FINAL REPORT
2015 UPPER GREEN RIVER WINTER OZONE STUDY

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Meteorological Solutions Inc.
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Appendix

A Monitoring and Quality Assurance Plan
B Microsoft Access Database Description

1.0 INTRODUCTION

The Wyoming Department of Environmental Quality (WDEQ) – Air Quality Division (AQD) sponsored the Upper Green Winter Ozone Study (UGWOS) during the period January 15 to March 31, 2015. This research program has been conducted each year since 2007 to investigate wintertime ozone formation in the Upper Green River Basin (UGRB) leading to concentrations of ambient ozone (O_3) exceeding the National Ambient Air Quality Standard (NAAQS) which is currently set at a daily maximum eight-hour average of 75 parts per billion (ppb). During each year's field effort, data are collected from a network of long-term air quality monitoring stations and various specialized ozone precursor measurement systems. Quality assurance project plans, data, and reports from previous UGWOS field efforts (2007-2014) are posted on the Monitoring Information Page of the WDEQ-AQD website.[1]

In 2015, AQD contracted with Meteorological Solutions Inc. a Trinity Consultants Company (MSI Trinity) to conduct a field measurement program which focused on the spatial distribution of ozone and ozone precursors. MSI Trinity was responsible for overall project management, quality assurance project plan development, volatile organic compound (VOC) canister collection, forecast assistance, project website hosting, project database, data collection and management, data validation and reporting as well as field monitoring operations. Field operations included the following:

- An air quality technician installed five (5) speciated hydrocarbon sampling systems using stainless steel canisters and carbonyl cartridges and collected speciated hydrocarbon samples on designated sampling days;

- An air quality technician performed routine quality control checks, troubleshooting, and repair of MSI Trinity operated existing WDEQ-AQD long-term monitoring sites in the project domain; and,

- Installation, calibration and operation of three (3) mesonet sites at three of the canister and carbonyl sampling sites providing continuous wind speed and direction, temperature data, and camera images.

MSI Trinity prepared the Quality Assurance Project Plan (QAPP) for this study; WDEQ-AQD personnel provided independent quality assurance audits of WDEQ-AQD's monitoring network.

Field operations for UGWOS 2015 began on January 15, 2015 and continued through March 31, 2015. With assistance from MSI Trinity meteorologists, daily weather outlooks were issued by the WDEQ-AQD forecast meteorologist in order to identify periods when ambient ozone concentrations in the UGRB were likely to be elevated and to provide an alert to field personnel so speciated VOC canister, carbonyl measurements could be implemented during designated sampling days. Four (4) designated VOC sampling days were forecasted. These sampling days were characterized by high pressure, light winds and sunny skies.

[1] http://deq.wyoming.gov/search/?division=&q=UGWOS+2014&=Submit

This report presents a summary of UGWOS 2015 field operations, quality assurance activities, and the results of the field measurement program. Section 2.0 presents an overview of field measurement operations including the ozone and ozone precursor measurements. This section also provides synoptic weather summaries for the designated VOC sampling days. Section 3.0 describes database management, quality assurance, data validation, and data archiving. Monitoring results are described in Section 4.0. Section 5.0 presents a summary of the findings, conclusions based on the findings, and recommendations. UGWOS 2015 measurement data are available in an ACCESS database on the AQD website.

2.0 SUMMARY OF FIELD OPERATIONS

This section provides a description of the field measurement platforms used during UGWOS 2015, operational forecasts, and synoptic weather summaries during designated VOC sampling periods.

2.1 Overview

UGWOS 2015 field operations were scheduled for January 15 through March 31, 2015. All UGWOS 2015 monitoring sites were installed, calibrated, and ready for operation by January 14, 2015. Forecasting for elevated ozone conditions started on January 15 and continued through March 31, 2015.

2.1.1 Planning Process

UGWOS 2015 relied largely on the long-term WDEQ-AQD monitoring stations and five VOC sampling locations. AQD-owned VOC sampling systems were utilized for the UGWOS 2015 VOC sampling effort. Sampling systems were retrieved in December 2014, cleaned, leak-checked, and tested for contamination prior to operational use during UGWOS 2015.

2.1.2 Monitoring Sites

Meteorological and air quality data for UGWOS 2015 were collected from seven (7) long-term WDEQ-AQD monitoring stations (Pinedale, Boulder, Daniel, Moxa Arch, Big Piney, Juel Springs, and South Pass) currently operating in the UGRB and from three (3) mesonet sites (Jonah, Mesa, and Paradise). A map showing the active measurement stations during UGWOS 2015 is shown in Figure 2.1.

A summary of the instrumentation and parameters measured at each sampling platform is presented in Table 2-1.

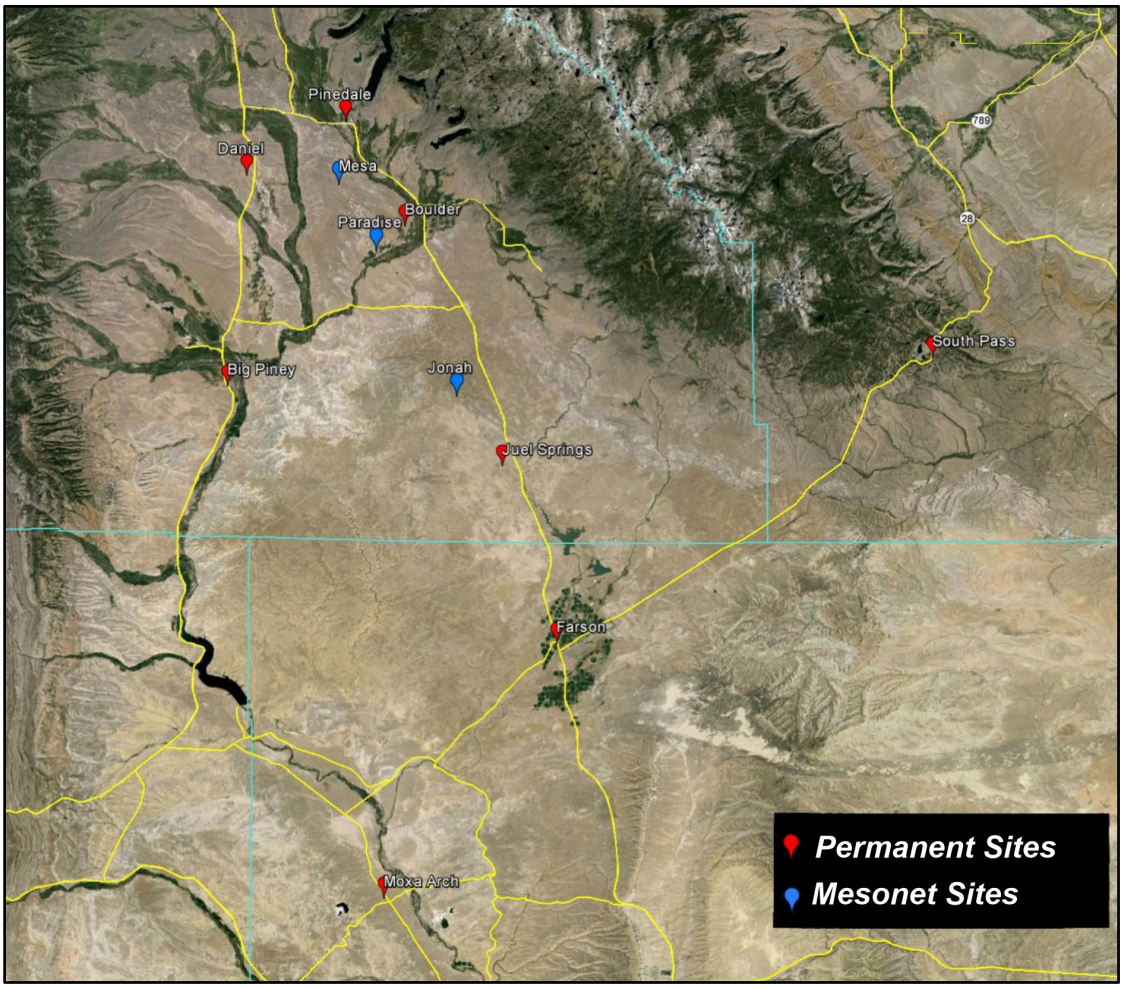

Figure 2.1 Active Monitoring Stations in the UGWOS 2015 Study Domain

Table 2-1 Summary of Measurement Methods Used During UGWOS 2015

Platform	Measurement	Instrumentation	
		Method	Model
Boulder Special Measurements	True NO_2	Chemiluminescence	T-API 200EU w/Photolytic Converter
	NO_y	Chemiluminescence	T-API T200U w/501Y NO_y Converter
	Methane/TNMHC	FID	Baseline-Mocon 9000
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID
WDEQ Long-Term Monitoring Sites	Ozone	UV Photometric	T-API 400E/400A
	NO_x	Chemiluminescence	T-API 200E/200A
	PM_{10}	Tapered Element Oscillating Microbalance Beta Attenuation Monitor	TEOM 1400a (Daniel, Boulder[1], South Pass) Met One BAM 1020 (Boulder[1] & Moxa)
	$PM_{2.5}$	Beta Attenuation	Met One BAM 1020 (Pinedale)
	SO_2	Pulsed Fluorescence	Thermo 43i (Moxa)
	TUVR	Incoming and reflected short wave radiation	Eppley TUVR (Boulder & Moxa)
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID (Big Piney & Boulder)
Mesonet Sites	Wind Speed	Propeller Anemometer	RM Young 05305
	Wind Direction	Vane	RM Young 05305
	Temperature	Thermistor Probe	CSI 109
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID

[1]The TEOM at Boulder was replaced with a Met One BAM 1020 on February 19, 2015.

2.1.3 UGWOS Website

For the 2015 field study, the UGWOS website was hosted by MSI Trinity and allowed remote access to near real-time station data for all UGWOS and UGRB long-term monitoring sites. An example of the UGWOS web-site home page with the most current ozone concentrations and web-site menu is presented in Figure 2.2 below. The web-site displayed near real-time ozone and meteorological information for the following stations:

- Big Piney
- Boulder
- Daniel
- Juel Springs
- Jonah Field
- Mesa
- Moxa Arch
- Paradise
- Pinedale
- South Pass

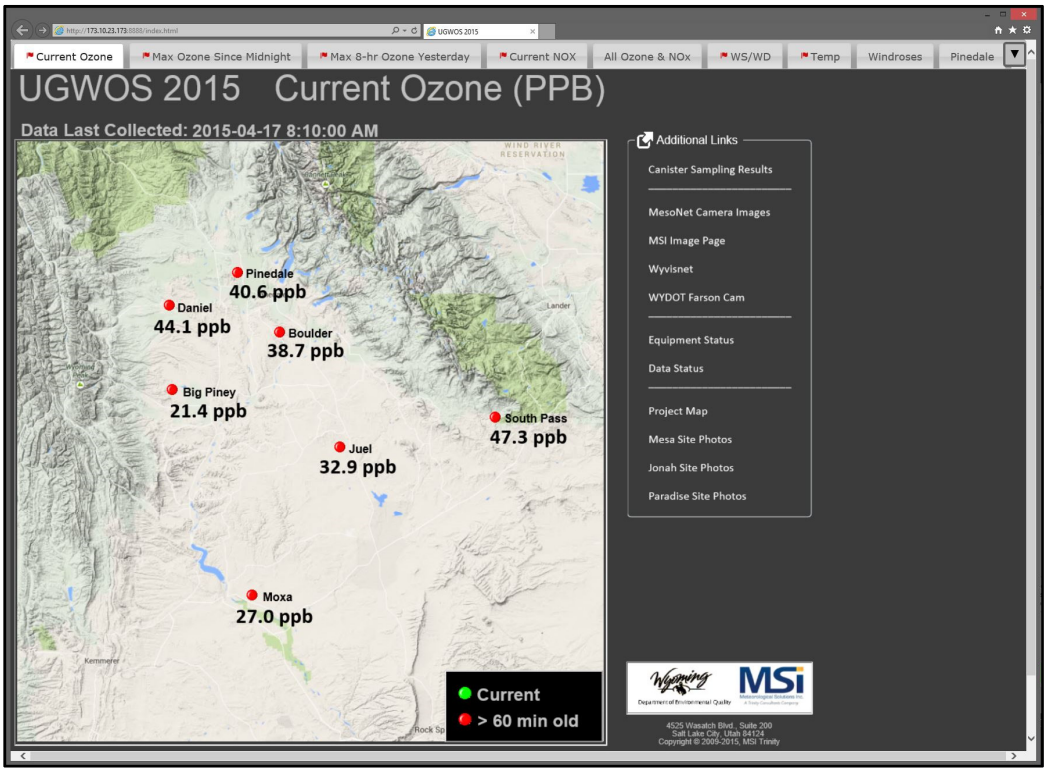

Figure 2.2 Current Ozone Concentrations with Website Menu

In addition to continually updated ozone information, wind speed, wind direction, temperature and oxides of nitrogen data were also displayed on similar pages. Data were plotted on a project base map and updated as often as every five minutes. Recent air quality and meteorological data were also presented as a single station display in strip chart format (See Figure 2.3). Ozone or meteorological parameters from all sites were displayed simultaneously on an individual page for a user-selected time period (Figure 2.4). Camera images from the mesonet (Figure 2.5) and long-term monitoring sites were posted on the website and updated as often as every 15 minutes. A site equipment matrix provided information which was updated whenever equipment status changed (Figure 2.6). A monitoring site data retrieval status table (Figure 2.7) was updated continually on the website showing the latest time/date when data were retrieved from each site. The project website also provided links to the Wyvisnet and the WYDOT Farson camera.

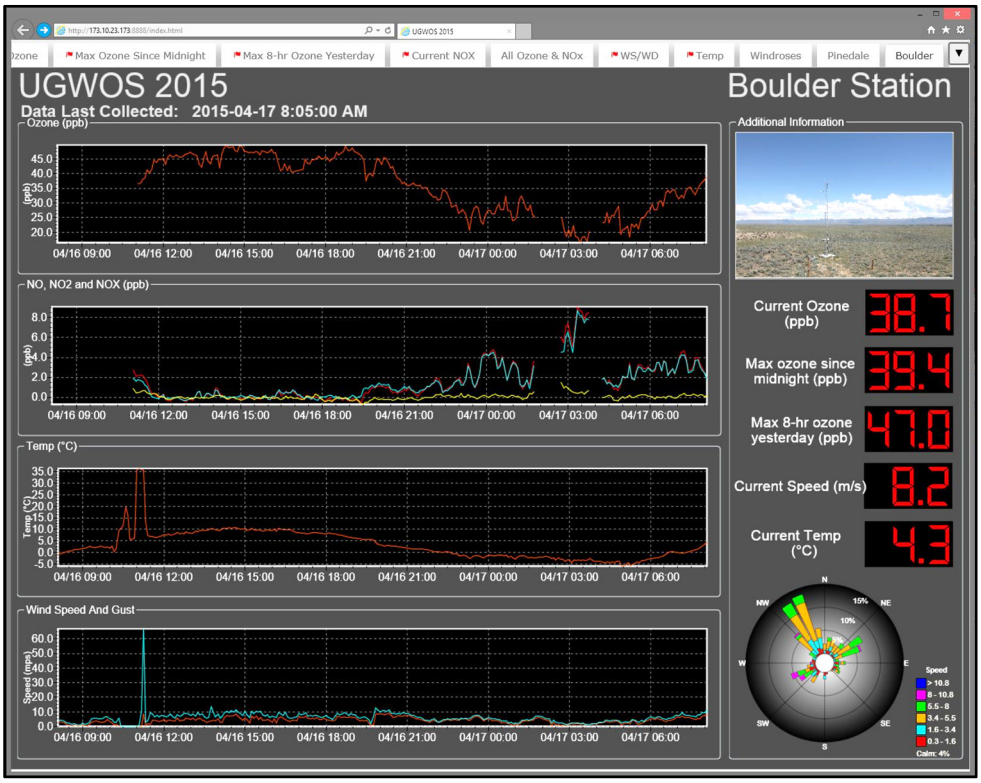

Figure 2.3 Single Station Strip Chart Example

Figure 2.4 Ozone Strip Charts from All Sites for a User-Selected Time Period

Figure 2.5 Images from Mesonet Site Cameras Updated on the Website Every 15 Minutes

Last Modified on 03/25/2015 14:02:32 UGWOS 2015

													Chemiluminescent			Photolytic			Total Reactive Nitrogen		
No.	Site Name	Site Operator	Camera	Canister	Carbonyl	WS	WD	TEMP	RH	THC	O3	PM	NO	NO2	NOX	NO	NO2	NOX	NO	NO2	NOY
1	Boulder	MSI	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	Daniel	ARS	X			X	X	X	X		X		X	X	X						
3	Juel Spring	MSI	X			X	X	X	X		X		X	X	X						
4	Pinedale	MSI	X			X	X	X	X		X	X	X	X	X						
5	Big Piney	MSI	X	X	X	X	X	X	X		X	X	X	X	X						
6	Moxa	MSI	X			X	X	X	X		X	X	X	X	X						
7	South Pass	ARS	X			X	X	X	X		X	X	X	X	X						
8	Paradise Mesonet	MSI	X	X	X	X	X	X													
9	Jonah Mesonet	MSI	X	X	X	X	X	X													
10	Mesa Mesonet	MSI	X	X	X	X	X	X													

X	Operational
X	Suspect
X	Delayed Connectivity/Data Transfer
X	Inoperative
X	Not installed yet

Figure 2.6 Current Equipment Status

UGWOS 2015 Real-Time Data Status

Last Updated: 4/2/2015 8:55 MST

Mesonet Sites			
Site	**Resolution**	**Last Data Point**	**Minutes ago**
Mesa	5 - minute	2015-04-02 08:50	5
Jonah	5 - minute	2015-04-01 10:45	1330
Paradise	5 - minute	2015-04-02 08:50	5
Big Piney VOC	5 - minute	2015-04-02 08:50	5
Boulder VOC	5 - minute	2015-04-02 08:55	
Permanent Sites			
South Pass	60 - minute	2015-04-02 08:00	55
	15 - minute	2015-04-02 08:15	40
Daniel	60 - minute	2015-04-02 08:00	55
	15 - minute	2015-04-02 08:15	40
Big Piney	5 - minute	2015-04-02 08:45	10
Moxa	5 - minute	2015-04-02 08:50	5
Boulder	5 - minute	2015-04-02 08:45	10
Juel	5 - minute	2015-04-02 08:50	5
Pinedale	5 - minute	2015-04-02 08:50	5

Status turns YELLOW at 90 minutes and RED at 150 minutes.

Figure 2.7 UGWOS 2015 Monitoring Site Data Retrieval Status

2.2 Field Measurements

Measurement stations which provided data for the UGWOS 2015 database included the long-term WDEQ-AQD monitoring stations operating in the UGRB study area and three mesonet sites which collected meteorological data and camera images on solar-powered tripods. During the field measurement season, VOC canister and carbonyl samples were collected on designated days at five locations - the three mesonet sites and two of the long-term monitoring stations – Boulder and Big Piney.

2.2.1 WDEQ Long-Term Monitoring Sites

WDEQ monitoring stations in the UGRB which were actively collecting data during UGWOS 2015 included Big Piney, Boulder, Daniel South, Juel Springs, Moxa, Pinedale, and South Pass. Long-term monitoring sites transmitted camera images taken from the site every 15 minutes. These sites also typically measured wind speed and direction at 10 meters, temperature, relative humidity, barometric pressure, solar radiation, and precipitation. Boulder and Moxa were equipped to measure total UV radiation including incoming and reflected short-wave radiation in the 295-385 nm range. Air quality parameters measured at the long-term sites included ozone, oxides of nitrogen, and particulate matter. The Boulder monitoring site included additional enhanced measurements described below. The Moxa site also measured sulfur dioxide. Figure 2.8 presents a photograph of the Big Piney long-term monitoring site. Figure 2.9 shows the more extensive long-term monitoring station at Boulder. Figure 2.10 presents a photograph of the Boulder station interior.

Figure 2.8 Photograph of Big Piney Monitoring Station

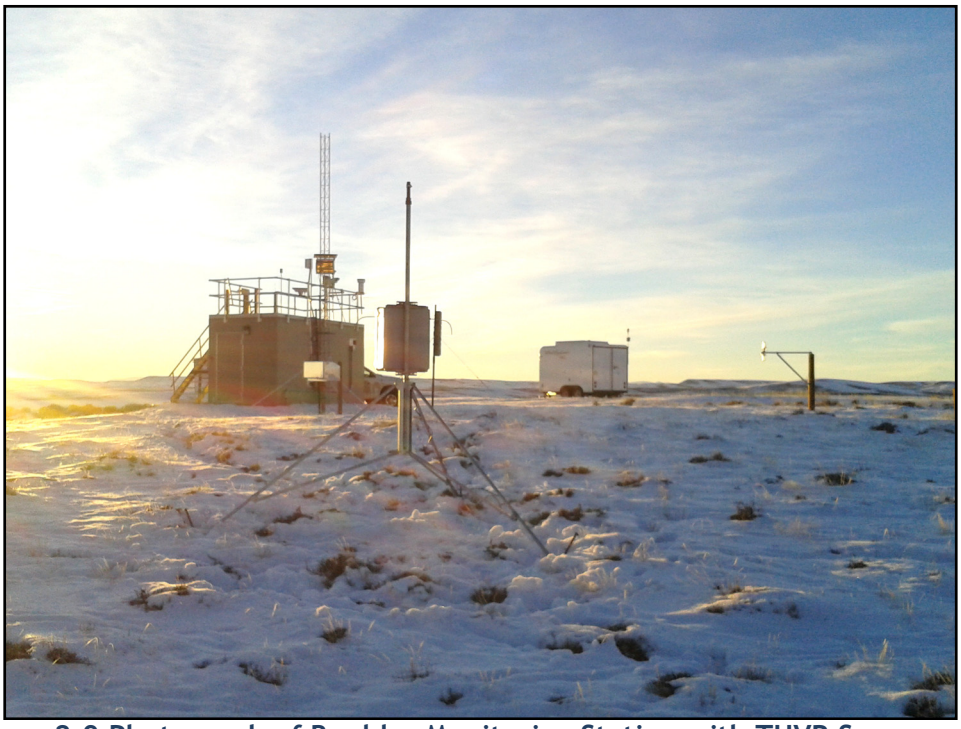

Figure 2.9 Photograph of Boulder Monitoring Station with TUVR Sensors and UGWOS VOC Sampling Tripod

Figure 2.10 Photograph of Interior of Boulder Monitoring Station

2.2.2 Specialized Measurements at Boulder

True NO_2 measurements continued at the Boulder monitoring site using a Teledyne-Advanced Pollution Instrumentation (T-API) Model 200EUP trace level oxides of nitrogen analyzer with photolytic converter. This type of converter allows for better speciation of lower levels of NO_2 than standard chemiluminescent oxides of nitrogen analyzer. As sample gas passes through the converter chamber, it is exposed to blue light at specific wavelengths (350-420 nm) from an array of ultraviolet light-emitting diodes. Exposure to blue light selectively converts the NO_2 to NO with negligible radiant heating or interference from other gases.

NO_y is measured at the Boulder site using a T-API Model T200U analyzer with a Model 501Y converter mounted at the sample inlet point. This configuration allows for minimal time delay between the sample inlet port and the remotely mounted molybdenum converter. The system is designed to measure the concentration of NO, NO_2, and other compounds that are too unstable to be measured when brought in through the standard conventional ambient air sample inlet system. Sampling the ambient air directly into the remote converter enables the conversion of labile components of NO_y which might normally be lost in a conventional system with longer transit time between the sample inlet and the converter.

Total UV radiation (both incoming and reflected UV) was again measured at the Boulder site as it was during UGWOS efforts since 2007 using a pair of Eppley TUVR sensors with one pointed upward and the other pointed downward. Reflected UV provides a convenient indication of the presence of snow cover on the ground surface at the Boulder site.

Speciated VOC measurements are performed year-round using the TO-14 canister sampling method at the Boulder monitoring station. Canister samples are triggered automatically when the rolling 15-minute average of the continuously monitored non-methane hydrocarbon (NMHC) levels exceeded 1.5 parts per million (ppm). Sampled canisters are submitted to Environmental Analytical Services (EAS) laboratory after each event for modified TO-14 analysis. During the study, Boulder was also equipped with DNPH-coated (Carbonyl) cartridges to collect samples of formaldehyde and acetaldehyde.

The Method TO-14 detailed hydrocarbon analysis (DHA) for Photochemical Assessment Monitoring Station (PAMS) compounds use cryogenic trapping and a gas chromatograph with a flame ionization detector (FID) to measure hydrocarbons collected in SUMMA® canisters. A modified version of this method which followed the protocol contained in the EPA Guidance Document "Technical Assistance Documents for Sampling and Analysis of Ozone Precursors", EPA/600-R-98/161, (September 1998), was utilized. This method was used in determining 90 individual hydrocarbons, including the 55 PAMS compounds in air and gas samples.

Carbonyl cartridges were analyzed using Method TO-11. EPA TO-11 is a method for collecting aldehydes and ketones in air samples on DNPH cartridges. The cartridges are desorbed and analyzed by high pressure liquid chromatography (HPLC) using UV detection. Formaldehyde and acetaldehyde were the compounds of interest for this study.

2.2.3 Mesonet Monitoring Stations

During 2015, three mesonet stations were operated at Mesa, Paradise, and Jonah Field. These locations have been utilized in previous UGWOS field programs. These sites consisted of solar-powered (with battery backup) tripods equipped with instrumentation to continuously measure wind speed, wind direction, and temperature. Campbell Scientific CR850 dataloggers recorded five-minute average data and remote telemetry provided updates to the UGWOS project website every five minutes.

Mesonet sites included a wind sensor mounted at approximately three meters above ground level; ambient temperature was positioned at approximately two meters above ground level. Remote telemetry at each site included a wireless modem/router enabling data collection of five-minute average digital data with remote polling by MSI Trinity's server in Salt Lake City. Camera images were collected and transmitted every 15 minutes. Tripod-mounted VOC canister and carbonyl sampling systems were activated at each site on designated days and collected three-hour integrated samples from 04:00 to 07:00 MST. Samples were analyzed by EAS laboratories using the TO-11 and modified TO-14 methods as described in Section 3.2. Photographs of the three mesonet monitoring stations are shown in Figures 2.11 through 2.13.

Figure 2.11 Mesa Mesonet Site

Figure 2.12 Paradise Mesonet Site

Figure 2.13 Jonah Field Mesonet Site

2.2.4 VOC Canister and Cartridge Sampling

Ambient air samples were collected in specially prepared stainless steel canisters using the sub-atmospheric sampling method. An adjustable flow controller was used to control the sample flow rate into the canister for a three-hour integrated sample with some negative pressure still remaining in the canister at the end of the period. In addition, carbonyl samples were collected concurrently with the VOC canisters using DNPH-coated cartridges outfitted with the ozone scrubbers and connected to constant flow pump systems. Canisters and cartridges were typically loaded into each system on the day before a sampling event. The site datalogger activated a solenoid valve and pump system to start the sampling process at the designated sampling time (04:00 MST) and closed at the end of the three-hour period. Canisters and cartridges were retrieved immediately following each event and shipped within a few days to EAS laboratory for modified TO-14 and TO-11 analysis, respectively (description in Section 3.2).

The automated VOC sampling equipment owned by AQD was tested for contamination prior to the start of the UGWOS field season by first flushing each system with clean ambient air followed by ultra-pure air and then connecting a clean, evacuated canister to each system. The canister with flow controller mounted was allowed to sample ultra-pure air for a normal three-hour sampling period. Samples were sent to EAS laboratory for analysis to confirm that each system was free of contamination.

VOC canister and carbonyl cartridge sampling systems were set up at Big Piney and Boulder as well as at the three mesonet sites at Mesa, Paradise, and Jonah Field. The existing VOC canister sampling system at the Boulder site operated in its normal configuration (which triggers a canister sample when the rolling 15-minute average NMHC value recorded by the site analyzer exceeds 1.5 ppm) during the UGWOS field season. An additional tripod-mounted sampling system was placed at Boulder for conducting VOC and carbonyl sampling on chosen sampling days.

VOC and DNPH sampling days were chosen by WDEQ-AQD based on input from forecasters. There were four designated VOC canister sampling days when conditions were forecasted to be high pressure, light winds and sunny skies. VOC samples were collected on the following dates: January 16, March 8, March 9, and March 10, 2015.

2.3 Designated VOC Canister and Cartridge Sampling Days

Due to a reduced scope of work for UGWOS 2015, weather and ozone development forecasts were not issued during the study period. However, VOC canister sampling was conducted on WDEQ designated sampling days. Sampling days were based on forecasts by WDEQ with input from MSI Trinity meteorologists of stable, high pressure conditions with light winds and sunny skies. There were a total of four designated VOC sampling days during UGWOS 2015.

2.3.1 Synoptic Weather Summaries of Canister Sampling Events

There were five days, January 16, February 14, March 8, March 9, and March 10 when VOC canister sampling occurred. Samples were taken in the morning between the hours of 07:00 and 10:00 MST on January 16 and between 04:00 and 07:00 MST for March 8, 9, and 10. The automated VOC sampling system at Boulder triggered a canister sample at 02:45 MST on February 14. Weather conditions for the VOC sampling days are summarized below.

January 16, 2015

During the first day of canister sampling, Wyoming experienced a broad area of westerly flow at the 700 millibar (mb) level. There was a weak transient ridge just west of the state that was moving eastward towards Wyoming. Upper level barometric pressure over the region slowly increased during the morning. Wind speeds at 700 mb were approximately 13 meters per second (mps) and the temperature was approximately 0.0°C but cooled throughout the morning with temperatures near -4.0°C by late afternoon.

At the surface, a high pressure ridge centered over Colorado covered western Wyoming in the morning. Mean sea level (MSL) pressure was approximately 1,026 mb over the study area. Morning surface wind speeds were light ranging from 0.5 to 4.0 mps. Along with the light wind speeds, the wind directions were variable. During the afternoon and into the early evening hours, the wind direction was southwesterly and wind speeds increased to 11.0 to 12.0 mps at Farson, Juel Springs, and Moxa Arch. Boulder, Paradise and Pinedale recorded light winds during the afternoon from 1.0 to 4.0 mps. Directions were variable through mid-afternoon turning more northwesterly to westerly in the late afternoon and early evening. Surface temperatures during the morning ranged from -13.0° to -3.0°C at 07:00 MST to approximately -9.0° to 0.0°C at 10:00 MST. During the afternoon across the UGRB maximum temperatures ranged from -1.0°C to 5.0°C. Figures 2.14 and 2.15 present the 700 mb and surface weather charts, respectively, obtained from the National Center for Environmental Prediction, Hydrometeorological Prediction Center for the morning of January 16.

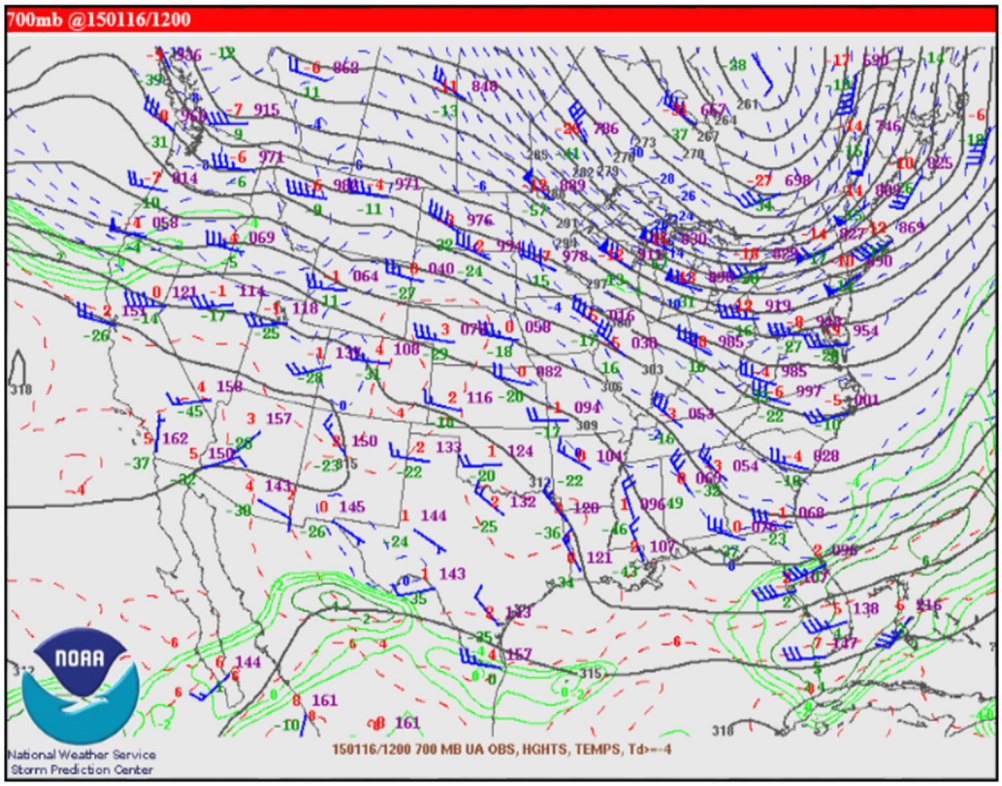

Figure 2.14 700 mb Level Chart at 05:00 MST January 16, 2015

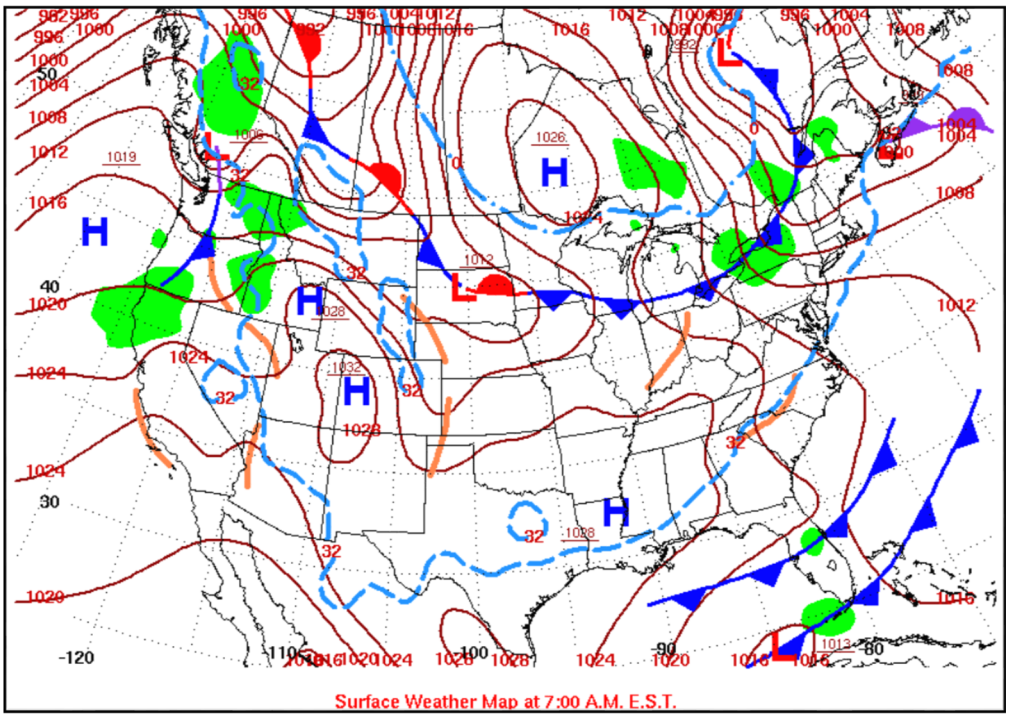

Figure 2.15 Surface Chart at 05:00 MST January 16, 2015

February 14, 2015

Although not a designated sampling day, the Boulder canister system triggered an automated sample at 02:45 MST on February 14, 2015. On this day, a ridge of high pressure at 700 mb was located off the West Coast and an area of higher pressure had moved into the Great Basin and central Rockies on February 13. This high weakened on February 14 as a trough of low pressure moved down out of southwest Canada and into the northern Rockies. Winds at the 700 mb pressure level ranged from 10 to 13 mps from the west-northwest and the temperature was approximately 5.5°C on the morning of the sounding, which is mild for mid-February.

Surface conditions on February 14 showed high pressure stretching from northern Idaho southeast along the western Wyoming border into western Colorado. The highest pressure with this feature was over western Colorado. MSL pressure over the study area ranged from 1020 to 1024 mb on the morning of February 14. Surface temperatures ranged from approximately -7.0°C to approximately 0.0°C from 02:45 to 06:00 MST. Afternoon maximum temperatures reached approximately 7.0°C at Mesa to 13.0°C at Moxa Arch. Winds were light at the surface with speeds below 3.0 mps during the afternoon. Wind direction was variable within the UGRB. In the afternoon, wind speeds increased slowly, peaking between 14:00 and 16:00 with speeds of 2.0 to 11.0 mps. Moxa Arch had the strongest wind speeds at 11.2 mps. Daniel had northeasterly winds during the mid-afternoon while Big Piney had southeasterly winds. Figures 2.16 and 2.17 present the 700 mb and surface weather charts, respectively, for the morning of February 14.

