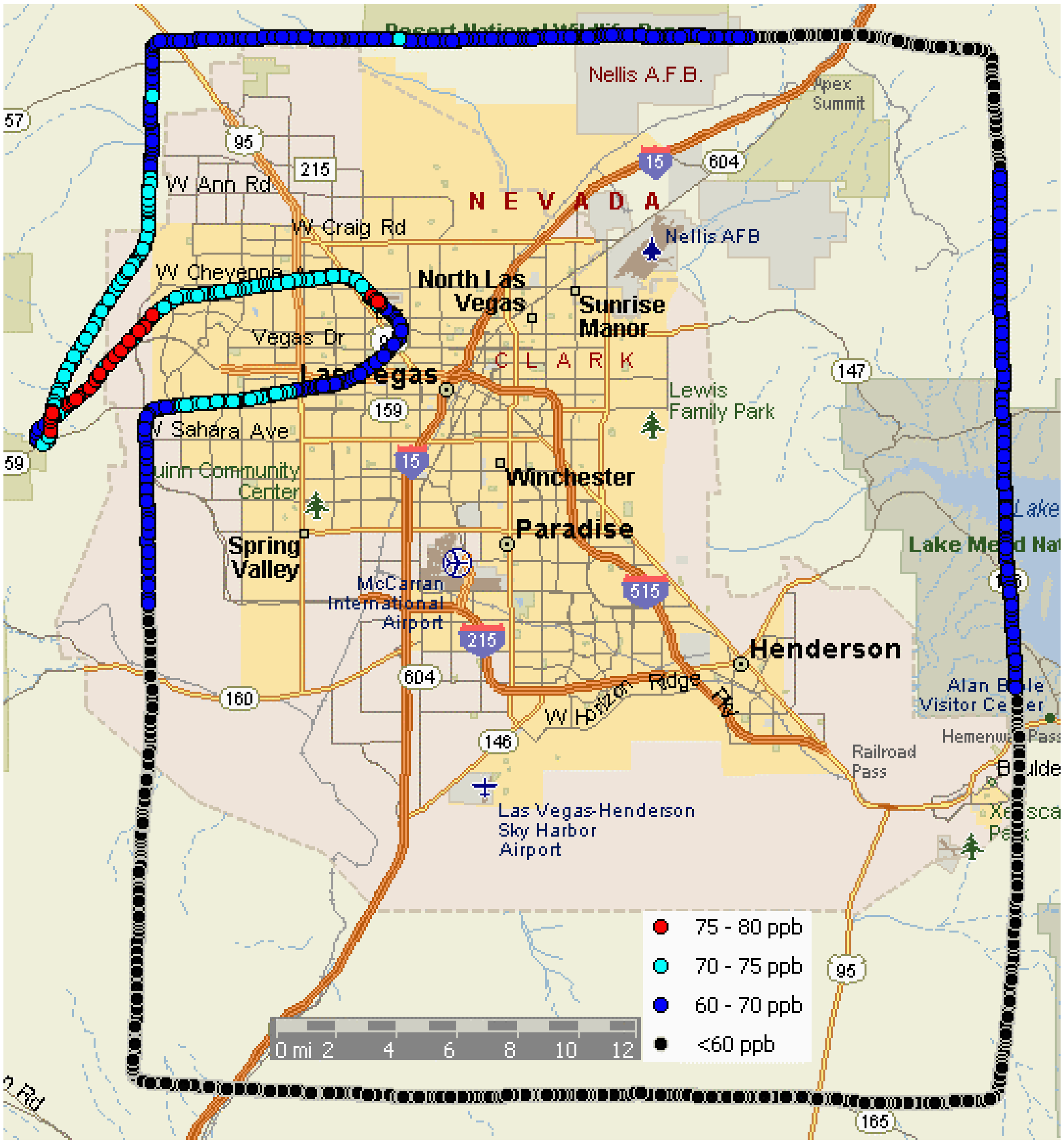


Figure 7-61. Aircraft Flight Observations of Ozone on August 27

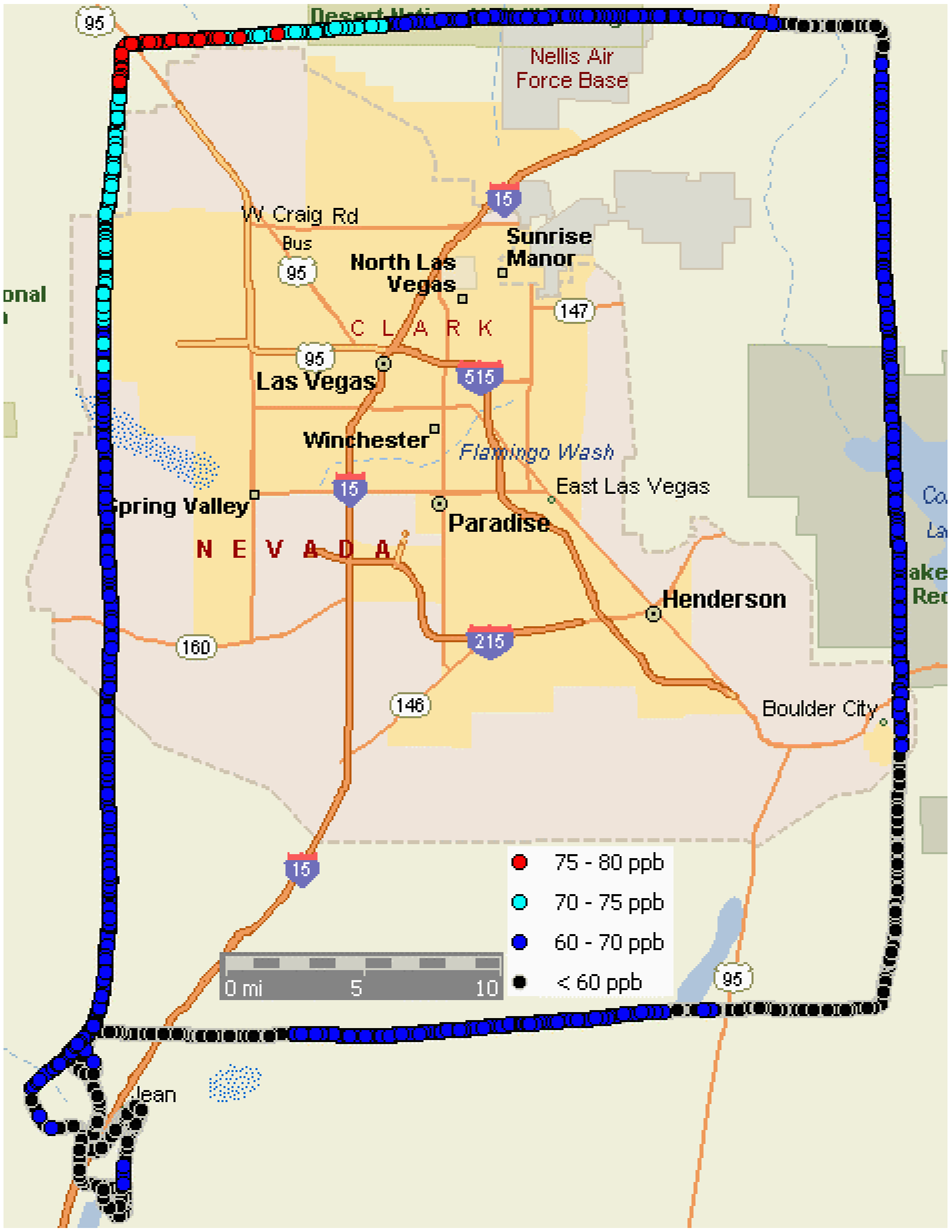


Figure 7-62. Aircraft Flight Observations of Ozone on August 28

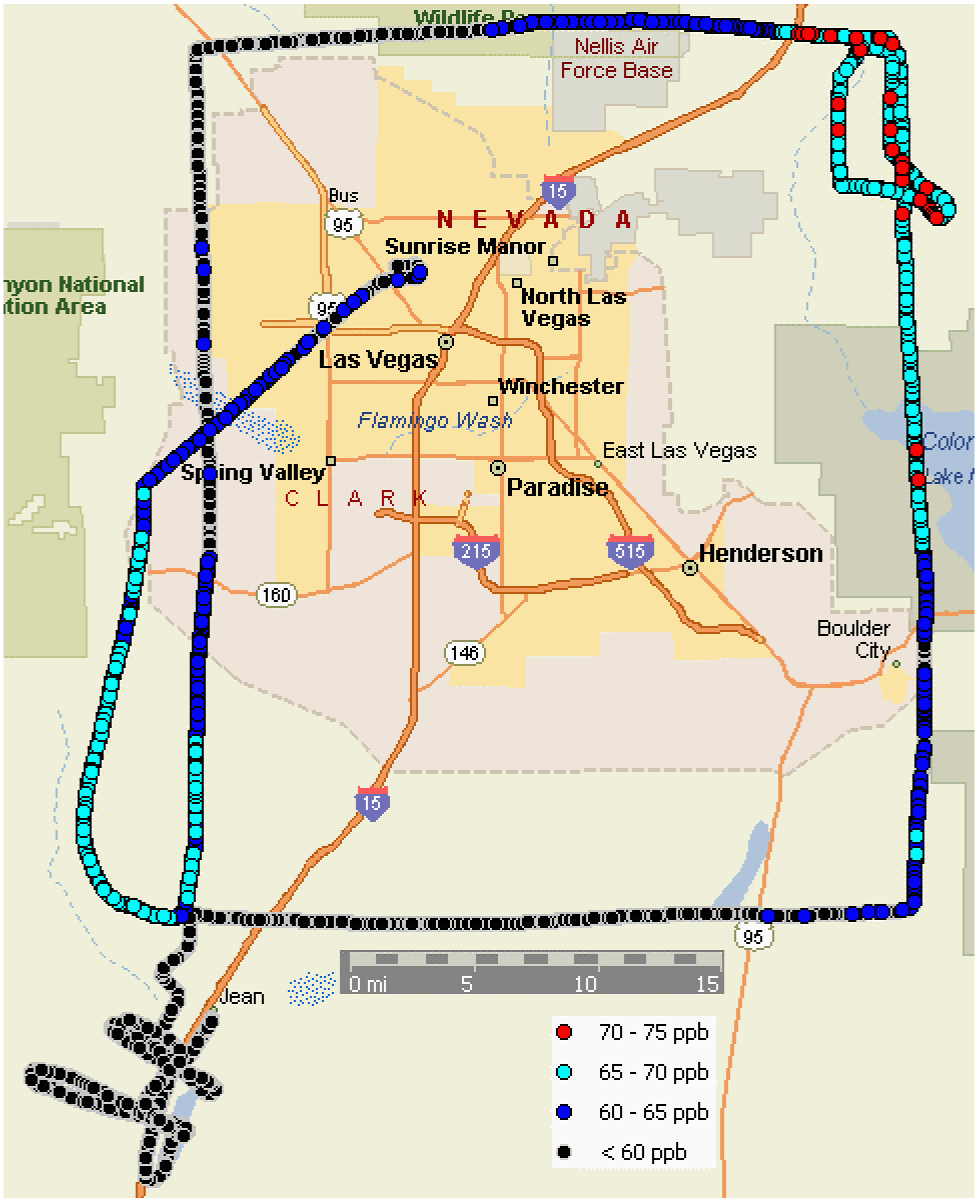


Figure 7-63. Aircraft Flight Observations of Ozone on August 29

## 7.10 Remote Upper-air Meteorological Measurements

This section includes a summary of observations obtained from the SODAR and Radar Profiler remote upper-air measurements. Additional details are available in the DRI report included as **Appendix A**.

