

# FINAL REPORT 2013 UPPER GREEN RIVER WINTER OZONE STUDY

Prepared for:

Ms. Cara Keslar  
Wyoming DEQ - Air Quality Division  
Herschler Building  
122 West 25<sup>th</sup> Street  
Cheyenne, Wyoming 82002

By the TEAM of:

Meteorological Solutions Inc.  
T & B Systems

August 2013



**FINAL REPORT  
2013 UPPER GREEN RIVER WINTER OZONE STUDY  
TABLE OF CONTENTS**

<u>Section</u>	<u>Page</u>
1.0 INTRODUCTION .....	1-1
2.0 SUMMARY OF FIELD OPERATIONS.....	2-1
2.1 Overview.....	2-1
2.1.1 Planning Process .....	2-1
2.1.2 Monitoring Sites.....	2-2
2.1.3 UGWOS Website.....	2-5
2.2 Field Measurements .....	2-11
2.2.1 WDEQ Long-Term Monitoring Sites .....	2-12
2.2.2 True NO <sub>2</sub> Measurements.....	2-15
2.2.3 Mobile Trailer Measurements: Big Piney and Jonah Field .....	2-16
2.2.4 Mesonet Monitoring Stations.....	2-19
2.2.5 VOC Canister Sampling .....	2-22
2.2.6 miniSODAR™.....	2-23
2.2.7 Ozonesondes/Radiosondes.....	2-24
2.3 Designated VOC Canister Sampling Days .....	2-24
2.3.1 Forecasts for IOP/VOC Canister Sampling Events .....	2-25
2.3.2 Synoptic Weather Summaries of Canister Sampling Events .....	2-27
3.0 DATA QUALITY ASSURANCE, VALIDATION AND ARCHIVING .....	3-1
3.1 Database Management .....	3-1
3.2 Quality Assurance Program .....	3-3
3.2.1 Calibrations .....	3-8
3.2.2 Quality Assurance Audits .....	3-9
3.2.2.1 Performance Audits .....	3-9
3.2.2.2 System Audits .....	3-12
3.2.2.3 Processing of the miniSODAR™ data .....	3-15
3.3 Data Archiving.....	3-15
4.0 DATA ANALYSIS.....	4-1
4.1 Summary of 2013 Meteorological and Air Quality Conditions and Comparison with Prior Years .....	4-1
4.1.1 700 mb Comparison 2013 versus 2007-2012 .....	4-1
4.1.2 UGWOS Snow Cover in 2012 and 2013 .....	4-4

**Table of Contents  
Continued**

<u>Section</u>	<u>Page</u>
4.2	Ozone Spatial and Temporal Distribution ..... 4-6
4.2.1	Discussion of Spatial and Temporal Distribution of O <sub>3</sub> during Designated VOC Canister Sampling Periods ..... 4-11
4.2.2	Surface Wind Patterns Affiliated with Elevated Ozone during Designated VOC Sampling Periods..... 4-15
4.2.3	Comparison of Ozone in 2013 with 2005-2012..... 4-18
4.2.4	Comparison of NO <sub>x</sub> and PM during UGWOS 2013 with 2006-2012 ... 4-20
4.2.5	Comparison of NMHC and THC during UGWOS 2013 with 2010-2012 ..... 4-23
4.3	VOC Canister Sampling ..... 4-26
4.3.1	Jonah and Jonah 2 ..... 4-32
4.3.2	Comparison of 2013 to 2012 Study ..... 4-34
4.3.3	VOC Maximum Incremental Reactivity Analysis..... 4-36
4.3.3	VOC Quality Control Results ..... 4-38
4.4	miniSODAR™ Data ..... 4-41
4.5	Ozonesondes/Radiosondes..... 4-45
5.0	SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS..... 5-1
5.1	Summary ..... 5-1
5.1.1	UGWOS 2013 Field Operations ..... 5-2
5.2	Conclusions/Observations..... 5-3
5.3	Recommendations..... 5-5
5.3.1	WDEQ Upper Air Sounding System ..... 5-5
5.3.2	Tall Tower Measurements ..... 5-6
5.3.3	Expansion of Surface-Based Monitoring Network during UGWOS Using WDEQ-Owned Mesonet/VOC Canister Sampling Equipment ... 5-7
5.3.4	Lidar and Radiometer Measurements using the San Jose State Fire Research Lab..... 5-7
5.3.5	Ceilometer..... 5-9
5.3.6	Unmanned Aircraft ..... 5-9
5.3.7	Nocturnal Transport of NO <sub>x</sub> along Drainage Basins ..... 5-11
5.3.8	Improved miniSodar Data Assimilation and Analysis..... 5-13
6.0	ACKNOWLEDGEMENTS 2013..... 6-1
7.0	REFERENCES ..... 7-1

**Table**

2-1	Summary of Measurement Methods Used During UGWOS 2013..... 2-4
-----	--

**Table of Contents**  
**Continued**

<b><u>Table</u></b>	<b><u>Page</u></b>
3-1 Data Quality Control Codes Used in UGWOS Database .....	3-2
3-2 Method TO-14 DHA Compound List.....	3-5
3-3 Summary of QC Criteria for TO-14 Modified for DHA and PAMS Hydrocarbon Analysis.....	3-8
3-4 Mesonet Ozone Audit Results .....	3-11
3-5 Jonah Air Quality Audit Result Summary .....	3-11
4-1 Intensive Operational Periods by Year .....	4-3
4-2 Maximum Eight-Hour Average Ozone Concentrations (ppb) for Boulder (BD), Daniel (DN), Jonah, Juel Springs, Mesa, Pinedale (PD), Warbonnet (WB), Wyoming Range (WR), and Big Piney (BP) on Days When at Least One Site Recorded Concentrations >55 ppb.....	4-11
4-3 Eight-Hour Monthly Average and Maximum Ozone by Year for Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Wyoming Range .....	4-19
4-4 Monthly Average One-Hour NO and NO <sub>2</sub> Concentrations by Year for Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Wyoming Range .....	4-21
4-5 Monthly Average PM <sub>10</sub> and PM <sub>2.5</sub> Concentrations by Year for Boulder, Daniel, Pinedale, and Wyoming Range.....	4-22
4-6 Monthly Average CH <sub>4</sub> , NMHC, and THC Concentrations by Year for Boulder and Big Piney.....	4-23
4-7 Number of Days That Highest 1-Hr NMHC Concentration Exceeded 2.0 ppm and 4.0 ppm at Boulder and Bug Piney .....	4-24
4-8 Wind Speed Statistics for VOC Sample Locations.....	4-31
4-9 Top Compounds by Concentration and Potential Reactivity.....	4-38
4-9 VOC Quality Control Results .....	4-38
4-10 Boulder Mixing Height and Meteorological Metrics – January 15 through February 28.....	4-42

**Figure**

2.1 Active Monitoring Stations in the UGWOS 2013 Study Domain.....	2-3
2.2 Current Ozone Concentrations with Website Menu .....	2-6
2.3 Single Station Strip Charts Example.....	2-7
2.4 Ozone Strip Charts from All Sites for a User-Selected Time Period .....	2-8
2.5 VOC Canister Sample Composition for Each Sampling Site.....	2-8
2.6 Project Weather/Ozone Outlook Example.....	2-9
2.7 Example of a Radiosonde Balloon Flight Plot from January 17, 2013 .....	2-9
2.8 Images from Mesonet Site Cameras Updated on the Website Every 15 Minutes .....	2-10
2.9 Current Equipment Status .....	2-10
2.10 UGWOS 2013 Monitoring Site Data Retrieval Status .....	2-11
2.11 Photograph of Pinedale Monitoring Station .....	2-13
2.12 Boulder Monitoring Site during UGWOS 2013 .....	2-14

**Table of Contents**  
**Continued**

<b><u>Figure</u></b>	<b><u>Page</u></b>
2.13 Boulder Meteorological Station with TUVR Sensors and UGWOS VOC Sampling Tripod.....	2-14
2.14 Photograph of Interior of Boulder Monitoring Station.....	2-15
2.15 Mobile Trailer and VOC Sampling Tripod at the Big Piney Site.....	2-17
2.16 Jonah Field Monitoring Site with Adjacent VOC Tripod.....	2-18
2.17 Jonah 2 VOC Monitoring Site .....	2-19
2.18 Mesa Mesonet Site.....	2-20
2.19 Warbonnet Mesonet Site.....	2-21
2.20 Paradise Mesonet Site.....	2-21
2.21 miniSODAR™.....	2-23
2.22 Example Weather Outlook.....	2-26
2.23 700 mb Level Chart at 0500 MST January 20, 2013.....	2-28
2.24 Surface Chart at 0500 MST January 20, 2013.....	2-28
2.25 700 mb Level Chart at 0500 MST February 3, 2013.....	2-29
2.26 Surface Chart at 0500 MST February 3, 2013.....	2-30
2.27 700 mb Chart at 0500 MST March 14, 2013.....	2-31
2.28 Surface Chart at 0500 MST March 14, 2013.....	2-32
2.29 700 mb Chart at 0500 MST March 28, 2013.....	2-33
2.30 Surface Chart at 0500 MST March 28, 2013.....	2-33
4.1 700 mb Averages for 2007-2013 .....	4-2
4.2 Boulder Site January 15, 2012 (left) and 2013 (right).....	4-5
4.3 Boulder Site March 2, 2012 (left) and 2013 (right).....	4-6
4.4 Estimated Snow Depth at Boulder Based on Snow Stick Images .....	4-6
4.5 Maximum Eight-Hour and One-Hour Average Ozone Concentrations in the UGRB during UGWOS 2013 .....	4-7
4.6 Running Eight-Hour Ozone Concentrations during UGWOS 2013.....	4-8
4.7 Daily Maximum Eight-Hour Ozone Concentrations, UGWOS 2013 .....	4-10
4.8 One-Hour Average Ozone during Designated VOC Sampling Period 1.....	4-13
4.9 One-Hour Average Ozone during Designated VOC Sampling Period 2.....	4-13
4.10 One-Hour Average Ozone during Designated VOC Sampling Period 3.....	4-14
4.11 One-Hour Average Ozone during Designated VOC Sampling Period 4.....	4-15
4.12 One-Hour Average Ozone and Wind at Paradise and Juel Springs during VOC Sampling Period 1 .....	4-16
4.13 One-Hour Average Ozone and Wind at Paradise and Juel Springs during VOC Sampling Period 2.....	4-17
4.14 Comparison of Maximum 8-Hour Ozone and Daily Average NMHC at Boulder for UGWOS 2011-2013. Linear regression fit for 2013 data is shown.....	4-24
4.15 Comparison of Maximum 8-Hour Ozone and Daily Average NMHC at Big Piney for UGWOS 2012-2013. Linear regression fit for 2013 data is shown.....	4-25
4.16 VOC Concentrations from Canisters Collected at Boulder, Juel Springs, Jonah, and Jonah 2 .....	4-27

**Table of Contents  
Continued**

<b><u>Figure</u></b>	<b><u>Page</u></b>
4.17 VOC Concentrations from Canisters Collected at Paradise, Warbonnet, Mesa, and Big Piney.....	4-28
4.18 Relative Composition from Canisters Collected at Boulder, Juel Springs, Jonah, and Jonah 2 .....	4-29
4.19 Relative Composition from Canisters Collected at Paradise, Warbonnet, Mesa, and Big Piney.....	4-30
4.20 Total NMHC and Sample Time Windroses for Jonah and Jonah 2.....	4-33
4.21 Boulder VOC Data From UGWOS 2012 and 2013.....	4-35
4.22 Percent Composition of VOC Classifications.....	4-36
4.23 Actual and MIR Enhanced Total NMHC .....	4-37
4.24 February 3, 2013 Collocated Sample Comparison from Juel Springs.....	4-39
4.25 March 14, 2013 Collocated Sample Comparison from Warbonnet.....	4-39
4.26 March 28, 2013 Collocated Sample Comparison from Big Piney.....	4-40
4.27 January 19, 2013 Unintentional Collocated Sample Comparison from Boulder.....	4-41
4.28 Radiosonde Balloon Launch on January 17, 2013 Test Day .....	4-45
4.29 Morning Radiosonde on January 17, 2013 Test Day.....	4-46
4.30 Afternoon Ozonesonde/Radiosonde on January 17, 2013 Test Day .....	4-46

**Appendix**

- A Monitoring and Quality Assurance Plan
- B Microsoft Access Database Description

## 1.0 INTRODUCTION

The Wyoming Department of Environmental Quality – Air Quality Division (AQD) sponsored the Upper Green Winter Ozone Study (UGWOS) during the period January 15 to March 31, 2013. 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<sub>3</sub>) 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 were collected from a network of long-term air quality monitoring stations, temporary monitoring stations, upper air data from soundings and/or miniSODAR™, and various specialized ozone precursor measurement systems. Quality assurance project plans, data, and reports from previous UGWOS field efforts (2007-2012) are posted on the Monitoring Information Page of the WDEQ-AQD website.<sup>1</sup>

In 2013, AQD contracted with Meteorological Solutions Inc. (MSI) and sub-contractor T & B Systems to conduct a field measurement program which emphasized the spatial distribution of ozone and ozone precursors. MSI was responsible for overall project management, station siting, ozone event forecasting, 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 stationed full-time in the project area for the duration of the UGWOS field effort to install and operate eight (8) canister sampling sites, perform routine quality control checks on air quality sites, and provide immediate troubleshooting and repair for UGWOS and existing long-term monitoring sites in the project domain;
- Installation, calibration and operation of three mesonet sites providing continuous ozone, wind speed and direction, temperature and camera images;

---

<sup>1</sup> <http://deq.state.wy.us/aqd/Monitoring%20Data.asp>

- Installation, calibration, and operation of a temporary ambient air monitoring station in the Jonah Field which provided continuous measurements of O<sub>3</sub> and oxides of nitrogen (NO<sub>x</sub>) as well as wind speed, wind direction, temperature and camera images;
- Speciated hydrocarbon sampling using stainless steel canisters at eight (8) sites on designated sampling days; and
- Ozonesonde/radiosonde operations (2 flights per day) during periods when conditions favoring potential elevated ozone episodes were forecast.

T & B Systems provided independent quality assurance audits, an updated Quality Assurance Project Plan (QAPP) and data collection and validation and analysis for AQD's miniSODAR™ which continued to operate at the Boulder monitoring site.

Field operations for UGWOS 2013 started on January 15, 2013 and continued through March 31, 2013. Daily weather outlooks were issued by MSI's 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 additional speciated VOC canister and upper air ozonesonde/radiosonde measurements could be implemented during these Intensive Operational Periods (IOP's). IOP conditions never materialized during the UGWOS 2013 field measurement season and instead there were five designated volatile organic compound (VOC) sampling days which were forecast to be characterized by high pressure, light winds and sunny skies.

This report presents a summary of UGWOS 2013 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 and 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 2013 measurement data are available in an ACCESS database on the AQD website.

## **2.0 SUMMARY OF FIELD OPERATIONS**

This section provides a description of measurement platforms active during UGWOS 2013, operational forecasts, and synoptic weather summaries during 2013 designated VOC sampling periods.

### **2.1 Overview**

UGWOS 2013 field operations were scheduled for January 15, 2013 through March 31, 2013. All UGWOS 2013 monitoring sites were installed, calibrated, and ready for operations by January 14, 2013. Forecasting for elevated ozone conditions started on January 15, 2013 and continued through March 31, 2013.

#### **2.1.1 Planning Process**

A siting trip was conducted with AQD personnel on December 12, 2012 to locate a suitable replacement for the former Jonah site to monitor ambient conditions in the Jonah Field area. After investigating several possible alternatives, a site just outside the property line of the Linn Energy facility was selected as the best alternative since the facility was willing to allow access to their power. This monitoring location is approximately six kilometers west of the 2012 site and representative of the Jonah Field.

During UGWOS 2013, three (3) tripod-mounted solar-powered mesonet sites were operated at locations utilized during previous measurement programs. These included two former mesonet sites – Mesa and Warbonnet, and the 2011 location of tethered balloon measurements now designated as the Paradise site.

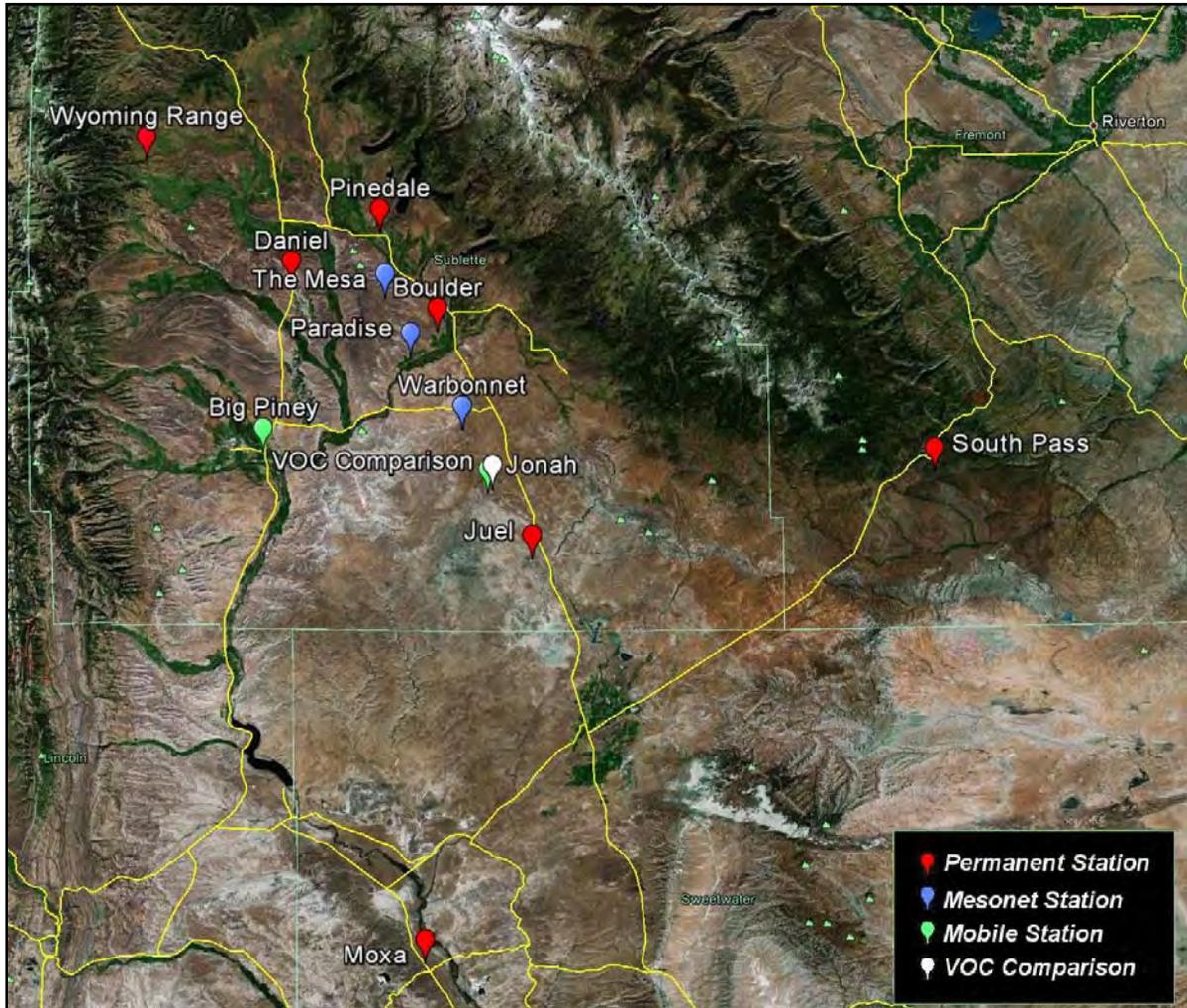
These sites, as well as an additional control site for VOC canister measurements conducted at the new location of the Jonah site mentioned above, required clearance for wildlife concerns and Bureau of Land Management (BLM) approval. BLM approval for the three mesonet sites was granted on January 7, 2013 and on January 22, 2013 for the additional Jonah VOC control site designated as Jonah 2.

As in 2012, AQD-owned VOC sampling systems were utilized for the UGWOS 2013 VOC sampling effort. Sampling systems were retrieved in December, 2012, cleaned, leak-checked and tested for contamination prior to operational use during UGWOS 2013.

### **2.1.2 Monitoring Sites**

All of the currently operating long-term WDEQ-AQD monitoring stations in the UGRB, three mesonet sites, the WDEQ miniSODAR, mobile trailers at Big Piney and in the Jonah field, and a VOC measurement control site for the Jonah field station provided meteorological and air quality data for the UGWOS 2013 database. A map showing the measurement stations active during the UGWOS 2013 program 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 2013 Study Domain**

**Table 2-1**

**Summary of Measurement Methods Used During UGWOS 2013**

Platform	Measurement	Instrumentation	
		Method	Model
Big Piney Mobile Trailer	Ozone	UV Photometric	T-API 400E
	NO <sub>x</sub>	Chemiluminescence	T-API 200E
	Methane/THC/NMHC	FID	Baseline-Mocon 9000
	PM <sub>2.5</sub> , PM <sub>10</sub> , PM <sub>10-2.5</sub>	Beta Attenuation	BAM 1020
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	WS, WD, Temp., RH, BP,Solar Rad.,Precip.	Various	Various
Jonah Field Mobile Trailer	Ozone	UV Photometric	Thermo 49i
	NO <sub>x</sub>	Chemiluminescence	Thermo 42i
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	WS, WD, Temp.	Various	Various
Boulder Special Measurements	True NO <sub>2</sub>	Chemiluminescence	T-API 200EU w/Photolytic Converter
	NO <sub>y</sub>	Chemiluminescence	T-API T200U w/501Y NO <sub>y</sub> Converter
	Methane/TNMHC	FID	Baseline-Mocon 9000
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
WDEQ Long-Term Monitoring Sites	Ozone	UV Photometric	T-API 400E/400A
	NO <sub>x</sub>	Chemiluminescence	T-API 200E/200A
	PM <sub>10</sub>	Tapered Element Oscillating Microbalance Beta Attenuation Monitor	TEOM 1400a (Daniel, Boulder, South Pass)  BAM 1020(Moxa and Wyoming Range)
	PM <sub>2.5</sub>	Beta Attenuation	BAM 1020 (Pinedale & Wyoming Range)
	SO <sub>2</sub>	Pulsed Fluorescence	Thermo 43i (Moxa)
	TUVR	Incoming and reflected short wave radiation	Eppley TUVR (Boulder & Moxa)

**Table 2-1 Continued**

**Summary of Measurement Methods Used During UGWOS 2013**

Platform	Measurement	Instrumentation	
		Method	Model
Mini-SODAR	Upper Level Winds	Doppler Sodar	ASC 4000 mini-SODAR
	Mixing Height	Doppler Sodar	ASC 4000 mini-SODAR
	Surface wind speed, wind direction, temp., RH, pressure and precip. detection	Integrated sonic anemometer, thermistor, RH and pressure sensors with separate precip. detection sensor	Vaisala WXT-510
Mesonet Sites	Wind Speed	Propeller Anemometer	RM Young 05305
	Wind Direction	Vane	RM Young 05305
	Temperature	Thermistor Probe	CSI 109
	Ozone	UV Photometric	2B Technologies, 202
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
Ozonesonde/Radiosonde	Ozone /Meteorology Vertical Profiles	Electrochemical Conc. Cell Balloon-Borne Ozone/Radiosonde	EN-SCI Model 2Z ECC Ozonesonde iMet-3050 403 MHz GPS Upper Air Sounding System

**2.1.3 UGWOS Website**

The UGWOS website was again hosted by MSI for the 2013 field study 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:

- Wyoming Range
- Pinedale
- Daniel
- Boulder
- Juel Springs
- Jonah Field
- Warbonnet
- Mesa
- Paradise
- Moxa
- Big Piney
- South Pass

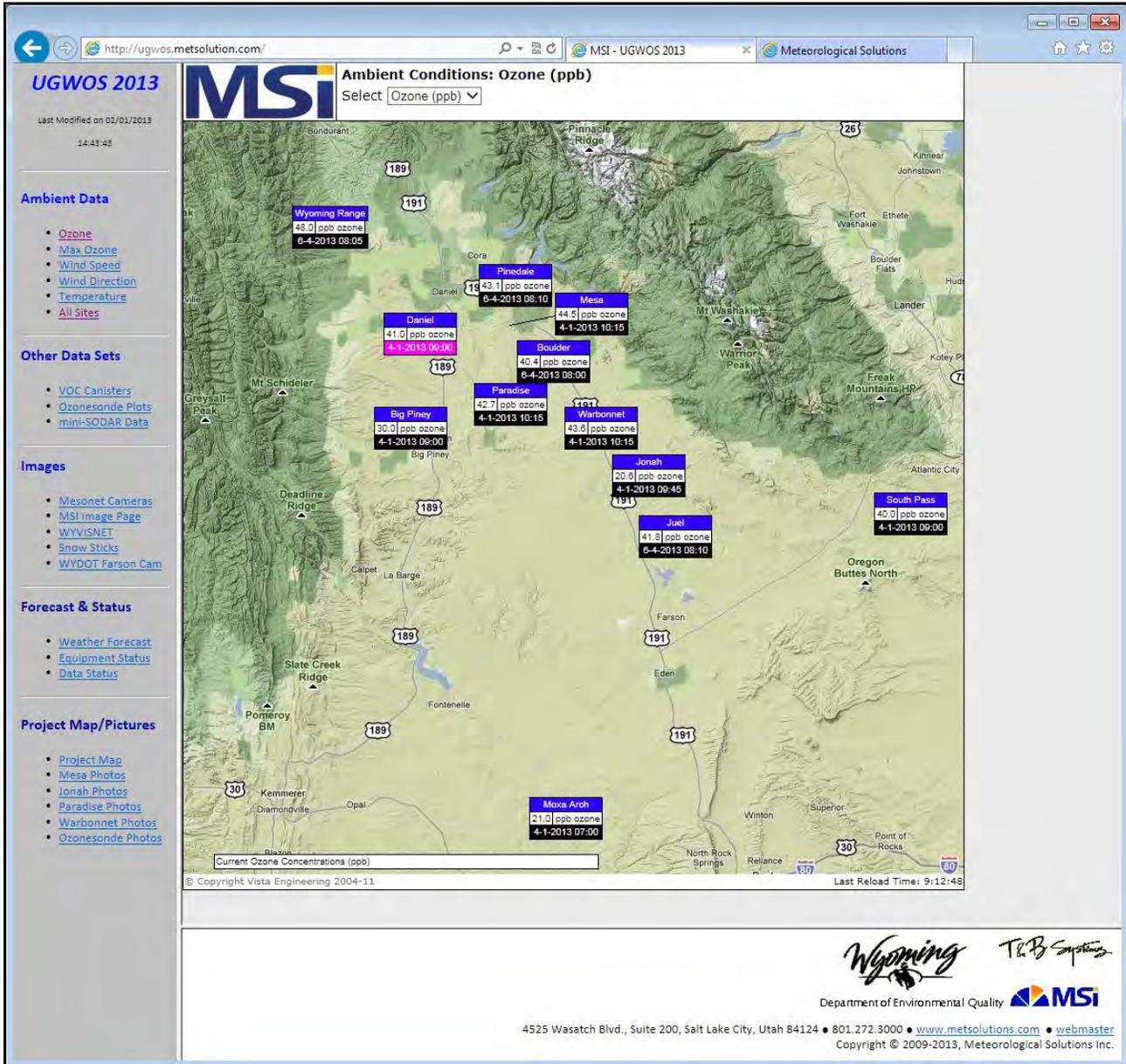


Figure 2.2 Current Ozone Concentrations with Website Menu

In addition to continually updated ozone information, wind speed, wind direction, and temperature data were 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). VOC canister sample data were available as bar graphs for each site's samples showing sample composition as ppbC for the following groupings: oxygenates, olefins, naphthenes, aromatics, isoparaffins, and paraffins (Figure 2.5). The project weather and ozone outlook page was updated on a daily basis (Figure 2.6). Ozonesonde/radiosonde sounding plots were posted on the web page soon after sounding runs were completed (Figure 2.7). Camera images from mesonet (Figure 2.8) 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 2.9). A monitoring site data retrieval status table (Figure 2.10) 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, the miniSODAR data, and the WYDOT Farson camera.

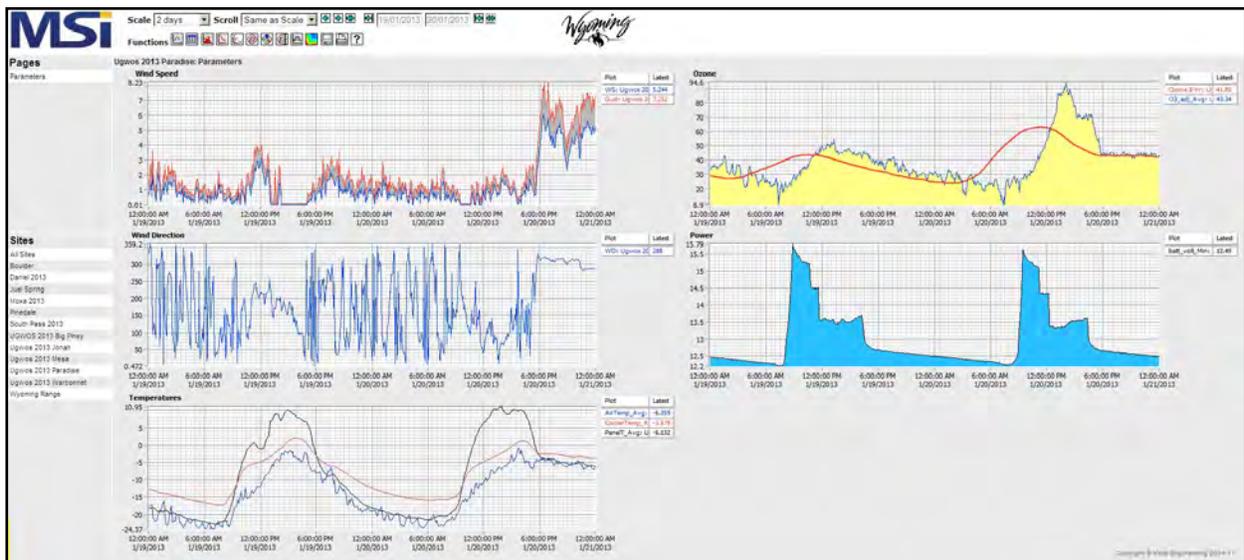


Figure 2.3 Single Station Strip Charts Example

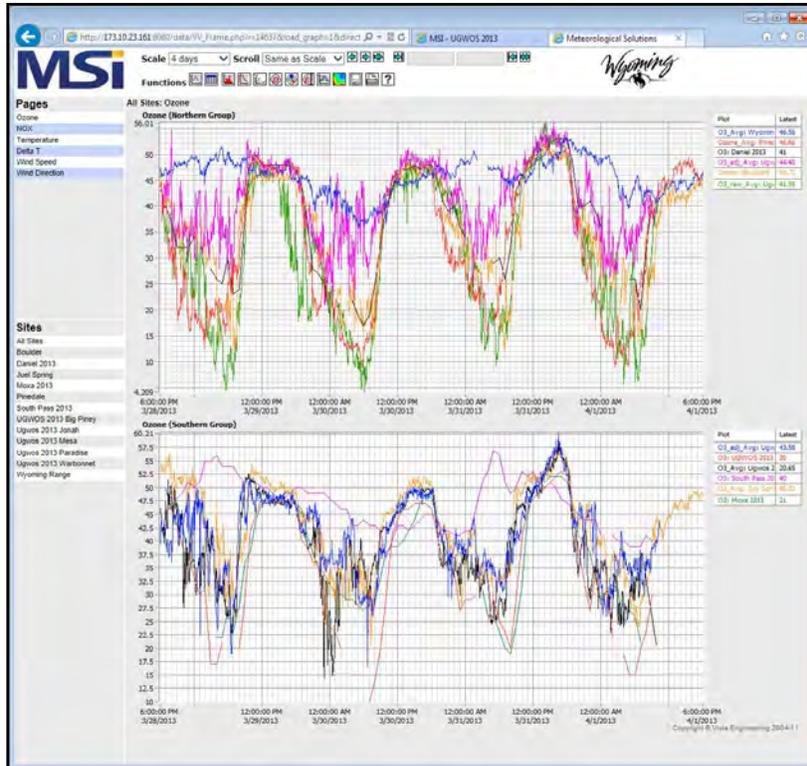


Figure 2.4 Ozone Strip Charts from All Sites for a User-Selected Time Period



Figure 2.5 VOC Canister Sample Composition for Each Sampling Site

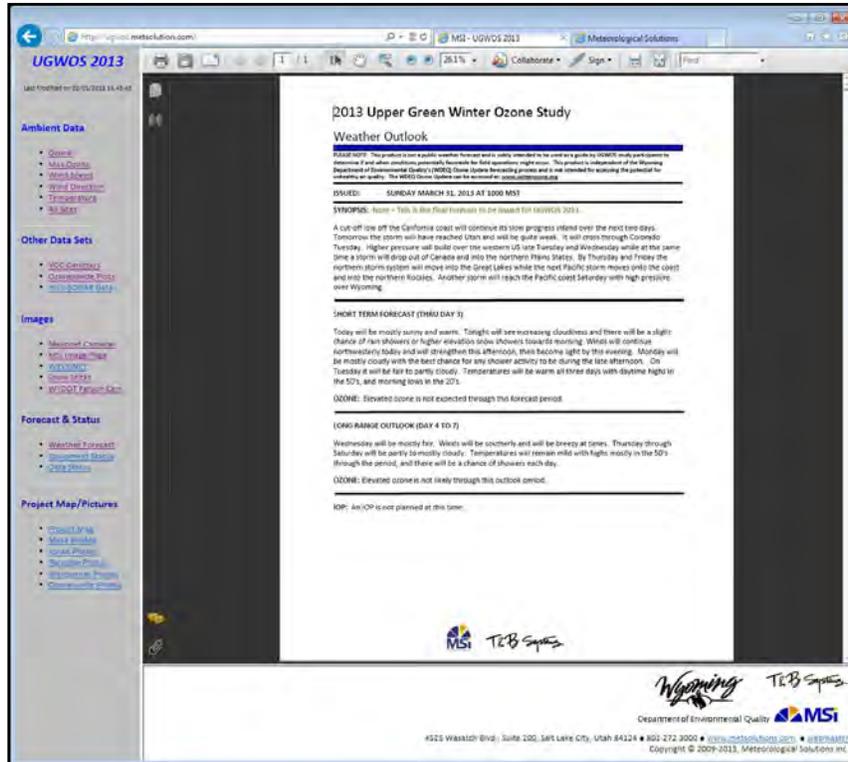


Figure 2.6 Project Weather/Ozone Outlook Example

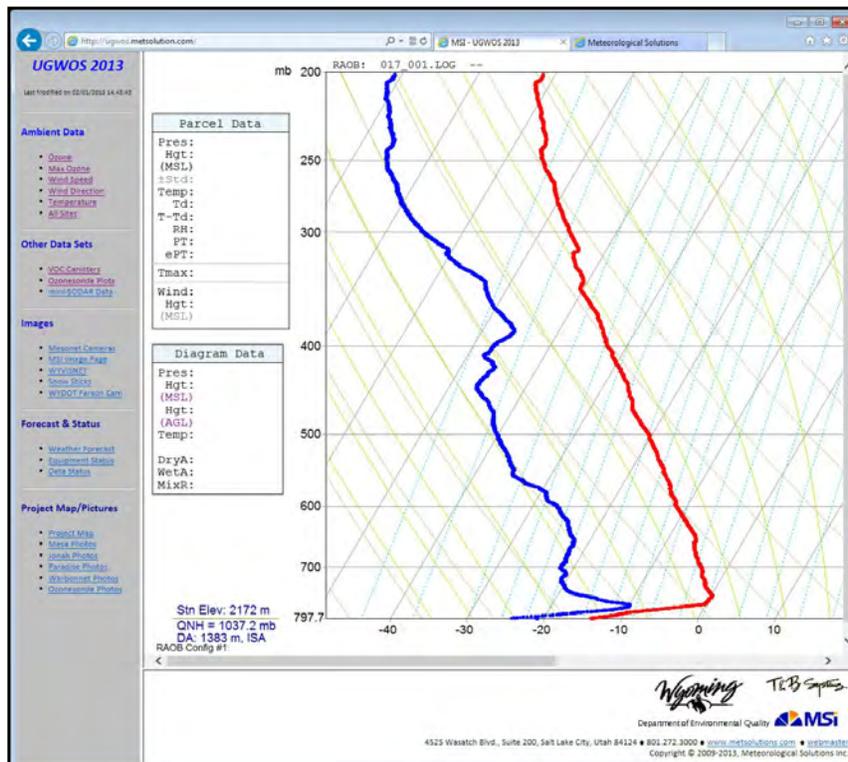


Figure 2.7 Example of a Radiosonde Balloon Flight Plot from January 17, 2013

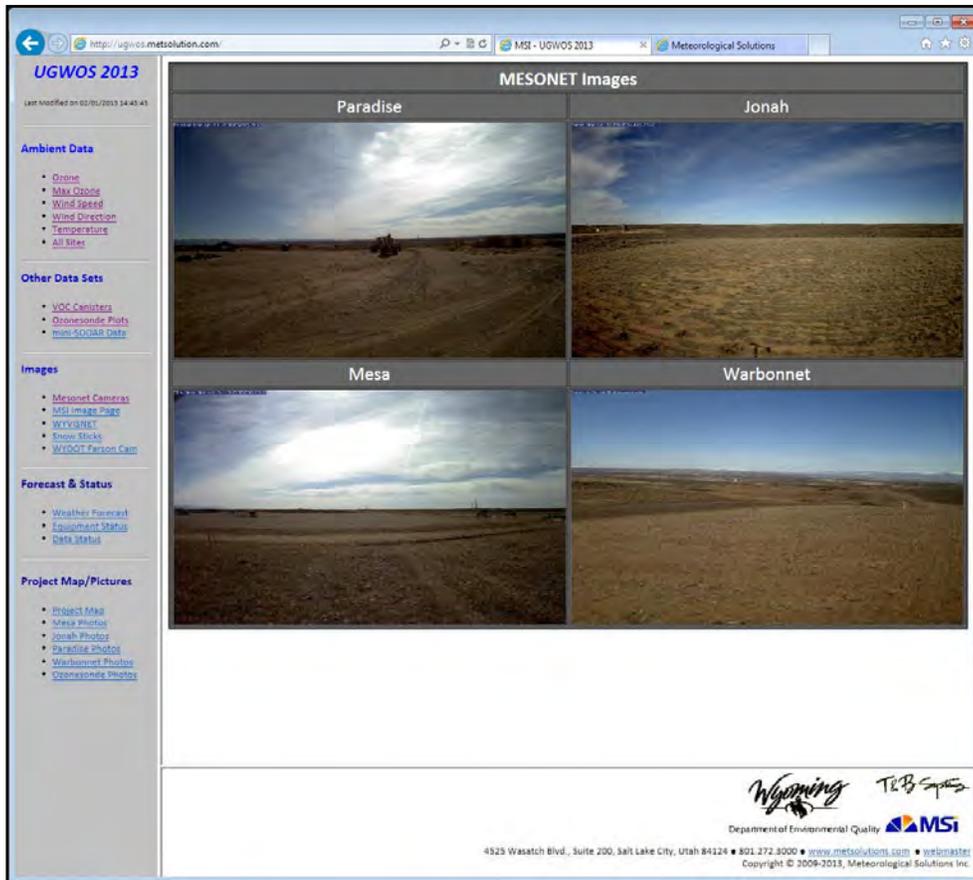


Figure 2.8 Images from Mesonet Site Cameras Updated on the Website Every 15 Minutes

