2012 UTAH OZONE STUDY

Prepared by

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January 2013

DAQK-15-13

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I. ACKNOWLEDGMENTS

Many DAQ staff members assisted in the completion of the 2012 Utah Ozone Study. Thanks to Neal Olson for technical support and general input into the project. Thank you to Colleen Delaney for her work in developing this project and assisting in locating study sites. Thanks to Larry Larkin for assistance in field work. Finally I would like to thank Bryce Bird, Brock LeBaron, Dave McNeill and Bo Call for supporting the study.

Thank you to Bob Swensen and Nate Brooks of the Summit County Health Department for assistance on locating sites in Summit County, for allowing DAQ to locate equipment in their mobile air quality monitoring trailer and for the use of particulate matter and meteorological data collected in Kamas. I would like to thank the following people and organizations, in no particular order, for their permission to locate air quality monitoring equipment on their property: Larry St. Claire of Brigham Young University, Stan Kitchen with the US Forest Service, Steve Jackson with the Tooele Valley Airport, Mark Anderson, City Manager of Heber City, Randy McKnight, City Manager of Nephi City, Mont Cooper with the Park City Fire Service District, Todd Hansen with the Park City School District, Shered Mullins of the Bureau of Land Management, Laura Melling with Gunlock State Park, Curt Perry with Mt. Pleasant City, Joan Card with the Municaplity of Park City, Wayne Sadler and Brian Davenport of Mountain Regional Special Service District, Alan Riding with Delta City Corporation, Kenneth Adams, Superintendent of Morgan School District and the Huntsville Fire Department.

II. EXECUTIVE SUMMARY

The current National Ambient Air Quality Standard (NAAQS) for ozone is an 8-hour average of 75 parts per billion (ppb). Since 2010, The Environmental Protection Agency (EPA) has proposed lowering to ozone NAAQS to an 8-hour average of 65-70 ppb, but has since postponed the proposal. The third year of a Utah Division of Air Quality (DAQ) special ozone study focused on monitoring ozone in three regions of Utah: the mountain valleys east of the Wasatch Front with a focus on the Park City area, the Tooele Valley and rural western Utah.

Ozone concentrations at the mountain valley sites during 2012 were moderate to high with eight of ten sites having at least one day when ozone concentrations exceeded 75 ppb. The highest ozone was found at three sites in the Park City area (Parleys Summit, Snyderville and Silver Summit) and Heber where there were four to ten days with ozone exceeding 75 ppb. For comparison, Salt Lake City experienced seven days with ozone exceeding 75 ppb. In general, ozone in the Park City area of Summit County was equal to or higher than ozone in Salt Lake City and at other Wasatch Front sites. Ozone in Morgan and Huntsville was moderately high, but generally lower than ozone observations at the DAQ site in Harrisville. High ozone in the Park City area was most strongly influenced by transport of ozone and ozone precursors from Salt Lake City. Analysis of dominant wind patterns and timing of maximum daily ozone suggests clear transport of pollutants from Salt Lake City, up the Parleys Canyon corridor and into the Park City area and Kamas. Ozone formation at all mountain valley sites was also likely enhanced by increased ultraviolet radiation at higher elevation sites, which is supported by solar radiation data. Smoke from wildfires and biogenic emissions volatile organic compounds in mountain forests also may have impacted ozone at mountain valley sites.

In the Tooele Valley, ozone concentrations in Erda and East Erda were significantly higher than ozone at the DAQ site in Tooele. Erda was one of the highest ozone sites in all of Utah during 2012 and the three year average of the 4th highest 8-hour ozone concentrations was 77 ppb, equaled only by the DAQ site in Salt Lake City. High ozone in the northern portion of the Tooele Valley was likely influenced by Great Salt Lake; high albedo off the lake surface likely enhanced ozone formation and routine off-shore lake winds blew air from Great Salt Lake into Tooele Valley. Ozone concentrations at Badger Island, a site on a causeway in the middle of Great Salt Lake, were the highest observed in Utah with thirteen days exceeding 75 ppb. Ozone concentrations at Badger Island typically formed earlier in the day and persisted longer into the afternoon than at Tooele Valley sites.

Ozone concentrations at rural Utah sites, except at Antelope Island where ozone was very high, were typically lower than other Utah sites. Peak seasonal ozone concentrations occurred in May and early June at all rural sites and maximum 8-hour ozone concentrations exceeded 75 ppb at least once at all sites except Nephi where ozone concentrations peaked at 75 ppb. Badger Springs, in extreme southwestern Utah, was one of the highest ozone sites in Utah; 8-hour ozone concentrations exceeded 75 ppb on ten days. The 4th highest 8-hour ozone concentration exceeded 70 ppb at all rural Utah sites. High ozone concentrations in rural Utah were potentially influenced by regional transport of ozone, springtime emissions of biogenic volatile organic compounds, stratospheric ozone intrusion and wildfire smoke.

III. INTRODUCTION

In 2008, the Environmental Protection Agency (EPA) lowered the ozone National Ambient Air Quality Standard (NAAQS) from 80 to 75 ppb. Following a three-year examination of ozone along the Wasatch Front (2006-2008), the Utah Division of Air Quality (DAQ) recommended establishing an ozone nonattainment area that included Salt Lake, Davis and western Weber counties. DAQ also recommended that the remainder of Utah should be classified as “Attainment” or “Unclassifiable” under the ozone NAAQS. EPA responded to DAQ’s recommendations by suggesting that, based on 2007-2009 monitoring data, the Salt Lake-Ogden-Clearfield Combined Statistical Area (CSA) be designated as a nonattainment area for ozone which includes eight counties: Box Elder, Davis, Morgan, Salt Lake, Summit, Tooele, Wasatch and Weber.

Ozone monitoring in 2010-2012 showed that all counties along the Wasatch Front were in attainment of the ozone NAAQS. Monitors in Box Elder, Salt Lake, Tooele, Utah, Washington and Weber Counties had three-year averages that met the NAAQS, but the 4th highest 8-hour ozone concentrations were between 70 ppb and 75 ppb. Permanent DAQ monitors in Carbon and Duschesne Counties also reported a 4th highest 8-hour ozone concentrations were between 70 ppb and 75 ppb, but three years of data were not collected. Three-year averages of 4th highest 8-hour ozone concentrations at a non-regulatory monitor in Tooele County (Erda) exceeded the ozone NAAQS and a monitor in Summit County (Silver Summit) nearly exceeded the ozone NAAQS. Following EPA’s proposal for area designations, implementation of the 2007 NAAQS was delayed as the decision on the standard was reviewed. In 2011, EPA decided not to proceed with the review of the ozone NAAQS and that the designations for the 2007 NAAQS would be made based on 2009-2011 data. Final decision on the ozone NAAQS is still forthcoming, but it seems likely that the standard may be lowered to 60-70 ppb.

Monitoring data from many sites along the Wasatch Front, as well as from several ozone monitors operated by the National Park Service or Bureau of Land Management in more remote areas of Utah measured three-year averages of the 4th highest 8-hour ozone concentration over 65 ppb. DAQ ozone studies in 2010-2011 found many sites outside the Wasatch Front where peak ozone concentrations ranged from 70-75 ppb. The 2012 summer ozone study focused on monitoring in mountain valleys east of Wasatch Front cities, the Tooele Valley and rural western Utah. During 2010 and 2011, moderate to high ozone concentrations were observed in Summit County, Heber and Huntsville. Ten monitoring sites in mountain valleys were established to determine the extent of ozone pollution in mountain valleys, the area of highest ozone concentration in the Park City area and the causes of high ozone concentrations in mountain valleys. Monitoring in Erda during 2010-2011 found that ozone concentrations were significantly higher than ozone at the permanent DAQ site in Tooele. Additional monitoring in the Tooele Valley during 2012 was established primarily to determine the area of highest ozone concentrations and secondarily to continue to examine the role of Great Salt Lake on ozone formation in the Tooele Valley. Finally, ozone monitoring continued, or was established at five rural western Utah sites due to continue to investigate the cause of high springtime ozone concentrations in rural Utah.

IV. METHODS and PROCEDURES

1. Overview

The 2012 summer ozone study was divided in three sub-studies: the mountain valley ozone study, the Tooele Valley ozone study and the rural Utah ozone study. The primary goal of the mountain valley study was to determine the extent and magnitude of ozone pollution in mountain valleys to the east of major Wasatch Front cities. The Tooele Valley ozone study was designed as a small-scale ozone saturation study to determine the location of highest ozone concentration in Tooele Valley. Finally, the primary goals of the rural Utah ozone study were to understand factors that contribute to periodic high ozone concentrations in rural Utah areas and to assess regional transport of ozone. The location of eighteen sites is shown in Figure 1. See Figure 3 for Park City area sites.

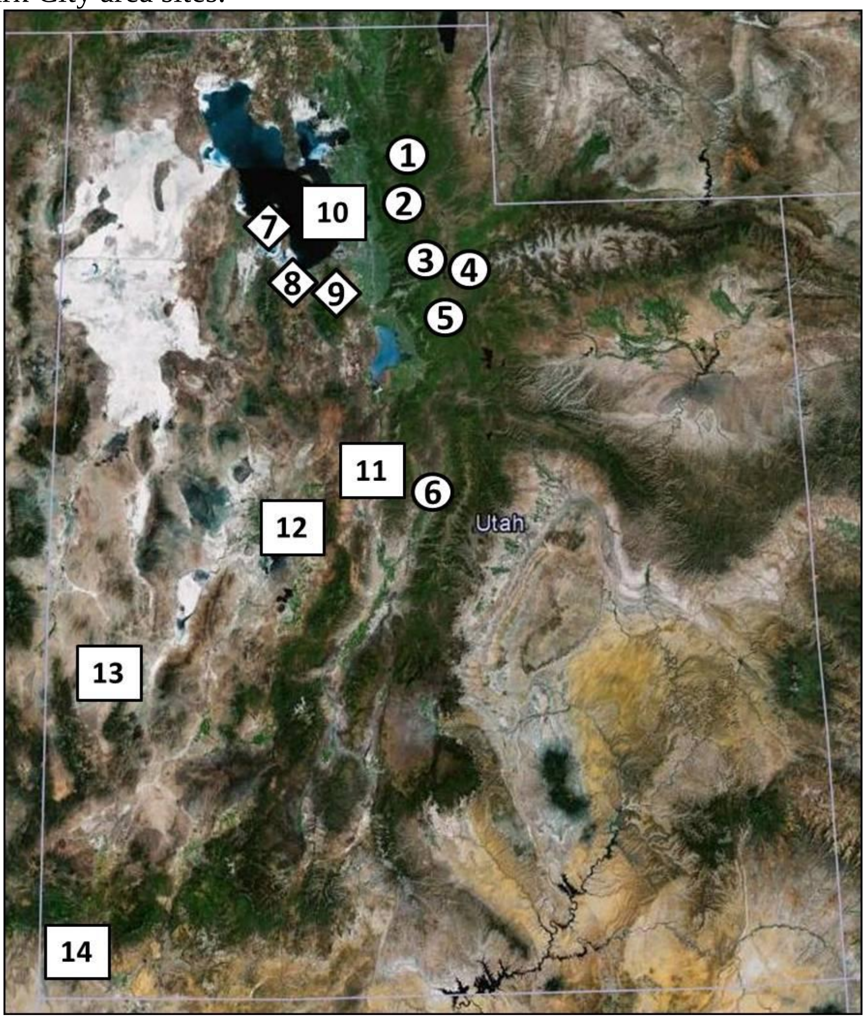

Figure 1. Map of Utah showing sites where ozone was monitored during March-October of 2012. Circles represent mountain valley study sites, diamonds represent Tooele County study sites and squares represent rural Utah study sites. The sites are as follows: 1) Huntsville, 2) Morgan, 3) Park City area sites (see Figure 3), 4) Kamas, 5) Heber, 6) Mt. Pleasant, 7) Badger Island, 8) Erda, 9) East Erda, 10) Antelope Island, 11) Nephi, 12) Delta, 13) Desert Range, 14) Badger Springs.

2. Site description and data collection

During 2012, ozone was monitored at eighteen sites throughout Utah. Ozone was monitored at ten sites for the mountain valley study, with five sites located in the Park City area. Mountain valley ozone monitoring sites included Huntsville, Morgan, Parleys Summit, Jeremy Ranch, Snyderville, Park City, Silver Summit, Kamas, Heber and Mt. Pleasant. Ozone monitoring in mountain valleys focused on the Park City area because moderate to high ozone was observed in 2010 and 2011 in Silver Summit. The site in Mt. Pleasant was chosen as a control for the mountain valley study. The geography surrounding the Mt. Pleasant site was similar to other mountain valley sites, but no large cities or emission sources were located upwind. Tooele Valley ozone monitoring sites included Badger Island, Erda and East Erda. Permanent DAQ sites were located in Tooele and at the Great Salt Lake marina (Beach) on the northeastern edge of Tooele County. Five additional ozone monitoring sites were located in rural areas of Utah at Antelope Island, Nephi, Delta, Desert Range and Badger Springs. Table 1 lists the exact location and geographic description of each site.

Ozone was monitored at all eighteen sites using 2B Technologies Model 205 portable ozone monitors. At five sites, portable ozone monitoring stations (POMS), built by Air Resources Specialists (Fort Collins, CO) were installed. POMS sites used a Metronics All-in-One weather sensor to measure wind speed and wind direction (via a sonic anemometer), air temperature, relative humidity and pressure (Figure 2). The inlet for ozone monitors and meteorological instruments were installed at a height of approximately 2 meters . At the other thirteen sites, ozone monitoring stations were built by DAQ staff. Ozone monitors, data loggers and batteries (where necessary) were stored in a waterproof case underneath a tripod (Figure 2). Metal conduit was attached to the tripod to protect teflon inlet lines for ozone monitors, which were also positioned 2 meters above the ground. Meteorological variables were measured at

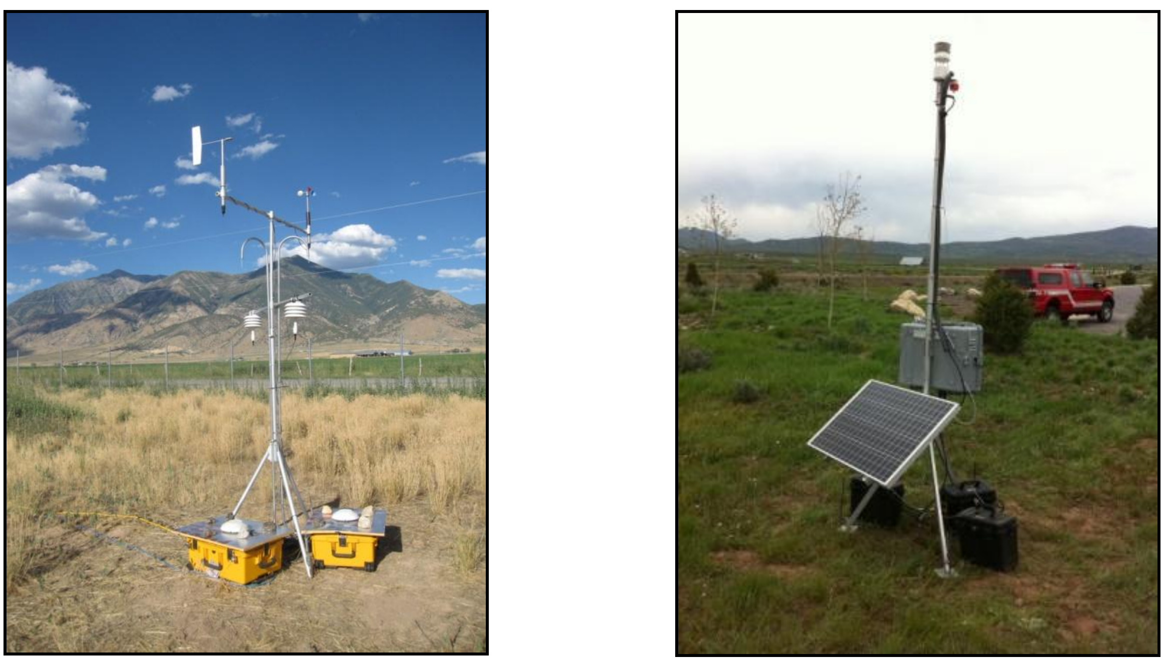

Figure 2. Two types of equipment at ozone monitoring equi0pment; a system built by DAQ staff at Nephi (left) and a POMS in Silver Summit (right).

Site	Location	Elevation	Data Collected	Study	Site Land Use	Topography
Antelope Island	41.039° N, 112.231° W	4445’	Ozone; weather data from DAQ site	Tooele Valley	State park, grassland	Island/ lake
Badger Island	40.943° N, 112.566° W	4213’	Ozone; weather data from DAQ site	Tooele Valley	Grassland, shrimp fishery	Island/ lake
Badger Spring	37.139° N, 114.024° W	4054’	Ozone, air temp, humidity, wind speed/direction	Rural	Desert, Joshua tree forest	Foothills of Beaver Dam Wash Mtns.
Delta	39.387° N, 112.504° W	4764’	Ozone, air temp, wind speed/direction	Rural	Airport, grassland	Flat valley
Desert Range	38.595° N, 113.752° W	5266’	Ozone, air temp, wind speed/direction	Rural	Grassland	Flat valley
East Erda	40.611° N, 112.2275° W	4444’	Ozone, air temp, humidity, wind speed/direction	Tooele Valley	Commercial	Foothills of Oquirrh Mtns
Erda	40.612° N, 112.348° W	4309’	Ozone, air temp; weather data from Mesowest site	Tooele Valley	Airport	Flat valley
Heber	40.481° N, 111.428° W	5618’	Ozone, weather data from Mesowest site	Mtn. Valley	Airport, grassland	Flat valley near mountains
Huntsville	41.254° N, 111.758° W	4949’	Ozone, air temp, humidity, wind speed/direction	Mtn. Valley	Fire station, grassland	Flat valley
Jeremy Ranch	40.755° N, 111.566° W	6294’	Ozone, air temp, humidity, wind speed/direction	Mtn. Valley	School, bus depot, commercial	Flat valley above a large creek
Kamas	40.645° N, 111.28° W	6485’	Ozone, air temp, humidity, wind speed/direction, particulate matter	Mtn. Valley	Municipal office	Flat valley near mountains
Morgan	41.037° N, 111.676° W	5074’	Ozone, air temp, humidity, wind speed/direction, precipitation	Mtn. Valley	School, commercial	Flat valley near mountains
Mt. Pleasant	39.528° N, 111.471° W	5877’	Ozone, air temp, humidity, wind speed/direction, precipitation	Mtn Valley	Airport, grassland	Flat valley
Nephi	39.738° N, 111.866° W	5027’	Ozone, air temp, wind speed/direction	Rural	Airport, agricultural	Flat valley
Parleys Summit	40.75° N, 111.622° W	7025’	Ozone, air temp, humidity, wind speed/direction, precipitation	Mtn. Valley	Forest, residential, highway	Mountain pass
Park City	40.644° N, 111.495° W	7105’	Ozone	Mtn. Valley	Urban, residential	Narrow valley in mountains
Silver Summit	40.773° N, 111.471° W	6508’	Ozone, air temp, humidity, wind speed/direction	Mtn. Valley	Fire station, grassland	Flat valley near 1000’ high hill
Snyderville	40.697° N, 111.541° W	6564’	Ozone, air temp, humidity, wind speed/direction, precipitation	Mtn. Valley	School, residential	Flat valley near mountains

Table 1. Physical description of eighteen temporary ozone sites.

five additional sites using a Vaisalla WXT520 weather sensors, which recorded wind direction, wind speed (also via sonic anemometer), air temperature, relative humidity, pressure and rain/hail amount. Finally, wind speed, wind direction and air temperature were measured at three sites using a MetOne model 010 wind direction sensor, a MetOne model 020 wind speed sensor and a MetOne model 592 temperature sensor with radiation shield. Weather data for the four additional sites was gathered from collocated DAQ sites or other collocated, publically available meteorological sites. No meteorological data was collected from downtown Park City. Table 1 lists the equipment used at each site.