### 7.10.1 Data Recoverability

**Figures 7-64 to 7-65** show data recovery percentage plots for each of the SODAR sites. The blue bars on the plots show the percent data recovered for the wind speed/wind direction. The gray bars on the plot show recovery percentages for sigma w, the standard deviation of the vertical wind velocity. Note that the overall data recovery for the Mini-SODAR was low (<70 percent) because of the instrument problems from the middle of June to the beginning of July. The problem was resolved after a visit from AeroVironment in July. Data recovery for that site is very good excluding that time period.

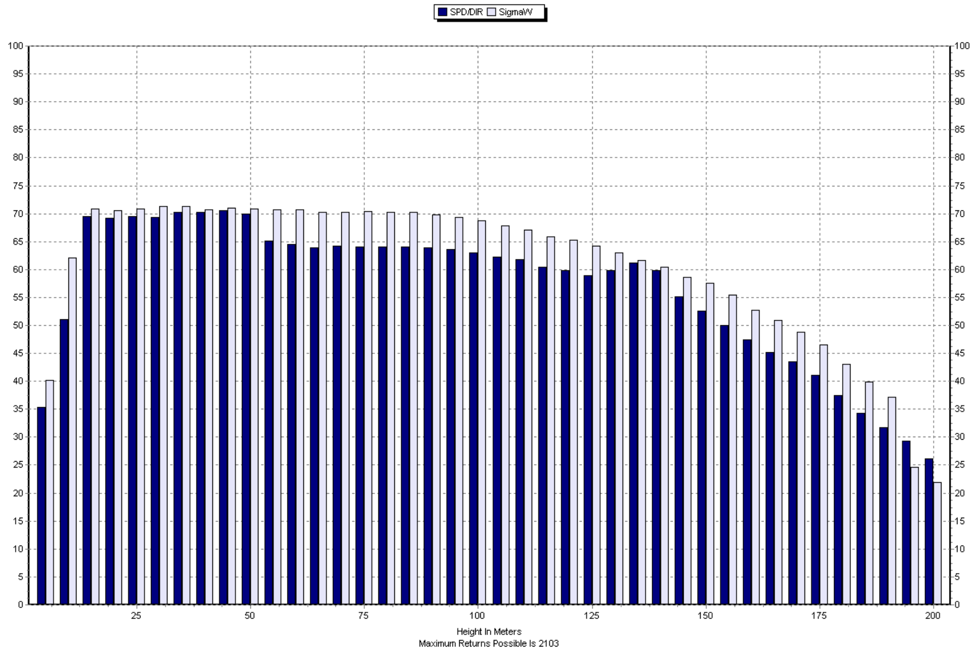


Figure 7-64. North Las Vegas Airport Mini-SODAR data recovery from installation date to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

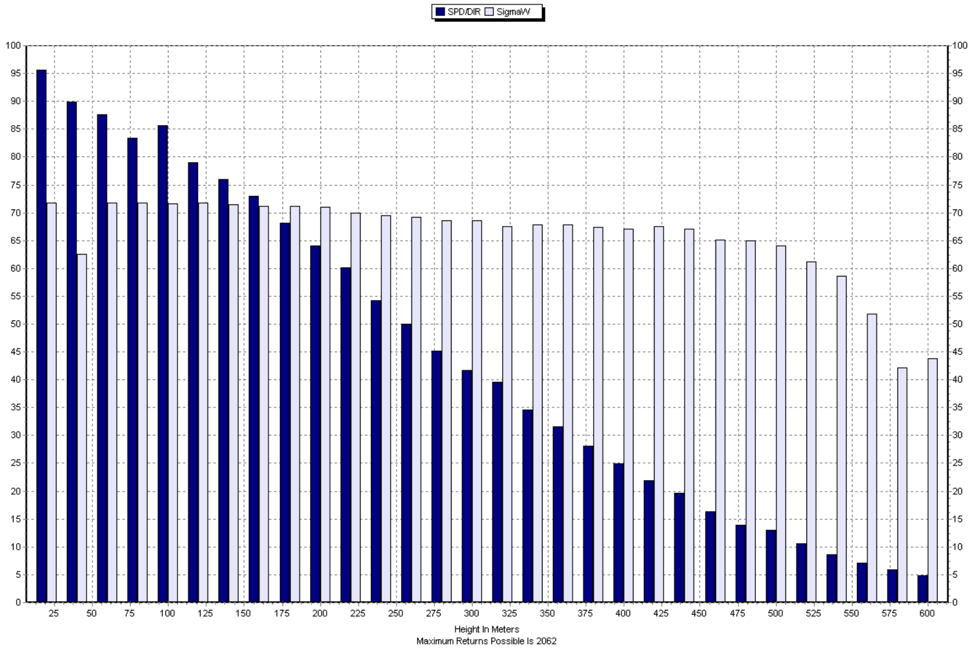


Figure 7-65. Data recovery for Jean airport site from installation date to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

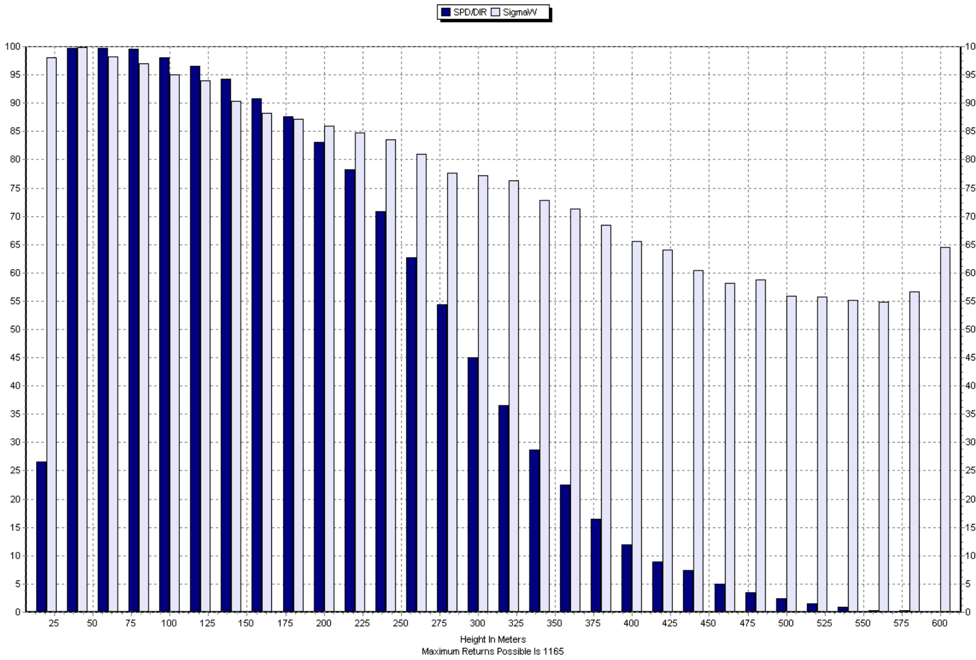


Figure 7-66. Data recovery of the Speedway SODAR from installation to August 31, 2005. ark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

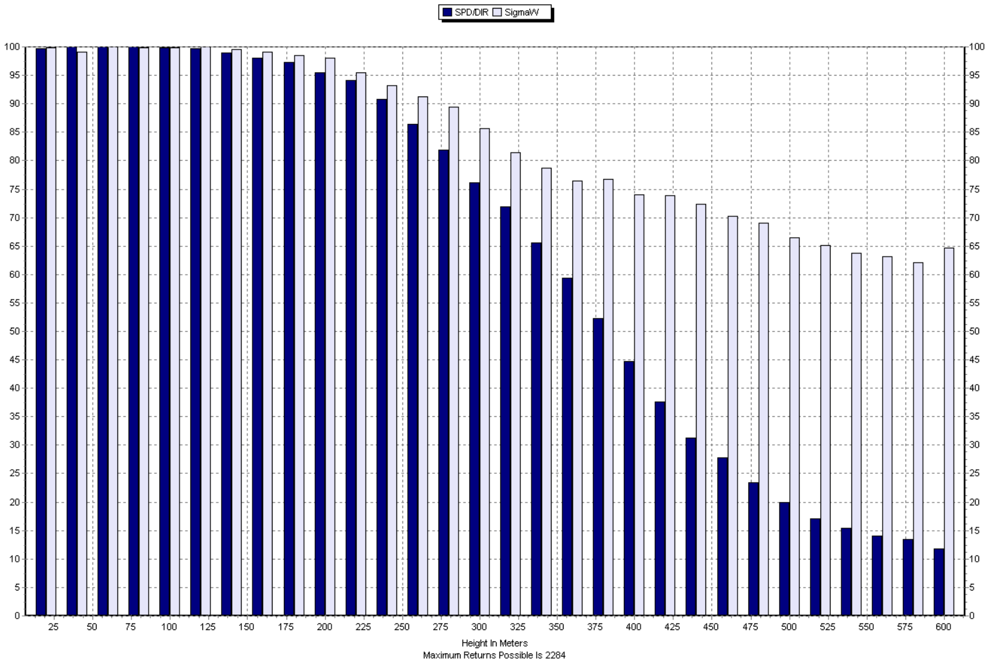


Figure 7-67. Data Recovery at the Floyd Lamb State Park Site from Installation to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

### 7.10.2 Upper-Air Meteorology Cluster Analysis

DRI performed an analysis (cluster analysis) to form groups of days that had similar wind field patterns. This analysis used surface wind sites from the standard Clark County DAQEM network plus additional sites operated in support of CCROPS. Only sites that had a nearly complete data set for the period of May 15, 2005- August 31, 2005 were used.