UGWOS 2011

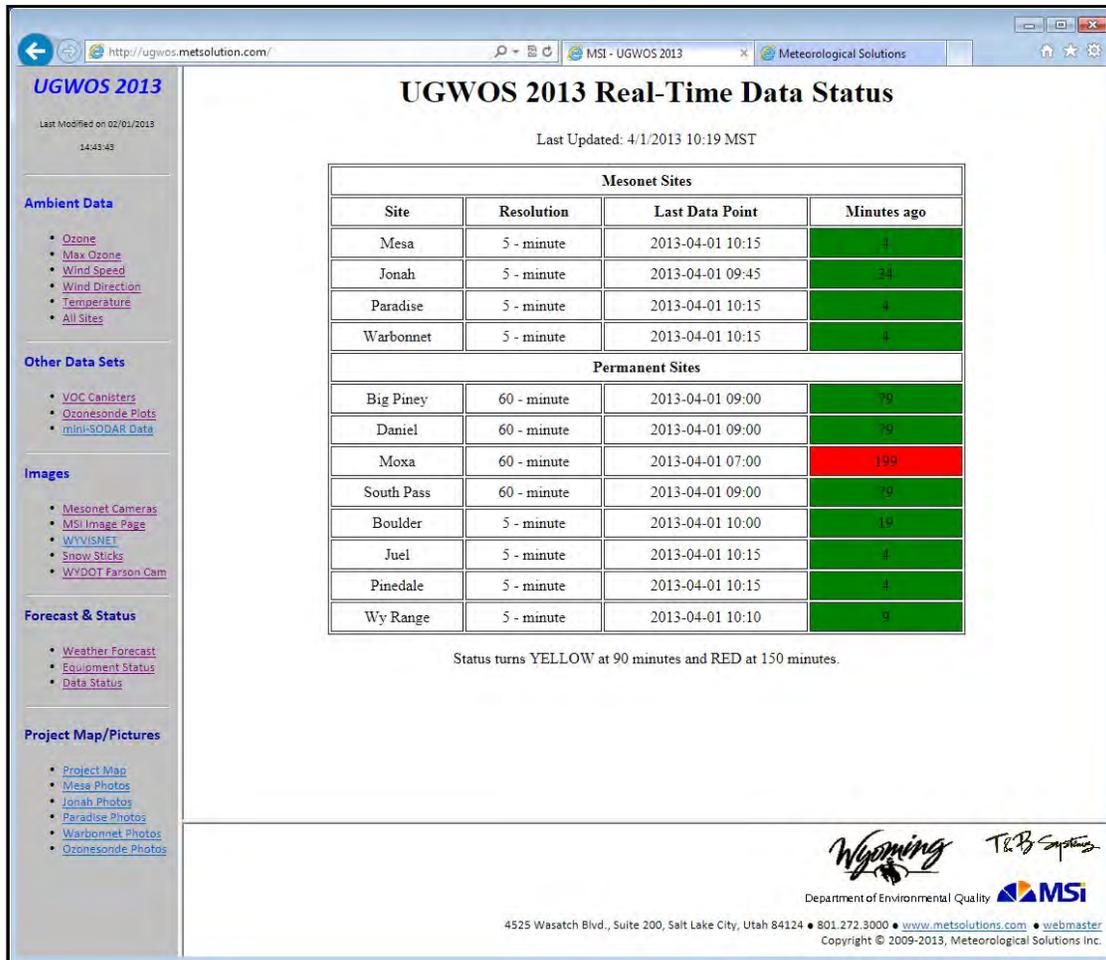
UGWOS 2011 Equipment Matrix and Current Status - Last Modified on 03/01/2011 18:02:23

No.	Site Name	Site Operator	Telemetry	WS	WD	TEMP	RH	THC	O3	PM	HONO	NO	NO2	NOX	Formaldehyde
1	Boulder	ARS	X	X	X	X	X	X	X	X	X	X	X	X	X
2	Daniel	JML	X	X	X	X	X	X	X	X	X	X	X	X	X
3	Juni Spring	MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
4	Pinedale	MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
5	Wyoming Range	MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
6	Moxa	ARS	X	X	X	X	X	X	X	X	X	X	X	X	X
7	South Pass	ARS	X	X	X	X	X	X	X	X	X	X	X	X	X
8	HONO (at Boulder)	U of H/MSI	X								X				X
9	Trailer / Tethered Balloon	ARS/T&B/MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
10	Tall Tower 5 meter level	T&B/MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
11	Tall Tower 25 meter level	T&B/MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
12	Tall Tower 50 meter level	T&B/MSI	X	X	X	X	X	X	X	X	X	X	X	X	X
13	Tall Tower 75 meter level	T&B/MSI	X	X	X	X	X	X	X	X	X	X	X	X	X

h	Operational
X	Suspect
X	Delayed Connectivity
X	Inoperative
X	Not installed yet

Department of Environmental Quality  
 Wyoming T&B Synthesis ENVIRON  
 4525 Wasatch Blvd., Suite 200, Salt Lake City, Utah 84124 • 801.272.3000 • www.metsolutions.com • webmaster

Figure 2.9 Current Equipment Status



**Figure 2.10 UGWOS 2013 Monitoring Site Data Retrieval Status**

## 2.2 Field Measurements

Measurement stations which provided data for the UGWOS 2013 database included the long-term WDEQ-AQD monitoring stations operating in the UGRB study area, two WDEQ mobile trailer monitoring sites at Big Piney and the Jonah Field, and the WDEQ mini-SODAR located adjacent to the Boulder monitoring station. Three mesonet sites collected ozone, meteorological data and camera images on solar-powered tripods during UGWOS 2013. During the field measurement season, VOC canister samples were collected on designated days at eight locations - the two mobile trailer sites, the three mesonet sites, the Jonah 2 site and two of the long-term monitoring stations – Boulder and Juel Springs. The Ozone/Radiosonde tracking system was set up and operated at the Boulder monitoring site.

### **2.2.1 WDEQ Long-Term Monitoring Sites**

WDEQ monitoring stations in the UGRB which were actively collecting data during UGWOS 2013 included Wyoming Range, Daniel South, Boulder, Pinedale, Juel Springs, South Pass, and Moxa. Long-term monitoring sites transmit camera images taken from the site every 15 minutes. These sites also typically measure wind speed and direction at 10 meters, temperature, relative humidity, barometric pressure, solar radiation and precipitation. Boulder and Moxa were also 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 measures sulfur dioxide. Figure 2.11 presents a photograph of the Pinedale long-term monitoring site. Figures 2.12 and 2.13 show the more extensive long-term monitoring station at Boulder. Figure 2.14 presents a photograph of the Boulder station interior.



**Figure 2.11 Photograph of Pinedale Monitoring Station**



**Figure 2.12 Boulder Monitoring Site during UGWOS 2013**



**Figure 2.13 Boulder Meteorological Station with TUVR Sensors and UGWOS VOC Sampling Tripod**



**Figure 2.14 Photograph of Interior of Boulder Monitoring Station**

### **2.2.2 True NO<sub>2</sub> Measurements**

True NO<sub>2</sub> measurements continued at the Boulder monitoring site using a Teledyne-Advanced Pollution Instrumentation (T-API) Model 200EU Trace Level Oxides of Nitrogen analyzer with photolytic converter. This type of converter allows for better speciation of lower levels of NO<sub>2</sub> 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<sub>2</sub> to NO with negligible radiant heating or interference from other gases.

NO<sub>y</sub> was 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<sub>2</sub> 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<sub>y</sub> which might normally be lost in a conventional system with longer transit time between the sample inlet and the converter.

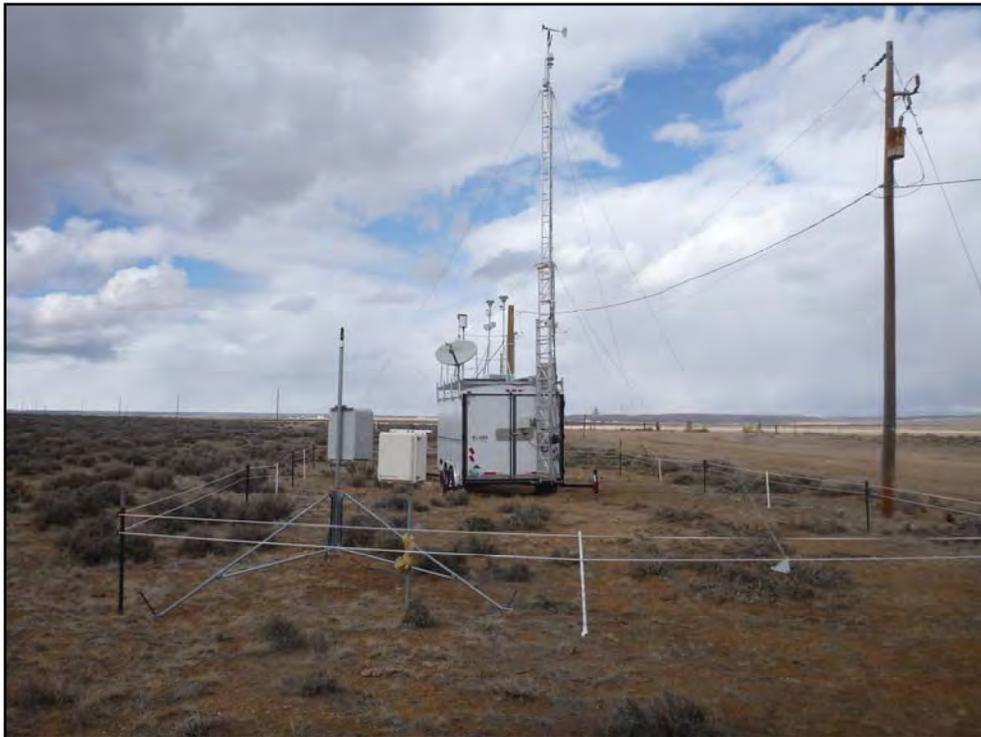
Total UV radiation (both incoming and reflected UV) was again measured at the Boulder site as it was during UGWOS efforts since 2007 using a pair of Eppley TUVR sensors with one pointed upward and the other pointed downward. Reflected UV provides a convenient indication of the presence of snow cover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

In addition, speciated VOC measurements are performed year-round using the TO-14 canister sampling method at the Boulder monitoring station. Canister samples were triggered automatically when continuously monitored non-methane hydrocarbon (NMHC) levels exceeded 2.0 parts per million (ppm). Samples were submitted to Environmental Analytical Services (EAS) laboratory after each event for modified TO-14 analysis as described in Section 3.2.

The Method TO-14 detailed hydrocarbon analysis (DHA) for 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 to determining 90 individual hydrocarbons, including the 55 PAMS compounds in air and gas samples.

### 2.2.3 Mobile Trailer Measurements: Big Piney and Jonah Field

One of AQD's mobile monitoring trailers operated by Air Resource Specialists (ARS) was located south of Big Piney. A VOC sampling system was located adjacent to the mobile trailer during the UGWOS 2013 field season. This trailer was outfitted with a 10-meter meteorological tower, a camera, and ozone, oxides of nitrogen, continuous particulate and hydrocarbon analyzers. Figure 2.15 shows a view of the mobile trailer including the VOC sampling system mounted on a tripod adjacent to the trailer.



**Figure 2.15 Mobile Trailer and VOC Sampling Tripod at the Big Piney Site**

Another AQD mobile trailer, installed and operated by MSI, was located in the Jonah field utilizing electric power from the nearby Linn Energy facility. This trailer collected wind and temperature data, camera images, and continuous ozone and oxides of nitrogen data using USEPA equivalent method analyzers. A VOC canister sampling system was mounted on a tripod adjacent to the trailer. As a control on Jonah site VOC canister measurements, a VOC canister sampling tripod was operated on the same schedule at a site designated as Jonah 2 located approximately 410 meters to the north-northeast. Figure 2.16 presents a view of the Jonah field monitoring site; Figure 2.17 shows a photo of the Jonah 2 site.



**Figure 2.16 Jonah Field Monitoring Site with Adjacent VOC Tripod**



**Figure 2.17 Jonah 2 VOC Monitoring Site**

#### **2.2.4 Mesonet Monitoring Stations**

During 2013, three mesonet stations were operated at locations used during previous UGWOS field programs. Locations included Mesa, Warbonnet and Paradise (formerly the Tethered Balloon Trailer Site). Sites were solar-powered with battery backup and continuously measured ambient ozone, 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 (agl); ambient temperature and the ambient ozone sample inlet were positioned at approximately two meters agl. As in past programs, ozone at the mesonet sites was measured utilizing 2b Technologies portable ozone analyzers housed in insulated coolers. Although these analyzers now have EPA equivalent method designation when the operating range is 10-40 degrees centigrade (°C), they were operated in much colder environments during the 2013 program (as low as -19° C with an average temperature of approximately 0° C for the measurement season).

Each 2b ozone analyzer was outfitted with low temperature modifications including an ozone lamp heater and rotary vane pump. Remote telemetry at each site included a wireless modem/router enabling data collection of five-minute average digital data with remote polling by MSI's server in Salt Lake City. Camera images were collected and transmitted every 15 minutes. Tripod-mounted VOC canister sampling systems were activated at each site on designated days and collected three-hour integrated samples from 07:00 to 10:00 MST. Samples were analyzed by EAS laboratories using the modified TO-14 method as described in Section 3.2. Photographs of the three mesonet monitoring stations are shown in Figures 2.18 through 2.20.



**Figure 2.18 Mesa Mesonet Site**



**Figure 2.19 Warbonnet Mesonet Site**



**Figure 2.20 Paradise Mesonet Site**

### **2.2.5 VOC Canister 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. Canisters were typically loaded into each system on the day before a sampling event. A solenoid valve was activated by a datalogger to start the sampling process at the time selected (07:00-10:00) and closed at the end of the period. Canisters were retrieved immediately following each event and shipped within a few days to EAS laboratory for modified TO-14 analysis (description in Section 3.2) using gas chromatography with a flame ionization detector (GC/FID).

The automated VOC canister 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. One of the ten sampling systems was removed from service after a second round of purging, sampling zero air and analysis showed some residual contamination. Based on the analytical results from each sample, the remaining nine systems were declared clean.

VOC canister sampling systems were set up at Boulder, Juel Springs, Big Piney, Jonah Field, and the Jonah Field control site designated as Jonah 2 as well as at the three mesonet sites – Paradise, Mesa, and Warbonnet. The existing VOC canister sampling system at the Boulder site operated in its normal configuration (which triggers a canister sample when the NMHC value recorded by the site analyzer exceeds 2.0 ppm) during the UGWOS field season. An additional tripod-mounted sampling system was placed at Boulder for conducting VOC canister sampling on designated sampling days from 0700-1000.

Measurements of VOC's were originally scheduled to be conducted during designated IOPs. During UGWOS 2013, there were no designated IOPs, i.e. periods when elevated ambient ozone concentrations were expected to develop. There were, however, five designated VOC canister sampling days when conditions were forecast to be high pressure, light winds and sunny skies which included the following dates: January 19, January 20, February 3, March 14, and March 28, 2013.

### 2.2.6 miniSODAR™

The WDEQ Wind Explorer miniSODAR™ was maintained and operated adjacent to the Boulder monitoring station and continuously measured winds at the surface and aloft and provided mixing height information up to approximately 250 meters. Figure 2.21 shows the miniSODAR at its Boulder monitoring site location.



**Figure 2.21 miniSODAR™**

### **2.2.7 Ozonesondes/Radiosondes**

During UGWOS 2013, MSI operated AQD's ozonesonde/radiosonde upper air sounding system based at the Boulder monitoring site to provide vertical profiles of ozone and meteorology in the atmosphere above the study area. Radiosonde releases providing meteorological information were planned for the morning flights and radiosondes with attached ozonesondes to provide a vertical profile of ozone concentrations in the atmosphere above the UGRB were scheduled for the afternoons. MSI dedicated an air quality technician to prepare the sondes and conduct the soundings with the full-time UGWOS technician available as backup. Both technicians were trained prior to the start of the field program.

The operational plan called for soundings to be performed during designated IOPs. Since no IOPs were declared during UGWOS 2013, upper air soundings were limited to test runs conducted on January 17, 2013.

### **2.3 Designated VOC Canister Sampling Days**

During UGWOS 2013, weather and ozone development forecasts were issued daily to identify periods when conditions would be conducive to producing elevated ambient ozone concentrations in the study area. These periods would then be treated as IOP's when additional field activities, namely VOC canister sampling at eight (8) sites and ozone/radiosonde balloon launches, would take place. During UGWOS 2013, conditions conducive to significant elevated ozone formation never materialized and no IOP's were forecast. Instead, in order to provide additional speciated hydrocarbon data for the study domain, VOC canister sampling days were designated based on a forecast of stable, high pressure conditions with light winds and sunny skies.

This section describes the weather and ozone development outlooks issued daily to forecast elevated ozone episodes as well as the synoptic weather summaries of conditions during the designated VOC canister sampling days during UGWOS 2013.

### **2.3.1 Forecasts for IOP/VOC Canister Sampling Events**

Operational forecasts, as in past years, were issued on a daily basis in 2013. These forecasts were developed to assist in the planning for IOP events and other field operations. They were issued and posted on the UGWOS web site each morning by 10 AM MST.

The format of the operational forecasts in 2013 did not change from the 2012 study. The forecast form contained four sections. The first section provided a synopsis of current weather conditions over the western U.S. and described what the weather pattern was like and how weather systems in the current pattern would move during the following week. The second section provided a short term forecast for the study area that covered expected weather and ozone conditions for the day of the forecast and the following two days.

The third section was a longer range outlook that covered the period from four to seven days after the issuance date. This section provided expected weather conditions for the study area as well as what ozone development might occur during this period. The fourth section provided a brief statement indicating the status of IOP's and/or canister sampling events and what the possibilities of future events were. Figure 2.22 shows an example of a forecast issued in 2013 prior to a canister sampling event in February.

## 2013 Upper Green Winter Ozone Study

### Weather Outlook

**PLEASE NOTE:** This product is not a public weather forecast and is solely intended to be used as a guide by UGWOS study participants to determine if and when conditions potentially favorable for field operations might occur. This product is independent of the Wyoming Department of Environmental Quality's (WDEQ) Ozone Update forecasting process and is not intended for assessing the potential for unhealthy air quality. The WDEQ Ozone Update can be accessed at: [www.winterozone.org](http://www.winterozone.org)

**ISSUED:** FRIDAY FEBRUARY 1, 2013 AT 1000 MST

#### SYNOPSIS

A weak system will rapidly cross over the state today, but the strong winds aloft have pulled off to the east now and high pressure near the coast this morning will push inland today and peak in strength on Saturday. The ridge line will remain west of Wyoming and just inland from the coast. This ridge will weaken Sunday and Monday with stronger northwesterly winds sagging back south over Wyoming on Monday. One storm next week will move by north of the state Wednesday with another dropping out of the north Pacific and into the southwestern US for the end of the week.

#### SHORT TERM FORECAST (THRU DAY 3)

Today will see lighter winds and the cloudiness will be on the decrease by this afternoon with lingering snow showers through this morning. Tonight and Saturday will be mostly clear with light winds and building higher pressure. Inversions should strengthen tonight and Saturday night. On Sunday it will be mostly clear with the high pressure aloft weakening and with the surface high pressure center moving back to the west. Winds will be light.

**OZONE:** Elevated ozone is not expected today. There is a chance for elevated hourly or sub-hourly ozone readings on Saturday and again on Sunday.

#### LONG RANGE OUTLOOK (DAY 4 TO 7)

High pressure will continue to weaken on Monday and stronger northwest winds will develop aloft and likely at the surface as well. Weak high pressure will be over the state Tuesday and this will transition into westerly flow aloft Wednesday. Southwesterly flow is expected over the state on Thursday. Skies will be fair to partly cloudy through the period with breezy conditions at times. Temperatures will be a little above normal for early February. Strong surface inversions are not expected through this period.

**OZONE:** Elevated ozone is not expected through this period.

**IOP:** No IOP's are planned at this time. However, canister samples will be taken at all sites on Sunday.

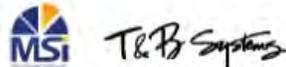


Figure 2.22 Example Weather Outlook

### **2.3.2 Synoptic Weather Summaries of Canister Sampling Events**

For 2013 there were no IOP's declared. However, there were four periods when VOC canister sampling occurred. The samples were taken in the morning hours between 0700-1000. The first sampling event occurred during the mornings on two consecutive days and the following three events were each conducted during the mornings on a single day.

#### ***January 19-20, 2013***

High pressure covered much of the western United States (US) on both days, with little change in the pattern from day to day, although pressure increased slightly from January 19 to 20. At the 700 millibar (mb) level, a high pressure ridge stretched from the Washington coastline south to western Arizona. A broad trough of low pressure was centered in northeastern Canada. The jet stream between the pressure centers pushed southeast out of British Columbia into the northern Plains and across the Great Lakes region. Wind speeds at 700 mb were as high as 28 meters per second (mps) across Montana and North Dakota, but over western Wyoming speeds were approximately 3 to 8 mps from the northwest.

At the surface, high pressure was covering much of southern Idaho, northern Nevada and Utah, and western Colorado and Wyoming. The surface pressure strengthened slightly over the study area from approximately 1032 mb on January 19 to 1038 mb on January 20.

Winds were light at the surface both mornings with speeds mostly under 4 mps. Winds were predominately from the northwest on January 19 but variable on January 20. Temperatures across the study area during the sampling on January 19 ranged from approximately -19<sup>0</sup>C to -5<sup>0</sup>C. Temperatures on January 20 were similar to the previous day temperatures, ranging from -19<sup>0</sup>C to -8<sup>0</sup>C. These temperatures were just slightly higher than the morning lows which occurred in the hour or two prior to when sampling began.

Figure 2.23 presents the 700 mb level chart for the morning of January 20; Figure 2.24 presents the surface weather chart, obtained from the National Centers for Environmental Prediction, Hydrometeorological Prediction Center, from the morning of January 20.

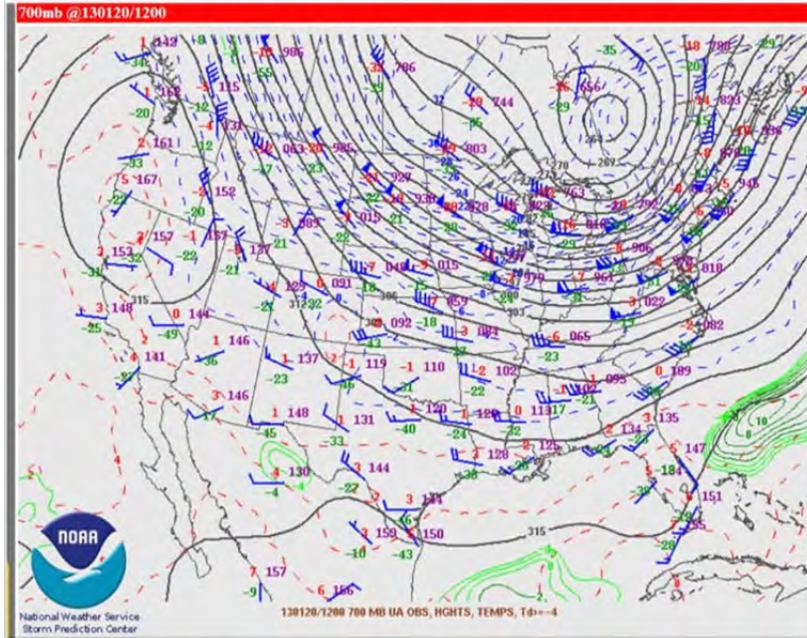


Figure 2.23 700 mb Level Chart at 0500 MST January 20, 2013

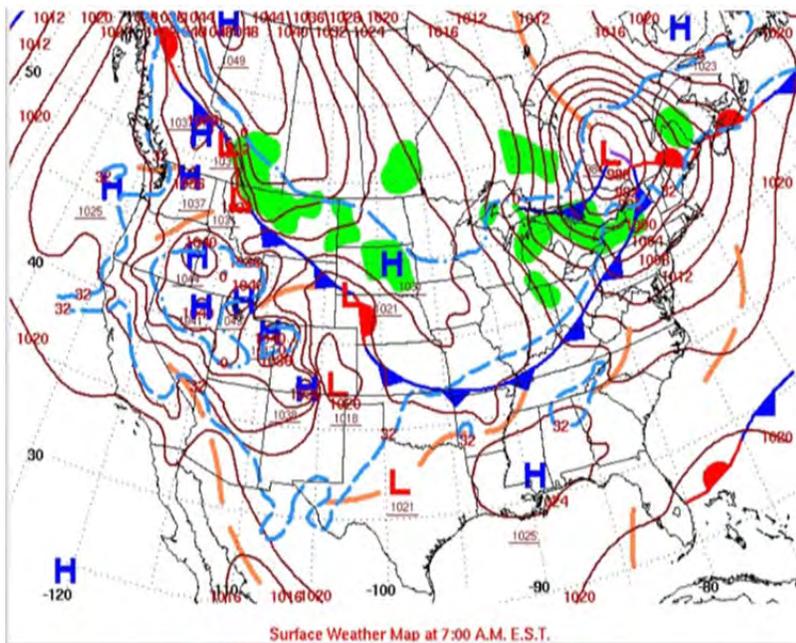


Figure 2.24 Surface Chart at 0500 MST January 20, 2013

February 3, 2013

The second period of VOC sampling occurred on February 3, 2013. The overall weather pattern was very similar to conditions during the first sampling period. High pressure aloft at 700 mb was found along the west coast, although a very weak storm system pushed through this ridge to the south of Wyoming during the day. A deep trough of low pressure aloft was over northeast Canada as well as much of the eastern US. Winds at 700 mb over western Wyoming were around 5 mps from the west.

At the surface, winds were under 4 mps from the northwest through northeast. Surface high pressure was centered over Idaho into northwest Colorado. The surface pressure over the study area was approximately 1024 mb in the morning. Morning temperatures during the sample period ranged from  $-13^{\circ}\text{C}$  to  $-6^{\circ}\text{C}$ . These were some of the coldest readings of the morning in the Basin. Figures 2.25 and 2.26 present the 700 mb and surface weather charts, respectively, for the morning of February 3.

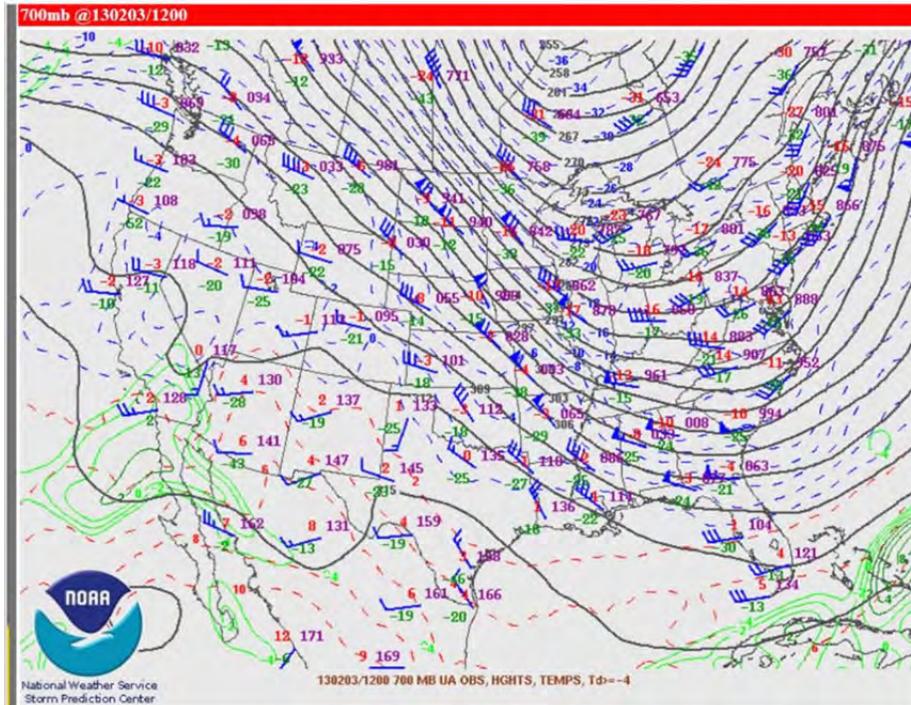


Figure 2.25 700 mb Level Chart at 0500 MST February 3, 2013

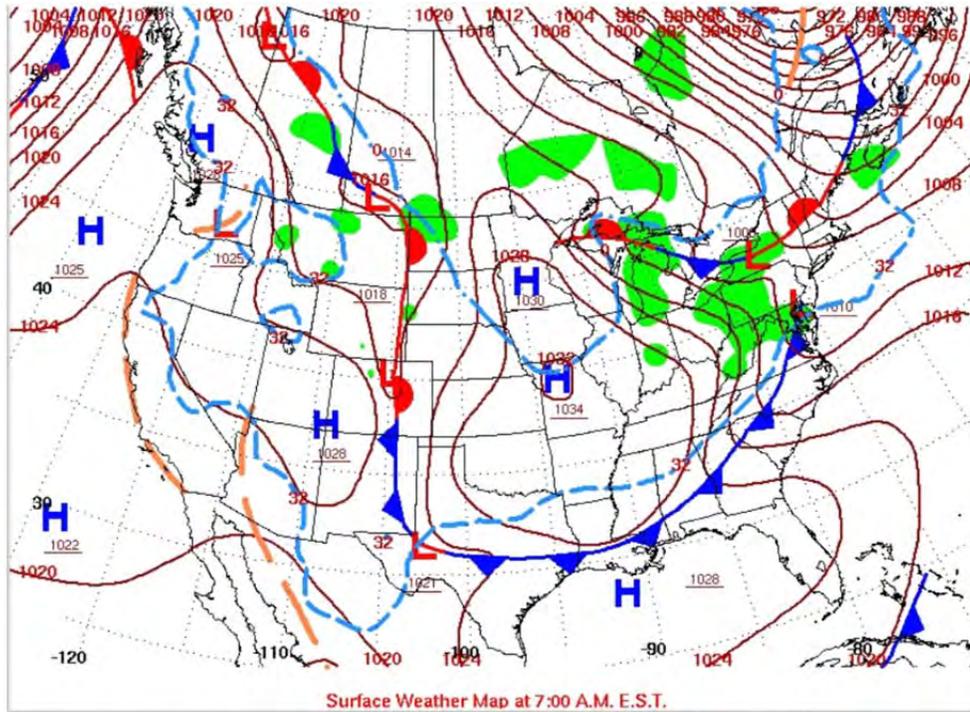
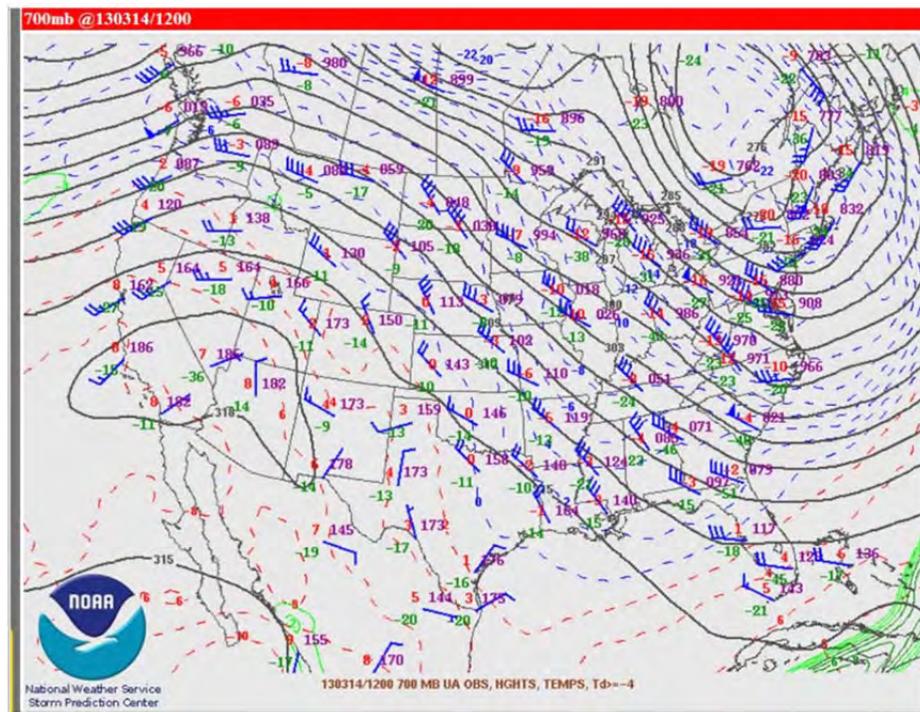


Figure 2.26 Surface Chart at 0500 MST February 3, 2013

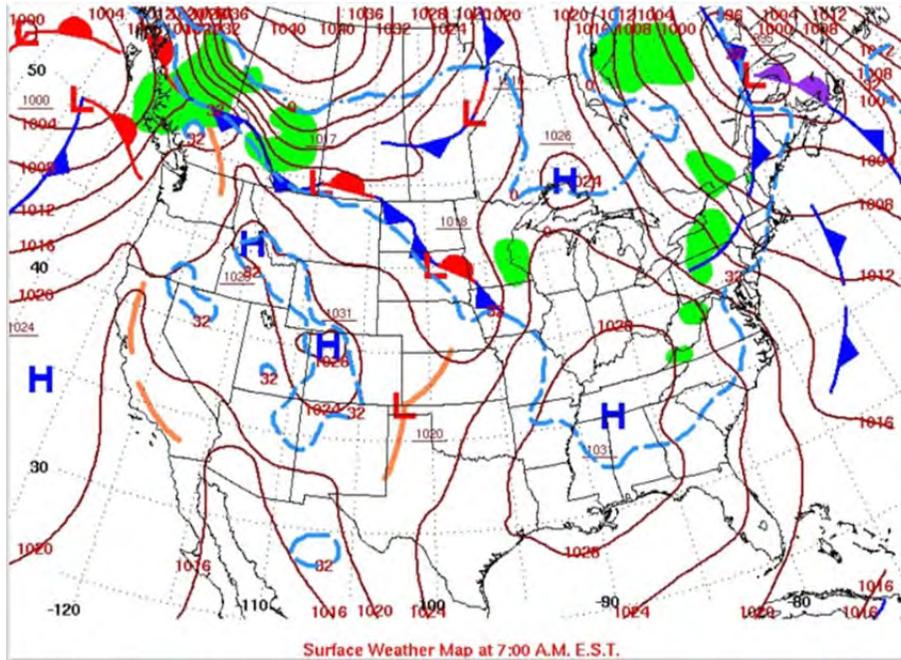
*March 14, 2013*

The third period of VOC sampling occurred on March 14, 2013. Again, the weather pattern was similar to the first and second sampling periods. High pressure aloft was stronger and closer to Wyoming. The ridge line was lying from Idaho south to the high pressure center located over the California/Nevada/Arizona triple point. A trough of low pressure at 700 mb stretched from the low center in southeast Canada down the east coast to Florida. Winds over western Wyoming at 700 mb were at 10 to 13 mps from the northwest.