Ozone monitoring sites were installed between March and June of 2012 and collected data through the end of September (Table 2). During installation of a site, the ozone monitor was calibrated *in situ* using a 2B Technologies Model 306 portable ozone calibration source. If meteorological equipment was installed, an audit was performed to ensure the accuracy of the data. Once a site was installed, DAQ staff visited the site semi-weekly to download data and to verify data accuracy by conducting a precision, zero and span (PZS) check of the ozone monitors. PZS checks of ozone monitors were completed using Model 306 portable ozone calibration source. The Model 306 calibration source was calibrated at least once a month at the Air Monitoring Center using a Teledyne Model 400E ozone analyzer, which was calibrated with the Thermo Scientific 49i-Primary Standard. A PZS was done semi-weekly on the model 306 ozone calibrator. For specific procedures of PZS and calibrating ozone monitors see the Standard Operating Procedure for the Model 205 ozone monitor and the Model 306 ozone calibration source (Appendix 1). Collected ozone data was considered valid if the precision and span values were ±7% and the zero value was ±5 ppb. If a PZS check of an ozone monitor fell outside the aforementioned standard, data was considered invalid and the monitor was recalibrated

SITE	Study	Deployment dates	Days of valid data
Huntsville	Mt. Valley	6/7 - 9/24	110
Morgan	Mt. Valley	6/7 - 9/24	110
Parleys Summit	Mt. Valley	6/9 – 9/27	111
Jeremy Ranch	Mt. Valley	6/9 – 9/20	104
Snyderville	Mt. Valley	6/16 – 9/24	101
Park City	Mt. Valley	8/2 – 9/27	57
Silver Summit	Mt. Valley	6/9 – 10/3	117
Kamas	Mt. Valley	6/1 – 9/20	112
Heber	Mt. Valley	6/8 – 9/20	119
Mt. Pleasant	Mt. Valley	8/9 – 10/1	54
Badger Island	Tooele Valley	5/5 – 10/2	151
Erda	Tooele Valley	5/1 – 10/3	156
East Erda	Tooele Valley	5/1 – 10/3	156
Antelope Island	Rural Utah	5/15 – 10/3	142
Nephi	Rural Utah	5/18 – 10/1	137
Delta	Rural Utah	5/3 – 10/1	152
Desert Range	Rural Utah	3/29 – 8/28	153
Badger Springs	Rural Utah	3/7 – 10/10	218

Table 2. The dates when ozone data was collected and the number of days of valid ozone data for all eighteen sites.

3. Precision and bias

Precision and bias were calculated for sites using the EPA's Data Assessment Statistical Calculator.[1] Table 3 shows the precision and bias for selected sites. To meet EPA standards for precision and bias, each dataset must have precision of 0-7%, a bias within +/- 7% and data completeness of >75%. The EPA data completeness standard is based on quarterly data. Data completeness for this study was calculated using the total number of hours from the time the site was installed until the site was dismantled. All data collected passed EPA standards for precision and bias. Standards for data completeness were also met at all sites.

Location	***Precision (%)***	***Bias (%)***	***Sample size***	***Data Completeness (%)***
Huntsville	3.89	+3.29	9	96.2
Antelope Island	1.62	-2.00	11	99.5
Morgan	2.52	+2.09	9	93.8
Erda	1.65	+1.72	12	99.3
East Erda	1.90	+2.36	12	99.2
Badger Island	2.92	+3.75	13	94.4
Parleys Summit	3.56	+/- 2.6	7	99.3
Jeremy Ranch	4.12	+/-3.29	8	93.5
Snyderville	2.29	+2.50	8	91.5
Park City	4.51	+/-3.12	5	91.7
Silver Summit	4.62	+4.52	10	96.8
Kamas	4.04	-4.04	7	89.6
Heber	2.92	+3.38	9	99.8
Mt. Pleasant	2.54	+2.99	8	99.2
Nephi	3.11	+3.33	11	98.9
Delta	2.81	+/-2.70	12	98.0
Desert Range	4.29	-3.47	10	93.5
Badger Spring	6.84	+/-4.96	10	99.2
Lytle Ranch	4.06	+5.17	5	99.8
Gunlock Res.	3.86	-3.1	5	99.8

Table 3. Results from quality assurance tests of summer ozone data. Samples size indicates the number of precision, zero and span checks perform on the ozone monitor at each site.

[1] Environmental Protection Agency, Data Assessment Statistical Calculator , http://www.epa.gov/ttn/amtic/qareport.html.; accessed 11/01/12.

V. MOUNTAIN VALLEY OZONE STUDY

1. Results

During summer 2012, ozone monitors and meteorological equipment were located at nine sites in mountain valleys east of the Wasatch Front. Figure 3 shows the location of five monitoring sites in the Park City area and four other mountain valley ozone monitoring sites. A tenth site was located in Mt. Pleasant in Sanpete Valley, approximately 70 miles south of Park City. The site in Mt. Pleasant was used as an experimental control for the mountain valley study; the geography and elevation of Sanpete Valley is similar to the mountain valleys further north, but lacked the presence of a large city to the west. The primary goals of monitoring ozone in the northern Utah mountain valleys were 1) to determine the magnitude of ozone pollution, 2) to determine the location of highest ozone concentrations in the Park City area of Summit County and 3) to assess causes of high ozone concentrations in the mountain valleys.

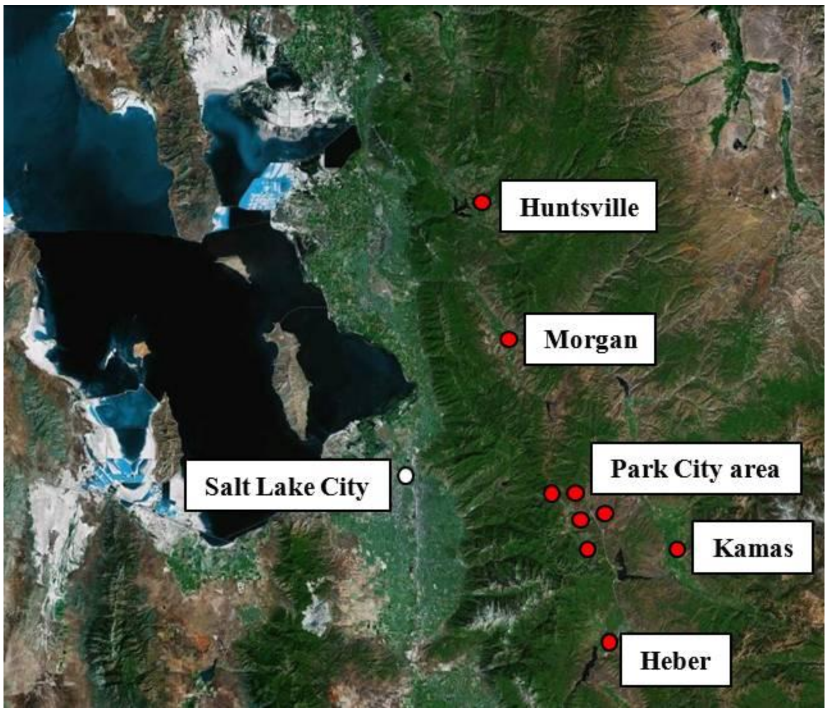

Figure 3. Map of ozone monitoring sites in mountain valleys east of the Wasatch Front. Red dots denote summer 2012 ozone monitoring sites, white dots denote permanent DAQ sites. The cluster of five sites in the Park City area includes sites at Parleys Summit, Jeremy Ranch, Snyderville, Silver Summit and downtown Park City.

In general, peak ozone concentrations at the mountain valley sites adjacent to large metropolitan areas were relatively high and similar to those observed in the cities of the Wasatch Front. Table 4 summarizes ozone data collected at ten mountain valley sites; ozone data from the DAQ site at Hawthorne Elementary School in Salt Lake City (Hawthorne), Harrisville and North Provo are included for comparison. The highest ozone concentrations at mountain valley sites occurred in the Park City area and typically equaled or exceeded ozone concentrations observed in Salt Lake City. Four of the five Park City area sites had peak 1-hour ozone values

SITE	Maximum hourly ozone	Maximum daily 8-hour ozone	Mean daily maximum 1-hour ozone	Mean daily maximum 8-hour ozone	4th highest 8-hour ozone	Mean hourly ozone
Huntsville	85	73	64.4	58.3	73	40.6
Morgan	86	78	66.3	60.4	71	41.5
Parleys Summit	94	83	71.3	65.0	79	50.8
Jeremy Ranch	91	83	68.3	62.0	74	37.2
Silver Summit	93	85	70.3	64.5	77	44.1
Snyderville	93	84	70.6	64.9	79	47.3
Park City	87	81	65.9	61.7	74	51.9
Kamas	89	79	62.2	58.0	73	45.6
Mt. Pleasant	81	73	61.6	58.2	68	44.8
Heber	89	79	66.0	61.1	76	41.2
Salt Lake City	104	83	68.2	59.5	79	37.8
Harrisville	96	82	-	61.9	77	-
North Provo	96	81	-	58.9	77	-

Table 4. Summary of ozone data (in ppb) collected during summer 2012 from mountain valley sites. For comparison across sites, only data from 7/1/12 – 9/20/12 was included.

greater than 90 ppb and all five Park City area sites had peak 8-hour ozone values greater than 80 ppb. Peak hourly ozone concentrations were higher in Salt Lake City compared to all the mountain valley sites, but peak 8-hour ozone concentrations at Parleys Summit, Jeremy Ranch, Silver Summit and Snyderville equaled or exceeded observations in Salt Lake City. Peak hourly and 8-hour ozone concentrations at Morgan and Huntsville were lower than in Harrisville and peak hourly and 8-hour ozone concentrations in Heber were similar to, but slightly lower than observations in North Provo. The fourth highest 8-hour ozone concentration exceeded the current ozone NAAQS at Parleys Summit, Silver Summit, Snyderville and Heber. Overall, ozone concentrations in Mt. Pleasant were the lowest observed among mountain valley sites. Ozone concentrations were generally low in Kamas, but 8-hour ozone concentrations exceeded 75 ppb on three occasions, two of which may have been impacted by wildfire smoke from the Wood Hollow fire in northern Sanpete County.

From a regulatory perspective, it is especially important to understand if the mountain valley sites exceeded the current ozone NAAQS or a future, potentially lower ozone NAAQS. Figure 4 shows the number of days when daily maximum 8-hour ozone concentrations exceeded 75 (panel A) and 70 ppb (panel B). Parleys Summit had the most days with ozone concentrations exceeding 70 and 75 ppb. Under the current ozone NAAQS, exceedances occurred at Parleys Summit, Silver Summit, Snyderville and Heber, based on one year of data. Silver Summit did not exceed the ozone NAAQS after three years of data collection; the three year average of the 4th highest 8-hour ozone concentration was 74 ppb in Silver Summit. Data collection in Park City began later than other sites (8/2/12), so the three days greater than 75 ppb observed likely underrepresents the total number of days greater than 75 ppb in Park City. As with other measures of maximum ozone concentration, the number of days with ozone concentrations greater than 75 and 70 ppb at Parleys Summit, Silver Summit and Snyderville

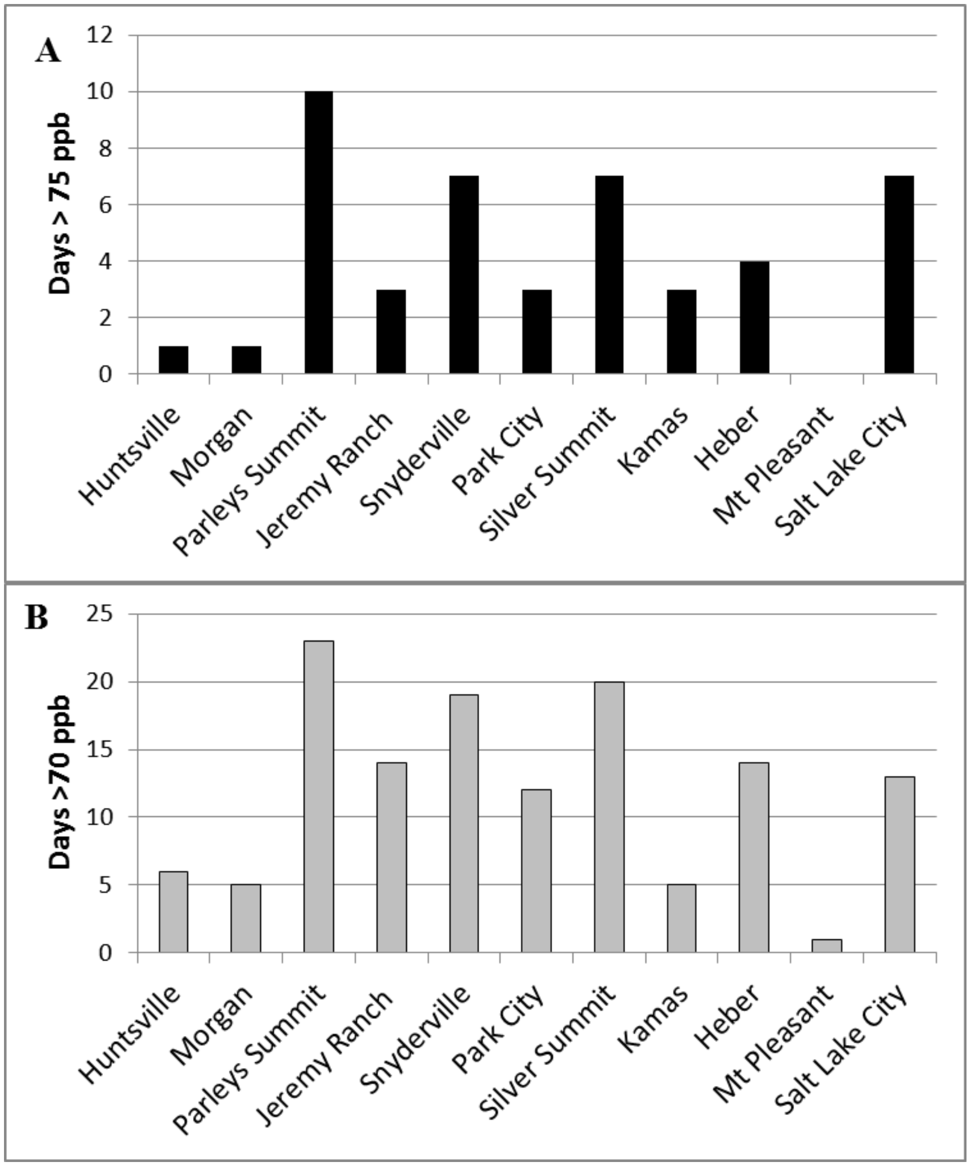

Figure 4. Total number of days during summer 2012 (6/1 – 10/1/12) when 8-hour daily maximum ozone concentrations exceeded 75 ppb (A) and 70 ppb (B) at the northern Utah mountain valley sites.

was equal to or greater than that observed in Salt Lake City. Heber experienced more days with ozone greater than 70 ppb (14) than Salt Lake City (13) and North Provo (10 days). In Mt. Pleasant, there were no days with ozone concentrations greater than 75 ppb and only one day with ozone concentrations greater than 70 ppb.

Ozone concentrations in the Park City area were higher than ozone concentrations observed at the other mountain valley sites. In order to identify the site with the highest ozone concentration in the Park City area, a comparison of daily maximum 1-hour and 8-hour ozone concentrations using a paired t-test was performed. Data from 8/2/12 – 9/20/12 was used to normalize data set size. Table 5 shows the results of a paired t-test using daily 1-hour maximum ozone concentrations at Parleys Summit, Jeremy Ranch, Silver Summit, Snyderville, Park City, Kamas, Mt. Pleasant and Salt Lake City; Table 6 shows results of a paired t-test comparing daily

Site	*Jeremy Ranch*	*Silver Summit*	*Snyder-ville*	*Park City*	*Kamas*	*Mt. Pleasant*	*Salt Lake City*
Parleys Summit	<0.001	0.05	0.175	<0.001	<0.001	<0.001	0.003
Jeremy Ranch	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.937
Silver Summit	-	-	0.405	<0.001	<0.001	<0.001	0.05
Snyderville	-	-	-	<0.001	<0.001	<0.001	0.02
Park City	-	-	-	-	<0.001	<0.001	0.06
Kamas	-	-	-	-	-	0.403	<0.001
Mt. Pleasant	-	-	-	-	-	-	<0.001

Table 5. Results from a paired t-test using daily maximum 1-hour ozone concentrations from 8/2/12 – 9/20/12 at six mountain valley sites and Salt Lake City. Differences were considered significant if $p < 0.05$.

Site	*Jeremy Ranch*	*Silver Summit*	*Snyder-ville*	*Park City*	*Kamas*	*Mt. Pleasant*	*Salt Lake City*
Parleys Summit	<0.001	0.237	0.972	<0.001	<0.001	<0.001	0.003
Jeremy Ranch	-	<0.001	<0.001	0.377	<0.001	<0.001	0.937
Silver Summit	-	-	0.134	<0.001	<0.001	<0.001	0.05
Snyderville	-	-	-	<0.001	<0.001	<0.001	0.02
Park City	-	-	-	-	<0.001	0.004	0.101
Kamas	-	-	-	-	-	0.854	0.245
Mt. Pleasant	-	-	-	-	-	-	0.755

Table 6. Results from a paired t-test using daily maximum 8-hour ozone concentrations from 8/2/12 – 9/20/12 at six mountain valley sites and Salt Lake City. Differences were considered significant if $p < 0.05$.

maximum 8-hour ozone concentrations from the same group of sites. Results from the paired t-test show significant differences between sites, while Table 4 shows mean values of daily maximum 1-hour and 8-hour ozone concentrations to determine the direction of significant differences. Daily 1-hour and 8-hour ozone concentrations at all Park City area sites were greater than ozone concentrations observed at Kamas and Mt. Pleasant. Mean maximum daily 1-hour and 8-hour ozone concentrations at Parleys Summit, Silver Summit and Snyderville were greater than that observed in Salt Lake City. Comparing among Park City area sites, ozone concentrations at Parleys Summit, Silver Summit and Snyderville were significantly greater than ozone concentrations in Park City and Jeremy Ranch. Relatively lower ozone concentrations at Jeremy Ranch may be driven by the large diurnal ozone variability; mean hourly ozone concentrations at Jeremy Ranch (Table 4) were lowest among Park City area sites and lower than Salt Lake City. Large diurnal variation in ozone concentration may be due to the site's close proximity to Interstate 80. Paired t-test showed that daily maximum 1-hour ozone concentrations at Parleys Summit were significantly greater than Silver Summit, but not different from Snyderville. Daily maximum 1-hour and 8-hour ozone concentrations at Silver Summit and Snyderville were not significantly different. Also, no significant differences between daily maximum 8-hour ozone concentrations at Parleys Summit, Silver Summit and Snyderville were observed. Based on statistical and summary ozone data comparison, ozone concentrations were highest at Parleys Summit, with only slightly lower ozone values in Silver Summit and Snyderville.

By most measures, ozone concentrations in the Park City area were equivalent to or higher than ozone concentrations in Salt Lake City. Figure 5 compares daily maximum 8-hour ozone concentrations at Park City area sites to Salt Lake City during a high ozone episode. On 21 of the 23 days shown in Figure 5, ozone concentrations were higher at a Park City area site compared to Salt Lake City. Salt Lake City was generally the lowest ozone concentration site (Figure 5) while Parleys Summit or Snyderville had the highest ozone concentrations. Mean daily maximum 8-hour ozone concentrations were 71.9 ppb in Snyderville and 66.7 ppb in Salt Lake City over this time period; even greater than when using ozone data from the entire summer.

Correlations using daily maximum 1-hour ozone concentrations were made between the mountain valley sites and permanent DAQ sites. Correlations with hourly ozone data between sites were not used because diurnal variability differed greatly between sites. Daily maximum 1-hour ozone data between the Park City sites were strongly correlated (r^2=0.85-0.99). The strength of correlations between sites generally decreased as distance between sites increased. Daily maximum 1-hour ozone from Parleys Summit was strongly correlated to Jeremy Ranch (r^2=0.987), but more weakly correlated to Park City (r^2=0.851), Heber (r^2=0.777) or Mt. Pleasant (r^2=0.716). Daily maximum 1-hour ozone data from Park City area sites was more strongly correlated to Salt Lake City (r^2=0.814 - 0.862) than North Provo (r^2=0.722 - 0.795) or Harrisville (r^2=0.742 - 0.790).