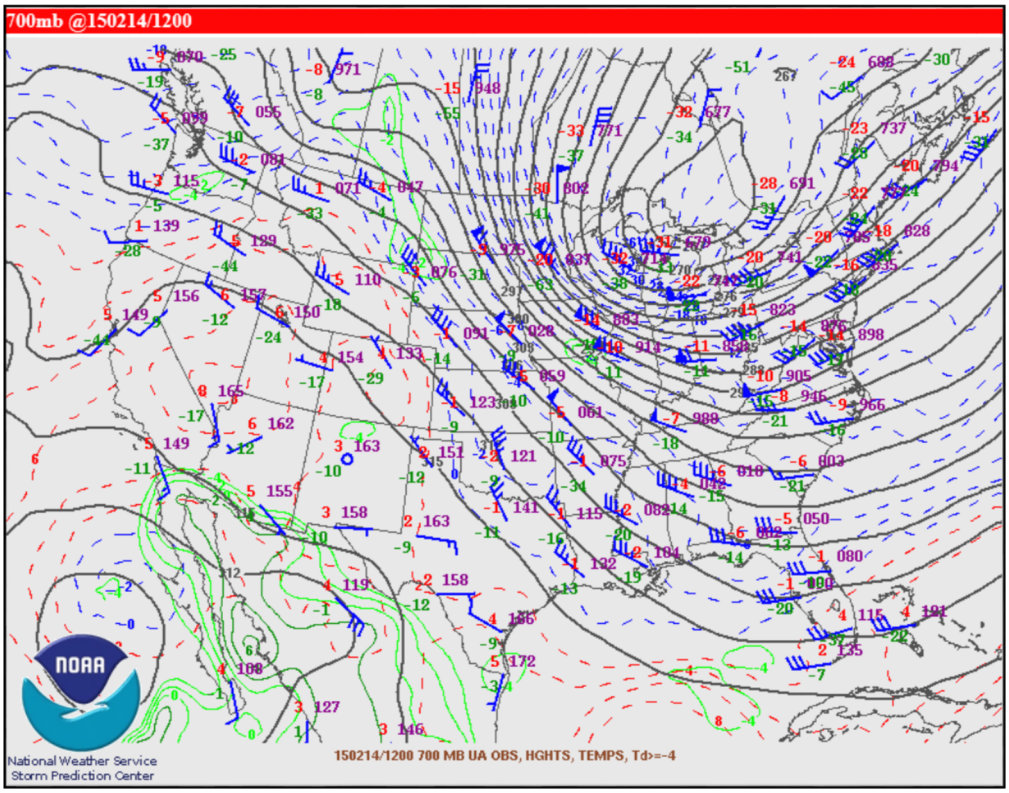

Figure 2.16 700 mb Level Chart at 05:00 MST February 14, 2015

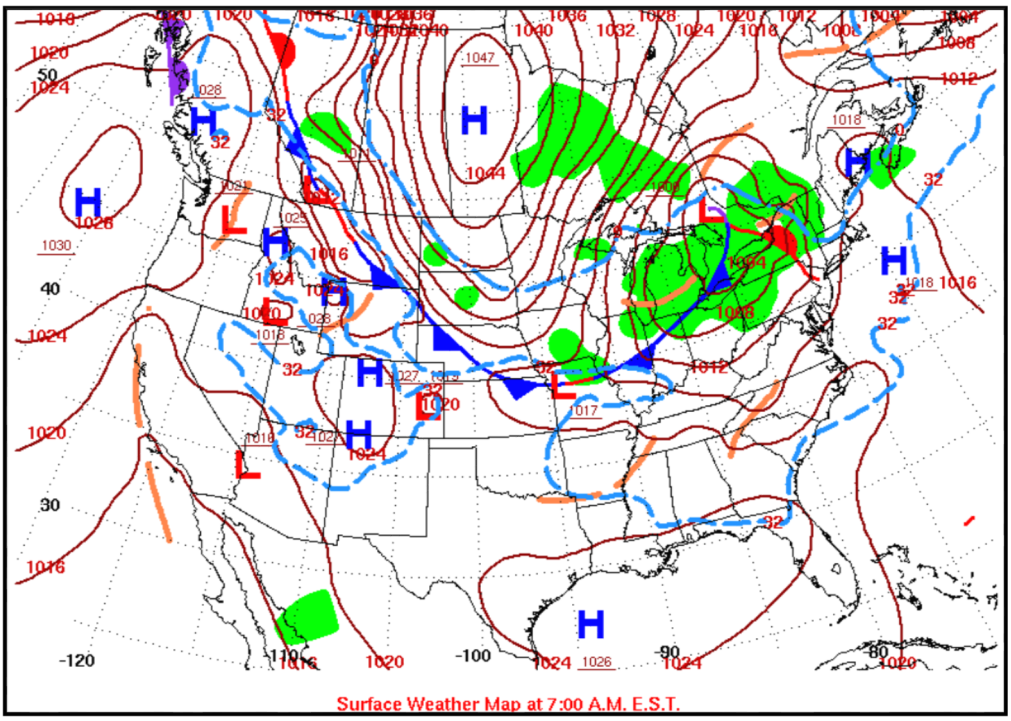

Figure 2.17 Surface Chart at 05:00 MST February 14, 2015

March 8-10, 2015

The final period of VOC sampling occurred over a three-day period on March 8, 9 and 10, 2015. The sampling took place between 04:00 and 07:00 MST on all three days. High pressure was centered off the Pacific coast on March 8 with a trough of lower pressure stretching from eastern Colorado south into northern Mexico. The high pressure ridge axis pushed slowly inland through March 10 and was centered over southern California northward into southern Utah. The ridge covered much of the western United States west of the Rockies on March 10 and continued to push eastward throughout the period. Winds at 700 mb were light and west to northwesterly on March 8 and 9 turning northerly on March 10 as the ridge approached the state from the west. Winds were from the west later on March 10. Wind speeds for the period ranged from 5.0 to 8.0 mps at 700 mb.

Morning surface wind speeds within the basin over the three-day period were at or below 6 mps. The Boulder site was the windiest of all sites with speeds of 3 to 6 mps. Morning wind directions were variable all three days. Surface high pressure strengthened over Oregon on March 9 and pushed east into the central Rockies on March 10. On both March 9 and 10, the MSL pressure over the study area climbed to as high as 1020 mb. Morning surface temperatures during the three-day period were relatively consistent ranging from -3.0°C to -13.0°C on March 8 and 9 to -1.0°C to -11.0°C on March 10. By afternoon, maximum temperatures ranged from 4.0°C to 13.0°C each day. Figures 2.18 and 2.19 present the 700 mb and surface weather charts, respectively, for March 9, the middle of the three-day sampling period.

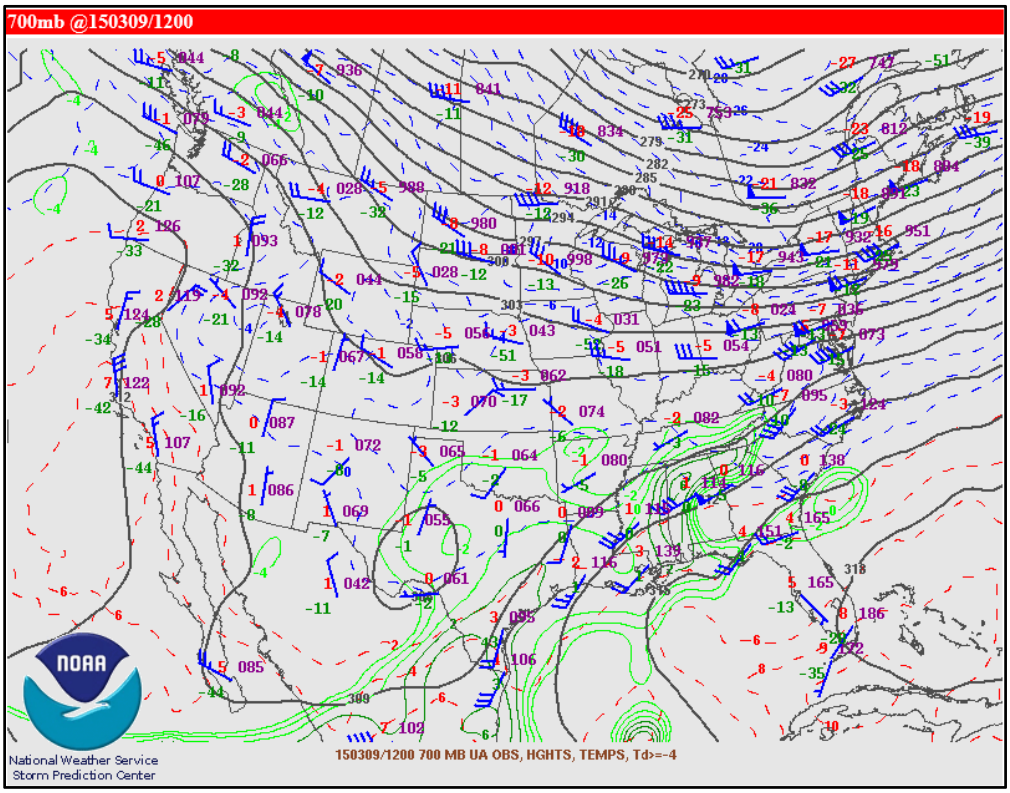

Figure 2.18 700 mb Level Chart at 05:00 MST March 9, 2015

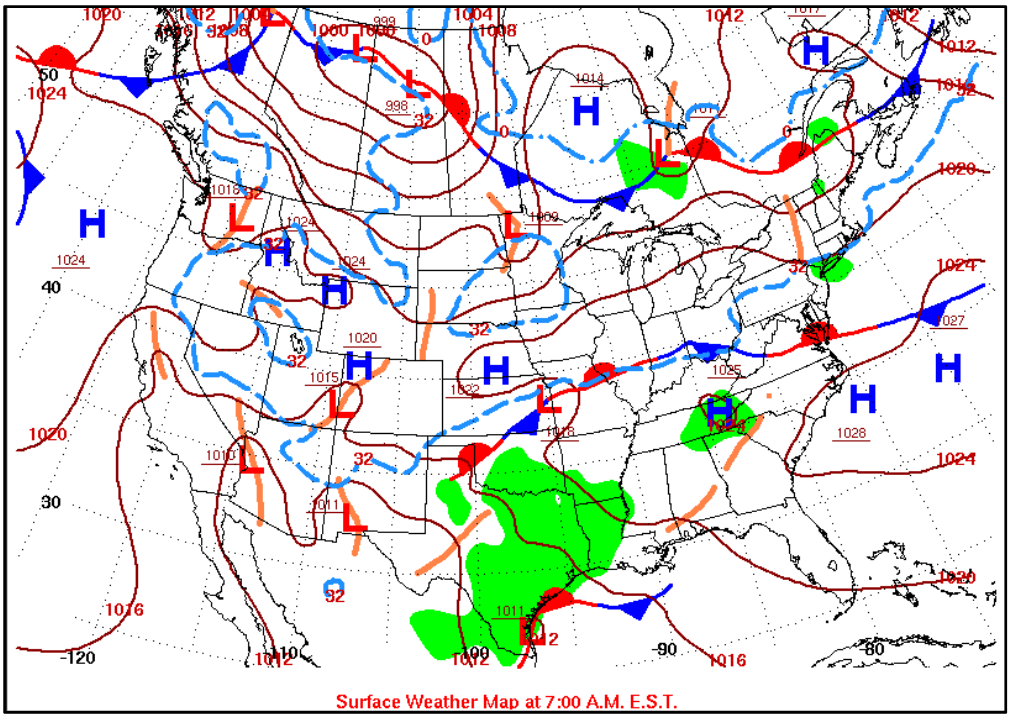

Figure 2.19 Surface Chart at 05:00 MST March 9, 2015

3.0 DATA QUALITY ASSURANCE, VALIDATION AND ARCHIVING

A primary study objective was to produce a validated data set from the field measurements that is well defined and documented. The data management system used, Microsoft Access, was designed to be straightforward and easy for users to obtain data and provide updates. All data were quality-assured and submitted to MSI Trinity's UGWOS Data Manager for entry to the project database. A brief summary of procedures used is provided below.

3.1 Database Management

The overall goal of the data management effort was to create a well-documented system such that data could be readily input and easily accessed from the database. A Monitoring and Quality Assurance document was prepared and approved by all the project participants and can be found on the AQD website.

Each of the participants that provided data was responsible for reviewing and validating their respective data to Level 1 as described in Watson, et. al. (2001)[1]. This included flagging data during instrument downtime and performance tests, applying any adjustments for calibration deviation, investigating extreme values, and applying appropriate flags. Quality control (QC) codes used for the UGWOS data set are presented in Table 3-1. QC codes include simple validation codes as well as AQS null codes developed by the EPA.

[1] Watson, J.G.; Turpin, B.J.; and Chow, J.C. (2001). The measurement process: Precision, accuracy, and validity. In Air Sampling Instruments for Evaluation of Atmospheric Contaminants, Ninth Edition, 9th ed., B.S. Cohen and C.S.J. McCammon, Eds. American Conference of Governmental Industrial Hygienists, Cincinnati, OH, pp. 201-216.

Table 3-1 Data Quality Control Codes Used in UGWOS Database

QC	Description
V	Valid Data
M	Missing Data
I	Invalid Data
S	Suspect Data. Data appears to be a data spike or outside normal data range
U	Data which has not been validated - User is responsible for validation.
B	Below Detection Limit
AA	Sample Pressure out of Limits
AB	Technician Unavailable
AC	Construction/Repairs in Area
AD	Shelter Storm Damage
AE	Shelter Temperature Outside Limits
AF	Scheduled but not Collected
AG	Sample Time out of Limits
AH	Sample Flow Rate out of Limits
AI	Insufficient Data (cannot calculate)
AJ	Filter Damage
AK	Filter Leak
AL	Voided by Operator
AM	Miscellaneous Void
AN	Machine Malfunction
AO	Bad Weather
AP	Vandalism
AQ	Collection Error
AR	Lab Error
AS	Poor Quality Assurance Results
AT	Calibration
AU	Monitoring Waived
AV	Power Failure
AW	Wildlife Damage
AX	Precision Check
AY	Q C Control Points (zero/span)
AZ	Q C Audit
BA	Maintenance/Routine Repairs
BB	Unable to Reach Site
BC	Multi-point Calibration
BD	Auto Calibration
BE	Building/Site Repair
BF	Precision/Zero/Span
BG	Missing ozone data not likely to exceed level of standard
BH	Interference/co-elution/misidentification
BI	Lost or damaged in transit
BJ	Operator Error
BK	Site computer/data logger down
BL	QA Audit
BM	Accuracy check
BN	Sample Value Exceeds Media Limit
DA	Aberrant Data (Corrupt Files, Spikes, Shifts)

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 was in local standard time (Mountain Standard Time) and the averaging period reference was standardized to hour beginning (0 – 23). Standards for time reference, averaging period, parameter names and units are consistent throughout the database. Data fields have a second column for each measured value for the accompanying QC code, as needed. Data flagged as invalid or missing were marked with the adverse AQS Null code value or the value –9999. Suspect data or data that were not validated to Level 1 standards were flagged as such with the data still included in the database.

3.2 Quality Assurance Program

A Monitoring and Quality Assurance Plan was submitted to the WDEQ-AQD and approved encompassing all aspects of the monitoring program (see Appendix A). This document provides a detailed discussion of the quality assurance program implemented during this study.

As part of the quality assurance program, quality control procedures were implemented to assess and maintain control of the quality of the data collected. A summary of key elements of the QC program for each measurement is presented in the remainder of this section.

All UGWOS equipment underwent a complete checkout and acceptance prior to the start of monitoring. Standard Operating Procedures (SOPs) for measurements were completed prior to the start of monitoring. Ozone and oxides of nitrogen analyzers were routinely checked using a traceable transfer standard or reference gas following operating procedures consistent with EPA guidelines. Ozone transfer standards (Level 3) were verified prior to the start of the program and again at the end by checks against a primary standard (Level 2) ozone standard maintained at MSI Trinity's instrumentation laboratory in Salt Lake City. MSI Trinity's Level 2 ozone standard was last verified to a standard reference photometer (Level 1) by USEPA Region 8 on February 19, 2015.

Data from mesonet sites and long-term monitoring sites operated by MSI Trinity were retrieved remotely at least every 15 minutes. Data from other sites in the UGRB were retrieved hourly. Data updates were posted on the UGWOS website immediately after retrieval and were available to project participants. Data from all sites in the project area were reviewed and inspected daily to confirm normal operation and identify outliers or indications that instrumentation needed attention or repair. MSI Trinity had a technician available to quickly respond to and rectify problems to enhance data recovery.

During testing and on specified sampling days during the field program, field sample data sheets were generated for each VOC canister and DNPH cartridge indicating sample ID, sample date and time, canister start and stop pressure, and cartridge flow. Sample media were sent back to the laboratory for analysis following each sampling event accompanied by a chain-of-custody form.

VOC canisters were analyzed using Method TO-14, Detailed Hydrocarbon Analysis (DHA) for PAMS Compounds. The method was used to determine 90 individual hydrocarbons including the 55 PAMS compounds in air and gas samples. EAS performed a modified version of the method following the protocols found in EPA's document, "Technical Assistance Document for Sampling and Analysis of Ozone Precursors", (EPA/600-R-98/161, September 1998). This methodology is also referred to as EAS Method TO-3 DHA Modified. Carbonyl cartridges were analyzed using Method TO-11, high pressure liquid chromatography (HPLC) using UV detection. Formaldehyde and acetaldehyde were the compounds of interest for this study.

Method TO-14 DHA and TO-11 HPLC compound list, method detection limits, limits of quantification, and other laboratory criteria are presented in Tables 3-2 and 3-3, respectively.

Table 3-2 Method TO-14 DHA Compound List

Analyte	MDL ppbV	LOQ ppbV	Duplicate RPD
Ethene	0.5	1.5	<25
Acetylene	0.5	1.5	<25
Ethane	0.5	1.5	<25
Propene	0.5	1.5	<25
Propane	0.5	1.5	<25
i-Butane	0.5	1.5	<25
Methanol	0.5	1.5	<25
1-Butene	0.5	1.5	<25
1,3-Butadiene	0.5	1.5	<25
n-Butane	0.5	1.5	<25
t-2-Butene	0.5	1.5	<25
c-2-Butene	0.5	1.5	<25
Ethanol	0.5	1.5	<25
3-Methyl-1-butene	0.5	1.5	<25
Acetone	0.5	1.5	<25
i-Pentane	0.5	1.5	<25
l-Pentene	0.5	1.5	<25
Isopropanol	0.5	1.5	<25
2-Methyl-1-butene	0.5	1.5	<25
n-Pentane	0.5	1.5	<25
Isoprene	0.5	1.5	<25
t-2-Pentene	0.5	1.5	<25
c-2-Pentene	0.5	1.5	<25
Tert butyl alcohol	0.5	1.5	<25
2-Methyl-2-butene	0.5	1.5	<25
2,2-Dimethylbutane	0.5	1.5	<25
Cyclopentene	0.5	1.5	<25
n-Propanol	0.5	1.5	<25
Cyclopentane	0.5	1.5	<25
Methyl tert butyl ether	0.5	1.5	<25
2,3-Dimethylbutane	0.5	1.5	<25
2-Methylpentane	0.5	1.5	<25
3-Methylpentane	0.5	1.5	<25
1-Hexene	0.5	1.5	<25
n-Hexane	0.5	1.5	<25
Diisopropyl ether	0.5	1.5	<25
3-Methylcyclopentene	0.5	1.5	<25
Ethyl tert butyl ether	0.5	1.5	<25
Methylcyclopentane	0.5	1.5	<25
2,4-Dimethylpentane	0.5	1.5	<25
Benzene	0.5	1.5	<25
Cyclohexane	0.5	1.5	<25

MDL – Method Detection Limit
LOQ – Limit of Quantification
RPD – Relative Percent Difference

Table 3-2 (Continued) Method TO-14 DHA Compound List

Analyte	MDL ppbV	LOQ ppbV	Duplicate RPD
2-Methylhexane	0.5	1.5	<25
2,3-Dimethylpentane	0.5	1.5	<25
3-Methylhexane	0.5	1.5	<25
2-Methyl-1hexene	0.5	1.5	<25
Tert amyl methyl ether	0.5	1.5	<25
2,2,4-Trimethylpentane	0.5	1.5	<25
n-Heptane	0.5	1.5	<25
Methylcyclohexane	0.5	1.5	<25
2,5-Dimethylhexane	0.5	1.5	<25
2,4-Dimethylhexane	0.5	1.5	<25
2,3,4-Trimethylpentane	0.5	1.5	<25
Toluene	0.5	1.5	<25
2,3-Dimethylhexane	0.5	1.5	<25
2-Methylheptane	0.5	1.5	<25
4-Methylheptane	0.5	1.5	<25
3-Ethyl-3-methylpentane	0.5	1.5	<25
3-Methylheptane	0.5	1.5	<25
2-Methyl-1-heptene	0.5	1.5	<25
n-Octane	0.5	1.5	<25
Ethylbenzene	0.5	1.5	<25
m,p-xylene	0.5	1.5	<25
Styrene	0.5	1.5	<25
o-xylene	0.5	1.5	<25
1-Nonene	0.5	1.5	<25
N-Nonane	0.5	1.5	<25
i-Propylbenzene	0.5	1.5	<25
n-propylbenzene	0.5	1.5	<25
a-Pinene	0.5	1.5	<25
3-Ethyltoluene	0.5	1.5	<25
4-Ethyltoluene	0.5	1.5	<25
1,3,5-Trimethylbenzene	0.5	1.5	<25
2-Ethyltoluene	0.5	1.5	<25
b-Pinene	0.5	1.5	<25
1,2,4-Trimethlybenzene	0.5	1.5	<25
n-Decane	0.5	1.5	<25
1,2,3-Trimethlybenzene	0.5	1.5	<25
Indan	0.5	1.5	<25
d-Limonene	0.5	1.5	<25
1,3-Diethylbenzene	0.5	1.5	<25
1,4-Diethylbenzene	0.5	1.5	<25
n-Butylbenzene	0.5	1.5	<25
1,4-Dimethyl-2-ethylbenzene	0.5	1.5	<25

MDL – Method Detection Limit
LOQ – Limit of Quantification
RPD – Relative Percent Difference

Table 3-2 (Continued) Method TO-14 DHA Compound List

Analyte	MDL ppbV	LOQ ppbV	Duplicate RPD
1,3-Dimethyl-4-ethylbenzene	0.5	1.5	<25
1,2-Dimethyl-4-ethylbenzene	0.5	1.5	<25
Undecane	0.5	1.5	<25
1,2,4,5-Tetramethylbenzene	0.5	1.5	<25
1,2,3,5-Tetramethylbenzene	0.5	1.5	<25
Napthalene	0.5	1.5	<25
Dodecane	0.5	1.5	<25

MDL – Method Detection Limit
LOQ – Limit of Quantification
RPD – Relative Percent Difference

Table 3-3 Method TO-11 HPLC Compound List

Analyte	MDL µg	LOQ µg	Duplicate RPD
Formaldehyde	0.08	0.24	<20
Acetaldehyde	0.08	0.24	<20

MDL – Method Detection Limit
LOQ – Limit of Quantification
RPD – Relative Percent Difference

The FID is calibrated using propane and hexane and the responses of individual hydrocarbons are calculated against these compounds in ppbC according to the procedure described in the guidance document.

On-going laboratory QA was performed on each batch of samples as they were received and analyzed by the lab including method blanks, QC duplicates, lab control spikes and lab control duplicates. A summary of the QC Criteria for TO-14 Modified for DHA and PAMS Hydrocarbon Analysis is presented in Table 3-4.

Table 3-4 Summary of QC Criteria for TO-14 Modified for DHA and PAMS Hydrocarbon Analysis

Parameter	EAS TO-14 DHA Modified
Initial Calibration	Five point's relative response factors run on hexane.
Calibration Check Sample (CCS)	Run after initial calibration curve – 55 PAMS
Continuing Calibration Verification (CCV)	Hexane daily (24 hours)
Method Blank	Target analytes less than LOQ
Laboratory Control Spike	With daily batch sample
Duplicate-Either Lab Control Duplicate or Sample Duplicate	With daily batch sample
Canister Holding Times	30 days
Canister Certification	Certification <0.2 ppbv by full scan GC/MS

3.2.1 Calibrations

The purpose of a calibration is to establish a relationship between the ambient conditions and an instrument's response by challenging the instrument with known reference values and adjusting the instrument to respond properly to those values within established tolerances. The calibration method for each of the air quality and meteorological parameters is detailed in the Monitoring and Quality Assurance Plan.

Meteorological sensors at the mesonet sites were calibrated at the beginning and end of the study. Wind speed sensors were calibrated using an R.M. Young constant rpm motor simulating wind speeds at several points across the sensor's operating range. Wind direction sensors were calibrated by confirming orientation and checking responses at standard increments. Temperatures were calibrated using water/ice baths.

3.2.2 Quality Assurance Audits

As part of the UGWOS quality assurance program, an independent audit program was implemented to verify the site operations and data accuracy. The WDEQ-AQD auditor and the equipment used for the audit were independent of the measurement program. Audits were performed at some of the long-term permanent stations by WDEQ-AQD personnel in accordance with the principles set forth by the US EPA.

3.3 Data Archiving

All validated data were merged into an integrated relational Microsoft Access database. The database contents and format are described in Appendix B. Data were formatted into the final database with the following unit configurations and naming conventions:

- Parts per billion for O_3, NO, NO_2, NO_x, NO_y, and SO_2
- Micrograms per cubic meter for PM_{10} and $PM_{2.5}$
- Parts per million for methane, non-methane hydrocarbons, and total hydrocarbons
- Micrograms per cubic meter, parts per billion by volume, and parts per billion by Carbon for VOC data
- SITE = Alpha-numeric site code identifier
- DATE = (MM/DD/YYYY)
- HOUR= Nearest whole begin hour (HH) (MST)
- TIME = Time stamp of data (HHMM) (MST)
- QC CODE, (WS_QC, WD_QC, O3_QC, etc.) = As described in Table 3-1
- NOTES = any additional information

The Access database was spot-checked for accuracy against validated input files containing meteorological and air quality parameters.

4.0 DATA ANALYSIS

This section discusses an analysis of the meteorological and air quality measurements collected during the UGWOS 2015 field effort.

4.1 Summary of 2015 Meteorological and Air Quality Conditions and Comparison with Prior Years

This section describes meteorological and air quality conditions and measurements recorded during UGWOS 2015 and compares the results to previous UGWOS studies.

4.1.1 700 mb Comparison 2015 versus 2007-2014

2015 is the ninth consecutive winter season that the WDEQ has sponsored the UGWOS project. A comparison of the 700 mb pressure level data during the 2015 UGWOS study with the previous eight study periods is provided below.

Prior to 2007, a study of weather conditions during periods when ozone was elevated at monitoring stations in and near the UGRB was conducted. From this study, a list of objective criteria for forecasting these elevated ozone episodes was developed using several weather parameters. These criteria, based on the 700 mb pressure height, have been used as guidance in forecasting elevated ozone in the UGWOS study area since that time. The criteria that were used in forecasting elevated ozone for the UGWOS study are as follows:

- 700 mb height level is 3,060 meters or higher
- Temperature is between 0.0° and -8.0 degrees °C
- Wind speeds are less than 20 knots or approximately 10 meters per second (mps)

Averages developed from the 700 mb level parameters for 2015 indicate an average height of 3,082 meters. This is significantly higher than any other of the previous eight study years. The average 700 mb temperature in 2015 was -3.7 °C which was the warmest average temperature of the nine study years. Wind speed over the UGRB for the 2015 study averaged approximately 6.6 mps. This was the slowest average speed of the nine-year period. Figure 4.1 presents the average conditions for 2015 observed at the 700 mb pressure level, from January 15 through March 31, as well as the average conditions for the prior eight study years. It should be noted that in earlier reports (2007 through 2012) 700 mb averages were based on the February and March period only.

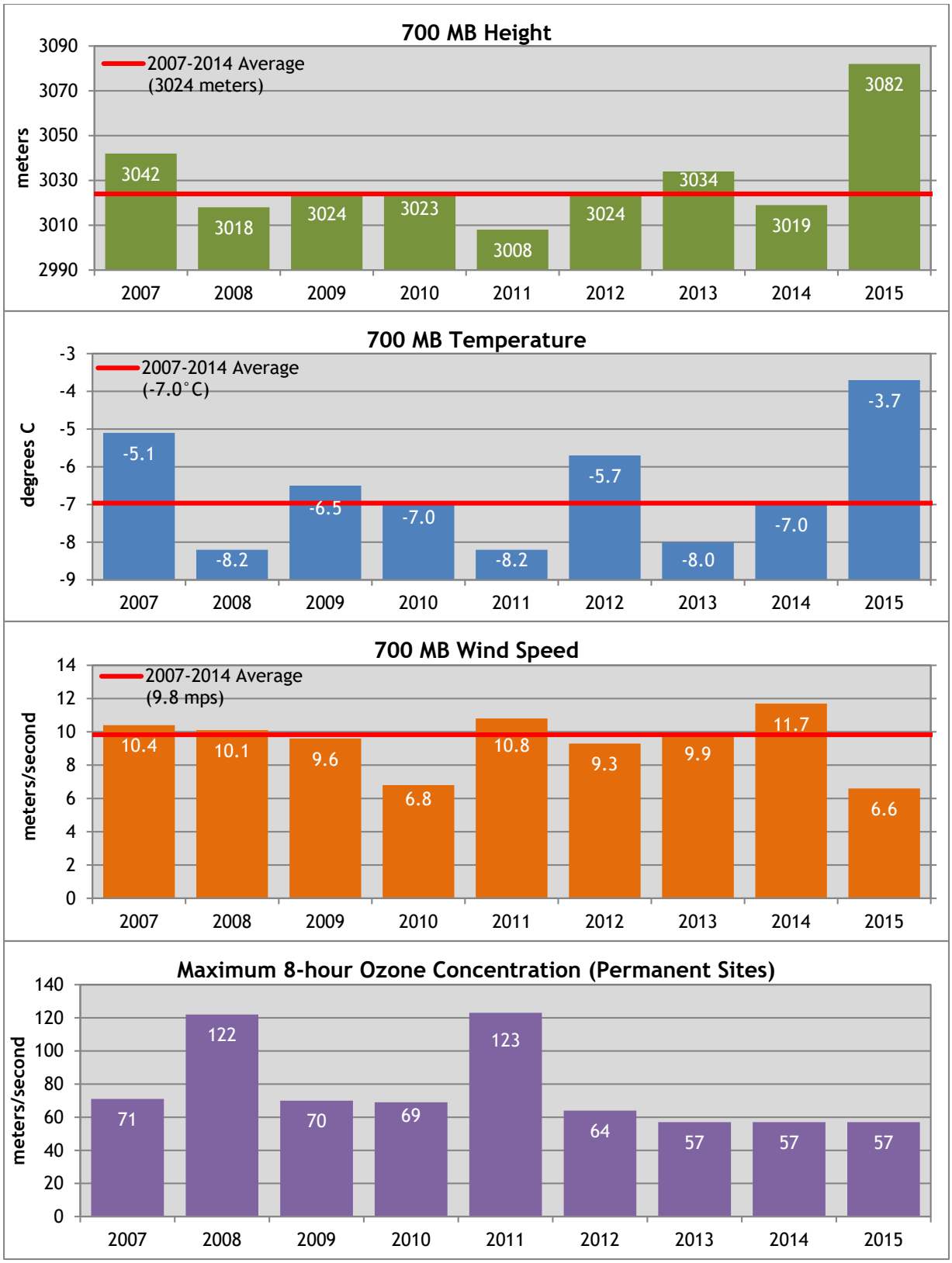

Figure 4.1 700 mb Averages and Maximum 8-Hour Ozone Concentrations for 2007 through 2015

During the 2007 through 2015 UGWOS study periods, there were a total of 41 days when Intensive Operating Periods (IOPs) occurred. Four of these years, 2010, 2013, 2014 and 2015 had no declared IOPs. Seven out of the nine years had no eight-hour ambient ozone concentrations above 75 ppb. The highest eight-hour ozone concentration measured during UGWOS 2015 was 61 ppb. Table 4-1 provides the IOP information for each project year.

Table 4-1 Intensive Operational Periods by Year

Year	Number of IOPs	Number of IOP Days	Number of Sites with 8-hour Ozone > 75 ppb	IOP dates
2007	1	6	0	March 14-19
2008	3	10	5	February 18 – 21, 27-29 March 10 - 12
2009	3	9	0	February 3 – 5, 21-22 February 28 – March 3
2010	0	0	0	--
2011	2	7	7	February 28 – March 2 March 9 - 12
2012	6	9	0	January 29 February 5-6, 16, 27 March 4-5, 8-9
2013	0	0	0	--
2014	0	0	0	--
2015	0	0	0	--
Total	15	41	--	--

Reanalysis data[2] were examined for the IOP dates listed in Table 4-1. The 700 mb level yielded an average height of 3,071 meters, an average temperature of -5.8°C, and an average wind speed of 8.1 mps.

For 2015, WDEQ designated four sample dates, January 16, and March 8, 9, and 10 when VOC canister sampling occurred. These days were chosen when high pressure, light winds, and sunny skies were expected. Reanalysis data were also examined for these sample days and this analysis showed the 700 mb level to have an average height of 3,094 meters. The average 700 mb temperature and average wind speed was -0.6°C and 6.8 mps, respectively.

Analysis of weather conditions of the four designated VOC sampling days were found to meet the forecast criteria set for ozone formation. Similarly to 2014, there were no elevated ozone concentrations measured in 2015. This suggests that a greater emphasis may need to be placed on overall snow cover for the basin as being an indicative variable for ozone formation.

4.1.2 UGWOS Snow Cover in 2012 through 2015

As has been discussed in past UGWOS reports, snow cover is one of the more important elements in the development of conditions which favor elevated ozone in the UGRB during the late winter and early spring months. The 2015 study began with a deeper snow cover than prior years. However, very little snow fell during the study period and snow depth decreased throughout the remainder of the study. From January 15 through March 31, 2015, there were no extended periods of high pressure over the study area.

[2] Reanalysis data have been developed by The National Centers for Environmental Prediction (NCEP)/ (National Center for Atmospheric Research NCAR). It consists of continually updated globally gridded weather data sets that represent the state of the Earth's atmosphere.

This type of weather pattern did not allow stagnant conditions (inversions) to develop which in turn did not allow for the accumulation, containment, and concentration of the precursors necessary for ozone development. The 2015 study was the fourth year in a row in which the weather pattern was unfavorable for elevated ozone development.

Due to the lack of measured snow depth information for the UGRB, UGWOS reports prior to 2013 provided a comparison of estimated snow depths by using data provided by NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) web site[3]. In 2012, both NOHRSC data and the snow stick images were used to estimate snow depths and the datasets agreed fairly well. However, in 2013 the comparison between NOHRSC and snow stick images did not correlate well; thus, it was decided to use WDEQ's snow stick images located at various monitoring sites in the UGRB to provide snow depth comparisons. Snow stick images were used for UGWOS 2015. In particular, the images from the Boulder monitoring site were used.

As previously mentioned and similar to 2012 through 2014, the 2015 study period was unfavorable for elevated ozone development. The storm systems that moved across the study area provided occasional light precipitation (snow) to the UGRB in 2015 as recorded by monitoring stations operated by the AQD and the Collaborative Community Rain Hail and Snow Network (CoCoRaHS) which has a station located near Pinedale. Measureable precipitation (snow) occurred within the project area on 23 days during the 2015 study. This was considerably less than 2014 when snow was reported on 40 days and 41 days in 2013. The occurrence of snow on 23 days represents 30 percent of the study days having at least light precipitation somewhere in the area.

Table 4-2 shows the days when measureable precipitation fell in the study area during 2015. The periods of most snowfall during the 2015 study occurred on February 3-4, 9, and 21. Figure 4.3 shows snow conditions on March 31 at the Boulder site for 2012 through 2015. Figure 4.4 shows the estimated snow depths at the Boulder monitoring site at the beginning and middle of each month. These depths were taken from snow stick images at the Boulder location. As seen from the images, patchy snow persisted at Boulder until March 23 in 2012 and until March 15 in 2013. In 2014 there was patchy snow lasting through the March 31. For 2015, patchy snow was visible through March 11.