Surface conditions were similar to the previous sample dates as well with high pressure centered over central Idaho, across western Wyoming into western Colorado. The surface pressure over the study area was approximately 1026 mb. Winds were very light with speeds between 1 and 2 mps. Directions were variable but tended to be from the northwest to northeast. Temperatures were warmer than previous sampling periods and ranged from  $-6^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  at the beginning of sampling, warming to  $0^{\circ}\text{C}$  to  $5^{\circ}\text{C}$  by 10 AM. Figure 2.27 presents the 700 mb weather chart for the morning of March 14. Figure 2.28 presents the surface weather chart for the morning of March 14.



**Figure 2.27 700 mb Level Chart at 0500 MST March 14, 2013**



**Figure 2.28 Surface Chart 0500 MST March 14, 2013**

***March 28, 2013***

The final VOC sampling period occurred on March 28, 2013. A relatively weak high pressure ridge over the western US was in place from Idaho southeast into Arizona and New Mexico. Lower pressure was found along the east coast. The 700 mb winds over western Wyoming were approximately 8 mps from the west to southwest.

At the surface, the wind speeds were at or less than 3 mps during the sampling. Wind directions were northwesterly initially, trending toward southeasterly by the very end of the sampling period. There was strong surface high pressure over the Midwest, while a stationary front was found along the eastern side of the Rockies from Montana through eastern Wyoming and south into New Mexico. The surface pressure over the UGWOS study area was approximately 1017 mb. Temperatures ranged from  $-6^{\circ}\text{C}$  to  $-4^{\circ}\text{C}$  at 7 AM which were morning lows, and warmed to  $0^{\circ}\text{C}$  to  $6^{\circ}\text{C}$  by 10 AM.

Figure 2.29 presents the 700 mb weather chart for the morning of March 28. Figure 2.30 presents the surface weather chart for the morning of March 28.

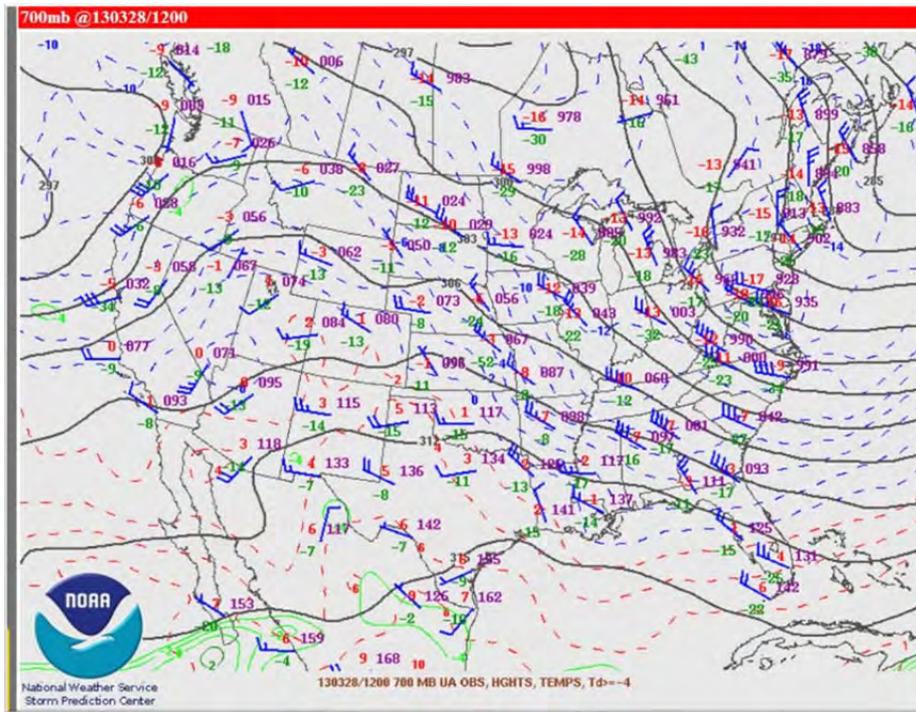


Figure 2.29 700 mb Level Chart at 0500 MST March 28, 2013

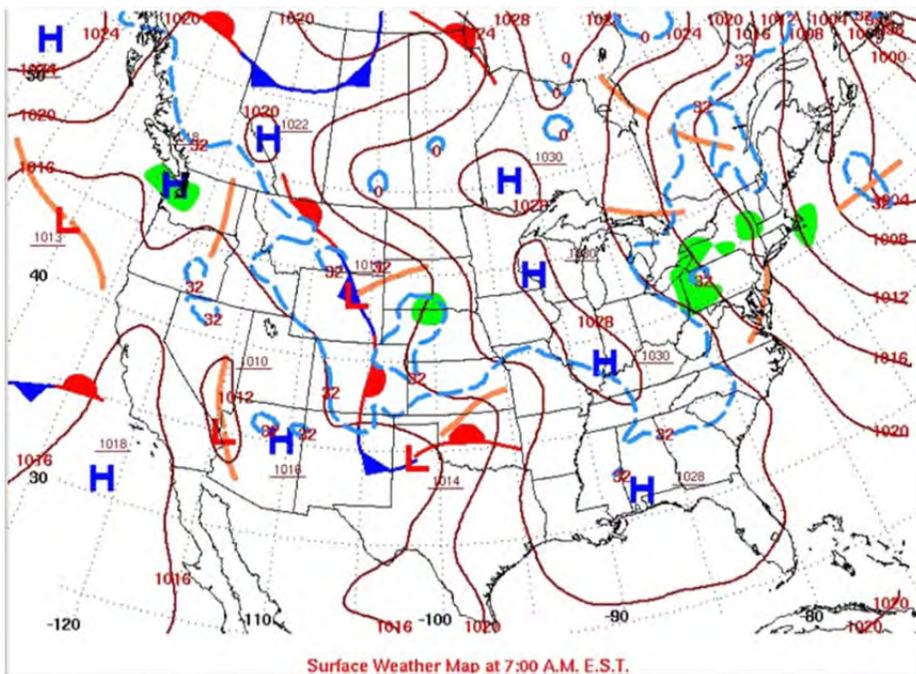


Figure 2.30 Surface Chart at 0500 MST March 28, 2013

### **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'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)<sup>1</sup>. 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.

---

<sup>1</sup> 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**

<b>QC</b>	<b>Description</b>
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
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

**Table 3-1 Continued**

**Data Quality Control Codes Used in UGWOS Database**

<b>QC</b>	<b>Description</b>
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

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 AQS Null code value or the value –9999. Suspect data or data that haven't been validated (one-minute Mobile Trailer data) 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.

All UGWOS 2013 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 were verified prior to the start of the program and again at the end by checks against a primary standard maintained at MSI's instrumentation laboratory in Salt Lake City. MSI's primary ozone standard was last verified by USEPA Region VIII on January 3, 2013. The oxides of nitrogen analyzer at the Jonah Field site was checked using an EPA Protocol Nitric Oxide calibration gas. Mass flow controller flows in the calibrator used at the Jonah Field site were calibrated at the start of the field program.

Data from mesonet sites, the Jonah Field site and long-term monitoring sites operated by MSI 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's air quality technician, stationed in the Pinedale, Wyoming area for the duration of the field program, was able to respond to and rectify problems quickly which enhanced data recovery.

WDEQ tripod-mounted portable VOC sampling systems were leak checked, cleaned and checked for contamination prior to the start of the UGWOS 2013 study. System components were first purged with clean ambient (humidified) air and then ultrapure air before testing. VOC canisters were 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 were free of contamination. During testing and on specified sampling days during the field program, a field sample data sheet was generated for each VOC canister indicating sample ID, sample date and time, and canister start and stop pressure. VOC canisters were sent back to the laboratory for analysis following each sampling event accompanied by a chain-of-custody form. Analysis was performed using Method TO-14, Detailed Hydrocarbon Analysis (DHA) for PAMS Compounds. 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). The method was used to determine 90 individual hydrocarbons including the 55 PAMS compounds in air and gas samples. The Method TO-14 DHA compound list, method detection limits, limits of quantification and other laboratory criteria are presented in Table 3-2.

**Table 3-2**  
**Method TO-14 DHA Compound List**

Analyte	MDL ppbV	LOQ ppbV	Criteria			Duplicate %Rel. Percent Diff.
			ICAL % RSD	CCV % Diff.	LCS % Diff.	
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

1. MDL – Method Detection Limit

3. ICAL – Initial Calibration

5. LCS – Laboratory Control Spike

2. LOQ – Limit of Quantification

4. CCV – Continuing Calibration Verification

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

Analyte	MDL ppbV	LOQ ppbV	Criteria			Duplicate %Rel. Percent Diff.
			ICAL % RSD	CCV % Diff.	LCS % Diff.	
1-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			75-130	<25
Cyclohexane	0.5	1.5				<25
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			75-130	<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			75-130	<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

1. MDL – Method Detection Limit

2. LOQ – Limit of Quantification

3. ICAL – Initial Calibration

4. CCV – Continuing Calibration Verification

5. LCS – Laboratory Control Spike

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

Analyte	MDL ppbV	LOQ ppbV	Criteria			Duplicate %Rel. Percent Diff.
			ICAL % RSD	CCV % Diff.	LCS % Diff.	
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			75-130	<25
Styrene	0.5	1.5				<25
o-xylene	0.5	1.5			75-130	<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			75-130	
2-Ethyltoluene	0.5	1.5				<25
b-Pinene	0.5	1.5				<25
1,2,4-Trimethylbenzene	0.5	1.5				<25
n-Decane	0.5	1.5				<25
1,2,3-Trimethylbenzene	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
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

1. MDL – Method Detection Limit

3. ICAL – Initial Calibration

5. LCS – Laboratory Control Spike

2. LOQ – Limit of Quantification

4. CCV – Continuing Calibration Verification

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 3-3. All canister QA results are included in the UGWOS database.

**Table 3-3**

**Summary of QC Criteria for TO-14 Modified for DHA and PAMS Hydrocarbon Analysis**

<b>Parameter</b>	<b>EAS TO-14 DHA Modified</b>
Initial Calibration	Five points 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

The status of the miniSODAR™ was checked daily via remote access of the data. When problems were noted, the UGWOS field technician was called upon to assist in correcting them. In addition, the miniSODAR™ data were available in real time so that team members were able to use the data to assist in special monitoring and forecasting. Additional information on quality assurance procedures for these data is provided in Appendix A.

**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 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. Temperature sensors were calibrated using water/ice baths.

Air quality analyzers were calibrated at the start of the UGWOS 2013 study and calibration was verified again at the end. Zero/span/one point QC checks were conducted approximately every two-weeks during the study.

### **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 auditor and the equipment used for the audit were independent of the measurement program. Audits were performed in accordance with the principles set forth by the US EPA.

#### **3.2.2.1 Performance Audits**

##### ***Air Quality Variables***

Mesonet ozone analyzers and ozonesonde measurements were audited using a Dasibi Model 1008 PC transfer standard that is certified against T&B Systems' primary standard maintained following EPA's guidelines at their office in Valencia, California. The Model 1008 PC is an ozone photometer equipped with self-contained zero air and ozone generation. For the mesonet audits, the transfer standard was operated within the SUV used during the audit. The transfer standard was powered using a true sine wave inverter, and was allowed to warm up prior to the audit to a point where the temperature within the standard's photometer cell was relatively stable. Ozone concentrations were fed to the mesonet site's sample inlet with an 8-foot ¼" Teflon line, with a venting tee placed at the inlet. The airflow to the tee was approximately 2 lpm, minimizing residence time within the line.

Gaseous analyzers at the UGWOS Jonah site were audited using a Teledyne Advanced Pollution Instrumentation (T-API) Model 700EU mass flow-controlled dilution calibrator to dilute known concentrations of audit gas with zero air and create known audit concentrations. EPA protocol gases from Scott-Marrin were used. The T-API calibrator is also equipped with an integrated photometer which was used as an ozone transfer standard. The T-API photometer is certified quarterly against a primary photometer maintained by T&B Systems following EPA guidelines.

Wind speed sensors were audited using an R.M. Young constant rpm motor simulating wind speeds at several points across the sensor's operating range. Wind direction sensors were audited by checking the sensor orientation and responses in 30° or 45° increments using the marks on the wind direction sensor. The wind speed starting threshold was checked using an R.M. Young torque disc. Wind sensors were left in place during the audit to minimize the audit effort and prevent any accidental damage to the monitoring system. This setup has the potential to result in decreased precision of the wind direction checks, particularly under windy or extremely cold conditions. In addition, wind direction starting thresholds could not be directly checked, though the bearings were inspected by feel.

Temperature sensors were audited using a water bath and a certified audit sensor. Three points were checked using an ice bath and two upscale water bath points between 10°C and 30°C. For sites where the ambient temperature during the audit was lower than -10°C, ambient temperatures were cold enough during the audit to provide an additional check at a sub-zero level using a collocated temperature sensor.

Ozone audit results are summarized in Table 3-4. Note that site readings consist of five-minute averaged "adjusted" values which take into account results from the most recent performance checks conducted by MSI. All of the results showed agreement within about 4%, easily meeting the audit criteria of  $\pm 10\%$ . Audits of the mesonet meteorological systems revealed that all wind and temperature sensors were operating correctly.

All special study gaseous analyzers at the Jonah site trailer easily met the audit criteria, and audits of the meteorological systems at both the Jonah and Jonah 2 sites revealed that all wind and temperature sensors were operating correctly. Results of the audit of the gaseous analyzers are presented in Table 3-5.

**Table 3-4**  
**Mesonet Ozone Audit Results**

Site	Max diff (%)	Slope	Intercept (ppm)	Correl
Warbonnet	-2.5	0.9792	-0.0004	1.0000
Mesa	-4.2	0.9585	0.0007	1.0000
Paradise	-0.9	0.9948	0.0000	0.9999

**Table 3-5**  
**Jonah Air Quality Audit Result Summary**

Site: Jonah Trailer Project: UGWOS QA Audits Operator: MSI  AMBIENT AIR QUALITY MONITORS					
Audit Date	Parameter	Max Diff. (%)	DAS Slope	DAS Intercept	DAS Correlation
2/6/2013	Ozone	-2.7	0.980	0.000	1.0000
2/6/2013	Nitric Oxide	-1.1	1.005	0.000	1.0000
2/6/2013	Nitrogen Oxides	-2.3	1.009	-0.001	0.9999
2/6/2013	Nitrogen Dioxide	-3.0	1.013	-0.001	1.0000
Audit Criteria: Max Diff $\pm 15\%$ , Slope $1.000 \pm 0.15$ ; Intercept $0 \pm 0.015$ ppm (THC $0 \pm 0.9$ ppm); Correlation $> 0.9950$					

***Ozonesondes***

MSI personnel were requested to activate an ozonesonde, which was then challenged with ozone concentrations from the audit transfer standard. MSI then processed the resulting data into files containing concentrations in ppb, which were then reviewed by the auditors. Initial comparisons between the ozonesonde and the audit transfer standard showed the ozonesonde readings 18% low.

After review of both the ozonesonde operations and the audit equipment (including verification of the audit concentrations using the independently audited Boulder ozone analyzer), it was determined that the most likely parameter affecting the ozonesonde readings was the ozonesonde sample flow rate (in seconds per 100 ml) used to initiate a given ozonesonde flight, which is directly proportional to the calculated ozone concentration. The value stamped on the ozonesonde pump was 28.0 - 28.2 s/100ml, whereas the value measured by the factory-supplied bubble flow meter (measured by recording the time in seconds for the bubble to travel 100 ml) was 23.5 s/100ml – a discrepancy that was unusually high based on the experience of the auditors. Using an available MSI mass flow meter, the operating technician measured the flow as 28.4 s/100ml (corrected to actual conditions), very close to the factory value. This flow rate was further confirmed using an audit Bios flow meter. Further investigation revealed that the volume marked on the bubble flow meter was significantly less than 100 ml (approximately 87 ml based on somewhat crude attempts to estimate the volume using available equipment). Using the factory value of 28.2 s/100ml produced readings that agreed within 1% of the audit values. Based on the above, it was decided that pump flow rates would be determined using the site's mass flow meter rather than the bubble meter.

The response times of the ozonesonde basically met the specifications presented in the QAPP, with 67% of the reading reached in 20 to 25 seconds and 85% of the reading reached within 40 seconds. This successfully addressed concerns initiated from review of the 2011 ozonesonde data.

### **3.2.2.2 System Audits**

A system audit of the field operations was conducted in late January 2012 by David Yoho of T&B Systems with remote assistance on the miniSODAR™ from Bob Baxter. The audit addressed the following field related elements:

- Siting of the equipment used for the intensive measurements
- Quality assurance and Quality Control procedures implemented
- Documentation of the field activities

- Data collection and chain of custody procedures

Observations from the system audits are presented below:

### *Air Quality Variables*

The data collection procedures and siting of the UGWOS specific measurements were reviewed. No problems were noted.

### *Ozonesondes*

The overall care in the preparation of the sondes appeared quite good, however, there were some procedural steps that should be modified to help prevent any potential contamination of ozonesonde cells or fluids used to charge the cells. These steps include the following:

- Individual cups should be used for the full strength anode and cathode solutions as well as individual cups for the distilled water used to rinse the anode and cathode syringes following the sonde preparation. These cups were appropriately labeled at the site but the methods used for the cell preparation didn't follow a rigorous procedure (described below) to prevent any potential contamination of the cells or main storage containers of the cathode or anode solutions. Additionally, the auditor recommended that a separate larger container or bucket be used as the waste water for all fluids from the cells and syringe rinses.
- When preparing the cathode cell for launch, the operator drew the solution directly from the large pre-mixed cathode solution container with the syringe. This method has the potential to contaminate the solution in this pre-mixed solution container with material that may be on or in the syringe.

It was recommended that the procedure be changed for both the anode and cathode solutions so that a small amount of solution is poured from the pre-mixed storage containers into the respective cathode and anode solution cups and that any leftover solutions in these cups never be poured back into the pre-mixed storage containers. Any fluids needed to charge the cells are then drawn directly from the small anode and cathode cups using the syringes. Any fluids that remain in the anode and cathode cups after charging the cells are then disposed of in the waste container and not poured back into the pre-mixed containers.

- When rinsing containers, cups, cells, and syringes, generous amounts of distilled water should be used. A small rinse bottle was being used by the operator and a potential for leftover material was observed if the rinsing was not thorough. This is where a larger wastewater bucket would help encourage the use of more distilled water to completely clean items and prevent leftover materials from being on the preparation utensils.
- An additional step was recommended to inspect the cell electrical connections at the base of the cell during the preparation phase to determine if any corrosion or leakage was present that may indicate a leak or breach of the electrical bridge between the anode and cathode cells. This step also included a visual inspection of the anode color to make sure it was still amber in color and had not turned clear, which would indicate a leak in the cell.

### ***MiniSODAR™***

The miniSODAR™ has been operational at the site for over three years with good data recovery. Prior to arrival at the site, the data were reviewed for internal consistency. While at the site a review of the level of the antenna was conducted. No problems were noted.

- A review of the miniSODAR™ vista showed an open view in all operational directions.
- The orientation of the miniSODAR™ (Antenna Rotation Angle) was measured to be 230°. This agreed with the software setting on the miniSODAR™. The reflector board was measured to be within the expected tolerance of 45° ±0.5°. The level of the antenna was found to be within the expected tolerance of 0.0° ±0.5°.

### **3.2.2.3 Processing of the miniSODAR™ data**

The processing of the miniSODAR data at the Boulder site was performed using three steps, as described below:

1. The 10-minute miniSODAR™ wind records were combined into hourly vector averages based on at least three intervals within the hour having valid wind data. During the merging process, additional screening criteria were applied to accept/reject individual values into the averaging calculation based on specified QC criteria. These criteria included echo intensities, signal to noise ratio, calculated radial velocity, standard deviation of the component values, and the reported percent of returns in the raw average.
2. The internal consistency of the hourly merged data was reviewed in a time-height cross-section display and periods of meteorologically inconsistent data were invalidated. This review was performed by a trained meteorologist.
3. The resulting hourly validated data from the miniSODAR™ database were exported into a comma delimited data set for submission.

## **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<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>x</sub>, NO<sub>y</sub>, and SO<sub>2</sub>

- Micrograms per cubic meter for PM<sub>10</sub> and PM<sub>2.5</sub>
- 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, START\_TIME or END\_TIME = Time stamp of data (HHMM) (MST)
- HEIGHT = Elevation in meters above MSL
- 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 2013 field effort.

### **4.1 Summary of 2013 Meteorological and Air Quality Conditions and Comparison with Prior Years**

This section describes meteorological and air quality conditions and measurements recorded during UGWOS 2013 and how they compared with previous UGWOS studies.

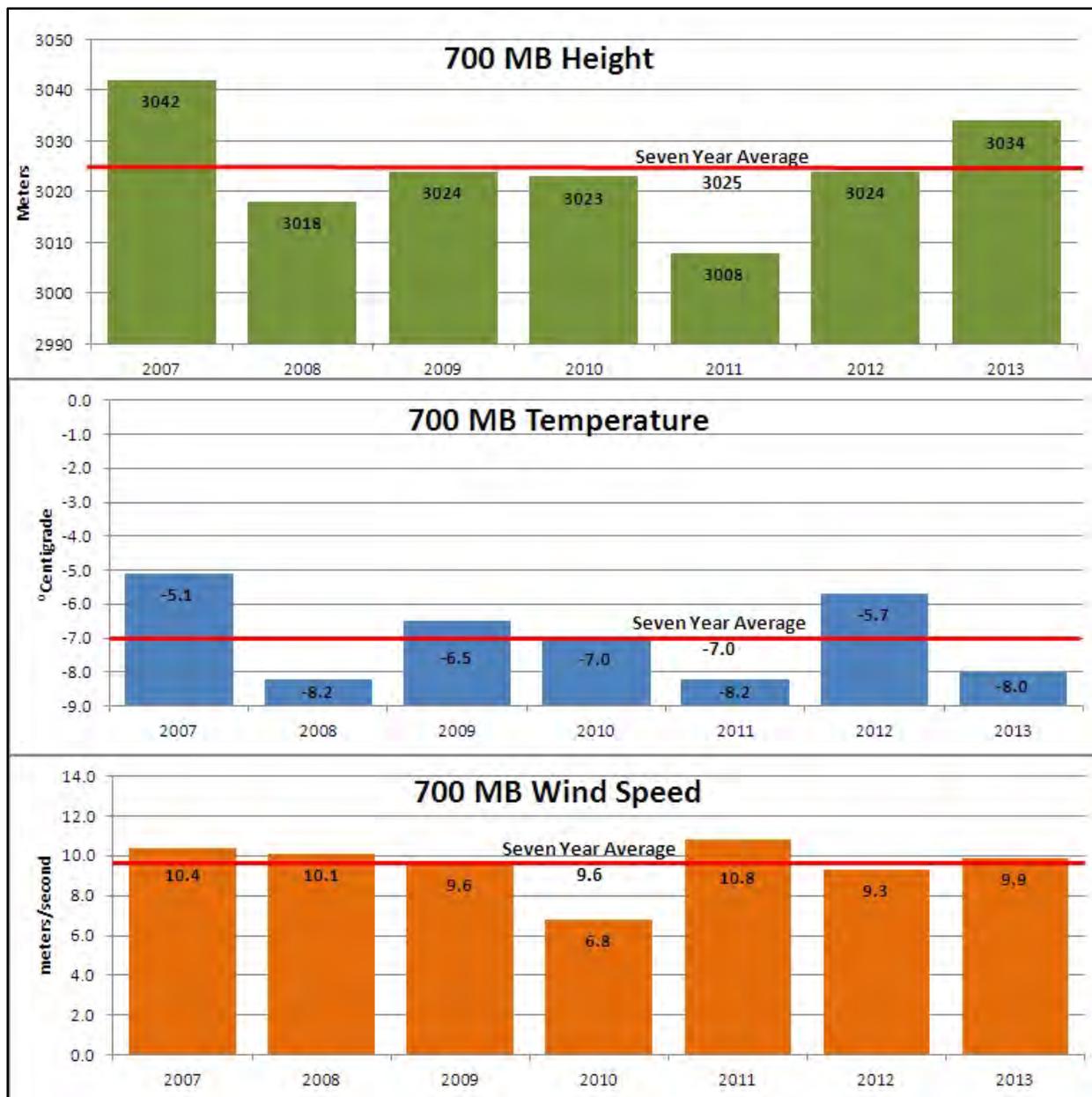
#### **4.1.1 700 mb Comparison 2013 versus 2007-2012**

The WDEQ has sponsored the UGWOS project for seven consecutive winter seasons. A comparison of the 700 mb pressure level data during the 2013 UGWOS study with the previous six study periods is provided in this section.

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 were developed using several weather parameters. These criteria have been used as guidance in forecasting elevated ozone in the UGWOS study area since that time. The various 700 mb pressure height criteria that have been used in forecasting elevated ozone for the UGWOS study are as follows:

- Height level is 3,060 meters or higher @ 700 mb
- Temperature is between 0° and -8°C
- Wind speeds are less than 20 knots (~10 mps)

The 700 mb level parameters for 2013 do not indicate any outliers, despite being a study period nearly free of elevated ozone. Figure 4.1 presents 700 mb averages for 2013 and past UGWOS study periods (February and March) as well as the seven-year average.



**Figure 4.1 700 mb Averages for 2007-2013**

During the 2007 through 2013 UGWOS study periods, there were a total of forty one days when IOP's occurred. Two of these years, 2010 and 2013 had no declared IOP's. Four out of the seven years had no eight-hour ambient ozone concentrations above 75 ppb. UGWOS 2013 had no elevated eight-hour or hourly ozone, although brief sub-hourly readings developed at a few locations. Table 4-1 provides the IOP information for each of the project years.

**Table 4-1**  
**Intensive Operational Periods by Year**

<b>Year</b>	<b>Number of IOP's</b>	<b>Number of IOP Days</b>	<b>Number of Sites with 8-hour Ozone &gt; 75 ppb</b>	<b>IOP dates</b>
2007	1	6	0	March 14-19
2008	3	10	5	February 18 - 21 February 27 - 29 March 10 - 12
2009	3	9	0	February 3 - 5 February 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 February 16 February 27 March 4-5 March 8-9
2013	0	0	0	--
<b>Total</b>	<b>15</b>	<b>41</b>	<b>--</b>	<b>--</b>

Using reanalysis data<sup>2</sup> and incorporating only IOP days over the last seven years yielded an average 700 mb height of 3071 mb, an average 700 mb temperature of -5.8°C, and an average 700 mb wind speed of 8.1 mps.

For 2013, WDEQ did designate days when VOC canister sampling was to occur. VOC samples were collected on January 19 and 20, February 3, March 14, and March 28. These days were designated when high pressure, light winds and sunny skies were expected. Unlike IOP days, the formation of elevated ozone was not required. Reanalysis data were used to calculate averaged 700 mb criteria parameters for the 2013 designated VOC sampling days. Over the five VOC canister sampling days, the average 700 mb height was 3112 meters, the average 700 mb temperature was -2.1°C, and the average 700 mb wind speed was 7.5 mps.

<sup>2</sup> <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>. Accessed July 1, 2013.

#### 4.1.2 UGWOS Snow Cover in 2012 and 2013

Snow cover is one of the more important elements in developing conditions which favor elevated ozone in the UGRB during the late winter and early spring months. Although 2013 started out with several inches of snow cover, the weather pattern was active enough that strong high pressure did not remain in place. This weather pattern did not allow stagnant conditions to develop over a long enough period of time to accumulate, contain and concentrate the precursors necessary for ozone development. A similar situation occurred in 2012 which also had a significant snow cover in place, and elevated ozone failed to develop during that study period as well.

Due to the lack of measured snow depth information for the UGRB, previous UGWOS reports provided a comparison of estimated snow depths between the current report year and the previous years using data provided by NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) web site<sup>3</sup>. In 2012, both NOHRSC data and the snow stick images were used to estimate snow depths and the datasets agreed fairly well.

During the course of the 2013 study it was apparent that snow depth data on the NOHRSC web site was overestimating actual snow depth based on snow stick imagery. This overestimation was considerable which would make the 2013 NOHRSC data suspect. Prior to 2012, snow stick information was not available and, therefore, judgments cannot be made as to whether the NOHRSC estimates were biased in other years as well.

In light of the bias in the NOHRSC data for 2013, a comparison of snow depth was made using the snow stick images from 2012.

---

<sup>3</sup> <http://www.nohrsc.noaa.gov/interactive> NOHRSC Interactive Snow Information data provided by NOAA/NWS, Chanhassen, MN, USA, Accessed Jan-May 2013.

Similar to 2012, storm systems frequently made their way across the west during the 2013 study. These systems provided mostly light precipitation to the UGRB as recorded by monitoring stations operated by the AQD.

Precipitation (snow) occurred on 41 days during the 2013 study within the study area. This equals 54 percent of the 76 days in this year's study period. This reinforces the fact that 2013 was an active year for storms while snow stick images show that little precipitation (snow) occurred with each storm.

In general, the UGRB experienced a deeper snowpack in 2012 than 2013. However, the beginning of the study in 2012 lacked any snow at Boulder while 2013 started out with several inches. Figure 4.2 shows conditions on January 15 in both years.

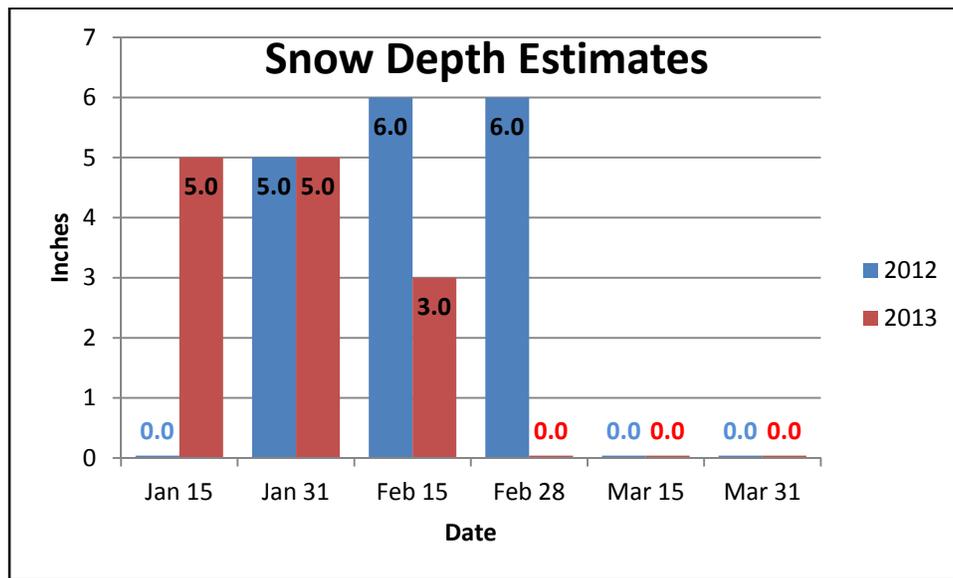


**Figure 4.2 Boulder Site January 15, 2012 (left) and 2013 (right)**

After January 21, 2012 storms during that year brought snow levels up to similar depths seen in 2013 over the later part of January and early February. Snow depths in 2013 began lowering by mid-February, and from this point forward into early March the 2012 study period had more snow on the ground than did 2013. Figure 4.3 shows snow conditions both years for early March at the Boulder site. Figure 4.4 shows the estimated snow depths at the Boulder site taken from images of the snow stick at that location. Patchy snow persisted in the Boulder camera images until March 23 in 2012 and until March 15 in 2013.



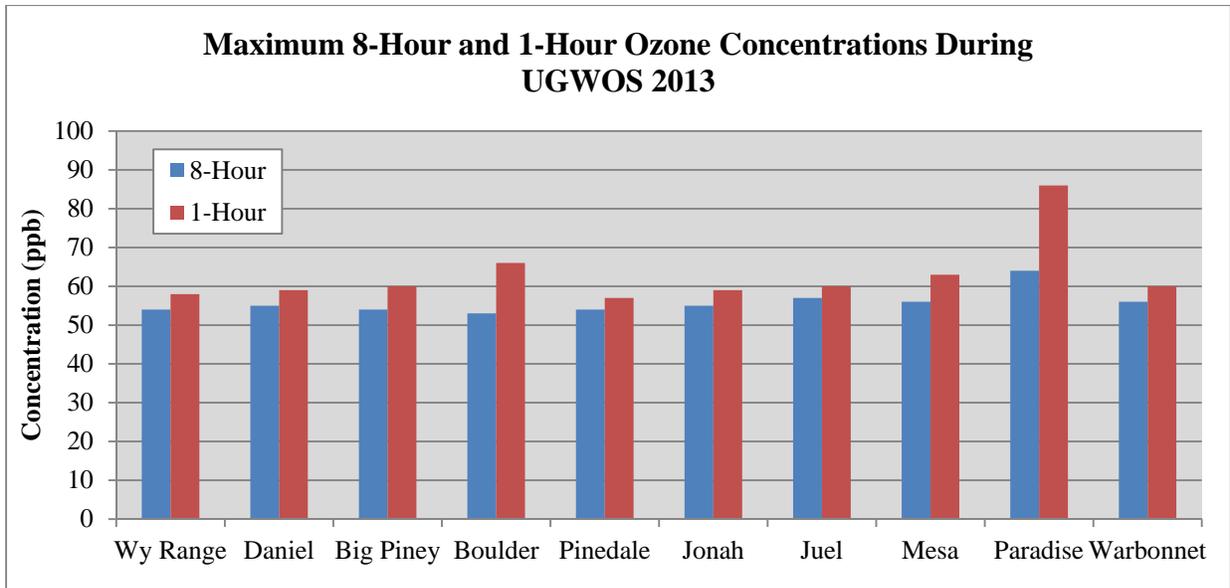
**Figure 4.3 Boulder Site March 2, 2012 (left) and 2013 (right)**



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

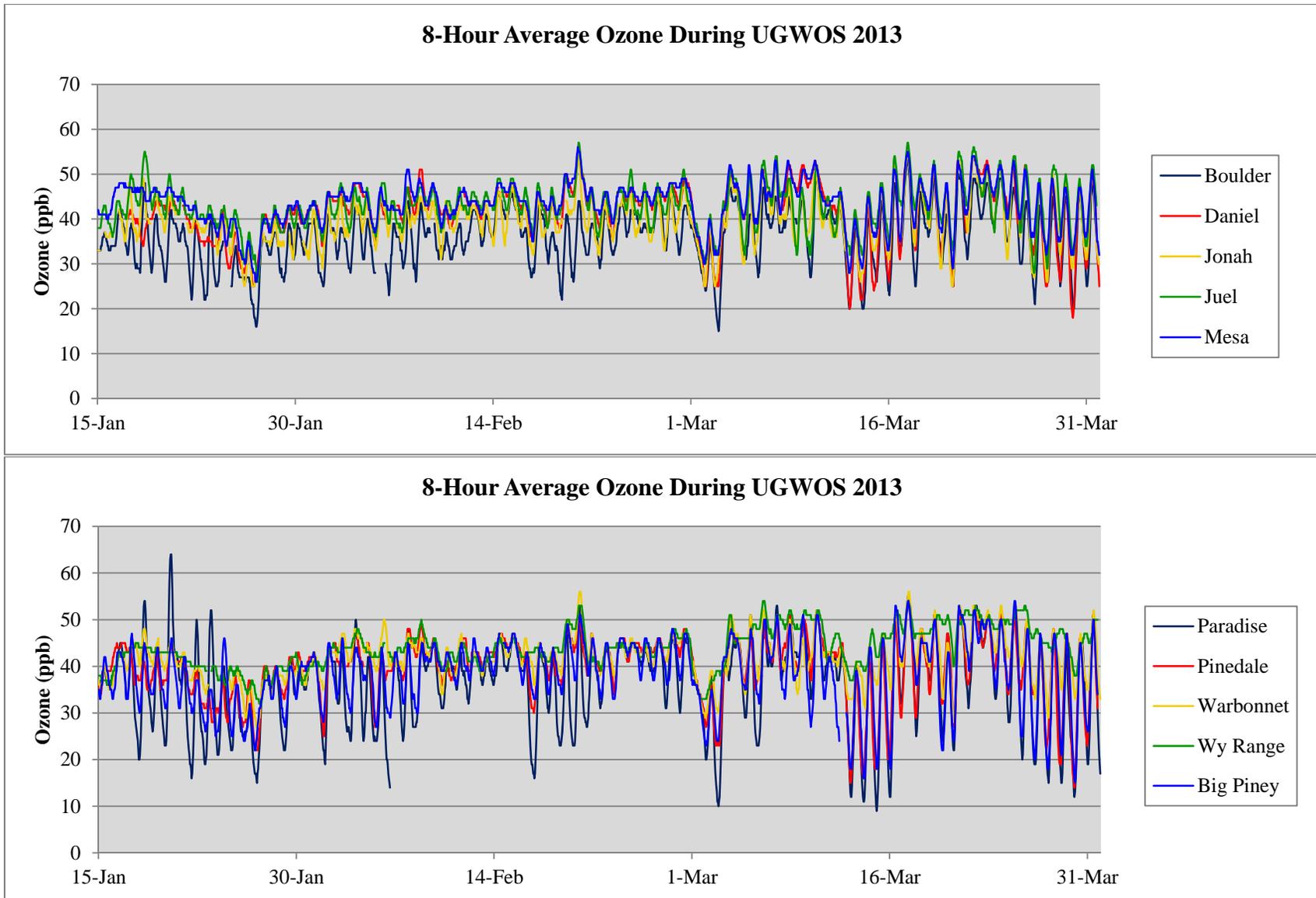
## 4.2 Ozone Spatial and Temporal Distribution

Ozone levels measured during the UGWOS 2013 campaign were fairly low. The highest 8-hour ozone concentration recorded was 64 ppb, which is below the US EPA NAAQS of 75 ppb, and was recorded at only one site on one day. The second highest 8-hour ozone concentration recorded was 57 ppb. The maximum eight-hour and one-hour ozone concentrations at all UGWOS 2013 monitoring sites are presented in Figure 4.5.