Unlike the comparison between Park City area sites and Salt Lake City, ozone concentrations in Harrisville were typically higher than ozone concentrations observed in Huntsville or Morgan. Ozone concentrations in Ogden were lower than Morgan and Huntsville, however. Figure 6 shows daily maximum 8-hour ozone concentrations in Huntsville, Morgan, Harrisville and Ogden during a three week high ozone episode. Ozone concentrations were generally highest in Harrisville with lower concentrations in Morgan, Huntsville and Ogden. Similarities between ozone trends in Huntsville, Morgan and Harrisville, shown in Figure 6, were also evident in correlations using daily maximum 1-hour ozone data from the entire summer. Daily maximum 1-hour ozone concentrations in Harrisville were very strongly correlated to Huntsville (r^2 = 0.932) and Morgan (r^2 = 0.899), but correlations between Huntsville and Morgan ozone data with Ogden ozone data were much weaker (r^2 = 0.742, r^2 = 0.651).

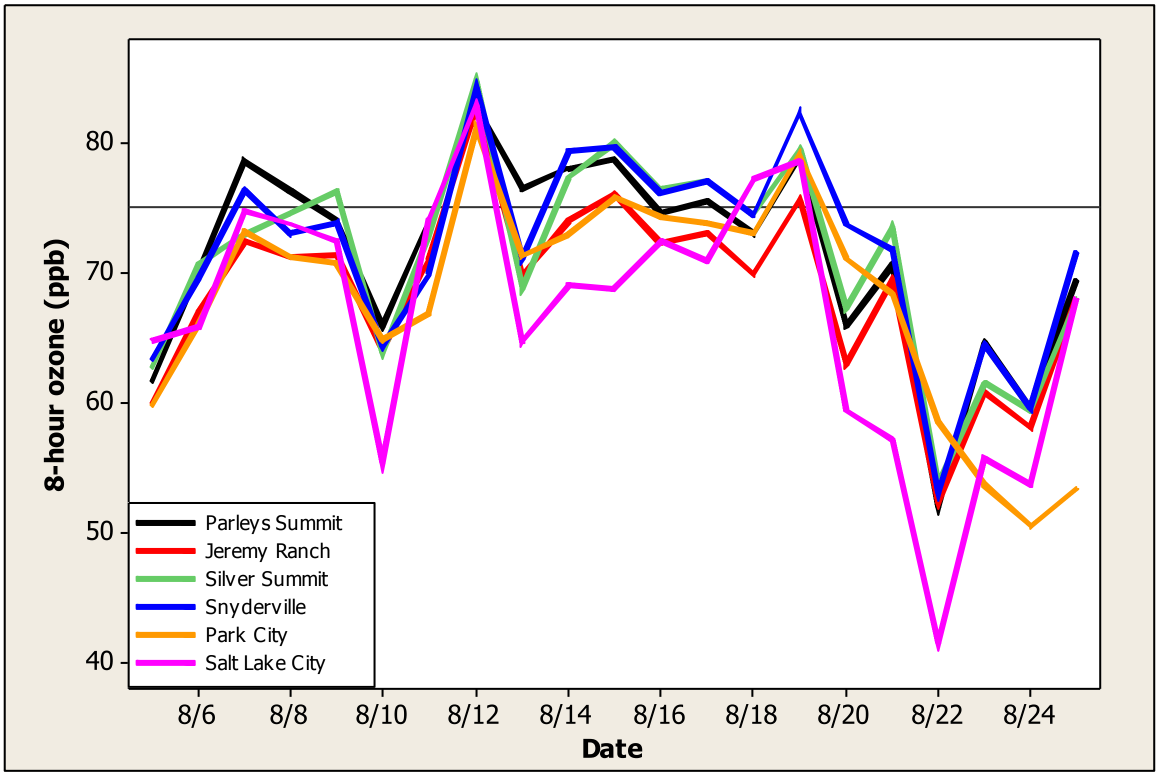

Figure 5. Daily maximum 8-hour ozone (ppb) at Park City area sites and Salt Lake City from 8/5 – 8/25/12.

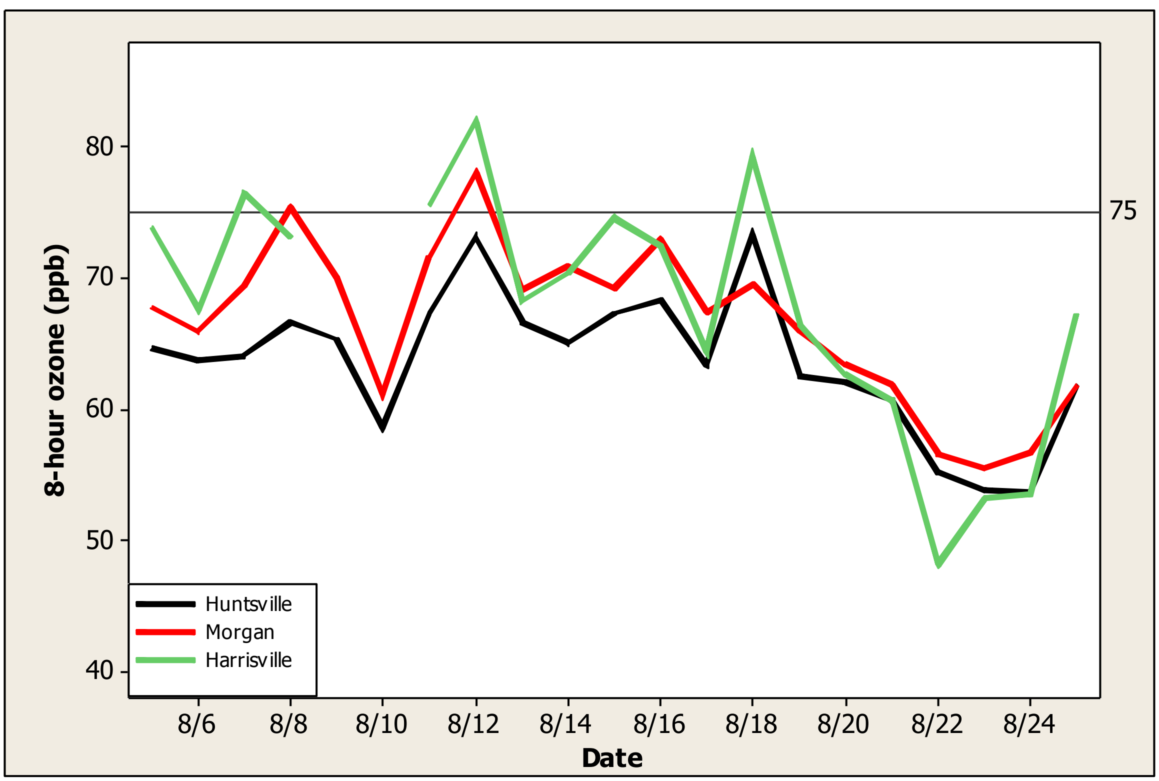

Figure 6. Daily maximum 8-hour ozone concentrations in Huntsville, Morgan and Harrisville from 8/5 – 8/25/12.

Daily maximum 8-hour ozone concentrations in Heber, Kamas and North Provo are compared in Figure 7. Among the group of sites in Figure 7, North Provo is the closest Wasatch Front site to Heber and North Provo and Salt Lake City are nearly equidistant from Kamas. During this high ozone episode, peak ozone was alternately found in either Heber or North Provo, but mean daily maximum 8-hour ozone concentrations were significantly higher in Heber (66.9 ppb) compared to North Provo (63.6 ppb; paired t-test, $t=2.39$, $p=0.01$). Mean daily maximum 8-hour ozone concentrations in Kamas (63.3 ppb) were not significantly different from North Provo. Daily maximum 1-hour ozone data from Heber, over the entire summer, was most strongly correlated to ozone other nearby mountain valley sites than to North Provo (r^2 = 0.858) or Salt Lake City (r^2 = 0.819). Daily maximum 1-hour ozone data from Kamas was also strongly correlated to North Provo (r^2 = 0.829) and Salt Lake City (r^2 = 0.794).

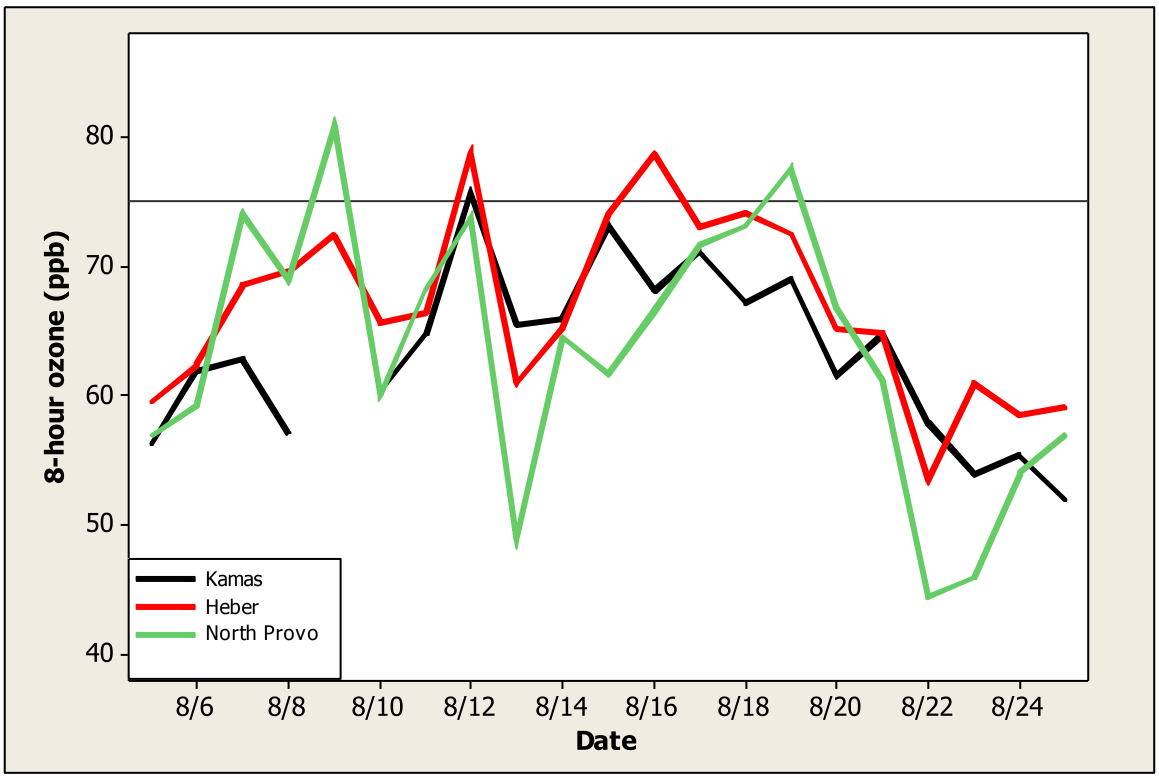

Figure 7. Daily maximum 8-hour ozone concentrations in Kamas, Heber and North Provo from 8/5/ - 8/25/12.

Ozone was monitored in Mt. Pleasant because it is located in a mountain valley geographically similar to the other mountain valley study sites in northern Utah, but lacks a large upwind emission source. The site in Mt. Pleasant was considered a potential experimental control for the mountain valley study. Figure 8 compares daily maximum 8-hour ozone concentrations from four mountain valley sites during a high ozone episode. Ozone concentrations in Mt. Pleasant were always lower than ozone at Parleys Summit during this high ozone episode, but ozone concentrations in Mt. Pleasant did exceed ozone concentrations in

Morgan and Heber on several days. Daytime winds were typically from the west in Mt. Pleasant on days with high ozone concentrations; a southwesterly wind was more common in Mt. Pleasant on days with low ozone concentrations. From 8/9/12 to 9/21/12, mean daily maximum 8-hour ozone concentrations were 6.3 ppb higher in Parleys Summit, 2.5 ppb higher in Heber and 1.6 ppb higher in Morgan compared to Mt. Pleasant. Nephi was the closest low elevation ozone monitoring site to Mt. Pleasant (25 miles northwest). Mean daily maximum 8-hour ozone concentrations were 4.2 ppb higher in Mt. Pleasant compared to Nephi. Ozone concentrations in both Nephi and Mt. Pleasant should not be greatly affected from precursor emissions from nearby large cities (ie Wasatch Front cities). The primary difference between the site in Nephi and Mt. Pleasant was elevation; Mt Pleasant is approximately 850 feet higher than Nephi.

Much of the previous data analysis did not include a comparison of hourly ozone concentrations because diurnal variation in ozone concentrations generally varied between sites much more than peak ozone concentration. However, an examination of diurnal variability in ozone concentrations is important to understand patterns of ozone formation and the conditions present at different sites. Figure 9 shows mean diurnal variability in ozone at all mountain valley sites. Greater diurnal variation in ozone concentration is typically characteristic of more urban sites, while lower diurnal ozone variability is typically characteristic of more rural sites.[2] Mean diurnal ozone variability in Jeremy Ranch, Silver Summit, Snyderville and Heber was greater than 50 ppb and similar to Salt Lake City and North Provo, suggesting urban site characteristics.

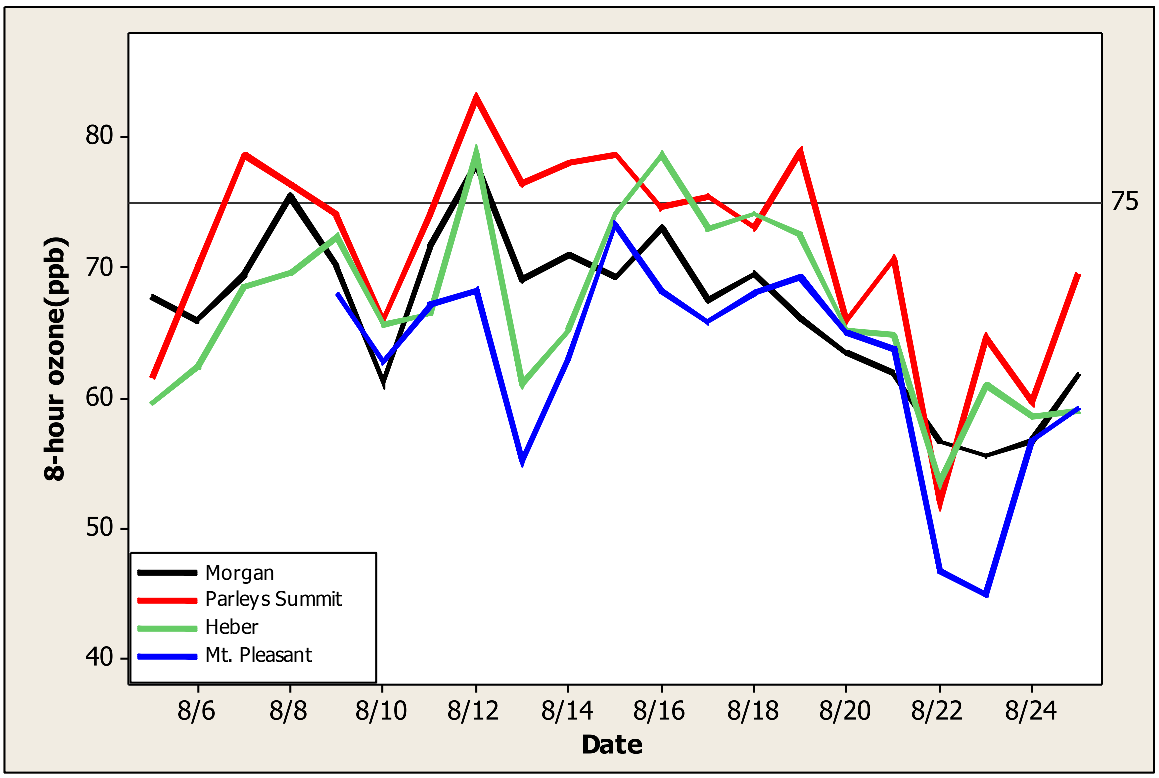

Figure 8. Daily maximum 8-hour ozone concentrations in Morgan, Parleys Summit, Heber and Mt. Pleasant from 8/5/ - 8/25/12.

[2] Cooper, O.R., R. Gao, D. Tarasick, T. Leblanc, C. Sweeney 2012) Long-term ozone trends at rural ozone monitoring sites across the United States, 1990-2010. *JGR-Atmospheres*, **117**:issue D22. DOI: 10.1029/2012JD018261

The lowest diurnal variation in ozone concentration was observed in Park City, Kamas and Mt. Pleasant and intermediate diurnal variability in ozone concentration was observed in Huntsville, Morgan and Parleys Summit. Figure 10 compares hourly ozone concentrations at several mountain valley sites and Salt Lake City. Variation of maximum ozone concentrations between sites was much less than variation in minimum nighttime ozone at sites in Figure 10 with the lowest nighttime ozone concentrations occurring in Salt Lake City and Silver Summit. One interesting pattern to note was a secondary nighttime peak in ozone that occurred in Park City on 8/11 and 8/14 which could represents transport of ozone formed earlier in the day at higher elevations. Figure 11 compares six mountain valley and Wasatch Front sites across the entire summer ozone season from 6/9 – 9/30/12. Although the sites represent a relatively large geographic spread, from Harrisville in the north to Salt Lake City in the south to Kamas in the east, there were clear regional patterns with moderate ozone concentrations in July, peak ozone concentrations across all sites in August and lower ozone concentrations in September. The peak in northern Utah ozone from 8/5 – 8/20/12 may have been influenced by smoke from fires in Idaho, which will be discussed later in the section (pages 25-26).

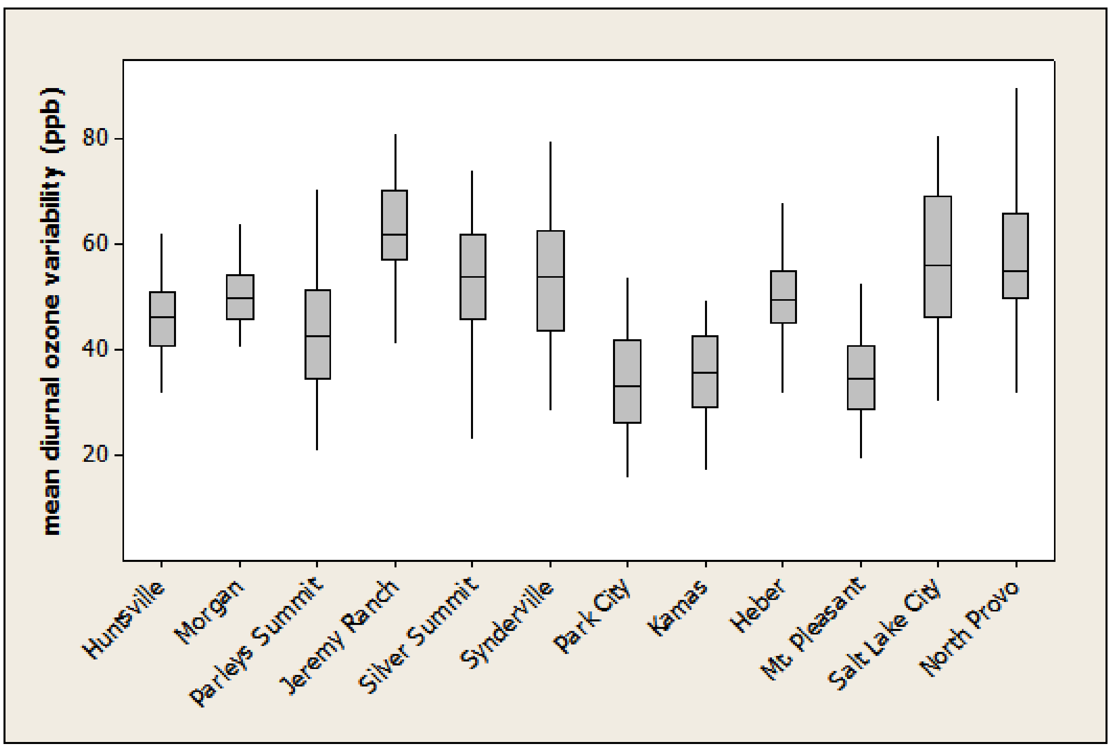

Figure 9. Box and whisker plot depicting mean diurnal ozone concentration variation at all mountain valley sites. Each box represents the 95th percentile confidence interval, the horizontal line represents mean ozone variation and vertical lines represent standard of deviation.