Table 4-2 Days with Measureable Snow in the Upper Green River Basin in 2015

January	February	March
16,19,23, 28, 31	3-5, 9-10, 15, 21-23,25-28	1-3, 23-24

The overall snowpack in the 2015 study was also less than in previous years. Figure 4.2 presents camera images taken at the Boulder site on January 15 for UGWOS study years 2012 through 2015.

[3] http://www.nohrsc.noaa.gov/interactive NOHRSC Interactive Snow Information data provided by NOAA/NWS, Chanhassen, MN, USA.

Figure 4.2 Boulder Site January 15, 2015 (Top) through 2012 (Bottom)

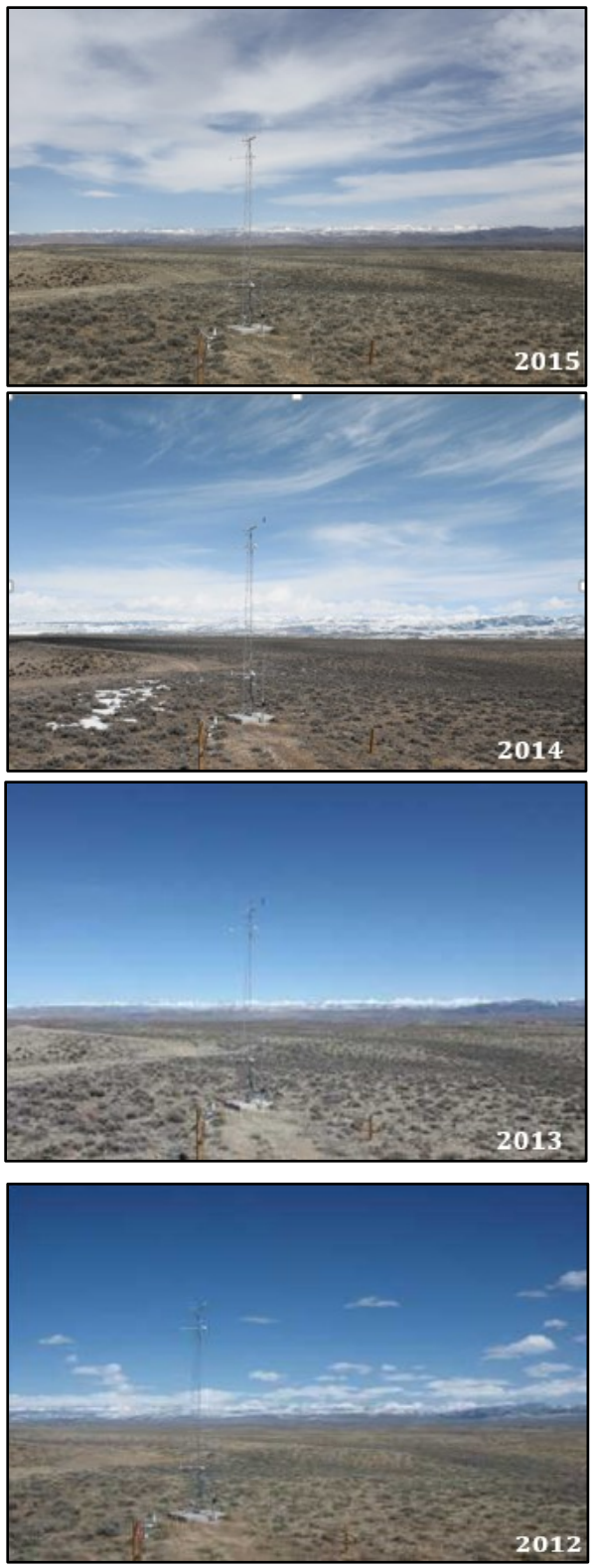

Figure 4.3 Boulder Site March 31, 2015 (Top) through 2012 (Bottom)

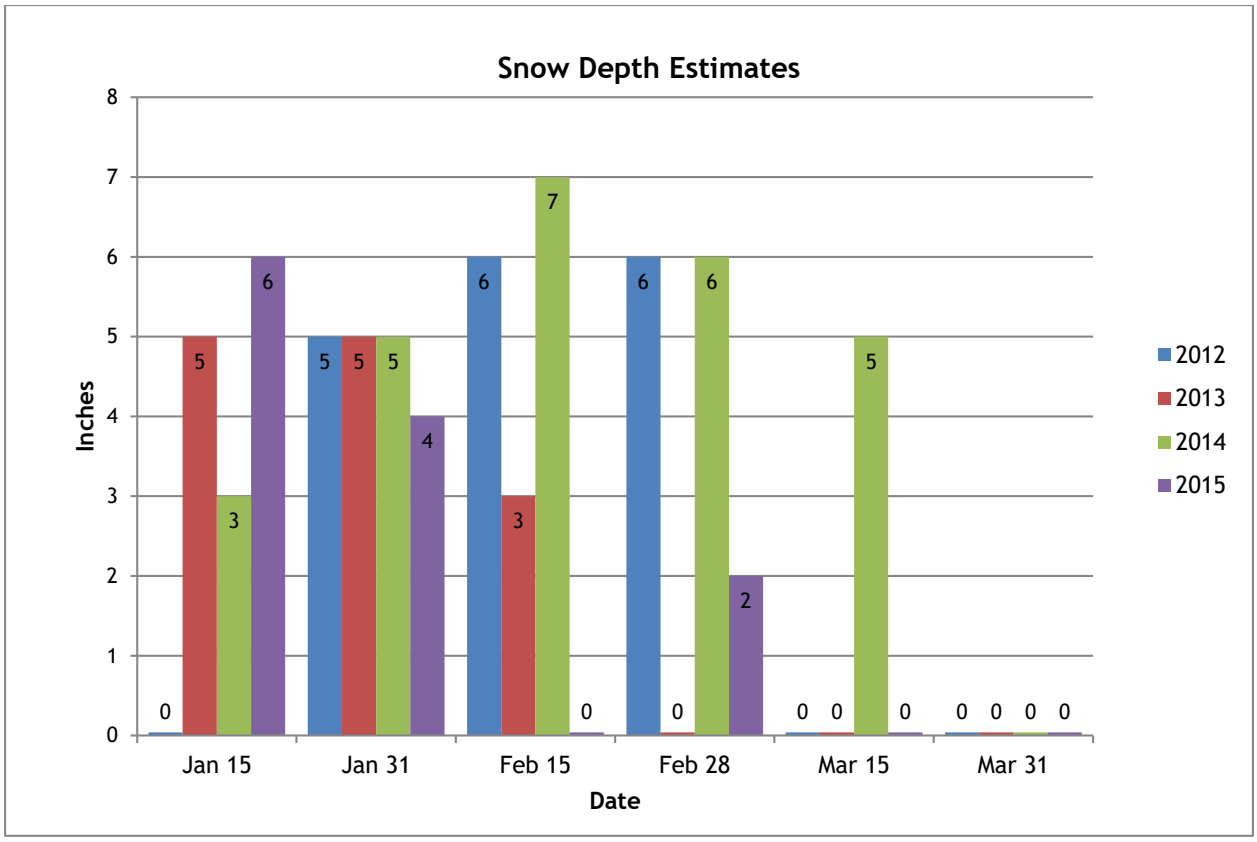

Figure 4.4 Estimated Snow Depth at Boulder Based on Snow Stick Images

4.2 Ozone Spatial and Temporal Distribution

Peak ozone levels measured during the UGWOS 2015 campaign were low relative to those observed in prior UGWOS campaigns. The highest 8-hour ozone concentration recorded was 61 ppb, which is well below the U.S. EPA NAAQS of 75 ppb. This maximum occurred on only one day and only at the Moxa site. The second highest 8-hour ozone concentration was 59 ppb also recorded at the Moxa site and the third highest 8-hour ozone concentration was 58 ppb recorded at Moxa and South Pass. None of the top three peak ozone levels occurred during conditions favorable to the photochemical production of ozone. The highest and third highest concentrations occurred in the last few days of March and followed a stratospheric ozone intrusion and the second highest concentration occurred on a day with strong winds. The maximum eight-hour and one-hour ozone concentrations at all UGWOS 2015 monitoring sites are presented in Figure 4.5.

At an elevation of 2,526 meters, South Pass is approximately 400 meters above the floor of the UGRB and has the highest elevation of any monitoring site in the study area. Ozone levels measured at South Pass were frequently higher and had less variability than those measured at other sites. Its elevation makes it less susceptible to NO_x scavenging and more apt to ventilate with the free atmosphere. While the Moxa site has a relatively low elevation of 1,919 meters, its location over 60 km to the south of the Juel Spring site is far removed from the central study area. Ozone levels measured at Moxa were often incongruent with those from other sites in the study area, indicating that Moxa was often not sampling the same air mass as other sites in the study area. Thus, caution should be taken when comparing ozone data from South Pass and Moxa with that from other UGWOS sites.

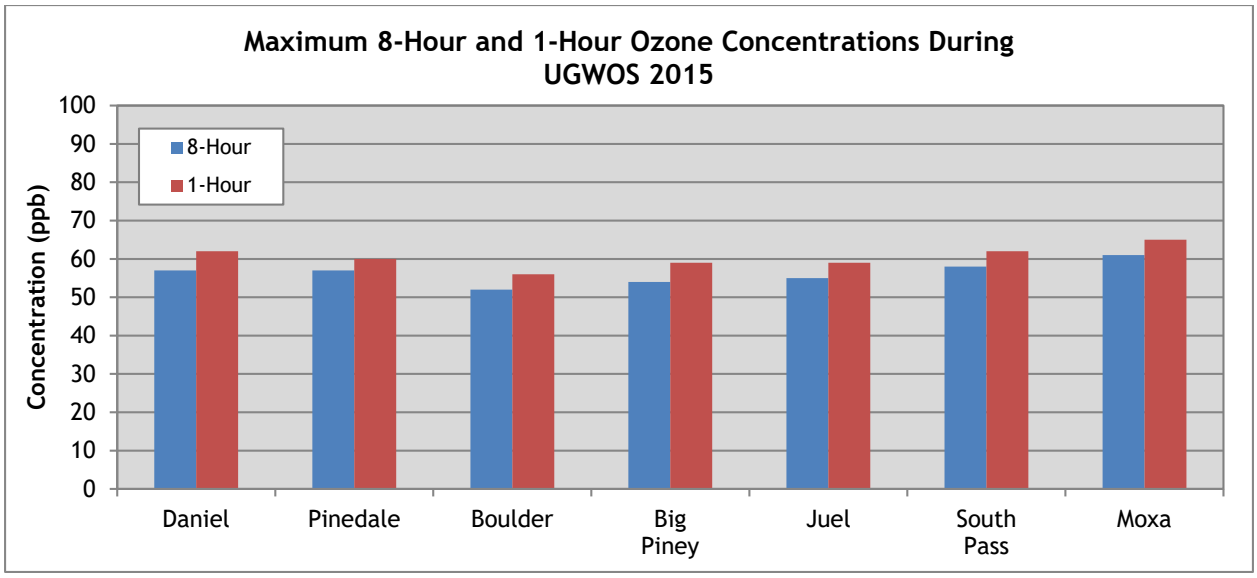

Figure 4.5 Maximum Eight-Hour and One-Hour Average Ozone Concentrations in the UGRB during UGWOS 2015

As seen in previous UGWOS studies, the diurnal distribution of ozone followed a predictable pattern. Ozone concentration minimums often occurred near dawn (07:00 MST), then quickly recover to background levels by noon. Peak ozone concentrations occurred in the early afternoon (13:00 – 15:00 MST), then concentrations slowly decreased during the late afternoon through overnight hours. Figure 4.6 presents the diurnal composite hourly ozone concentrations for all sites during UGWOS 2015. Figure 4.7 presents the running eight-hour average ozone levels for all monitoring sites during UGWOS 2015.

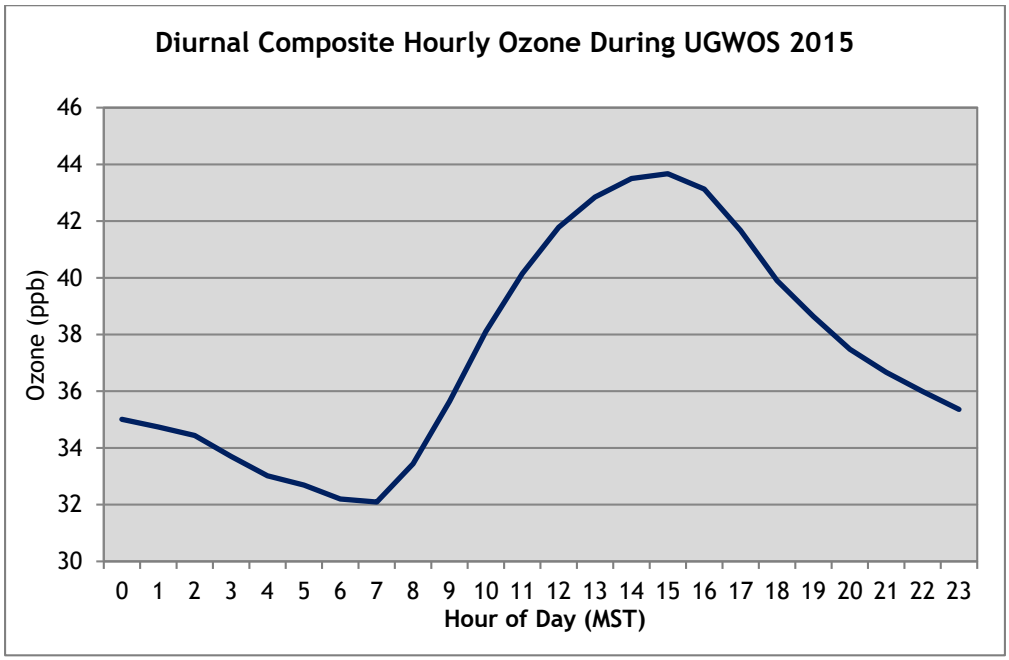

Figure 4.6 Diurnal Composite Hourly Ozone Concentrations for all Sites during UGWOS 2015

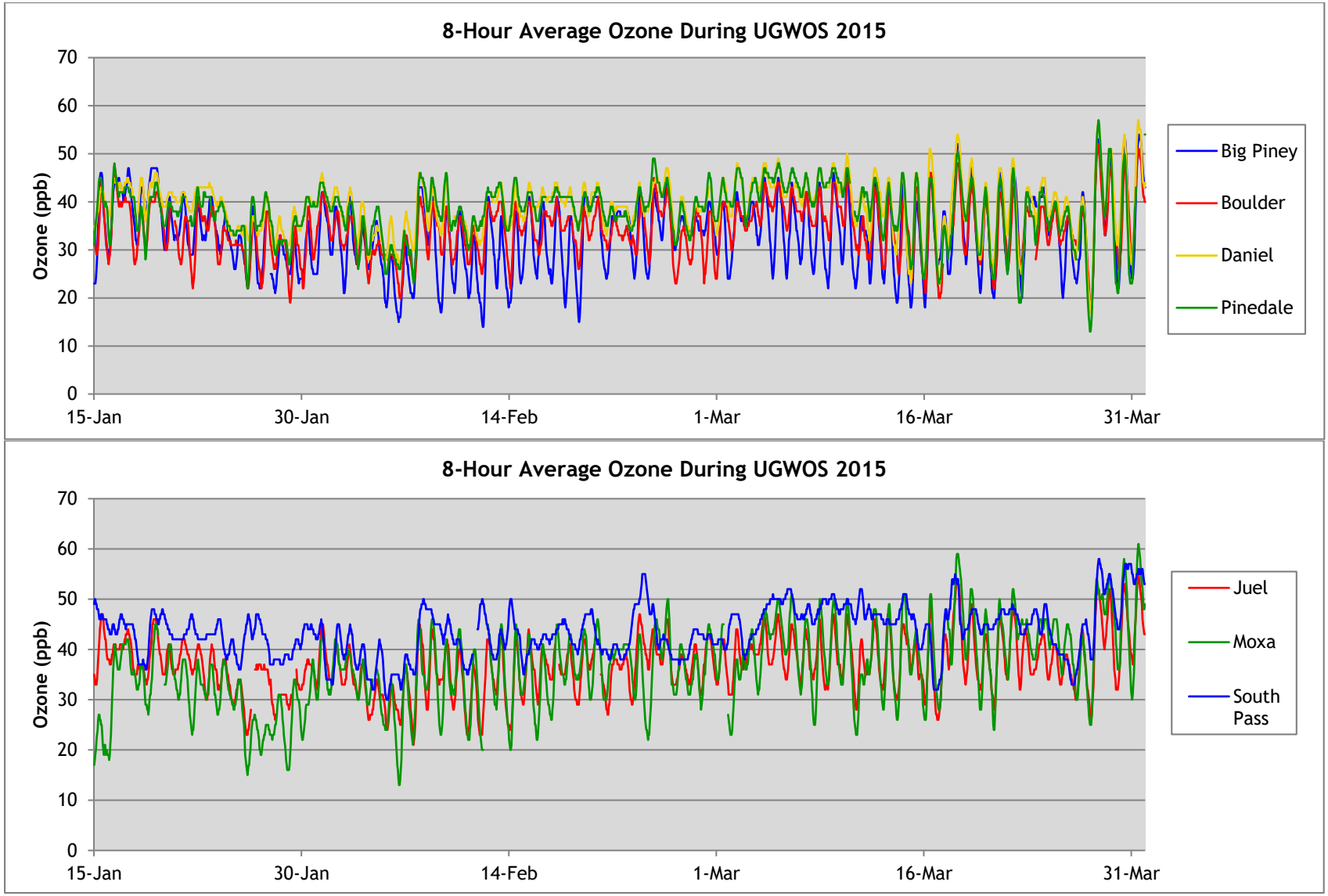

Figure 4.7 Running Eight-Hour Ozone Concentrations during UGWOS 2015

The sites with the highest afternoon ozone concentrations were typically South Pass and Moxa while Boulder, Big Piney, Moxa, and occasionally Daniel typically observed the lowest morning minimum ozone concentrations. NO_x scavenging may contribute to the low morning ozone minimum concentrations at those sites. In previous years, the magnitude of the diurnal ozone cycle increased towards the end of the study period, coincident with warmer temperatures and higher sun angles. This year the increase in the magnitude of the diurnal ozone cycle was modest. A stratospheric ozone intrusion occurred on March 28 following the passage of a mid-latitude cyclone and associated cold front. March 28 through March 31 observed the highest ozone concentrations of the study period.

Figure 4.8 presents the daily maximum eight-hour average ozone concentrations for all sites during UGWOS 2015. South Pass and/or Moxa experienced the highest ozone concentrations 89 percent of the time. Omitting those two stations due to their unrepresentativeness of the conditions in the UGRB, Daniel experienced the highest ozone concentrations 63 percent of the time.

Table 4-3 presents maximum eight-hour average ozone concentrations for all sites where a concentration exceeding 55 ppb was observed anywhere in the UGWOS domain. The UGWOS network daily maximum is indicated in the right-most column of the table. Table 4-3 shows that elevated ozone was most commonly observed at Moxa.

Table 4-3 Maximum Eight-hour Average Ozone Concentrations (ppb) for Boulder, Daniel, Juel Springs (Juel), Pinedale, Moxa, Big Piney, and South Pass on Days When at Least One Site Recorded Concentrations > 55 ppb

Station	Boulder	Daniel	Juel	Pinedale	Moxa	Big Piney	South Pass	Network Max
Mar 18	48	54	54	50	59	52	55	**59**
Mar 28	52	56	52	57	54	53	58	**58**
Mar 30	48	54	53	50	58	53	57	**58**
Mar 31	51	57	55	54	61	54	56	**61**

Values > 55 in Yellow
Values > 60 in Red

4.2.1 Spatial and Temporal Distribution of O_3 during Designated VOC Canister Sample Days

This section will focus on the spatial and temporal distribution of ozone in the UGRB during each VOC canister sample day. Since there were no ozone measurements taken at the mesonet sites this year, ozone data from the permanent monitoring sites will be analyzed.

There were four designated VOC canister sample days during UGWOS 2015: January 16, March 8, March 9, and March 10. VOC canister samples were taken at each mesonet site (Mesa, Jonah, and Paradise), and at the Boulder and Big Piney permanent monitoring sites.

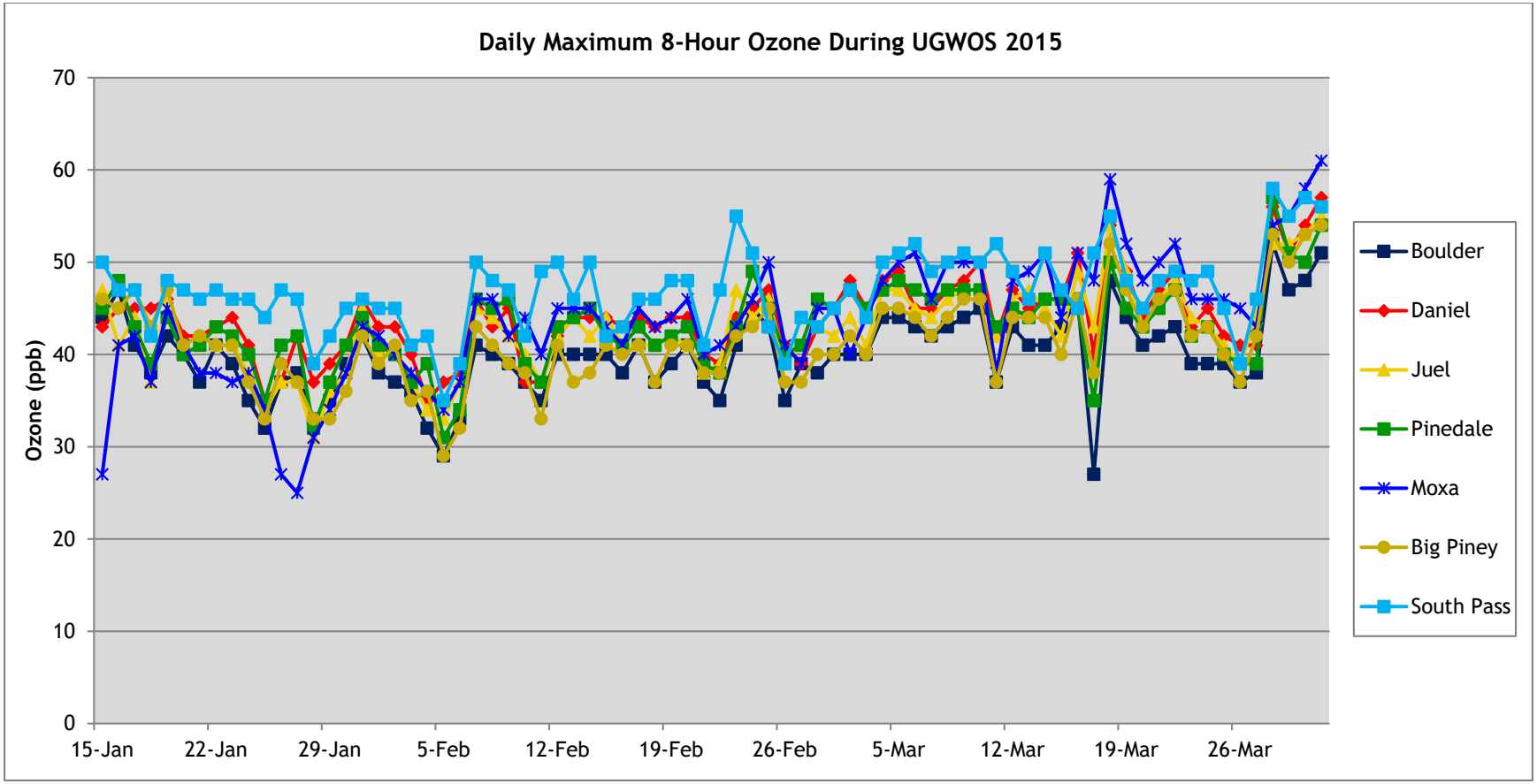

Figure 4.8 Daily Maximum Eight-Hour Ozone Concentrations, UGWOS 2015

The first designated VOC canister sample day was January 16. With the exception of the Boulder and Pinedale sites, hourly ozone concentrations remained below 50 ppb. Pinedale observed the highest ozone concentrations within the UGRB at 54 ppb. In the morning hours, several sites including Moxa, Pinedale, Boulder, and Big Piney experienced depressed ozone concentrations to varying degrees due to NO_x scavenging. Ozone concentrations at higher elevation sites such as South Pass were not depressed during the morning hours. Beyond 13:00 MST, ozone concentrations at most of the sites remained clustered between 37 ppb and 49 ppb for the rest of the day. The hourly ozone concentrations for January 16 are presented in Figure 4.9.

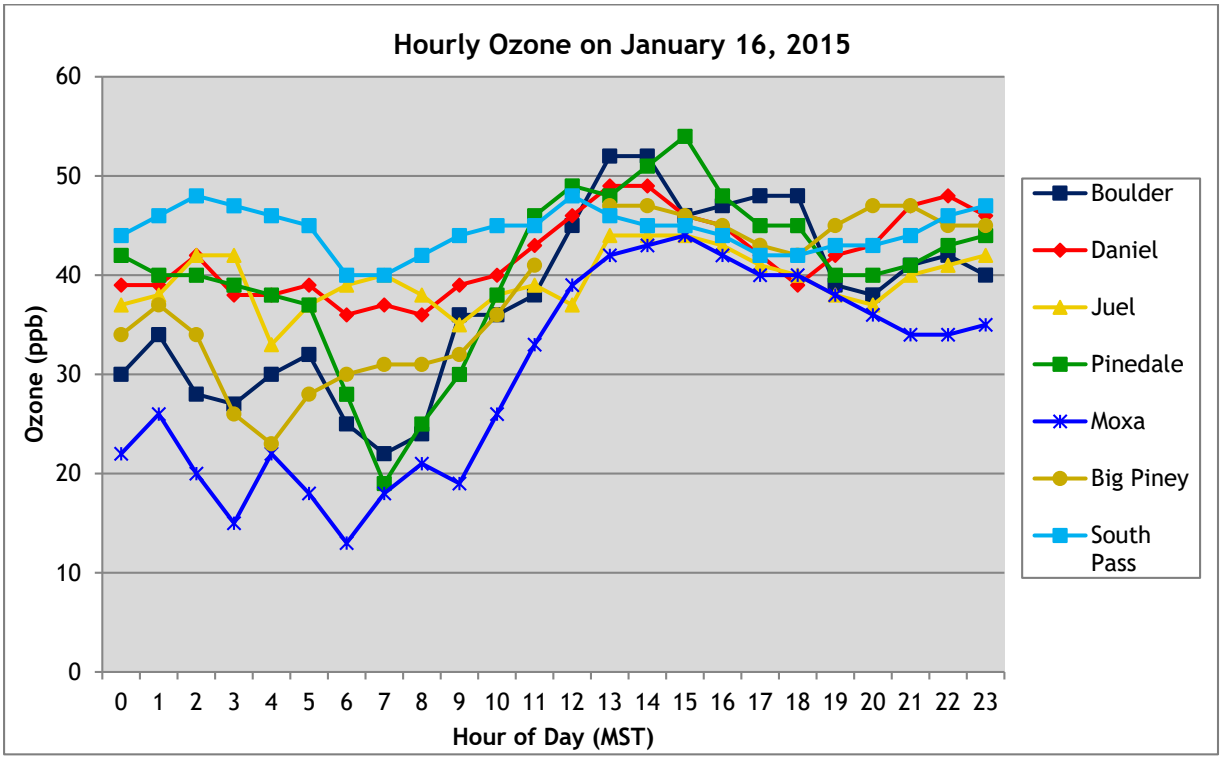

Figure 4.9 One-Hour Average Ozone during Designated VOC Sample Day 1

The second, third, and fourth designated VOC canister sample days were March 8, March 9, and March 10, respectively. Moxa and/or South Pass observed the highest ozone concentrations on each of the three days, the highest being 54 ppb observed at the Moxa site on March 8. Excluding these two sites, which are on the edge of the primary UGWOS area, ozone concentrations were no higher than 51 ppb. Depressed ozone concentrations associated with NO_x scavenging were observed during the morning hours at Big Piney, Moxa, and to a lesser extent at Boulder. Afternoon ozone concentrations at all sites excluding Moxa and South Pass were clustered between 44 ppb and 51 ppb each afternoon. The hourly ozone concentrations for March 8-10 are presented in Figure 4.10.

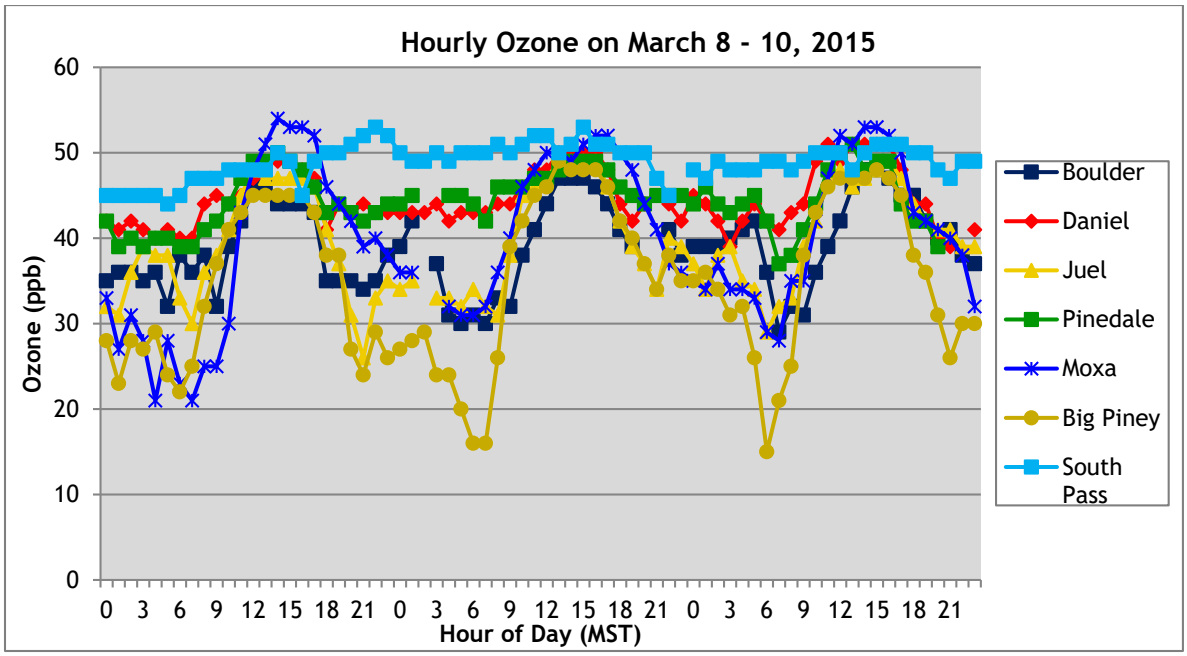

Figure 4.10 One-Hour Average Ozone during Designated VOC Sample Days 2, 3, and 4

4.2.2 Surface Wind Patterns Affiliated with Elevated Ozone during Designated VOC Sample Days

This section will focus on the wind patterns that occurred at sites that observed elevated ozone on designated VOC sample days. In past UGWOS campaigns, elevated ozone episodes were associated with a characteristic wind shift that recirculated pollutants within the basin. Northwest wind during the night was followed by southeast wind during the day coincident with climbing ozone concentrations. For each designated VOC sample day in this year's study, the hourly average wind data (represented by wind barbs) are superimposed upon a line plot of hourly ozone concentrations. Wind barbs point in the direction from which wind is blowing. Since observed wind speeds during the sample days are usually low, a full barb will represent a wind speed of 5 meters per second.

Boulder and Pinedale were the two monitoring sites that observed the highest concentrations of ozone on January 16. The wind at Boulder and Pinedale was generally from the northwest up until 06:00 MST, during which time ozone concentrations were drifting slowly downward. Between 06:00 and 09:00 MST, the wind was light and variable and ozone concentrations were depressed owing to NO_x scavenging. The wind was still light and variable as ozone concentrations rose to their peak values around 15:00 MST. During the late afternoon, the wind picked up out of the northwest and persisted for the rest of the day while ozone concentrations slowly fell from the afternoon maximum. Hourly wind and ozone data for Pinedale and Boulder for the January 16 VOC sample day are presented in Figure 4.11.

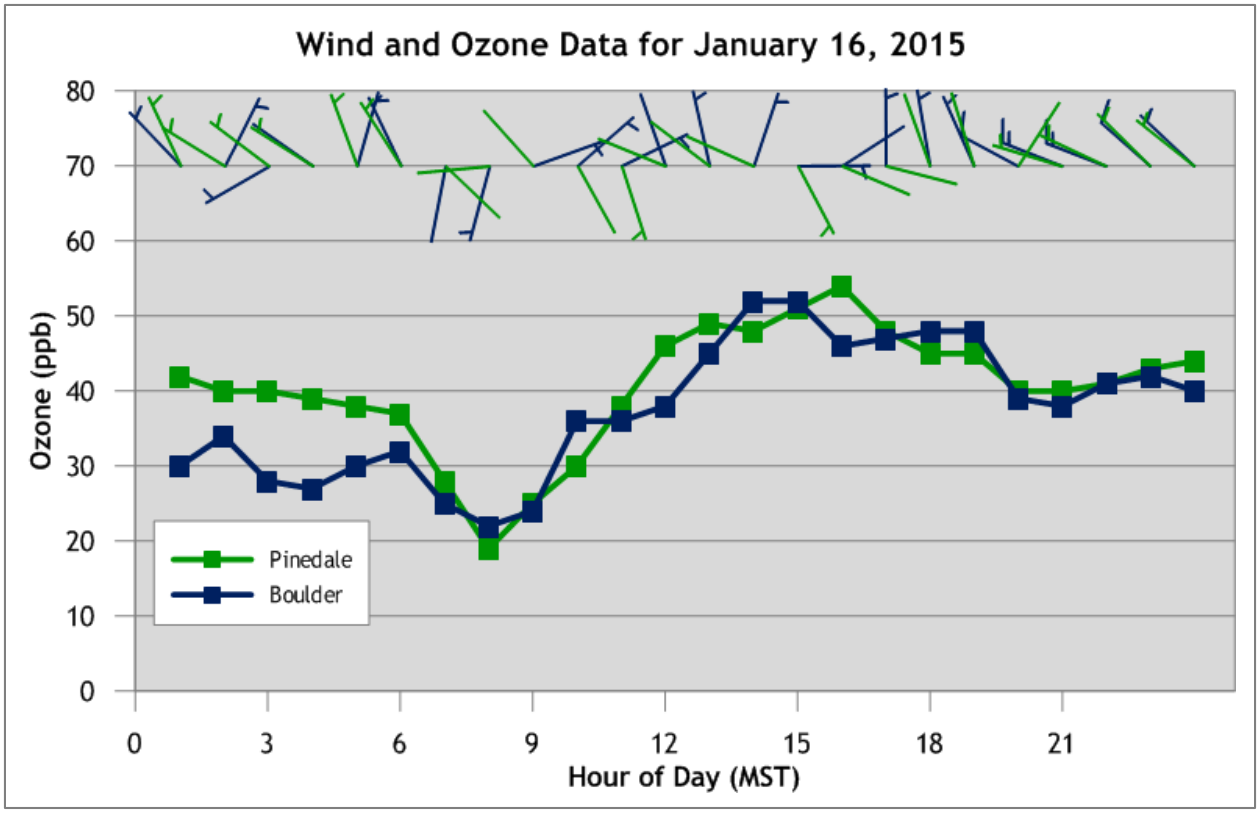

Figure 4.11 One-Hour Average Ozone and Wind at Pinedale and Boulder during VOC Sample Day 1

The highest ozone concentrations during the second, third, and fourth designated VOC sample days (March 8 to March 10) were recorded at South Pass and Moxa. However, since these two sites are not within the core UGWOS study area, data from Daniel and Pinedale will also be included in the analysis. The wind at South Pass followed a predictable diurnal pattern of northwesterly drainage wind at night followed by southerly to southwesterly upslope wind during the day. Ozone concentrations during the three-day period varied little. The wind at Moxa early on March 8 varied from southerly to westerly to northerly during which time ozone concentrations were suppressed due to NO_x scavenging. Ozone concentrations recovered dramatically between 09:00 MST and 12:00 MST during which time the wind was light from the south. The wind increased from the west during the afternoon of March 8 at Moxa while ozone concentrations held steady near 52 ppb for a few hours, then ozone concentrations dropped off after 18:00 MST. The wind at Moxa for the duration of the three-day period was largely southwesterly to southerly at night and westerly to northwesterly during the day. With few exceptions, the wind at Daniel and Pinedale was consistently from the northwest quadrant throughout the duration of the period. Thus, very little, if any, recirculation of pollutants occurred within the northern UGRB during this period. The rise in ozone concentrations observed each afternoon at Moxa, Pinedale, and Daniel was likely due to improved ventilation to the free atmosphere and not due to photochemical processes. Hourly wind and ozone data for Moxa, South Pass, Daniel, and Pinedale during the second, third, and fourth VOC sample days are presented in Figure 4.12.