For each hour for each day winds at all sites used were decomposed into their U (west-east) and V (south-north) components. The clustering algorithm computed differences between each pair of days on an hour-by-hour, site-by site basis. A hierarchical method was used that shows the grouping of days and the difference levels where groups are joined, resulting in 14 groups. Many of these groups had only one day. On inspection it was noted that these single day groups typically had passage of some type of front or were affected by thunderstorm downdrafts that resulted in different diurnal patterns in winds from any other day (e.g., if one day had a cold front pass at 3 pm, it would not be grouped with a day that had a cold front pass at 9 am).

There were 4 groups containing 5 or more days, on which detailed analysis was conducted. Average ozone concentrations were computed for each ozone monitoring site for each of these four clusters and for each diurnal period. Resultant winds were also computed for each wind site used in the cluster analysis for each diurnal time period and day cluster. The winds and ozone concentrations were then plotted on maps to aid the interpretation.

HYSPLIT (version 4.6) back-trajectories using the EDAS meteorological fields at 40-km resolution were computed and plotted for each cluster. Eight back-trajectories per day were computed and inspected with starting heights of 500, 1500, and 2500 meters. These starting heights were selected to characterize certain air mass pathways that might occur during various mixing heights. For example, during mid-day in the summer, atmospheric pollutants are typically well mixed through a deep layer several kilometers due to heating of the surface. The grouping of days by the cluster analysis is summarized in **Table 7-7.**

Table 7-7. Percentage of Days in Each Cluster, by Month; Total Number of Days Per Cluster

| Dates | Strong SW flow (Cluster 1) | Light northerly flow (Cluster 6) | SJV+LV increment (Cluster 7) | Local terrain forced flow (Cluster 13) | Others |
|---|---|---|---|---|---|
| May 15-31 | 29 | 6 | 6 | 47 | 12 |
| June | 43 | 3 | 0 | 37 | 17 |
| July | 13 | 6 | 35 | 35 | 3 |
| Aug | 16 | 3 | 13 | 55 | 13 |
| Total Days Per Cluster | 27 | 5 | 16 | 47 | 14 |

Strong southwesterly was most frequent in early summer (May and June). Light northerly was relatively infrequent and occurred once or twice in each month. San Joaquin Valley plus Las Vegas increment occurred mainly in July. Local terrain-forced flow occurred frequently all months and had highest frequency in August.

**Local Terrain Forced Flow Cluster**

With over 40 percent of the days contained in this cluster, it may be considered as representing "typical" summer conditions. Four days from this cluster exceeded the NAAQS at DAQEM sites, although two of these (June 29 and June 30) were affected by fires. From 7-10 am winds are light and typically upslope (from the east due to morning heating of the east facing slope of the western Las Vegas Valley and the Spring Mountains. Ozone concentrations average <60 ppb at all sites during this time period. For the 11 am to 6 pm period, winds become generally southeasterly, possibly due to the development of a valley wind circulation with winds becoming more aligned with the axis of the Las Vegas Valley, toward higher valley elevations. Average ozone concentrations are >60 ppb at nearly all sites, > 65 ppb at sites in the northwest Las Vegas Valley and > 70 ppb at the Paiute site. Elevated concentrations in the northwestern Las Vegas Valley are likely due to reaction of precursors from the Las Vegas urban area adding ozone to the background of about 60 ppb (value at Jean). At 7-11 pm (not shown), winds are similar to the midnight – 6 am period and ozone concentrations are <60 ppb at all sites.

The frequency of higher-level winds measured by the radar wind profiler (>1200 m agl) from each one degree direction increment for all clusters is shown in **Figure 7-68.** (These levels are likely to be a good indicator of regional transport directions). Figure 7-68 shows that there is a pronounced peak in wind direction frequency from the SSW, peaking at about 202 degrees. **Figure 7-69** shows the difference in wind direction frequency between Local terrain forced and all days. As the average of all days is strongly influenced by Local terrain forced, differences are small. A somewhat lower frequency of southwesterly winds and a slightly higher frequency of other directions are observed. So the predominant SW flow during the whole summer is a little less dominant during local terrain forced days. HYSPLIT back-trajectories for all Local terrain forced days show a wide variety of flow directions, with flows from the south Coast Air

Basin and from the Sea of Cortez common, as well as flows from the generally north direction. Transport from the San Joaquin Valley is not especially pronounced for Local terrain forced flow.

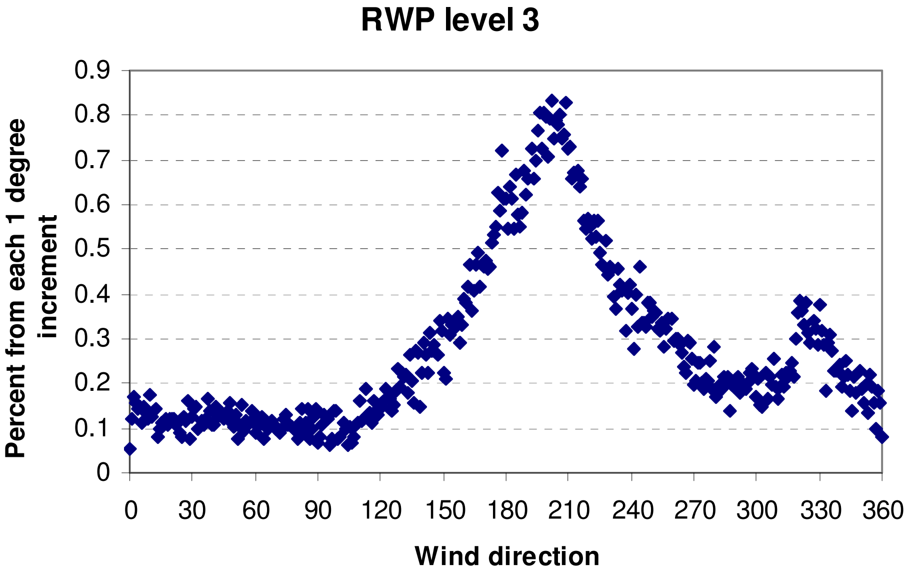


Figure 7-68. Frequency of Wind Directions at RWP Level 3

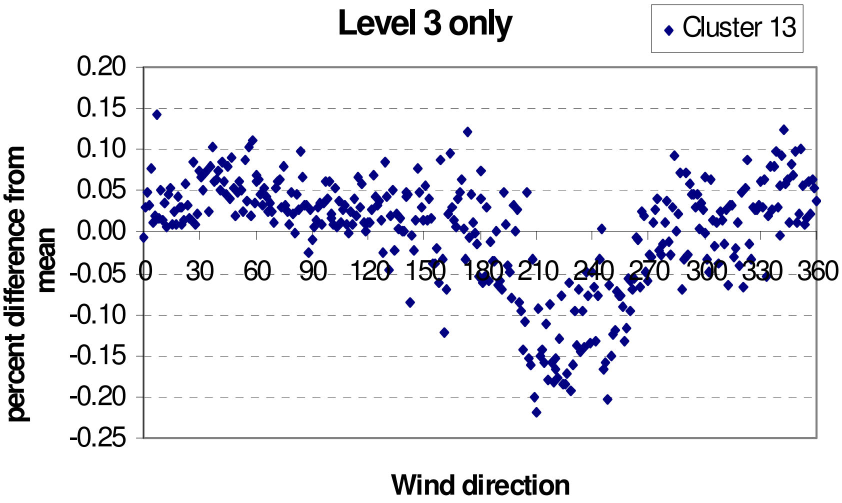


Figure 7-69. Showing Difference in Wind Direction Frequency (percent) Between "Local" and All Days

## San Joaquin Valley plus Las Vegas (SJV + LV) Increment Cluster

SJV + LV increment cluster had the highest average ozone concentrations at many sites. Three SJV + LV increment days (July 3, July 8, July 15) exceeded the NAAQS at DAQEM monitoring sites in northwest Las Vegas. SJV + LV increment had similar surface wind patterns to local terrain forced but typically had higher wind speeds and showed more westerly to southwesterly winds during night and morning hours at sites such as Jean, Sloane, and Lower Potosi. Background ozone concentrations at Jean, Lower Potosi, and Black Mountain were also higher compared to local terrain forced days providing a higher background to which the Las Vegas urban area effects are added. For the hours 10 am to 4 pm ozone concentrations increase dramatically in the northwestern Las Vegas Valley, with an average of 79 ppb at the Pauite site. Winds are from the southeast over much of the valley from the south at Apex and the SW at Jean. Average ozone at Jean for these hours was 70 ppb. The increment at Paiute due to the urban area thus appears to be about 9 ppb.

The radar wind profiler wind direction frequency plot (**Figure 7-70**) shows an enhanced frequency of flow from the WSW and less from the SSW compared to the summer average. HYSPLIT back-trajectories indicate transport for most of the periods from the San Joaquin Valley. If correct, this suggests the San Joaquin Valley as the main source region for the high background ozone during SJV + LV increment days.