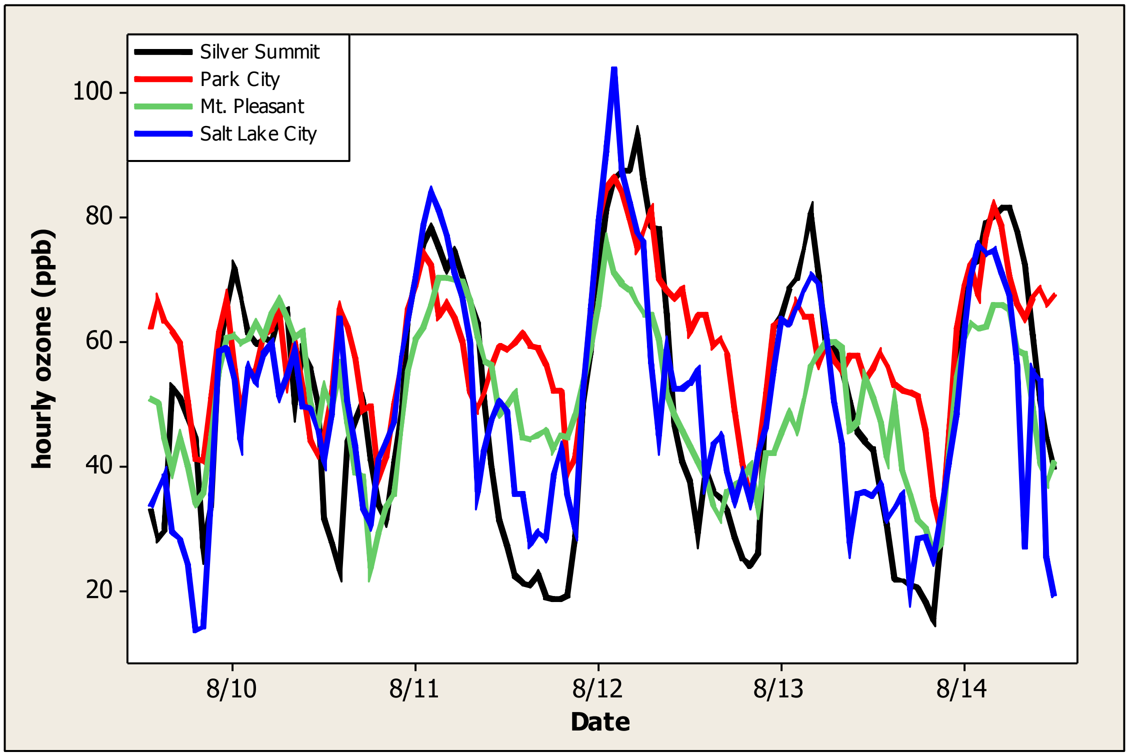

Figure 10. Hourly ozone concentrations at select mountain valley sites and Salt Lake City from 8/10 – 8/14/12.

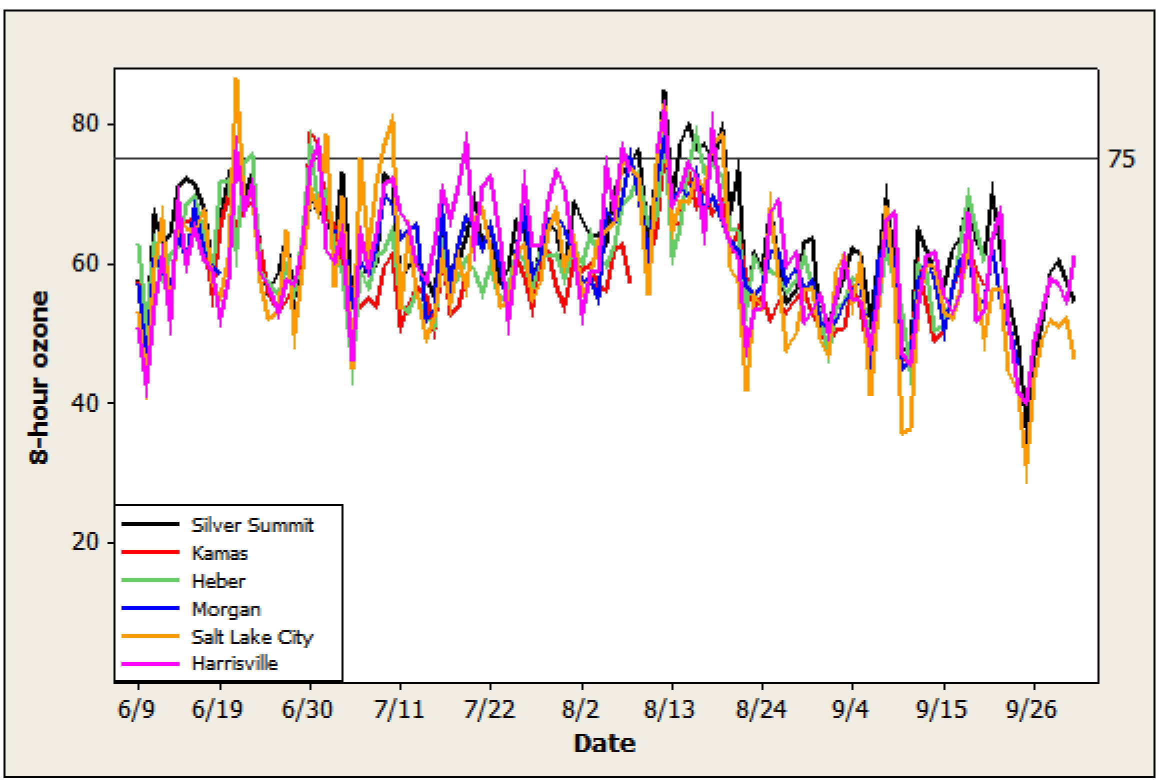

Figure 11. Maximum daily 8-hour ozone concentrations at Wasatch Front and mountain Valley sites from 6/9 – 9/30/12. Sites in clude Silver Summit, Kamas, Heber, Morgan, Salt Lake City and Harrisville.

2. Discussion – Park City Area

Ozone concentrations were high at mountain valley sites primarily due to transport of ozone and ozone precursors from Wasatch Front cities and higher solar radiation at higher elevation sites. Other factors contributing to ozone formation at the mountain valley sites likely included local emissions of ozone precursors, biogenic volatile organic compound emission and long range transport of ozone precursors. Transport of ozone and ozone precursors from Wasatch Front cities to mountain valley sites was supported by dominant wind patterns at mountain valley sites and the timing of peak ozone in Salt Lake City compared to Park City area sites. Figure 12 shows daytime wind direction from four Park City area sites on high ozone days (8-hour ozone > 75 ppb). Daytime wind direction on high ozone days was primarily from the west at Parleys Summit and Jeremy Ranch and from the west-northwest at Snyderville and Silver Summit. Daytime winds at Parleys Summit and Jeremy Ranch generally came from the direction of Salt Lake City, while wind in Snyderville and Silver Summit generally originated from Parleys Summit suggesting air mass flow from Salt Lake City to the Park City area via Parleys Canyon. Figure 13 shows daytime wind direction from four Park City area sites on low ozone days (8-hour ozone < 68 ppb). Wind patterns on high and low ozone days were similar at

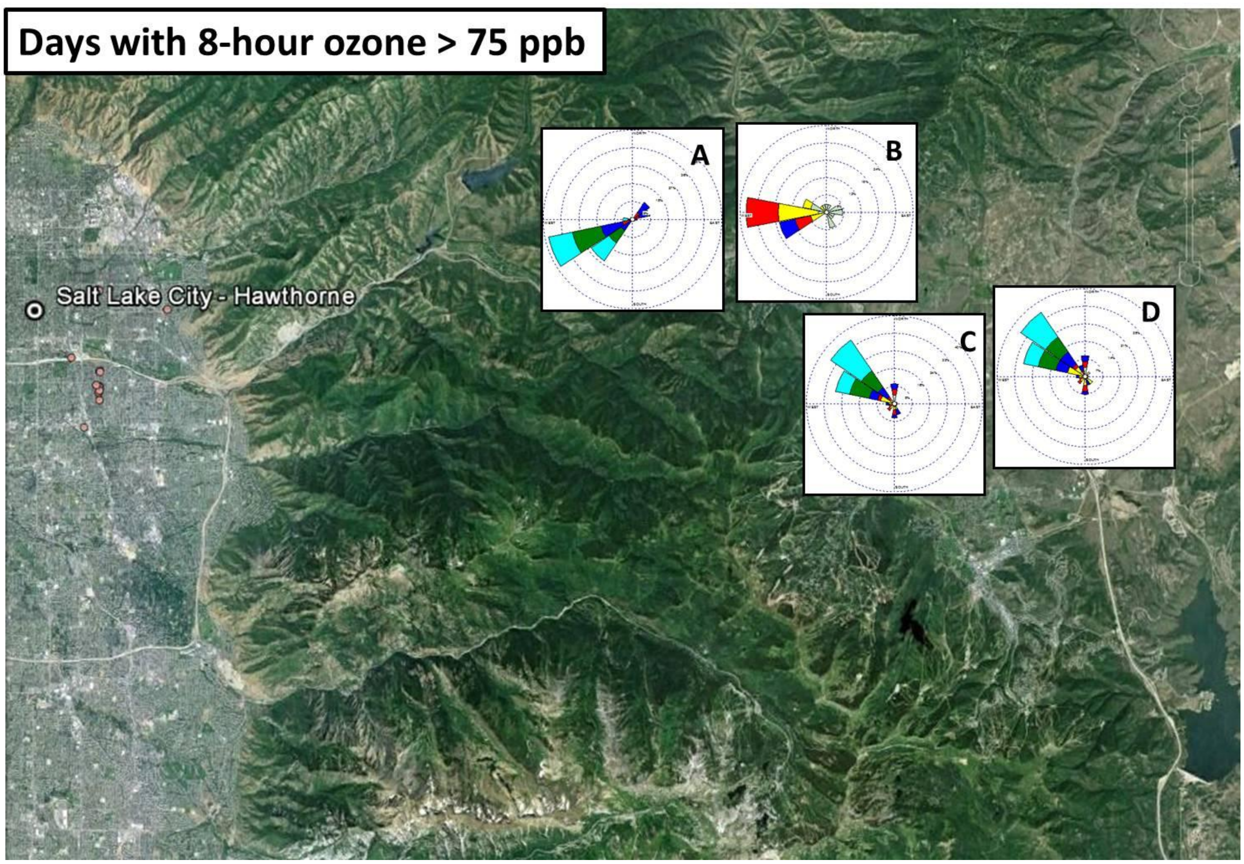

Figure 12. Wind roses showing daytime wind direction (8:00-19:00 MST) on days when 8-hour ozone concentrations were greater than 75 ppb at Parleys Summit (A), Jeremy Ranch (B), Snyderville (C) and Silver Summit (D). Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

Jeremy Ranch, Snyderville and Silver Summit, but less dominantly from the west to northwest on low ozone days. Wind patterns at Parleys Summit were nearly identical on high and low ozone days. Wind direction in Jeremy Ranch was from the west 50% of the time on high ozone days, but only 34% of the time on low ozone days. Similar differences in wind direction were observed in Snyderville and Silver Summit. Winds came from the west-northwest 50% of the time at Snyderville and Silver Summit on high ozone days and 29% and 34% of the time at Snyderville and Silver Summit, respectively, on low ozone days. Overall, an examination of wind patterns at Park City area sites suggests the flow of air masses from Salt Lake City to the Park City area up the Parleys Canyon corridor. Transport of air masses from Salt Lake City to the Park City area appeared to occur for a longer duration on high ozone days compared to low ozone days.

Transport of ozone and ozone precursors from Salt Lake City to the Park City area was also supported by an analysis of the timing of peak ozone concentrations. Transport of air masses from Salt Lake City to the Park City area occurred on most days of the summer. High ozone at Park City area sites was likely influenced by both the transport of ozone and ozone

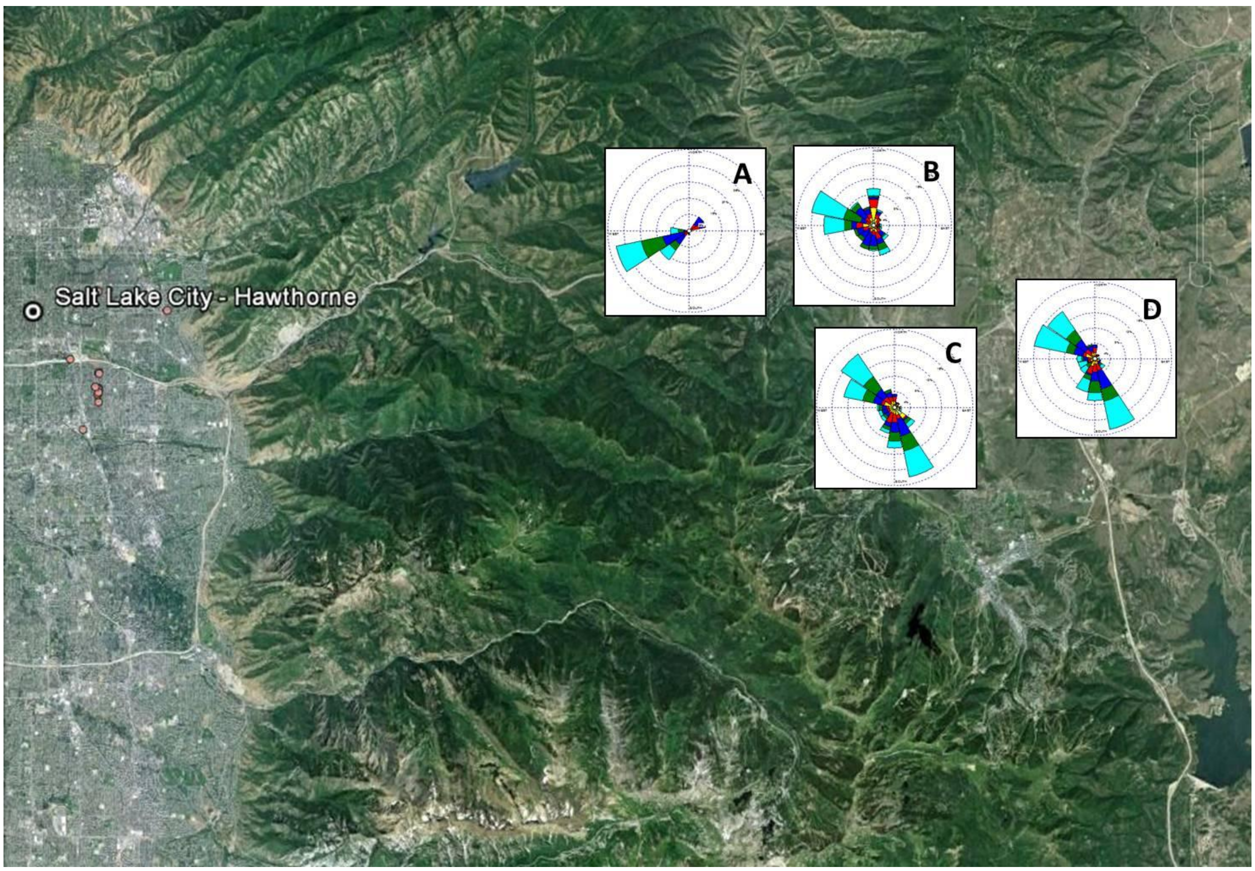

Figure 13. Wind roses showing daytime wind direction (8:00-19:00 MST) on days when 8-hour ozone concentrations were less than 68 ppb at Parleys Summit (A), Jeremy Ranch (B), Snyderville (C) and Silver Summit (D). Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

precursors from Salt Lake City. An examination of the timing of peak ozone concentrations in Salt Lake City and Park City area sites showed evidence for both ozone and ozone precursor transport. Figure 14 shows hourly ozone concentrations at six sites between Salt Lake City and Kamas on 8/12/12 at 13:00, 15:00, 16:00 and 17:00 as ozone concentrations reached their peak. Ozone peaked in Salt Lake City first at 13:00 followed by peak ozone concentrations at Parleys Summit at 15:00, then peak ozone in Jeremy Ranch, Snyderville and Silver Summit at 16:00 and finally peak ozone concentrations in Kamas at 17:00. The progression of peak ozone concentrations from early afternoon in Salt Lake City to late afternoon in Kamas suggests ozone transport from Salt Lake City, up Parleys Canyon to Park City area sites and into Kamas. Wildfire smoke from fires in Idaho may have impacted ozone formation on 8/12/12; $PM_{2.5}$ concentrations reached 20.1 µg m^{-3} in Salt Lake City on 8/12. Wind patterns at Park City area sites on 8/12/12 were similar to those shown in Figure 12. Since high hourly ozone concentrations were observed in both Salt Lake City and Park City area sites, transport from Salt Lake City was likely dominated by ozone transport.

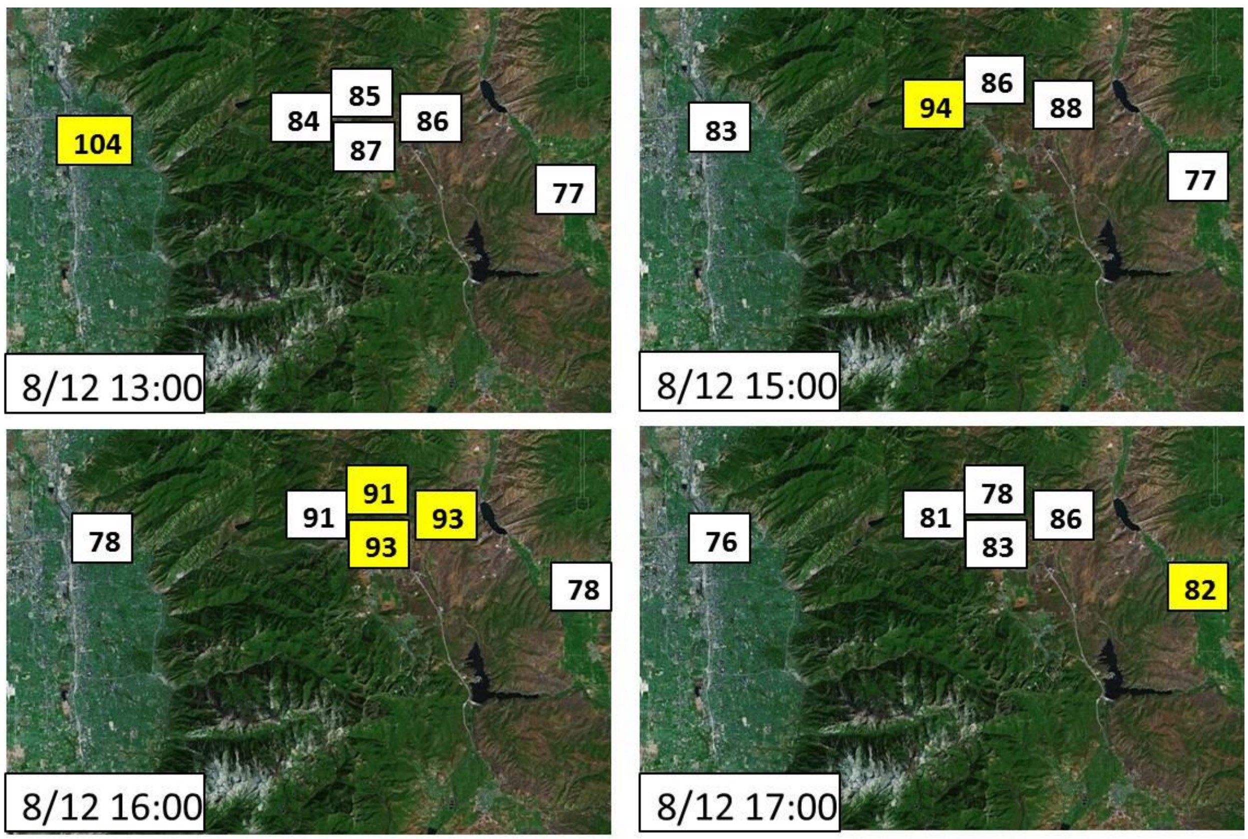

Figure 14. Hourly ozone concentrations at Salt Lake City, Parleys Summit, Jeremy Ranch, Snyderville, Silver Summit and Kamas on 8/12/12 at 13:00, 15:00, 16:00 and 17:00. The maximum hourly ozone concentration observed on 8/12/12 at each site is denoted by a yellow box.