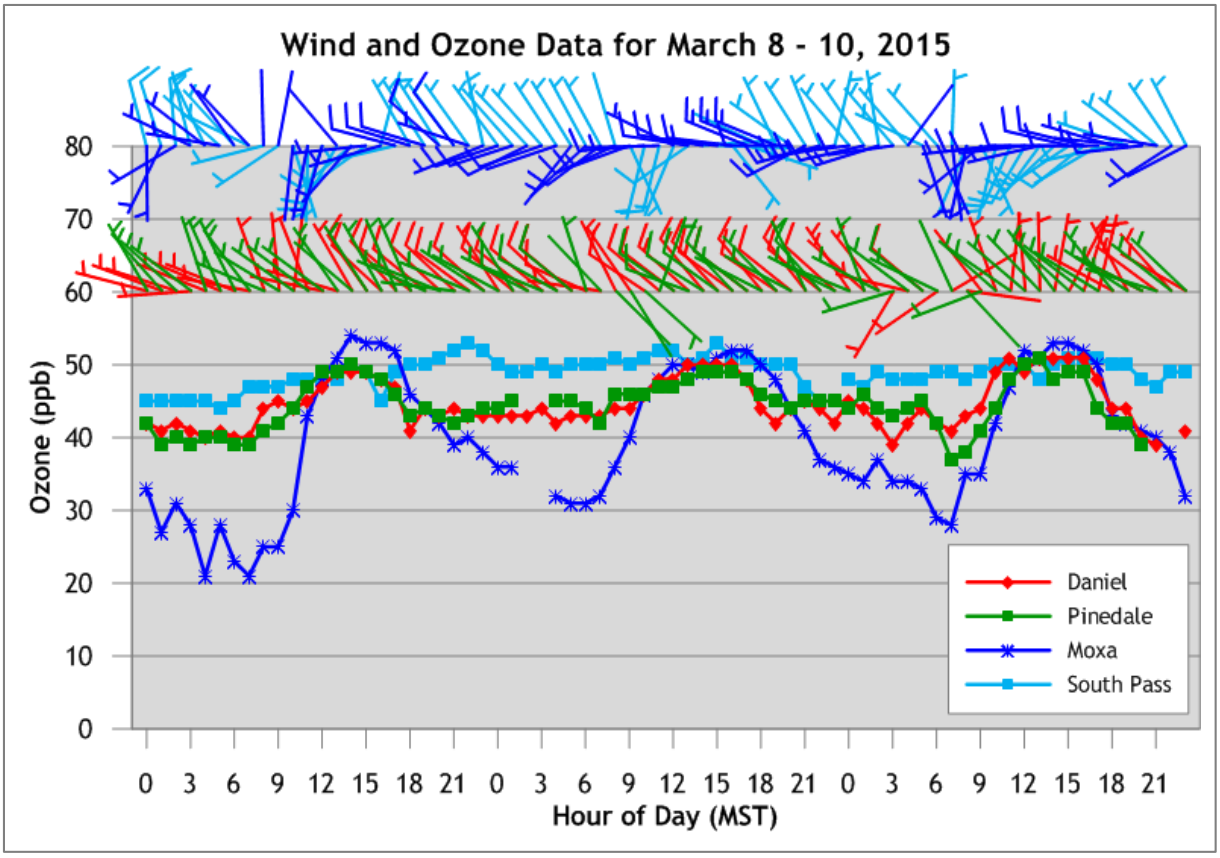

Figure 4.12 One-Hour Average Ozone and Wind at Daniel, Pinedale, Moxa, and South Pass during VOC Sample Days 2, 3, and 4

4.2.3 Comparison of Ozone in 2015 with 2005-2014

Ozone data have been recorded at long-term monitoring sites in the UGRB since 2005. The Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Big Piney sites utilize Federal Equivalent Method (FEM) air quality monitors. After the conclusion of the 2009 UGWOS campaign, the monitoring equipment at Jonah was dismantled and moved to its current location at Juel Springs. For the 2010 UGWOS campaign, the WDEQ BAM trailer with FEM analyzers was placed at the former Jonah long-term site. For the 2012 UGWOS campaign, power was not available at the former long-term site. Therefore, the WDEQ BAM trailer was located at the entrance to the Jonah field on the Luman Road, 10.4 kilometers northeast of the former long-term site. For the 2013 and 2014 UGWOS campaigns, the WDEQ BAM trailer was located inside the Jonah field, 6.2 kilometers northeast of the former long-term site, where a source of power was available. There were no ozone measurements taken at Jonah in 2015. In 2014, a permanent monitoring site was established at Big Piney and replaced a WDEQ mobile trailer (using FEM monitors) that had been there since 2012. Eight-hour ozone averages and maxima by month from these sites are presented in Table 4-4.

With only three exceptions, monthly average 8-hour ozone concentrations tied or established new historical low values at every site for every month during the 2015 UGWOS campaign. Maximum eight-hour ozone concentrations were also low compared to those of previous years and several new monthly low maximums were established.

Table 4-4 Eight-Hour Monthly Average and Maximum Ozone by Year for Jonah, Boulder (BD), Daniel (DN), Pinedale (PD), Juel Springs, and Big Piney (BP)

January	Average 8-Hour Ozone (ppb)						Maximum 8-Hour Ozone (ppb)					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2005	35	NA	NA	NA	NA	NA	78	NA	NA	NA	NA	NA
2006	33	41	43	NA	NA	NA	49	67	53	NA	NA	NA
2007	27	43	40	NA	NA	NA	57	71	53	NA	NA	NA
2008	29	39	42	NA	NA	NA	47	58	56	NA	NA	NA
2009	24	34	37	NA	38*	NA	52	55	48	NA	64*	NA
2010	34•†	38	39	36	40	NA	57•†	69	49	61	55	NA
2011	NA	39	41	40	42	NA	NA	69	59	62	63	NA
2012	34•†	34	35	33	35	30†	47•†	52	43	42	50	41†
2013	37•†	32	39	37	41	34†	49•†	48	50	46	55	47†
2014	39•†	34	40	39	38	36	48•†	47	49	48	47	47
2015	NA	32	37	35	35	33	NA	50	46	48	49	47
February	Average 8-Hour Ozone (ppb)						Maximum 8-Hour Ozone (ppb)					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2005	42	51	NA	NA	NA	NA	98	89	NA	NA	NA	NA
2006	39	48	49	NA	NA	NA	93	71	82	NA	NA	NA
2007	29	42	40	NA	NA	NA	46	59	57	NA	NA	NA
2008	40	54	50	NA	NA	NA	102	122	76	NA	NA	NA
2009	33	42	43	NA	40*	NA	69	67	64	NA	62*	NA
2010	44†	51	46	42	46	NA	54†	62	52	57	53	NA
2011	NA	46	47	44	47	NA	NA	87	74	59	68	NA
2012	38†	40	40	38	41	35	50†	64	54	50	53	48†
2013	40†	37	44	42	43	40	54†	46	53	50	57	51†
2014	37†	35	40	38	37	37	47†	51	51	57	51	47
2015	NA	33	38	37	35	31	NA	45	47	49	47	45
March	Average 8-Hour Ozone (ppb)						Maximum 8-Hour Ozone (ppb)					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2005	40	48	NA	NA	NA	NA	58	71	NA	NA	NA	NA
2006	44	48	50	NA	NA	NA	68	67	71	NA	NA	NA
2007	32	44	40	NA	NA	NA	44	65	55	NA	NA	NA
2008	39	53	50	NA	NA	NA	98	102	75	NA	NA	NA
2009	39	46	43	NA	42*	NA	63	70	67	NA	67*	NA
2010	48†	53	48	41	49	NA	55†	66	54	57	53	NA
2011	NA	54	52	51	53	NA	NA	123	85	89	94	NA
2012	42†	41	39	39	43	37†	61†	62	58	59	56	56†
2013	40†	37	41	39	43	38†	55†	53	55	54	57	54†
2014	39†	40	43	42	40	38	53†	53	57	54	53	53
2015	NA	35	39	38	39	34	NA	52	57	57	55	54

* Temporary Mesonet site with 2B ozone analyzer prior to long-term site.
† WDEQ trailer with FEM monitor
• January 15-31
NA – Data not available

4.2.4 Comparison of NO_x and PM during UGWOS 2015 with 2006-2014

Average monthly NO and NO_2 concentrations at AQD monitoring sites in the UGRB are presented in Table 4-5. During 2015, the monthly average concentrations ranged from below average to above average compared to previous years. The highest monthly average NO was 0.6 ppb and the highest monthly average NO_2 was 3.6 ppb.

Table 4-5 Monthly Average One-Hour NO and NO_2 Concentrations by Year for Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Big Piney

Jan.	1-Hour NO (ppb)						1-Hour NO_2 (ppb)					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2006	11.2	1.7	0.04	NA	NA	NA	16.9	7.2	0.5	NA	NA	NA
2007	24.6	0.9	0.05	NA	NA	NA	22.6	4.5	0.7	NA	NA	NA
2008	27.2	NA	0.01	NA	NA	NA	26.2	NA	0.2	NA	NA	NA
2009	20.6	2.5	0.01	NA	NA	NA	24.4	5.6	0.2	NA	NA	NA
2010	4.9*†	2.1	NA	0.8	1.3	NA	11.2*†	8.0	0.7	4.3	2.9	NA
2011	NA	1.7	0.02	1.6	0.6	NA	NA	7.0	0.1	3.9	3.3	NA
2012	1.3*†	0.4	0	1.0	0.2	0.4†	3.3*†	2.2	0.0	4.1	0.3	2.3†
2013	1.4*†	0.5	NA	0.8	0.3	0.7†	3.6*†	6.2	NA	2.1	2.1	2.6†
2014	1.5*†	0.1	0.03	0.2	0.2	0.5	3.1*†	1.4	0.5	2.3	0.7	1.9
2015	NA	0.4	0.4	0.6	0.1	0.5	NA	3.6	0.4	2.2	2.0	2.4
Feb.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2006	16.3	0.9	0.04	NA	NA	NA	18.1	4.8	0.7	NA	NA	NA
2007	19.6	0.4	0.01	NA	NA	NA	16.8	1.7	0.1	NA	NA	NA
2008	24.0	NA	0	NA	NA	NA	19.0	NA	0.1	NA	NA	NA
2009	10.6	1.9	0	NA	NA	NA	16.2	5.7	0.4	NA	NA	NA
2010	8.1†	1.3	NA	0.4	1.3	NA	10.4†	4.6	0.3	2.6	2.9	NA
2011	NA	0.8	0.02	1.8	0.5	NA	NA	4.8	0.6	5.5	2.5	NA
2012	0.7†	0.6	0.04	1.2	0.1	0.3†	2.5†	2.6	0.0	4.1	0.9	2.5†
2013	0.5†	0.2	0.07	0.3	0.2	0.5†	2.2†	2.5	0.1	1.5	1.5	1.3†
2014	1.8†	0.2	0.05	0.7	0.2	0.3	3.4†	1.8	0.9	3.8	0.6	1.5
2015	NA	0.2	0.08	0.4	0.02	0.2	NA	1.4	0.2	1.6	1.1	1.1
Mar.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
Year	Jonah	BD	DN	PD	Juel	BP	Jonah	BD	DN	PD	Juel	BP
2006	0.3	0.01	4.4	NA	NA	NA	9.0	1.8	0.4	NA	NA	NA
2007	0.2	0	20.3	NA	NA	NA	16.1	0.7	0.05	NA	NA	NA
2008	0.03	0	13.1	NA	NA	NA	14.6	0.9	0.02	NA	NA	NA
2009	0.3	0	2.6	NA	NA	NA	6.9	2.0	0.2	NA	NA	NA
2010	0.2†	NA	7.0	0.9	1.3	NA	6.6†	1.7	0.4	1.9	1.2	NA
2011	0.9	0	NA	2.4	0.4	NA	NA	4.9	0.5	7.4	2.5	NA
2012	0†	0.1	0	1.3	0.1	0.1†	0.8†	0.4	0.0	4.3	1.1	1.4†
2013	0.1†	0.1	0.09	0.1	0.1	0.2†	1.3†	1.5	0.1	1.4	1.0	1.2†
2014	0.7†	0.04	0.03	0.4	0.1	0.1	1.6†	0.5	0.7	1.1	0.7	1.0
2015	NA	0.07	0	0.2	0	0.2	NA	1.7	0.2	1.3	1.1	1.1

* January 15-31
† WDEQ trailer with FEM monitor
NA – Data not available

Average monthly PM_{10} and $PM_{2.5}$ concentrations at AQD monitoring sites in the UGRB are presented in Table 4-6. Monthly average concentrations of PM_{10} during 2015 were below average to average compared to previous years. Monthly average concentrations of $PM_{2.5}$ at Pinedale ranged from below average to above average compared to previous years.

Table 4-6 Monthly Average PM_{10} and $PM_{2.5}$ Concentrations by Year for Boulder, Daniel, Pinedale, and Wyoming Range

January	Average PM_{10} (µg/m³)			Average $PM_{2.5}$ (µg/m³)	
Year	Boulder	Daniel	Wyoming Range	Pinedale	Wyoming Range
2006	7.1	5.0	NA	NA	NA
2007	NA	5.2	NA	NA	NA
2008	6.9	6.4	NA	NA	NA
2009	6.7	4.9	NA	4.1	NA
2010	6.7	4.3	NA	4.1*	NA
2011	6.7	4.4	1.6	4.4	0.8
2012	5.7	4.6	3.7	5.1	0.5
2013	5.5	5.7	1.2	5.3	0.9
2014	4.5	3.8	NA	4.0	NA
2015	8.2•	3.3	NA	5.8	NA
February	**Average PM_{10} (µg/m³)**			**Average $PM_{2.5}$ (µg/m³)**	
Year	Boulder	Daniel	Wyoming Range	Pinedale	Wyoming Range
2006	7.4	6.1	NA	NA	NA
2007	5.0	4.8	NA	NA	NA
2008	7.4	5.7	NA	NA	NA
2009	6.9	6.6	NA	3.6	NA
2010	6.3	4.4	NA	2.4	NA
2011	10.3	6.4	4.4	5.1	2.1
2012	6.0	4.5	3.6	4.8	1.2
2013	4.7	4.0	1.8	2.6	1.0
2014	4.5	3.9	NA	6.6	NA
2015	5.2	3.9	NA	3.8	NA
March	**Average PM_{10} (µg/m³)**			**Average $PM_{2.5}$ (µg/m³)**	
Year	Boulder	Daniel	Wyoming Range	Pinedale	Wyoming Range
2006	7.7	6.8	NA	NA	NA
2007	8.5	6.7	NA	NA	NA
2008	7.5	6.7	NA	NA	NA
2009	10.9	11.2	NA	4.3	NA
2010	8.2	6.6	NA	3.0	NA
2011	11.1	7.3†	5.7	5.5	3.1
2012	10.0	9.4	8.4	7.0	2.7
2013	7.6	7.1	7.5	3.0	1.5
2014	5.8	4.1	NA	5.3	NA
2015	5.6	7.0	NA	3.8	NA

* January 15-31, 2010.
† March 1-20, 2011.
• January 1-6, 25-31, 2015
NA – Data not available

4.2.5 Comparison of NMHC and THC during UGWOS 2015 with 2010-2014

Average monthly CH_4, NMHC, and THC concentrations at the Boulder and Big Piney monitoring sites are presented in Table 4-7. Methane/THC measurements during 2015 were generally low with a few new monthly average minimums established.

Table 4-7 Monthly Average CH_4, NMHC and THC Concentrations by Year for Boulder and Big Piney

January	Average CH_4 (ppm)		Average NMHC (ppm)		Average THC (ppm)	
Year	Boulder	Big Piney	Boulder	Big Piney	Boulder	Big Piney
2010	NA	NA	NA	NA	NA	NA
2011	6.76	NA	1.05	NA	7.77	NA
2012	2.10*	2.09	0.14*	0.10	2.24*	2.19
2013	2.57	2.37	0.52	0.22	3.09	2.58
2014	2.25	NA	0.22	NA	2.47	NA
2015	2.33	NA	0.32	NA	2.65	NA
February	**Average CH_4 (ppm)**		**Average NMHC (ppm)**		**Average THC (ppm)**	
Year	Boulder	Big Piney	Boulder	Big Piney	Boulder	Big Piney
2010	2.46	NA	0.28	NA	2.75	NA
2011	2.39	NA	0.32	NA	2.70	NA
2012	2.46	2.12	0.26	0.11	2.72	2.24
2013	2.24	2.10	0.40	0.11	2.64	2.20
2014	2.20	NA	0.27	NA	2.47	NA
2015	2.04	NA	0.16	NA	2.20	NA
March	**Average CH_4 (ppm)**		**Average NMHC (ppm)**		**Average THC (ppm)**	
Year	Boulder	Big Piney	Boulder	Big Piney	Boulder	Big Piney
2010	2.14	NA	0.13	NA	2.27	NA
2011	2.37	NA	0.31	NA	2.69	NA
2012	2.14	2.01	0.15	0.08	2.29	2.09
2013	2.18	1.93	0.29	0.08	2.46	2.01
2014	2.02	NA	0.17	NA	2.19	NA
2015	2.10	NA	0.16	NA	2.26	NA

* January 1-22, 2012.
NA – Data not available

Alternatively, NHMC activity can be summarized by calculating the number of days that the highest 1-hour NMHC exceeds given thresholds. Table 4-8 presents the count of days at Boulder and Big Piney that the highest 1-hour NMHC concentration exceeded 2.0 ppm and 4.0 ppm. Using this metric, NMHC activity during 2015 was very low.

Table 4-8 Number of Days That Highest 1-Hr NMHC Concentration Exceeded 2.0 ppm and 4.0 ppm at Boulder and Big Piney

	Boulder		Big Piney	
Year	Days > 2 ppm	Days > 4 ppm	Days > 2 ppm	Days > 4 ppm
2010	1	0	NA	NA
2011	16	3	NA	NA
2012	0	0	0	0
2013	4	1	0	0
2014	0	0	NA	NA
2015	0	0	NA	NA

4.3 VOC Sampling

To investigate the spatial distribution of ozone precursor concentrations in and around the gas and oil fields located in the UGRB, VOC canister and carbonyl cartridge samples were collected at Boulder and Big Piney monitoring stations as well as the UGWOS-specific mesonet sites (Mesa, Paradise, and Jonah Field). Although conditions during the 2015 UGWOS study period were not favorable for elevated ozone, WDEQ-AQD elected to collect canister and carbonyl samples on four days (January 16, March 8, March 9, and March 10) during which high pressure was located over the study area and light winds were present. On February 14, the canister sampling system at Boulder automatically collected a sample at 02:45 MST.

4.3.1 VOC Canister Sampling

Samples were collected using 6-liter SUMMA canisters connected to canister samplers which were programmed to collect three-hour samples between the hours of 07:00 and 10:00 MST on January 16 and between 04:00 and 07:00 MST on March 8, March 9, and March 10. Tables 4-9 through 4-13 present the VOC concentration data and average concentrations, after removal of non-detected compounds, for Boulder, Big Piney, Jonah Field, Mesa, and Paradise, respectively. Figures 4.13 and 4.14 present a graphical summary of the VOC samples combined into five hydrocarbon categories (paraffins, isoparaffins, aromatics, naphthenes, and olefins) and oxygenates at each of the five sampling locations. Figures 4.15 and 4.16 present the composition percentage of each hydrocarbon category in the samples. Dates in which samples were taken are shown on the x-axis and are presented in chronological order to compare site concentrations throughout the study period.

Table 4-9 VOC Concentration and Summary Data for Samples Collected at Boulder

Compound	Sample Dates					Average
	16-Jan	14-Feb	8-Mar	9-Mar	10-Mar	
Ethene (ppbV)	--	1.71	--	--	0.38	0.42
Acetylene (ppbV)	3.41	--	0.35	0.55	--	0.86
Ethane (ppbV)	77.12	24.29	4.54	3.20	6.68	23.17
Propene (ppbV)	--	0.54	0.15	--	--	0.14
Propane (ppbV)	47.76	18.72	5.27	1.67	2.60	15.20
i-Butane (ppbV)	1.19	5.76	2.88	0.47	0.63	2.19
Methanol (ppbV)	--	--	--	0.70	--	0.14
1-Butene (ppbV)	--	0.81	--	--	--	0.16
n-Butane (ppbV)	12.14	6.57	1.38	0.70	0.68	4.29
t-2-Butene (ppbV)	--	--	--	--	0.46	0.09
i-Pentane (ppbV)	6.27	4.73	0.97	--	--	2.39
1-Pentene (ppbV)	--	1.03	--	0.37	--	0.28
n-Pentane (ppbV)	4.27	5.56	1.06	0.52	0.48	2.38
2-Methylpentane (ppbV)	1.50	0.35	0.09	--	--	0.39
3-Methylpentane (ppbV)	--	1.16	0.23	--	--	0.28
n-Hexane (ppbV)	2.44	0.22	0.17	0.28	--	0.62
Methylcyclopentane (ppbV)	1.13	--	--	--	--	0.23
2,4-Dimethylpentane (ppbV)	--	1.42	--	0.12	--	0.31
Benzene (ppbV)	3.01	0.12	0.30	--	0.27	0.74
2-Methylhexane (ppbV)	1.40	--	--	--	0.08	0.30
2,3-Dimethylpentane (ppbV)	--	--	--	0.08	--	0.02
3-Methylhexane (ppbV)	--	1.89	--	--	--	0.38
2,2,4-Trimethylpentane (ppbV)	--	--	0.14	--	--	0.03
n-Heptane (ppbV)	1.27	0.82	0.04	0.32	0.46	0.58
Methylcyclohexane (ppbV)	2.92	0.40	--	--	--	0.66
2,5-Dimethylhexane (ppbV)	--	--	0.13	--	--	0.03
2,4-Dimethylhexane (ppbV)	--	1.37	--	--	--	0.27
2,3,4-Trimethylpentane (ppbV)	--	0.07	0.25	--	--	0.06
Toluene (ppbV)	3.62	2.60	0.25	0.07	--	1.31
2-Methylheptane (ppbV)	--	--	--	0.10	0.08	0.04
4-Methylheptane (ppbV)	--	0.16	--	--	--	0.03
3-Methylheptane (ppbV)	--	0.11	--	--	--	0.02
n-Octane (ppbV)	0.86	--	--	--	--	0.17
Ethylbenzene (ppbV)	--	0.93	0.18	--	--	0.22
m,p-xylene (ppbV)	--	0.22	0.22	0.11	--	0.11
Styrene (ppbV)	--	0.74	--	--	--	0.15
o-xylene (ppbV)	--	--	0.09	--	--	0.02
n-Nonane (ppbV)	--	0.19	--	--	--	0.04
i-Propylbenzene (ppbV)	--	--	--	0.06	--	0.01
1,3,5-Trimethylbenzene (ppbV)	--	0.24	0.06	--	--	0.06
2-Ethyltoluene (ppbV)	--	0.08	--	--	--	0.02
1,2,4-Trimethylbenzene (ppbV)	1.57	--	0.09	--	--	0.33
n-Decane (ppbV)	--	0.07	--	--	--	0.01
Combined Compound Class						
Paraffins (ppbC)	397.83	168.34	37.03	20.71	29.49	130.68
Isoparaffins (ppbC)	54.89	92.69	22.46	4.05	3.71	35.56
Aromatics (ppbC)	57.52	37.04	8.82	1.94	1.63	21.39
Napthlenes (ppbC)	27.21	2.78	0.00	0.00	0.00	6.00
Olefins (ppbC)	6.82	13.39	1.15	2.97	2.58	5.38
Oxygenates (ppbC)	0.00	0.00	0.00	0.70	0.00	0.14
Total Identified (ppbC)	544.27	314.24	69.46	30.37	37.41	199.15

Table 4-10 VOC Concentration and Summary Data for Samples Collected at Big Piney

Compound	Sample Dates				Average
	16-Jan	8-Mar	9-Mar	10-Mar	
Acetylene (ppbV)	1.71	--	--	0.25	0.49
Ethane (ppbV)	42.44	7.38	13.69	6.21	17.43
Propane (ppbV)	24.45	3.71	8.77	2.63	9.89
i-Butane (ppbV)	--	0.61	1.68	0.36	0.66
n-Butane (ppbV)	9.69	0.46	2.22	0.69	3.27
t-2-Butene (ppbV)	--	--	0.09	--	0.02
i-Pentane (ppbV)	3.72	--	--	--	0.93
n-Pentane (ppbV)	2.64	--	0.53	0.68	0.96
c-2-Pentene (ppbV)	--	--	--	0.55	0.14
2-Methylpentane (ppbV)	0.92	--	--	--	0.23
n-Hexane (ppbV)	1.89	--	0.11	0.21	0.55
Methylcyclopentane (ppbV)	0.61	--	--	--	0.15
Benzene (ppbV)	1.35	--	--	--	0.34
Cyclohexane (ppbV)	0.87	--	--	--	0.22
n-Heptane (ppbV)	0.67	--	--	--	0.17
Methylcyclohexane (ppbV)	1.50	--	--	--	0.38
Toluene (ppbV)	0.82	0.06	0.24	--	0.28
2-Methylheptane (ppbV)	--	--	0.15	--	0.04
m,p-xylene (ppbV)	0.55	--	0.12	--	0.17
o-xylene (ppbV)	--	0.32	--	--	0.08
Combined Compound Class					
Paraffins (ppbC)	226.13	27.72	65.84	27.69	86.85
Isoparaffins (ppbC)	24.13	2.45	7.94	1.45	8.99
Aromatics (ppbC)	18.31	2.94	2.64	0.02	5.98
Napthlenes (ppbC)	19.43	0.00	0.00	0.00	4.86
Olefins (ppbC)	3.43	0.00	0.34	3.24	1.75
Oxygenates (ppbC)	0.00	0.00	0.00	0.00	0.00
Total Identified (ppbC)	291.43	33.11	76.76	32.40	108.43

Table 4-11 VOC Concentration and Summary Data for Samples Collected at Jonah Field

Compound	Sample Dates				Average
	16-Jan	8-Mar	9-Mar	10-Mar	
Ethene (ppbV)	1.96	--	0.56	1.17	0.92
Acetylene (ppbV)	2.87	--	2.50	1.20	1.64
Ethane (ppbV)	241.98	39.84	10.18	78.83	92.71
Propene (ppbV)	--	--	0.37	--	0.09
Propane (ppbV)	105.40	17.82	11.15	32.54	41.73
i-Butane (ppbV)	27.21	3.66	2.97	7.09	10.23
n-Butane (ppbV)	31.07	4.83	3.54	9.50	12.24
t-2-Butene (ppbV)	--	--	0.16	--	0.04
i-Pentane (ppbV)	13.37	1.42	1.40	--	4.05
n-Pentane (ppbV)	11.66	1.99	1.63	5.01	5.07
2,2-Dimethylbutane (ppbV)	--	--	--	2.91	0.73
2-Methylpentane (ppbV)	4.52	--	0.17	--	1.17
3-Methylpentane (ppbV)	3.42	--	0.69	--	1.03
n-Hexane (ppbV)	5.47	--	0.18	0.22	1.47
Diisopropyl ether (ppbV)	--	--	0.09	--	0.02
3-Methylcyclopentene (ppbV)	--	--	--	0.58	0.15
Methylcyclopentane (ppbV)	0.24	--	0.93	--	0.29
2,4-Dimethylpentane (ppbV)	--	0.86	--	--	0.22
Benzene (ppbV)	6.29	0.32	0.60	--	1.80
Cyclohexane (ppbV)	4.04	--	0.07	--	1.03
2-Methylhexane (ppbV)	1.09	--	0.16	--	0.31
2,3-Dimethylpentane (ppbV)	0.34	--	--	--	0.09
3-Methylhexane (ppbV)	1.08	--	0.51	0.45	0.51
2-Methyl-1hexene (ppbV)	--	--	0.04	--	0.01
2,2,4-Trimethylpentane (ppbV)	0.58	--	0.66	--	0.31
n-Heptane (ppbV)	2.80	--	0.36	--	0.79
Methylcyclohexane (ppbV)	--	--	0.17	1.00	0.29
2,4-Dimethylhexane (ppbV)	0.50	--	--	0.26	0.19
2,3,4-Trimethylpentane (ppbV)	--	--	0.08	0.09	0.04
Toluene (ppbV)	8.30	0.63	1.87	0.22	2.76
2,3-Dimethylhexane (ppbV)	--	--	--	0.06	0.02
4-Methylheptane (ppbV)	--	--	0.10	0.17	0.07
3-Methylheptane (ppbV)	0.52	--	--	--	0.13
n-Octane (ppbV)	1.72	--	--	--	0.43
Ethylbenzene (ppbV)	0.41	--	0.06	0.03	0.13
m,p-xylene (ppbV)	2.60	0.21	0.48	0.93	1.06
o-xylene (ppbV)	0.41	--	0.12	0.10	0.16
n-Nonane (ppbV)	0.61	--	--	0.22	0.21
n-propylbenzene (ppbV)	--	--	--	0.08	0.02
1,3,5-Trimethylbenzene (ppbV)	--	--	0.10	0.03	0.03
1,2,4-Trimethylbenzene (ppbV)	0.37	--	0.21	0.08	0.17
n-Decane (ppbV)	0.26	--	--	--	0.07
1,2,3-Trimethylbenzene (ppbV)	--	--	--	0.08	0.02
Undecane (ppbV)	--	--	--	0.02	0.01
Combined Compound Class					
Paraffins (ppbC)	1057.04	162.38	79.76	321.84	405.26
Isoparaffins (ppbC)	253.72	27.75	35.52	53.69	92.67
Aromatics (ppbC)	126.57	8.00	24.73	12.30	42.90
Napthlenes (ppbC)	25.65	0.00	7.25	10.44	10.84
Olefins (ppbC)	9.66	0.00	8.12	4.75	5.63
Oxygenates (ppbC)	0.00	0.00	0.55	0.00	0.14
Total Identified (ppbC)	1472.64	198.13	155.93	403.02	557.43

Table 4-12 VOC Concentration and Summary Data for Samples Collected at Mesa

Compound	Sample Dates				Average
	16-Jan	8-Mar	9-Mar	10-Mar	
Acetylene (ppbV)	2.51	--	--	1.32	0.96
Ethane (ppbV)	20.93	19.89	7.94	2.88	12.91
Propane (ppbV)	104.21	9.92	2.61	1.19	29.48
i-Butane (ppbV)	22.68	1.85	0.67	0.54	6.44
n-Butane (ppbV)	11.33	2.81	1.46	0.41	4.00
i-Pentane (ppbV)	6.99	0.92	0.52	0.69	2.28
n-Pentane (ppbV)	5.48	1.04	0.35	0.27	1.79
2,2-Dimethylbutane (ppbV)	--	0.86	--	--	0.22
2-Methylpentane (ppbV)	2.71	--	--	--	0.68
3-Methylpentane (ppbV)	1.49	--	--	--	0.37
n-Hexane (ppbV)	4.53	--	0.36	--	1.22
Methylcyclopentane (ppbV)	2.10	0.74	--	--	0.71
Benzene (ppbV)	5.44	0.35	--	--	1.45
Cyclohexane (ppbV)	2.97	--	--	--	0.74
2-Methylhexane (ppbV)	0.96	--	0.15	--	0.28
3-Methylhexane (ppbV)	1.05	--	--	--	0.26
n-Heptane (ppbV)	3.00	--	--	--	0.75
Methylcyclohexane (ppbV)	--	--	0.08	--	0.02
2,4-Dimethylhexane (ppbV)	--	--	0.07	--	0.02
2,3,4-Trimethylpentane (ppbV)	--	--	0.04	--	0.01
Toluene (ppbV)	9.47	1.25	0.21	0.34	2.82
4-Methylheptane (ppbV)	--	--	0.47	--	0.12
n-Octane (ppbV)	1.58	--	--	--	0.40
Ethylbenzene (ppbV)	--	0.07	0.43	--	0.13
m,p-xylene (ppbV)	3.33	0.47	0.72	0.28	1.20
o-xylene (ppbV)	--	0.13	--	--	0.03
n-Nonane (ppbV)	--	--	0.07	0.06	0.03
1,3,5-Trimethylbenzene (ppbV)	--	0.18	0.29	--	0.12
1,2,4-Trimethylbenzene (ppbV)	--	0.21	0.19	--	0.10
n-Decane (ppbV)	--	--	0.13	--	0.03
Combined Compound Class					
Paraffins (ppbC)	488.02	85.95	35.36	12.85	155.55
Isoparaffins (ppbC)	164.88	17.18	10.99	5.61	49.67
Aromatics (ppbC)	125.56	19.78	14.92	4.68	41.24
Napthlenes (ppbC)	30.46	4.43	0.56	0.00	8.86
Olefins (ppbC)	5.01	0.00	0.00	2.64	1.91
Oxygenates (ppbC)	0.00	0.00	0.00	0.00	0.00
Total Identified (ppbC)	813.93	127.34	61.83	25.78	257.22

Table 4-13 VOC Concentration and Summary Data for Samples Collected at Paradise

Compound	Sample Dates				Average
	16-Jan	8-Mar	9-Mar	10-Mar	
Ethene (ppbV)	--	--	1.20	1.56	0.69
Acetylene (ppbV)	--	0.26	1.57	0.53	0.59
Ethane (ppbV)	154.01	14.06	57.19	47.87	68.28
Propene (ppbV)	0.93	--	--	--	0.23
Propane (ppbV)	69.36	3.51	23.23	51.98	37.02
i-Butane (ppbV)	1.05	1.29	4.61	9.59	4.14
n-Butane (ppbV)	16.63	1.70	5.92	17.78	10.51
i-Pentane (ppbV)	13.33	1.55	1.87	4.03	5.20
n-Pentane (ppbV)	6.44	0.79	1.34	4.10	3.17
2,2-Dimethylbutane (ppbV)	--	--	--	0.06	0.02
Cyclopentane (ppbV)	--	--	--	0.29	0.07
2-Methylpentane (ppbV)	2.00	--	--	1.00	0.75
3-Methylpentane (ppbV)	1.47	0.07	--	0.58	0.53
n-Hexane (ppbV)	3.23	0.22	0.35	0.58	1.10
3-Methylcyclopentene (ppbV)	--	--	0.94	--	0.24
Methylcyclopentane (ppbV)	1.54	0.08	0.32	--	0.49
Benzene (ppbV)	4.12	0.06	--	0.78	1.24
Cyclohexane (ppbV)	2.30	--	--	--	0.58
2-Methylhexane (ppbV)	0.94	0.23	--	--	0.29
2,3-Dimethylpentane (ppbV)	--	--	0.38	--	0.10
3-Methylhexane (ppbV)	1.23	0.32	--	--	0.39
2,2,4-Trimethylpentane (ppbV)	--	0.07	--	--	0.02
n-Heptane (ppbV)	1.74	--	--	0.51	0.56
Methylcyclohexane (ppbV)	3.45	--	0.23	--	0.92
2,5-Dimethylhexane (ppbV)	--	0.07	--	--	0.02
2,4-Dimethylhexane (ppbV)	--	0.17	0.16	0.33	0.17
2,3,4-Trimethylpentane (ppbV)	--	--	0.16	--	0.04
Toluene (ppbV)	3.87	0.20	0.73	1.63	1.61
4-Methylheptane (ppbV)	0.75	--	--	--	0.19
n-Octane (ppbV)	--	--	--	0.21	0.05
Ethylbenzene (ppbV)	--	0.05	0.24	--	0.07
m,p-xylene (ppbV)	--	0.13	0.74	1.30	0.54
o-xylene (ppbV)	--	0.15	0.15	0.45	0.19
n-Nonane (ppbV)	--	--	0.04	0.19	0.06
n-propylbenzene (ppbV)	--	--	0.10	--	0.03
1,3,5-Trimethylbenzene (ppbV)	--	0.06	0.83	0.25	0.29
1,2,4-Trimethylbenzene (ppbV)	--	0.08	--	0.32	0.10
n-Decane (ppbV)	--	--	0.03	--	0.01
1,2,3-Trimethylbenzene (ppbV)	--	--	0.50	0.44	0.24
Undecane (ppbV)	--	0.09	--	--	0.02
Dodecane (ppbV)	--	0.09	--	0.07	0.04
Combined Compound Class					
Paraffins (ppbC)	646.42	52.87	217.26	354.66	317.80
Isoparaffins (ppbC)	112.87	19.65	32.97	70.99	59.12
Aromatics (ppbC)	51.87	5.63	27.09	39.25	30.96
Napthlenes (ppbC)	47.23	0.48	9.14	1.47	14.58
Olefins (ppbC)	2.78	0.53	5.53	4.17	3.25
Oxygenates (ppbC)	0.00	0.00	0.00	0.00	0.00
Total Identified (ppbC)	861.17	79.16	291.99	470.54	425.72