**Figure 4.5 Maximum Eight-Hour and One-Hour Average Ozone Concentrations in the UGRB during UGWOS 2013**

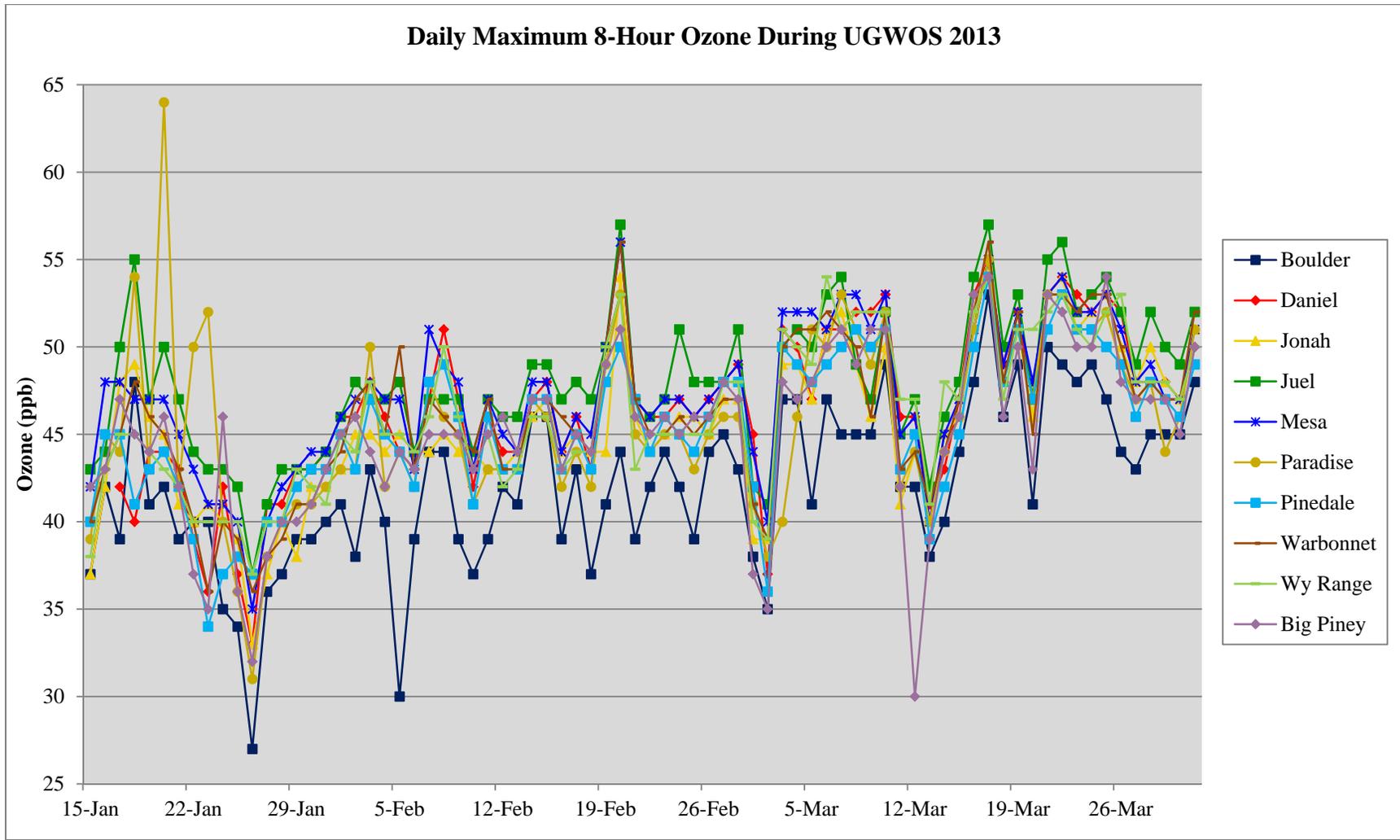
As seen in previous UGWOS studies, the diurnal distribution of ozone followed a predictable pattern. Ozone concentration minimums often occurred near dawn (0700 MST), then quickly recovered to at least background levels (35-45 ppb) by noon. Peak ozone concentrations occurred in the early afternoon (1300 – 1500 MST), then concentrations slowly decreased during the late afternoon through overnight hours. Figure 4.6 presents the running eight-hour average ozone levels for all monitoring sites during UGWOS 2013.



**Figure 4.6 Running Eight-Hour Ozone Concentrations during UGWOS 2013**

Ozone concentration afternoon maximums occurred most frequently at Juel and Mesa while ozone concentration morning minimums occurred at Paradise, Big Piney and occasionally at Pinedale and Boulder. NO<sub>x</sub> scavenging may contribute to the suppressed morning ozone minimum concentrations at those sites. As seen in previous years, there was an increase in the magnitude of the diurnal ozone cycle around the first week of March, coincident with warmer temperatures and higher sun angles. Looking at the entire study period, ozone concentrations at all the monitoring sites generally rose and fell together as large-scale weather systems moved through the UGRB.

Figure 4.7 presents the daily maximum eight-hour average ozone concentrations for all sites during UGWOS 2013. Juel Springs and/or Mesa experienced the highest ozone concentrations 81 percent of the time.



**Figure 4.7 Daily Maximum Eight-Hour Ozone Concentrations, UGWOS 2013**

Table 4-2 presents maximum eight-hour average ozone concentrations on any day where it exceeded 55 ppb at any site in the UGRB. The UGRB network daily maximum is indicated in the right-most column of the table. Table 4-2 shows that elevated ozone was most commonly observed at Juel Springs and Warbonnet.

**Table 4-2**

**Maximum Eight-hour Average Ozone Concentrations (ppb) for Boulder (BD), Daniel (DN), Jonah, Juel Springs, Mesa, Pinedale (PD), Warbonnet (WB), Wyoming Range (WR), and Big Piney (BP) on Days When at Least One Site Recorded Concentrations > 55 ppb**

Station	BD	DN	Jonah	Juel Springs	Mesa	Paradise	PD	WB	WR	BP	Network Max
Jan 20	42	44	45	50	47	64	44	45	43	46	64
Feb 20	44	53	54	57	56	53	50	56	53	51	57
Mar 17	53	55	55	57	55	55	54	56	54	54	57
Mar 22	49	54	54	56	54	53	53	53	53	52	56

Values > 55 in Yellow

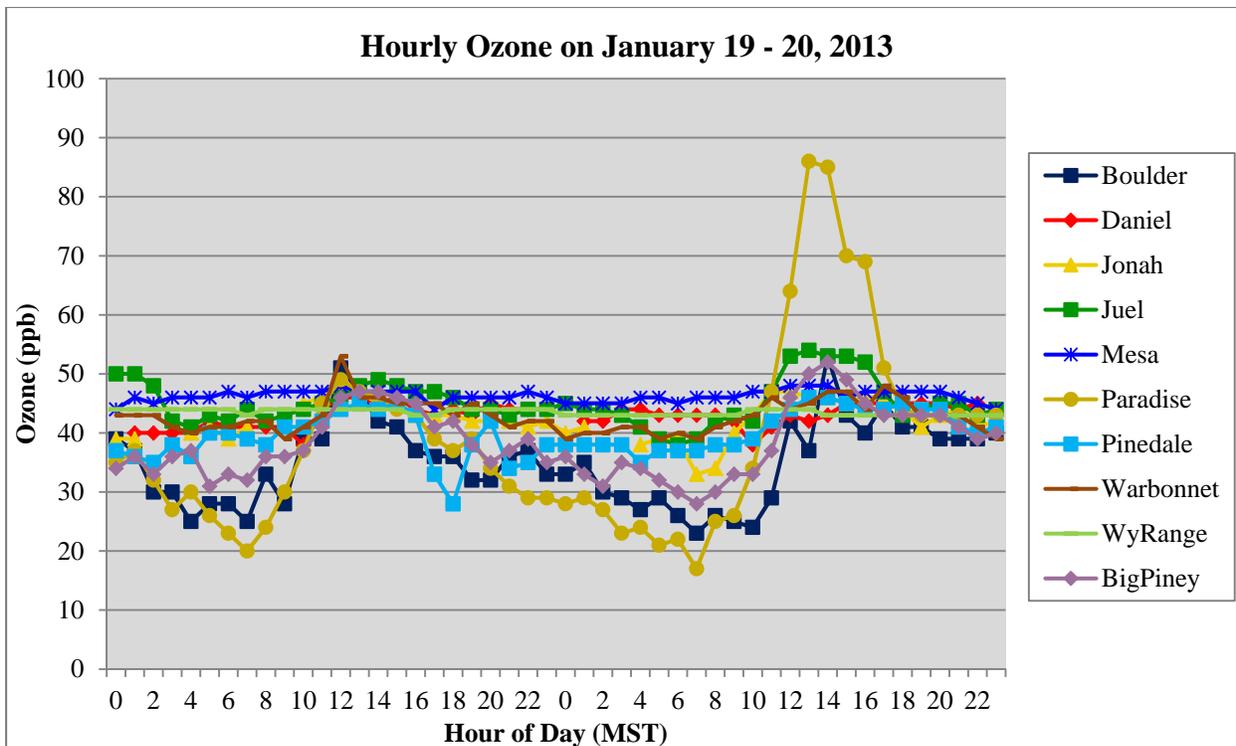
Values > 60 in Red

#### **4.2.1 Discussion of Spatial and Temporal Distribution of O<sub>3</sub> during Designated VOC Canister Sampling Periods**

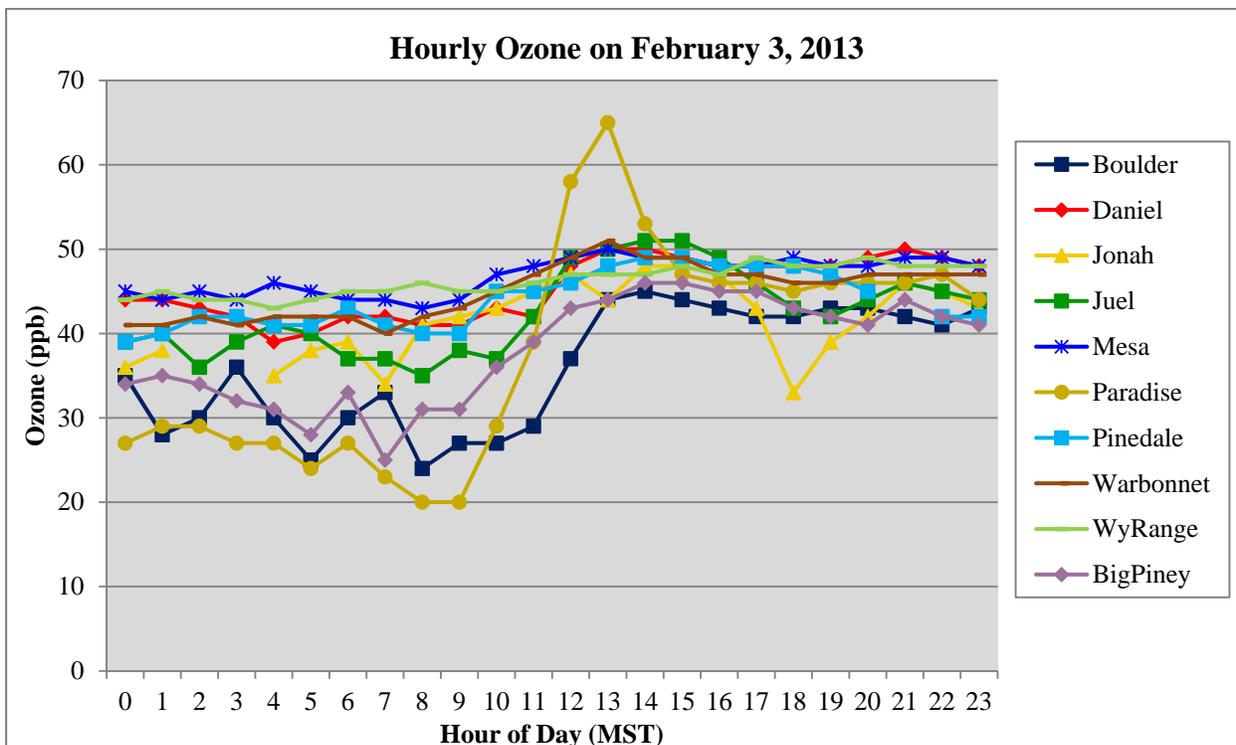
There were four designated VOC canister sampling periods during UGWOS 2013: January 19 to January 20, February 3, March 14, and March 28. VOC canister samples were taken at each mesonet site (Mesa, Warbonnet, and Paradise), at the Jonah Field site and at each of the following long-term monitoring sites: Boulder, Juel Springs, and Big Piney. An additional VOC canister was placed a short distance away from the Jonah site to minimize the impact of local activity on the sample located immediately at the Jonah shelter. Thus, there were a total of eight distinct VOC canister sites. This section will focus on the spatial and temporal distribution of ozone in the UGRB during each VOC canister sampling period.

The first designated VOC canister sampling period occurred January 19 to January 20. With the exception of the Paradise site, hourly ozone concentrations on both days remained below 55 ppb. On January 20, the hourly ozone concentration at the Paradise site reached 86 ppb, but was not elevated long enough to exceed the 8-hour NAAQS of 75 ppb. Ozone concentrations at the Juel Springs site were also slightly elevated on January 20. During overnight hours, several sites including Paradise, Boulder, and Big Piney experienced depressed ozone concentrations to varying degrees likely due to NO<sub>x</sub> scavenging. Ozone concentrations at higher elevation sites such as Mesa and Wyoming Range were not depressed during the overnight hours. The hourly ozone concentrations for January 19 and January 20 are presented in Figure 4.8.

The second designated VOC canister sampling period was February 3. With the exception of the Paradise site, hourly ozone concentrations remained at or below 51 ppb. The Paradise site recorded a one-hour maximum ozone concentration of 65 ppb at 13:00. As with the first sample period, depressed nocturnal ozone values were observed at Paradise, Boulder, and Big Piney while little to no nocturnal depression of ozone concentrations was observed at Mesa and Wyoming Range. The hourly ozone concentrations for February 3 are presented in Figure 4.9.



**Figure 4.8 One-Hour Average Ozone during Designated VOC Sampling Period 1**



**Figure 4.9 One-Hour Average Ozone during Designated VOC Sampling Period 2**

The third and fourth designated VOC sampling periods occurred on March 14 and March 28, respectively. Hourly ozone concentrations on March 14 did not exceed 50 ppb while ozone concentrations on March 28 did not exceed 54 ppb. Juel Springs was consistently among the sites with the highest daytime ozone concentrations during these two periods. As seen in previous sampling periods, NO<sub>x</sub> scavenging appears to negatively affect ozone concentrations at low-elevation sites such as Paradise, Boulder, and Big Piney during the overnight hours while this effect is minimized at sites with higher elevation. The hourly ozone concentrations for March 14 and March 28 are presented in Figure 4.10 and Figure 4.11, respectively.

In conclusion, the Paradise site was the only site that demonstrated elevated ozone concentrations during any of the designated VOC sampling periods. Ozone concentrations at the Juel Springs site, although not elevated, were consistently among the highest of the remainder of the group. Nocturnal NO<sub>x</sub> scavenging was evident during each of the sample periods and seems to have the greatest impact on sites that are low in elevation and close to NO<sub>x</sub> sources.

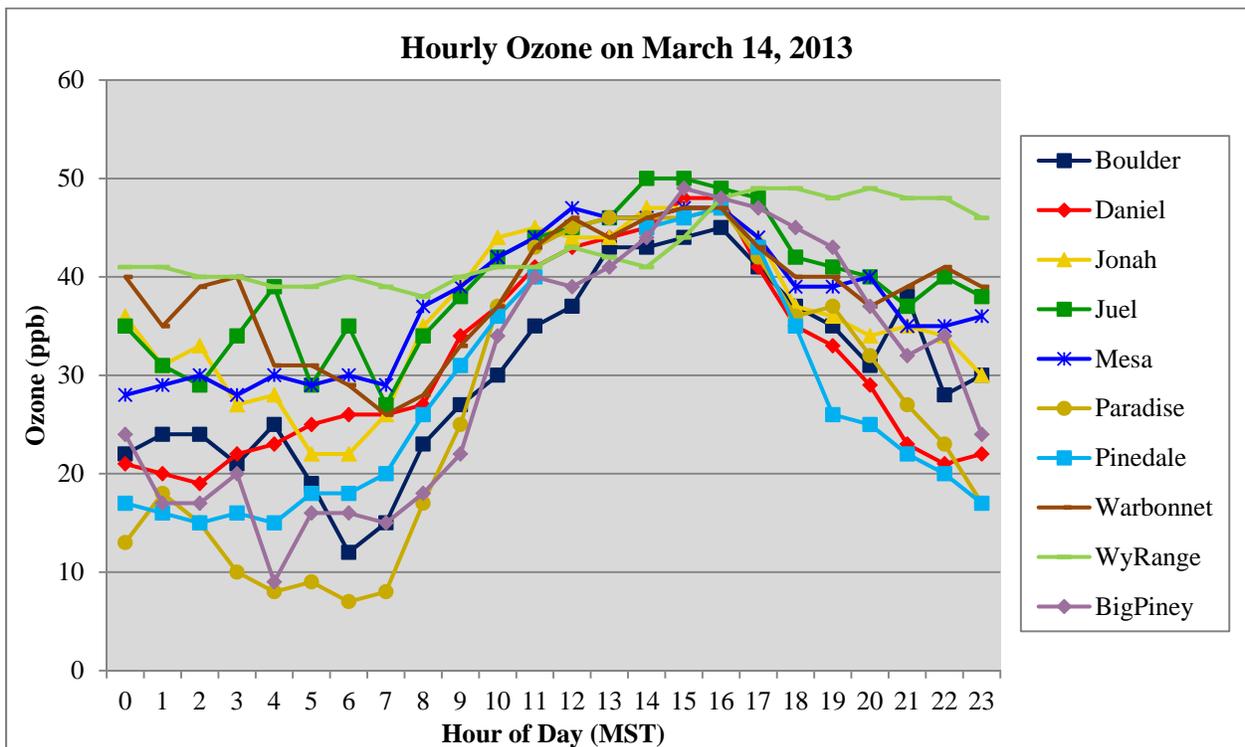
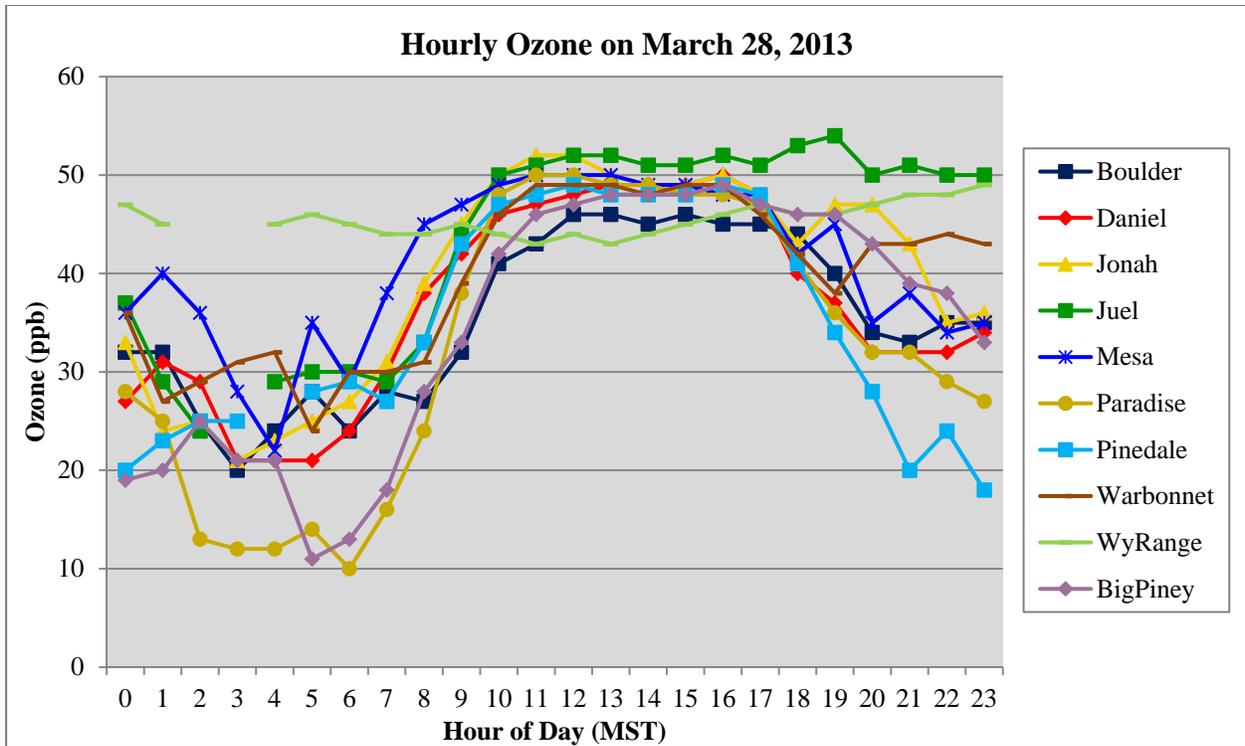


Figure 4.10 One-Hour Average Ozone during Designated VOC Sampling Period 3

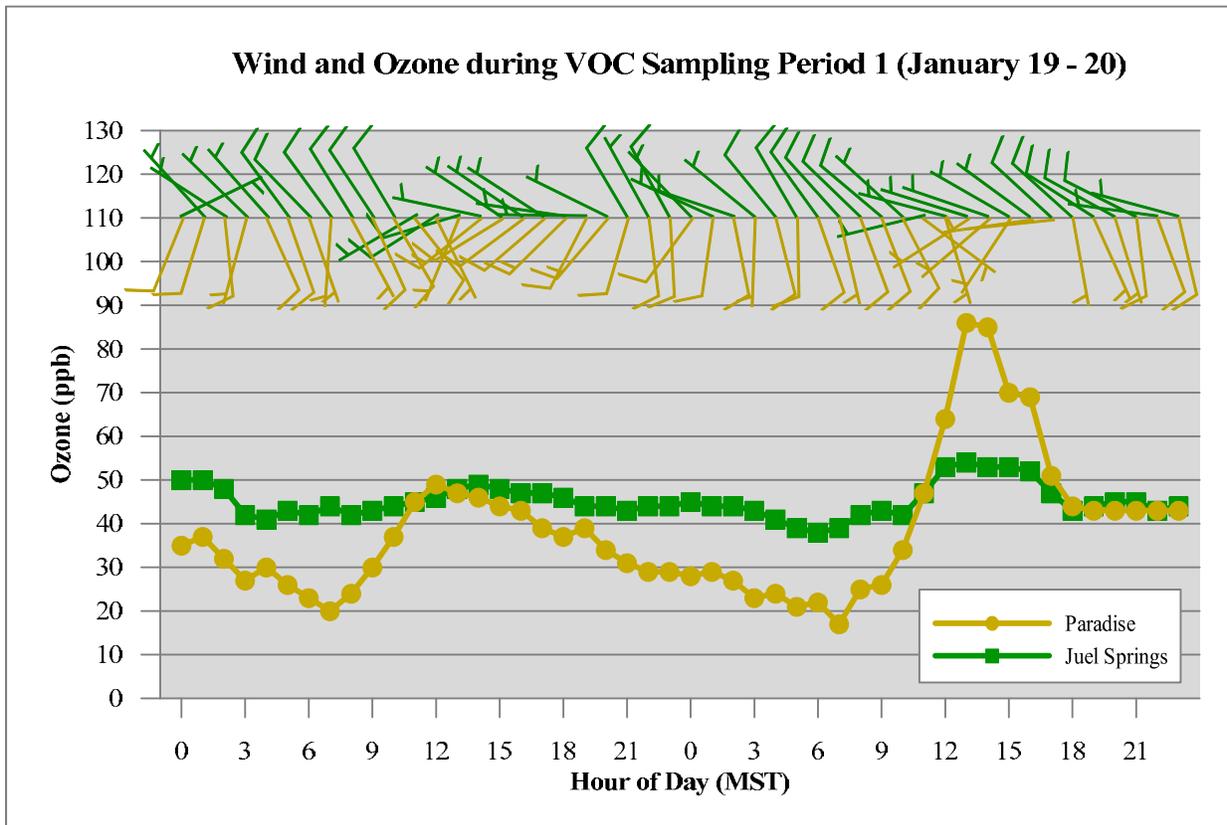


**Figure 4.11 One-Hour Average Ozone during Designated VOC Sampling Period 4**

#### **4.2.2 Surface Wind Patterns Affiliated with Elevated Ozone during Designated VOC Sampling Periods**

There were four VOC sampling periods during UGWOS 2013. This section will focus on the wind patterns that occurred at sites that observed elevated ozone during these periods. For this year’s campaign, Paradise and possibly Juel Springs were the only sites where the above statement holds true. Moreover, since there was no elevated ozone observed during the third and fourth sampling periods, only the first and second periods will be discussed. For each of these cases, the hourly average wind (represented by wind barbs) is 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 sampling periods are usually low, a full barb will represent a wind speed of 5 mps.

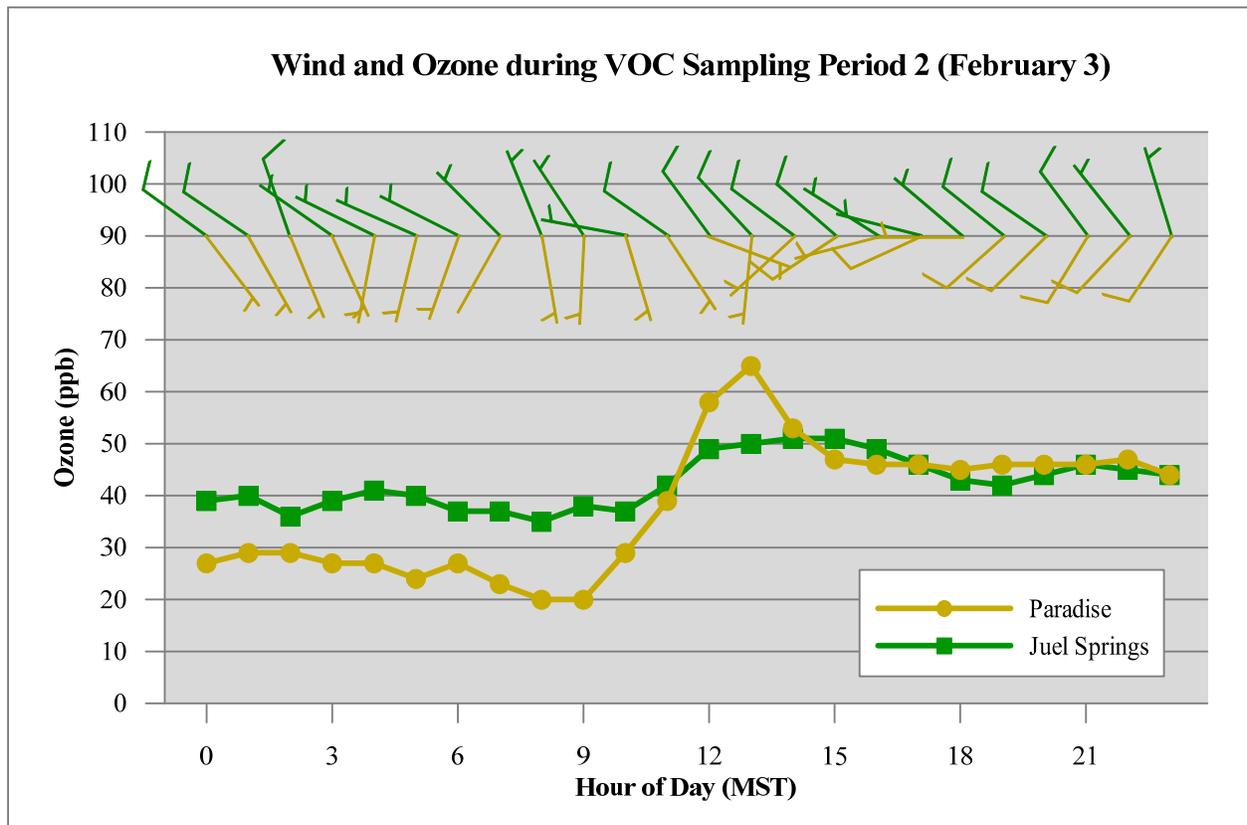
Paradise was the only site that observed one-hour ozone concentrations in excess of 60 ppb during sampling period 1, specifically on January 20. Ozone concentrations at the Juel Springs site were also slightly elevated relative to the remainder of the sites in the UGRB. Hourly wind and ozone for Paradise and Juel Springs during sampling period 1 are represented in Figure 4.12. Winds at the Paradise site were southerly, except for a shift to the southwest during the afternoon of both days of sampling period 1. Ozone concentrations build prior to the wind shift and the wind shift corresponds to the beginning of the decline in ozone concentrations. Winds at the Juel Springs site are generally northwesterly, except for a shift to westerly or southwesterly during the afternoon hours of both days of sampling period 1.



**Figure 4.12 One-Hour Average Ozone and Wind at Paradise and Juel Springs during VOC Sampling Period 1**

Paradise was the only site that observed hourly ozone concentrations in excess of 60 ppb during Sampling Period 2. Ozone concentrations at Juel Springs were not appreciably elevated compared to the remainder of the sites in the UGRB. Hourly wind and ozone for Paradise and Juel Springs during sampling period 2 are represented in Figure 4.13. As in the first sampling period, winds at the Paradise site were southerly during the overnight and morning hours, switching to westerly or southwesterly during the afternoon. Ozone concentrations during the morning were building prior to the wind shift, and then began to decline after the wind shift began. Winds at the Juel Springs site varied little from a northwesterly direction.

In past UGWOS campaigns, elevated ozone episodes at Jonah and Boulder were associated with a characteristic wind shift that recirculated pollutants within the UGRB. Northwest winds during the night were followed by southeast winds during the day as ozone concentrations climbed. This characteristic wind reversal pattern did not manifest itself during this year's sampling periods.



**Figure 4.13 One-Hour Average Ozone and Wind at Paradise and Juel Springs during VOC Sampling Period 2**

### **4.2.3 Comparison of Ozone in 2013 with 2005-2012**

Ozone data have been recorded at long-term monitoring sites in the UGRB since 2005. The Jonah, Boulder (BD), Daniel (DN), Pinedale (PD), Juel Springs, and Wyoming Range (WR) 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 this year's UGWOS campaign, 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. Eight-hour ozone averages and maxima by month from these sites are presented in Table 4-3.

**Table 4-3**

**Eight-Hour Monthly Average and Maximum Ozone by Year for  
Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Wyoming Range**

<b>January</b>	<b>Average 8-Hour Ozone (ppb)</b>						<b>Maximum 8-Hour Ozone (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
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	45	NA	69	59	62	63	54
2012	34•†	34	35	33	35	30	47•†	52	43	42	50	36
2013	37•†	32	39	37	41	40	49•†	48	50	46	55	51
<b>February</b>	<b>Average 8-Hour Ozone (ppb)</b>						<b>Maximum 8-Hour Ozone (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
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	51	NA	87	74	59	68	80
2012	38†	40	40	38	41	39	50†	64	54	50	53	52
2013	40†	37	44	42	43	44	54†	46	53	50	57	53
<b>March</b>	<b>Average 8-Hour Ozone (ppb)</b>						<b>Maximum 8-Hour Ozone (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
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	55	NA	123	85	89	94	83
2012	42†	41	39	39	43	40	61†	62	58	59	56	50
2013	40†	37	41	39	43	47	55†	53	55	54	57	54

\* Temporary Mesonet site with 2B ozone analyzer prior to long-term site.

† WDEQ trailer with FEM monitor after long-term site equipment moved to Juel Springs

• January 15-31

NA – Data not available

Monthly average 8-hour ozone concentrations were generally below average during the 2013 UGWOS campaign. Similarly, maximum eight-hour ozone concentrations were low compared to those of previous years. The highest 8-hour ozone concentration recorded at the long-term monitoring sites with FEM analyzers was 57 ppb observed at Juel Springs.

#### **4.2.4 Comparison of NO<sub>x</sub> and PM during UGWOS 2013 with 2006-2012**

Average monthly NO and NO<sub>2</sub> concentrations at AQD monitoring sites in the UGRB are presented in Table 4-4. During 2013, concentrations were low with no sites exceeding a monthly average of 1.4 ppb NO and 6.2 ppb NO<sub>2</sub>, respectively.

**Table 4-4**

**Monthly Average One-Hour NO and NO<sub>2</sub> Concentrations by Year for  
Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Wyoming Range**

<b>Jan.</b>	<b>1-Hour NO (ppb)</b>						<b>1-Hour NO<sub>2</sub> (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
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	0.1	NA	7.0	0.1	3.9	3.3	0.3
2012	1.3*†	0.4	0.00	1.0	0.2	0.0	3.3*†	2.2	0.0	4.1	0.3	0.5
2013	1.4*†	0.5	NA	0.8	0.3	0.0	3.6*†	6.2	NA	2.1	2.1	0.5
<b>Feb.</b>	<b>1-Hour NO (ppb)</b>						<b>1-Hour NO<sub>2</sub> (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
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	0.00	NA	NA	NA	19.0	NA	0.1	NA	NA	NA
2009	10.6	1.9	0.00	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	0.1	NA	4.8	0.6	5.5	2.5	1.0
2012	0.7†	0.6	0.04	1.2	0.1	0.0	2.5†	2.6	0.0	4.1	0.9	0.6
2013	0.5†	0.2	0.07	0.3	0.2	0.0	2.2†	2.5	0.1	1.5	1.5	0.6
<b>Mar.</b>	<b>1-Hour NO (ppb)</b>						<b>1-Hour NO<sub>2</sub> (ppb)</b>					
<b>Year</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>	<b>Jonah</b>	<b>BD</b>	<b>DN</b>	<b>PD</b>	<b>Juel</b>	<b>WR</b>
2006	0.3	0.01	4.4	NA	NA	NA	9.0	1.8	0.4	NA	NA	NA
2007	0.2	0.00	20.3	NA	NA	NA	16.1	0.7	0.05	NA	NA	NA
2008	0.03	0.00	13.1	NA	NA	NA	14.6	0.9	0.02	NA	NA	NA
2009	0.3	0.00	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	0.00	NA	2.4	0.4	0.1	NA	4.9	0.5	7.4	2.5	0.8
2012	-0.4†	0.1	0.00	1.3	0.1	0.0	0.8†	0.4	0.0	4.3	1.1	0.9
2013	0.1†	0.1	0.09	0.1	0.1	0.0	1.3†	1.5	0.1	1.4	1.0	0.6

\* January 15-31

† WDEQ trailer with FEM monitor after long-term site equipment moved to Juel Springs

NA – Data not available

Average monthly PM<sub>10</sub> and PM<sub>2.5</sub> concentrations at AQD monitoring sites in the UGRB are presented in Table 4-5. Monthly average concentrations during 2013 were generally lower than those from prior years.

**Table 4-5**  
**Monthly Average PM<sub>10</sub> and PM<sub>2.5</sub> Concentrations by Year for**  
**Boulder, Daniel, Pinedale, and Wyoming Range**

<b>January</b>		<b>Average PM<sub>10</sub> (µg/m<sup>3</sup>)</b>			<b>Average PM<sub>2.5</sub> (µg/m<sup>3</sup>)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Daniel</b>	<b>Wyoming Range</b>	<b>Pinedale</b>	<b>Wyoming Range</b>	
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	
<b>February</b>		<b>Average PM<sub>10</sub> (µg/m<sup>3</sup>)</b>			<b>Average PM<sub>2.5</sub> (µg/m<sup>3</sup>)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Daniel</b>	<b>Wyoming Range</b>	<b>Pinedale</b>	<b>Wyoming Range</b>	
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	
<b>March</b>		<b>Average PM<sub>10</sub> (µg/m<sup>3</sup>)</b>			<b>Average PM<sub>2.5</sub> (µg/m<sup>3</sup>)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Daniel</b>	<b>Wyoming Range</b>	<b>Pinedale</b>	<b>Wyoming Range</b>	
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	

\* January 15-31, 2010.

† March 1-20, 2011.

NA – Data not available

#### 4.2.5 Comparison of NMHC and THC during UGWOS 2013 with 2010-2012

Average monthly CH<sub>4</sub>, NMHC, and THC concentrations at the Boulder and Big Piney monitoring sites are presented in Table 4-6. Methane/THC measurements during 2013 were generally slightly higher than those during 2012, but not as high as those measured during 2011, which was a high-ozone year.

**Table 4-6**  
**Monthly Average CH<sub>4</sub>, NMHC and THC Concentrations by Year for**  
**Boulder and Big Piney**

<b>January</b>	<b>Average CH<sub>4</sub> (ppm)</b>		<b>Average NMHC (ppm)</b>		<b>Average THC (ppm)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>
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
<b>February</b>	<b>Average CH<sub>4</sub> (ppm)</b>		<b>Average NMHC (ppm)</b>		<b>Average THC (ppm)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>
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
<b>March</b>	<b>Average CH<sub>4</sub> (ppm)</b>		<b>Average NMHC (ppm)</b>		<b>Average THC (ppm)</b>	
<b>Year</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>	<b>Boulder</b>	<b>Big Piney</b>
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

\* January 1-22, 2012.