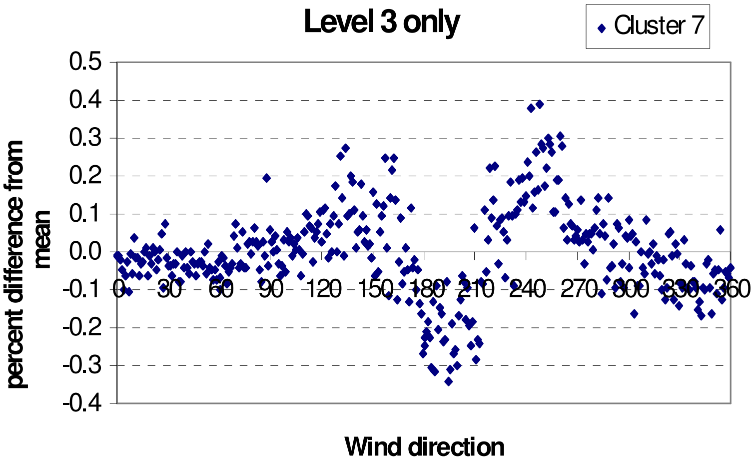


Figure 7-70. Showing Difference in Wind Direction Frequency (%) for SJV + LV Cluster

## Strong Southwesterly Flow Cluster

Strong southwesterly, the second most frequent cluster had generally more southerly and southwesterly winds compared to local terrain forced and SJV + LV increment. Southeasterly upslope flow from the Las Vegas urban area was much less for Strong southwesterly. By the afternoon, winds are from the southwest at all sites, overcoming local terrain forcing effects. The occurrence of strong southwesterly flow is most frequent in May and June when regional to synoptic scale forcing is more pronounced than in July and August. The highest average 8-hour concentrations for this cluster were at Jean (65 ppb). One day from this cluster exceeded the NAAQS at a DAQEM site (Jean, July 2, 86 ppb). The radar wind profiler data showed an enhancement of flow from the southwest for strong southwesterly days compared to the summer average **(Figure 7-71)**. Back-trajectories showed a large majority going over either the San Joaquin Valley or the South Coast Air Basin. The pathways show flow just offshore along the California Coast and either entering the San Joaquin Valley through the San Francisco Bay or moving inland in the Los Angeles Basin. These trajectories enter the Mohave Desert and then continue toward Las Vegas. Under these conditions the South Coast area and the San Joaquin Valley would contribute in a substantial way to background ozone concentrations in Clark County.

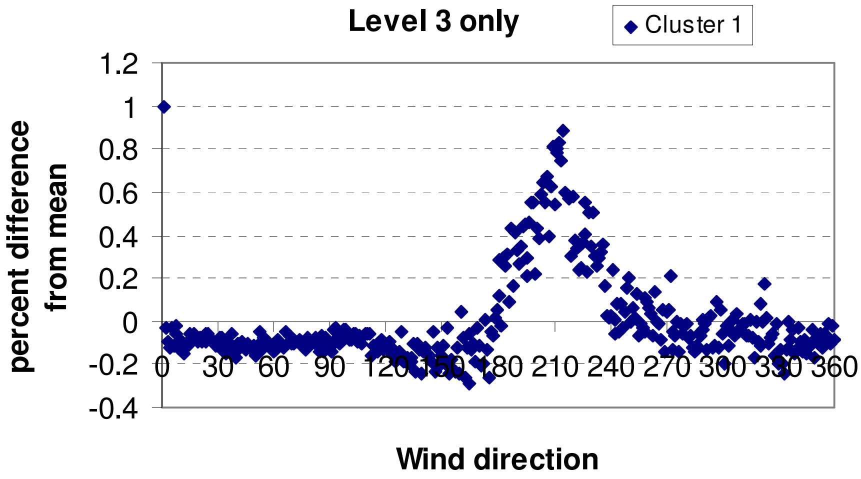


Figure 7-71. Showing Difference in Wind Direction Frequency (percent) for Strong Southwesterly Flow Cluster

## Light Northerly Flow Cluster

Light northerly was characterized by generally northwesterly flow at the surface and aloft. During the afternoon, flow became more westerly to southwesterly except in the northwestern Las Vegas Valley where wind remained northwesterly. **Figure 7-72** shows the difference in wind direction frequency for light northerly for >1200 m agl from the wind profiler data. The data showed a much higher frequency from the NW and lower frequency from the SSW compared to the summer mean.

**Table 7-8** summarizes observations from the cluster analysis.

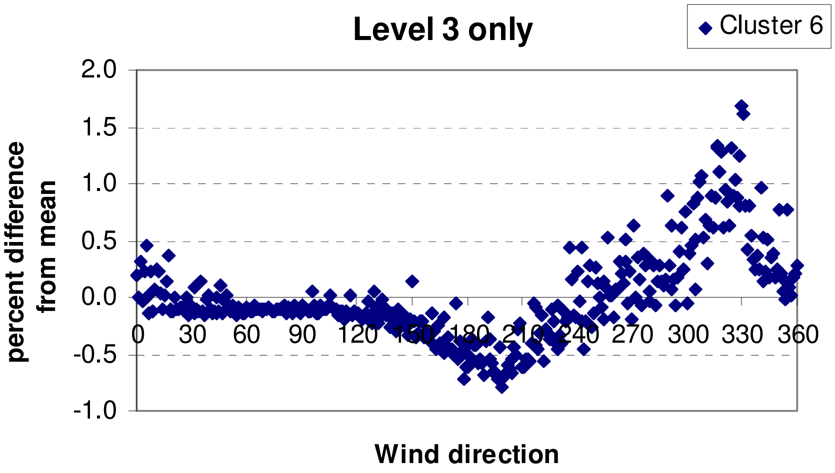


Figure 7-72. Showing Difference in Wind Direction Frequency (percent) for Light Northerly Flow Cluster

Table 7-8. Cluster Analysis Summary

| Cluster | Regional Winds | Surface Winds (midday) | Trajectory pathways | Ozone levels | Las Vegas Ozone Increment |
|---|---|---|---|---|---|
| Strong SW | SW | SW | SJV, South Coast | Highest at background sites<br>– 1 exceedance | None apparent |
| Light N | N | N | N | Highest at Boulder City –<br>No exceedances | 11 ppb |
| SJV + LV | WSW | SE | SJV | Highest NW LV Valley –<br>3 exceedances | 8 ppb |
| Local Terrain Forced | Varied | SE | Varied | Highest in NW LV Valley –<br>4 exceedances<br>(2 fire days) | 9 ppb |

### 7.10.3 Radar Profiler Data Summary

The radar wind profiler (RWP) measurements were subject to cluster analyses also in order to describe the major features observed. This statistical technique was applied to the RWP data to form groups of heights with similar wind directions over each hour of the day. Hours of the day were also clustered to form groups of hours with similar vertical profiles of wind direction. Cluster analysis minimizes within group variance while maximizing between group variances. This method allows the analyst to greatly reduce the number of patterns to look at, while still maintaining information about all vertical levels and diurnal periods.

The cluster analysis formed the following clusters of heights for the RWP data:

Level 1: 176 m - 544 m agl
Level-2: 590 m – 1047 m agl
Level-3: 1183 m – 3711 m agl

The following time periods were clustered:

2200-0300 hrs (10 pm- 3 am)
0400-0800 hrs (4am- 8am)
0900-1000 hrs (9-10 am)
1100-1400 hrs (11 am–2 pm)
1500-1800 hrs (3 pm- 6 pm)
1900-2100 hrs (7 pm-9pm)

This resulted in a total of 18 unique height/time period combinations. For each of these a wind rose was constructed to help visualize the characteristics by time/height.

Not surprisingly, the highest height level shows the least diurnal variation in wind direction. For all hours, winds at level 3 (1183-3711 m agl) are predominantly from the south to southwest. Lower level winds are more variable, being significantly affected by upslope/downslope flows and mountain/valley circulations. Higher-level winds will be closer to winds measured above the influence of local terrain.

### Level-3 Winds (1183 to 3711 m agl)

In **Figure 7-73** the level-3 RWP winds for 3 times of day- hrs 19-21, 22-3, and 11-14 are shown. At the 19-21 hr period, the upper winds show their greatest variability. Winds almost equally distributed in the directions S to WSW, with a smaller fraction from the northwest and few easterlies. In the overnight hours 22-03, winds become more southerly dominated, with somewhat more from the SE and SSE and fewer from the NW quadrant. This may represent more channeling by the north-south oriented mountain ranges at nighttime, with less downward mixing of southwesterly winds above the Spring Mountains. At 11-14 hrs the winds at level-3 have their least variation in direction and are mainly from the southwest. (The wind rose for hrs 15-18 is very similar).

### Level-1 winds (178-544 m agl)

Level 1 winds are the most likely to be similar to surface layer winds and driven largely by local terrain features. Wind rose plots are noticeably different at this level for each of the analysis time periods **(Figure 7-74)**. The 22-03 hr period has the greatest variation in wind direction. Predominant directions are from the southwest, followed by the northwest and northeast. Northwesterly winds are presumably due to drainage flow from the northwestern Las Vegas Valley (along US95). The northeasterlies are less obvious. They may be due to drainage flow from the Las Vegas Range and/or other ranges near the northeastern Las Vegas Valley. The southwesterlies are likely the continuation of earlier evening southwesterlies driven mostly by the regional winds. At 04-08 hrs, the southwesterlies essentially disappear and NNW and ENE are the most frequent directions. From 09-10 hrs and 11-14 hrs the winds are almost totally from the east to southeast and have virtually no westerly component. These are presumably upslope flows due to morning heating of the southeast facing slopes of the Spring Mountains.

There is a rotation from 09-10 hrs to 11-14 hrs with winds shifting in a clockwise manner from the east to the southeast. From 15-18 hrs the winds have a broad distribution from the southeast through southwest. Finally by 19-21 hrs winds become dominated by westerlies, with a peak frequency from the WSW. It is worth noting that winds with a northerly component are frequent during nighttime (22-03 and 04-08), they are almost non-existent for RWP level-1 from 11-21 hrs.

### Level-2 Winds (590-1047 m agl)

Level-2 winds (590-1047 m agl) not surprisingly show characteristics intermediate between level-1 and level-3, but are more similar to level-1 winds. They are not shown separately here, but appear in the **Appendix A** and are shown in some examples comparing winds at the three levels in the subsection below.