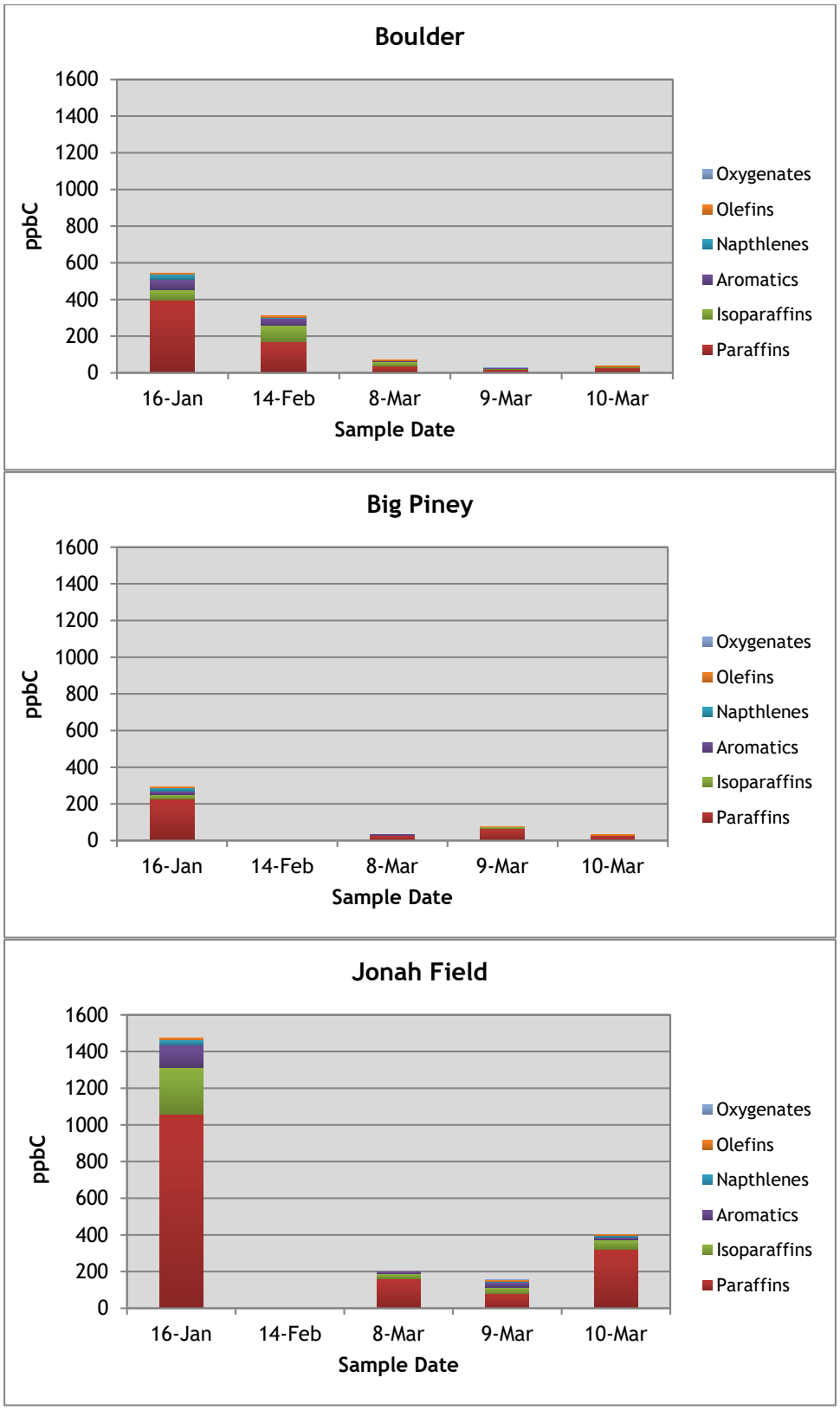

Figure 4.13 VOC Concentrations from Canisters Collected at Boulder, Big Piney, and Jonah Field

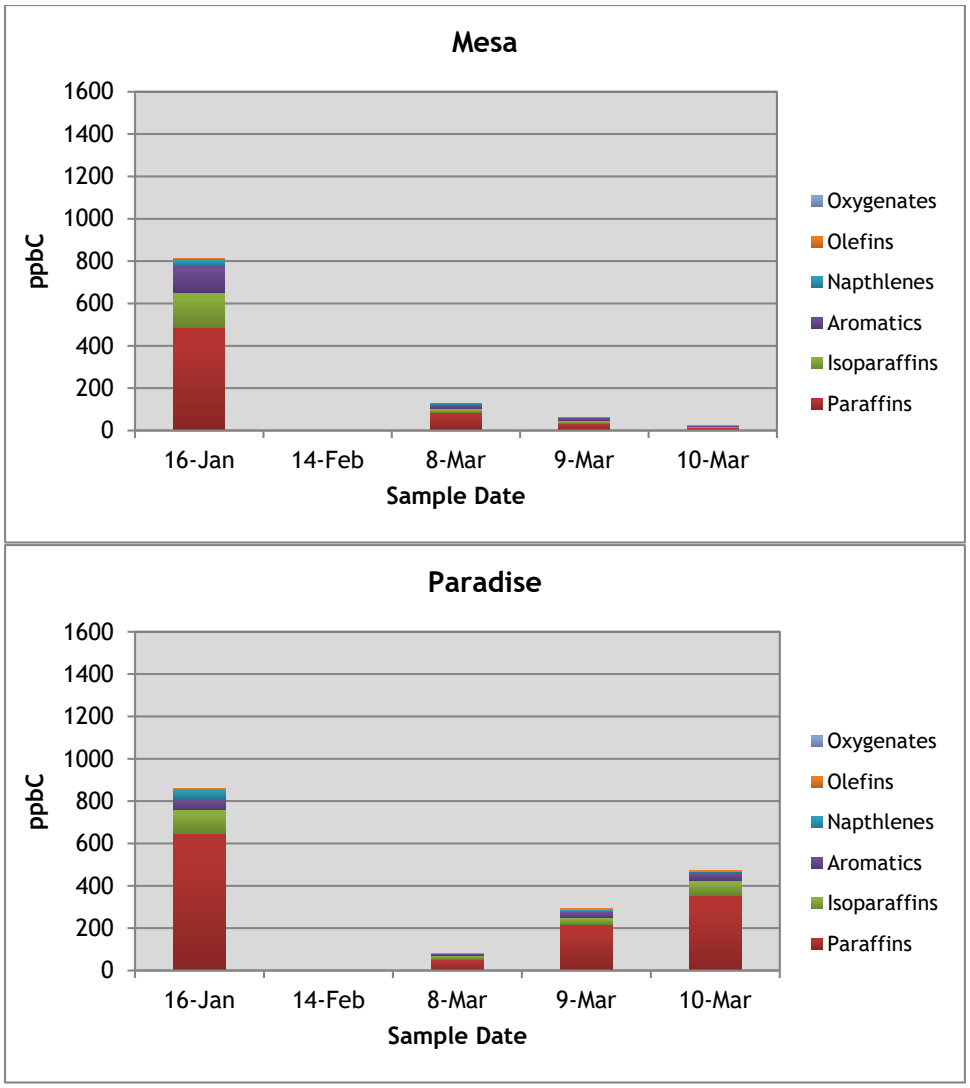

Figure 4.14 VOC Concentrations from Canisters Collected at Mesa and Paradise

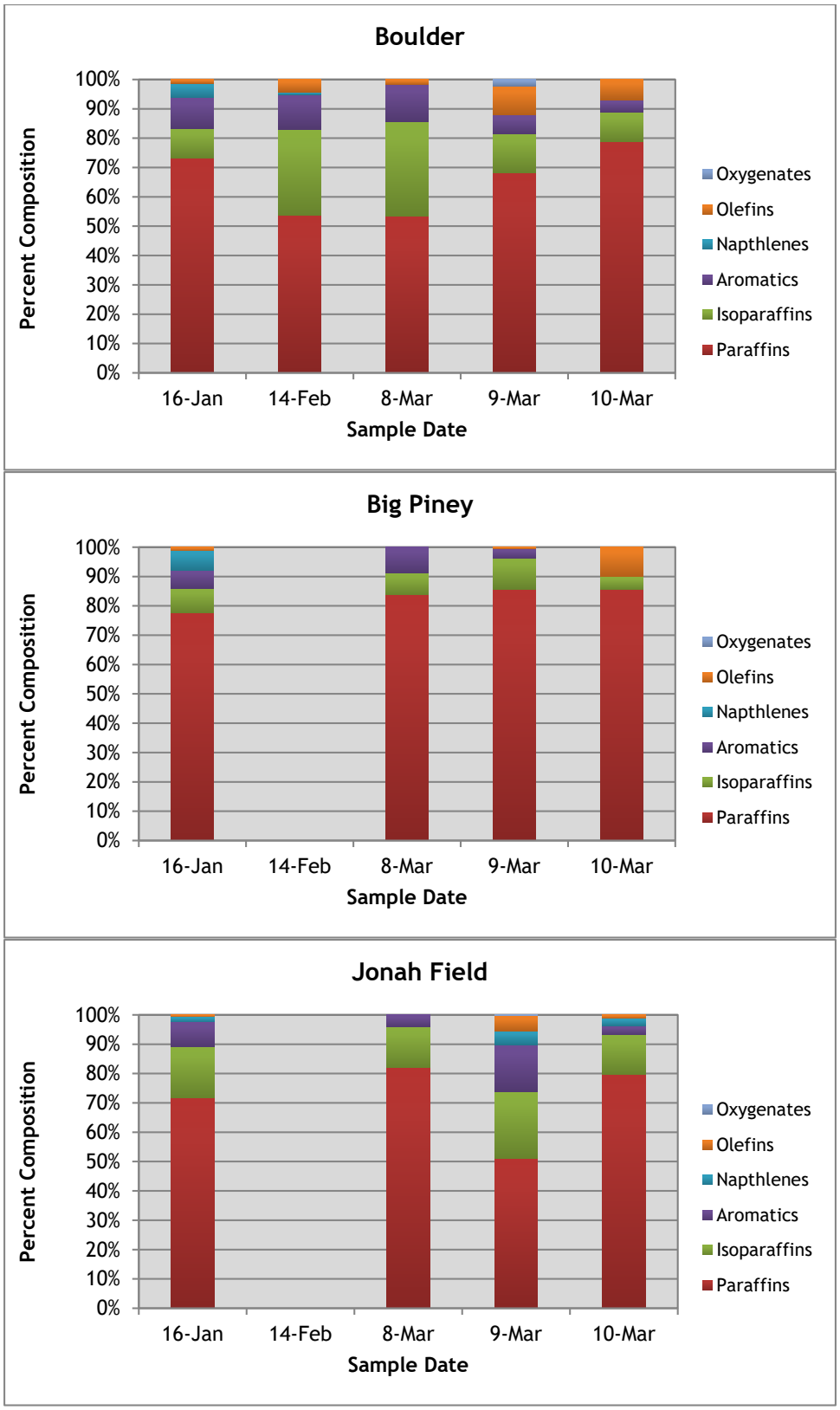

Figure 4.15 Relative Composition from Canisters Collected at Boulder, Big Piney, and Jonah Field

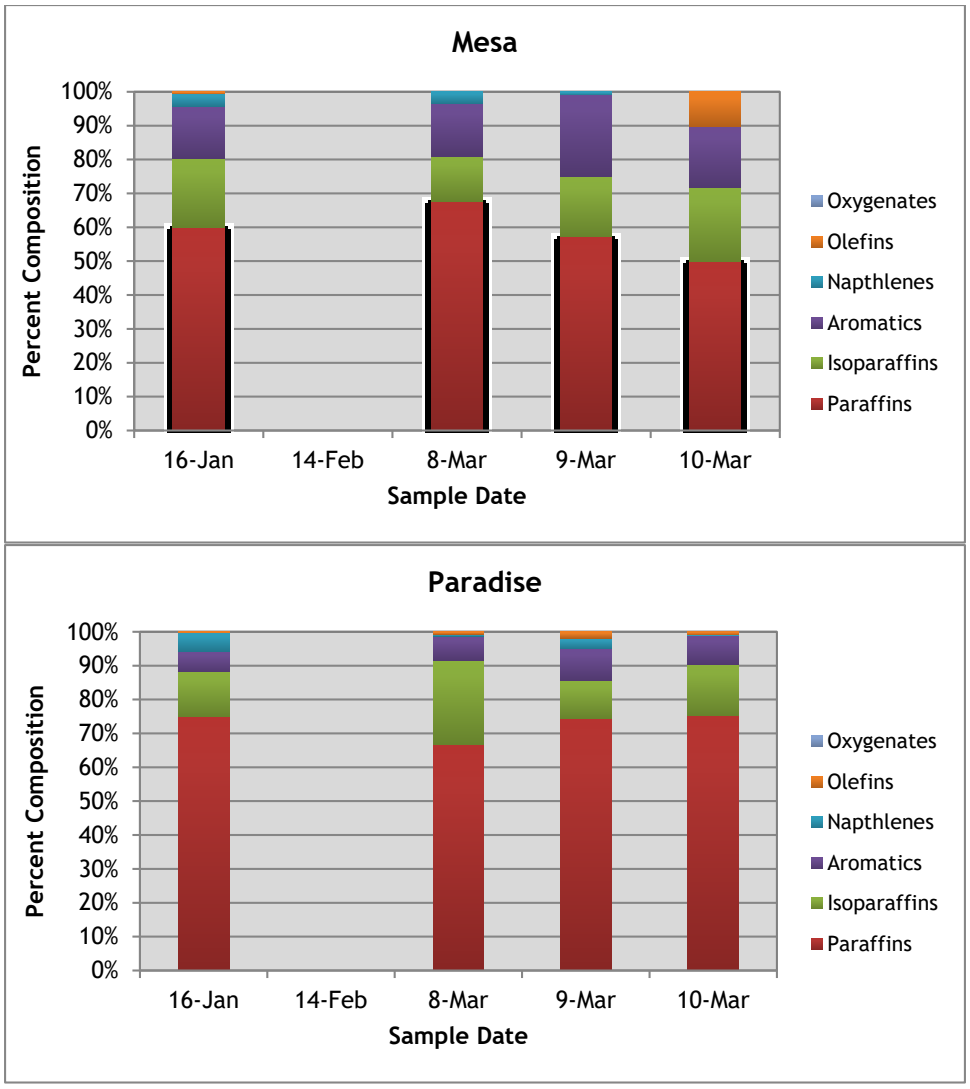

Figure 4.16 Relative Composition from Canisters Collected at Mesa and Paradise

VOC samples collected on January 16 at the Jonah Field were observed to have the highest total non-methane hydrocarbon concentrations at 278.4 ppbV (1472.6 ppbC of total identified compounds) of any of the sampling sites. Throughout the study, Jonah and Paradise regularly had the highest concentrations in the basin. This is to be expected given the relative location of these sites to oil and gas development. Figure 4.17 presents the 2015 study average sample composition by site.

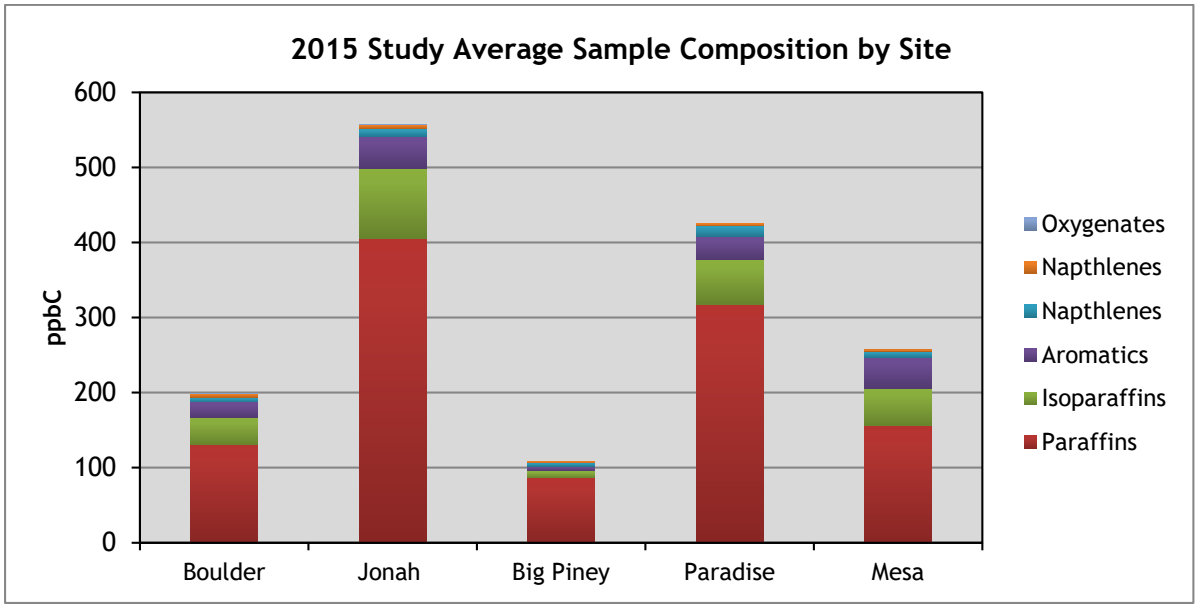

Figure 4.17 2015 Study Average Sample Composition by Site

4.3.2 Carbonyl Samples

Carbonyl samples were collected concurrently with canister samples using DNPH-coated cartridges outfitted with ozone scrubbers and connected to constant flow pump systems. Table 4-14 presents the concentration data and average concentrations for carbonyl samples collected throughout the study period. Figures 4.18 and 4.19 present a summary of the formaldehyde and acetaldehyde concentrations measured at each of the five sampling locations. Dates in which samples were taken are shown on the x-axis and are presented in chronological order to compare site concentrations throughout the study period.

Table 4-14 Carbonyl Sample Concentrations by Site and Date

Compound	Sample Dates				Average
	16-Jan	8-Mar	9-Mar	10-Mar	
Boulder					
Formaldehyde (ppbV)	1.16	1.82	1.09	1.29	1.34
Acetaldehyde (ppbV)	0.70	0.67	0.52	0.50	0.60
Big Piney					
Formaldehyde (ppbV)	0.98	0.55	0.73	1.26	0.88
Acetaldehyde (ppbV)	0.86	0.30	0.54	0.61	0.58
Jonah					
Formaldehyde (ppbV)	0.93	1.13	0.81	2.76	1.41
Acetaldehyde (ppbV)	0.97	0.42	0.29	0.49	0.54
Mesa					
Formaldehyde (ppbV)	4.01	1.30	1.28	1.56	2.04
Acetaldehyde (ppbV)	0.70	0.50	0.29	0.30	0.45
Paradise					
Formaldehyde (ppbV)	0.95	2.00	1.24	1.25	1.36
Acetaldehyde (ppbV)	1.69	0.54	0.44	0.37	0.76

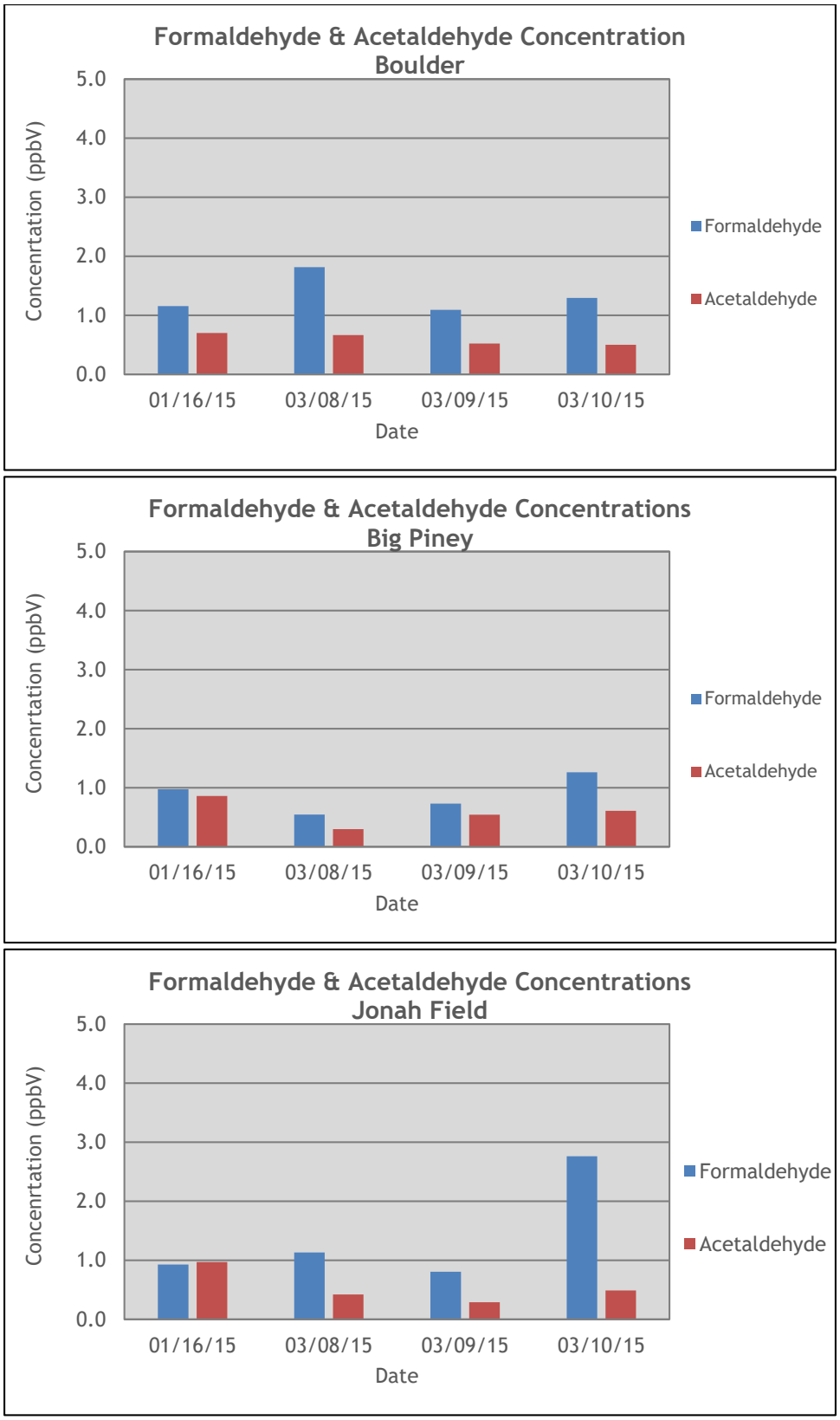

Figure 4.18 Formaldehyde and Acetaldehyde Concentrations at Big Piney, Boulder, and Jonah Field

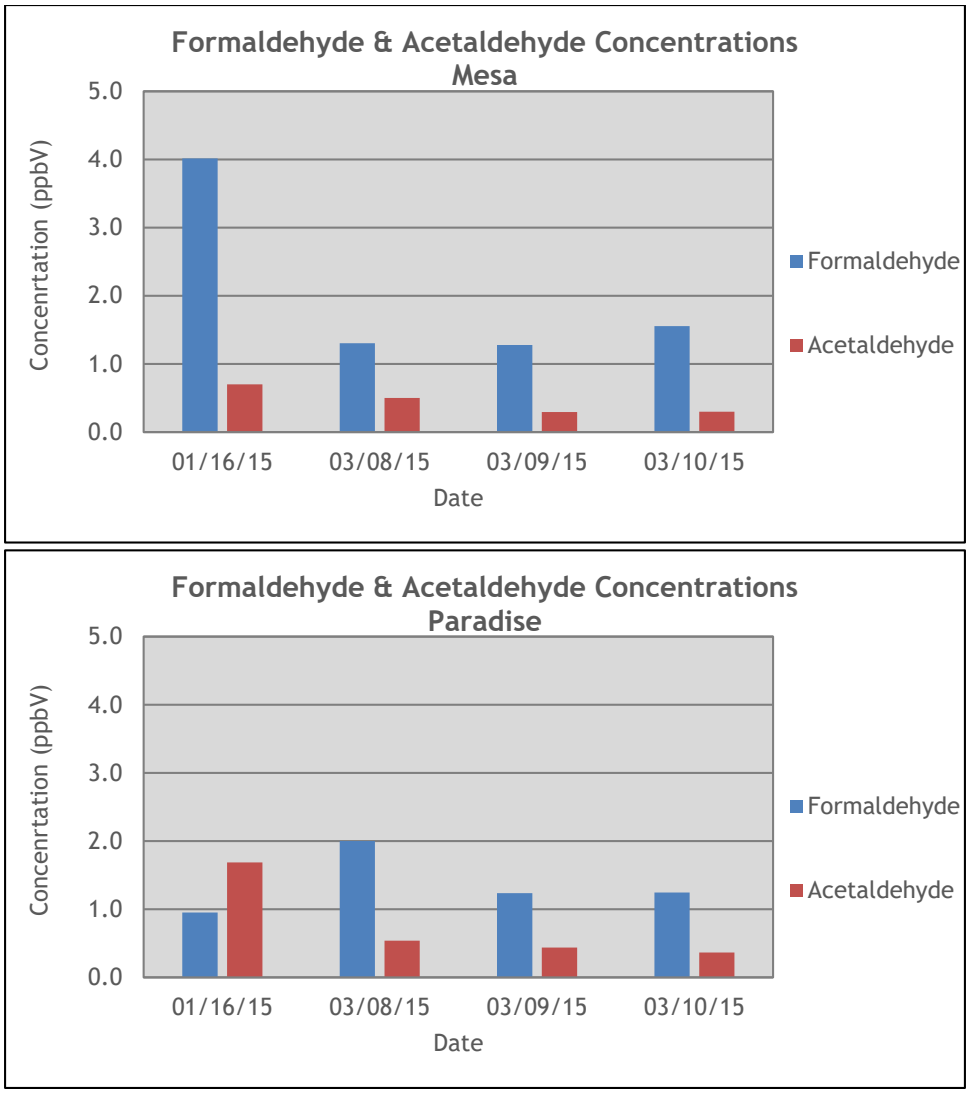

Figure 4.19 Formaldehyde and Acetaldehyde Concentrations at Mesa and Paradise

4.3.3 Top VOC Compounds and Maximum Incremental Reactivity Analysis

Average concentrations of VOC species at each sampling site and weighted maximum incremental reactivity (MIR) average, sorted left to right on decreasing unweighted average concentrations are presented in Figures 4.20 through 4.24. MIR weighted (Carter 2009) concentrations reflect the relative importance of available VOC species on the formation of ground-level ozone. Potential ozone formation from VOC concentrations is calculated by multiplying the compound specific MIR value by the concentration of the corresponding compound.

The most abundant compounds were observed to be paraffins, which, given their low reactivities, were not as significant as toluene and m, p-xylenes which were often the most reactive compounds measured in the basin.

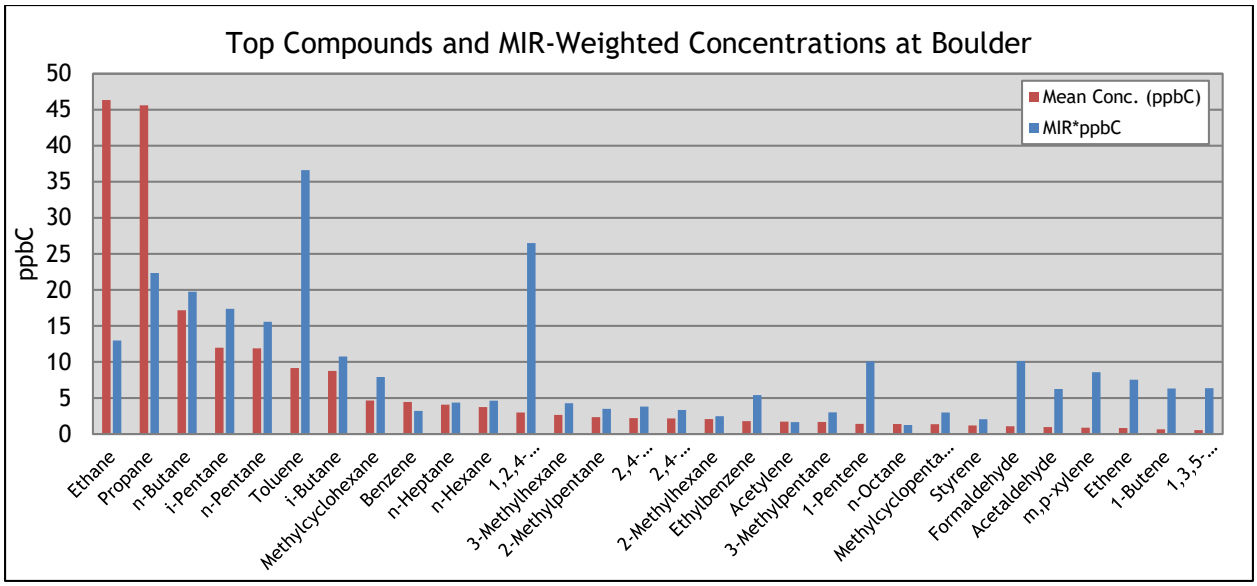

Figure 4.20 Average Concentration (in ppbC) and MIR Weighted Concentrations for Boulder

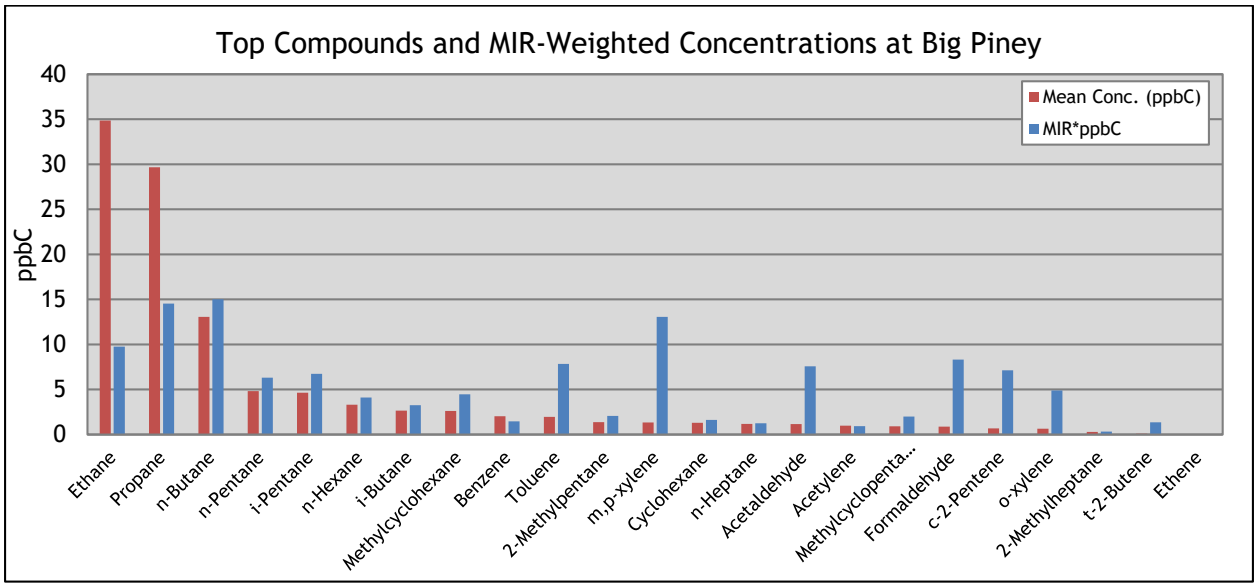

Figure 4.21 Average Concentration (in ppbC) and MIR Weighted Concentrations for Big Piney

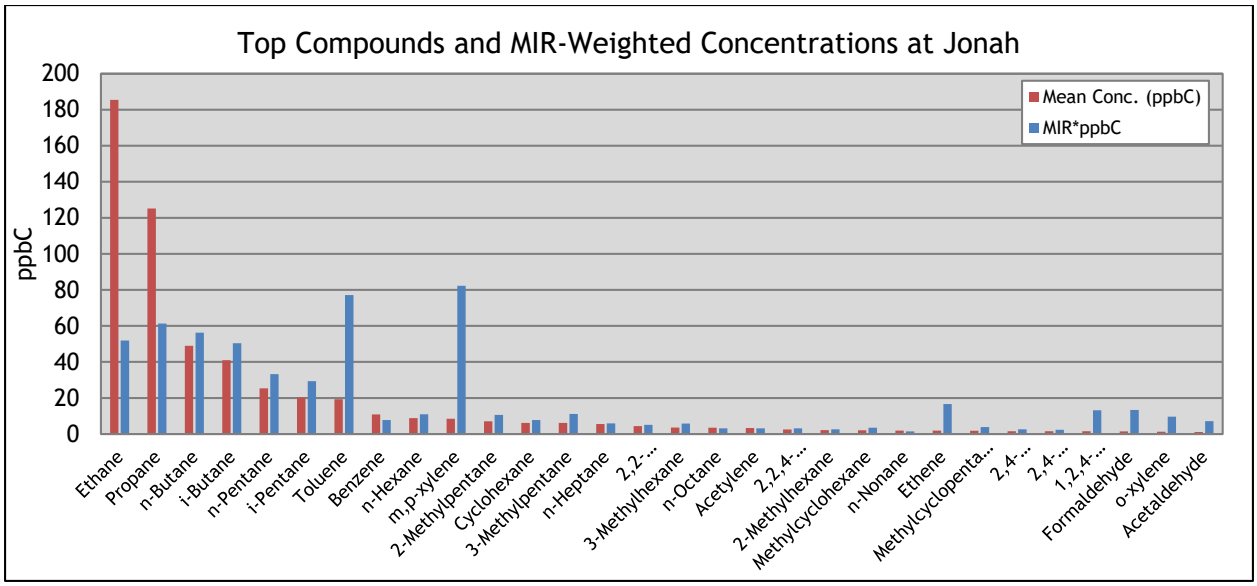

Figure 4.22 Average Concentration (in ppbC) and MIR Weighted Concentrations for Jonah Field

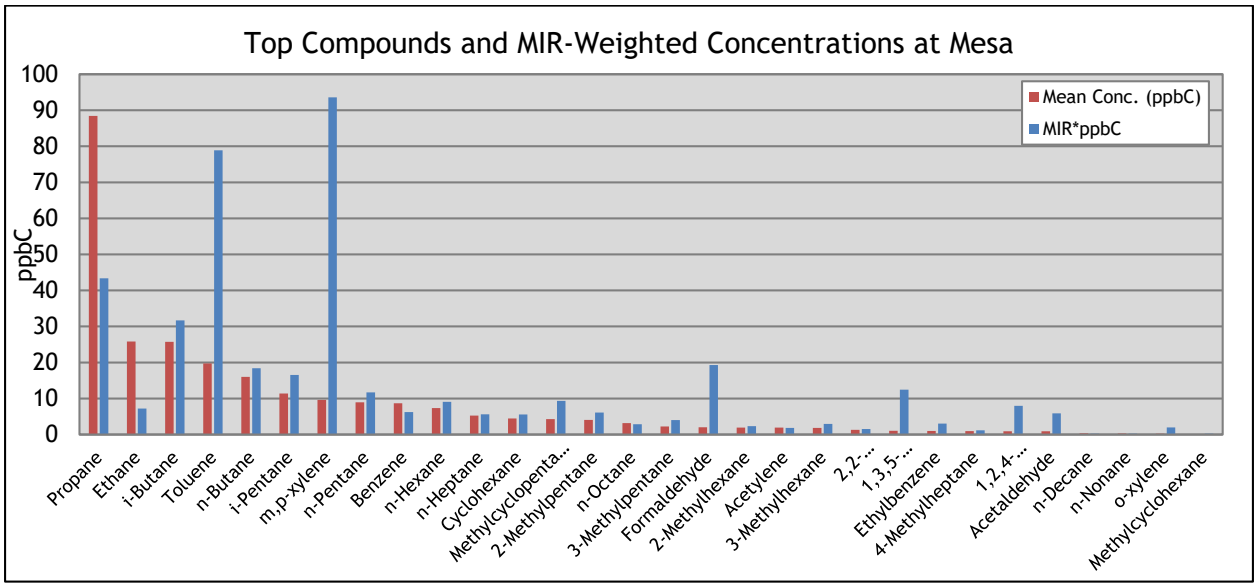

Figure 4.23 Average Concentration (in ppbC) and MIR Weighted Concentrations for Mesa

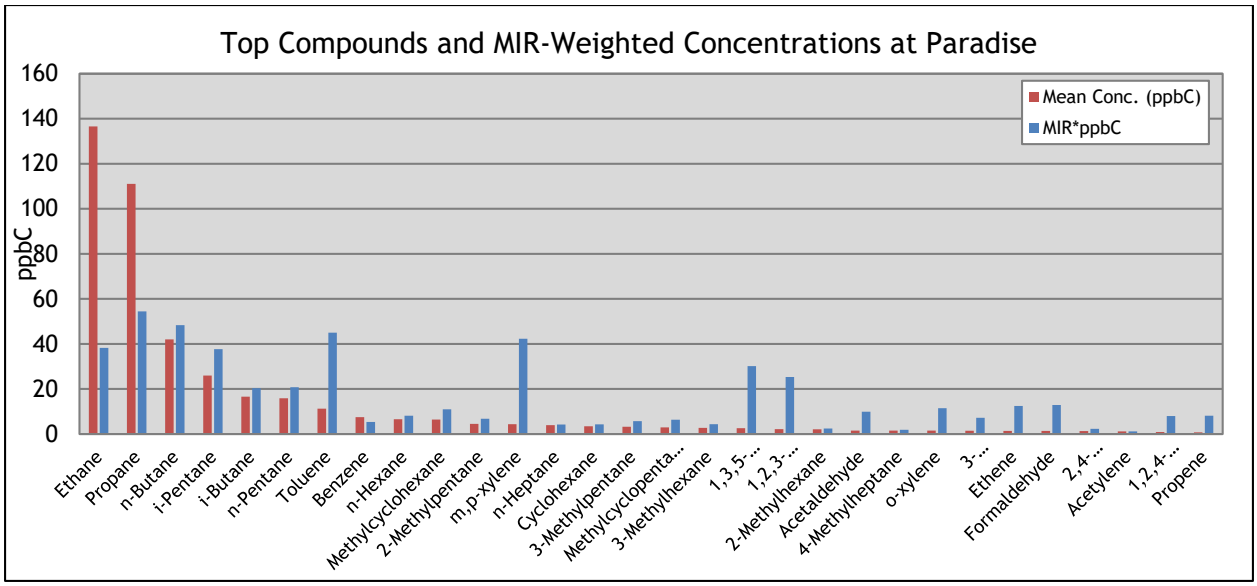

Figure 4.24 Average Concentration (in ppbC) and MIR Weighted Concentrations for Paradise

4.3.4 Comparison of VOC Measurements to Previous Study Years

This section compares VOC measurements made at the five 2015 sampling locations (Boulder, Big Piney, Jonah, Mesa, and Paradise) to historical measurements made in 2007, 2008, 2009, 2012, 2013, and 2014. VOC samples have been collected on and off through the study years. Of the VOC sampling sites in 2015, Boulder and Jonah are the only sites which have VOC data from the 2007, 2008, 2009, 2012, and 2013 campaigns. Big Piney collected VOC samples in 2012 through 2015. Due to site power availability, the Jonah site changed locations between the 2012 and 2013 campaigns and was moved approximately 3.75 miles west from the 2012 location.