NA – Data not available

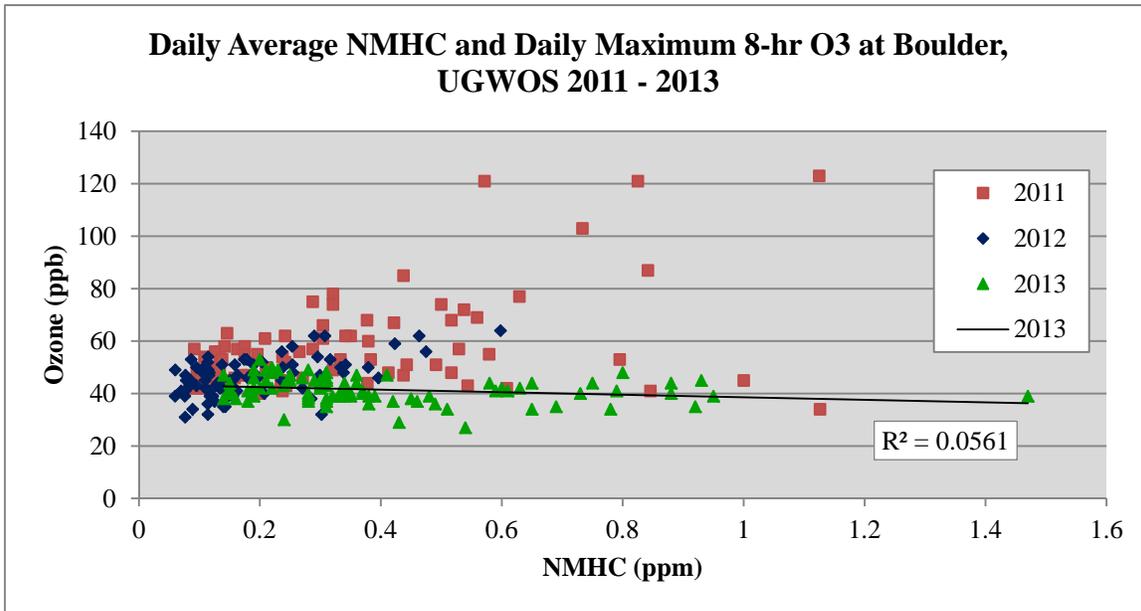
Alternatively, NMHC activity can be summarized by calculating the number of days that the highest 1-hour NMHC exceeds given thresholds. Table 4-7 presents the count of days at Boulder and Big Piney that the highest 1-hour NMHC concentration exceeded 2.0 ppm and 4.0 ppm. Using this metric, NMHC activity during 2013 was higher than last year, but not as great as in 2011.

**Table 4-7**

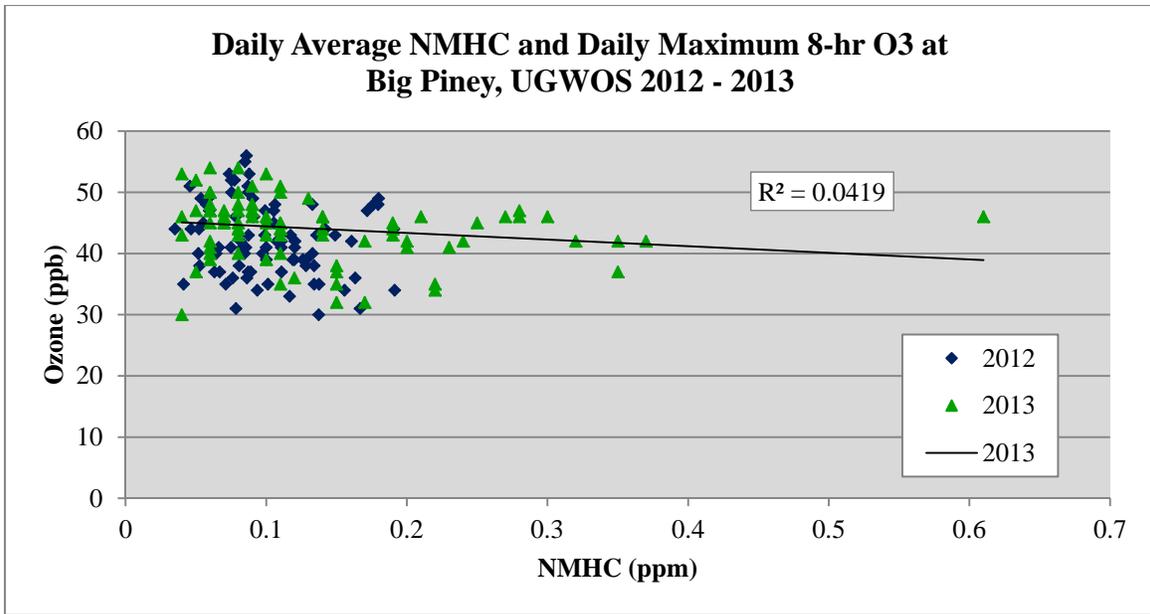
**Number of Days That Highest 1-Hr NMHC Concentration Exceeded 2.0 ppm and 4.0 ppm at Boulder and Big Piney**

Year	Boulder		Big Piney	
	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

For each day during UGWOS 2013, the maximum 8-hour ozone concentration and average NMHC concentration were calculated at the Boulder and Big Piney sites. These data are presented as scatter plots in Figure 4.14 for Boulder and Figure 4.15 for Big Piney along with similar data from previous years.



**Figure 4.14 Comparison of Maximum 8-hour Ozone and Daily Average NMHC at Boulder for UGWOS 2011 – 2013. Linear regression fit for 2013 data is shown.**



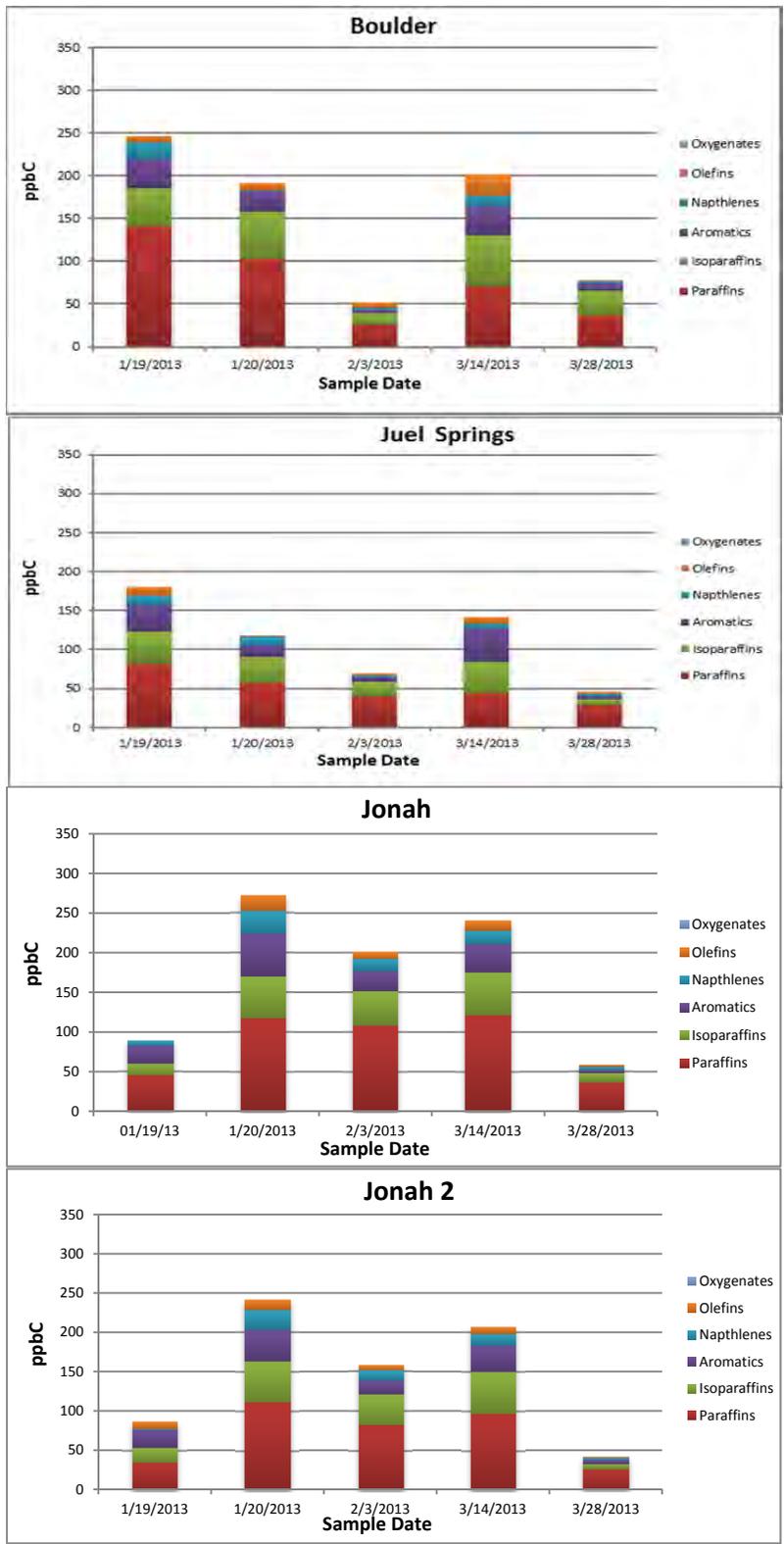
**Figure 4.15 Comparison of Maximum 8-hour Ozone and Daily Average NMHC at Big Piney for UGWOS 2012 – 2013. Linear regression fit for 2013 data is shown.**

While it is true that the highest ozone concentration measured in 2011 (123 ppb at Boulder) occurred on the same day as the highest NMHC concentration (1.1 ppm), there are several days that year in which NMHC were measured in relatively high concentrations without high ozone concentrations to match. In 2013, there were many days at Boulder which recorded levels of NMHC in excess of 0.5 ppm, which is similar to the levels associated with high ozone days in 2011. However, ozone levels on those days in 2013 were not associated with elevated ozone concentrations. At Big Piney, there were many days which recorded levels of NMHC higher than those in 2012 but were not associated with elevated ozone levels. For both sites in 2013, there was no correlation between daily average NMHC concentrations and daily maximum 8-hr ozone concentrations.

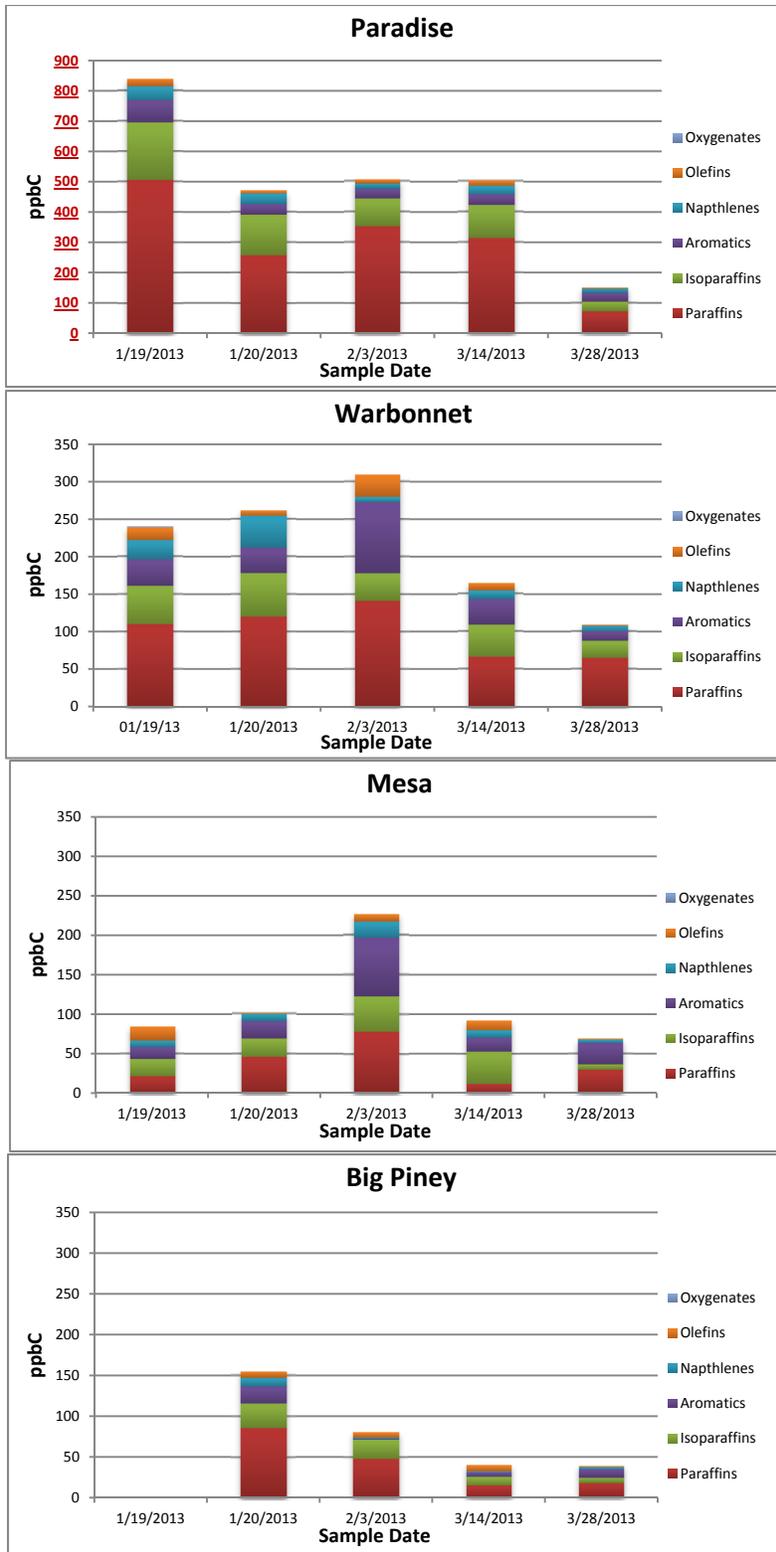
### 4.3 VOC Canister Sampling

The goal of the UGWOS 2013 VOC canister sampling stemmed from the UGWOS 2012 study to investigate the spatial distribution of precursor concentrations in and around the gas and oil fields located in the UGRB. To obtain a spatial distribution of precursors, VOC canister samples were collected at Boulder, Juel Springs, and Big Piney monitoring stations as well as the UGWOS-specific Jonah air quality site and three mesonet sites (Paradise, Mesa, and Warbonnet). In addition to the sampling at the Jonah site, VOC samples were also collected at a second Jonah site located 410 meters north-northeast of the air quality site. Although no IOPs were initiated during the 2013 UGWOS study period, five samples were taken at each station during periods in which a high pressure system was located over the study area and light winds were present.

VOC samples were collected using 6-liter SUMMA canisters connected to canister samplers which were programmed to collect 3-hour samples between the hours of 07:00 and 10:00 MST. Figures 4.16 and 4.17 present a summary of the VOC samples broken into five categories of hydrocarbons (Paraffins, Isoparaffins, Aromatics, Naphthenes, and Olefins) and Oxygenates at each of the eight sample locations. Figures 4.18 and 4.19 present the percentage composition 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.



**Figure 4.16 VOC Concentrations from Canisters Collected at Boulder, Juel Springs, Jonah, and Jonah 2**



**Figure 4.17 VOC Concentrations from Canisters Collected at Paradise, Warbonnet, Mesa, and Big Piney**

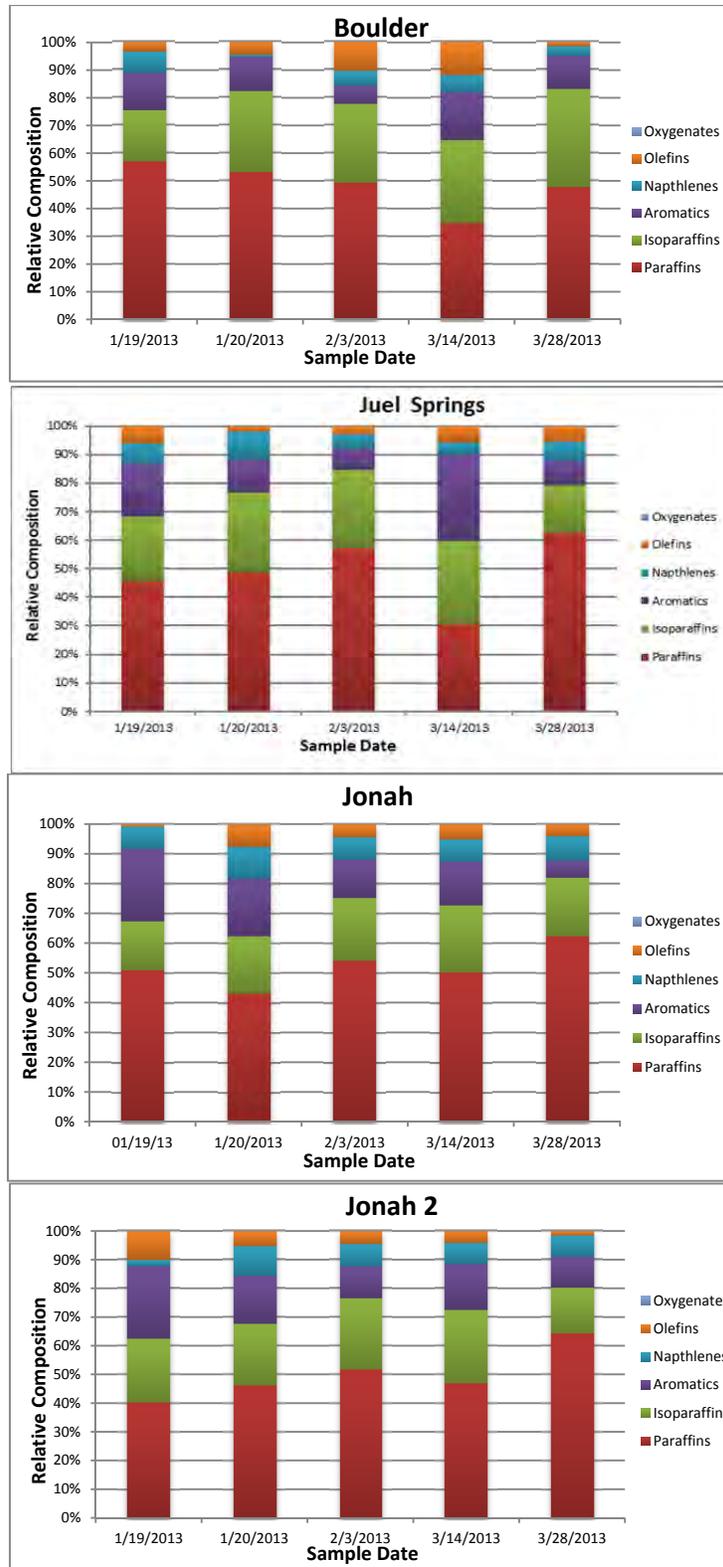
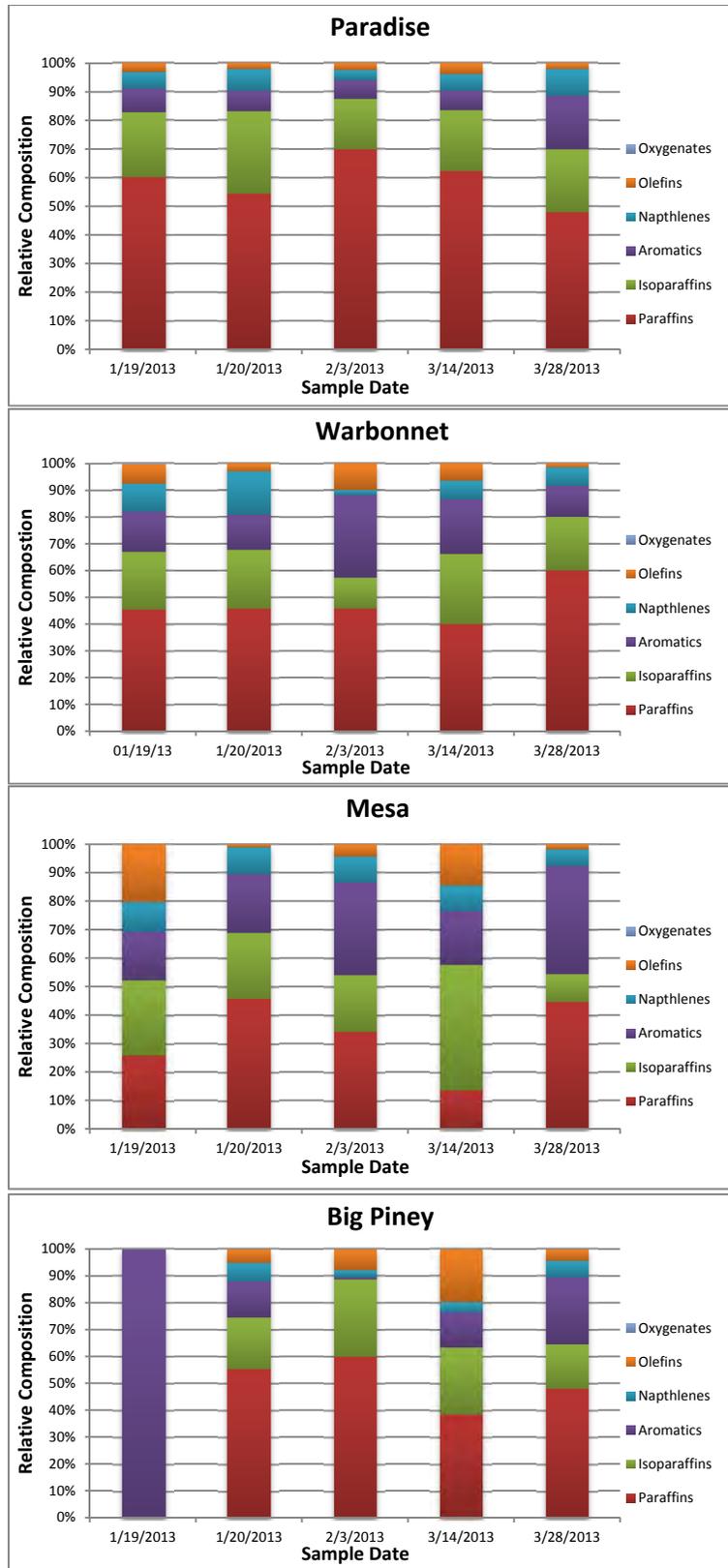


Figure 4.18 Relative Composition from Canisters Collected at Boulder, Juel Springs, Jonah, and Jonah 2



**Figure 4.19 Relative Composition from Canisters Collected at Paradise, Warbonnet, Mesa, and Big Piney**

VOC concentrations at Paradise were consistently higher than the other seven sample locations. The Paradise mesonet site was located 3.76 miles southwest of the Boulder air quality site in the heart of the gas and oil operations (primarily well production and liquid gathering system). The location of the Paradise site also placed it in the low lands adjacent to the New Fork River flood plain. To some extent, the lower elevation and surrounding terrain sheltered the site from regional wind patterns leading to lower wind speeds relative to other VOC sample sites. This is evident when looking at the wind statistics for the eight VOC sampling locations. Lower wind speeds lead to less dilution and the lower terrain allows for more localized pooling of VOCs from nearby sources. Table 4-8 presents the maximum and average wind speeds for the study period and for days in which VOC samples were taken.

**Table 4-8**  
**Wind Speed Statistics for VOC Sample Locations**

<i>Time Period</i>	<b>WS Stat.</b>	<b>Boulder</b>	<b>Warbonnet</b>	<b>Jonah</b>	<b>Jonah2</b>	<b>Paradise</b>	<b>Mesa</b>	<b>Big Piney</b>	
<i>Study Period</i>	Maximum	20.5	14.01	13.77	14.33	10.16	12.80	13.70	
	Average	4.24	3.61	3.49	3.73	2.68	3.61	2.44	
<i>Sample Days</i>	1/19/2013	Maximum	5.40	3.69	5.73	N/A <sup>1</sup>	2.40	5.16	3.80
		Average	2.39	2.77	3.63	N/A <sup>1</sup>	0.83	2.68	1.88
	1/20/2013	Maximum	8.90	6.33	5.95	N/A <sup>1</sup>	5.46	6.66	6.10
		Average	3.27	2.95	3.65	N/A <sup>1</sup>	1.73	3.74	1.97
	2/03/2013	Maximum	8.40	4.12	4.97	4.80	6.04	5.85	2.70
		Average	3.98	2.82	3.55	3.40	2.42	3.58	1.27
	3/14/2013	Maximum	5.40	4.40	4.77	4.74	3.44	3.10	5.70
		Average	2.89	1.87	2.06	2.31	1.32	1.83	2.37
	3/28/2013	Maximum	5.00	4.36	4.62	4.68	3.46	3.43	4.60
		Average	3.13	2.33	2.25	2.45	1.71	1.89	1.98
	<i>Cumulative Sample Days</i>	Maximum	8.90	6.33	5.95	4.80 <sup>1</sup>	6.04	6.66	6.10
		Average	3.13	2.55	3.03	2.72 <sup>1</sup>	1.60	2.74	1.90

<sup>1</sup>Jonah 2 wind measurements started on January 29<sup>th</sup> at 11:00

### 4.3.1 Jonah and Jonah 2

The original Jonah site was removed and access to power was not available at the original location. The site utilized in 2012 was located on the eastern edge of the Jonah Field. After investigating several possible alternatives, a site just outside the property line of the Linn Energy facility was selected as the best alternative since the facility was willing to allow access to their power. The location is approximately 6 kilometers west of the 2012 site and more representative of the Jonah Field. Concerns about the effects of regular truck traffic at the Linn Energy facility on VOC measurements prompted the installation of a control site (Jonah 2) approximately 410 meters north-northeast.

Results of the Jonah and Jonah 2 VOC sampling showed total NMHC concentrations had good correlation ( $R^2 = 0.9845$ ) with Jonah showing a slightly higher bias than Jonah 2. The agreement between the two sites shows that the measurements at Jonah are more representative of a mesoscale measurement and not heavily affected by the truck traffic from the Linn Energy facility. A windrose was created with sub-hourly wind data for each sample period (07:00 – 10:00) to help determine the origin of the VOC's. Wind patterns at both Jonah and Jonah 2 had good agreement though wind data at Jonah 2 did not commence until January 29. Windroses show the air mass moving predominantly out of the northwest and north-northwest on January 19, 20, and February 3. Winds were light and variable on March 14 and primarily out of the north on March 28 with light wind speeds. Figure 4.20 presents the results and sample period windroses from Jonah and Jonah 2.

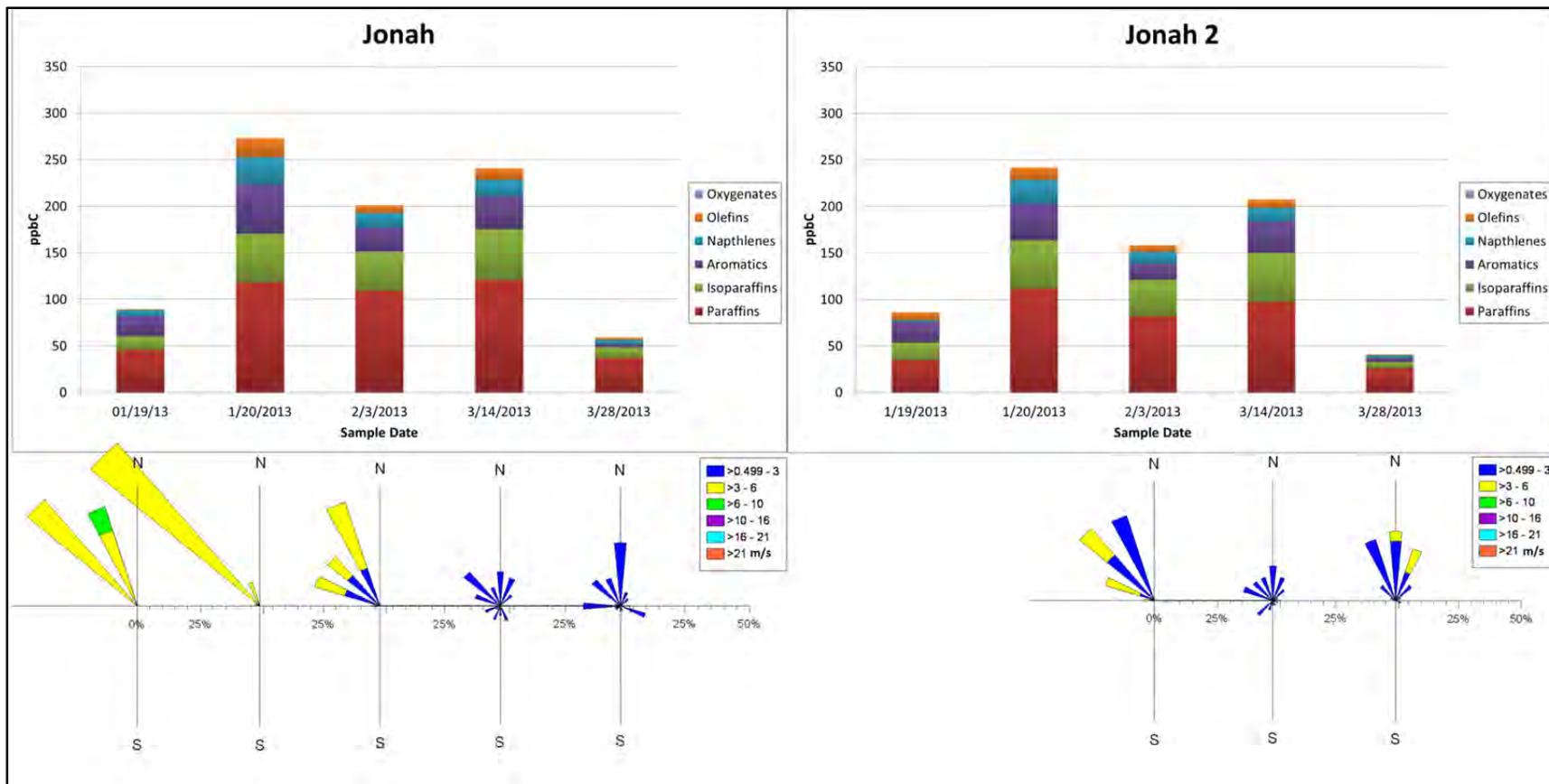
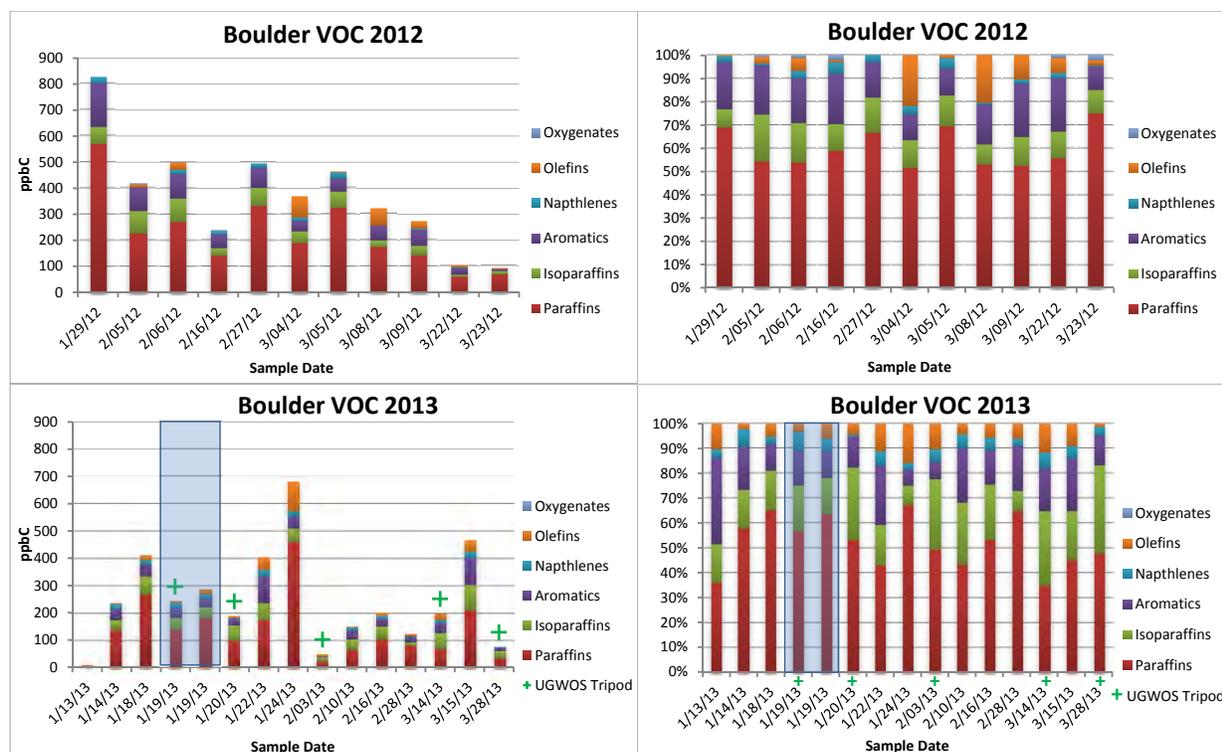


Figure 4.20 Total NMHC and Sample Time Windroses for Jonah and Jonah 2

### **4.3.2 Comparison of 2013 to 2012 Study**

Four locations (Jonah, Juel Springs, Big Piney, and Boulder) collected VOC samples in both 2012 and 2013. Due to site power availability, the Jonah site is the only site which collected VOC canister data that has a different location in 2013 from the 2012 study. The location of the Jonah site in 2013 was approximately 3.75 miles West from the 2012 location. This section describes the similarities and differences between the 2012 and 2013 studies. The anomalous VOC concentrations collected on March 8, 2012 at Juel Springs and January 19, 2013 at Big Piney will be left out of the comparison.

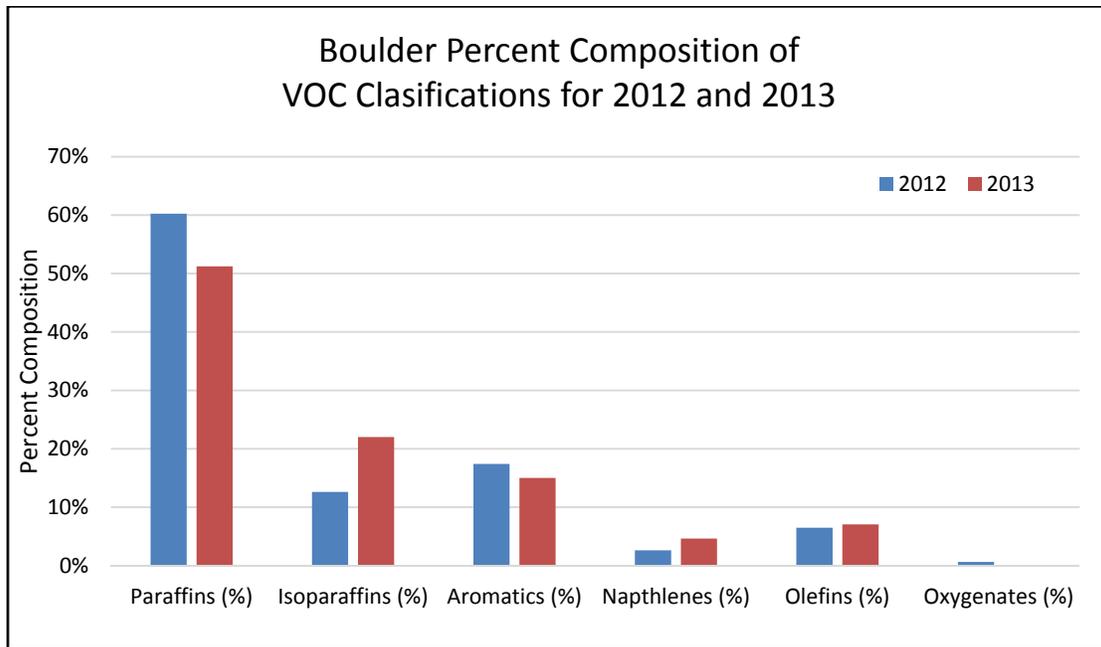
Throughout the UGWOS 2012 study period, eleven samples were collected at each site. Five samples were collected at each site during 2013 with the exception of Boulder. In addition to the UGWOS specific VOC sampling system set up at Boulder for the 2013 study, sampling of ozone precursors is being conducted by an automated system at the Boulder site through the use of SUMMA canister samples and subsequent laboratory analysis using EPA method TO-14A. Automated canister samples are initiated when NMHC concentrations on the Baseline-Mocon 9000 analyzer reaches a threshold of two (2) ppm in a five-minute period. Between the automated canister system and the UGWOS tripod system, the Boulder site collected a total of fifteen (15) samples during the UGWOS 2013 study period including an unintentional simultaneous (collocated) sample collected on the morning of January 19, 2013. Figure 4.21 presents a compilation of the Boulder VOC canister data from UGWOS 2012 and 2013.