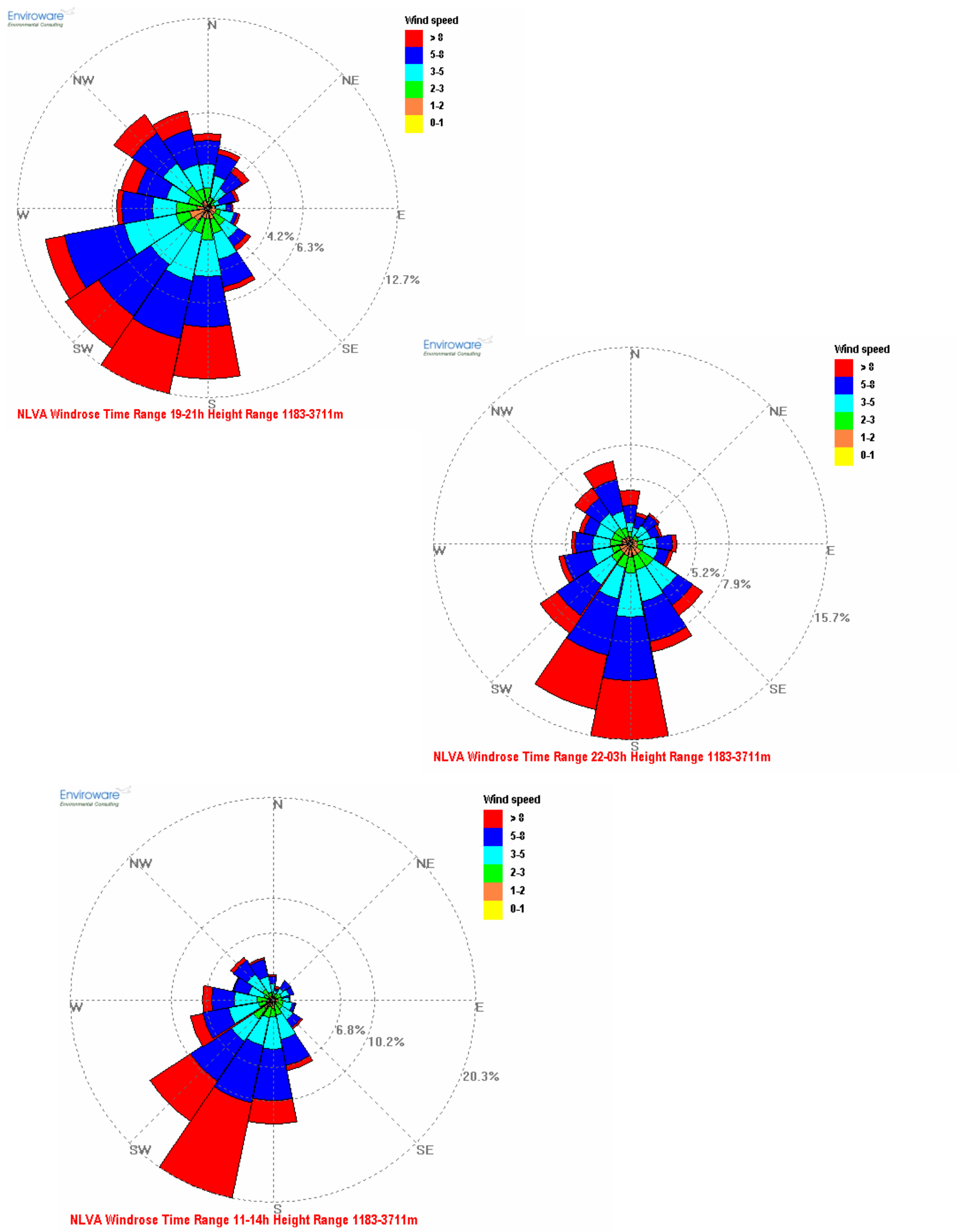


Figure 7-73. Level-3 Wind Roses for Hours 19-21(upper), 22-03 (middle), and 11-14 (lower) for the Radar Wind Profiler at the North Las Vegas Airport

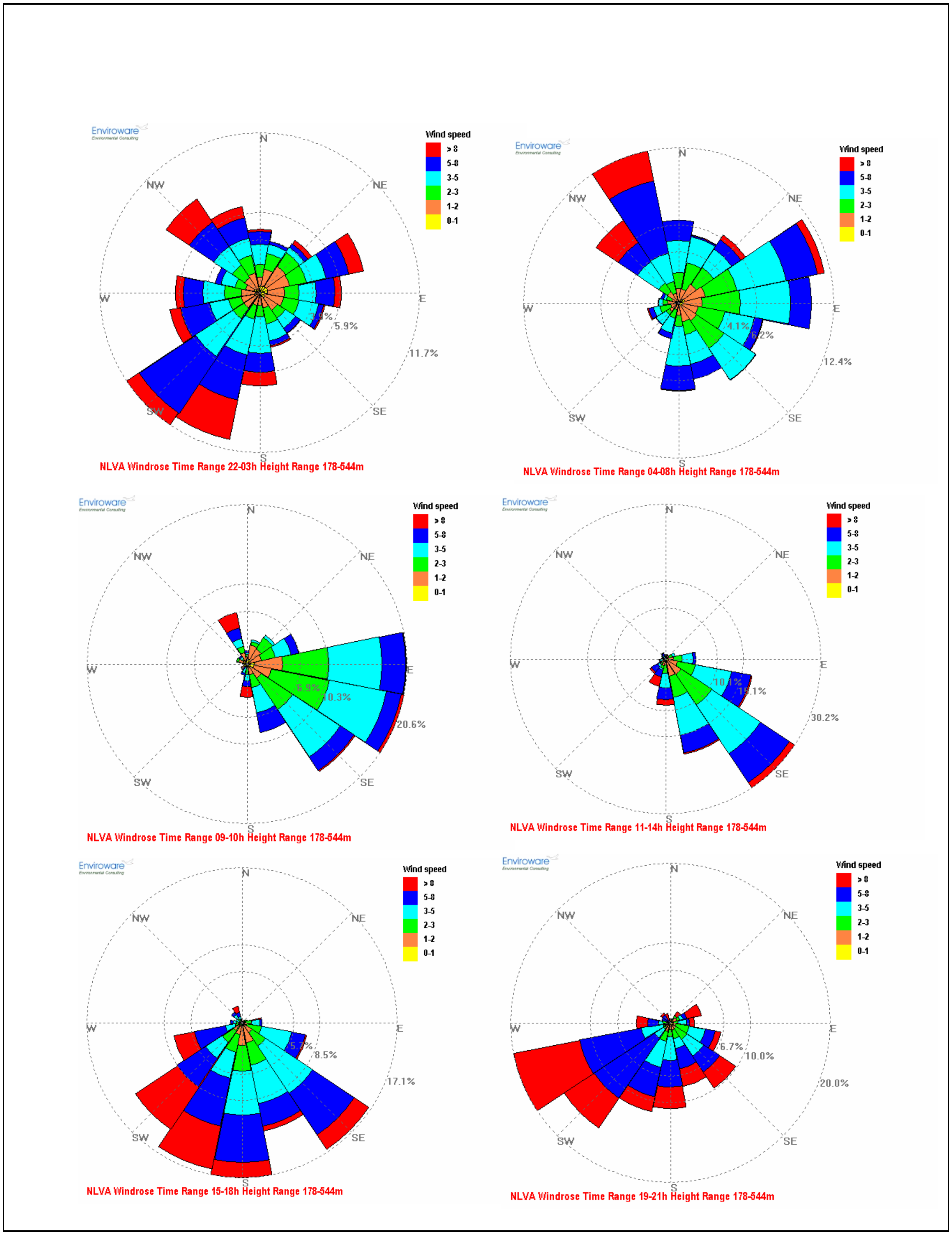


Figure 7-74. Level -1 Winds (177-544 m agl) by time of day for the Radar wind profiler at the North Las Vegas Airport

Comparison of lower and higher level winds by time of day

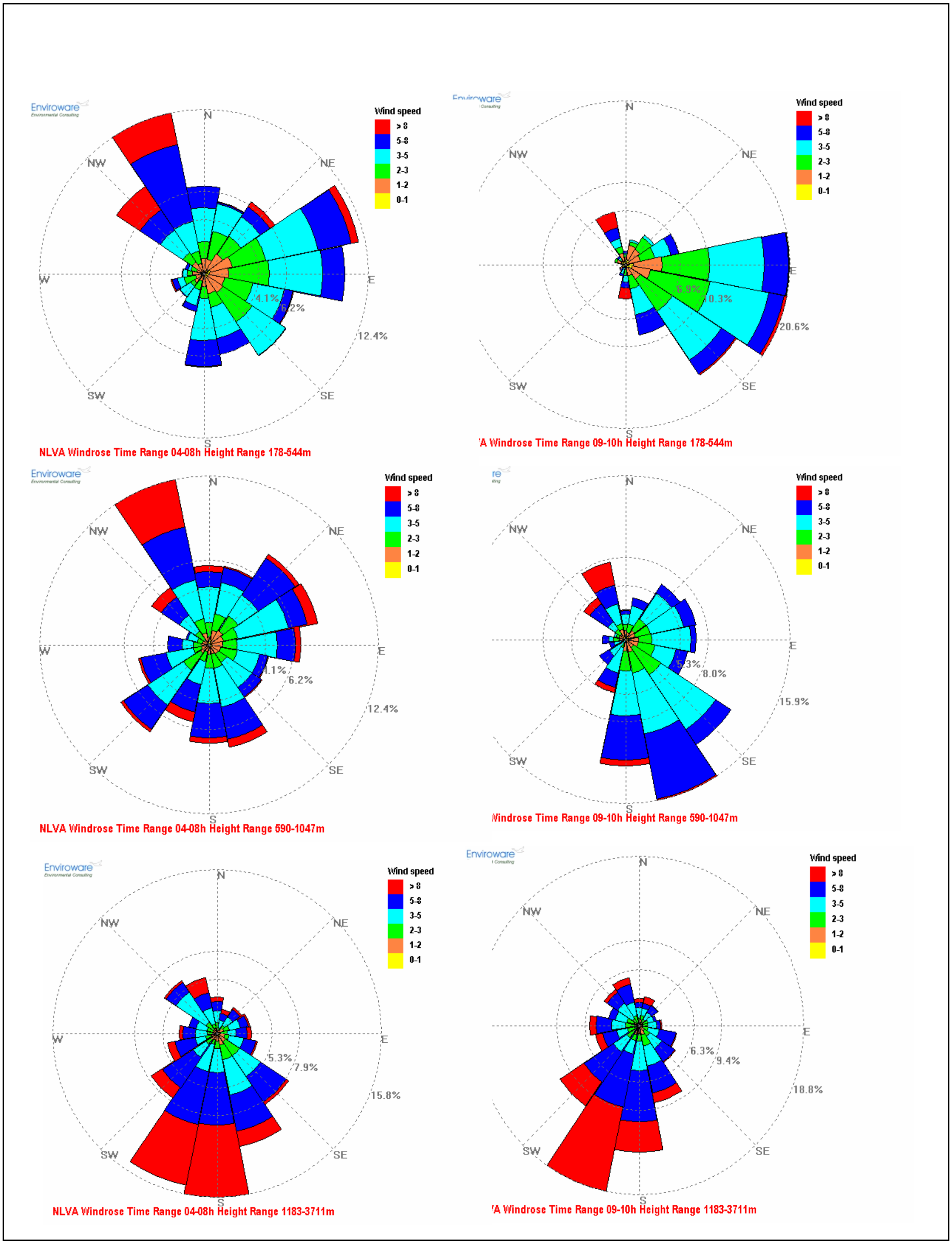
During nighttime and morning, more differences are noted between lower layer and higher layer winds (vertical wind shear). This is expected as lower layers are less coupled to upper layers and more likely to represent local upslope/downslope flows than regional flows.