Figure 15 shows hourly ozone concentrations at six sites between Salt Lake City and Kamas on 8/21/12 at 13:00, 15:00, 16:00 and 17:00 as ozone concentrations reached their peak. Figure 15 shows a scenario where an air mass was likely transported from Salt Lake City to the Park City area, but ozone concentrations were higher in the Park City area suggesting that transport was dominated by ozone precursor transport. Similar to ozone formation on 8/12/12, ozone concentrations peaked first in Salt Lake City at 13:00 followed by Parleys Summit at 15:00, Jeremy Ranch, Snyderville and Silver Summit at 16:00 and finally Kamas at 17:00. Daytime wind directions were very similar to those shown in Figure 12; western winds were most common at Parleys Summit and Jeremy Ranch, while a west-northwest wind blew during most of the day in Snyderville and Silver Summit. The primary difference between ozone formation on 8/12 and 8/21 was that ozone concentrations were significantly higher at Park City area sites compared to Salt Lake City on 8/21. Given that winds in the Park City area generally originated from Salt Lake City and the timing of peak ozone concentrations, it was likely that transport from Salt Lake City to the Park City area occurred. However, since ozone in Salt Lake City was relatively low compared to the Park City area, ozone precursors, rather than ozone, was likely transported.

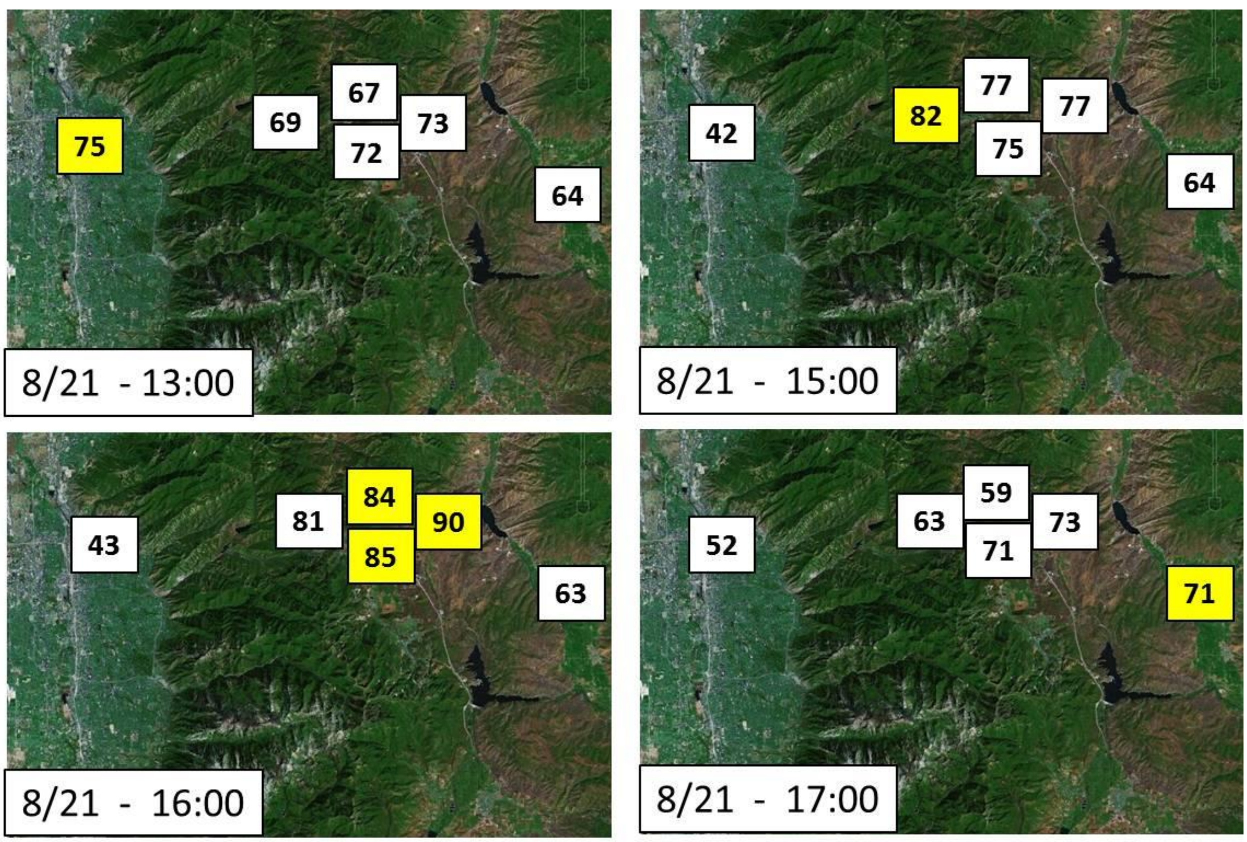

Figure 15. Hourly ozone concentrations at Salt Lake City, Parleys Summit, Jeremy Ranch, Snyderville, Silver Summit and Kamas on 8/21/12 at 13:00, 15:00, 16:00 and 17:00. The maximum hourly ozone concentration observed on 8/12/12 at each site is denoted by a yellow box.

Throughout the entire ozone season, 6/1 – 10/5/12, peak ozone concentrations in Salt Lake City occurred before peak ozone in the Park City area. The timing of peak ozone formation along a west to east transect from Salt Lake City typically showed a "bubble" of high ozone moving from west to east through the afternoon. Figure 16 shows the mean time of daily maximum hourly ozone concentrations at six sites between Salt Lake City and Kamas on days when ozone concentrations exceeded 75 ppb in Silver Summit. On average, the daily maximum hourly ozone concentration occurred at 14:00 MST in Salt Lake City. Ozone typically peaked next at Parleys Summit at 15:35. Following Parleys Canyon, it is 15 miles between the DAQ site in Salt Lake City and Parleys Summit. Given a 10 mile per hour wind, which is a common wind speed during the day at Parleys Summit, it would take 90 minutes to transport a parcel of air to Parleys Summit from the Hawthorne DAQ site. Wind speed, wind direction and timing of daily maximum ozone all support the notion that ozone and ozone precursors were transported from Salt Lake City to Parleys Summit and into the Park City area. The time of daily maximum ozone concentrations generally increased (with a slight anomaly in Snyderville) with distance from Salt Lake City. Even though ozone concentrations in Kamas were significantly lower than ozone at other Park City area sites, daily maximum ozone concentrations occurred on average at 16:44 in Kamas, the latest peak of all Park City area sites. Even though Kamas is approximately 35 miles away from Salt Lake City, it appeared that transport of ozone and ozone precursors from Salt Lake City affected ozone in Kamas.

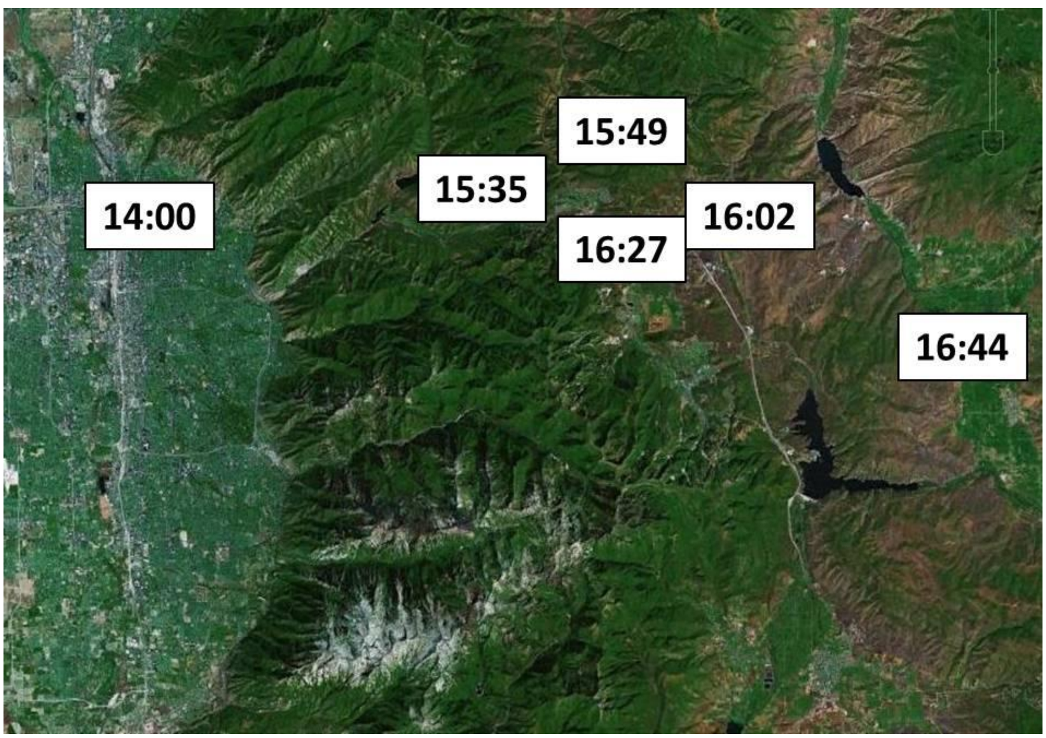

Figure 16. Mean time of daily maximum hourly ozone concentrations in Salt Lake City, Parleys Summit, Jeremy Ranch , Snyderville, Silver Summit and Kamas on days when the maximum hourly ozone was greater than 75 ppb in Silver Summit (n=7). Mean time of daily maximum ozone was calculated from all data collected between 6/1/12 – 10/5/12.

Based on the proximity of the Park City area sites to Salt Lake City, an analysis of wind patterns and the timing of daily maximum ozone, it was likely that transport of ozone and ozone precursors from Salt Lake City significantly impacted ozone concentrations at Park City area sites. However, it was also likely that higher solar radiation at mountain valley sites compared to Salt Lake City led to an increased rate of ozone formation and contributed to generally high ozone concentrations. Figure 17 compares photosynthetically active radiation (PAR) observed in Salt Lake City and Silver Summit. PAR was significantly higher in Silver Summit compared to Salt Lake City with peak PAR over 2,000 µmol m^{-2} sec^{-1} compared to peak PAR of less than 1,500 µmol m^{-2} sec^{-1} in Salt Lake City. From 7/10 – 10/4/12 mean daily maximum PAR was 1,747 µmol m^{-2} sec^{-1} in Silver Summit compared to 1,106 µmol m^{-2} sec^{-1} in Salt Lake City. PAR was higher in Silver Summit compared to Salt Lake City because the Silver Summit site was at a higher elevation (6508') compared to Salt Lake City (4291'). There is less attenuation of solar radiation by the atmosphere at high elevation sites compared to low elevation sites resulting in greater solar radiation reaching the ground surface at higher elevation sites. Ultraviolet radiation is a requisite component of ozone formation. Although PAR measurements do not include ultraviolet radiation wavelengths, an increase in in PAR is indicative of an increase in solar radiation reaching the ground surface which would include ultraviolet radiation. A long term study of ultraviolet irradiance in Switzerland showed that ultraviolet irradiance increased 9-24% for every 1,000 meters of elevation change[3]. Based on the research in Switzerland, there would theoretically be a 6-16% increase in ultraviolet radiation in Silver Summit compared to Salt Lake City considering the elevation difference of 2,217 feet. However, based on mean daily PAR, there was a 57% increase in PAR at Silver Summit compared to Salt Lake City. The PAR sensors used in Salt Lake City and Silver Summit were slightly different which could account for some of the differences in PAR. PAR data from the DAQ site at Salt Aire (northwest of Salt Lake City International Airport) and Badger Island, which use the same PAR sensor as Silver Summit, was much more similar to PAR data collected in Salt Lake City than in Silver Summit. While the magnitude of increase in PAR in Silver Summit compared to Salt Lake City cannot be fully explained, it was clear that higher PAR was observed at the higher elevations of Silver Summit and may have enhanced ozone formation in the Park City area.

[3] Blumthaler, M., W. Ambach, R. Ellinger (1997). Increase in solar UV radiation with altitude. *Journal of Photochemistry and Photobiology*. **39**:130-134.

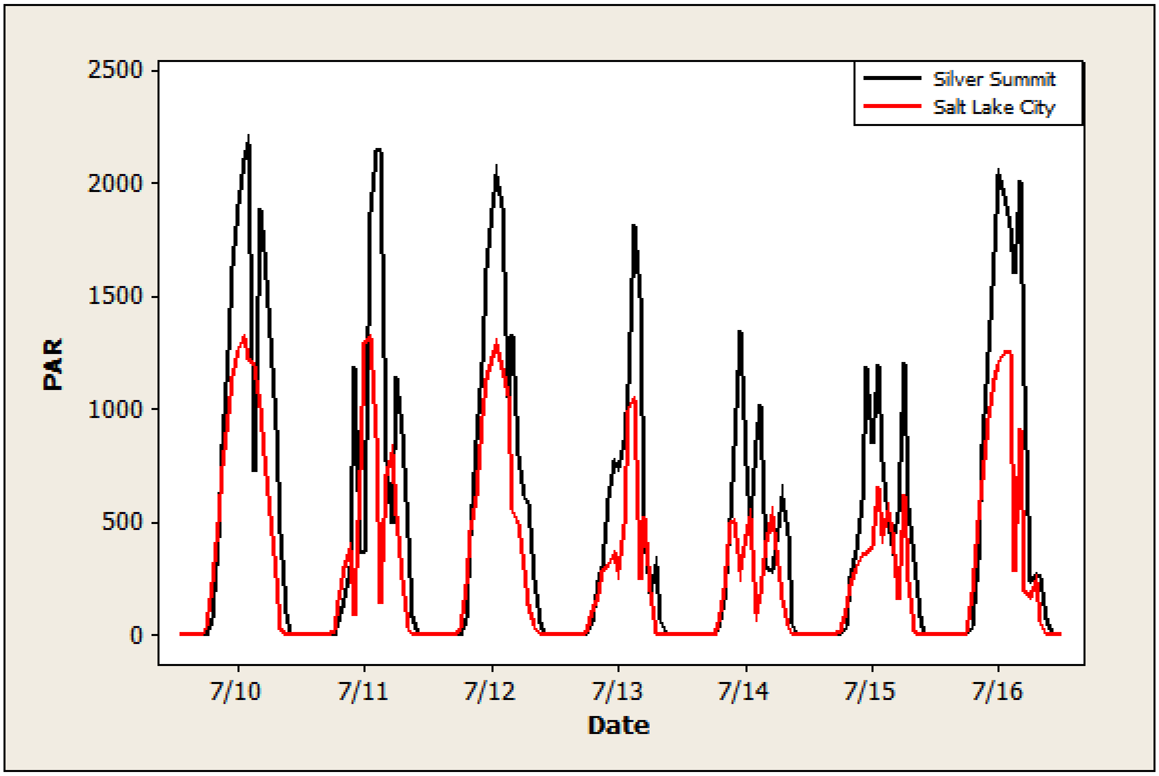

Figure 17. Hourly photosynthetically active radiation (PAR) in µmol m^{-2} sec^{-1} from Silver Summit and Salt Lake City.

Smoke from wildfires may have influenced ozone formation both in the mountain valleys and the Wasatch Front. Smoke from fires in Idaho infiltrated northern Utah in early to mid-August which corresponds to the time of peak seasonal ozone concentrations both in the mountain valleys and along the Wasatch Front. Figure 18 compares daily maximum 8-hour ozone concentrations in Salt Lake City and Silver Summit to daily $PM_{2.5}$ concentrations in Salt Lake City. Higher periods of $PM_{2.5}$ in Salt Lake City generally correlate with higher 8-hour ozone concentrations in both Salt Lake City and Silver Summit, especially in August. $PM_{2.5}$ concentrations in Salt Lake City were moderately correlated to daily maximum ozone concentrations in both Salt Lake City (r^2 = 0.41) and Silver Summit (r^2 = 0.48) from 6/10 – 8/30/12. When correlations between ozone and PM2.5 concentrations were made on high (>70 ppb) and moderate (>65 ppb) ozone days, a divergent pattern emerged where $PM_{2.5}$ in Salt Lake City was much more strongly correlated to ozone concentrations in Silver Summit than ozone concentrations in Salt Lake City. On high ozone days, PM2.5 in Salt Lake City was strongly correlated to ozone in Silver Summit (r^2 = 0.77, n=21), but not correlated to ozone concentrations in Salt Lake City (r^2 = -0.02, n=16). On moderate ozone days, $PM_{2.5}$ was still strongly correlated to ozone in Silver Summit (r^2 = 0.66, n=40), but weakly correlated to ozone concentrations in Salt Lake City (r^2 = 0.32, n=31). In general, there is conflicting research regarding the influence of wildfire smoke on ozone concentrations. Research indicates that there is an influence of wildfire smoke on ozone under certain conditions depending on the distance of an ozone monitoring site from the wildfire smoke (i.e. the age of wildfire smoke) and the composition of the smoke which is dependent on the type of fuels that burned[4,5]. It does appear that during the summer of 2012, wildfire smoke from fires in central Idaho did impact ozone concentrations in Utah, especially in the mountain valleys adjacent to the Wasatch Front. These fires may have also impacted ozone concentrations in rural western and southern Utah, as discussed in Rural Utah Ozone Study section (page 40).

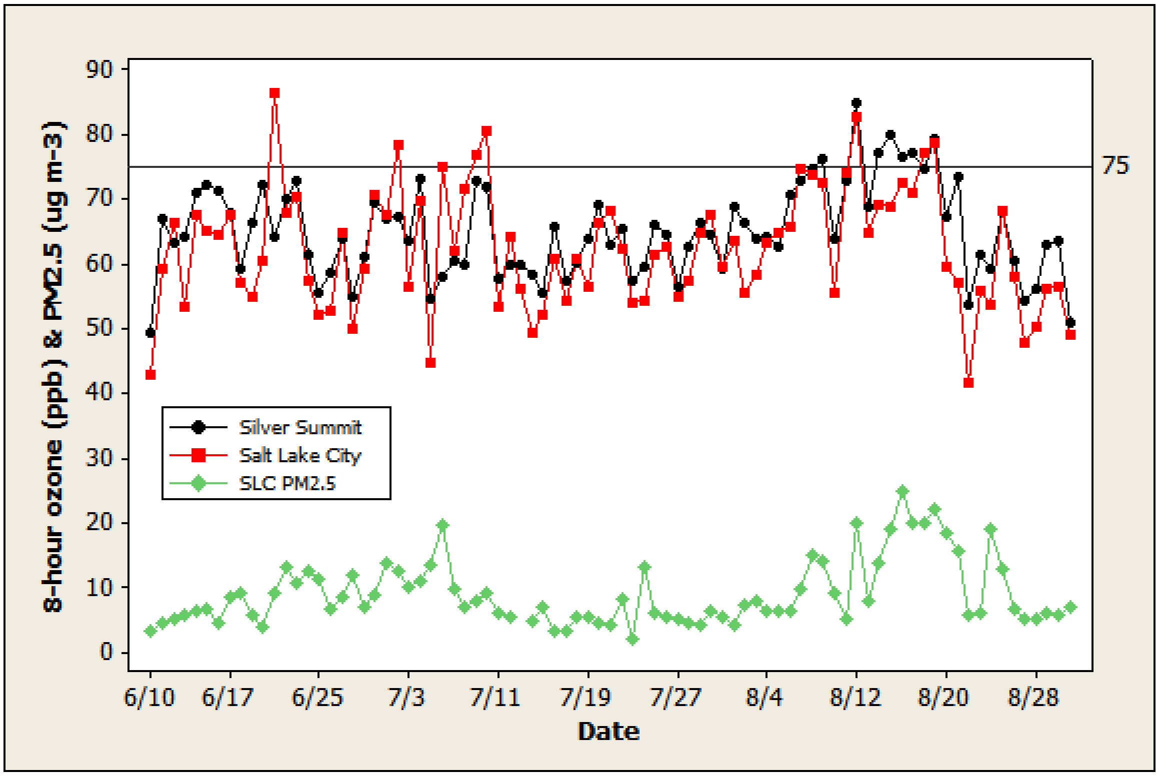

Figure 18. Daily maximum 8-hour ozone concentrations in Salt Lake City and silver Summit compared to daily PM2.5 measurements in Salt Lake City from 6/9/12 – 8/30/12. PM2.5 measurements came from 24 hour filter samples.