There were four (4) designated sampling days in 2015 (January 16, March 8, March 9, and March 10). In addition, the automated canister sampling system pulled a sample on February 14. Average concentrations for each of the five hydrocarbon categories (Paraffins, Isoparaffins, Aromatics, Napthlenes, and Olefins) and oxygenates were evaluated. VOC samples were scheduled based on forecast conditions as described in Section 2.3. The average concentrations of each hydrocarbon category were considered to be a representative distribution of VOCs by study year when predefined forecast conditions were met. Figures 4.25 through 4.29 present distribution of VOCs, by year, for each sampling site from 2007 to 2015.

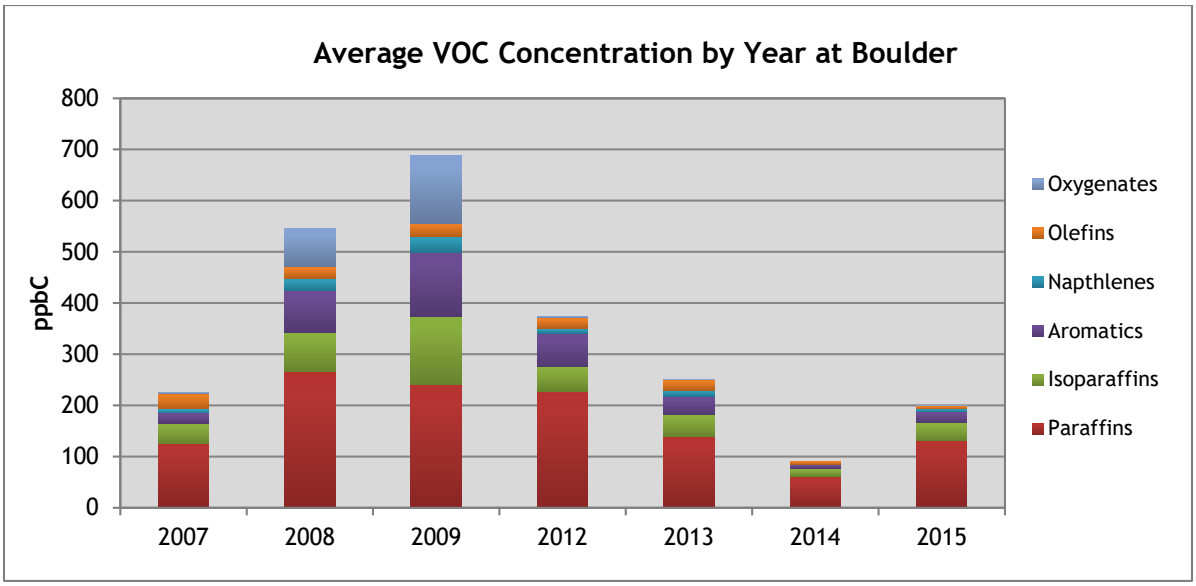

Figure 4.25 VOC Distribution by Study Year at Boulder

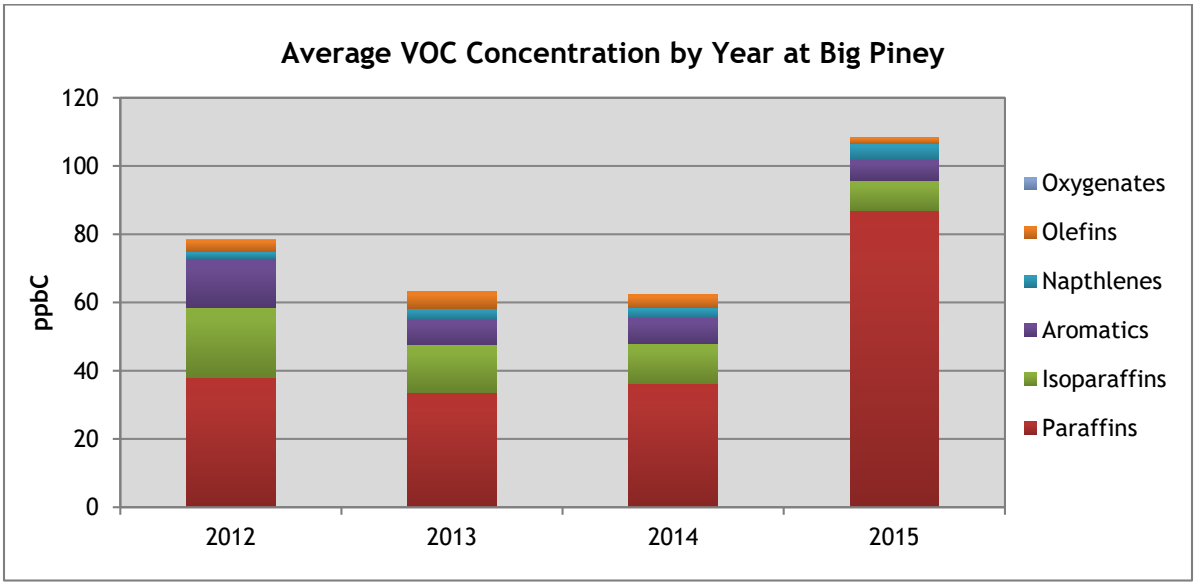

Figure 4.26 VOC Distribution by Study Year at Big Piney

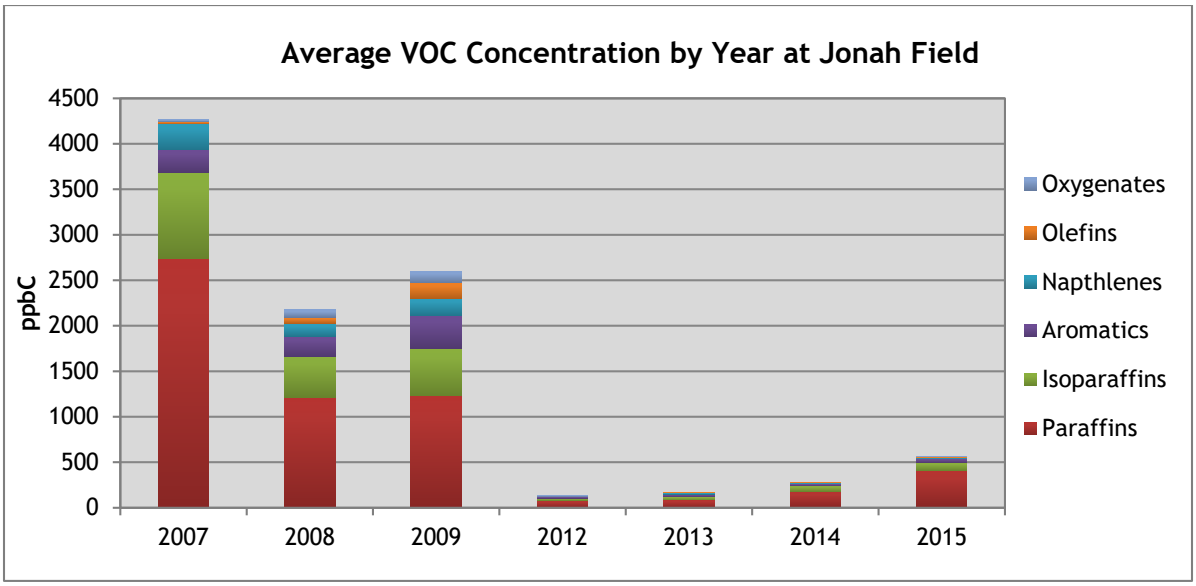

Figure 4.27 VOC Distribution by Study Year at Jonah Field

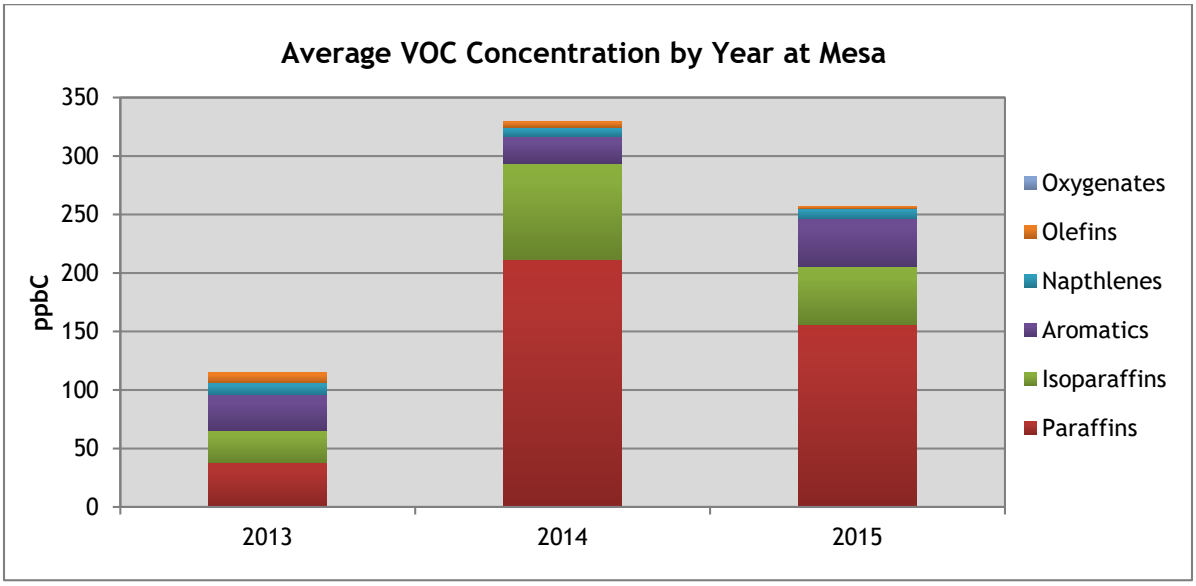

Figure 4.28 VOC Distribution by Study Year at Mesa

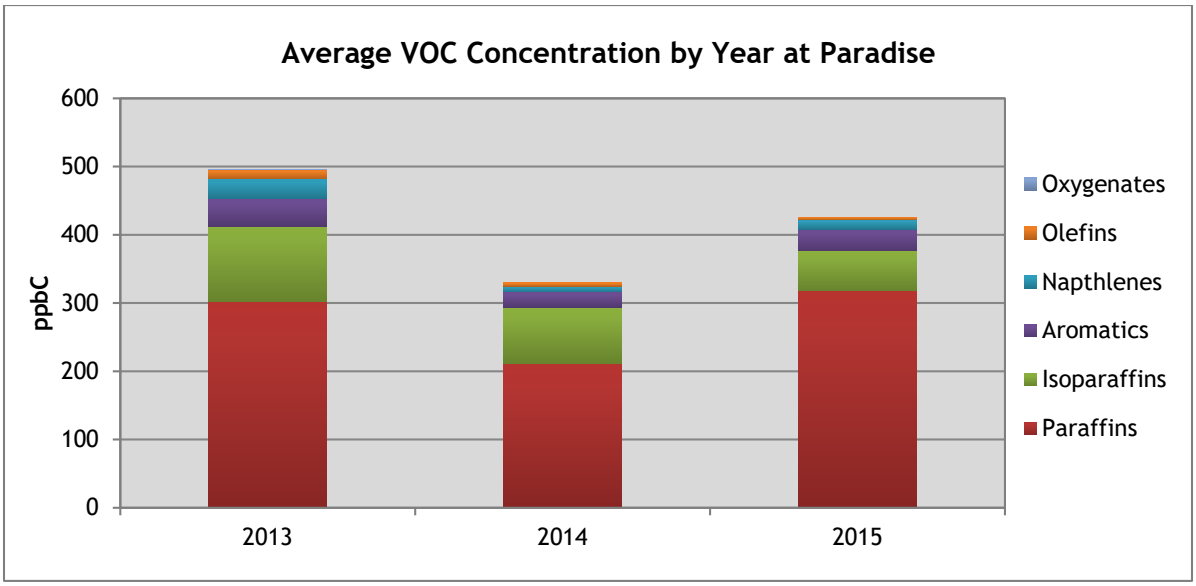

Figure 4.29 VOC Distribution by Study Year at Paradise

Historical concentrations at Boulder and Jonah show that VOCs measured during UGWOS 2015 were still much lower than concentrations measured in earlier UGWOS study years (2007, 2008, and 2009). However, with the exception of Mesa sampling location, VOC concentrations were higher than those measured during the 2014 study year. Although VOC concentrations were higher at Big Piney then seen in previous years, sample concentrations at Big Piney have been consistently very low when compared to stations located in the northeastern portion of the basin. Jonah and Paradise, located in the heart of oil and gas operations, measured the highest concentrations of VOCs during the 2015 study.

4.3.5 VOC Quality Control Results

Throughout the study period, collocated canister samples were taken to reduce uncertainty in concentration measurements. A separate tripod containing an identical canister sampling system was collocated at two different VOC canister sites (Mesa and Big Piney) once during the study period. Figures 4.30 and 4.31 present summaries of the collocated sample results collected on March 8 at Mesa and March 9 at Big Piney. The results of the collocated canisters show differences in total NMHC of 1.8 percent and 26.2 percent, respectively. The high percent difference at Big Piney on March 9 was a result of low concentrations and the duplicate sampler measuring higher concentrations of ethane and propane.

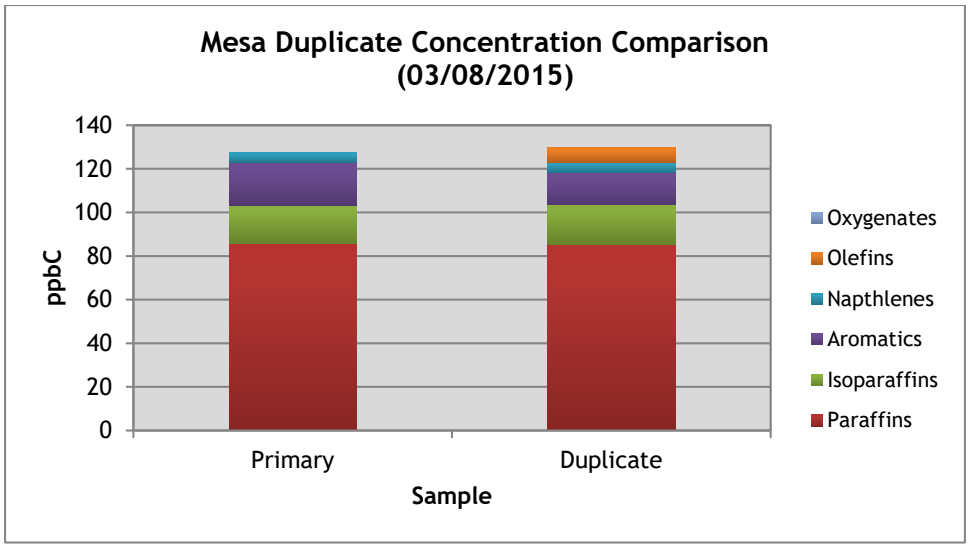

Figure 4.30 Collocated Sample Comparison from Mesa

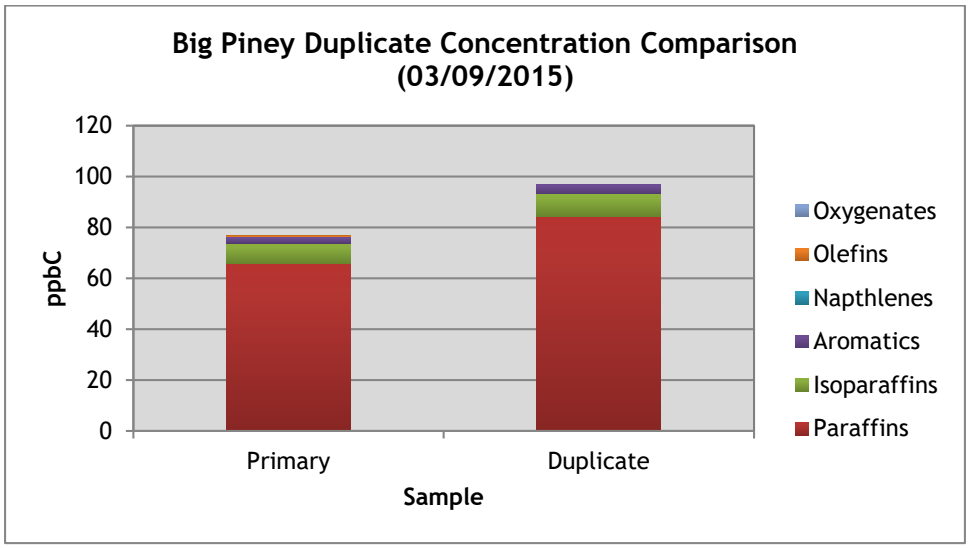

Figure 4.31 Collocated Sample Comparison from Big Piney

5.0 SUMMARY AND CONCLUSIONS

This section provides a summary of the UGWOS 2015 field measurement effort (January 15 through March 31, 2015), and observations and conclusions drawn from the data obtained during the study.

5.1 Summary

WDEQ-AQD has sponsored the Upper Green Winter Ozone Study (UGWOS) every year since 2007 in order to better understand the meteorological and chemical processes active in wintertime ozone production in Wyoming's Upper Green River Basin and to provide information leading to the development of effective mitigation strategies. Ozone formation mechanisms were the focus during the 2007-2009 studies. The 2010 study focused on monitoring spatial and temporal patterns of ozone and meteorology. Investigation of the vertical distribution of ozone and ozone precursors was the main objective of the 2011 effort. The 2012-2014 field measurement campaigns focused on the spatial distribution of ozone and ozone precursors using existing long-term monitoring stations, mobile trailers at Big Piney and Jonah Field with the addition of three mesonet sites and speciated VOC canister sampling systems at select monitoring sites. The 2015 campaign again focused on the spatial distribution of ozone and ozone precursors with the utilization of three mesonet sites. Speciated VOC canister samples as well as carbonyl samples for measurement of formaldehyde and acetaldehyde were collected at five sampling locations (Boulder, Big Piney, Mesa, Paradise, and Jonah Field).

The synoptic weather pattern during UGWOS 2015 was dominated by an upper-level ridge over the western continental United States and a trough over eastern United States. The ridge kept temperatures warmer than normal and deflected Pacific weather systems north keeping much of southern and central portions of the west coast very dry. Resultant flow experienced in southwestern Wyoming from this pattern was generally from the west to northwest, with dry conditions and warmer than normal temperatures.

During the UGWOS 2015 field season, there were no days when 8-hour ozone concentrations above the current EPA standard of 75 ppb were observed at any of the monitoring stations in the UGRB. The highest eight-hour ozone concentration for any site was 61 ppb which was observed at the Moxa Arch site on March 31, 2015. Although favorable conditions for ozone production never materialized, WDEQ-AQD designated four days for VOC sampling (January 16, March 8, March 9, and March 10).

5.1.1 UGWOS 2015 Field Operations

In contrast to previous years, daily weather and ozone outlook forecasts were not issued for UGWOS 2015. With assistance from MSI Trinity meteorologists, WDEQ designated VOC canister sampling days when conditions favoring elevated ozone events were expected. When a sampling day was determined, a MSI Trinity technician was deployed to prepare VOC canisters for sampling.

MSI Trinity hosted an UGWOS project website which provided access to continuously updated ozone and meteorological data, images remotely retrieved from monitoring sites, daily weather/ozone forecasts, and current equipment and data collection status.

UGWOS field operations in 2015 included three solar-powered mesonet sites located at sites utilized for measurements during previous UGWOS programs (Mesa, Paradise, and Jonah Field). Mesonet sites provided meteorological measurements, camera images and hosted VOC sampler equipment. Camera images from these temporary sites and from the WDEQ long-term monitoring sites in the study area (some with graduated snow sticks in the foreground) provided continually updated snow cover information.

Solar-powered tripod-mounted VOC canister sampling systems were set up to be operated simultaneously during designated sampling days at five monitoring sites. VOC monitoring sites included Big Piney, Boulder, Mesa, Paradise, and Jonah Field.

Existing WDEQ-AQD long-term monitoring stations (Big Piney, Boulder, Daniel, Pinedale, Juel Springs, South Pass, and Moxa Arch) provided surface air quality and meteorological measurements during the UGWOS field effort. The Boulder monitoring site is equipped with specialized measurements to further characterize the role of ozone precursors during ozone formation. Specialized measurements for reactive nitrogen species included trace level NO_y and "true NO_2." The NO_y analyzer is designed to measure oxides of nitrogen compounds that are too unstable to be measured when brought in through a conventional air sampling inlet system. The "true NO_2" measurements utilize a highly selective photolytic converter which allows for better speciation of lower levels of NO_2 than conventional oxides of nitrogen analyzers. In addition, Boulder measures total hydrocarbons which include methane and non-methane hydrocarbons.

During UGWOS 2015, conditions which favor elevated ambient ozone concentrations never materialized. VOC canister samples were collected on designated sampling days (January 16, March 8, March 9, and March 10) characterized by high pressure, sunny skies and light winds.

5.2 Conclusions/Observations

The following conclusions/observations are made based on an analysis of the UGWOS 2015 field study data:

- A dominant high pressure system located over the Pacific coast kept the jet stream centered north of the study area. This pattern kept much of the UGRB warmer than normal and suppressed the formation of significant temperature inversions.
- Snowpack at the beginning of the study was deeper than in recent study years. However, very little snow fell during the study period and snow cover quickly diminished with very little to no snow cover throughout the basin during the study period.
- Monthly average 8-hour ozone concentrations were generally below average and maximum 8-hour concentrations were low compared with those of previous UGWOS study years.
- The highest 8-hour ozone concentration recorded during the UGWOS 2015 study was 61 ppb which is well below the current U.S. EPA NAAQS of 75 ppb.
- With the exception of Mesa, overall sampled VOC concentrations were higher than observed in 2014. As expected due to location relative to active natural gas production operations, Jonah Field and Paradise measured the highest concentrations of total non-methane hydrocarbons in the study area.
- VOC canister sample results again showed relatively low concentrations (although overall higher than measurements taken in 2014) as might be expected given the lack of inversion formation to trap ozone precursors in the basin. The relative composition of VOC groups (paraffins, oxygenates, etc.) was similar to samples collected during previous UGWOS years. Toluene and m,p-xylene were the highest measured MIR-weighted compounds in the UGRB.
- UV radiation sensors at the Boulder site recorded lower daily average outgoing (reflected) UV radiation in 2015 than in previous UGWOS studies. This is consistent with the diminished snow cover during 2015 and implies that less UV radiation would be available for photolytic ozone production.

6.0 ACKNOWLEDGMENTS

Many individuals and groups in addition to the staff of MSI Trinity contributed to the successful completion of the 2015 Upper Green River Winter Ozone Study and its presentation in this report. Cara Keslar, serving as Project Manager for the WDEQ arranged funding, interfaced with Federal and State agencies and other WDEQ contractors, managed contracting details, and provided helpful direction, guidance and comments throughout the study. Many other WDEQ personnel provided assistance and were helpful in making 2015 a successful study. ARS provided meteorological and air quality data they were collecting for the WDEQ at the Daniel and South Pass sites.

7.0 REFERENCES

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Carter, W. P. L. (2009, Revised 2010), *Development of the SAPRC-07 Chemical Mechanism and Updated Ozone Reactivity Scales.*

APPENDIX A

Monitoring and Quality Assurance Plan

QUALITY ASSURANCE PROJECT PLAN FOR THE UPPER GREEN RIVER WINTER OZONE STUDY 2015

Prepared for:

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By

Meteorological Solutions Inc.
Project No. 011514127

January 2015

Revision 0

Meteorological Solutions Inc.
A Trinity Consultants Company

QUALITY ASSURANCE PROJECT PLAN
FOR THE UPPER GREEN RIVER
WINTER OZONE STUDY 2015

UGWOS 2015 QAPP APPROVAL

Ms. Cara Keslar UGWOS Project Manager Wyoming DEQ-AQD	Date
Mr. Steve Mugg Quality Assurance Coordinator Wyoming DEQ-AQD	Date
Mr. George Wilkerson UGWOS Project Director MSI Trinity	Date
Mr. Casey Lenhart UGWOS Field Manager MSI Trinity	Date
Ms. Linda Conger UGWOS Quality Assurance Coordinator MSI Trinity	Date

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SECTION 1.0 INTRODUCTION AND PROJECT OVERVIEW

This monitoring and quality assurance plan prepared for the Wyoming Department of Environmental Quality (WDEQ) Air Quality Division (AQD) provides the basis for the collection of air quality and meteorological data for the Upper Green River Winter Ozone Study (UGWOS) for the winter of 2015 (January 15 through March 31). While research in nature, the monitoring methods and objectives described in this plan are consistent whenever possible with U.S. Environmental Protection Agency (EPA) quality assurance guidance for the collection of air quality and meteorological data (US EPA 2008a and 2008b) and the most recent guidance for the collection of meteorological data for regulatory modeling applications (US EPA, 2000).

Over the past several years, high ozone events have been observed which have raised concerns regarding potential adverse health and ecological effects associated with monitored concentrations greater than the U.S. EPA's current eight-hour ozone standard of 0.075 ppm. Ozone formation in the Upper Green River Basin is unusual in that the highest concentrations have been recorded during the late winter and early spring (February to April) when sun angles are relatively low and temperatures are generally below freezing. This is in stark contrast to ozone exceedances in other areas, which occur during the warm summer months when abundant solar radiation and high temperatures act to increase precursor emissions and enhance the atmospheric reactions that result in ozone formation near the earth's surface (i.e., within the planetary boundary layer). Due to the pressing need to manage ozone air quality in the Upper Green River Basin and the limited amount of information available about the nature and causes of these unusual events, the WDEQ has funded comprehensive field studies during January through the end of March from 2007 to the current winter/early spring season (referred to as the Upper Green Winter Ozone Study or UGWOS). While meteorological conditions unfavorable to ozone formation encountered during the 2007 study period resulted in only limited monitoring, more favorable meteorological conditions during 2008 and 2011, and to a lesser degree during 2009, 2010, 2012, 2013, and 2014 resulted in several days of high ozone concentrations, including a large number of days in 2008 and 2011 when the 0.075 ppm Federal ozone standard was exceeded. Additional measurements have been planned for the winter of 2015. This QA plan addresses the 2015 monitoring effort.

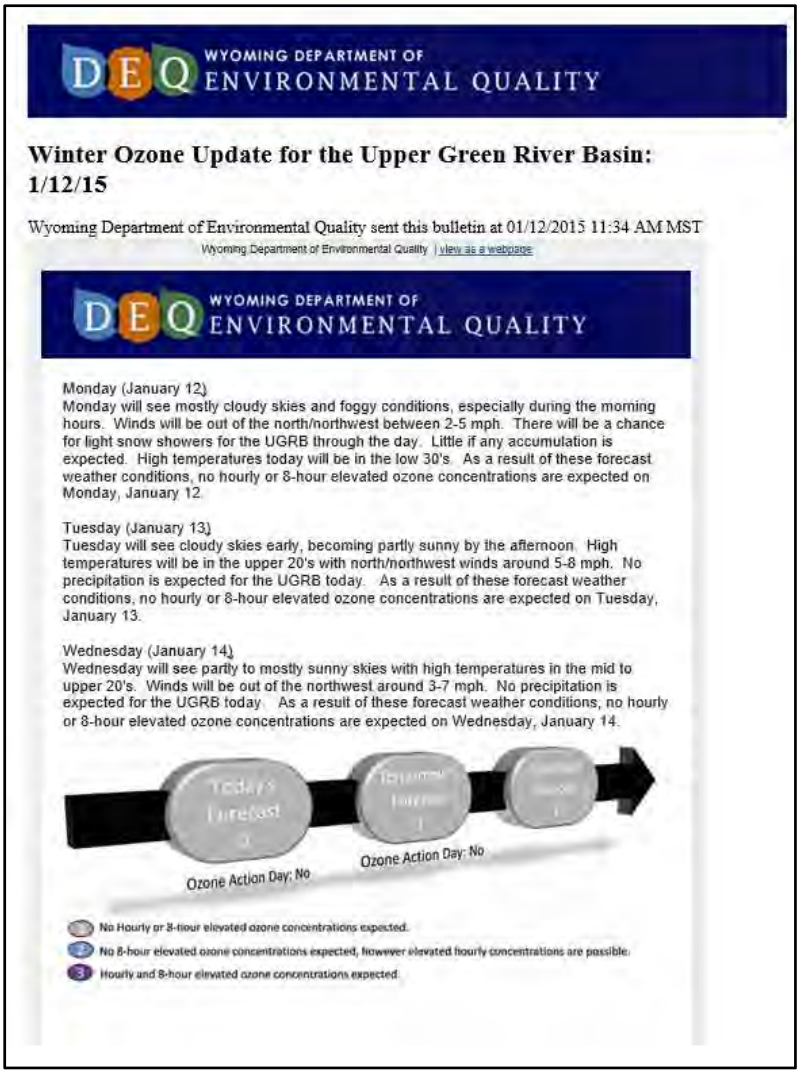
Similar to past years, data from the 2015 study will continue to be used to refine a conceptual model of ozone formation developed on the basis of prior year's studies of ozone formation. The conceptual model will be used along with the field data to develop accurate meteorological and air quality numerical simulations of the ozone events. Both the conceptual and numerical models will in turn be used to develop effective air quality management strategies needed to adequately protect public health and the environment in accordance with applicable State and Federal laws.

SECTION 2.0 SAMPLING PROGRAM DESCRIPTION

The sampling period for UGWOS 2015 will run from January 15, 2015 through March 31, 2015. Sampling that will be conducted for UGWOS during this period is described below.

2.1 Forecasting Protocol

The UGWOS effort for 2015 will not have an intensive operating period (IOP) component as in prior years. For 2015, MSI Trinity's meteorologist will assist WDEQ-AQD as requested in preparing the Daily Winter Ozone Update for the Upper Green River Basin bulletin. The MSI Trinity meteorologist will monitor weather conditions daily in order to be prepared to assist with, or as requested by the WDEQ-AQD to develop the ozone update. The ozone update for the Upper Green River Basin bulletin is posted on the WDEQ website at: http://deq.wyoming.gov/aqd/public-notices/air-air-quality-winter-ozone/. The bulleting is normally available by noon and covers the current day and the following two days. Figure 2.1 presents an example of this bulletin.



WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

Winter Ozone Update for the Upper Green River Basin: 1/12/15

Wyoming Department of Environmental Quality sent this bulletin at 01/12/2015 11:34 AM MST

Wyoming Department of Environmental Quality | view as a webpage

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

Monday (January 12)
Monday will see mostly cloudy skies and foggy conditions, especially during the morning hours. Winds will be out of the north/northwest between 2-5 mph. There will be a chance for light snow showers for the UGRB through the day. Little if any accumulation is expected. High temperatures today will be in the low 30's. As a result of these forecast weather conditions, no hourly or 8-hour elevated ozone concentrations are expected on Monday, January 12.

Tuesday (January 13)
Tuesday will see cloudy skies early, becoming partly sunny by the afternoon. High temperatures will be in the upper 20's with north/northwest winds around 5-8 mph. No precipitation is expected for the UGRB today. As a result of these forecast weather conditions, no hourly or 8-hour elevated ozone concentrations are expected on Tuesday, January 13.

Wednesday (January 14)
Wednesday will see partly to mostly sunny skies with high temperatures in the mid to upper 20's. Winds will be out of the northwest around 3-7 mph. No precipitation is expected for the UGRB today. As a result of these forecast weather conditions, no hourly or 8-hour elevated ozone concentrations are expected on Wednesday, January 14.

Figure 2.1 Example Daily Winter Ozone Update

In developing the forecast, the current conceptual model of the meteorological conditions conducive to the formation of high ozone levels is used. The model is specific to the Pinedale-Jonah fields during the winter and early spring and is characterized by mostly clear skies, light winds, extensive snow cover and a stable atmosphere. These conditions occur during periods when the synoptic weather is dominated by high pressure over the western Rockies, Intermountain area and the northern Great Basin. The primary broad scale characteristics dominating the Green River basin during the high probability events are weak pressure gradients within the context of a subsidence-dominated air mass.

In an effort to formulate the conceptual model, the synoptic scale weather patterns prior to occurrences of escalated ozone values in the study area during the winters of 2005 and 2006 were examined. Practical experience from the previous UGWOS studies has provided further understanding of conditions leading to higher ozone concentrations. Although many different nuances of the general pattern were encountered, the basic characteristics of the conceptual model did emerge. Figures 2.2 through 2.5 present composite views of the 700 mb and 500 mb configurations for all of the days with surface 8-hour averaged ozone concentrations greater than 60 ppb in 2004 through 2006. Figure 2.2 shows the ridging pattern of the 500 mb height contours; Figure 2.3 presents the wind speed isotachs at 500 mb; Figure 2.4 shows the ridging pattern of the 700 mb height contours; and Figure 2.5 demonstrates that there was warmer air aloft just above the surface, indicating air mass subsidence.