At hours 04-08 (**Figure 7-75)** (left panel) the peak frequencies are from the NW and NE at level-1 and few SW winds; at level-2 the NW & NE peak is apparent, but also a significant fraction from the SW; at level-3 south winds dominate.

At hours 9-10 (Figure 7-75 right panel) upslope flows from the E and ESE at level-1 are noted, with a clockwise shift toward SSE at level 2 and continuing shift to SSW at level 3. Wind speed increase with height as well.

By hours 15-18, **(Figure 7-76)** (left panel), winds at all levels (especially 1 and 2) continue their clockwise rotation. They become broadly southerly at levels 1 and 2 and mostly southwesterly at level-3. There is virtually no frequency of wind with a northerly component at levels 1 and 2.

At hours 19-21 (Figure 7-76 right panel) for levels 1 and 2 are from the SE through WSW, with a peak frequency of WSW at level 1 and SW at level 2. At level-3 there is a greater fraction of winds with a northerly component (mainly NW) than at levels 1 and 2.



NLVA Windrose Time Range 04-08h Height Range 178-544m

A Windrose Time Range 09-10h Height Range 178-544m

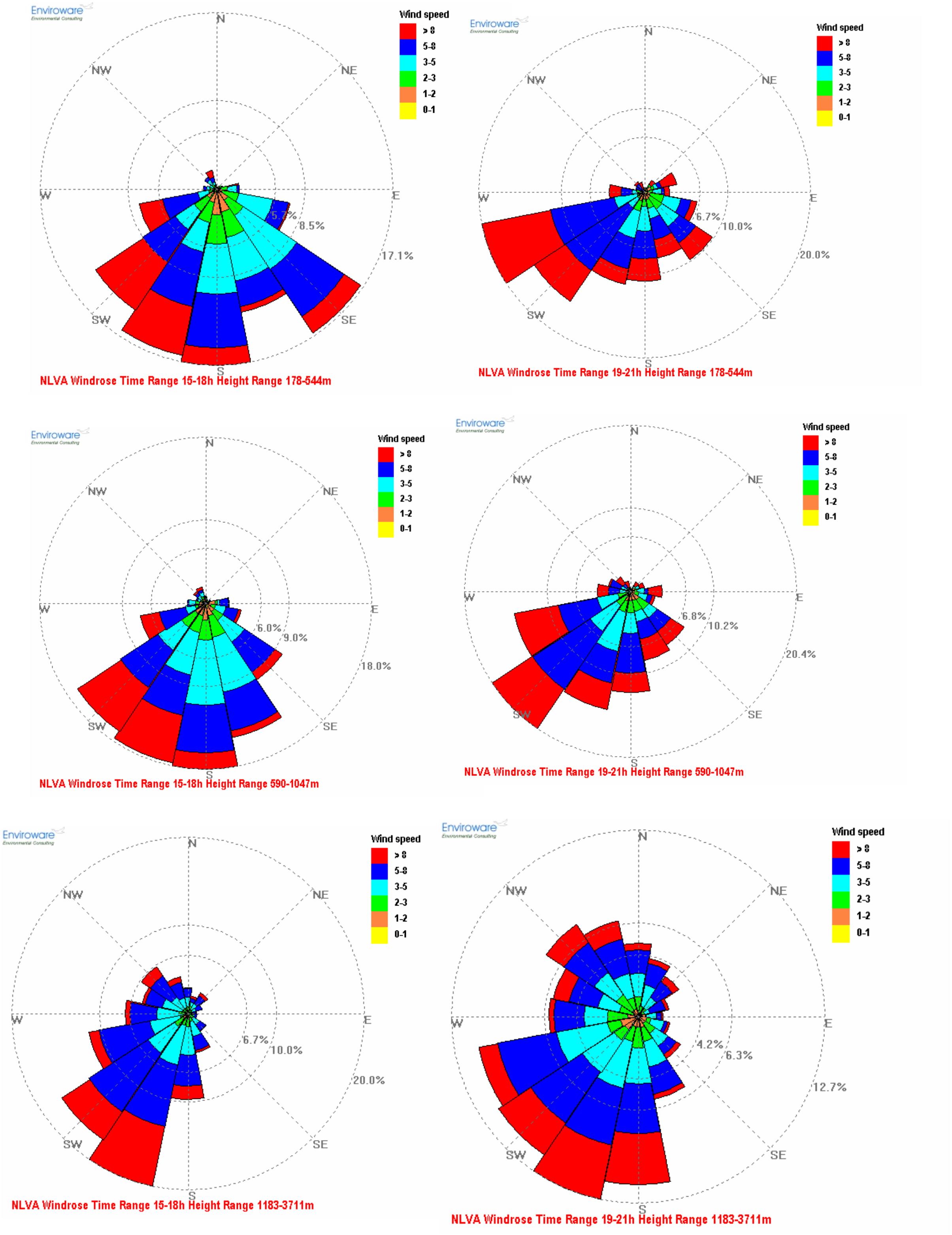
NLVA Windrose Time Range 04-08h Height Range 590-1047m

indrose Time Range 09-10h Height Range 590-1047m

NLVA Windrose Time Range 04-08h Height Range 1183-3711m

A Windrose Time Range 09-10h Height Range 1183-3711m

Figure 7-75. Vertical Profile of RWP Winds at North Las Vegas Airport for Hours 04-08 (left panel) and 09-10 (right panel)



NLVA Windrose Time Range 15-18h Height Range 178-544m

NLVA Windrose Time Range 19-21h Height Range 178-544m

NLVA Windrose Time Range 15-18h Height Range 590-1047m

NLVA Windrose Time Range 19-21h Height Range 590-1047m

NLVA Windrose Time Range 15-18h Height Range 1183-3711m

NLVA Windrose Time Range 19-21h Height Range 1183-3711m

Figure 7-76. Vertical Profile of RWP Winds at North Las Vegas Airport for Hours 15-18 (left panel) and 19-21 (right panel)

### 7.10.4 SODAR Data Summary

For the SODAR data cluster analysis, the following three level were used:

40-80 m agl
100-180 m agl
200-300 m agl

**Jean Airport SODAR**

The Jean SODAR data showed that winds at all levels were nearly always from the generally southwest direction. Wind roses for each of the 3 levels at hours 04-08 and 19-21 are shown in **Figure 7-77.** Differences in wind with height were minor in direction, but become consistently stronger with height. At 200-300 m the winds were nearly always greater than 8 m/s. At the 2 lower layers, wind direction frequency peaks from the SSW at all hours except 15-21 where it is slightly higher from the SW. At the highest level (200-300 m), wind direction frequency is highest from the southwest for all hours with a peak frequency from this one 22.5 degree sector of 61 percent at hours 19-21. At all hours the higher level has less variation in wind direction than the lower 2 levels.

A slight clockwise rotation in wind direction is apparent at all three levels as the day progresses.

**Tule Springs SODAR**

The most frequent wind direction at Tule Springs at nighttime and early is from the northwest, with a secondary maximum from the northeast **(Figure 7-78**). The northwest flow is expected to be drainage flow from the Spring Mountians. At hours 09-10 flow from the E to ESE is dominant (Figure 7-77), consistent with upslope flow caused by heating of the east facing slopes of the Spring Mountains.

At hours 15-18 there is substantial vertical shear in the wind direction with a clockwise rotation in direction with height **(Figure 7-79).** For this time period, winds are mainly from the SE at 40-80 m, S at 100-180 m, and W to NW at 200-300 m.