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[4] Bytnerowicz, A., D. Cayan, P. Riggan, S. Schilling, P. Dawson, M. Tyree, L. Wolden, R. Tissel and H. Preisler (2010) Analysis of the effects of combustion emissions and Santa Ana winds on ambient ozone during the October 2007 southern California wildfires. *Atmospheric Environment* **44**:678-687

[5] Paris, J.-D., A. Stohl, P. Nedelec, M. Yu Arshinov, M.V. Panchenko, V.P. Shmargunov, K.S. Law and B.D. Belan (2009) Wildfire smoke in the Siberian Arctic in summer: source characterization and plume evolution from airborne measurments. *Atmospheric Chemistry and Physics* **9**:9315-9327

VI. THE TOOELE VALLEY OZONE STUDY

1. Results – The Tooele Valley

Ozone was monitored in Erda at the Tooele Valley Airport from 2010-2012. Ozone concentrations observed in Erda during 2010 and 2011 were significantly higher than ozone observed at the permanent DAQ site in Tooele. In 2012, ozone monitoring continued in Erda and at the site in East Erda, 4 miles east of the Tooele Valley Airport. The goal of additional ozone monitoring in the Tooele Valley during 2012 was to determine the location of highest ozone concentrations and whether ozone observations in Erda were anomalous. An ozone monitor was also located at the DAQ remote meteorological site on Badger Island. The Badger Island site is located on a causeway in the middle of Great Salt Lake, distant from towns of the Tooele Valley, and is subject to different conditions of ozone formation than the other four Tooele Valley sites. In general ozone concentrations were significantly higher at Badger Island. Therefore, discussion of ozone concentrations at Badger Island will be found at the end of this section. The highest 1-hour and 8-hour ozone concentrations were observed in Erda (Table 6), but similar peak ozone concentrations were observed in East Erda, Tooele and the Beach. Erda observed greatest 4th highest 8-hour ozone concentration among Tooele Valley sites. The lowest 4th highest 8-hour ozone concentration was observed in Tooele. In all measures of ozone concentration, ozone concentrations in Erda were highest and ozone concentrations in Tooele were lowest in the Tooele Valley. In general, ozone concentrations were very similar in Erda, East Erda and the Beach site, while ozone concentrations in Tooele were significantly lower. Mean hourly ozone concentrations were lower at the Beach compared to Erda, East Erda and Tooele due to lower nighttime ozone concentrations at the Beach.

Both Erda and East Erda had six days with 8-hour ozone concentrations greater than 75 ppb while the Beach and Tooele had five and three days greater than 75 ppb, respectively (Figure 19). East Erda had fifteen days with 8-hour ozone concentrations greater than 70 ppb, while Erda had twelve days with ozone concentrations greater than 70 ppb. Tooele had the fewest number of days with ozone concentrations greater than 70 ppb (7 days). Comparing the number of days with ozone concentrations greater than 70 or 75 ppb, ozone concentrations in Erda and East Erda were significantly higher than was observed in Tooele.

SITE	Maximum hourly ozone	Maximum daily 8-hour ozone	4th highest 8-hour ozone	Mean daily maximum 1-hour ozone	Mean daily maximum 8-hour ozone	Mean hourly ozone
Erda	107	94	80	65.1	59.8	46.9
East Erda	101	92	78	64.7	59.7	46.6
Tooele	103	93	75	60.3	55.7	46.6
Beach	104	87	81	65.4	59.6	44.9
Badger Island	113	91	85	68.9	64.6	54.7

Table 6. Summary of ozone data collected during summer 2012 from Tooele Valley sites. For comparison across sites, only data from 5/1/12 – 10/2/12 was included.

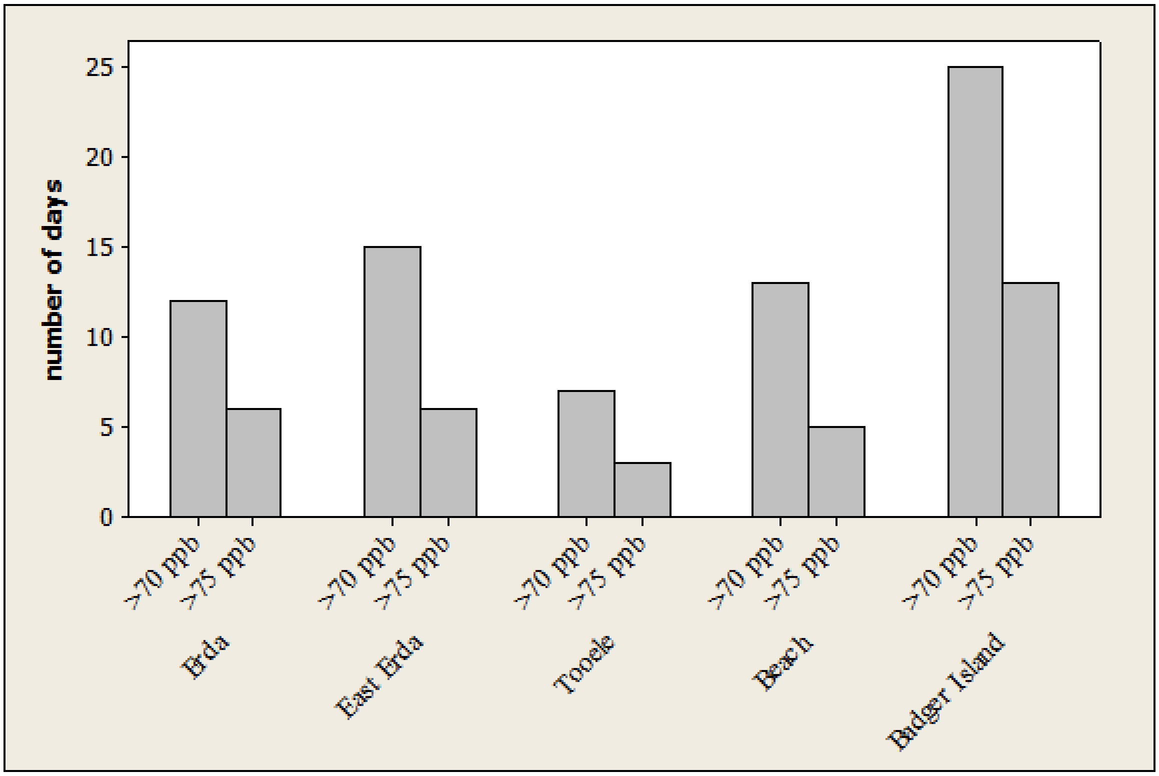

Figure 19. Comparison of the number of days when 8-hour ozone concentrations were greater than 70 ppb and 75 ppb at Tooele Valley sites.

An examination of dominant daytime wind patterns at the Tooele Valley sites shows that winds typically originate from the north-northeast to northwest (Figure 20**)**. A northern wind in the Tooele Valley means that winds blew over the Great Salt Lake before arriving at the Tooele Valley sites, suggesting that the Great Salt Lake influenced ozone formation in the Tooele Valley. When comparing wind patterns on low (< 68 ppb) and high (>75 ppb) ozone days in the Tooele Valley, it appeared that there was a slight bias to a northern wind direction on high ozone concentration days. The difference in wind patterns on high and low ozone concentration days was a non-significant difference, but wind originated from the southern half of the compass slightly more frequently on low ozone concentration days compared to high ozone concentration days in Erda, East Erda and Tooele. Patterns of daytime wind suggested that the Great Salt Lake influenced air masses in the Tooele Valley on all days during summer 2012, which was similar to patterns observed in the Tooele Valley in 2010-2011.

The four sites in the Tooele Valley were located in a small geographic area, but there was generally large spatial variability in ozone concentrations between the sites. Erda and East Erda, however, had very similar patterns of ozone concentrations and were strongly correlated to each other (r^2=0.86). Ozone concentrations in Erda were typically slightly elevated over East Erda, but within the margin of error of the ozone measurements. Erda ozone concentrations were moderately correlated to both the Beach and Tooele (r^2 = 0.65, r^2 = 0.65, respectively). East Erda ozone concentrations were more strongly correlated to the Beach and Tooele (r^2= 0.71, 0.66, respectively). Ozone concentrations at the Beach were more weakly correlated to Tooele (r^2=0.55), which could be attributed to different geography, wind patterns and proximity to the lake. Ozone concentrations at the Beach site was actually more strongly correlated to Salt Lake City (r^2=0.59) than Tooele.

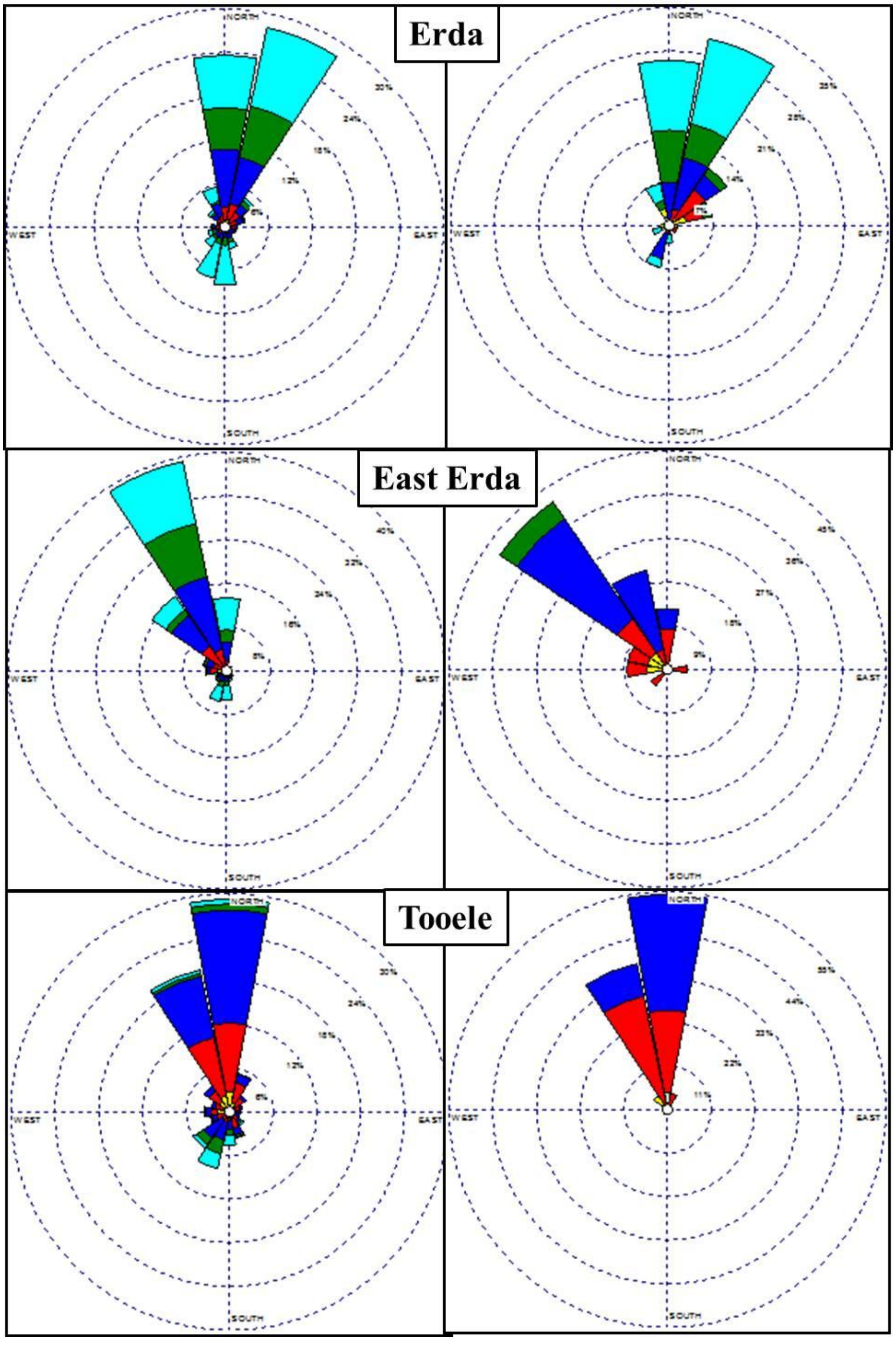

Figure 20. Wind roses showing daytime wind direction (8:00-19:00 MST) on days when 8-hour ozone concentrations were less than 68 ppb in the panels on the left and on days when 8-hour ozone concentrations were greater than 75 ppb in panels on the right for Erda, East Erda and Tooele. Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

Large spatial variability of ozone concentrations in the Tooele Valley and along the periphery of the Great Salt Lake was likely due to diverse geography and the influence of the Great Salt Lake. The Beach is on the Great Salt Lake at the northern point of the Oquirrh Mountains, where winds blowing from the lake travel into to either the Tooele Valley or the Salt Lake Valley. Erda is located in the central part of the Tooele Valley, five miles south of the Great Salt Lake shore at an elevation of 4310 feet. East Erda is located directly east of Erda, a mile from the base of the Oquirrh Mountains and 100 feet higher than Erda. The site in Tooele is in the foothills of the Oquirrh Mountains, at an elevation of 4960 feet, nearly 650 feet above Erda. Days with high ozone concentrations along the Wasatch Front were characterized by large-scale stagnant air masses and diurnal winds blowing away from the lake in the day and towards the lake at night. Ozone formation over the lake may be enhanced by increased albedo off the lake surface during early morning and late afternoon when reflectivity of the water was highest. In theory, increased albedo of the surface of the Great Salt Lake increases the availability of ultraviolet radiation and would increase the rate of ozone formation. In general the rate of ozone formation at Badger Island was greater than the rate of ozone formation at the Tooele Valley sites and ozone concentrations at Badger Island were generally higher in the morning and late afternoon compared to other sites. Ozone created over the lake was likely transported from the lake to the surrounding land areas including the Tooele Valley as daytime off-shore lake breezes began. However, daytime wind patterns from Badger Island did not support this hypothesis, but Badger Island was somewhat isolated from the Tooele Valley by the mountains on Stansbury Island to the southeast. The off-shore winds from the Great Salt Lake were slightly more pronounced on high ozone concentration days (see Figure 20). Daytime wind patterns on high ozone concentration days are shown in Figure 21 for sites in the Tooele Valley and DAQ sites surrounding the Great Salt Lake. The influence of the Great Salt Lake on daytime winds was not confined to the Tooele Valley; many sites around the periphery of the lake may be influenced by ozone formation over the lake. Ozone concentrations in the Tooele Valley were likely influenced by ozone formation over the Great Salt Lake and transport by off-shore lake winds, but further intensive study is needed to understand the precise role of the Great Salt Lake in ozone formation along the Wasatch Front.

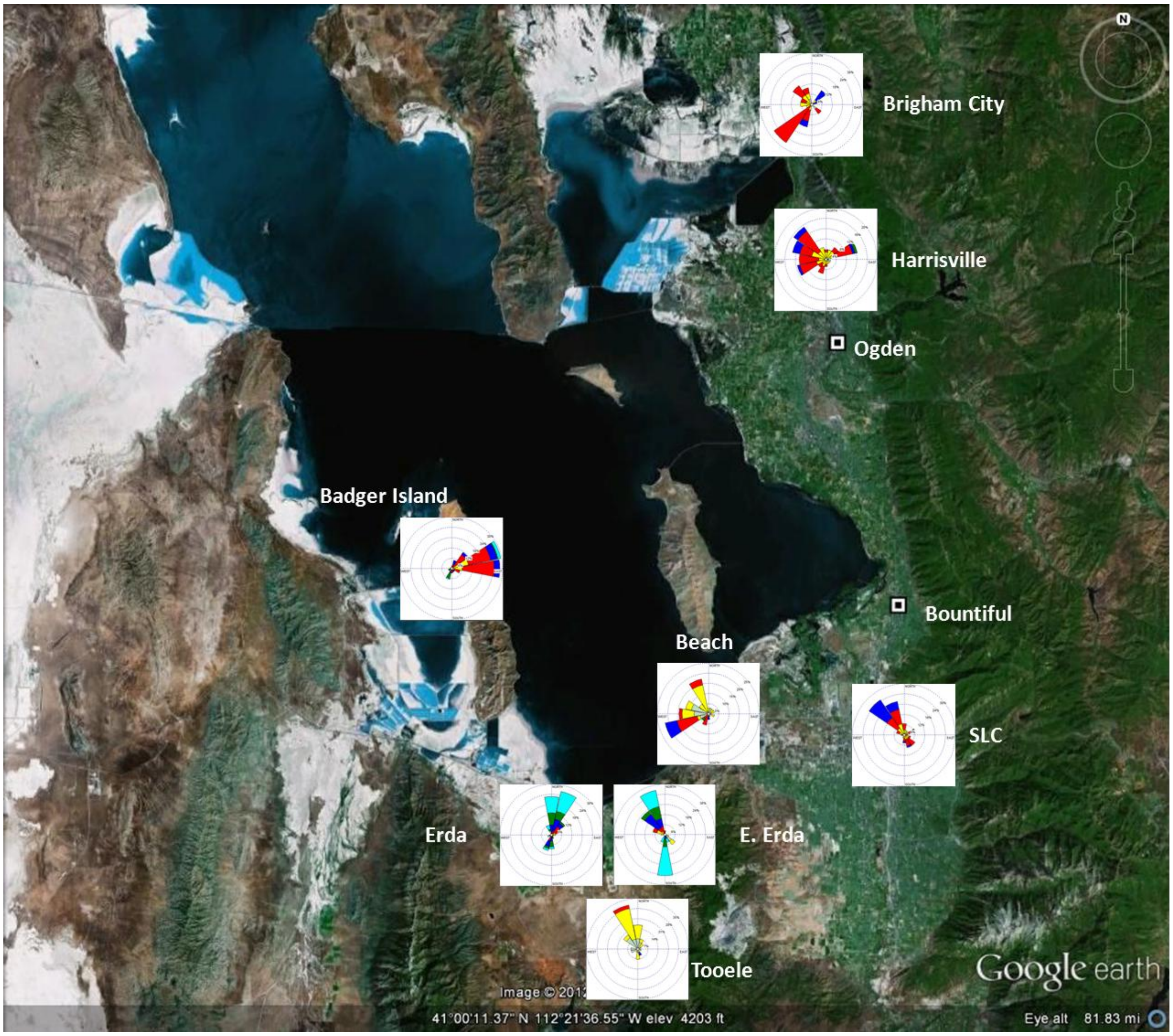

Figure 21. Daytime wind patterns on high ozone concentration days (>75 ppb) in 2012 at sites surrounding Great Salt Lake. Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

2. Results – Badger Island

By most measures, ozone concentrations at Badger Island were the highest observed in Utah during 2012. Table 6 and Figure 19 show that maximum 1-hour and 8-hour, mean daily maximum 1-hour and 8-hour and the number of days with ozone concentrations greater than 70 ppb and 75 ppb were greatest at Badger Island compared to the other Tooele Valley sites. Badger Island had thirteen days with 8-hour ozone concentrations greater than 75 ppb and 24 days with ozone concentrations greater than 70 ppb, by far the most observed in all of Utah. Another important pattern of ozone formation at Badger Island was that nighttime ozone concentrations were quite high compared to sites along the Wasatch Front and were similar to that observed at the most rural sites in Utah. There were many days, especially early and late in the ozone season, when ozone concentrations were uniquely high at Badger Island compared to sites along the Wasatch Front and in the mountain valleys. There were five days when Badger Island was the only site along the Wasatch Front and the mountain valleys with ozone concentrations exceeding 75 ppb and there were eight additional days when ozone concentrations at Badger Island and only one other site exceeded 75 ppb. Ozone concentrations were uniquely high at Badger Island likely due to its location in the middle of the Great Salt Lake. As discussed in the previous section, ozone formation at Badger Island was likely enhanced by increased ultraviolet radiation caused by increased albedo of the lake surface, especially during early morning and late afternoon. Ozone typically formed faster in the morning and stayed elevated later in the day compared to the Tooele Valley sites. One potential influence of high ozone concentrations at Badger Island could be chlorine emission from the MagCorp plant approximately fifteen miles to the west. However, an analysis of dominant daytime wind patterns at Badger Island on high and low ozone concentration days showed that winds were typically from the eastern half of the compass on all days (Figure 22). The most likely explanation of increased ozone concentrations at Badger Island was the effect of increased albedo from the Great Salt Lake; however, further investigation is needed to empirically determine the cause of high ozone concentrations.