**Figure 4.21 Boulder VOC Data from UGWOS 2012 and 2013**

Total NMHC concentrations measured via SUMMA canisters at Jonah, Big Piney, and Juel Springs were slightly higher in 2012 than those measured in 2013. Both years had relatively low concentrations throughout the study period when compared to canister data from the 2011 study. In 2011, during periods with high ozone concentrations, 12 canisters were collected by a tethered balloon near the 2013 Paradise location and grab sample concentrations of Total NMHC ranged from 625 ppbC to 7365 ppbC with an average concentration of 2569 ppbC. Maximum 3-hour sample concentrations of Total NMHC for Jonah, Juel Springs, and Big Piney were between 234 and 288 ppbC in 2012 and between 155 and 273 ppbC for 2013. Average concentrations of Total NMHC ranged from 78.5 to 128.7 ppbC for 2012 and between 78.7 and 172.7 ppbC for 2013. Of the four stations that were retained for VOC canister samples, Boulder had the highest concentrations of Total NMHC. For Boulder, maximum concentrations of Total NMHC from 3-hour canister samples ranged from 93.2 to 825.9 ppbC in 2012 and from 11.4 to 682.6 ppbC in 2013. Boulder is adjacent to the gas and oil operations in the Pinedale Anticline natural gas production field and is expected to have higher concentrations of Total NMHC when compared to the other three stations.

Between 2012 and 2013, there is good agreement with the composition of the Total NMHC concentrations when broken into percent contribution of each classification (Paraffins, Isoparaffins, Aromatics, Napthlenes, Olefins, and Oxygenates) with paraffins having the greatest percentage of total composition. Figure 4.22 presents the maximum and average percent contribution of each composition classification for Boulder.

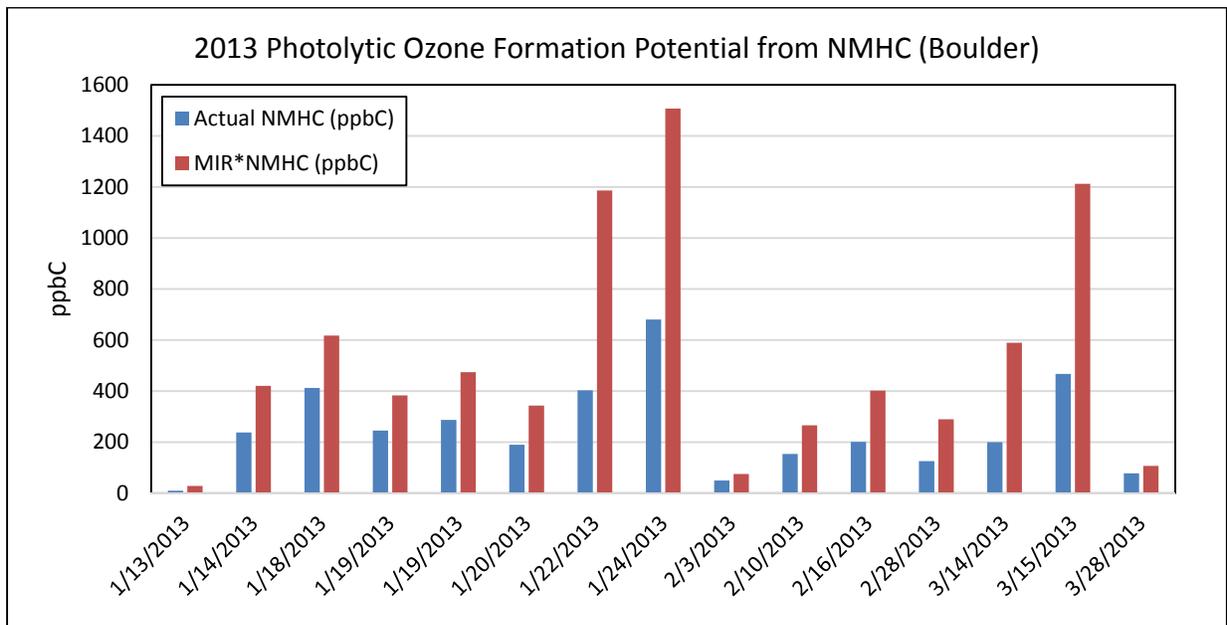


**Figure 4.22 Percent Composition of VOC Classifications**

### 4.3.3 VOC Maximum Incremental Reactivity Analysis

Though the measured Total NMHC was relatively low for both 2012 and 2013, ozone concentrations measured throughout the basin were also low when compared to previous study years. Non-methane organic compound species vary greatly in the degree to which they participate in photochemical reactions. Maximum incremental reactivity (MIR) values (Carter 2009) were used to determine the impacts of available VOCs 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 MIR enhanced values are summed for a Total NMHC ozone formation potential.

Figure 4.23 presents the relationship of the actual Total NMHC and MIR enhanced Total NMHC concentrations measured at Boulder. The ratio of the actual Total NMHC and MIR enhanced NMHC varies from day to day due to specific compounds with high MIR values being measured in the sample analysis. This led to an analysis to determine which measured compounds were the most abundant in 2013 based on the potential for ozone formation. Table 4-9 presents the top 15 compounds with the highest average concentrations measured as well as the top 15 compounds available for ozone formation. It was found that on average throughout the basin ethane was the most abundant compound measured as well as the most available compound to produce ozone. In 2013, the number of days with conditions favoring higher NMHC concentrations was considerably less than in 2011 (see Table 4-7) a year when the current ozone standard was exceeded on 13 days during the UGWOS 2011 study.



**Figure 4.23 Actual and MIR Enhanced Total NMHC**

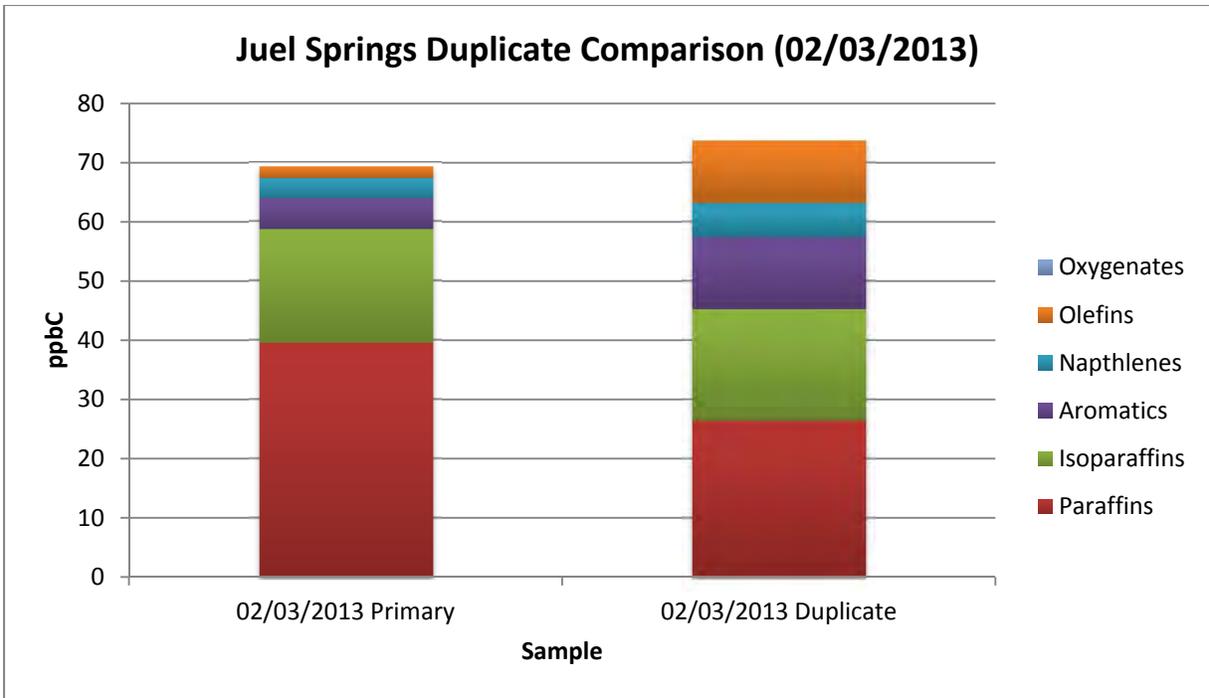
**Table 4-9**

**Top Compounds by Concentration and Potential Reactivity**

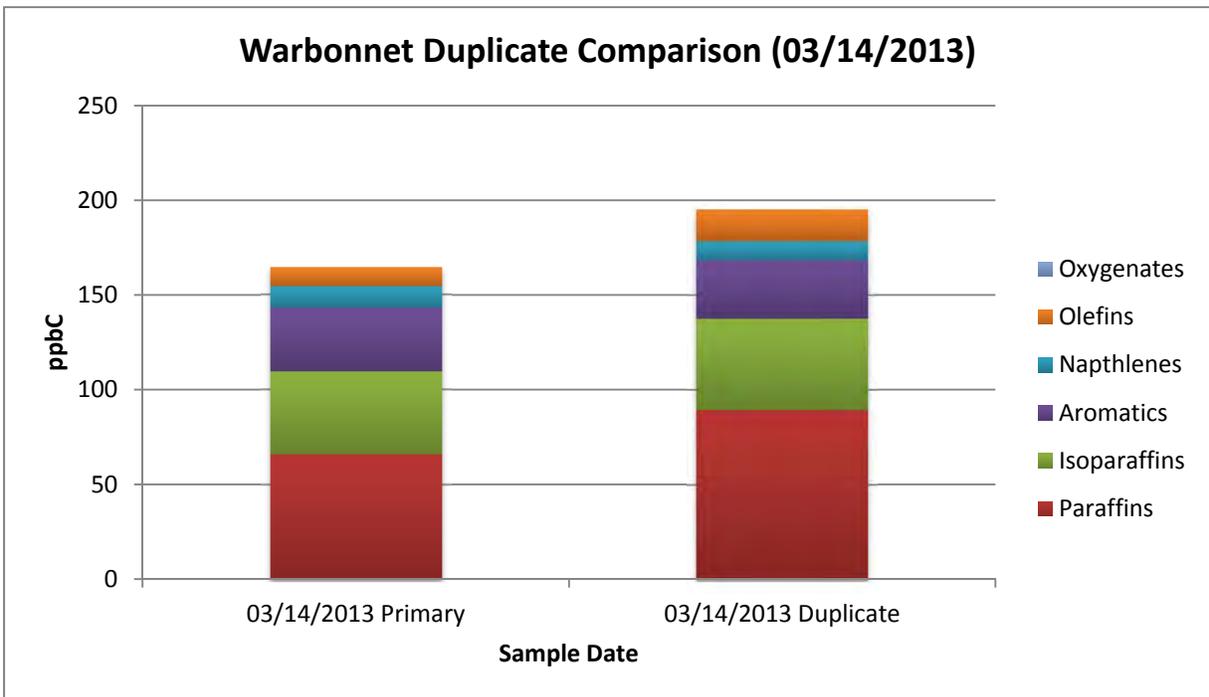
<i>Rank</i>	<b>Top 15 Compounds by Concentration</b>	<b>Top 15 Compounds by Reactivity (MIR)</b>
1	Ethane	Ethane
2	Propane	Toluene
3	i-Butane	m,p-xylene
4	n-Butane	Propane
5	i-Pentane	1-Butene
6	Toluene	i-Butane
7	n-Pentane	Propene
8	Methylcyclohexane	n-Butane
9	Benzene	i-Pentane
10	n-Hexane	1,2,4-Trimethylbenzene
11	Acetylene	Ethene
12	2,4-Dimethylpentane	Methylcyclohexane
13	Cyclohexane	o-xylene
14	2-Methylpentane	n-Pentane
15	m,p-xylene	n-Hexane

**4.3.4 VOC Quality Control Results**

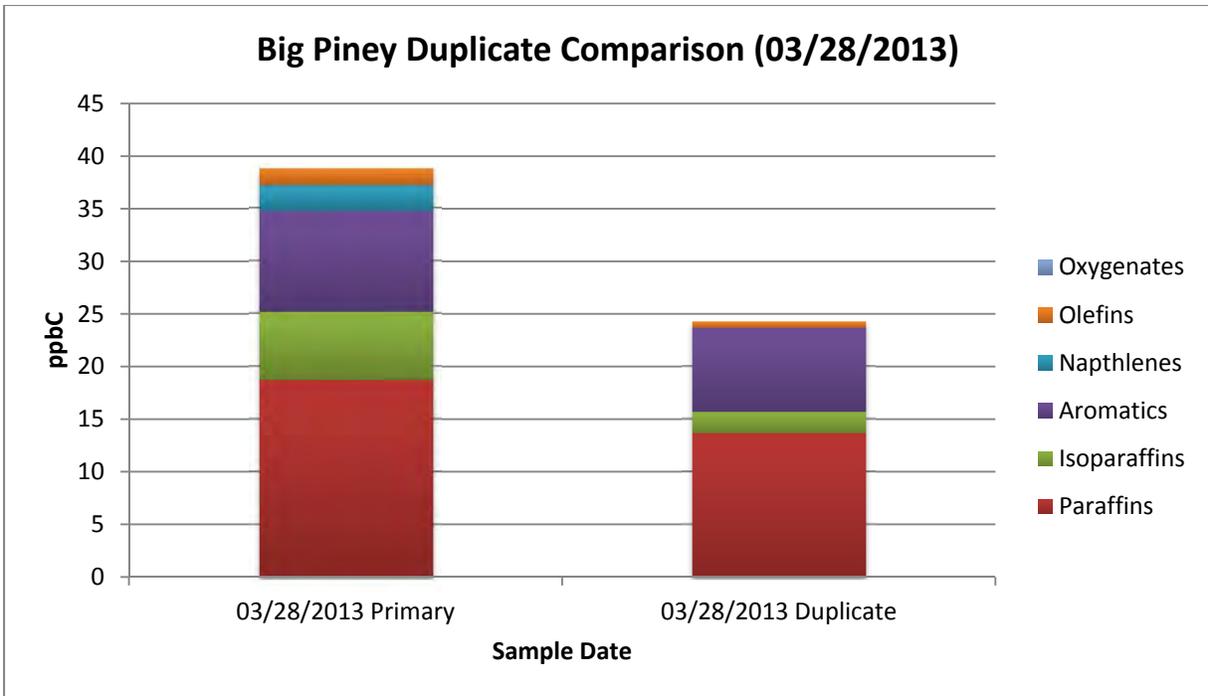
Throughout the study period, collocated samples were taken to reduce uncertainty in concentration measurements. A separate tripod containing an identical canister sampler system was collocated with three different VOC canister sites (Juel Springs, Warbonnet, and Big Piney) once during the study period. Figures 4.24, 4.25, and 4.26 present summaries of the collocated sample results collected on February 3 at Juel Springs, March 14 at Warbonnet, and March 28 at Big Piney. The results of the collocated canisters show differences in Sampled Total NMHC of 6.4%, 18.6%, and 37.5% for Juel Springs, Warbonnet, and Big Piney, respectively. The high percent differences are a result of low concentrations measured throughout the study period. For such low concentrations, the agreement between the collocated samples was relatively good and did not have any major outliers.



**Figure 4.24 February 3, 2013 Collocated Sample Comparison from Juel Springs**

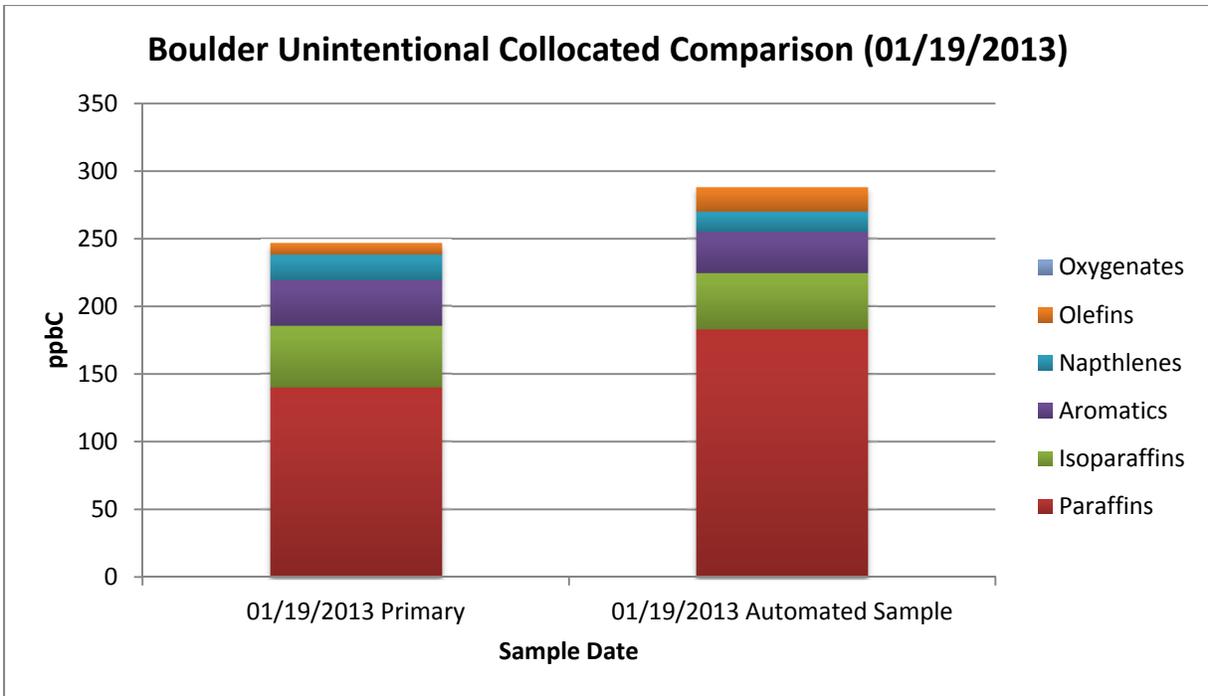


**Figure 4.25 March 14, 2013 Collocated Sample Comparison from Warbonnet**



**Figure 4.26 March 28, 2013 Collocated Sample Comparison from Big Piney**

On the morning of January 19, 2013, an unintentional simultaneous (collocated) VOC sample was taken when the automated ozone precursor system triggered a three hour sample which began at 06:50. A VOC sample was scheduled at 07:00 on January 19<sup>th</sup> for the UGWOS samplers. A comparison of the unintentional collocated sample is presented in Figure 4.27. The measured Total NMHC was the highest concentration of the four collocated samples taken during the study period and were 16.9% different from one another with the automated canister sample having a higher concentration mostly from the paraffin family of compounds.



**Figure 4.27 January 19, 2013 Unintentional Collocated Sample Comparison from Boulder**

#### 4.4 miniSODAR™ Data

As with the previous UGWOS studies, the most relevant data obtained from the miniSODAR™ (Sodar) were the mixing heights estimated from the Sodar's facsimile data.

As noted in other sections of this report, the winter of 2013 was characterized by the lowest ozone concentrations of the last five years recorded at the Boulder monitoring site. Review of outgoing UV radiation data from the Boulder site confirms that snow was all but gone by March 1. Consequently, rather than expending resources on data that deviated from the study interests, mixing heights were only estimated for the period January 15 through February 28, 2013.

Table 4-10 summarizes and compares key mixing height metrics for 2009, 2010, 2012, and 2013. Metrics were calculated for the period of January 15 through February 28 for each year from Boulder site data in order to be comparable with the 2013 data. Note that since the 2011 study concentrated on two specific episodes, mixing heights were not estimated for the entire study period, and 2011 consequently is not included in the table.

**Table 4-10**

**Boulder Mixing Height and Meteorological Metrics – January 15 through February 28**

	<b>2009</b>	<b>2010</b>	<b>2012</b>	<b>2013</b>
Percentage of hours with reported mixing height (%)	53	56	43	44
Percentage of afternoon hours with reported mixing heights (%)	48	15	21	29
Overall average of reported mixing heights (m)	90*	46	54	48
Days with low mixing heights through afternoon	10	3	4	9
Days with Eight-Hour peak ozone > 60 ppb	4	2	2	0
Days with One-Hour peak ozone > 60 ppb	8	8	12	1
Highest Eight-Hour average ozone (ppb)	69	69	64	53
Average Two-meter temperature (°C)	-9.3	-8.6	-10.2	-8.9
Average delta temperature (°C)	-0.59	-0.54	0.57	0.15
Average incoming UV radiation, hrs 7 - 17 (W/m <sup>2</sup> )	20	18.4	18.5	18.6
Average outgoing UV radiation, hrs 7 - 17 (W/m <sup>2</sup> )	16.9	12.7	15.5	9.7
Total available (incoming + outgoing) UV radiation hrs 7 - 17 (W/m <sup>2</sup> )	36.9	31.1	34.0	28.3

\*Sodar site located at original location at an elevation approximately 50m lower than current site – thus mixing layer heights are similar to other years.

Review of Table 4-9 shows the following:

- The percentage of hours during which a measured mixing height was detected is similar from year-to-year, with the Sodar identifying a defined top to the mixing layer approximately 50% of the time. 2013 is no exception, though with only 44% of hours, it was at the low end of the spectrum, equating to a higher percentage of hours when the near-surface atmosphere was well mixed.

- In contrast, there is more variability between years in the percentage of hours from noon to early afternoon period (hours 11 – 15) during which a measured mixing height was estimated. Relatively stable conditions during this period continue to appear necessary for the formation of higher ozone concentrations, as noted in previous reports. While the number of days with peak one-hour average ozone concentrations exceeding 60 ppb is similar for 2009, 2010, and 2012, the higher frequency of peak eight-hour average concentrations in 2009 is consistent with somewhat more stable conditions overall during that year. In contrast, the number of peak one-hour ozone concentrations exceeding 60 ppb during 2013 is extremely low (only one day), despite having the second highest percentage of afternoon hours with low mixing heights.
- The number of days when mixing heights remained low throughout the afternoon typically has an indication of overall stability for the winter season. Once again, 2013 is a bit of an anomaly, with a higher percentage of such days than 2010 and 2012, but notably lower ozone readings than those recorded during these years. The percentage is similar to that noted in 2009, which had the most days with the peak eight-hour average greater than 60 ppb. In contrast, the peak eight-hour average measured at Boulder for 2013 was only 53 ppb.

Thus, 2013 had mixing heights that were similar in many ways with the other three years, and that actually look slightly more favorable for increased ozone concentrations when compared with the other three years. Despite this, ozone concentrations measured at the Boulder site during 2013 were very low – the lowest of any UGWOS year.

To investigate possible meteorological differences between the years that would account for this observation, averages for temperature, delta temperature (inversion strength), and UV radiation were calculated for each year and are presented in Table 4-9. What immediately stands out is the significantly lower daily average outgoing UV radiation for 2013 and the total available (sum of the incoming and outgoing) UV, values that are consistent with the low snow amounts associated with this year. Previous UGWOS reports have consistently noted the importance of snow for both increasing the amount of effective UV radiation and maintaining surface inversions and low mixing layers. The 2013 data implies that of these two issues, increased UV radiation available for ozone production may be the more critical factor.

Another factor that deserves consideration from the observed data is the lower outgoing, or reflected UV from the snow cover implies that the surface absorbed the UV and is likely reradiating the energy in the infrared spectrum. This energy, while no longer in a spectrum that will enhance ozone production, will likely affect the atmospheric mixing properties by producing a more thermally turbulent air mass in the mixed layer. This increased thermally induced turbulence will potentially lower the associated pollutant concentrations through better vertical mixing within the mixed layer. While not performed as part of this analysis, consideration should be given to a more detailed analysis of the vertical velocity data from the miniSODAR™ to help understand the role of potentially increased vertical motion. In particular, the vertical turbulence, as reported by the standard deviation of the vertical wind speed, may shed light on the mixing associated with the periods of snow cover versus no snow cover.

## 4.5 Ozonesondes/Radiosondes

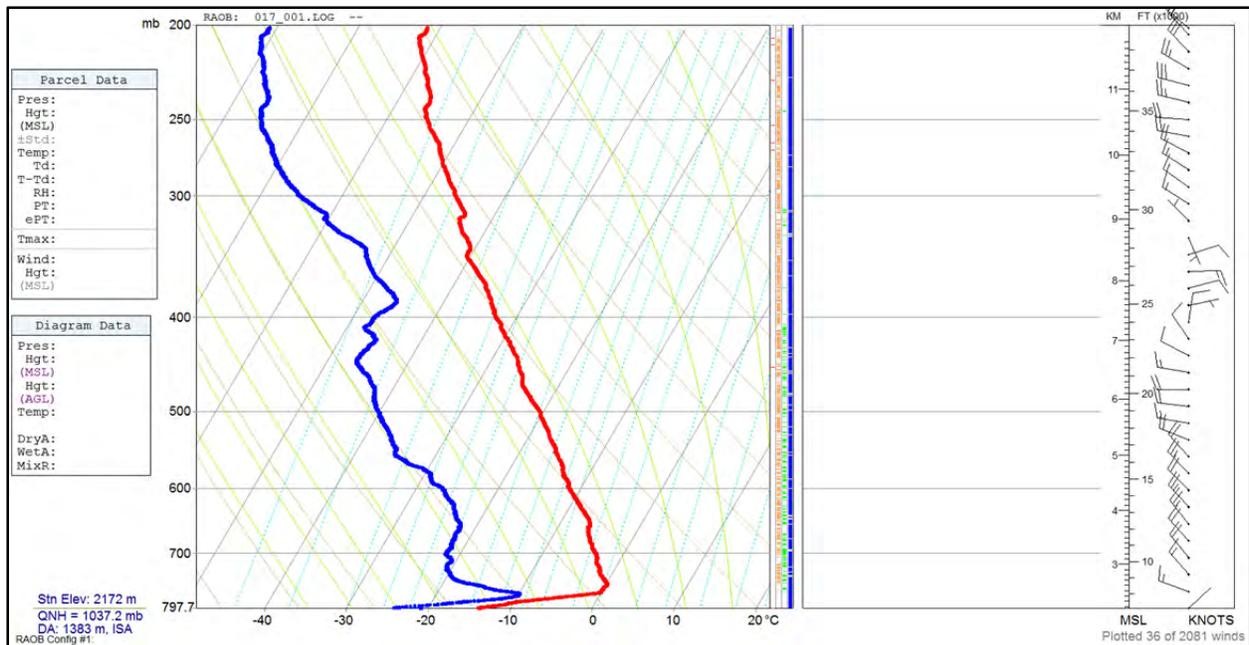
The WDEQ-AQD upper air sounding system was set up and operated by MSI technicians at the Boulder monitoring site during UGWOS 2013. The operational plan called for soundings to occur on IOP days with radiosonde balloon launches in the morning and combination ozonesonde/radiosonde balloon launches in the afternoon. MSI would travel to the Boulder monitoring site on the day before the start of an IOP and begin ozonesonde preparations to be ready for launches on IOP days. There were no IOP's declared to trigger ozonesonde/radiosonde releases during the 2013 UGWOS program. However, test flights were conducted just after the start of the field program and an audit of ozonesonde operations was conducted on February 5, 2013.

During the system “shakedown” day on January 17, 2013, MSI released two test balloons. The morning launch consisted only of a radiosonde. The balloon in the afternoon consisted of a radiosonde coupled with an ozonesonde. Figure 4.28 shows a photo of radiosonde balloon preparations prior to the morning launch on test day.



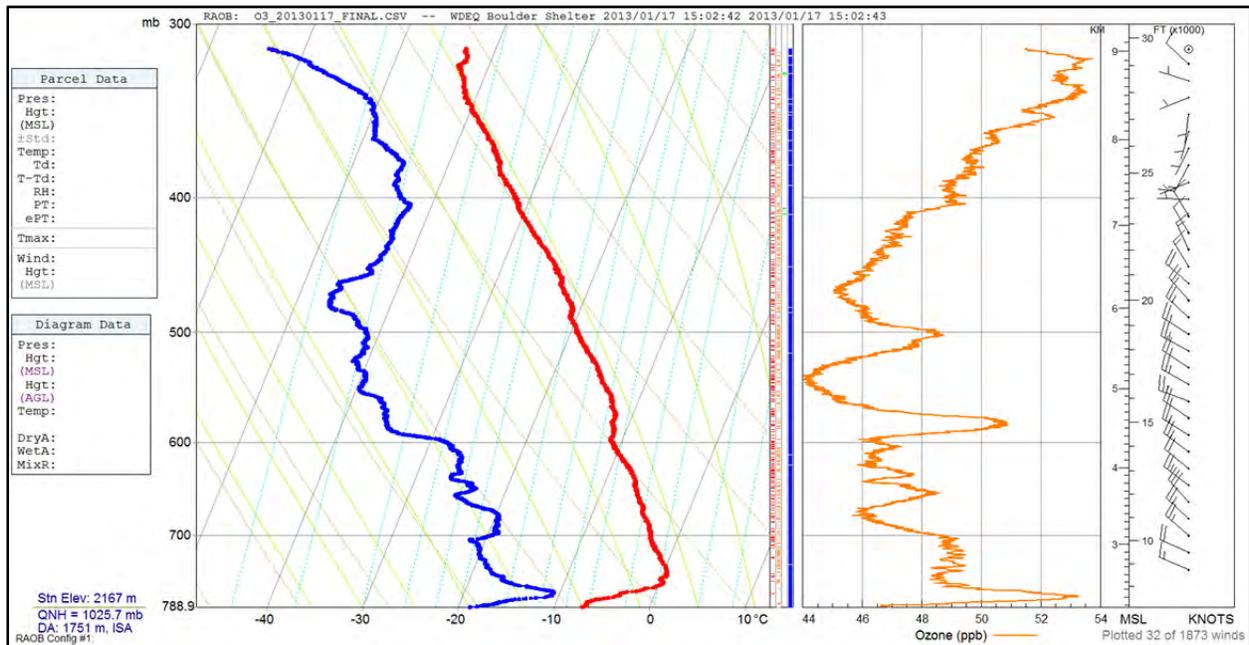
**Figure 4.28 Radiosonde Balloon Launch on January 17, 2013 Test Day**

The radiosonde was released at 11:15 on January 17, 2013 and was tracked until 12:00 (See Figure 4.29).



**Figure 4.29 Morning Radiosonde on January 17, 2013 Test Day**

The afternoon ozonesonde was collocated with the Boulder monitoring site's ozone analyzer sample inlet prior to launch as a quality control check. The Boulder ozone analyzer indicated an ambient ozone concentration of 45 ppb while the ozonesonde package read 42.3 ppb. The balloon was launched at 15:40 and was tracked until 16:22 (See Figure 4.30).



**Figure 4.30 Afternoon Ozonesonde/Radiosonde on January 17, 2013 Test Day**

On February 5, 2013, an audit was conducted by T&B Systems on the ozonesonde preparation process. An ozonesonde was prepared completely in a ready to launch status, tested with a few different known ozone concentration inputs, but never released into the atmosphere. An error was discovered in the ozonesonde pump flow rate measuring device labeling, and pre-flight pump flow measuring procedures were corrected (See more details in Section 3 – Quality Assurance Audit Results of this report).

## **5.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS**

This section provides a summary of the UGWOS 2013 field measurement effort (January 15 through March 31, 2013), observations and conclusions drawn from the data obtained during the study, and recommendations for future measurements.

### **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 thrust of the 2011 effort. The 2012 field measurement campaign focused on the spatial distribution of ozone and ozone precursors using existing long-term monitoring stations and added mobile trailers at Big Piney and Jonah Field. During 2013, the spatial distribution of ozone and ozone precursors was again emphasized with the addition of three mesonet sites and speciated VOC canister sampling systems at eight of the monitoring sites.

During UGWOS 2013, the synoptic weather pattern was similar to what occurred during UGWOS 2012. Weak storms again frequently affected the project area with considerable atmospheric mixing and little accumulation of snow. Extended periods of high pressure with strong surface-based inversions did not occur. During the UGWOS 2013 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 64 ppb observed at the Paradise mesonet site on January 20, 2013.

### 5.1.1 UGWOS 2013 Field Operations

As in previous years, weather and ozone outlook forecasts were issued daily during UGWOS 2013 to alert AQD and contractor personnel when conditions favoring elevated ozone events were expected. Daily forecasts provided sufficient time for MSI's air quality field technicians to activate additional measurements during IOPs including a network of speciated VOC samplers and a balloon-borne ozonesonde/radiosonde upper air sounding system.

MSI 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, ozonesonde/radiosonde sounding plots and current equipment and data collection status.

UGWOS field operations in 2013 included a temporary ambient air monitoring trailer in the Jonah Field which provided continuous measurements of meteorology, ozone and oxides of nitrogen as well as digital scene images recorded by the site camera. Three solar-powered mesonet sites providing continuous ozone and meteorological measurements as well as camera images were located at sites utilized for measurements during previous UGWOS programs including the Warbonnet, Mesa and Paradise (formerly the tethered balloon site) monitoring sites. 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 IOPs at eight monitoring sites in the UGRB. VOC monitoring sites included Boulder, Juel Springs, Big Piney, Jonah Field, Jonah 2 (a control site for Jonah Field) as well as the three mesonet sites mentioned above. A dedicated air quality technician was stationed in the project area to operate VOC sampling equipment and provide fast response to repair any monitoring site instrument failures. The AQD upper air sounding system utilizing radiosondes and ozonesondes was assembled, tested and placed in a state of readiness for twice daily operation by MSI field technicians during IOP's from the Boulder site.

Existing WDEQ-AQD long-term monitoring stations provided surface air quality and meteorological measurements during the UGWOS field effort including Boulder, Daniel, Pinedale, Wyoming Range, Juel Spring, South Pass, and Moxa. The Boulder monitoring site continued to operate with more extensive specialized measurements to further characterize the role of ozone precursors during ozone formation. Specialized measurements for reactive nitrogen species included trace level  $\text{NO}_y$  and “true  $\text{NO}_2$ .” The  $\text{NO}_y$  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  $\text{NO}_2$ ” measurements utilize a highly selective photolytic converter which allows for better speciation of lower levels of  $\text{NO}_2$  than conventional oxides of nitrogen analyzers. The WDEQ-AQD Wind Explorer mini-SODAR continued to operate adjacent to the Boulder monitoring station for the duration of the UGWOS 2013 study period. One of AQD’s mobile monitoring trailers continued to be located at Big Piney to monitor air quality downwind of Big Piney/La Barge development and it provided air quality data for the west side of the UGWOS domain.

During UGWOS 2013, conditions which favor elevated ambient ozone concentrations never materialized and no IOP’s were declared during the two and one-half month field study. Instead, VOC canister samples were collected on designated sampling days 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 2013 field study data:

- Weather conditions were similar to 2012, with frequent mostly weak storms crossing over or near to the UGRB. No strong or persistent high pressure systems occurred that affected western Wyoming.
- There were no designated IOP’s during the 2013 study period. This is the second year in which this has occurred. There were no IOP’s declared during UGWOS 2010.

- The general snow cover was similar to 2012. January had the best conditions over the UGRB, after which the snow cover slowly eroded until late February when the snow melt accelerated. Snow cover was gone by early March.
- 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 2013 study was 64 ppb which is well below the current USEPA NAAQS of 75 ppb.
- Measured VOC concentrations were consistently higher at the Paradise site than at the other monitoring/sampling locations. This may be due to its proximity to oil and gas emissions sources combined with its topographic location in the lowlands adjacent to the New Fork River flood plain – an area prone to more stable atmospheric conditions (lower wind speeds) and localized pooling of pollutants from nearby sources.
- VOC canister sample results again showed relatively low concentrations (even somewhat lower than in 2012) as might be expected during a measurement season when no significant elevated ozone developed. The relative composition of VOC groups (paraffins, oxygenates, etc.) was similar to samples collected during previous UGWOS years.
- UV radiation sensors at the Boulder site recorded lower daily average outgoing (reflected) UV radiation in 2013 than in previous UGWOS studies. This is consistent with the diminished snow cover during 2013 and implies that less UV radiation would be available for photolytic ozone production.

## 5.3 Recommendations

Recommendations for future measurements/objectives are proposed and presented below.

### 5.3.1 WDEQ Upper Air Sounding System

We would again assign a high priority to conducting radiosonde/ozonesonde balloon borne soundings each morning and afternoon to document atmospheric profiles above the study area. Sounding data would provide valuable information to the project meteorologist for forecasting high ozone periods. The soundings would provide:

- Temperature – This would be used to define inversion daily mixing height and mixing height evolution. The location of the inversion base is dependent on the weather conditions that produce the inversion, i.e. sinking air aloft (or subsidence), with stronger subsidence producing lower inversion bases leading to higher pollution concentrations.
- Wind direction and speed – Wind data would be used to help define movement of air masses within an inversion and the possibility of the erosion of the inversion.
- Pressure – This would be used to verify computer weather model projections of pressure center movements and changes in strength, providing the meteorologist more confidence in how developing storm systems might affect the study area.
- Dew point/relative humidity – This would be used to help identify periods of precipitation within the study area with greater accuracy.

Having on-site sounding data available would help to improve elevated ozone period forecasts. A database of daily soundings during all atmospheric conditions and not just during IOP or elevated ozone periods would be developed. Documenting local sounding conditions that occur during non-elevated ozone periods would be used to further clarify and define what meteorological conditions are necessary for ozone development.

Local sounding data would also be integrated with nearby National Weather Service soundings taken in Salt Lake City, Utah, Riverton, Wyoming, and Grand Junction Colorado, along with computer weather model output and other synoptic data. This would strengthen the overall understanding of weather conditions by the meteorologist.

Most of the WDEQ sonde inventory purchased for the 2013 study is still available for future use.