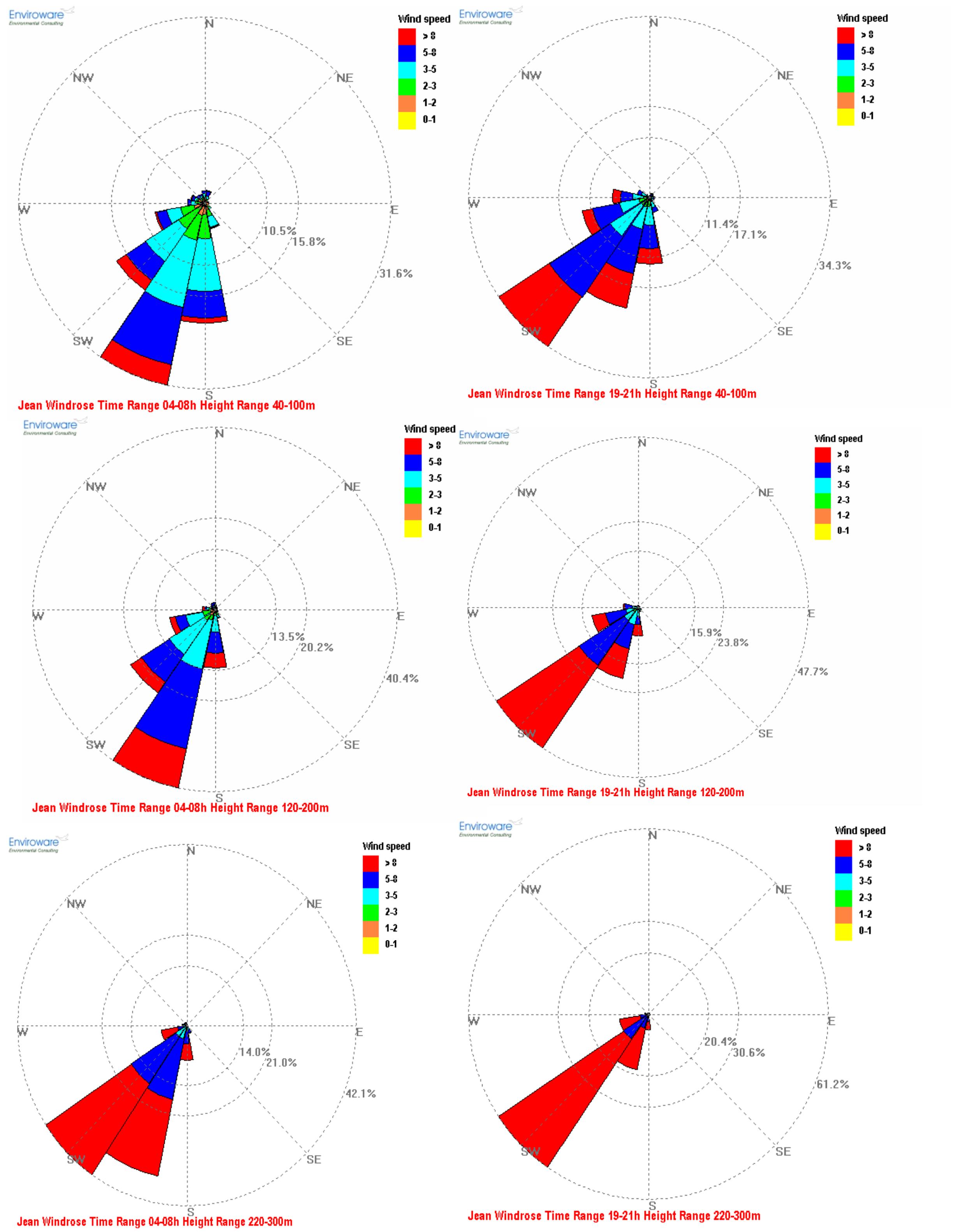
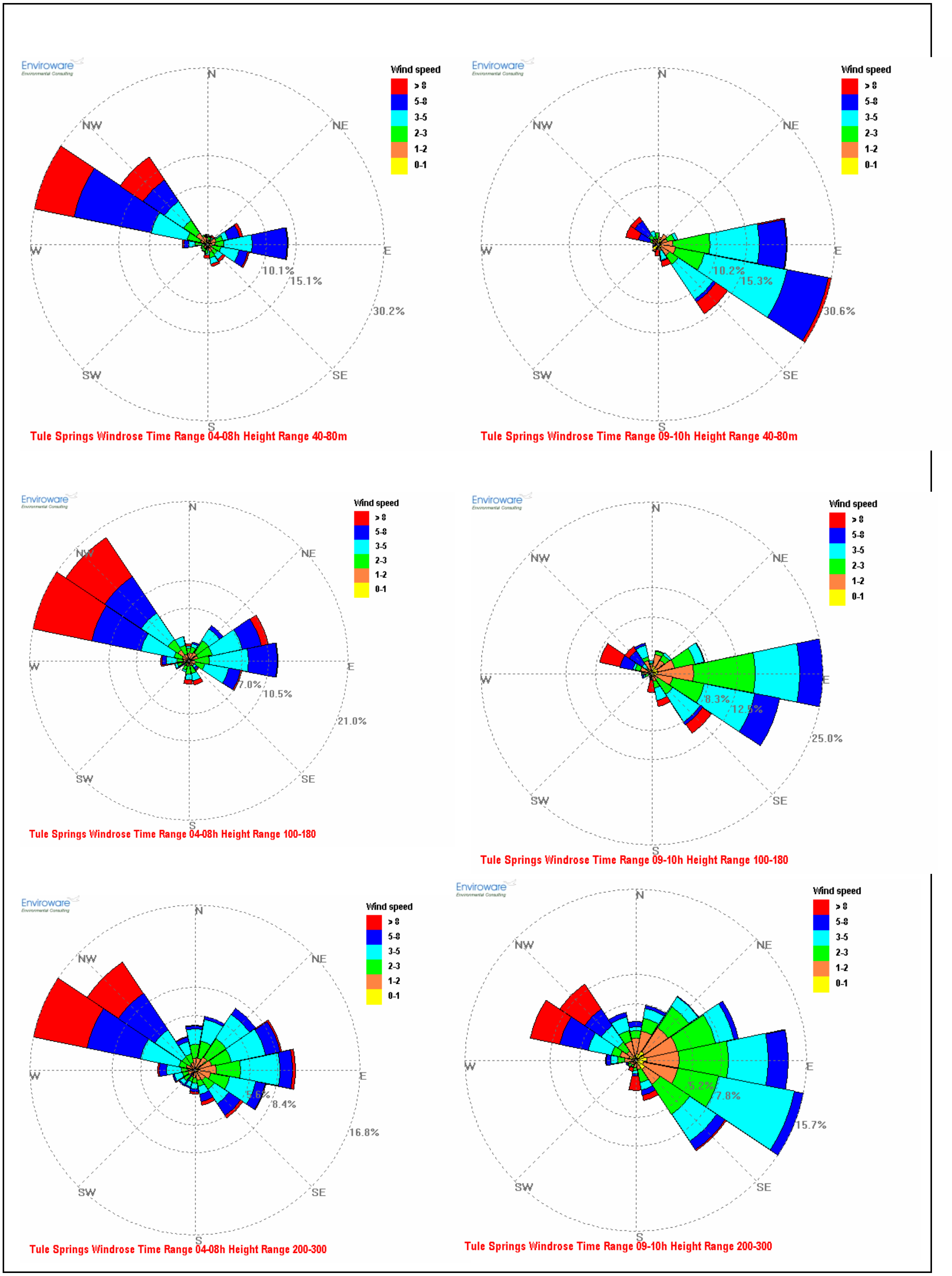


Figure 7-77. Vertical Profile of Winds for Jean SODAR Site Hours 04-08 (left panel) and 19-21 (right panel)



Tule Springs Windrose Time Range 04-08h Height Range 40-80m

Tule Springs Windrose Time Range 09-10h Height Range 40-80m

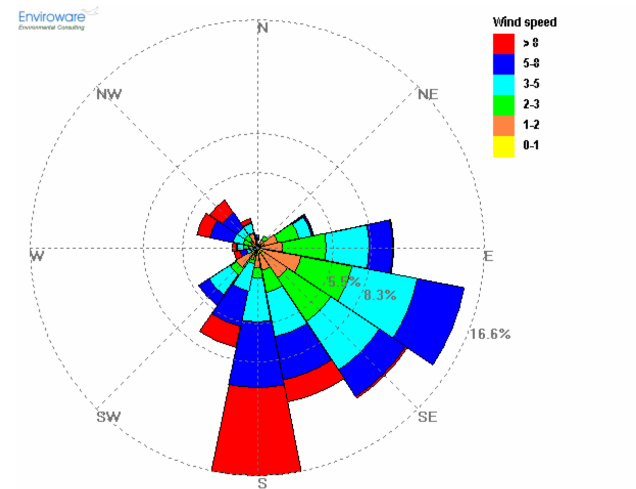
Tule Springs Windrose Time Range 04-08h Height Range 100-180

Tule Springs Windrose Time Range 09-10h Height Range 100-180

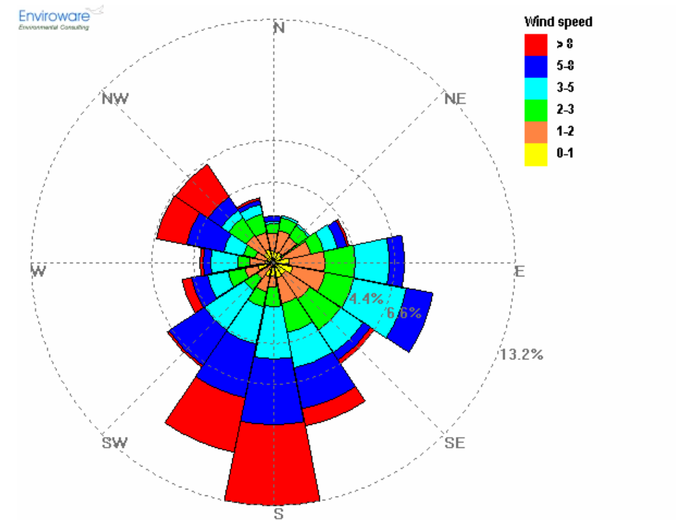
Tule Springs Windrose Time Range 04-08h Height Range 200-300

Tule Springs Windrose Time Range 09-10h Height Range 200-300

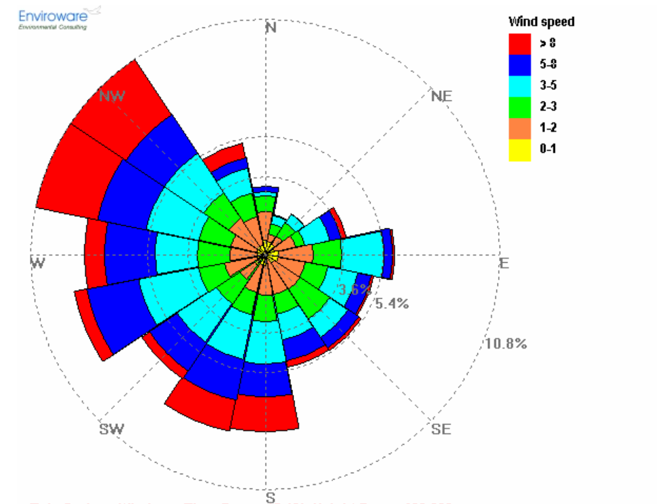
Figure 7-78. Wind Roses for 40-80 m, 100-180 m, and 200-300 m agl at Tule Springs for Hours 04-08 (left panel) and 09-10 (right panel)



Tule Springs Windrose Time Range 15-18h Height Range 40-80m



Tule Springs Windrose Time Range 15-18h Height Range 100-180



Tule Springs Windrose Time Range 15-18h Height Range 200-300

Figure 7-79. Vertical Variation in Winds at Tule Springs for Hours 15-18

**Las Vegas Motor Speedway SODAR**

At the Speedway SODAR site, except for hours 22-3, winds at all levels for all time are dominated by E or ESE directions. For the hour 22-3 time period, wind directions are more variable and show a clockwise rotation with height **(Figure 7-80 left panel)**. At hours 9-10 the range of wind directions is narrowest, reaching 61 percent frequency from the ESE at the 220-300 m level. There is a substantial increase in wind speed with height for the 9-10 am period with most of the winds at 200-300 m being above 8 m/s, and nearly none at the 40-80 m level being > 8m/s (Figure 7-79 right panel).