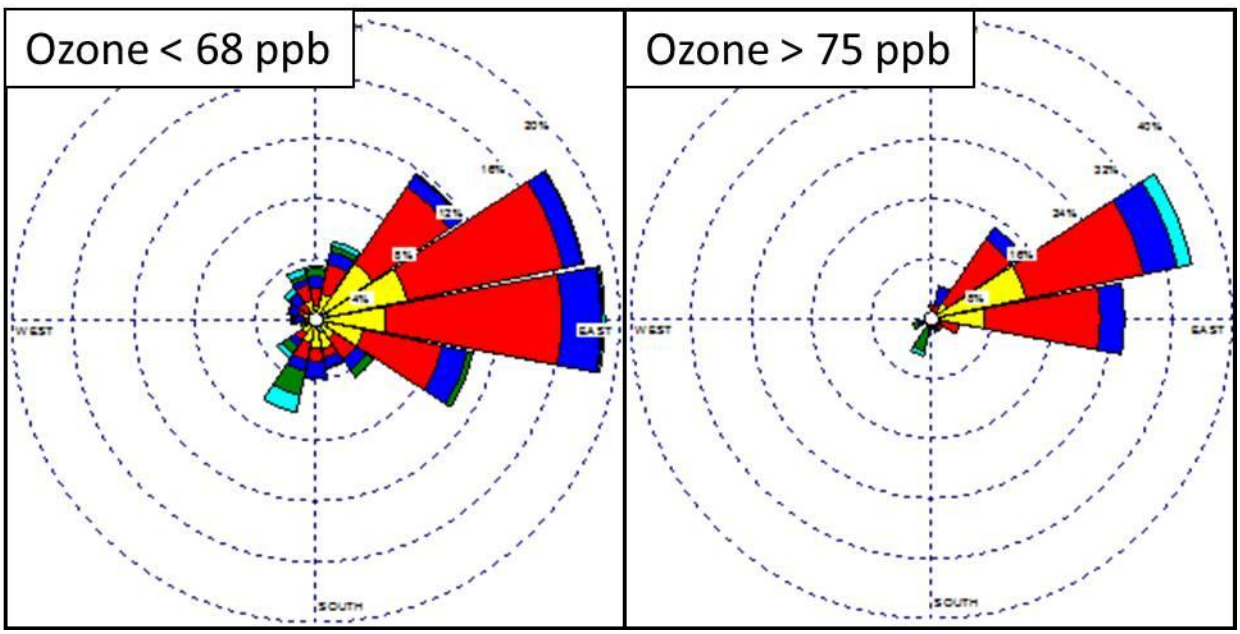

Figure 22. Wind roses showing daytime wind direction (8:00-19:00 MST) on days when 8-hour ozone concentrations were less than 68 ppb and on days when 8-hour ozone concentrations were greater than 75 ppb in panels at Badger Island during summer 2012. Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

3. Erda ozone 2010-2012

Finally, it is important to note that ozone concentrations in Erda were the highest observed in Utah during 2012 and over the past three years. The ozone NAAQS is determined by averaging the 4th highest annual 8-hour ozone concentration over a three year period. Ozone concentrations have been measured at the same location in Erda from 2010-2012. Three year averages were calculated for all permanent regulatory ozone monitors in the Tooele Valley and along the Wasatch Front. Erda had the highest three year 4th highest 8-hour ozone concentration in Utah at 77 ppb. Tooele's three year average for the same time frame is 74 ppb, while the Beach is 75 ppb. Only Erda and Salt Lake City, which has a three year average of 76 ppb, exceeded the current ozone NAAQS (Figure 23).

Figure 23. Three year averages of the 4th highest 8-hour ozone concentrations along the Wasatch Front for 2010-2012. Red circles denote exceedances of the current ozone NAAQS, while yellow denotes ozone nearly exceeding the NAAQS. All sites except Erda are regulatory monitors.

VII. RURAL UTAH OZONE STUDY

Five additional ozone monitors with meteorological equipment were located in rural western Utah at Antelope Island, Nephi, Delta, Desert Range and Badger Springs (see Figure 1). All rural sites except Antelope Island were at least 40 miles distant from an urban emission source. In general, ozone concentrations at rural sites were moderate to high. Table 7 summarizes ozone data collected at rural sites during spring and summer of 2012. The highest ozone concentrations were observed on Antelope Island with a maximum 8-hour ozone concentration of 89 ppb. Antelope Island and Badger Springs were the only sites where ozone concentrations exceeded 75 ppb; on Antelope Island, there were five days and at Badger Springs there were ten days. The only site in the entire DAQ monitoring network that had more days with ozone concentrations exceeding 75 ppb than Badger Springs was Badger Island with thirteen days. In Nephi, there were no days with 8-hour ozone concentrations exceeding 75 ppb, but at Desert Range and Delta, there was one day with ozone concentrations greater than 75 ppb. Diurnal variability in ozone concentrations was similar at Antelope Island, Nephi, Delta and Desert Range, but significantly lower at Badger Springs. Badger Springs was the only rural sites that had a diurnal pattern of ozone concentrations consistent with a truly rural site. Figure 24 shows the number of days when ozone concentrations exceeded 70 ppb at rural sites. Antelope Island and Badger Springs both had over 20 days with 8-hour ozone concentrations greater than 70 ppb. Ozone concentrations were surprisingly high at Badger Springs considering its rural location; St. George is 25 miles to the east and Las Vegas is 100 miles to the west. Desert Range and Nephi had the fewest days with 8-hour ozone greater than 70 ppb and there were eight days when ozone concentrations were greater than 70 ppb in Delta.

SITE	Maximum hourly ozone	Maximum 8-hour ozone	4th highest 8-hour ozone	Mean daily maximum 1-hour ozone	Mean daily maximum 8-hour ozone	Mean hourly ozone	Mean diurnal variability
Antelope Island	109	89	79	66.0	61.0	50.6	30.4
Nephi	86	75	72	61.8	57.6	43.3	38.8
Delta	82	76	71	62.2	59.0	46.6	35.3
Desert Range	84	76	72	60.9	57.9	46.2	31.0
Badger Springs	89	80	76	61.9	60.7	54.4	15.0
Spanish Fork	102	88	76	66.8	60.2	47.2	37.2
Great Basin N.P.	99	81	76	63.0	60.4	54.5	17.3
Zion N.P.	86	81	76	61.9	60.2	51.4	20.8

Table 7. Summary of ozone data collected during summer 2012 from rural Utah sites. For comparison across sites, data from 3/29 – 8/28/12 at Desert Range, Badger Springs, Great Basin National Park (N.P.) and Zion N.P. were used and data from 5/18 – 10/1/12 at Antelope Island, Nephi, Delta and Spanish Fork was used. All ozone data is in parts per billion (ppb). Spanish Fork, Great Basin and Zion N.P. were presented to compare 2012 summer monitoring locations to permanent ozone monitor locations.

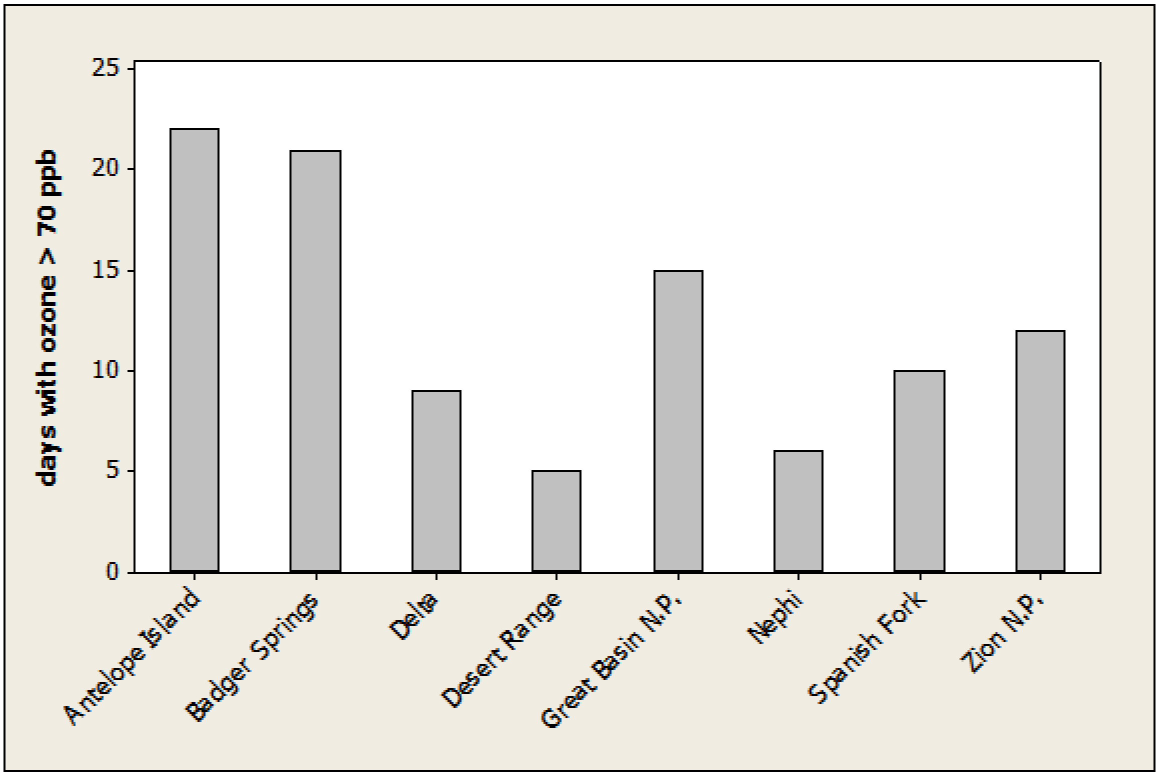

Figure 24. The number of days when daily maximum 8-hour ozone concentrations exceeded 70 ppb.

Although the Beaver Dam Wash Mountains and 50 miles separate sites at Badger Springs and Zion N.P., ozone concentrations were very similar at both sites, but there were more days in Badger Springs when ozone concentrations exceeded 75 ppb (10) compared to Zion N.P. (4). Diurnal variation of ozone concentrations was much lower in Badger Springs compared to Zion N.P. The National Park Service ozone monitoring site in Great Basin National Park was located approximately 35 miles northwest of and at a slightly higher elevation than the ozone site at Desert Range. Despite the close proximity of the two sites, ozone concentrations were significantly higher in Great Basin N.P. than at Desert Range. Diurnal variation of ozone concentrations was significantly less in Great Basin N.P. Finally, ozone concentrations in Spanish Fork were higher than ozone in Nephi, even though Nephi is only 30 miles south of Spanish Fork. General patterns of ozone formation in Nephi were typical of a rural environment, while patterns of ozone formation in Spanish Fork were more characteristic of an urban environment.

Although up to 250 miles separates the seven sites from Spanish Fork to Badger Springs, there were occasions where daily maximum 8-hour ozone concentrations followed similar trends across western and southwestern Utah. Figure 25 shows daily maximum 8-hour ozone concentrations at seven sites in late May 2012. Ozone concentrations were generally highest at Great Basin N.P. and lowest at Spanish Fork in late May, but trends in ozone were very similar, suggesting a regional influence on ozone formation. Over this late May period, ozone concentrations were lowest at the most urban site (Spanish Fork) and highest at the most rural sites (Great Basin N.P., Zion N.P. and Badger Springs). The magnitude of ozone concentrations varied among these seven sites, but all sites followed the same trend in ozone, especially from 5/27 – 5/31/12.

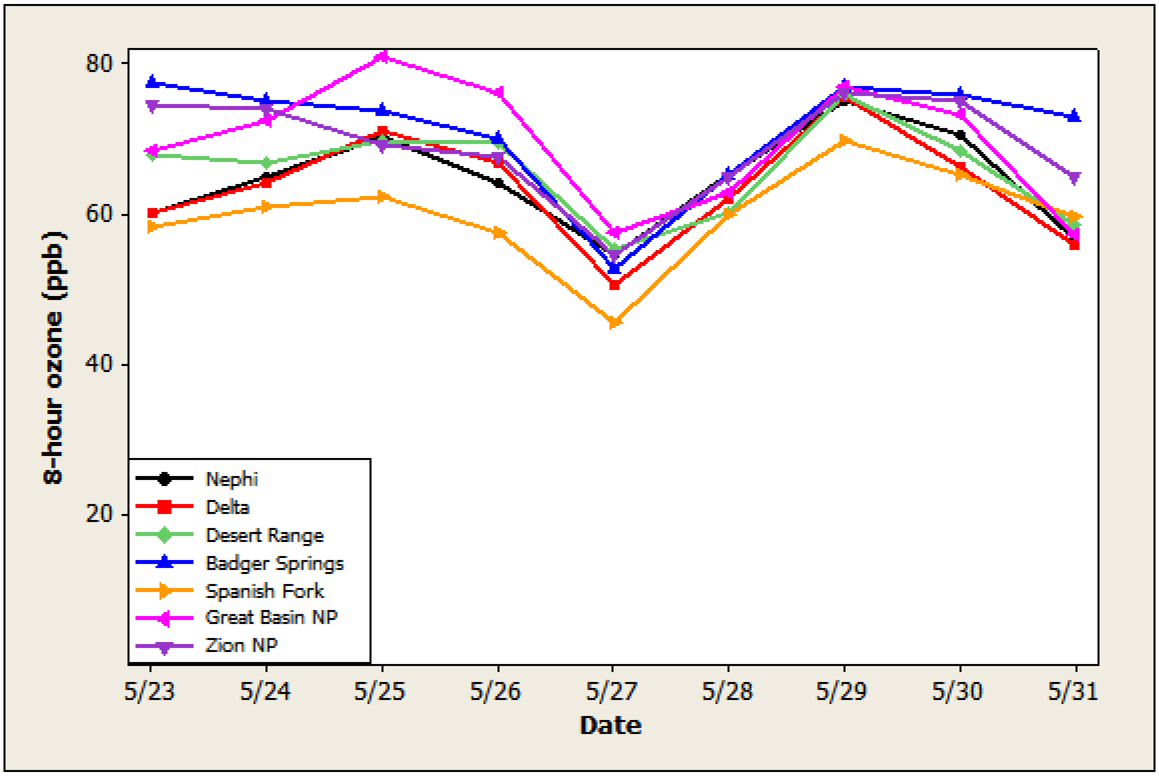

Figure 25. Daily maxium 8-hour ozone at Nephi, Delta, Desert Range, Badger Springs, Spanish Fork, Great Basin N.P. and Zion N.P. from 5/23 – 5/31/12.

Daily maximum 8-hour ozone concentrations at the seven sites in Figure 25 were highly correlated from 5/23 – 5/31 with the strongest correlation between Delta and Nephi (r^2 = 0.954) and the weakest correlation between Nephi and Badger Springs (r^2 = 0.579). Comparisons between most sites were correlated with $r^2 > 0.70$. This time period, and others in the late spring to early summer, may have been affected by the intrusion of stratospheric ozone. The effect of stratospheric ozone intrusion on ozone in rural Utah will be explored in the "Discussion" section.

Although there were strong correlations between sites spanning large distances in western Utah during some time periods, the degree of correlation of ozone concentrations between rural Utah sites over the entire summer was most dependent on distance. Table 8 shows the results of correlations between daily maximum 1-hour ozone concentrations at rural sites across western Utah. The strongest correlations between daily maximum 1-hour ozone concentrations were observed at Zion N.P. and Badger Springs (r^2 = 0.874), Desert Range and Great Basin N.P. (r^2 = 0.818) and Spanish Fork and Nephi (r^2 = 0.735). All of these sites were located approximately 35 miles apart. Despite a separation of nearly 100 miles, ozone concentrations at Desert Range and Badger Springs were strongly correlated (r^2 = 0.706). Correlations at other sites were lower and generally decreased as distance between sites increased. Daily maximum 1-hour ozone concentrations in Nephi and Mt. Pleasant were also strongly correlated (r^2 = 0.882). Comparisons between Mt. Pleasant and other sites were not used due to the relatively few ozone observations in Mt. Pleasant (from 8/9 – 10/1/12).

SITE	Badger Springs	Zion N.P.	Desert Range	Great Basin N.P.	Delta	Nephi
Zion N.P.	**0.874**	-	-	-	-	-
Desert Range	**0.706**	**0.653**	-	-	-	-
Great Basin N.P.	**0.648**	0.514	**0.818**	-	-	-
Delta	0.417	0.435	**0.633**	0.483	-	-
Nephi	0.430	0.369	0.517	0.383	**0.601**	-
Spanish Fork	0.087	0.535	0.226	0.062	0.502	**0.735**

Table 8. Correlations between daily maximum 1-hour ozone concentrations in Nephi, Delta, Desert Range, Badger Springs, Spanish Fork, Great Basin N.P. and Zion N.P. Data from 5/18/12 – 8/28/12 was used for comparison.

There were several factors that help to explain variation in ozone at rural Utah sites including dominant wind patterns, relative humidity, regional transport urban pollution and wildfire smoke and stratospheric ozone intrusions. At all rural Utah sites, except Delta, there were differences in dominant wind patterns on high and low ozone days. Figure 26 shows daytime wind patterns on high and low ozone days at Nephi, Desert Range and Badger Springs. High ozone days were defined as days when ozone exceeded 70 ppb and low ozone days were days when ozone was less than 70 ppb. On days with high ozone, winds in Nephi were mostly commonly from the north; during 28% of the hours on high ozone days, the wind blew from the north, compared to only 14% of the hours on low ozone days. Also, winds were much more commonly from the south-southeast on low ozone days compared to high ozone days. Winds originated from the south-southeast during 48% of the hours on low ozone days compared to 33% of the hours on high ozone days. Spanish Fork is 35 miles north of Nephi and Provo is 45 miles north, which represented a potential source of ozone and ozone precursors. On the six days when 8-hour ozone exceeded 70 ppb in Nephi, 8-hour ozone in Spanish Fork ranged from 67 – 89 ppb and ranged from 65 – 80 ppb in North Provo. However, there are no significant sources of ozone or ozone precursors to the south or southeast of Nephi. At Desert Range, daytime wind directions were more commonly from the south on high ozone days compared to low ozone days; the wind direction was from the south during 39% of the hours on high ozone days compared to 28% of the hours on low ozone days. While there was no nearby source of ozone or ozone precursors south of Desert Range, ozone concentrations there were potentially influenced by regional transport from St. George, Las Vegas or southern California, although air mass back trajectory analyses on high ozone days did not directly suggest ozone transport. Finally, southwest winds were slightly more common on high ozone days at Badger Springs (37% of hours) than on low ozone days (24%). As with Desert Range, there is no nearby source of ozone and ozone precursors, but Las Vegas and southern California to the southwest of Badger Springs may have impacted ozone formation under certain conditions.