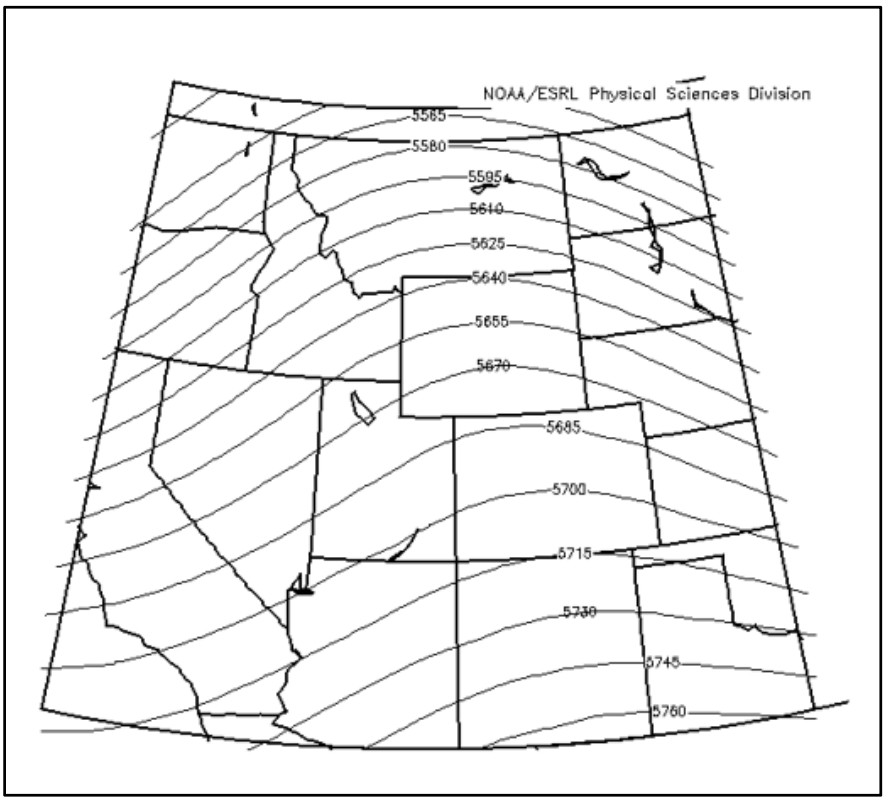


Figure 2.2 Composite 500 mb Heights during High Ozone Periods

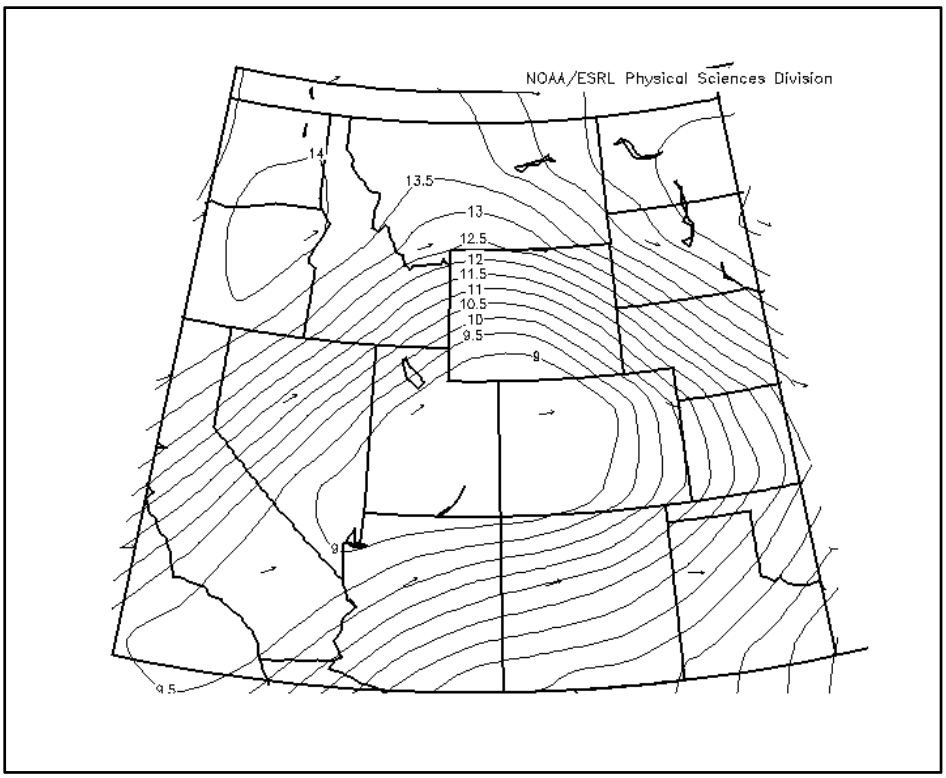


Figure 2.3 Composite 500 mb Winds during High Ozone Periods

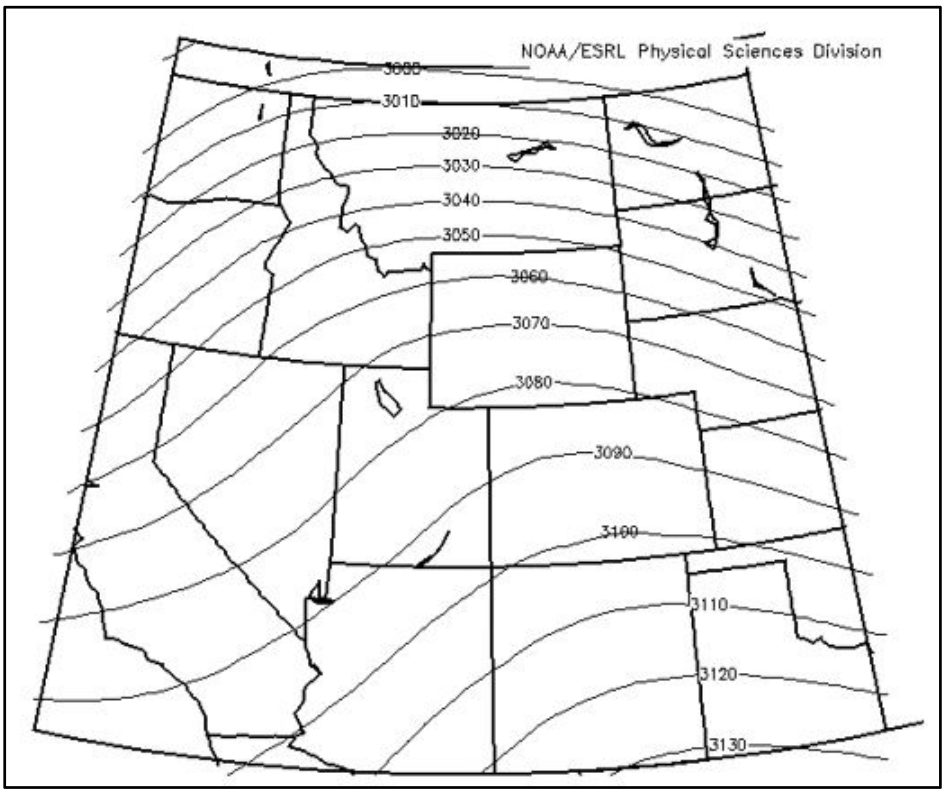


Figure 2.4 Composite 700 mb Heights during High Ozone Periods

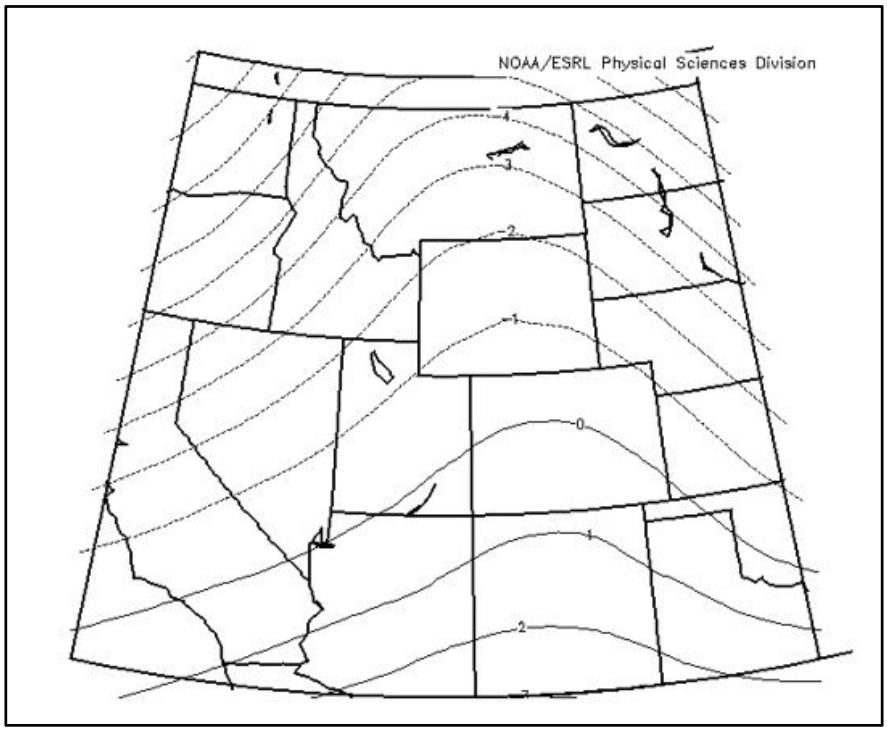


Figure 2.5 Composite 700 mb Temperature during High Ozone Periods

National Weather Service numerical synoptic-scale models such as the North American Mesoscale model (NAM), the Global Forecast System model (GFS), and the European model (ECMWF) coupled with regional NWS Forecast Discussion guidance, will provide the experienced WDEQ-AQD and MSI Trinity weather forecasters with the basis for daily long and medium range operational forecasts. Additional factors that appears to prove critical in operational forecasting is the presence of sufficient snow cover and the angle of the sun which when working together provide the strong UV radiation flux and enhanced low level stability that are needed for development of high ozone concentrations.

2.2 Continuous Measurements

Project-specific measurements to be continuously obtained over the complete field program period are presented below.

2.2.1 Mesonet Measurements

Surface wind speed, wind direction, and temperature measurements will be taken from at a three-site network mesonetwork (mesonet). These three sites are located at: Jonah, Mesa, and Paradise. In addition, each mesonet site will be equipped with a video camera, which will obtain images every 15 minutes. All sites will be equipped with cellular telemetry, allowing remote polling and real-time review of data. A snow stick will be installed at each site to give an estimate of snow depth at each of the sites. The snow sticks will be in prominent view of each of the camera locations.

2.2.2 VOC Canister Sampling

Speciated VOC measurements will be performed using the TO-14 canister sampling method with expanded analyte list; formaldehyde and acetaldehyde sampling will be performed using the TO-11 sampling method DNPH cartridges. VOC and DNPH sampling will be at five sites, Boulder, Big Piney, Mesa, Jonah and Paradise on sample days chosen by the WDEQ-AQD based on input from the forecasters. VOC will be sampled as integrated 3-hour samples. VOC samples will be collected using 6-liter SUMMA canisters connected to canister samplers owned by the WDEQ, and with the existing canister sampling system at Boulder and Big Piney. Carbonyl samples will be collected using DNPH-coated cartridges outfitted with ozone scrubbers and connected to constant flow pump systems over the same time period as the canisters. Samples will be collected on WDEQ chosen days, typically from 07:00 a.m. to 10:00 a.m. Thus, up to 12 samples will be taken at each of the sites over the course of the study. In addition, two (2) quality control samples will be collected per sampling event, including zero air contamination samples, duplicates, and field blank samples.

3.0 MONITORING SITE DESCRIPTIONS

As indicated in the previous sections, mesonet sites will be located at Jonah, Mesa, and Paradise. Canister samples will be also collected at Boulder and Big Piney. Figure 3.1 presents a map of the UGWOS site locations. Table 3-1 presents coordinates for each of the sites. Photographs of the sites can be found in Appendix A. Also included in Figure 3.1 and Table 3-1 are the locations of additional ozone monitoring sites in the study region.

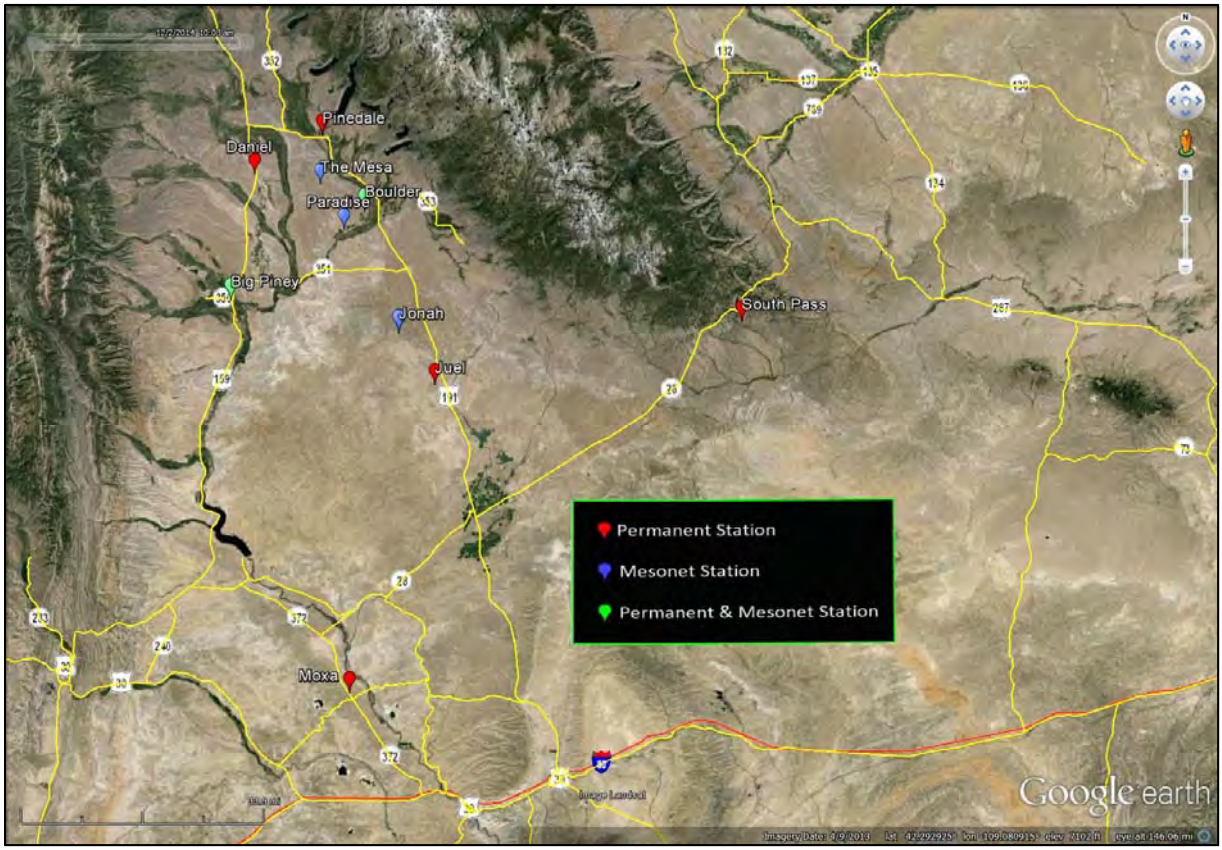


Figure 3.1. Map of UGWOS and Additional Ozone Monitoring Site Locations

Table 3-1 UGWOS 2015 Monitoring Locations

Site	Latitude	Longitude	Elevation (feet)
Mesonet Sites			
Jonah	42.47340	-109.6469	7,259
Mesa	42.78205	-109.8818	7,522
Paradise	42.68227	-109.8088	6,966
Existing Monitoring Sites			
Boulder	42.7188	-109.7529	7,078
Big Piney	42.4870	-110.0995	6,823
Daniel	42.7910	-110.0650	7,084
Farson	422.1184	-109.4541	6,619
Pinedale	42.8698	-109.8707	7,186
Juel Spring	42.3735	-109.5605	7,020
South Pass	42.5280	-108.7200	8,287
Moxa	41.7500	-109.7880	6,460

4.0 MONITORING EQUIPMENT DESCRIPTION

The following section describes the monitoring equipment that will be used for UGWOS 2015. Measurement Quality Objectives (MQOs) are presented for each of the monitoring methods.

4.1 VOC Sampling

WDEQ-owned VOC samplers were retrieved by MSI Trinity and bench checked prior to deployment. Figure 4.1 shows the sampler, with key components highlighted. These samplers are outfitted with a data logger that enables automatic start/stop operation so that samplers can be loaded with sampling media on the evening preceding a sampling event. Ambient air will be obtained from a ⅛" Teflon sample tube connected to a ¼ " stainless steel inlet tube, with the inlet positioned approximately two meters above ground level.

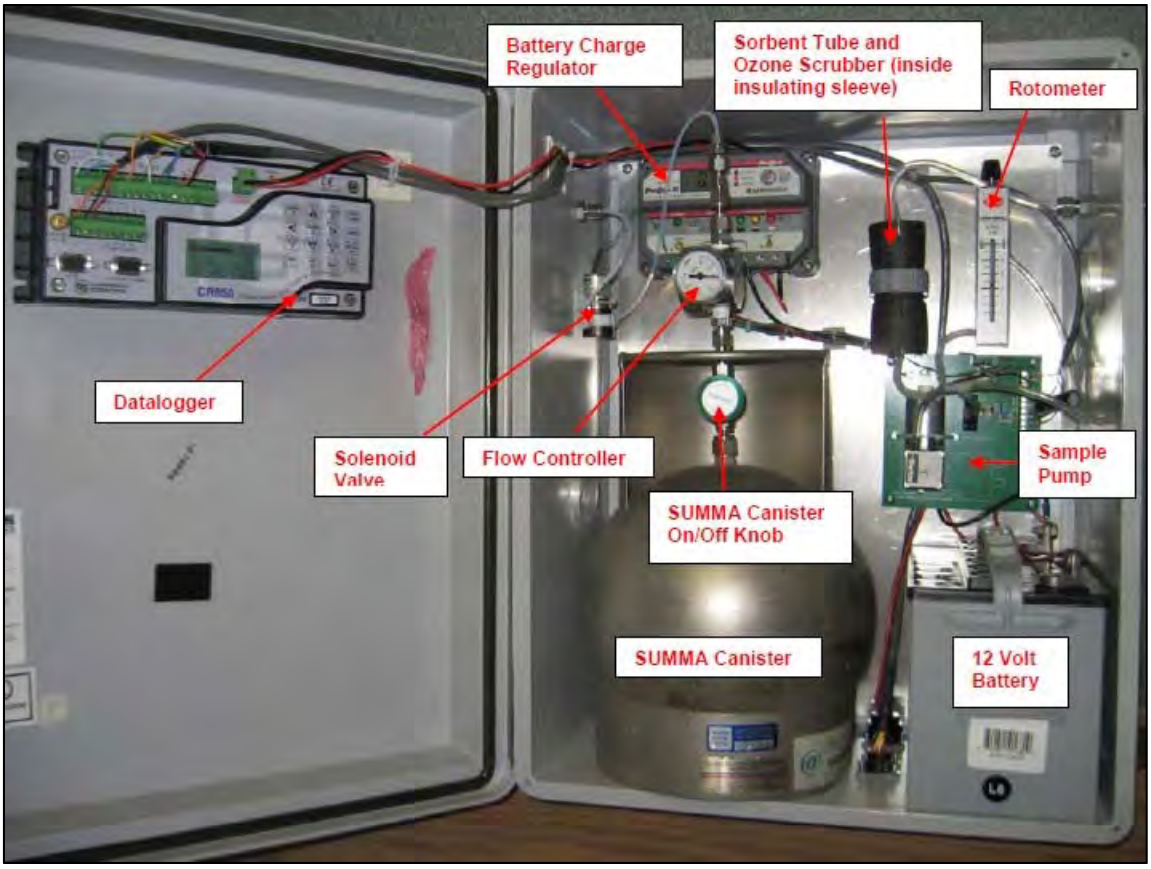


Figure 4.1 Canister Sampling System

Carbonyl measurements will be made by pulling ambient air at 1-2 LPM through DNPH cartridges with an ozone scrubber inserted upstream of the cartridge.

MSI Trinity's field technician will be responsible for loading and retrieving canisters and carbonyl cartridges into the samplers at each site, confirming sample run times, removing samples and filling out the affiliated documentation. Exposed sample media at the monitoring sites will be collected at the end of each intensive study day and sent to Environmental Analytical Service (EAS) laboratory for analysis. Field sample sheets will accompany samples and the required chain-of- custody documentation will accompany each shipment. Samplers will be cleaned prior to the start of the measurement program and tested for contamination.

VOC SUMMA canister samples will be analyzed using Method TO-14 with an expanded PAMS list of compounds listed in Table 4-1. Carbonyl samples will be analyzed using Method TO-11 for the compounds listed in Table 4-2. Analysis will be performed by EAS which is located in San Luis Obispo, CA.

Table 4-1 Target Compound List for EPA Method TO-14 Toxics in Air (Expanded for PAMS)

Ethene	2-Methylpentane	Ethylbenzene
Acetylene	3-Methylpentane	M,p-Xylene
Ethane	1-Hexene	Styrene
Propene	n-Hexane	o-Xylene
Propane	Diisopropyl ether	1-Nonene
i-Butane	3-Methylcyclopentene	n-Nonane
Methanol	Ethyl tert butyl ether	i-Propylbenzene
1-Butene	Methylcyclopentane	n-Propylbenzene
1,3-Butadiene	2,4-Dimethylpentane	a-Pinene
n-Butane	Benzene	3-Ethyltoluene
t-2-Butene	Dodecane	4-Ethyltoluene
c-2-Butene	Cyclohexane	1,3,5-Trimethylbenzene
Ethanol	2-Methylhexane	2-Ethyltoluene
3-Methyl-1-butene	2,3-Dimethylpentane	b-Pinene
Acetone	3-Methylhexane	1,2,4-Trimethylbenzene
i-Pentane	2-Methyl-1-hexene	n-Decane
1-Pentene	Tert amyl methyl ether	1,2,3-Trimethylbenzene
Isopropanol	2,2,4-Trimethylpentane	Indan
2-Methyl-1-butene	n-Heptane	d-Limonene
n-Pentane	Methylcyclohexane	1,3-Diethylbenzene
Isoprene	2,5-Dimethylhexane	1,4-Diethylbenzene
t-2-Pentene	2,4-Dimethylhexane	n-Butylbenzene
c-2-Pentene	2,3,4-Tirmethylpentane	1,4-Dimethyl-2-ethylbenzene
Tert butyl alcohol	Toluene	1,3-Dimethyl-4-ethylbenzene
2-Methly-2-butene	2,3-Dimethylhexane	1,2-Dimethyl-4-ethylbenzene
2,2-Dimethylbutane	2-Methylheptane	Undecane
Cyclopentene	4-Methylheptane	1,2,4,5-Tetramethylbenzene
n-Propanol	3-Ethyl-3-methylpentane	1,2,3,5-Tetramethylbenzene
Cyclopentane	3-Methylheptane	Naphthalene
Methyl tert butyl ether	2-Methyl-1-heptene	Total Petroleum Hydrocarbons
2,3-Dimethylbutane	n-Octane	Total non-Methane hydrocarbons
Sample: Composition Total Identified Paraffins, Isoparaffins, Aromatics, Napthlenes, Olefins, Oxygenates		

Table 4-2 Target Compound List for EPA Method TO-11 Volatile Organic Compounds

Compound
Formaldehyde
Acetaldehyde
Acrolein
Acetone
Propionaldehyde
Butyraldehyde
Methylethylketone
Benzaldehyde
Valeraldehyde
Cyclohexanone
Hexaldehyde

4.2 Mesonet Monitoring Sites

Three (3) mesonet monitoring sites located at Jonah, Mesa, and Paradise are included as part of the UGWOS 2015 sampling program. Each mesonet site consists of a three-meter tripod equipped with a wind speed and direction sensor, and a temperature probe. A photograph of a mesonet site is presented as Figure 4.2.

Figure 4.2 Photograph of Mesonet Site

Presented below is a description of the monitoring equipment that will be at each of the mesonet sites.

RM Young Model 05305 Wind Monitor AQ

For surface monitoring of wind speed and wind direction at the mesonet sites, R.M. Young 05305 Wind Monitor AQ wind speed and direction sensors will be utilized. The R.M. Young Model 05305 Wind Monitor AQ is made of UV-stabilized plastic with stainless steel and anodized aluminum fittings. Precision grade, stainless steel ball bearings are used. Transient protection and cable terminations are in a convenient junction box.

The wind speed sensor is a four blade helicoid propeller. Propeller rotation produces an AC sine wave voltage signal with frequency directly proportional to wind speed. Slip rings and brushes are eliminated for increased reliability. The starting threshold is 0.4 m/s.

The wind direction sensor is a rugged yet lightweight vane with a sufficiently low aspect ratio to assure good fidelity in fluctuating wind conditions. Vane angle is sensed by a precision potentiometer housed in a sealed chamber. With a known excitation voltage applied to the potentiometer, the output voltage is directly proportional to vane angle. A mounting orientation ring assures correct alignment of the wind direction reference when the instrument is removed for maintenance. The vane starting threshold is 0.5 m/s at 10 degrees displacement.

The sensors will be mounted on 3-meter tripods resulting in a measurement height of 3 meters. All sensors will be oriented to true north using either a professional transit adjusted for local declination, solar alignment.

Campbell Scientific 109-L Temperature Probe

Ambient temperature will be monitored using a Campbell Scientific 109 temperature probe. The 109-L Temperature Probe is a thermistor designed for use specifically with the CR200-series data loggers and has a measurement temperature range of -50° to +70°C.

The monitoring quality objectives for the supplemental surface wind and temperature measurements are presented in Table 4-3.

Table 4-3 Monitoring Quality Objectives

Wind Speed and Wind Direction	
Accuracy (instrument specifications)	
Horizontal Wind Speed	±(0.2 m/s + 5% of observed)
Horizontal Wind Direction	±5 degrees
Precision (performance checks)	
Horizontal Wind Speed	±0.2 m/s
Horizontal Wind Direction	±2 degrees
Output Resolution	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	1 deg.
Starting Threshold	0.5 m/s
Temperature	
Accuracy (performance checks)	±0.5°C
Precision (performance checks)	±0.2°C
Resolution	0.1°C

Campbell Scientific CR850 Data Loggers

All data will be stored at each mesonet site using a Campbell Scientific CR850 data logger. Both 5-minute and 60-minute averages will be stored, though the 5-minute data will be validated and used to create 60-minute averages. GPRS cellular modems will be used to retrieve the data via a real-time data connection with attempts every 15 minutes.

StarDot Video Cameras

StarDot video cameras will be used to automatically obtain high resolution images from each of the sites every 15 minutes. These cameras produce 1.2 megapixel images and utilize an on-board web and FTP server to deliver images.

5.0 DATA REPORTING

5.1 Data Management Plan

A primary study objective of the UGWOS study is to produce an adequately validated data set from the field measurements that is well defined and documented, and available to researchers in a timely manner. The overall goal of the data management effort is to create a system that is straightforward and easy for users to obtain data and provide updates.

MSI Trinity will collect all measurements remotely on at least an hourly basis. Preliminary data will be posted on a near real-time basis on a password-protected UGWOS web site at http://ugwos.metsolution.com. Both five-minute and hourly averages will be stored in data acquisition systems. Five-minute data will be validated and used to calculate hourly averages. The data loggers are all equipped with internal memory that can store data for the duration of the study. Thus, if telemetry fails at a given site, data can be collected manually. All polled data are backed up at least daily, minimizing the chance of data loss. Camera images as well as daily forecasts will be displayed on the web site. Figures 5.1 and 5.2 are example graphics that will be presented on the internal website.

Each data provider will be responsible for reviewing and validating their collected data. The raw data will be validated to Level 1 as described in "The Measurement Process: Precision, Accuracy, and Validity" (Watson, 2001) before being submitted to the database. This includes flagging values for instrument downtime and performance tests, applying any adjustments for calibration deviation, investigating extreme values and applying appropriate quality control codes. Quality control codes used for UGWOS 2015 include simple validation codes as well as AQS null codes developed by the EPA and are presented in Table 5-1. Each data provider will be 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 will be 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 will provide the Monitoring Quality Objective (MQOs) defining 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 do not meet the primary MQOs but are still deemed useable and can be defined with a secondary set of MQOs, these additional MQOs and the dates to which they apply will also be submitted.

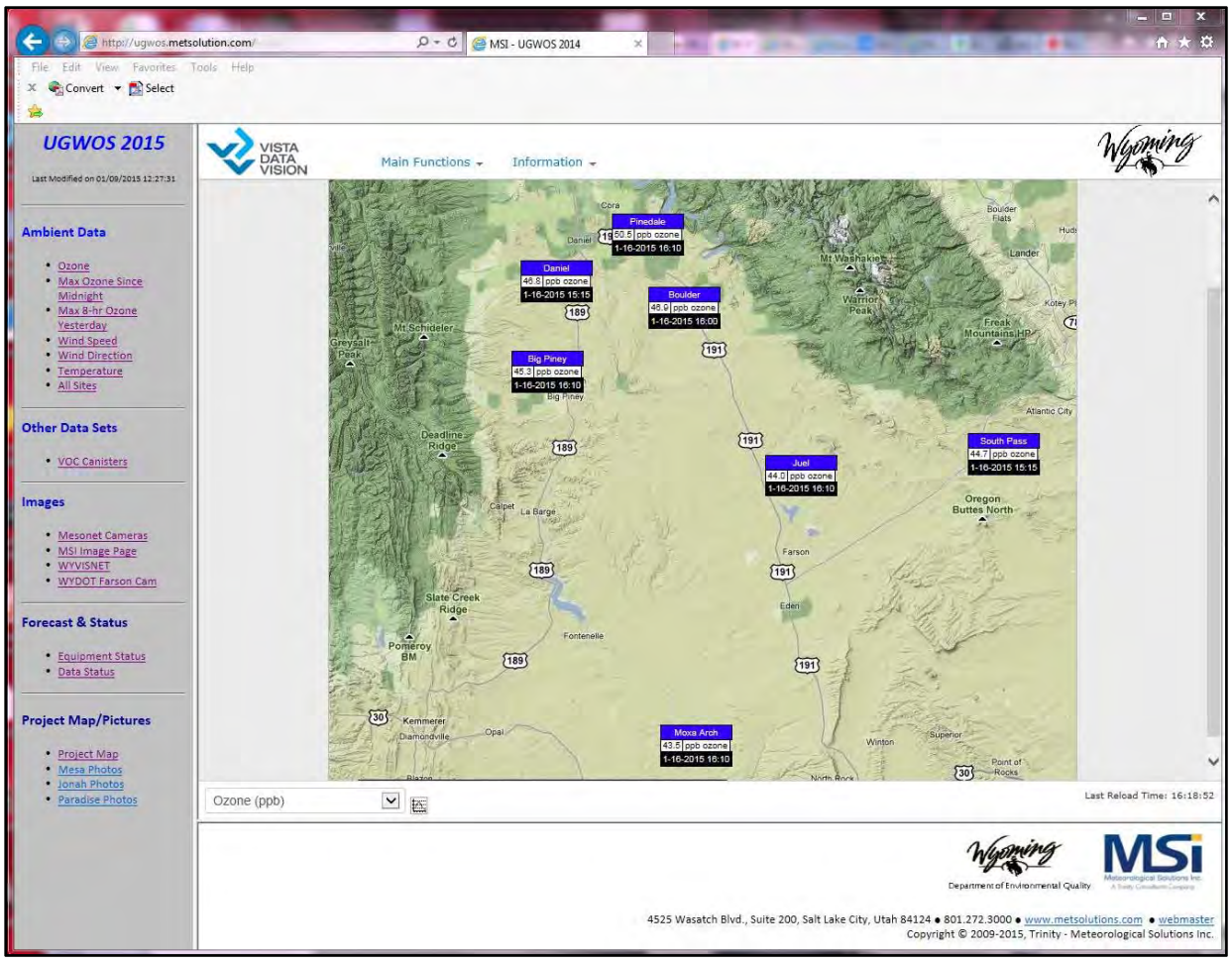


Figure 5.1 Ambient Ozone Map

Last Modified on 01/15/2015 12:42:02 UGWOS 2015

Equipment Matrix and Current Status

													Chemiluminescent			Photolytic			Total Reactive Nitrogen		
No.	Site Name	Site Operator	Camera	Canister	Carbonyl	WS	WD	TEMP	RH	THC	O3	PM	NO	NO2	NOX	NO	NO2	NOX	NO	NO2	NOY
1	Boulder	MSI	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	Daniel	ARS	X			X	X	X	X		X		X	X	X						
3	Juel Spring	MSI	X			X	X	X	X		X		X	X	X						
4	Pinedale	MSI	X			X	X	X	X		X	X	X	X	X						
5	Big Piney	MSI	X	X	X	X	X	X	X		X	X	X	X	X						
6	Moxa	MSI	X			X	X	X	X		X	X	X	X	X						
7	South Pass	ARS	X			X	X	X	X		X	X	X	X	X						
8	Paradise Mesonet	MSI	X	X	X	X	X	X													
9	Jonah Mesonet	MSI	X	X	X	X	X	X													
10	Mesa Mesonet	MSI	X	X	X	X	X	X													

X	Operational
X	Suspect
X	Delayed Connectivity/Data Transfer
X	Inoperative
X	Not installed yet

Figure 5.2 Equipment Status

Table 5-1 Data Quality Control Codes

Flag	Description
V	Valid Data
U/ND	Non-Detect
M	Missing
I	Invalid
J	Estimated amount - Concentration below reporting limit (RL) and above minimum detection level (MDL)
U	Data which has not been validated - User is responsible for validation.
B	Compound was detected in batch method blank above reporting limit (RL)
E	This compound exceeds the calibration range for this sample volume
F	Higher detection limit because of matrix interference
AA	Sample Pressure out of Limits
AB	Technician Unavailable
AC	Construction/Repairs in Area
AD	Shelter Storm Damage
AE	Shelter Temperature Outside Limits
AF	Scheduled but not Collected
AG	Sample Time out of Limits
AH	Sample Flow Rate out of Limits
AI	Insufficient Data (cannot calculate)
AJ	Filter Damage
AK	Filter Leak
AL	Voided by Operator
AM	Miscellaneous Void
AN	Machine Malfunction
AO	Bad Weather
AP	Vandalism
AQ	Collection Error
AR	Lab Error
AS	Poor Quality Assurance Results
AT	Calibration
AU	Monitoring Waived
AV	Power Failure
AW	Wildlife Damage
AX	Precision Check
AY	Q C Control Points (zero/span)
AZ	Q C Audit
BA	Maintenance/Routine Repairs
BB	Unable to Reach Site
BC	Multi-point Calibration
BD	Auto Calibration
BE	Building/Site Repair

Table 5-1 Data Quality Control Codes (Continued)

BF	Precision/Zero/Span
BG	Missing ozone data not likely to exceed level of standard
BH	Interference/co-elution/misidentification
BI	Lost or damaged in transit
BJ	Operator Error
BK	Site computer/data logger down
BL	QA Audit
BM	Accuracy check
BN	Sample Value Exceeds Media Limit
DA	Aberrant Data

Once the data have been validated to Level 1, the data will be prepared for submittal to the database in a form that clearly defines the time reference, averaging period, parameter names and units. The time reference for the database is **local standard time (Mountain Standard Time)** and the averaging period reference will be standardized to **hour beginning (0 – 23)**. The data will be 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.

Data will be 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. QC codes include simple validation codes as well as AQS null codes developed by the EPA.

5.2 Database Management Design

MSI Trinity will be responsible for assimilating the submitted data into an integrated relational Microsoft ACCESS database and is managing the data for subsequent distribution and analysis. The database will consist of both information and data files. The goal is to make the database very usable by data analysts and all participants.

The following describes the design for the database, which was similarly implemented during the UGWOS 2007 - 2014 field studies. The database includes an inventory spreadsheet file to help users track and ensure that all of the data were submitted and processed in a timely and consistent manner. All data files submitted will be 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 is in place for identifying the version and or modification date of all data files. All files are backed up daily.

The data have the following file 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.

Ozone 8-hour averaged data

SITE, DATE, HOUR, O3_8HR, O38HR_QC

Hourly Surface Air Quality data

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.

VOC Data

VOC canisters and carbonyl cartridges will be collected during IOPs. The canister data is analyzed using the TO-14 method and the carbonyl cartridges using the TO-11 method by EAS. Data files are formatted in a similar format to what is uploaded into the database. VOC data will be presented in two data tables. VOC will have individual compounds presented by canister sample and sample date. A second table in the database will have a summary of compound classifications.

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

- Parts per billion (ppb) for O_3, NO, NO_2, and NO_x
- Meters per second for wind speed (as a general rule, metric units will be used)
- Degrees Celsius for ambient temperature
- Watts/m^2 for radiation
- Micrograms per cubic meter, parts per billion by volume, and parts per billion by Carbon for VOC canister data
- SITE = Alpha-numeric site code identifier
- DATE = (MM/DD/YY)
- HOUR= Nearest whole begin hour (HH) (MST)
- TIME, START_TIME or END_TIME = Time stamp of data (HH:MM:SS) (MST)
- HEIGHT = Elevation in meters above MSL
- QC_CODE, 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 will be available for download on an FTP server.

5.2 Data Reporting

Files of all data collected during the study will be transmitted to WDEQ-AQD by June 15, 2015. MSI Trinity will review the validated data collected during the field study and prepare descriptive summaries in a report format for delivery to WDEQ-AQD. MSI Trinity will prepare summaries of air quality and meteorological conditions during the study period.

In addition, MSI Trinity will prepare more detailed descriptive analyses of the air quality and meteorology measured during any high ozone events during the study period. As part of the Level 1 data validation procedures, MSI Trinity will carefully examine all of the measurements. This process typically provides insight into the critical processes that determine the extent of pollution loading such as atmospheric stability, wind shear (low-level jets, etc), layers aloft, and boundary layer development (growth rate, peak mixing heights), including the nocturnal boundary, convective boundary, and residual layer. The meteorology leading up to and during periods with high ozone levels and the diurnal behavior of ozone aloft during these periods will be characterized.