### **5.3.2 Tall Tower Measurements**

We believe a consistent dataset, measuring meteorological conditions not just during high ozone periods but during “normal” periods as well would be extremely valuable. We believe this tower should be located in an area that would initially measure the formation of stable atmospheric conditions as to provide earlier indication of a possible ozone event. Because this would be a permanent measurement platform it would provide an ever expanding robust dataset that we believe could become the cornerstone of the ozone forecasting program.

Based on an updated quotation, a solar-powered 100-meter tower with multi-level meteorological sensors would cost approximately \$165K including installation, initial calibration, and data collection for one year as well as display on MSI’s VDV website during this period. The cost of this tower might be covered using residual funds from the current UGWOS project.

Equipment costs include:

- RM Young Wind Monitor AQ at 3 levels (10, 50 and 100m)
- RM Young Motor Asp. Temp at 4 levels (2, 10, 50 and 100m)
- Barometric Pressure
- CR3000 datalogger w/enclosure
- Raven digital telemetry w/1 year service
- 100 meter tower with TS-2000 elevator and FAA lighting
- Solar array/batteries/enclosure

### **5.3.3 Expansion of Surface-Based Monitoring Network during UGWOS Using WDEQ-Owned Mesonet/VOC Canister Sampling Equipment**

The surface-based monitoring network was expanded for the UGWOS 2013 field effort to include the 3 mesonet sites (Mesa, Warbonnet and Paradise), the Jonah Field site and the 8 locations utilized for VOC canister sampling (Mesa, Warbonnet, Paradise, Jonah, Jonah 2, Boulder, Juel Springs and Big Piney). These sites were selected to provide additional data for investigation of the spatial distribution of ozone and ozone precursors during elevated ozone events in the UGRB. Although elevated ozone events did not develop in 2013, we recommend repeating this network expansion at the same sites in the future since these data are still needed during elevated ozone conditions and AQD already owns this equipment.

### **5.3.4 Lidar and Radiometer Measurements using the San Jose State Fire Research Lab**

Consistent with previous recommendations, we continue to feel that additional measurements of the surface mixing height is important, as this continues to be a key metric needed for understanding and short-term forecasting of ozone episodes. The height and physical boundaries of the capping of the surface layer provides information regarding the potential of concentrating ozone and ozone precursors within the capped layer. Expanding the understanding of the strength of the inversion and stability within this layer will help in forecasting the potential breakup or changes in the capping layer characteristics and the effect of winds and on the inversion behavior. T&B Systems has opened discussions with Dr. Craig Clements, who is the director of San Jose State's Fire Research Laboratory. Their mobile lab is equipped with a scanning Lidar, profiling radiometer, surface meteorological equipment, and rawinsonde launching equipment. Used extensively in the field during the summer fire season, the mobile lab is typically available during the winter for other studies. Thus, a possible scenario is to move the mobile lab to the UGWOS area during the winter months and bring in San Jose State students to operate the lab during IOPs.

Use of the lab would provide an economical opportunity to investigate the use of a scanning radiometer for obtaining continuous real time temperature profile data. As noted in previous recommendations, a radiometer can provide more easily interpretable mixing height information than the Sodar provides. A Lidar provides an interpretive analysis of mixing, similar to a sodar, but uses the backscatter from aerosols in the mixed layer. As evidenced by field observations during episode events, there are adequate aerosols present to provide a strong backscatter profile within the trapped layers. Typically operated in a horizontal/vertical scanning mode for the fire research, the Lidar would be operated in a more detailed vertical mode to provide mixing height information to augment the data from the radiometer and provide a higher resolution picture of the atmospheric structure. This measurement of mixing using the aerosol backscatter combined with the measurements from the radiometer will provide some needed information on the relationship of the thermal profile to the aerosols that have been trapped within the mixed layer. It will also evaluate the performance of the radiometer and its value during the wintertime limited mixing conditions. The Lidar has a vertical range of about 300 meters, which would be sufficient for identifying mixing heights of interest. The Lidar data could also be used to further evaluate the extraction of mixing height data from the miniSODAR fax displays, allowing a tuning of the interpretative process to further improve the accuracy of the data.

Operations would be conducted by a collaboration of San Jose State and UGWOS Team personnel, with the UGWOS Team necessary to guide operations in order to meet the UGWOS-specific goals of which San Jose State is unfamiliar. We can continue the conversation with Dr. Clements if there is interest in this recommendation.

### **5.3.5 Ceilometer**

The use of a ceilometer to assist in identifying atmospheric structure could also be very beneficial. Ceilometers provide vertical data similar to that obtained from the Lidar, using aerosol scattering to map the extent of the aerosol-rich air underneath a capped layer, effectively measuring the mixing height. Ceilometers are much simpler than Lidars and considerably less expensive, and thus could be an economical means of providing continuous mixing height data that would be useful in monitoring and potentially assisting with short-term forecasting of ozone events driven by shallow mixing heights. The use of ceilometers deserves further investigation. While not currently part of the Fire Research mobile laboratory, use of the mobile lab would provide an excellent opportunity to evaluate the use and performance of this relatively inexpensive instrument. Lease programs may be available to economically add this instrument to the laboratory operations.

### **5.3.6 Unmanned Aircraft**

T&B Systems is also investigating the use of recently developed off-the-shelf remote controlled aircraft for obtaining temperature and ozone soundings. We are currently reviewing a multi-rotor, GPS-guided helicopter (quad-copter) that provides a very stable platform with an operating range of 300 meters. Models exist that can lift a payload of up to five pounds, which is sufficient to lift a sonde package containing a 2B Technologies Model OEM-106 “Ozone Monitor on a Board.”

Use of such a system would address several limitations currently associated with traditional ozonesondes:

- **Cost.** Ozonesondes currently cost approximately \$800/flight in non-recoverable supplies and equipment. Furthermore, typically for UGWOS, only the first several hundred meters of flight (roughly the first two minutes) are of interest. Preparation time, both for preparation of the sonde and preparation for the flight, makes frequent flights cost-prohibitive.

A quad-copter system provides a relatively inexpensive ozone sounding method that is better suited for near surface sounding such as those desired for UGWOS. Soundings can be repeated economically at a high frequency, based solely on the supply of rechargeable batteries saving ozonesonde resources for less frequent profiling of ozone concentrations above the immediate surface layer.

- **Response time.** Ozonesondes are limited in the spatial precision of their measurements due to both the response time of sampler and the vertical movement of the sonde through the area being sampled. Thus, the accuracy of profile inflections showing the top of the surface layer and the effectiveness of layer cap in trapping ozone will be compromised to some degree. The quad-copter's GPS system can be used to maintain flight levels for longer periods of time, allowing definitive mapping of the layer cap.
- **Methodology.** The potassium iodide sampling methodology used by ozonesondes differs from the UV methodology used for routine surface monitoring of ozone. Use of this quad-copter system provides a standardized methodology for surface and elevated ozone measurements.

This combination of increased frequency, added flexibility and comparability, and increased spatial accuracy would provide a direct means of verifying and refining measurements from both existing and proposed continuous profiling measurements. One particularly notable use of the system would be to further understand the relationship between the facsimile structure retrieved from the Sodar and the controlling thermal structure measured by the system throughout the mixed layer. This will help enhance the understanding and interpretation of the facsimile information and provide more useful data, especially during periods when the Sodar data provides ambiguous results due to lack of turbulence or neutral layers in the structure. For example, the current Sodar installation does not typically show capping layers above about 100 meters.

It is unknown at this time whether this is an indication of an actual breaking down of the capping layer, or that capping layers are simply beyond the altitude range of the current system. A data set during the conditions of interest will help understand the temperature structure above the altitude range of the Sodar and how this currently unmeasured structure affects the mixing properties of the atmosphere. This improved understanding will then lead to better forecasts based on the facsimile data and potentially provide insight into forecasting of the lifting or breakup of layers.

Similarly, this low level quad-copter package would help validate the use of the continuous measurements made by the radiometer and ceilometer. In particular, one of the potential limitations of the radiometer is the performance under conditions with a complex temperature structure and multiple inversions. The fine detail obtained from the quad-copter measurements could help determine the performance of the radiometer under the conditions of interest and the resulting potential usefulness in real-time forecasting of the inversion strength and mixed layer depth.

T&B System's staff has already started research into, and anticipates some testing of, this potential sampling platform during the summer of 2013. Adding meteorological measurements to the platform could make it a viable option for collection of detailed air quality and meteorological data in the mixed layer.

### **5.3.7 Nocturnal Transport of NO<sub>x</sub> along Drainage Basins**

Previous UGWOS studies have not comprehensively sampled conditions along the very bottom of local drainage basins, adjacent to rivers and streams. The drainages created by the Green River and its tributaries may serve as a conduit for significant nocturnal transport of NO<sub>x</sub> and other pollutants. A number of prospective locations along the Green River system have been identified as possible temporary measurement sites for future UGWOS campaigns. A list of these prospective sites includes:

- Whelan Bridge Road near the town of La Barge. This site is adjacent to the Green River and is the southernmost proposed site.
- Miller Lane, approximately 2 miles west-southwest of the town of Big Piney. This site is near Middle Piney Creek and will sample air descending from the gas fields on the eastern slopes of the Wyoming Range.
- Unnamed road along the Green River 6.4 miles east of the town of Marbleton. This site will sample air immediately downstream of the confluence of the Green River and New Fork River.

Additionally, a number of locations have been identified as possible routes to conduct transects of drainages along highways during IOPs. A vehicle equipped with gaseous analyzers, meteorological equipment, and a global positioning system would be used to sample the conditions as the highway descends toward the river-bottom, transects the river, and ascends the opposite side of the drainage basin. A list of possible transect locations includes:

- Reardon Draw Road, crossing the Green River, 5.6 miles south-southeast of the town of Big Piney.
- State Highway 351, crossing the Green River, 7.5 miles east of the junction with U.S. Highway 189.
- State Highway 351, crossing the New Fork River, 11 miles west of the junction with U.S. Highway 191.
- U.S. Highway 189, crossing Cottonwood Creek, 9 miles south of the town of Daniel.
- Paradise Road, crossing the New Fork River near the town of Boulder.

The transect data combined with low level meteorological measurements would give an indication of the transport and dispersion of the elevated NO<sub>x</sub> air masses along the drainage basins and could provide valuable input data for subsequent dispersion modeling efforts.

### **5.3.8 Improved miniSodar Data Assimilation and Analysis**

There is a wide variety of meteorological data measured by the miniSodar beyond the reported wind speed and wind direction profile. In particular, the vertical wind speed and standard deviation of the vertical wind speed ( $\sigma_w$ ) are important parameters in understanding the turbulence and mixing properties in the lowest layers. Previous discussions have suggested there may be a relationship between these parameters and the mixing height, but no formal analyses have been conducted. To further understand the value and develop appropriate tools for making use of the data, it is recommended that analyses of the additional parameters collected by the miniSodar be performed to look at the turbulence parameters and how they can be used to better understand the mixing during the episodic periods. To a certain degree this process has already started with the ingest of Sodar data into the data display system that is being operated as part of the support for the miniSodar and BAM operations. Real-time data, including the vertical wind speed and  $\sigma_w$  data, are now available starting in late July, 2013 for analysis using Vista Data Vision. All of the prior data are available for reformatting and ingest to cover the periods of interest and allow analysis using Vista Data Vision

## **6.0 ACKNOWLEDGMENTS 2013**

Many individuals and groups in addition to the staff of Meteorological Solutions, Inc. and T&B Systems contributed to the successful completion of the 2013 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. Jennifer Frazier, WDEQ's Jonah Interagency Office representative, continued to provide field support facilitating project logistics and field measurements. Many other WDEQ personnel provided assistance and were helpful in making 2013 a successful study. ARS provided meteorological and air quality data they were collecting for the WDEQ at the Moxa, Daniel, South Pass and Big Piney sites. Linn Energy made power available for the Jonah Field monitoring site.

## 7.0 REFERENCES

[http://www.hpc.ncep.noaa.gov/dailywxmap/index\\_20021201.html](http://www.hpc.ncep.noaa.gov/dailywxmap/index_20021201.html). National Oceanic and Atmospheric Administration, *Daily Weather Maps*, accessed June 2013.

<http://www.spc.noaa.gov/obswx/maps/>. National Oceanic and Atmospheric Administration, National Weather Service Storm Prediction Center, *Surface and Upper Air Maps*, accessed June 2013.

**Appendix A**  
**Monitoring and Quality Assurance Plan**

# MONITORING AND QUALITY ASSURANCE PLAN

for the

## UPPER GREEN RIVER WINTER OZONE STUDY - 2013

Prepared for

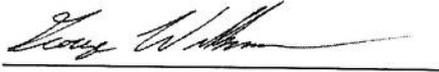
State of Wyoming  
Department of Environmental Quality, Air Quality Division  
122 West 25<sup>th</sup> Street  
Herschler Building, 2<sup>nd</sup> Floor East  
Cheyenne, WY 82002-006

January 15, 2013

Prepared by



## UGWOS 2013 QAPP APPROVAL



George Wilkerson, MSI  
UGWOS Project Manager

1/15/2013

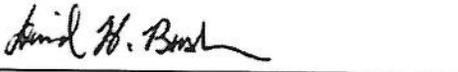
Date



Bill Hauze, MSI  
UGWOS Field Manager

1/15/2013

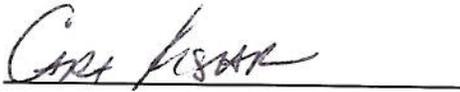
Date



David Bush, T&B Systems  
UGWOS Quality Assurance

1/15/2013

Date



Cara Keslar, WDEQ  
Monitoring Section Supervisor

2/26/13

Date

# DISTRIBUTION LIST

## **WDEQ**

Cara Keslar

Steve Mugg

## **MSI**

George Wilkerson

Bill Hauze

Tyler Ward

Dan Risch

Brian Olsen

## **T&B Systems**

David Bush

Bob Baxter

David Yoho

# TABLE OF CONTENTS

SECTION 1	INTRODUCTION AND PROJECT OVERVIEW.....	1-1
SECTION 2	SAMPLING PROGRAM DESCRIPTION	
	2.1 Forecasting Protocol .....	2-1
	2.2 Continuous Measurements .....	2-5
	2.3 Intensive Measurements .....	2-7
	2.4 Supplemental Monitoring and Data Collection .....	2-8
SECTION 3	MONITORING SITE DESCRIPTIONS	
	Monitoring Site Descriptions .....	3-1
SECTION 4	MONITORING EQUIPMENT DESCRIPTION	
	4.1 Mesonet Monitoring Sites .....	4-1
	4.2 Jonah Monitoring Site .....	4-4
	4.3 Remote Sensing Upper Air Meteorology.....	4-6
	4.4 Ozone/Rawindsondes .....	4-7
	4.5 VOC Sampling .....	4-9
SECTION 5	DATA MANAGEMENT AND REPORTING	
	5.1 Data Management Plan .....	5-1
	5.2 Data Reporting .....	5-6
SECTION 6	QUALITY ASSURANCE PROGRAM	
	6.1 Project Management.....	6-1
	6.2 Data Quality Objectives .....	6-1
	6.3 Assessment and Oversight .....	6-1
	6.4 Data Validation.....	6-6
SECTION 7	REFERENCES .....	7-1
APPENDIX A	Site Photos	
APPENDIX B	Standard Operating Procedures (SOPs)	

# SECTION 1

## INTRODUCTION AND PROJECT OVERVIEW

This monitoring and quality assurance plan 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 2013, sponsored by the Wyoming Department of Environmental Quality (WDEQ). While research in nature, the monitoring methods and objectives described in this plan are consistent whenever possible with 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).

Recent high ozone events observed in this area have raised concerns regarding potential adverse health and ecological effects associated with monitored concentrations greater than the U.S. Environmental Protection Agency's ozone standard (currently set at an 8-hour average concentration 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 currently available about the nature and causes of these unusual events, the WDEQ funded a comprehensive field study (the Upper Green Winter Ozone Study or UGWOS) which was conducted during the late winter – early spring seasons of 2007 through 2012. 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 and 2012, 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 2013. This QA plan addresses the 2013 monitoring effort.

Data from the 2013 study will 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

### SAMPLING PROGRAM DESCRIPTION

The sampling period for UGWOS 2013 will run from January 15, 2013 through March 31, 2013. Sampling that will be conducted for UGWOS during this period is described below.

#### 2.1 FORECASTING PROTOCOL

The UGWOS effort for 2013 will have an intensive operating period (IOP) component. As in prior years, the UGWOS team will continue to provide ozone forecasts throughout the study period to assist the WDEQ in identifying potential high ozone periods.

The current conceptual model of the meteorological conditions conducive to the formation of high ozone levels in the Pinedale-Jonah fields during the winter and early spring 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 2-1 through 2-4 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 2-1 shows the ridging pattern of the 500 mb height contours; Figure 2-2 presents the wind speed isotachs at 500 mb; Figure 2-3 shows the ridging pattern of the 700 mb height contours; and Figure 2-4 demonstrates that there was warmer air aloft just above the surface, indicating air mass subsidence.

National Weather Service numerical synoptic-scale models such as the North American Mesoscale model (NAM) and the Global Forecast System model (GFS), coupled with regional NWS Forecast Discussion guidance, will provide the experienced MSI and AQD weather forecasters with the basis for daily long and medium range operational forecasts. An additional factor that appears to prove critical in operational forecasting is the presence of sufficient snow cover to provide the strong UV radiation flux and enhanced low level stability needed for development of high ozone concentrations. Local observations will provide this information on a day-to-day basis.

Forecasts for Air Quality Division's (AQDs) 2013 UGWOS ozone monitoring project will be issued by the MSI project meteorologists each morning. Once the forecast is completed it will be emailed to project participants by 10:00 MST each morning, seven days a week. The forecast will be finalized on a form containing three sections. The first section will be a synopsis of the current weather features that will affect the study area over at least the next 48 hours. The second section will contain a detailed short-term forecast out through day three. This forecast contains a discussion of temperature, wind, precipitation and sky conditions, and will also emphasize parameters that are of specific interest to the study, as appropriate, such as high pressure ridge location, inversion development, and snow cover. At the end of this section there will be a discussion on the expected ozone development during this period. The third section is an outlook that will cover days four through seven. This outlook will be similar in content to the second section with only the time frame changing.

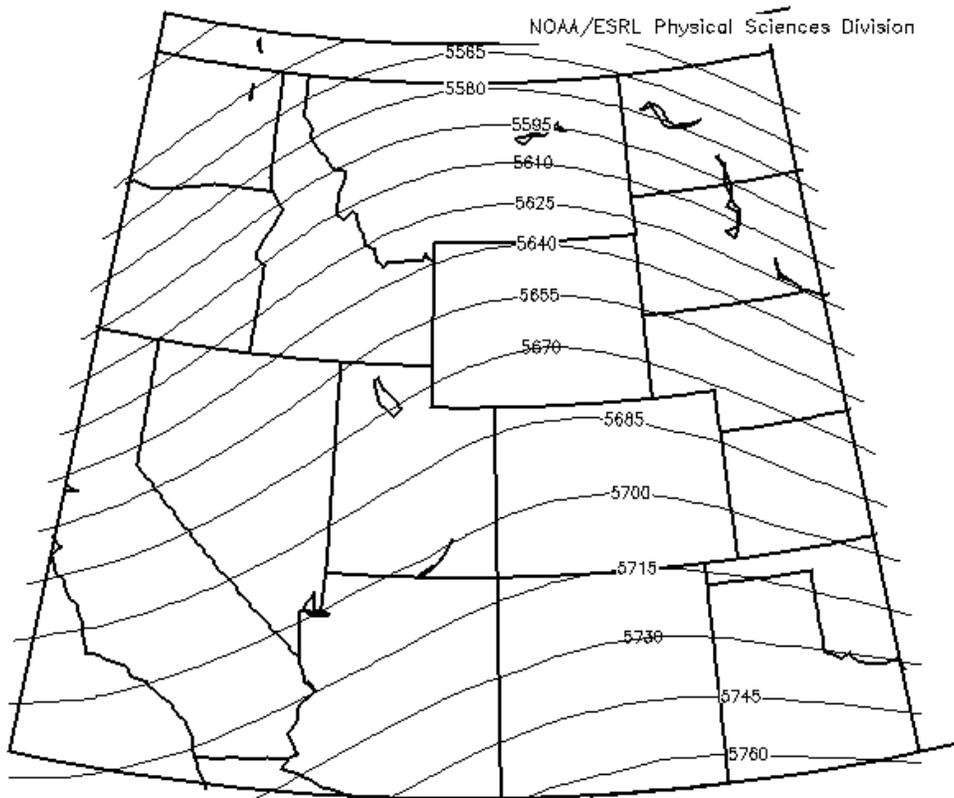


Figure 2-1 Composite 500 mb Heights During High Ozone Periods

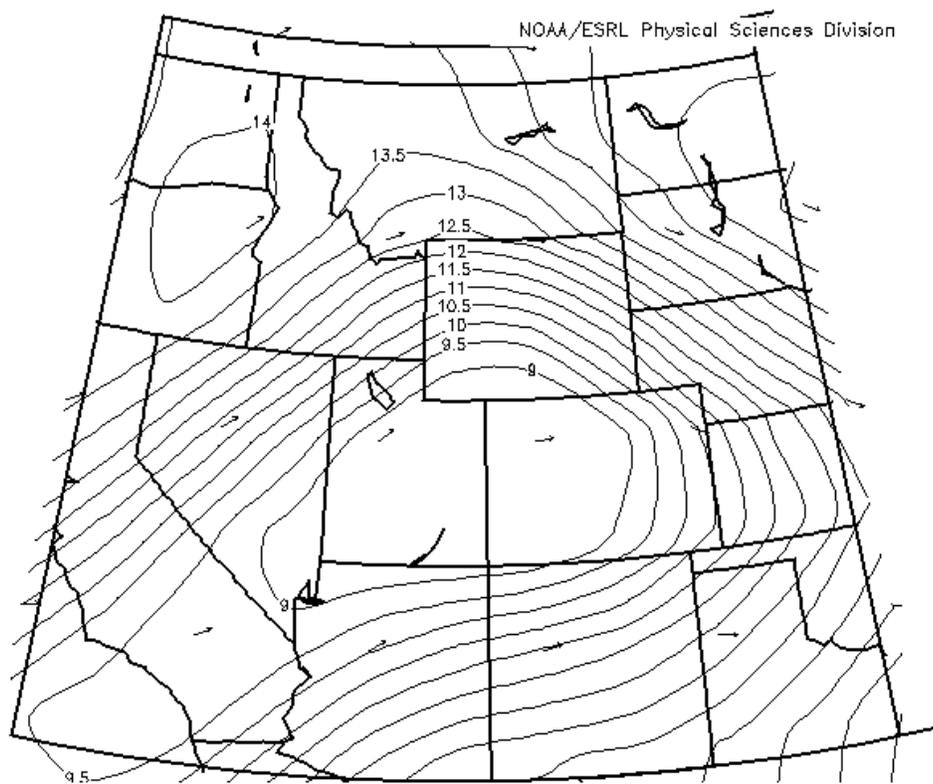


Figure 2-2 Composite 500 mb Winds During High Ozone Periods

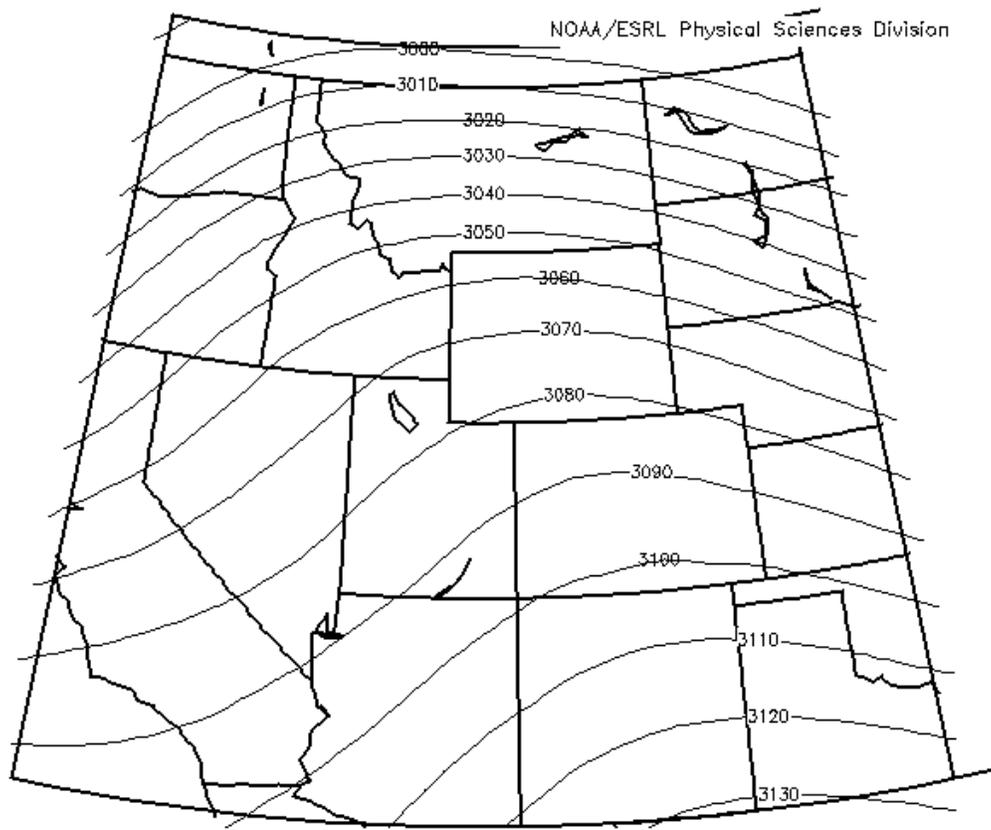


Figure 2-3 Composite 700 mb Heights During High Ozone Periods

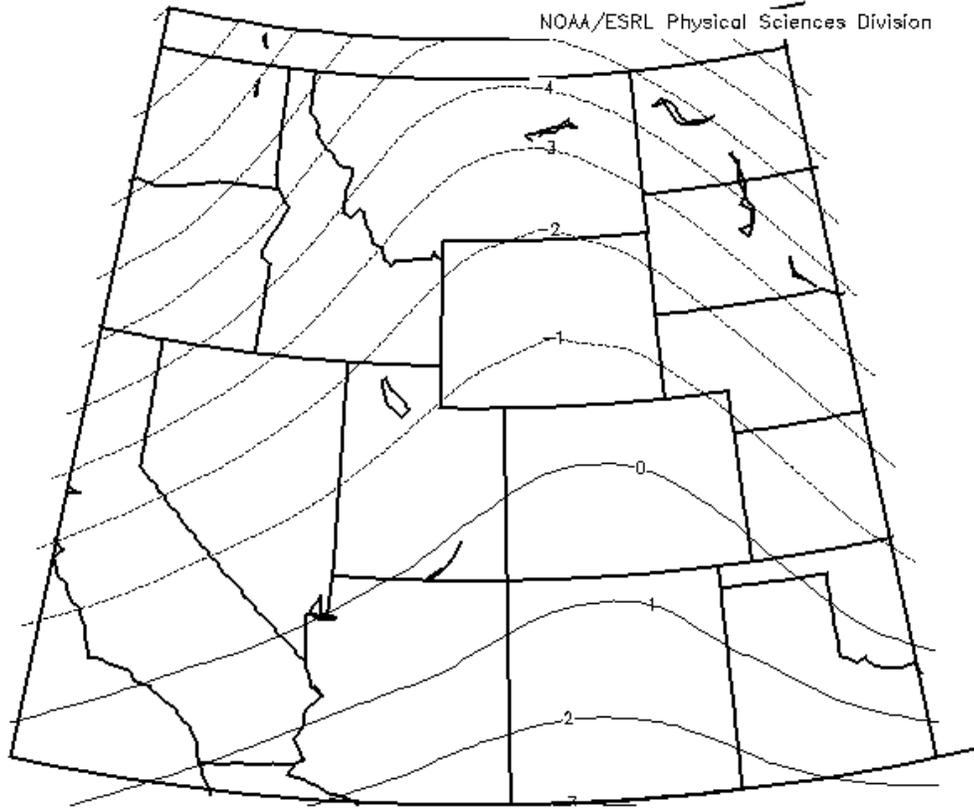


Figure 2-4 Composite 700 mb Temperature During High Ozone Periods

## 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 ozone, wind, and temperature measurements will be taken from a 3-site mesonet (mesonet). 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.

The mesonet ozone analyzers will operate continuously over the course of the study and routine performance checks of the analyzers will be conducted approximately once per week. Their operation on-site will be checked using the 2-B ozone generator and zero-scrubber, and any zero and span deviations noted. As in previous UGWOS field programs, MSI will provide an on-site technician who will be stationed in the project area for the duration of the field season. The technician will provide field support and routine calibrations for the monitoring measurements for the Jonah site and the mesonet sites, and will deploy/retrieve VOC samples at the Jonah, Juel Springs, Big Piney, Boulder and mesonet sites (see below). He will also be available to troubleshoot issues at all AQD sites in the study area (Wyoming Range, Daniel, Boulder, Pinedale, Juel Springs, Big Piney and Farson meteorological tower). The field technician will also be available to assist with UGWOS and AQD contracted audits during the study period.

### **2.2.2 Ozone and NO/NOx Measurements in the Jonah Area**

Continuous ozone and oxides of nitrogen will be performed at a location within the Jonah Field utilizing a WDEQ air monitoring trailer. Sampling at the Jonah site will include continuous measurement of ozone, oxides of nitrogen, wind speed, wind direction, temperature and pressure. The site will also be equipped with a video camera, providing 15-minute images. A datalogger and cellular telemetry will be supplied to retrieve data from the site on an hourly basis. Sites will be polled every 15 minutes to update data and post to project website. MSI will be responsible for the air quality and meteorological measurements, including routine checks, data validation, and database management.

### **2.2.3 SODAR Upper Level Winds**

For the 2013 monitoring effort, the WDEQ MiniSodar (sodar) will be maintained at the existing WDEQ monitoring site at Boulder. Both surface and winds aloft will be measured continuously. The sodar is equipped with a battery bank, solar panels and a backup generator, providing continuous measurements without the need of AC power. However, the chosen site for operations does include available AC power. Remote communications is made possible with a cellular modem. All data will be posted in near real-time on a web page as well as archived data posted automatically on a FTP server. These sodar data can be reviewed remotely, as necessary.

The WDEQ will service the sodar, as necessary. T&B Systems will review the data on a daily basis, validate the wind data, and reduce mixing height data for the study period.

## **2.3 INTENSIVE MEASUREMENTS**

During periods when high ozone levels are forecast, additional intensive measurements will be initiated. Up to 15 IOP days are budgeted for this study. IOP days will be identified using forecast information and consultation with WDEQ AQD. The key component of the IOPs is the collection of vertical profiles of ozone and meteorology profiles and VOC samples, as described below.

### **2.3.1 Ozone/rawinsonde Operations**

Free ascending balloon-borne measurements of ozone, temperature, relative humidity, and winds will be made during each IOP from the Boulder air quality monitoring site by MSI personnel using equipment maintained by the WY DEQ. Twenty ozonesondes will be available for the study. It is anticipated that two ozonesondes will be released on a given IOP day.

MSI personnel will conduct the ozonesonde measurements. This includes preparation of the ozonesondes prior to the flights. MSI will dedicate one technician for conducting the ozonesonde measurements, with MSI's dedicated UGWOS field technician available for backup support. Both technicians will be trained prior to the beginning of the study. At least one or two of the ozonesondes will be activated for the training.

### **2.3.2 VOC Sampling**

VOC sampling will be conducted at the Boulder, Big Piney, and Juel Springs sites, as well as at the UGWOS-specific Jonah air quality site and the three mesonet sites. In addition to the sampling at the Jonah site, VOC samples will also be conducted at a second site located 450 meters NNE of the air quality site. This site is located away from the immediate influence of the gas production facility adjacent to the air quality site, and is also collecting wind data to assist in the comparison of readings from the two sites.

VOC will be sampled as integrated 3-hour samples. VOC samples will be collected using 6-liter SUMMA canisters connected to canister samplers previously used by the WDEQ for the Pinedale air toxics study conducted in 2009/2010 and with the existing canister sampling system at Boulder. Samples will be collected on IOP days from 0700-1000. Thus, up to 15 samples will be taken at each of the sites over the course of the study. In addition, five (5) quality control samples will be collected at each site, including zero air contamination samples, duplicates, and field blank samples.

## 2.4 SUPPLEMENTAL MONITORING AND DATA COLLECTION

### Archiving of NOAA Products

Archiving of selected NOAA data products will occur on a daily basis. The items that will be archived for the period from January 15 through March 31, 2012 are listed below:

- 00Z and 12Z surface and upper air maps for 700 mb, 500 mb and 850 mb. (Also readily available from on-line archives)
- All rawinsonde sites in the United States for both 00Z and 12Z time periods. (Also readily available from on-line archives)
- Visual and IR, US east and west satellite images twice per day. (Also readily available from on-line archives)

In addition to the above, the following data are currently archived on the web and are available for analysis:

- Snowpack - available at NOAA's National Operational Hydrologic Remote Sensing Center
- Total Column Ozone - A web site from NASA provides historical ozone global charts, and Dobson Unit measurements for any lat/long on any particular day.
- Local Camera Images - The current local camera images from Daniel, Juel, Boulder and Pinedale can be viewed on line at the WDEQ or UGWOS web sites, and there is also a 2 week image archive on the WDEQ site which consists of an image at 9:00, 12:00, and 15:00 MST each day. Archived images can also be requested from Air Resource Specialists, Inc. Images from the Jonah Field and the three mesonet sites will be transferred every 15 minutes and posted on the UGWOS website.

## **SECTION 3**

### **MONITORING SITE DESCRIPTIONS**

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, both past and present, in the study region.

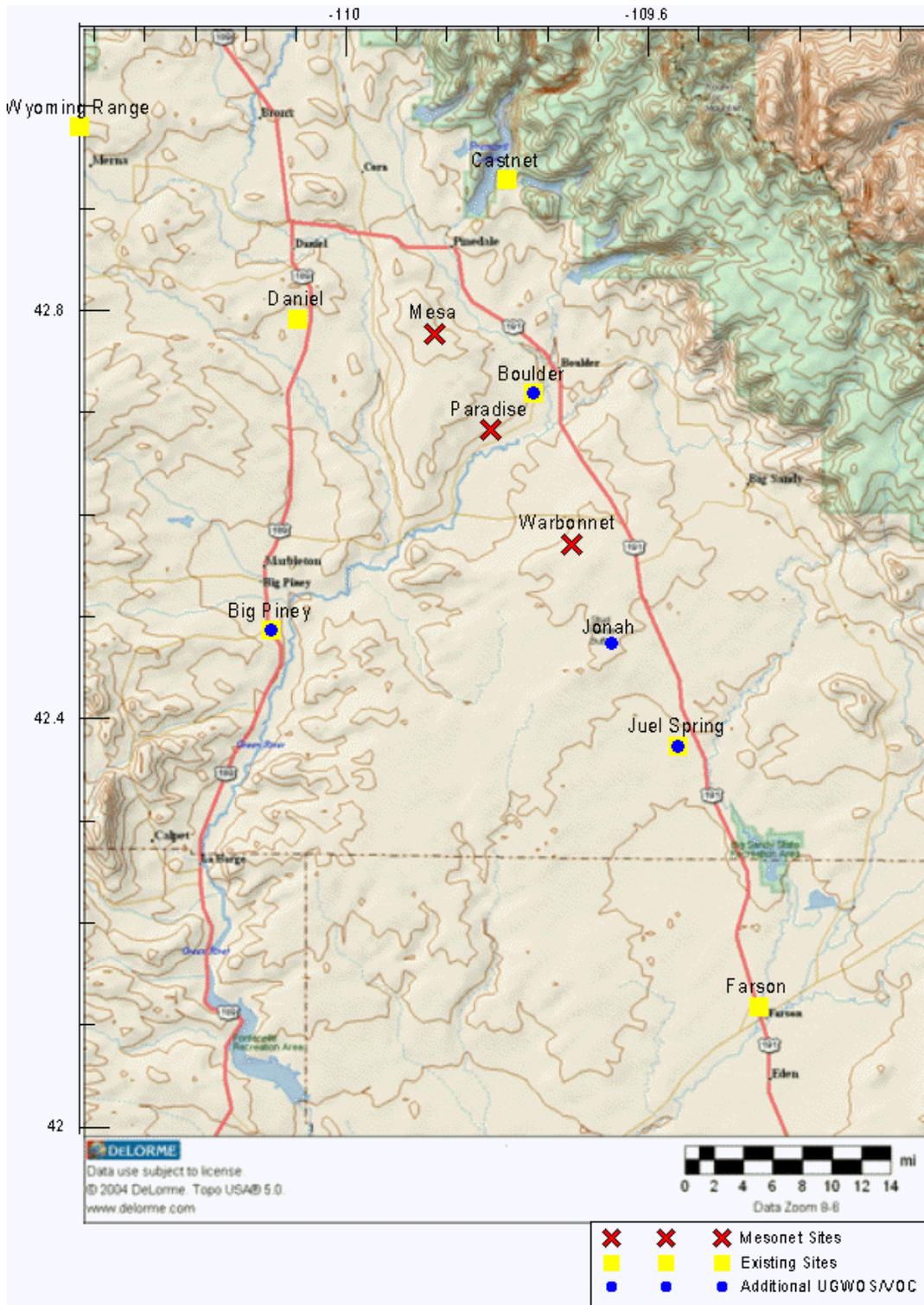


Figure 3-1. Map of UGWOS and Additional Ozone Monitoring Site Locations

Table 3-1. Monitoring Locations

	Latitude	Longitude	Elev.
<b>SODAR SITE</b>			
Boulder	42.7188	-109.7529	7078'
<b>MESONET SITES</b>			
Mesa	42.7774	-109.8829	7522'
Paradise	42.6825	-109.8090	6966'
Warbonnet	42.5703	-109.7022	7414'
<b>JONAH AREA SITE</b>			
Jonah (2013)	42.4736	-109.6497	7259'
Jonah 2 VOC	42.4770	-109.6476	7300'
<b>EXISTING MONITORING SITES OF INTEREST</b>			
Big Piney	42.4870	-110.0995	6823'
Daniel	42.7910	-110.0650	7084'
Castnet	42.9284	-109.7880	7853'
Farson	42.1184	-109.4541	6619'
Pinedale	42.8698	-109.8707	7186'
Juel Spring	42.3735	-109.5605	7020'
Wyoming Range	42.9801	-110.3530	8123'

## SECTION 4

### MONITORING EQUIPMENT DESCRIPTION

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

#### 4.1 MESONET MONITORING SITES

All equipment used at the mesonet ozone monitoring sites will be housed in 70 to 100-quart insulated containers. Two 110 amp-hour deep cycle 12-Volt battery will power all equipment. Each site will be equipped with solar panels, allowing continuous monitoring and an Airlink Raven digital cellular modem for remote telecommunications.