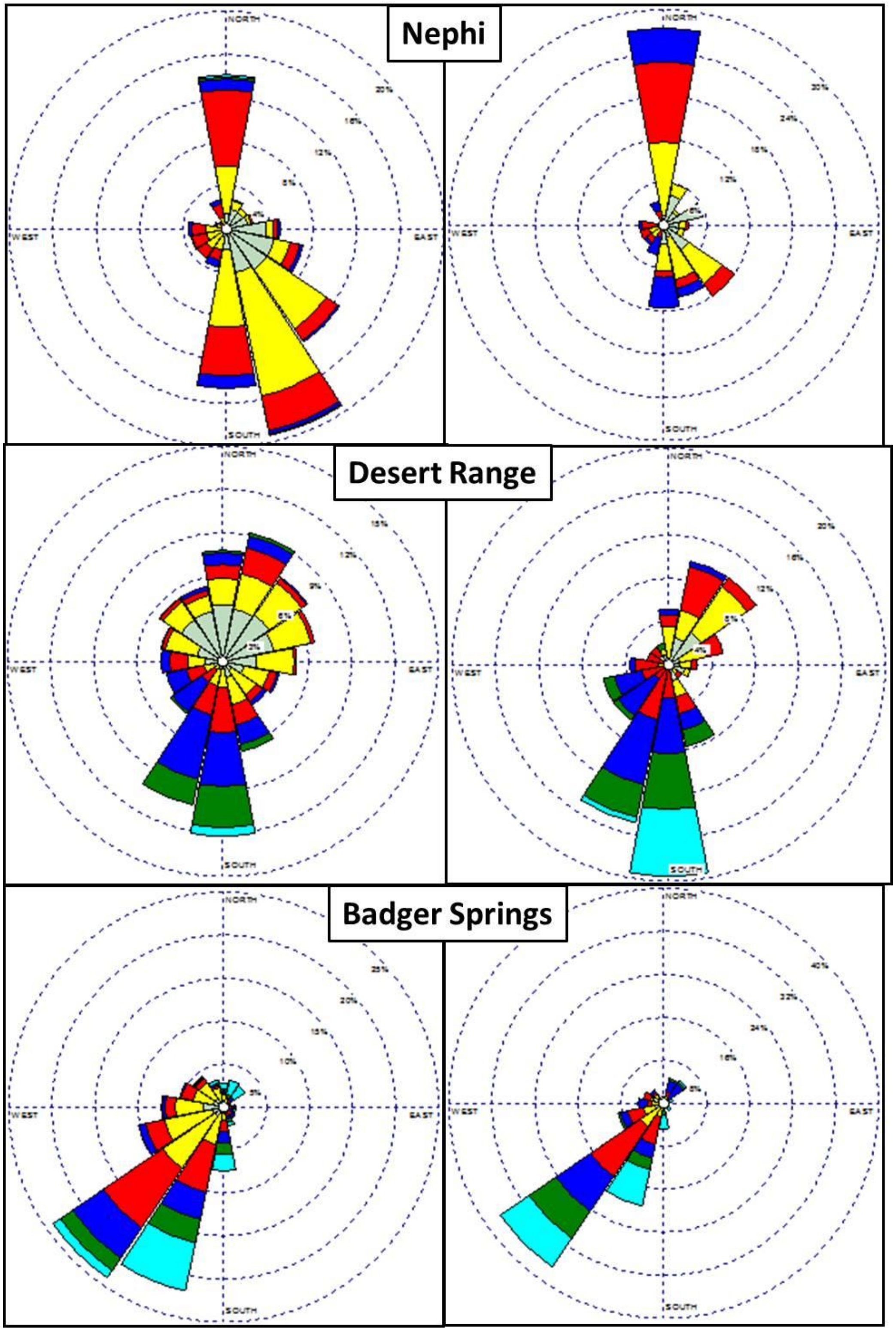

Figure 26. Daytime (9:00-19:00 MST) wind patterns in Nephi, Desert Range and Badger Springs on days with 8-hour ozone less than 70 ppb (left panels) and on days with 8-hour ozone greater than 70 ppb (right panels). Wedges on the wind rose point to the direction a wind blew from; larger wedges indicate a longer duration of wind from that direction. Different colors represent different wind speed classes.

Peak seasonal ozone concentrations in southern and western Utah typically occurred in late May to early June. This pattern was different than in urban areas of the Wasatch Front and the mountain valleys of northern Utah where peak seasonal ozone occurred in July – August. Figure 27 shows daily maximum 8-hour ozone concentrations at seven rural sites in southern and western Utah. Across sites from Nephi in the north to Badger Springs and Zion N.P. in the south, ozone concentrations generally increased until a broad peak in regional ozone in late May through early June. From June through early August, regional ozone concentrations generally decreased. However, there was an overall increase in ozone concentration across all seven sites from 8/9 – 8/20. Ozone concentrations at sites in the deserts of southern and western Utah typically peak in late spring, as observed in 2012. Reasons for a late spring seasonal peak in ozone concentrations may include emission of biogenic volatile organic compounds during springtime peaks in plant photosynthesis and more active regional transport and stratospheric ozone intrusion during strong spring storms. The secondary seasonal peak in ozone concentrations that occurred during the middle of August coincided with high ozone concentrations in Wasatch Front cities and mountain valleys of northern Utah. Peak daily maximum 8-hour ozone concentrations in mid-August varied from 63 ppb in Badger Springs to 74 ppb in Delta for rural Utah sites. Wildfire smoke from fires in Idaho affected air quality in Wasatch Front cities during the same time period. Fine particulate matter concentrations were often greater than 20 µg m^{-3} in Salt Lake City from 8/12 – 8/21/12; $PM_{2.5}$ concentrations were around 20 µg m^{-3} in Spanish Fork on 8/16 and 8/19. Spanish Fork was the closest site collecting particulate matter data to rural sites in western and southern Utah.

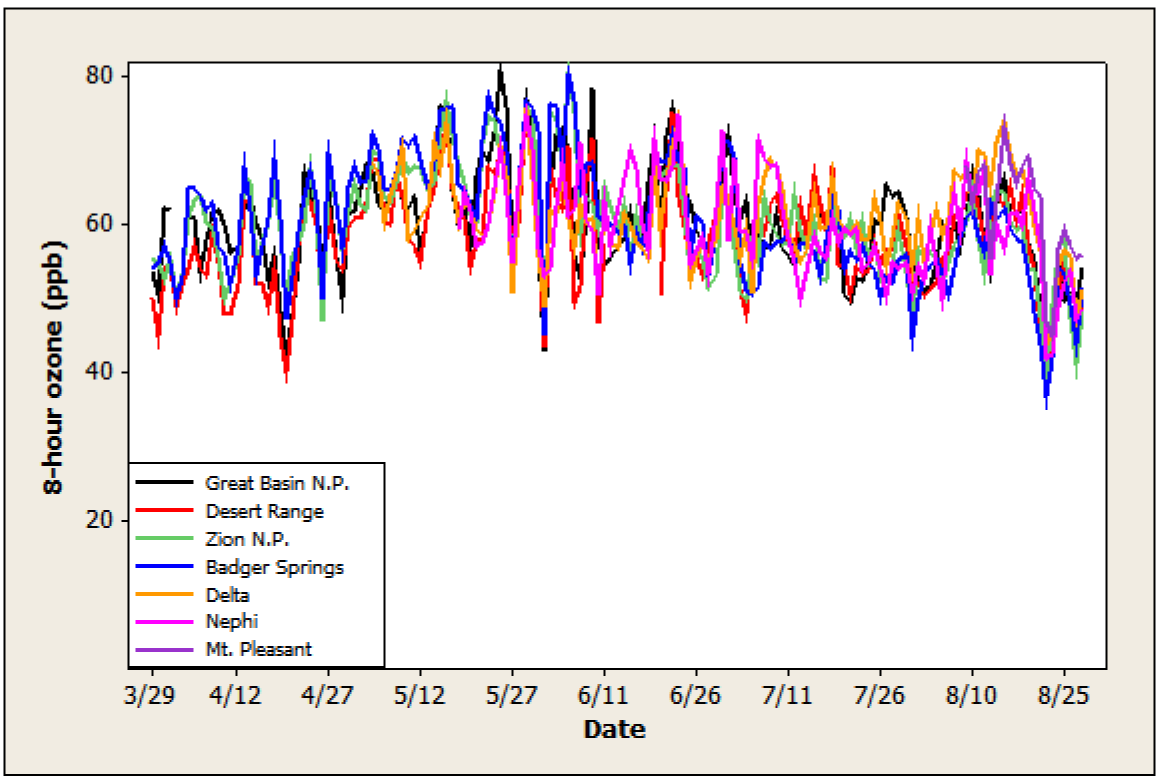

Figure 7. Daily maximum 8-hour ozone concentrations from sites in Nephi, Mt. Pleasant, Delta, Desert Range, Badger Springs, Great Basin N.P. and Zion N.P. from 3/29 – 8/28/12.

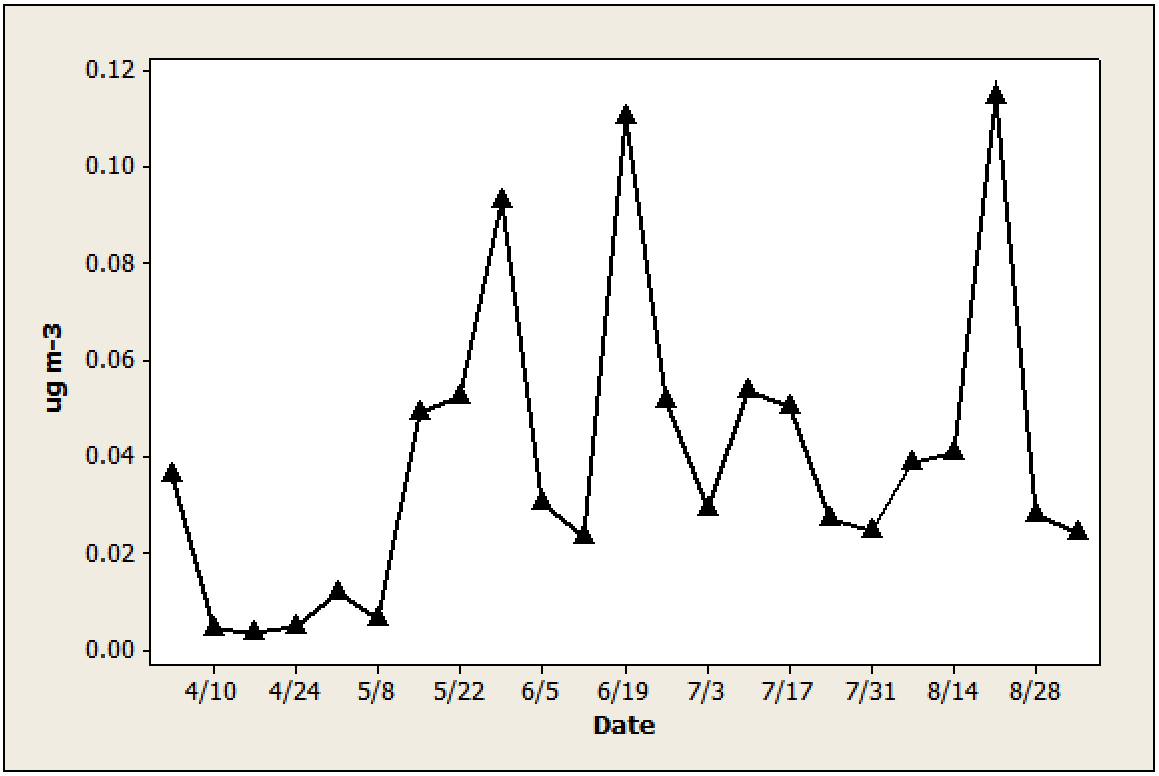

Figure 28. Weekly concentrations of potassium (K^+) ions collected in dry deposition in Great Basin N.P. Weekly samples were collected and each date represents the day a weekly sample was collected. Data was obtained from the Clean Air Status and Trends Network (CASTNET).

The Clean Air Status and Trends Network (CASTNET) monitors wet and dry atmospheric deposition from rural sites across the country, including a site in Great Basin N.P. Although no nearby sites collected particulate matter, dry deposition collected by CASTNET in Great Basin was analyzed for concentrations of potassium ions. Potassium is the most common inorganic component of plant material and wildfire smoke typically has relatively high concentrations of potassium ions[6]. Figure 28 shows weekly concentrations of potassium in dry deposition collected in Great Basin N.P. The highest concentration of potassium in Great Basin N.P. (0.1148 µg m^{-3}) was observed in a weekly sample ending on 8/21/12. During the week of 8/14 – 8/21/12, particulate matter concentrations were elevated in Salt Lake City, North Provo, Lindon and Spanish Fork. Based on data from the HYSPLIT Smoke Verification model (NOAA), wildfire smoke from Idaho drifted into central and southern Utah from 8/14-8/19 causing fine particulate matter concentrations of 1-5 µg m^3. The wildfire smoke present in central and southern Utah in mid-August may have enhanced ozone formation during this time period. During mid-August, ozone was higher in Nephi and Delta compared to Desert Range and Badger Spring; there was likely a higher concentration of particulate matter from Idaho wildfires in Delta and Nephi since the two sites are approximately 100 miles closer to the fires in Idaho. NOAA HYSPLIT Smoke Verification Model also showed a small amount of particulate matter

[6] Mphale, K. and M. Here (2007). Wildfire plume electrical conductivity. *Tellus*. **56**:766-772.

in the vicinity of Great Basin N.P. in the couple days before 5/29 and 6/19 when potassium ion concentrations were around 0.1 µg m^{-3}. Ozone in Great Basin N.P., Desert Range and Badger Springs was not elevated in the week prior to 6/19, but ozone concentrations were relatively high the week prior to 5/29, but factors other than wildfire smoke likely impacted higher ozone concentrations.

The intrusion of stratospheric ozone into the troposphere may contribute to high ozone concentrations in rural Utah during late spring. Stratospheric ozone may affect ground level ozone concentrations when strong storms in the spring cause tropospheric folding and mix stratospheric ozone down to the ground surface. Stratospheric ozone events may be characterized by the passage of a strong cold front high isotropic vorticity, sudden changes in surface ozone concentrations, high concentrations of total atmosphere column ozone, very low relative humidity and high surface wind speeds. Stratospheric ozone intrusion may have affected surface ozone concentrations on 12 of 22 days in Badger Springs when 8-hour ozone exceeded 70 ppb, on four of five days in Desert Range when 8-hour ozone concentrations exceeded 70 ppb and on four of nine days in Delta when 8-hour ozone concentrations exceeded 70 ppb.

Among sites in the rural Utah ozone study, the highest ozone concentrations were observed at Antelope Island (Table 7). Antelope Island was one of the highest ozone sites in Utah during 2012. Although Antelope Island was considered a rural site, it was only 20 miles southwest of Ogden and was strongly influenced by both the Wasatch Front and Great Salt Lake. Generally, ozone at Antelope Island was higher than ozone observed at nearby DAQ sites in Ogden and Harrisville. Figure 29 compares daily maximum 8-hour ozone concentrations at Antelope Island to ozone concentrations in Ogden and Harrisville. Ozone concentrations at Antelope Island were nearly always higher than ozone concentrations in Ogden and generally higher than ozone concentrations in Harrisville. Despite differences in the magnitude of ozone concentrations, daily maximum 8-hour ozone concentrations at Antelope Island were strongly correlated to ozone concentrations in Harrisville ($r^2 = 0.838$) and Ogden ($r^2 = 0.738$). Like Badger Island in Tooele County, ozone formation at Antelope Island was likely influenced by Great Salt Lake. Further investigation of the role of Great Salt Lake on ozone formation will occur in 2013.

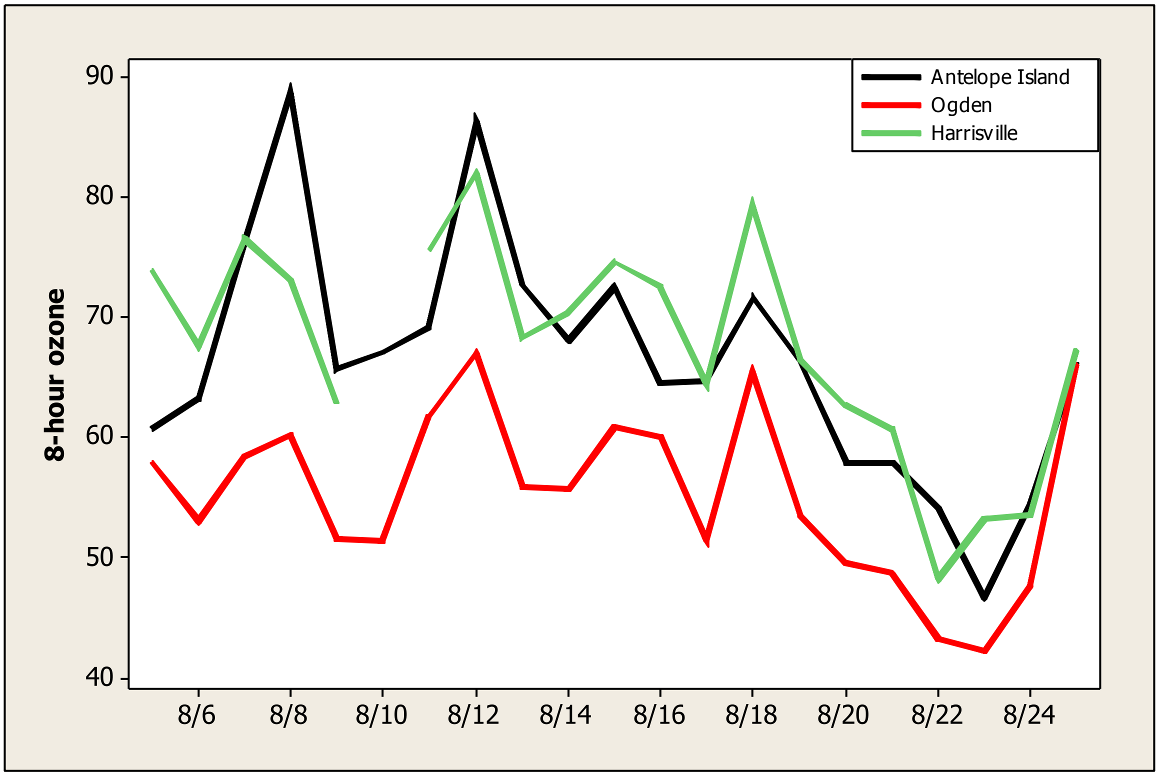

Figure 29. Daily maximum 8-hour ozone concentrations at Antelope Island, Ogden and Harrisville from 8/6 – 8/25/12.

VIII. CONCLUSIONS

1. Mountain valley ozone study

a. Ozone concentrations at mountain valley sites were similar to or greater than ozone concentrations observed along the Wasatch Front. At all mountain valley sites, except Huntsville and Mt. Pleasant (which was considered an experimental control), there was at least one day when ozone exceeded 75 ppb.

b. Ozone at Park City area sites was very high with three of five sites experiencing four of more days with ozone concentrations exceeding 75 ppb. In the Park City area, ozone was highest at Parleys Summit and nearly as high in Snyderville and Silver Summit. Transport of ozone and ozone precursors from Salt Lake City and higher solar radiation at higher elevations were the most significant factors leading to high ozone in the Park City area.

c. Ozone concentrations in Huntsville and Morgan were moderately high, but typically lower than the nearest DAQ monitoring site in Harrisville. Ozone exceeded 75 ppb on one day in Huntsville, but did not exceed 75 ppb in Morgan.

d. High ozone in August at mountain valley sites was also likely influenced by wildfire smoke from fires in Idaho. Ozone concentrations in Silver Summit, especially on days when ozone exceeded 70 ppb, were strongly correlated to 24-hour $PM_{2.5}$ measurements in Salt Lake City.

2. Tooele Valley ozone study

a. The highest ozone concentrations in Tooele Valley were observed in Erda. Ozone in East Erda was nearly as high, but ozone at both sites was significantly greater than ozone at the DAQ site in Tooele.

b. Erda and Salt Lake City were the only ozone monitoring sites in Utah to exceed the ozone NAAQS. The three year average of the 4^{th} highest 8-hour ozone concentration was 77 ppb in Erda.

c. Ozone concentrations at the Badger Island DAQ site were the highest observed in Utah during 2012. Ozone at Badger Island exceeded 75 ppb on thirteen days. Ozone formation at Badger Island was likely enhanced by increased albedo from Great Salt Lake. Ozone formation over Great Salt Lake likely impacted ozone concentrations in Tooele Valley where dominant daytime winds typically originated from the lake.

3. Rural Utah ozone study

a. At all rural ozone sites except Nephi, 8-hour ozone concentrations exceeded 75 ppb on at least one day. Ozone exceeded 75 ppb at Badger Springs on ten days, making it one of the highest ozone sites in Utah despite its remote location. The 4^{th} highest 8-hour ozone concentration exceeded 70 ppb at all rural Utah sites.

b. During certain time periods, ozone at all rural sites was very closely correlated, despite geographic separation of up to 250 miles, suggesting broad regional transport of ozone.

c. The highest ozone concentrations at rural Utah sites generally occurred in early summer, but a secondary peak in ozone occurred in August. Chemical speciation data from Great Basin National Park suggested that wildfire smoke was present in southern and western Utah during the secondary ozone peak in August.