In summary, during the periods most important for generation of ozone and transport of ozone and precursors, wind at all the sites measured except Jean show predominant flow from the southeast. At Jean flow is from the southwest all hours. The exception is winds higher level winds from the radar wind profiler which are mainly from the SSW. By late afternoon, winds become more variable in direction at all sites except Jean. All sites except Tule Springs show significant vertical shear in wind speed. The radar wind profiler, covering a much deeper depth than the SODARs also show substantial changes in wind direction frequencies with a clockwise rotation with height (e.g., from SE to SW).

During midday when ozone concentration are likely to be highest, low level transport is mainly upslope (from SE in northern Las Vegas Valley) and more south-southwesterly aloft. This allows for transport of ozone from southern California at higher levels and from the Las Vegas Valley at lower levels, with significant mixing expected due to the deep mixing depths for these hours. Overall, the winds show some complicated patterns that may be important in transport of ozone and precursors.

There is significant shear in wind speed direction with height at all sites. The directional shear is greatest at night while the speed shear is present both day and night.

Regarding the boundary layer growth, directional shears are less with height in the late afternoon to early evening. The lower level winds come more into alignment with the upper level winds implying mixing from the increased boundary layer depth.

There is no apparent indication of a nocturnal jet although there are significant increases in wind speed with height even in the first 300 meters or so with SODAR data.

Spatial variation is also discussed- Jean always showed southwesterly winds a all levels. The sites in the northern valley (North Las Vegas Airport, Tule Springs, and Speedway) showed mostly southeasterly flow at low levels during peak ozone hours and the wind profiler showed southwesterly flow aloft.

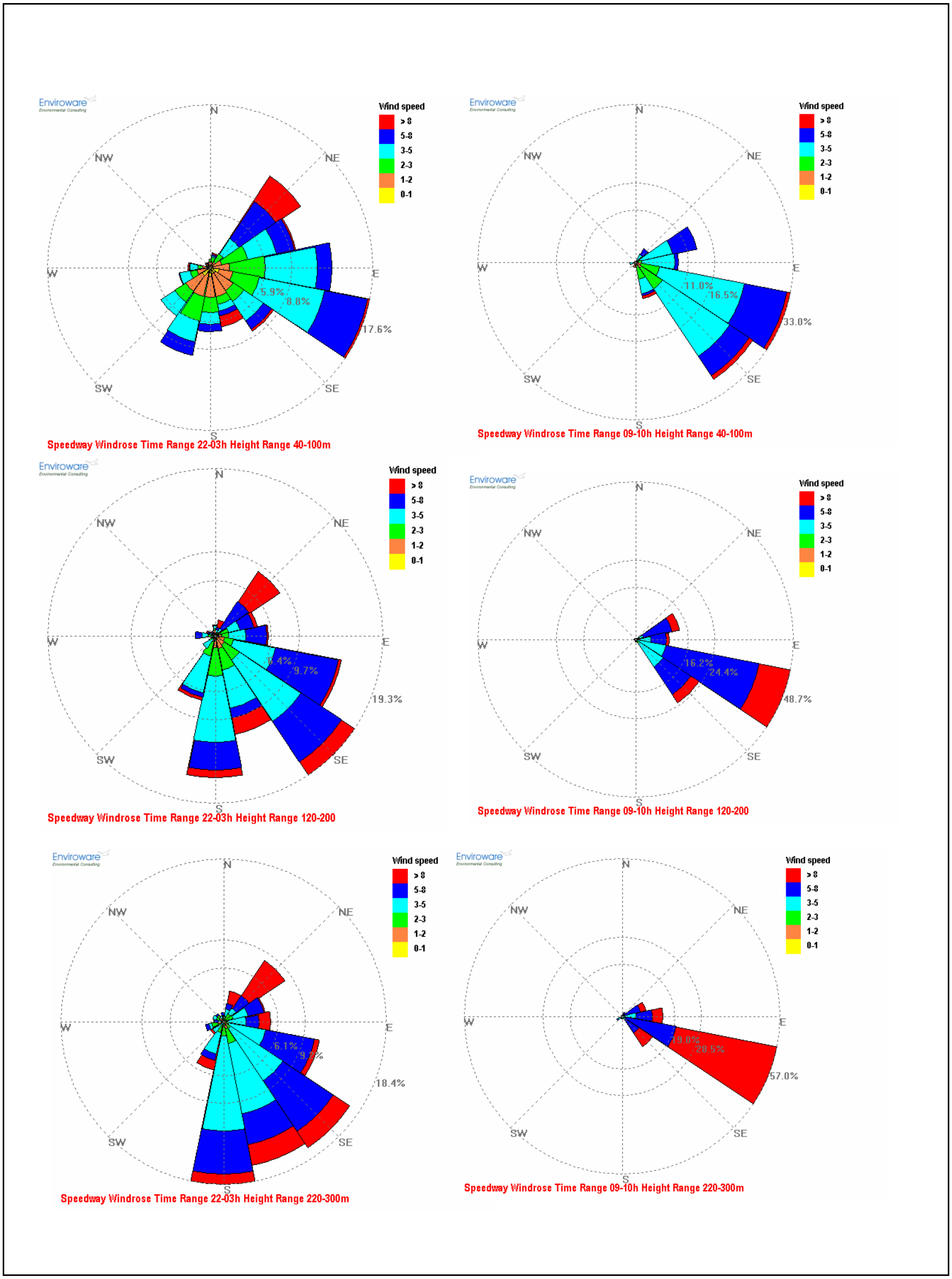


Figure 7-80. Vertical Profile of Winds at the Speedway SODAR Site for Hours 22-03 (left panel) and 09-10 (right panel). Note the vertical shear in wind direction at hours 22-03 and the vertical shear in wind speed at hours 15-18.

# 8. RECOMMENDATIONS

## 8.1 Recommended Monitoring Network Changes and Enhancements

On the basis of the existing and enhanced measurement network data collected during the 2005 field study, we have the following recommended monitoring network changes and enhancements:

- The Ozone Characterization Study revealed that ozone data from City Center was being impacted by emissions from an adjacent major highway. This was supported by the 2005 field study measurements. Indeed, the site does not currently meet EPA siting criteria for ozone due to its proximity to the highway. No data from City Center were used for any of the above analyses, as it appears to be not representative of regional ozone concentrations, with unrepresentatively low daytime readings due to titration by NO from vehicles on the freeway. For these reasons, it is recommended that ozone monitoring be terminated at City Center as it does not provide useful information regarding community health impacts. Data from the nearby JD Smith site appear to adequately represent this area.
- A permanent site at Paiute should be installed to ensure that peak ozone exposure in Clark County is measured.
- A permanent site at Indian Springs should be installed to further define the northwest extent of high ozone levels. Moreover, as growth and development continues to expand in the Valley, the ozone peak could conceivably shift further northwest.
- The ozone anomaly observed at Sunset Park was resolved by a special monitoring study in 2006. It was concluded that this feature was due to an artifact of the particular instrument used. Moreover, the 2006 measurements showed that the ozone levels measured at the existing Orr Street and Henderson sites are representative of Sunset Park; therefore, no additional monitoring is suggested.

In addition, the following monitoring should be considered:

- An additional ozone site in the foothills to the northwest of Las Vegas. The saturation network showed the urban ozone plume extending well into the foothill region. While the Lone Mountain site does a fairly good job of representing the area, an additional site may be warranted, especially as the area demographics changes. For example, housing developments are already extending to the Red Rock Canyon boundary. Kyle Canyon development and regions between will likely follow.
- Additional monitoring in the Craig Ranch area for similar reasons. Temporary monitoring should initially be considered to confirm the results obtained by the saturation network.
- To determine the importance of ozone aloft at night and early morning, and to aid in the daily ozone forecasts, monitoring could be conducted at one of the two CCROPS ridgetop sites. Based on preliminary analyses, both the Black Mountain and Lower Potosi sites did a good job of producing measurements representative of ozone concentrations aloft. However, the Black Mountain site is considerably closer to the DAQEM offices, and would therefore easier to service.
- Additional upper level wind measurements should be made to better characterize winds in the Las Vegas Valley during the ozone season. Because the low level winds are mainly from the SE in the northern Las Vegas Valley and from the SW at Jean, additional SODAR measurements should be made. Possible areas are in the southeastern Valley (Henderson), as no upper-air data is available there and there is a rapid growth in population and vehicle miles traveled, as well as some industrial sources. Another area to consider is the western valley.

## 8.2 Recommended Additional Analyses

To further enhance the understanding of the ozone issues we recommend the following additional analyses of the data collected during the 2005 study:

- Select periods from the 2005 field study for detailed analyses and as candidates for DAQEM's numerical modeling based on 1) the quality and extent of measured data, 2) initial indications of the contributions from interbasin transport and/or local sources, and 3) representativeness. Detailed descriptive analyses should be performed of the 3-dimensional wind field using all sonde, SODAR, and profiler measurements. The growth and decay of the surface boundary layer evaluated, and the characteristics of ozone and precursors both at the surface and aloft should be determined. This initial analysis suggests that the July 2 exceedance was the best candidate for overwhelming transport being the major contributor, and the July 14-18th period the best candidate for an exceedance primarily due to local sources. There were other episodes with greater exceedances but other factors such as wildfires would involve more complex emissions inventories and chemical processes.
- From the periods selected for detailed analyses and modeling, determine what features are critical to ozone processes. Compare these features with MM5 and ozone model outputs.
- Examine the hourly timing of peak ozone within the extended network. Characterize with respect to the 'conceptual model' developed from the detailed episode analysis.
- Using the entire data set, including aircraft measurements, quantify the contribution by the Las Vegas urban area to ozone concentrations under different meteorological scenarios.
- Integrate the ozone, VOC and $NO_y$ data to determine extent of reaction and what information can be extracted regarding major sources.
- Examine the meteorology and air quality measurements at locations such as Moapa, Meadview, Mesquite, and western Utah for downwind impacts.
- Examine more in detail interbasin transport routes (e.g., Coachella Valley in the south and Antelope Valley in the north of the SoCAB, and Tehachapi Pass for San Joaquin Valley).
- Investigate in greater detail the effect that wildfires have on ozone formation. Determine the extent of the smoke plume using existing PM and $NO_y$ data.
- Update and refine the existing CART model and forecasting protocol.