Supporting the analyses discussion, products that will be produced in this phase of the study include but are not limited to:

1. Time-series plots of continuous measurements such as ozone, ambient temperature, radiation;
2. Wind roses at the surface;
3. Pollution roses at the surface; and
4. Summary tables of 1-hour and 8-hour averaged ozone as well as statistical summaries showing hourly averages and maximums.

A final report will be prepared presenting:

- The above-mentioned information and associated analyses in an easy to comprehend format.
- A summary of field operations. A measure of the associated data capture rates will be included. Problems encountered during the field operations will be discussed.
- Details of the database design including descriptions of the metafiles; field descriptors; and the accuracy, precision, lower limits, resolution, and completeness of each measurement.

A draft version of the report will be provided to WDEQ-AQD by July 15, 2015. Voluminous tables and figures will be incorporated into electronic appendices as appropriate. All report materials will be made available via a secure FTP transfer site.

Section 6.0 QUALITY ASSURANCE PROGRAM

6.1 Project Management

Mr. George Wilkerson will serve as overall project manager. Mr. Casey Lenhart will serve as the Field Operations Manager for the study. He will be responsible for coordinating and verifying corrective action for any measurement-related problems. While it is not anticipated that the scope of the monitoring effort will change over the relatively short duration of the effort, any changes will result in a revised version of this QAPP. Ms. Linda Conger is responsible for the writing and distribution of the QAPP. Revisions will be distributed based on the distribution list at the beginning of this document.

Study personnel responsibilities and contact information are presented in Table 6-1. An organizational chart for UGWOS 2015 is provided in Figure 6.1.

Table 6-1 Project Responsibilities and Contact Information

Name	Organization	Key Responsibilities	Phone Numbers
Cara Keslar	Wyoming DEQ	Contract Manager	(307) 777-8684 (307) 286-2383 (cell)
Adam Deppe	Wyoming DEQ	Forecasting	(307) 777-8754
Steve Mugg	Wyoming DEQ	Quality Assurance Audits	(307) 777-7352
George Wilkerson	MSI Trinity	Project Manager	(801) 272-3000 Ext. 304
Dan Risch	MSI Trinity	Forecasting	(801) 272-3000 Ext. 306
Casey Lenhart	MSI Trinity	Field Manager, Reporting	(801) 272-3000 Ext. 307 (801) 979-7874 (cell)
Linda Conger	MSI Trinity	Quality Assurance Coordinator	(801) 272-3000 ext. 305
Brian Olsen	MSI Trinity	Data polling Data processing and validation, Reporting	(801) 272-3000 Ext. 311
Scott Adamson	MSI Trinity	Database and Data Validation, Reporting	(801)-272-3000 Ext. 302
Mike Peterson	MSI Trinity	Field Technician - VOC Canister Sampling	(801)-272-3000 Ext. 310 (801)-450-8706 (cell)
Adam Lenkowski	MSI Trinity	Field Technician - VOC Canister Sampling	(801)-272-3000 Ext. 309 (801)-419-2882 (cell)
Tyler Ward	MSI Trinity	Field Technician - VOC Canister Sampling	(928) 814-3926 (cell)
Isaac Legare	MSI Trinity	Field Technician - VOC Canister Sampling	(801) 272-3000 ext. 316 (801) 520-2867 (cell)

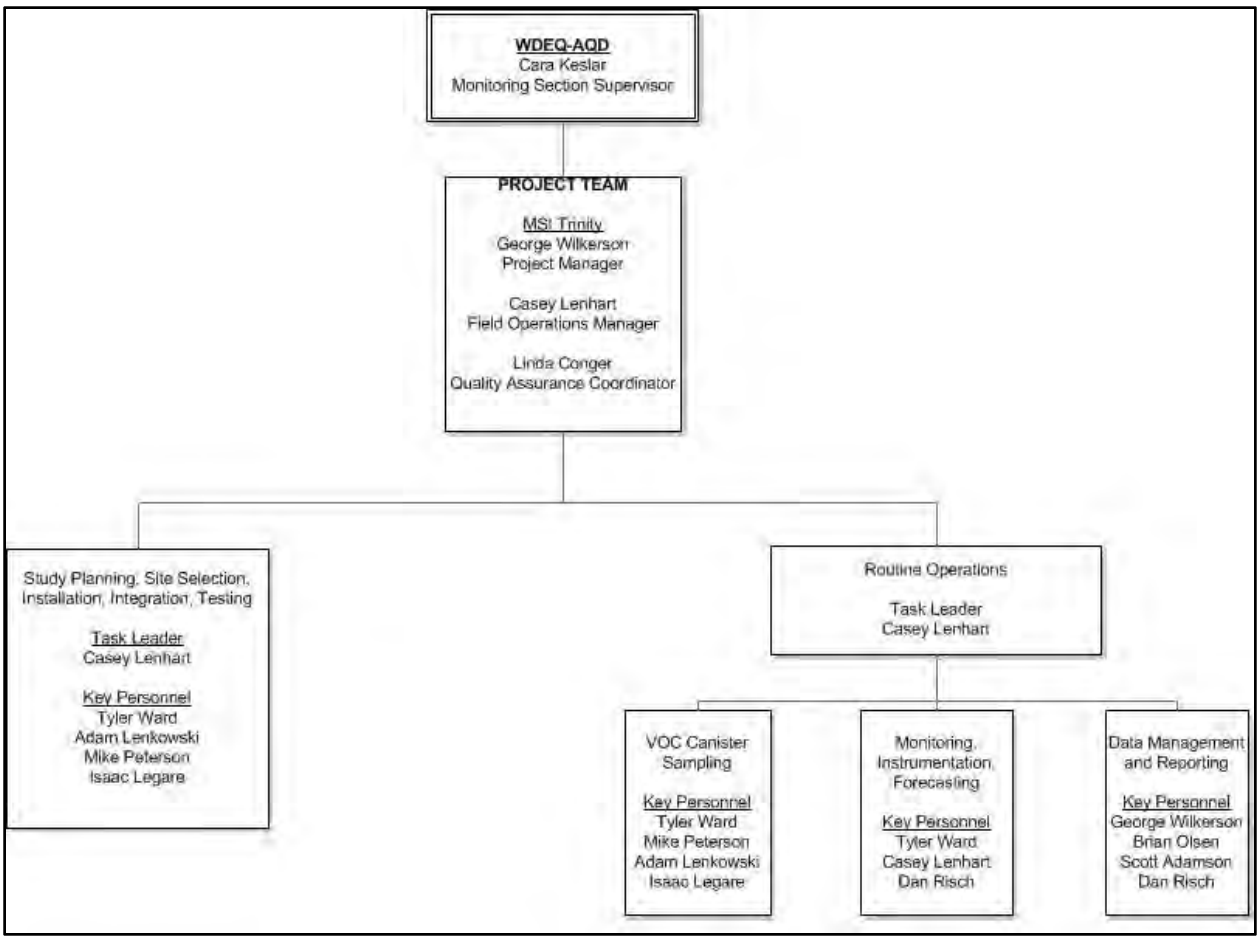


Figure 6.1 Organizational Chart

6.2 Data Quality Objectives

Specific measurement quality objectives have been presented for each measurement in Section 4 of this document. The overall objectives for the collection of valid data will be as follows:

- Air quality data - 80% of the possible data
- Meteorological data - 90% of the possible data

For the above calculation, data lost during calibrations, maintenance or audits are considered invalid.

6.3 Assessment and Oversight

As part of the quality assurance program, detailed quality control procedures have been implemented to assess and maintain control of the quality of the data collected. All equipment will undergo complete checkout and acceptance prior to the start of monitoring on January 15, 2015. This checkout will occur during the weeks prior to the start of monitoring, as well as during setup and installation of the equipment. Standard operating procedures (SOPs) for measurements will be developed for key monitoring activities. SOPs can be found in Appendix B.

A summary of key elements of the QC program for each measurement is presented below:

VOC Canister Sampling Systems

Tripod mounted portable VOC canister sampling systems will be flushed with ultrapure air and checked for contamination prior to the start of the UGWOS 2015 study. VOC canisters will be installed in each system, allowed to sample ultrapure air through the system inlet, and sent to the analytical laboratory for analysis to confirm that systems are free of contamination.

Calibrations

The purpose of a calibration is to establish a relationship between the ambient conditions and an instrument's response by challenging the instrument with known values and adjusting the instrument to respond properly to those values.

All meteorological sensors will be calibrated at the beginning and end of the study. Wind speed sensors will be calibrated using an R.M. Young constant rpm motor simulating wind speeds at several points across the sensor's operating range. Wind direction sensors will be calibrated by checking responses in a least 90° increments. Temperature sensors will be calibrated using a water bath and a certified thermometer.

The calibration method for each of the air quality and meteorological variables is summarized in Table 6-2.

Table 6-2 Calibration Methods for the Monitored Variables

Measurement Variable	Calibration Method
Wind Speed	Rotational rate using a selectable speed anemometer drive
Wind Direction	Alignment using true north and linearity with a directional protractor
Temperature	Water bath comparisons to a certified transfer standard

6.4 Data Validation

All data collected for UGWOS will be validated to Level 1 validation (see Section 5). As part of the validation effort, participant's data will be evaluated to verify that they meet the stated MQOs. If data clearly do not meet MQOs, they will be removed from the database as invalid data. If, however, data miss meeting the primary MQOs in a definable way to the point where the data are still considered useful, secondary MQOs will be assigned to the data in question. This use of secondary MQOs will be specifically documented in metafiles associated with the data.

7.0 REFERENCES

United States Environmental Protection Agency (2008): Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part I, Ambient Air Quality Monitoring Program Quality System Development. Document EPA-454/B-08-003. Office of Air Quality Planning and Standards.

United States Environmental Protection Agency (2008): Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV, Meteorological Measurements. Document EPA – 454/B-08-002. Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina.

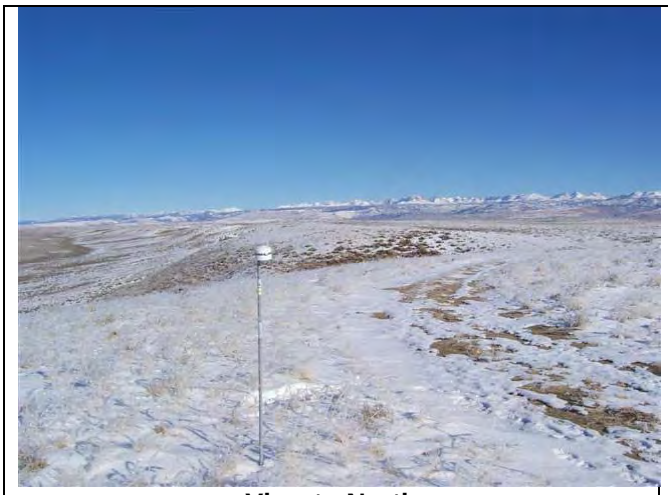
United States Environmental Protection Agency (1999): EPA Requirements for Quality Assurance Project Plans. Document EPA QA/R-5. U.S. EPA Quality Staff Interim Final Report, Research Triangle Park, North Carolina. November.

United States Environmental Protection Agency (2000). Meteorological Monitoring Guidance for Regulatory Modeling Applications. Document EPA-454/R-99-005. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

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.

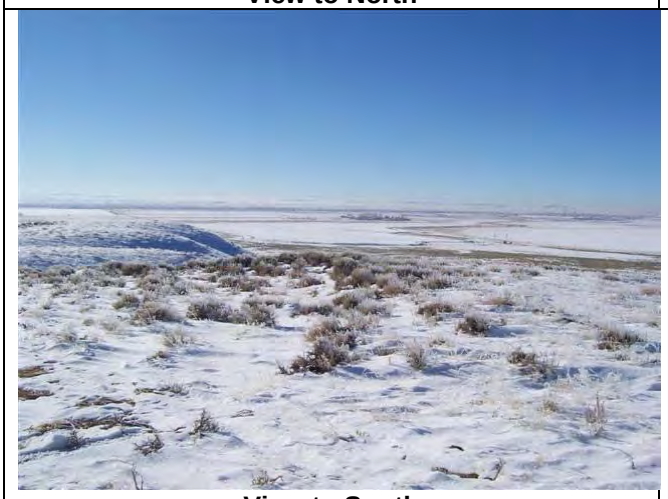
APPENDIX A

Site Photographs

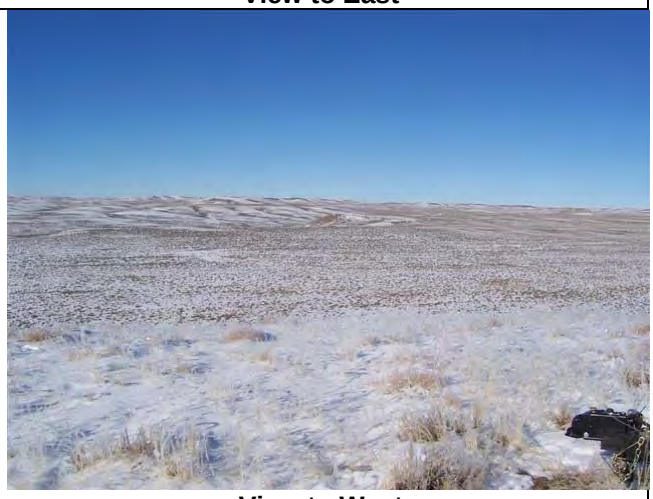


View to North

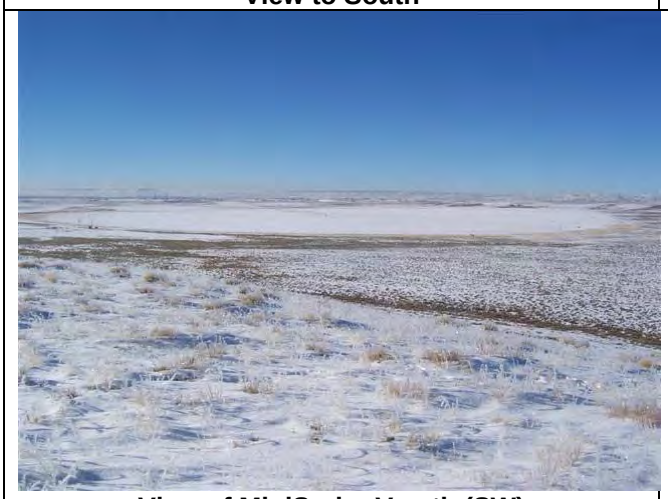
View to East



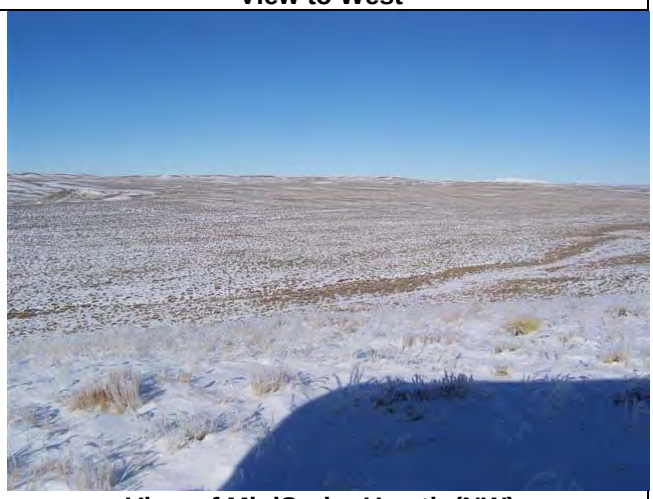
View to South



View to West



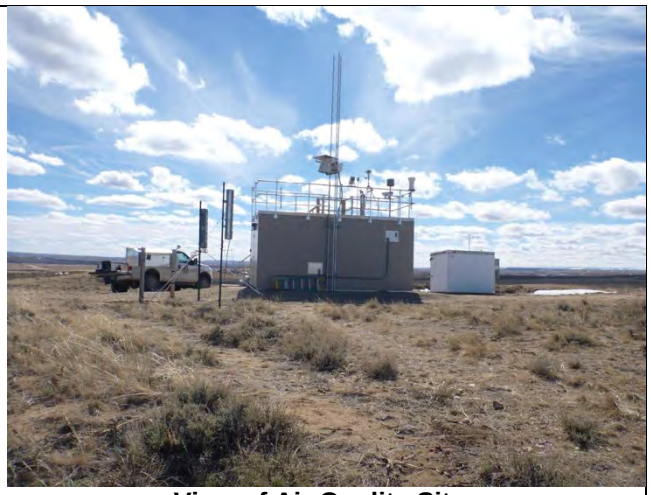
View of MiniSodar V path (SW)



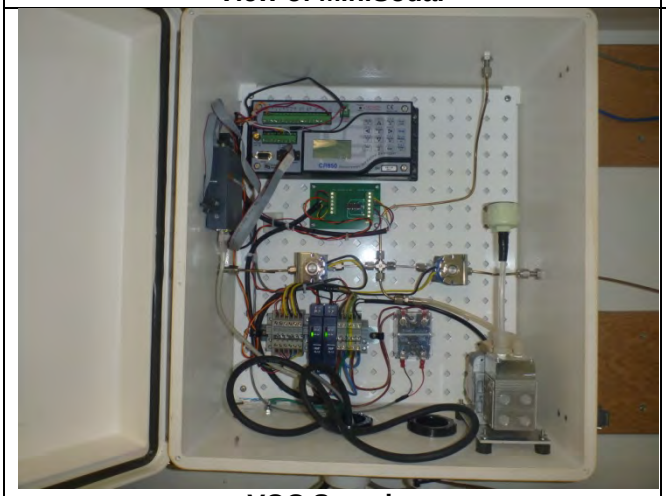
View of MiniSodar U path (NW)

Boulder Site

View of MiniSodar



View of Air Quality Site

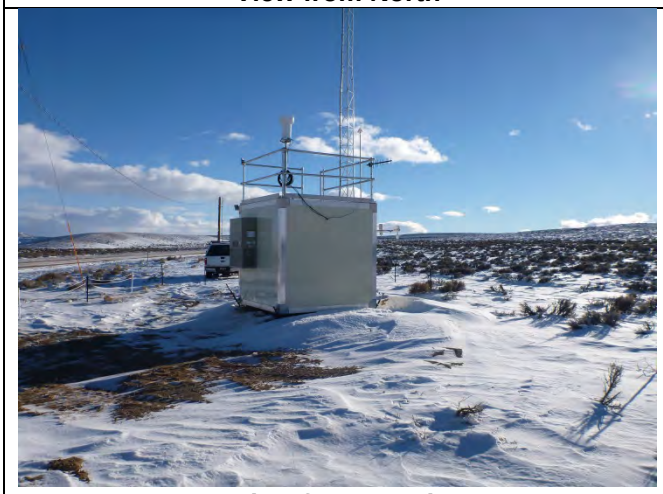


VOC Sampler

Boulder Site

View from North

View from East



View from South

View from West

Big Piney VOC Sampling

View from Jonah to North

View from Jonah to East

View from Jonah to South

View from Jonah to West

Air Quality Analyzers

Jonah Site

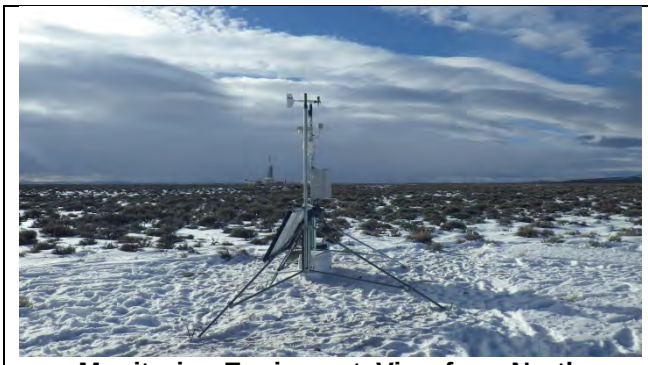
Monitoring Equipment, View from North

View from East

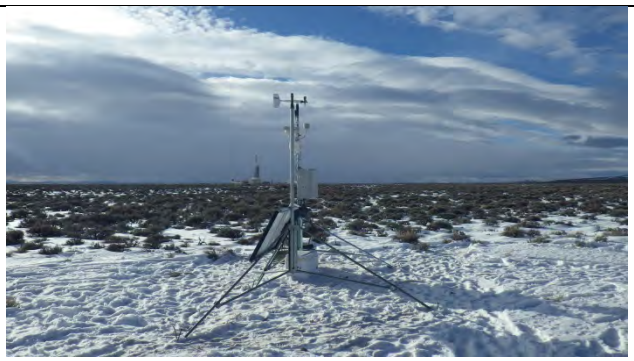
View from South

View from West

Paradise Site



Monitoring Equipment, View from North

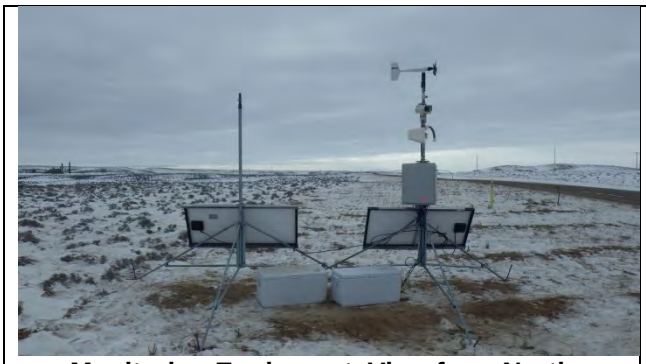


View from East

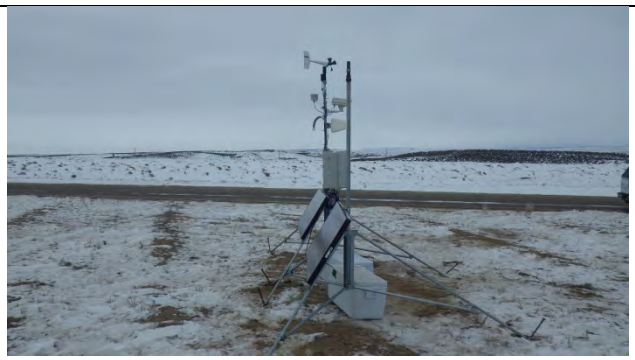
View from South

View from West

Mesa Site

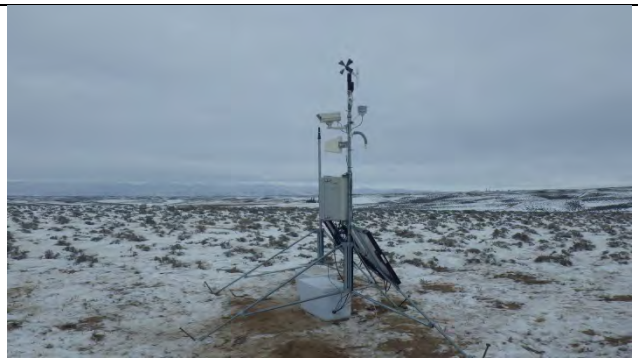


Monitoring Equipment, View from North



View from East

View from South



View from West

Warbonnet Site

APPENDIX B

Standard Operating Procedures

Meteorological Solutions Inc. A Trinity Consultants Company	**STANDARD OPERATING PROCEDURE**	Title: Sub-atmospheric Pressure Canister Sampling – Time-Integrated Samples Using Sampling System
		No: SOP 92 / Page: 1 of 2
		Revision No: 1 / Effective Date: 01/13/2015 08/07/2012 Rev. 0
Approval:	Date:	Concurred By:

This procedure describes collection of time-integrated ambient air samples in evacuated stainless steel SUMMA canisters to be submitted for subsequent analysis of target compounds at a central laboratory.

Equipment

1. Chain-of-Custody documentation.
2. Stainless steel canisters prepared for sampling at an approved laboratory.
3. Flow controllers capable of maintaining a constant flow rate over a sampling period of up to 24 hours.
4. Vacuum/pressure gauge.
5. Field sampling data sheets.
6. Wrenches.
7. Sampling system with data logger-controlled solenoid to automatically start and stop canister sampling.

Sampling Procedure

1. Ensure the canister valve is closed.
2. Remove the brass, screw-on cap from the upper valve of the stainless steel canister.
3. Connect the pressure gauge to the canister, open the canister valve, record the start pressure, and shut the valve.
4. Place canister inside sampling unit and connect the flow controller to it.
5. Connect the 1/8-inch sampling tube in the sampling system to the flow controller.
6. Open the upper valve of the clean evacuated canister by turning counter-clockwise.
7. Allow the data logger-controlled solenoid to start the sampler at the prescribed time (0700 MST).
8. Record the information on the form below. Any abnormalities surrounding the sample collection event should be recorded on the form.
9. The datalogger-controlled solenoid will stop the sample at the prescribed time (1000 MST).
10. After the sample has stopped, retrieve the canister from the system. First, close the canister valve by turning clockwise and remove the flow controller.
11. Connect the pressure gauge to the canister, open the valve, record the stop pressure, close the valve, and remove the pressure gauge.
12. Replace the brass, screw-on cap onto the upper valve of the stainless steel canister.
13. Put the stainless steel canister back into the shipping carton.
14. Put the sample collection form into the shipping carton.

15. Bring the canister back to the Pinedale project base for shipment to the analytical laboratory.
16. Ship to the analytical laboratory with chain-of-custody documentation.

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Canister Sampling
Field Data Sheet

A. General Information

Site Location:
Sampler ID:
Operator:

B. Sampling Information

Canister ID:
Sample ID Number:
Start Date:
Stop Date:
Start Time:
Stop Time:
Canister Start Pressure:
Canister Stop Pressure:

C. Additional Notes

Meteorological Solutions Inc. A Trinity Consultants Company — **STANDARD OPERATING PROCEDURE**	Title: Carbonyl Sampling - Three Hour	
	Number: SOP 131	Page: 1 of 2
	Revision No: 2	Effective Date: 01/13/2015 12/31/2014 (Rev 1)
Approval:	Date:	Concurred By:

This procedure describes collection of ambient air carbonyl samples in DNPH cartridges using sampler pumps to draw air through the cartridge at approximately 2 liters per minute for three hours. Samples are then submitted for subsequent analysis of target compounds at a central laboratory.

Equipment

1. DNPH cartridges
2. Ozone scrubbers compatible with the cartridges
3. Sampling form
4. Chain-of-Custody documentation
5. Sampler pump

Sampling Procedure

1. Sampling pumps are interfaced with a datalogger or timer set to run at the following times: (0700-1000).
2. Using clean disposable gloves, remove a DNPH cartridge and ozone scrubber from packaging, remove the end plugs from the cartridge and insert into the scrubber.
3. Insert the ozone scrubber end on to the stainless steel barbed fitting located on the intake sampling tube bulkhead.
4. Connect the Luer-lok fitting on the tygon tubing to the DNPH cartridge (yellow) to make a connection with the pump.
5. Fill out the sample form and make a sample label by writing in the sample I.D. (e.g.,BOL022820140700).
6. Connect flow gauge (BIOS/rotameter) to sample inlet. Manually turn on control port and record flow rate.
7. Reconnect sample line inlet.
8. After three-hour sample has been taken, disconnect sample line inlet, and repeat Step 6.
9. Using clean disposable gloves remove the DNPH cartridge and ozone scrubber from the system and discard the scrubber. Replace the end caps in the DNPH cartridge.
10. Place the DNPH cartridge in the white envelope with aluminized interior. Fold over and seal with a label containing the sample I.D.
11. Place the completed sampling form and sealed cartridge envelope in a plastic bag and place in the cooler with blue ice.
12. Transport carbonyl samples in the cooler on ice for shipment to the analytical laboratory. Store in a refrigerator until ready to ship.
13. Ship to the analytical laboratory in a cooler with ice and chain-of-custody documentation.

Carbonyl Sampling Form

A. General Information

Site Location (BOL, PIN, JON):
Sampler ID:
Operator:
Shipping Date:

B. Sampling Information

Sample Number:
Load Date/Time (0400 only):
Date (Start);
Date (Stop):
Start Time:
Stop Time:
Flow Rate:
Abnormalities:

APPENDIX B

Microsoft Access Database Description

The Upper Green Winter Ozone Study (UGWOS) 2015 Database

1. Introduction

This document describes the Upper Green Winter Ozone Study (UGWOS) database for 2015. Included are a review of the study measurements and descriptions of the key data reporting elements such as naming conventions, time reference and units. This document describes the overall structure of the database with a description of the data tables and file formats.

2. Overview of Measurements and Field Study Participants

The 2015 UGWOS field study included hourly measurements of surface meteorological and air quality data during the period of January through March 2015 in the upper Green River Basin region of southwestern Wyoming. VOC data were collected at five locations (Boulder, Jonah, Paradise, Mesa, and Big Piney) to determine spatial distribution of VOCs.

The following lists the UGWOS participants and the data they submitted:

<u>Wyoming Department of Environmental Quality:</u>

- WDEQ runs an ambient air quality network throughout the state of Wyoming. Air Quality sites included in UGWOS 2015 were located in or near Sublette County in southwestern Wyoming. The stations include:
    - Boulder (including 5-minute and 1-hour data collection),
    - Big Piney,
    - Daniel South,
    - Farson (Met Only),
    - Juel Springs,
    - Moxa Arch,
    - Pinedale, and
    - South Pass.

- The WDEQ Monitoring network data consisting of some or all of the parameters presented below:
    - Ozone
    - Particulates (PM_{10})
    - Fine Particulates ($PM_{2.5}$)
    - Oxides of Nitrogen ($NO/NO_2/NO_x$ or NO_Y)
    - Wind speed
    - Wind direction
    - Ambient Temperature
    - Additional met parameters (relative humidity, barometric pressure, solar radiation, sigma theta, and precipitation)

- UV Radiation
- Methane, Non-methane Hydrocarbons, Total Hydrocarbons

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- Canister and Carbonyl Cartridge Data
  - VOCs
  - Formaldehyde and Acetaldehyde
- Mesonet Stations
  - Mesa,
  - Paradise, and
  - Warbonnet.

Each contracted organization reviewed and validated their collected data to Level 1 before the data set was submitted to the database. The data were examined and any adjustments for calibration deviations were applied. Appropriate flags were assigned for extreme values, instrument downtime and performance tests. A description of the Quality Control (QC) codes used are given in Table 1 and also listed in the table **QC_flags** in the UGWOS 2015 database.

Table 1 - Data Flags

QC	Description
V	Valid Data
M	Missing Data
I	Invalid Data
S	Suspect Data - Data appears to be a data spike or outside normal data range
U	Data which has not been validated - User is responsible for validation.
N	Instrument Noise detected in sub hourly data used to create hourly average
B	Below Detection Limit
AA	Sample Pressure out of Limits
AB	Technician Unavailable
AC	Construction/Repairs in Area
AD	Shelter Storm Damage
AE	Shelter Temperature Outside Limits
AF	Scheduled but not Collected
AG	Sample Time out of Limits
AH	Sample Flow Rate out of Limits
AI	Insufficient Data (cannot calculate)
AJ	Filter Damage
AK	Filter Leak
AL	Voided by Operator
AM	Miscellaneous Void

Table 1 (Continued) - Data Flags

QC	Description
AN	Machine Malfunction
AO	Bad Weather
AP	Vandalism
AQ	Collection Error
AR	Lab Error
AS	Poor Quality Assurance Results
AT	Calibration
AU	Monitoring Waived
AV	Power Failure
AW	Wildlife Damage
AX	Precision Check
AY	Q C Control Points (zero/span)
AZ	Q C Audit
BA	Maintenance/Routine Repairs
BB	Unable to Reach Site
BC	Multi-point Calibration
BD	Auto Calibration
BE	Building/Site Repair
BF	Precision/Zero/Span
BG	Missing ozone data not likely to exceed level of standard
BH	Interference/co-elution/misidentification
BI	Lost or damaged in transit
BJ	Operator Error
BK	Site computer/data logger down
BL	QA Audit
BM	Accuracy check
BN	Sample Value Exceeds Media Limit
B	Below Detection Limit

3. UGWOS Database Design

Meteorological Solutions Inc. assimilated the submitted data into an Access 2013 database called UGWOS_2015_Database_Version#.#.accdb (where #.# indicates version number). The database consists of both information and data files. It has a simple straightforward design. The **Sites** table contains all of the site information (site name, site identification code used in all of the data tables, site location including latitude, longitude, elevation, and a tabular list of what parameters were measured at each site and the organization responsible). The **Parameters** table lists parameter codes used in the data tables. The table named **Updates** lists all information pertaining to modifications and versions of the data as well as dates of said modifications. The name of the database includes a version number to help users identify the most current version of the database.

All data files submitted were examined carefully to verify unique site codes for all sites, instruments, and parameters so that no orphan or duplicate records exist in any of the tables. The valid data were examined for completeness and reasonableness of data ranges. All invalid or missing data were verified to have the adverse AQS Null code values or the value –9999. All of the date and times are in begin hour (0-23) Mountain Standard Time. The data were organized and grouped together by platform, averaging period and data type.

The **Hourly Air Quality** table includes hourly average data of criteria pollutants (ozone, oxides of nitrogen, particulate matter, and sulfur dioxide) measured at each of the sites. Other pollutants such as methane, non-methane hydrocarbons and total hydrocarbons are also included in the Hourly Air Quality Table. Five-minute air quality data collected at the Boulder site were also provided in the database. These data are presented in the **5-minute Boulder Data** table. Sub-hourly data collected at Boulder went through quality assurance and were marked with the appropriate data validation QC flag.

Data included in the **Hourly Meteorology** table represent hourly averages of meteorological data parameters such as wind speed, wind direction, standard deviation of the wind direction, and temperature. Select sites have additional meteorological parameters such as relative humidity, solar radiation, barometric pressure, dew point temperature, precipitation, and UV radiation. Five-minute data from the Boulder site were quality assured and reported. These data are presented in the **5-minute Boulder Data** table.

The **8-Hour Ozone** table includes the leading 8-hour average of ozone for each of the sites.

Surface VOC data collected during IOPs at the Boulder, Jonah, Big Piney, Mesa, and Paradise sites are presented in the **VOC** table. A summary, grouping compounds by category type, for canister data collected at the VOC sites are available in **VOC Summary** table. Carbonyl sample concentrations of Formaldehyde and Acetaldehyde are presented in the **Carbonyl** table.

The data tables all have a flat format with the identifying information in the starting columns. The most common parameters are listed first. An empty data column and quality control flag indicates no measurements obtained at the site for that parameter. Additional documentation that includes a complete description of the data column, units, etc. is provided by Access 2013 in the information bar at the bottom of the Access window screen when the user is accessing the column. All data tables include a Record Number column at the end of the table, this column is intended to keep data sorted in chronological order by site to match the Sites table. With this option, a user can sort the table any way he or she chooses and have the capability of sorting the table into its original format.

The data have the following general unit configurations:

- Parts per billion for O_3, NO, NO_2, NO_x, NO_y, and SO_2
- Micrograms per cubic meter for PM_{10} and $PM_{2.5}$
- Parts per million for methane, non-methane hydrocarbons, and total hydrocarbons
- Micrograms per cubic meter, parts per billion by volume, and parts per billion by Carbon for VOC data,
- Meters per second for wind speed,
- Degrees Celsius for ambient temperature and dew point temperature,
- Watts per meter squared for solar radiation and ultra violet radiation,
- Percent for relative humidity, and
- Millibars for barometric pressure.

The 2015 UGWOS database contains data queries for quick data sorting based on a users needs. There are four queries for users to gain access to data (Days and Hours of Hourly Data, Individual Site Data, Sort 1-hour Ozone Data, and Sort 8-hour Ozone Data). Upon opening a query, the user will be asked some pertinent questions for the query. After the questions have been answered, the query will sort the data as designed. A more complete description of each query is below:

Days and Hours of Data- this query simply asks for the date and hours of data the user is looking for. The user is first asked to give a "Starting Date" and an "Ending Date"; these should fall within the UGWOS period of January 15, 2015 and March 31, 2015. Next the user will be asked for an hour beginning and an hour ending, the data are in hour beginning format (0-23). Data not between the specified beginning and ending hours will be removed for all days between the starting and ending dates.

Individual Site Data- The database has several tables with data sorted by air quality, meteorological, site information parameters, etc. This query takes all of the air quality and meteorological data from one station and places it into an individual table. The user will be asked for the five character alpha numeric "Station Code" found in the Sites table. Once a matching station code is entered the meteorological and air quality data will be output into one table.

Sort 1-hour Ozone Data- the purpose of this query and the **Sort 8-hour Ozone Data** query are to sort any data above a user specified threshold. The user will be asked to provide a level of which no data records with an ozone level below that threshold will be displayed. Common parameters are displayed in each data record.

All additional field names are described in the Parameters table. Users wishing to be notified of updates to the database can send their e-mail address to the UGWOS Database Manager, Scott Adamson, at scott.adamson@metsolution.com.

4. Summary

This document describes the 2015 UGWOS database. Feedback from study participants concerning this document and the database is requested and any suggestions for improvement are highly encouraged and appreciated.