The following equipment will be at each of the mesonet sites:

##### 2B Model 202 Ozone Analyzer

The 2B Ozone Monitor will be used for the mesonet Monitoring. This monitor has a low power consumption (12v DC, 0.33 amp, 4.0 Watt) relative to conventional instruments allowing operation with deep cycle batteries. Additionally, it does not require a temperature-controlled environment. The 2B Technologies Model 202 Ozone Monitor™ is designed to enable accurate and precise measurements of ozone ranging from low ppb (precision of ~1 ppbv) up to 100,000 ppb (0-100 ppm) based on the well-established technique of absorption of light at 254 nm. "Absorption spectroscopy" is a chemical analysis technique made possible by the phenomenon that a given molecule absorbs light at selected wavelengths. The wavelengths absorbed are characteristic of each molecule's atomic features. The amount of light radiation absorbed by a substance depends on two factors: the number of molecules in the path of the light, and the characteristics of the molecule (e.g., absorption cross-section). Measurement of changes in the light intensity as it passes through the molecules, and the use of calibration and reference data, enable the determination of the number of molecules encountered.

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

##### RM Young Model 05305 Wind Monitor AQ

For surface monitoring of wind speed and wind direction at the mesonet sites, we will employ RM Young 05305 Wind Monitor AQ wind speed and direction sensors. These sensors employ a propeller anemometer. The sensors will be mounted on 3-meter tripods (**Figure 4-1**), resulting in a measurement height of 3 meters. All sensors will be oriented to true north using either the GPS walk-off method or solar alignment method for orienting wind speed sensors.



Figure 4-1. Tripod mounting of wind sensors.

Monitoring quality objectives for the supplemental surface wind measurements are presented below.

Accuracy (instrument specifications)	
Horizontal Wind Speed	$\pm(0.2 \text{ m/s} + 5\% \text{ of observed})$
Horizontal Wind Direction	$\pm 5$ degrees
Precision (performance checks)	
Horizontal Wind Speed	$\pm 0.1 \text{ m/s}$
Horizontal Wind Direction	$\pm 2$ degrees
Output Resolution	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	1 deg.
Starting Threshold	0.5 m/s

#### 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  $-50^{\circ}$  to  $+70^{\circ}\text{C}$ .

Accuracy (performance checks)	$\pm 0.5^{\circ}\text{C}$
Precision (performance checks)	$\pm 0.2^{\circ}\text{C}$
Resolution	$0.1^{\circ}\text{C}$

#### Campbell Scientific CR206 Data Logger

All data will be stored at the Jonah Field and mesonet sites 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.. Based on the number of measurements and statistics being recorded, the CR850 can operate for a period well beyond the duration of the UGWOS field measurement season before it is necessary to download data. CDMA 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.

## **4.2 JONAH MONITORING SITE**

Air quality monitoring at the Jonah site will be conducted using the following equipment:

### Thermo Scientific Model 42i NO/NO<sub>2</sub>/NO<sub>x</sub> Analyzer – EPA Approval RFNA-1289-074

The Model 42i uses the chemiluminescence detection principle, coupled with state-of-the-art microprocessor technology to provide the sensitivity, stability and ease of use needed for ambient monitoring requirements. The analyzer uses multi-tasking software, which allows complete control of all functions while providing online indication of important operating parameters. Measurements are automatically compensated for temperature and pressure changes.

Accuracy	±5%
Precision	±5%
Resolution	1 ppb
Lower Quantifiable Limit	2 ppb

### Thermo Scientific Model 49i Ozone Analyzer – EPA Approval EQOA-0880-047

The Model 49i Ozone Analyzer is a microprocessor-controlled analyzer that uses a system based on the Beer-Lambert law for measuring low ranges of ozone in ambient air. The Model 49i Ozone Analyzer uses a dual-cell, UV photometric gas analyzer for measurement of ambient air monitoring. Because the instrument has both sample and reference flowing at the same time, a response time of 20 seconds can be achieved. Temperature and pressure corrections are performed automatically.

Accuracy	±5%
Precision	±5%
Resolution	1 ppb
Lower Quantifiable Limit	2 ppb

### Teledyne/API Model 700 Calibrator

The Model 700 is a microprocessor based calibrator for precision gas analyzers. Using a combination of highly accurate mass flow controllers and compressed sources of standard gases, calibration standards are provided for multipoint span and zero checks.

Up to 4 gas sources may be used. In addition, the Model 700 is equipped with an optional built-in, programmable ozone generator for accurate, dependable ozone calibrations and to produce NO<sub>2</sub> when blended with NO gas in the internal GPT chamber. As many as 50 independent calibration sequences may be programmed into the M700, covering time periods of up to one year. These sequences may be actuated manually, automatically, or by a remote signal. Dilution air is supplied to the calibrator using an API Model 701 zero air system.

RM Young Model 05305 Wind Monitor AQ

For monitoring of wind speed and wind direction a 10-meter tower and RM Young 05305 Wind Monitor AQ wind speed and direction sensor will be employed. These sensors use a propeller-type anemometer. The direction vane will be oriented to true north using either a compass or the GPS walkoff method.

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

### Campbell Scientific 109 Temperature Sensor

The temperature will be measured using a Campbell Scientific model 109 sensor. The temperature sensor will be mounted in a naturally aspirated radiation shield.

Absolute Accuracy	$\pm 0.5^{\circ}\text{C}$
Precision	$\pm 0.2^{\circ}\text{C}$
Resolution	$0.1^{\circ}\text{C}$

### **4.3 REMOTE SENSING UPPER AIR METEOROLOGY**

An ASC Model 4000 miniSodar will be used to collect the upper air meteorology data, providing vertically and temporally resolved boundary layer winds and boundary layer depth (i.e., mixing height) data. The system also includes a surface-based meteorological system. The Sodar provides continuous (hourly and 10-minute) wind data with a vertical resolution of 5 meters at heights from approximately 20 meters up to approximately 200 meters agl. The exact height coverage at any given time depends on atmospheric conditions. Continuous (hourly or sub-hourly) boundary layer depth can be derived from the Sodar reflectivity data. An example of this is shown in **Figure 4-2**. The sodar will be operated under a configuration that produces the highest quality data for the typical atmospheric conditions found in the Upper Green River Basin.

Accuracy (instrument specifications)	
Horizontal Wind Speed	0.5 m/s
Horizontal Wind Direction	$\pm 5^{\circ}$
Maximum Altitude	200 meters
Sampling Height Increment	5 meters and greater
Minimum Sampling Height	20 meters
Transmit Frequency	4500 Hz.
Averaging and Reporting Interval	1 to 60 minutes

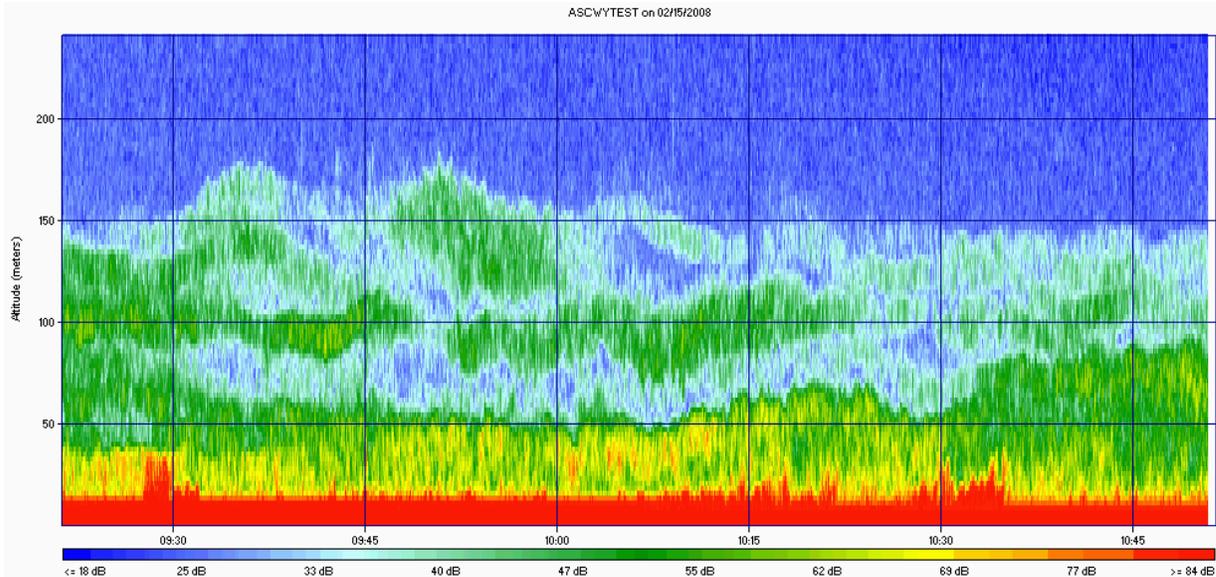


Figure 4-2. Example of sodar backscatter data capturing the daytime mixing height layers under cold wintertime conditions.

#### 4.4 OZONE/RAWINSONDES

To profile ozone concentrations from the surface to the tropopause, we will use balloon-borne ozonesondes, with measurements placed at the Boulder air quality site. The ozonesonde system has three primary components, described below:

##### iMet-3050 403 MHz GPS Upper-Air Sounding System

The iMet-3050 is an automated sounding system that operates in the 403 MHz meteorological frequency band. Pressure, temperature, and humidity data (PTU) are collected by the radiosonde and transmitted to the ground station by a digitally coded message sent once per second.

The System Computer receives the PTU data, the radiosonde GPS data, and the differential GPS data that is then processed by the iMetOS into meteorological data and met products. iMetOS also provides graphical displays, data communications and archiving capabilities.

##### iMet-1 RSB Radiosondes

The iMet-1 RSB radiosonde is 9 x 9 x 18 cm, weighs 260 grams, and is powered by an alkaline dry cell battery. The radiosonde transmitter sends its modulated signals in the 403 MHz range. Temperature is measured using a bead thermistor and relative humidity using a capacitive hygistor. The iMet-1 RSB incorporates a low-noise integrated circuit GPS receiver. Winds aloft are calculated from the change in balloon position (determined from navaid) with time. Height is obtained directly from GPS positioning and, unlike older systems, pressure is now a derived parameter, calculated from the hydrostatic equation, using measured height, temperature, and humidity.

<b>Accuracy (instrument specifications)</b>	
Horizontal Wind Speed	$\pm 1.0 \text{ ms}^{-1}$
Horizontal Wind Direction	Unknown
Temperature	$\pm 0.2^\circ \text{ C}$
Relative Humidity	$\pm 5.0\%$
<b>Output Resolution</b>	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	0.1°
Temperature	$<0.01^\circ \text{ C}$
Relative Humidity	$<0.1\%$

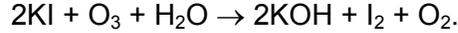
#### EN-SCI Corporation 2ZV7-ECC Ozonesondes

EN-SCI Corporation KZ-ECC ozonesonde system will be used in conjunction with the radiosonde package described above. Ozone is measured with an electrochemical concentration cell (ECC) ozonesonde coupled through an electronic interface to the radiosonde.

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

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

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



The cell converts the iodine to iodide according to:



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

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

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

As an integral part of the ozonesonde operations, the ozone analyzer readings at the Boulder site will provide ground-truth data.

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

#### 4.5 VOC SAMPLING

WDEQ-owned samplers will be retrieved by MSI and bench checked prior to deployment. **Figure 4-3** 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 1/8" Teflon sample tube connected to a 1/4 " stainless steel inlet tube, with the inlet positioned approximately two meters above ground level. Note that these samplers, which were originally used in 2009/2010 for the Pinedale air toxics study, are designed for obtaining both canister and sorbent tube samples. Only the canister sampling portion of the sampler will be used.

MSI's field technician will be responsible for loading and retrieving canisters 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 brought to the project field office in Pinedale for packaging and shipment 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 samples will be analyzed using Method TO-14 with an expanded PAMS list of compounds (see Table 4-1). Analysis will be performed by Environmental Analytical Services, Inc., San Luis Obispo, CA.

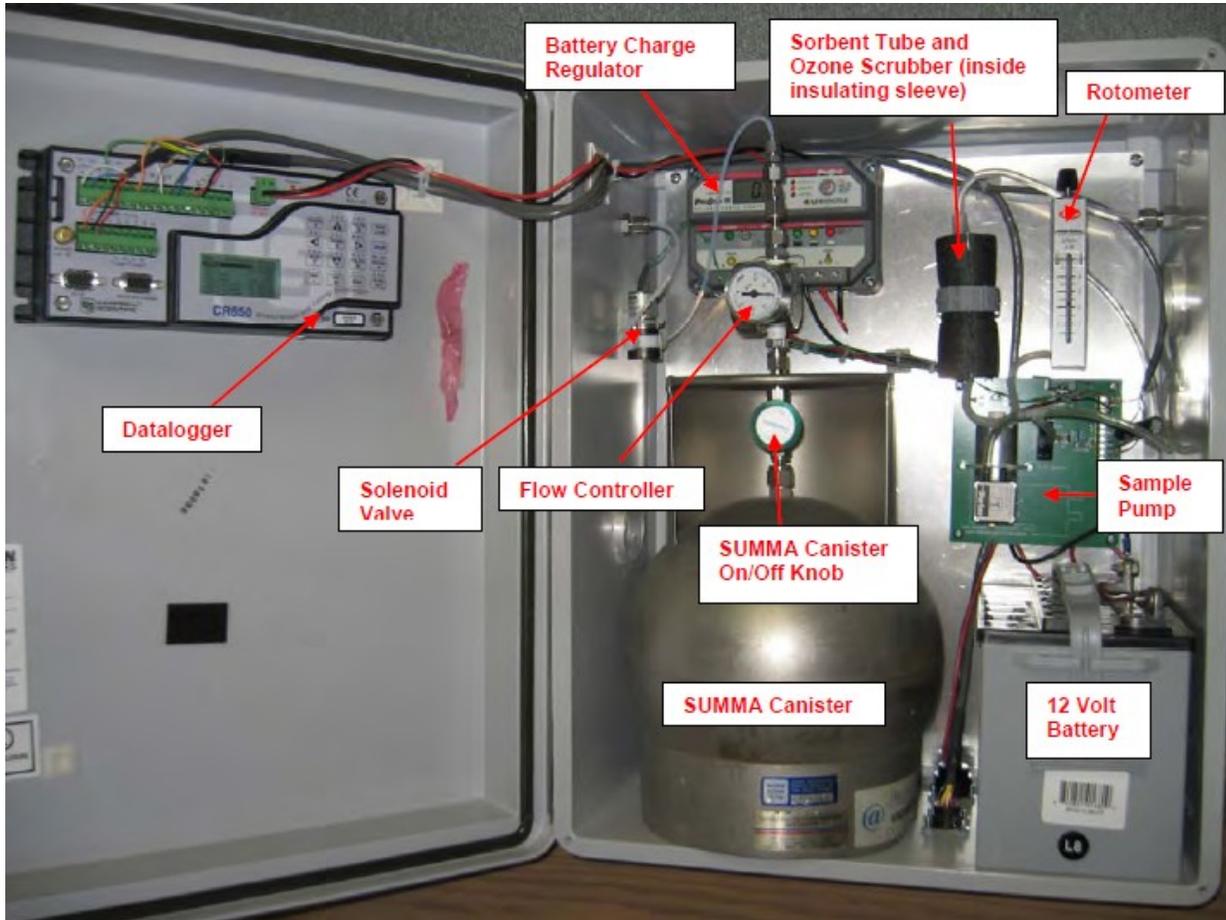


Figure 4-3. Canister Sampler. Only those components associated with the SUMMA canister will be employed.

Table 4-1. Target compound list for EPA Method TO-14 Toxics in Air (Expanded for PAMS).

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

## SECTION 5

### DATA REPORTING

#### 5.1 DATA MANAGEMENT PLAN

A primary study objective 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 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 5-minute and hourly averages will be stored in data acquisition systems 5-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 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.

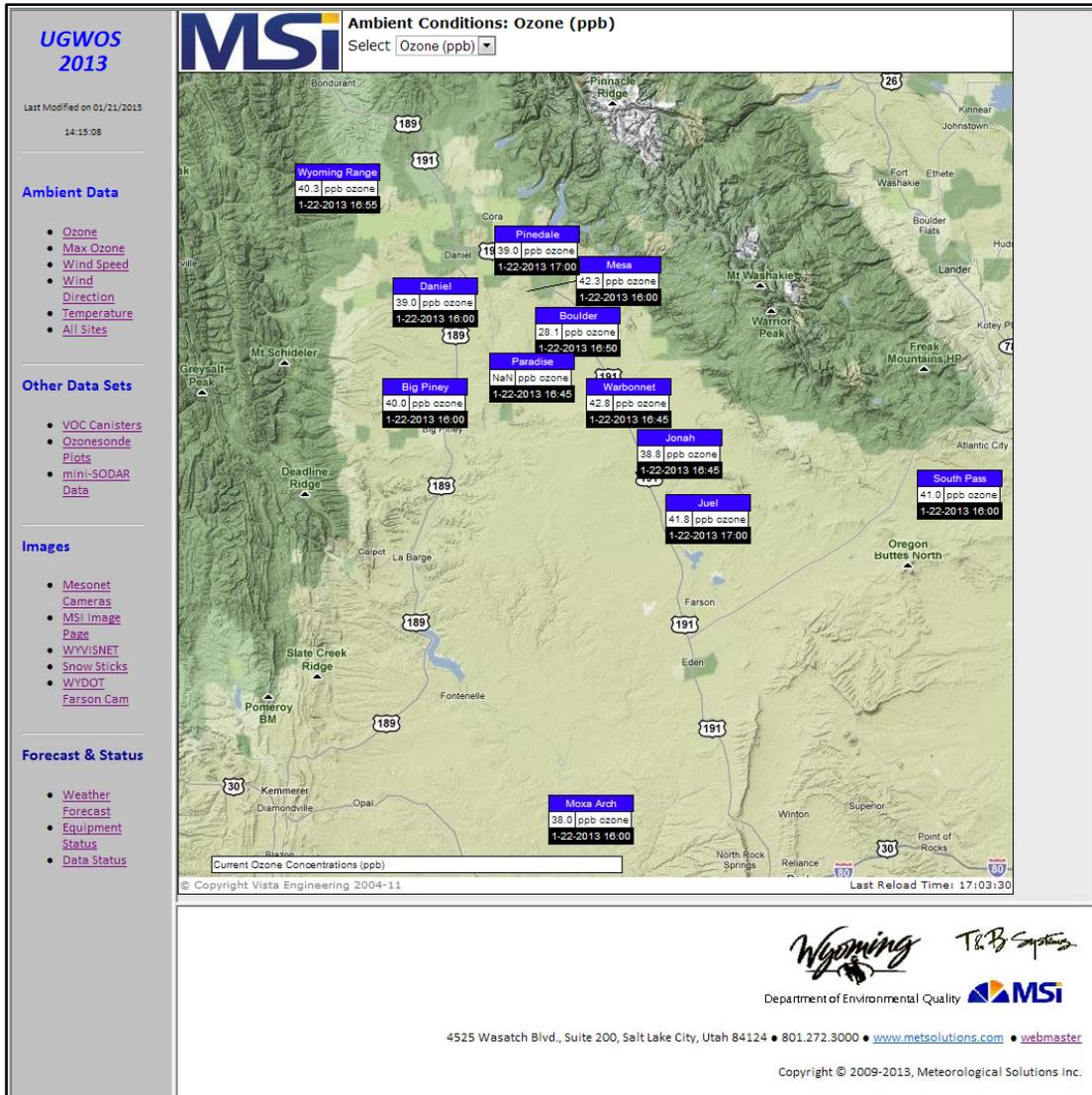


Figure 5-1 – Ambient Ozone Concentration Map

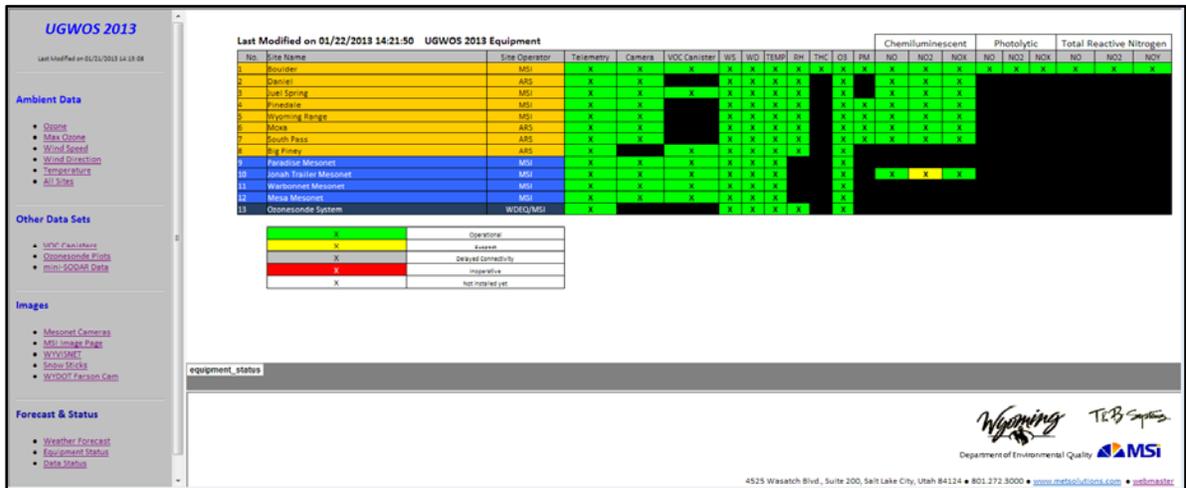


Figure 5-22 – Equipment Status

Table 5-1. Data Quality Control Codes.

Flag	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)

Table 5-1 (Continued). Data Quality Control Codes.

<b>Flag</b>	<b>Description</b>
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
B	Below Detection Limit

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.

### **Database Management Design**

MSI 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 2007, 2008, 2009 and 2010 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 flat format:

#### Surface Hourly Meteorological Data

**SITE, DATE, HOUR, WS, WS\_QC, WD, WD\_QC, TP, TP\_QC**, and any additional met parameters and QC codes, if collected.

#### Ozone 8-hour averaged:

**SITE, DATE, HOUR, O3\_8HR, O38HR\_QC**

#### Hourly Surface Air Quality:

**SITE, DATE, HOUR, OZONE, O3\_QC, NO, NO\_QC, NOx, NOx\_QC, NOy, NOy\_QC, PAN, PAN\_QC** and any additional air quality parameters if collected and QC codes.

#### Upper level meteorological and air quality data

SODAR data will be stored in both a flat file format and a CDF (common data format) or similar tabular format. CDF files are used for plotting the data. Participants should include both flat files and CDF files with their data submissions. The final flat format will be as follows:

## **SITE, DATE, HOUR, TIME, HEIGHT, WS, WS\_QC, WD, WD\_QC**

Radiosonde and Ozonesonde data will also be collected during IOPs. These data are assembled in Sonde Data (met) and Sonde Data (ozone) data tables. GPS coordinates and elevation (by altimeter and GPS reading) as well as meteorological and ozone readings will be available in these tables.

### VOC Canister Data

VOC canisters will be collected during IOPs. The canister data is analyzed using the TO-14 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<sub>3</sub>, NO, NO<sub>2</sub>, and NO<sub>x</sub>
- Meters per second for wind speed (as a general rule, metric units will be used)
- Degrees Celsius for ambient temperature
- Watts/m<sup>2</sup> 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, O<sub>3</sub>\_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 by June 1, 2013.

The team will review the validated data collected during the field study and prepare descriptive summaries in a report format for delivery to WDEQ. The Team will prepare summaries of air quality and meteorological conditions during the study period. In addition, the Team 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, the Team 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. Vertical profiles of winds;
3. Wind roses at the surface;
4. Pollution roses at the surface; and
5. 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 by July 1, 2013. 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

### QUALITY ASSURANCE PROGRAM

#### 6.1 PROJECT MANAGEMENT

Mr. George Wilkerson will serve as overall project manager. Mr. Bill Hauze 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.

An organizational chart for UGWOS 2013 is provided in **Figure 6-1**. Study personnel responsibilities and contact information are presented in **Table 6-1**.

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. Mr. David Bush 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.

#### 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

##### QUALITY CONTROL PROCEDURES

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, 2013. 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.

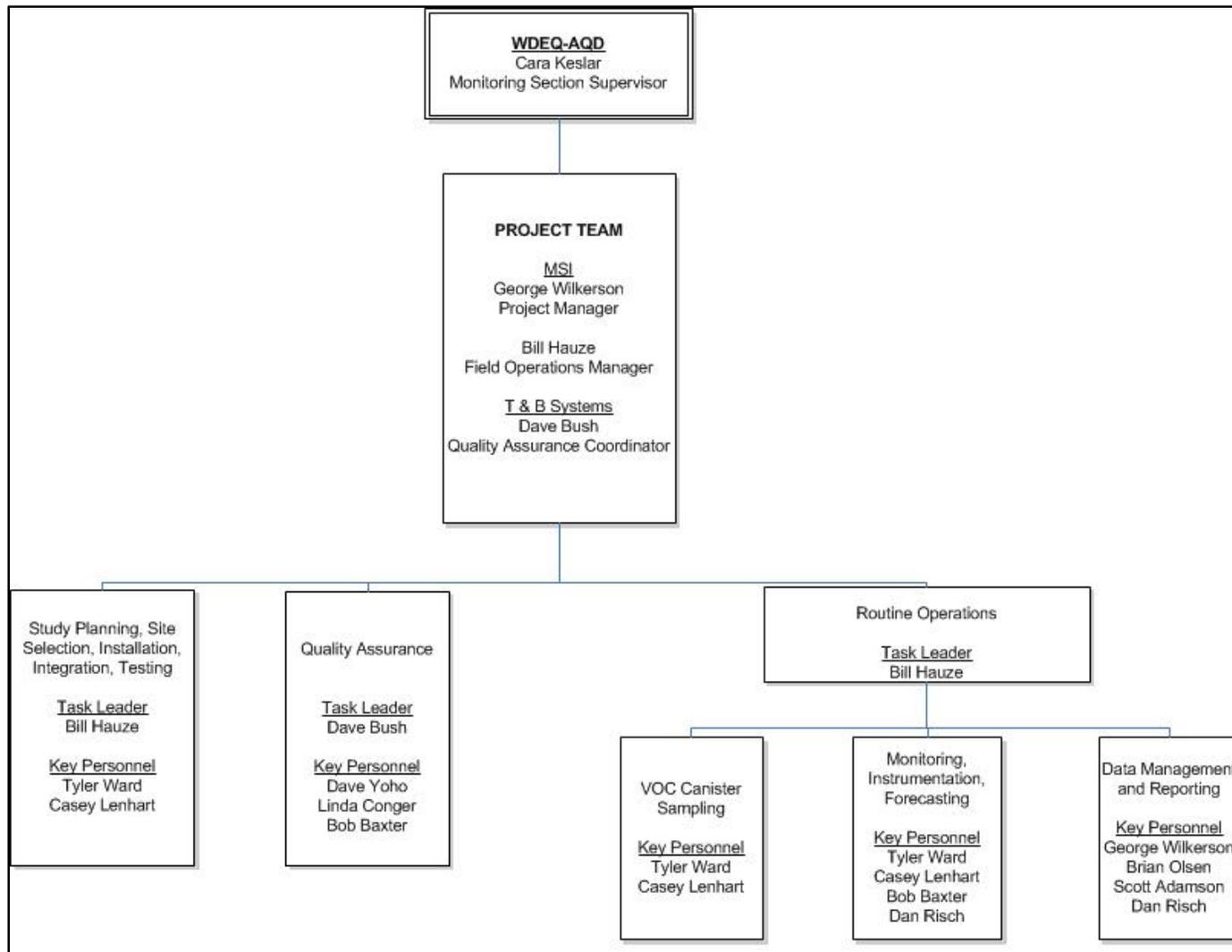


Figure 6-1. Project organization.

Table 6-2. Project responsibilities and contacts

Name	Organization	Key Responsibilities	Phone Numbers
Cara Keslar	Wyoming DEQ	Contract Manager	(307) 777-8684 (307) 286-2383 (cell)
Jennifer Frazier	Wyoming DEQ	General study support	(307) 7497912 (cell)
Ryan McCammon	Wyoming DEQ	Forecasting	(307) 777-7104
George Wilkerson	MSI	Project Manager	(801) 272-3000 Ext. 304
Bill Hauze	MSI	Field Manager, Reporting	(801) 272-3000 Ext. 308 (801) 450-3776 (cell)
Dan Risch	MSI	Forecasting	(801) 272-3000 Ext. 306
Casey Lenhart	MSI	Measurement System and Remote Telemetry Configuration and Testing	(801) 272-3000 Ext. 307
Brian Olsen	MSI	Data polling Data processing and validation, Reporting	(801) 272-3000 Ext. 311
Scott Adamson	MSI	Database and Data Validation, Reporting	(801)-272-3000 Ext. 302
Tyler Ward	MSI	Full-time onsite field technician	(928) 814-3926 (cell)
David Bush	T&B Systems	Quality Assurance QAPP	(530) 647-1169 (530) 903-6831 (cell)
Bob Baxter	T&B Systems	Sodar operations	(661) 294-1103 (661) 645-0526 (cell)
David Yoho	T&B Systems	Quality Assurance audits	(661) 294-1103 (661) 212-3008 (cell)

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

#### Station Checks

Performance of all UGWOS 2013 Jonah monitoring site equipment will be checked daily via remote polling, with site visits occurring at least weekly.

#### Ozone Transfer Standards

All ozone analyzers and samplers will be routinely checked using a certified transfer standard, following operating procedures consistent with EPA guidelines. For FEM ozone analyzer, these checks will be conducted using a transfer standard certified against a primary standard maintained following EPA's guidelines at MSI's office in Salt Lake City, UT. For the mesonet equipment, a 2B model 306 (S/N 2) portable ozone calibrator will be used. This portable ozone calibrator will also be compared regularly against MSI's primary standard. A pass/fail criterion of +/-10% will be used when

evaluating the span and calibration data, after which corrective measures will be implemented.

#### Mesonet Analyzers

Mesonet 2B ozone analyzers will be checked using certified standards, following operating procedures consistent with EPA guidelines. This will consist of zero, precision, and span checks conducted at least weekly.

#### Jonah Ozone, NO/NOx Analyzers

Analyzers for the UGWOS 2013 Jonah monitoring effort will be checked using certified standards, following operating procedures consistent with EPA guidelines. This will consist of zero, precision, and span checks conducted automatically every 3 days.

#### 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 2013 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.

The siting of the Jonah VOC measurements will be verified throughout the study by installing an additional VOC sampler (Jonah 2) several hundred meters away from potential sources near the Jonah site. Samples from both locations will be collected and compared to evaluate whether or not measurements from the Jonah location are biased by local sources.

#### MiniSodar

The status of the instruments will be checked daily via remote access of the data. If any problems are encountered that could affect data recovery, repairs will be made promptly. The data will be transferred hourly to T&B's server, using a cellular modem. Data can also be accessed in real time via a web site so that team members can use the data to assist in special monitoring and forecasting. The link to the web site is: <http://tbsys.serveftp.net/ugwossodar/>.

### **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. The calibration method for each of the air quality and meteorological variables is summarized in **Table 6-3**.

Calibrations of the ozone instruments and the NO/NOx analyzer will be performed upon initial installation and at the end of the study period. Additional calibrations will be performed on an as-needed basis in the event of equipment repair or replacement. All calibrations will be performed in accordance with manufacturers' recommendations and consistent with USEPA guidance (USEPA, 1994, 1995, 2000).

Calibrations and zero/span checks of all ozone monitoring equipment will be conducted using a transfer standard certified against MSI's primary standard, which is maintained following EPA's guidelines at their office in Salt Lake City, UT, as well as against the US EPA Region 8 primary standard maintained at Golden, CO.

The NO/NOx analyzer will be calibrated using a certified dilution calibrator and a certified gas standard. Standard gas phase titration (GPT) methodologies will be used for calibration of NO<sub>2</sub> channels.

All meteorological sensors will be calibrated at the beginning and end of the study. Wind speed sensors will be calibrated using an RM 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.

Table 6-3. Calibration methods for the monitored variables.

Measurement Variable	Calibration Method
Ozone (O <sub>3</sub> )	Multipoint comparison of ozone concentrations with ozone transfer standard
NO/NOx	Multipoint comparison of concentrations against a dilution of a certified gas standard
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

## INDEPENDENT AUDITS

As part of the quality assurance program, an independent audit program will be implemented that will use an independent entity to verify the site operations and data accuracy. These audits will be performed using personnel independent of the measurement program. This will establish confidence in the data collected and allow the measurement processes to be supported through independent verification. Audits will be performed in accordance with the principles of the US EPA.

System audits will be conducted of all data collection operations, including the Jonah monitoring effort, the MiniSodar setup, the VOC sampling, and the mesonet operations. System audits will address the following:

- Siting
- Adherence to SOPs
- QA/QC procedures
- Documentation
- Data collection and chain of custody

Mr. David Bush will conduct the system audits of the UGWOS-specific operations. Mr. Bush is independent of all UGWOS 2012 measurements. He will also conduct

performance audits of the mesonet sites. Wind speed sensors will be audited using an RM Young constant rpm motor simulating wind speeds at several points across the sensor's operating range. Wind direction sensors will be audited by checking responses in 90° increments. Temperature sensors will be audited using a water bath and a certified audit sensor. The ozone monitors will be audited using an ozone transfer standard that is certified against T&B's primary standard maintained following EPA's guidelines at their office in Valencia, CA.

Performance audits of the measurements at the Jonah site will be conducted by Mr. David Yoho. Performance audits will be conducted using equipment and standards independent of those used in the field. The ozone analyzers will be audited using an ozone transfer standard that is certified against T&B's primary standard maintained following EPA's guidelines at their office in Valencia, CA. The nitrogen oxide analyzer will be audited using a certified dilution system and a certified cylinder of NO. The standards used for the UGWOS audits will be the same as those used for the Wyoming state-wide audit program conducted by T&B Systems for the WDEQ. Mr. Yoho will conduct the audits during his regular quarterly audit trip to the area.

All audits will be conducted near the beginning of the study, after the continuous measurements have become operational. Comments and recommendations resulting from the audits will be discussed with measurement personnel at the time of the audit, with a written memo report provided to study management within 48 hours of the audit. Mr. Bush will work with Mr. Hauze to verify that any deficiencies noted during the audit are addressed.

#### **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.

## SECTION 7

### 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 PHOTOS**



**View to North**



**View to East**



**View to South**



**View to West**



**View of MiniSodar V path (SW)**



**View of MiniSodar U path (NW)**

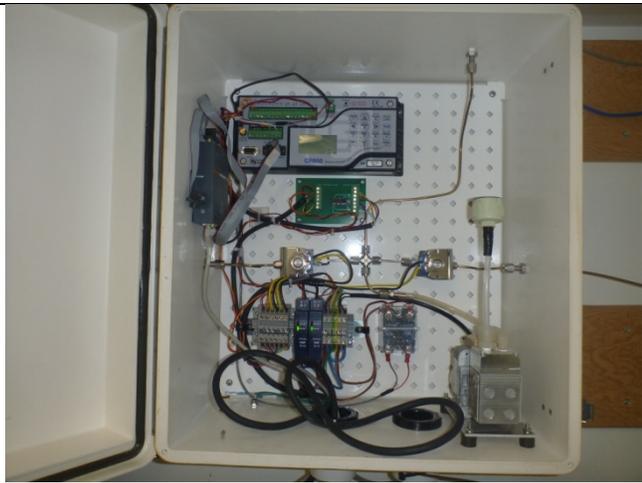
**Boulder Site**



**View of MiniSodar**



**View of Air Quality Site**



**VOC Sampler**

**Boulder Site**



**Air Quality Site, View to North**



**View to East**



**View to South**



**View to West**



**Air Quality Site, with VOC Sampler on right**

**Big Piney VOC Sampling**



**View to North**



**Air Quality Site, View to East**



**View to South**



**View to West, with VOC Sampler**



**Air Quality Analyzers**

**Jonah Site**



**Monitoring Equipment, View to North**



**View to East**

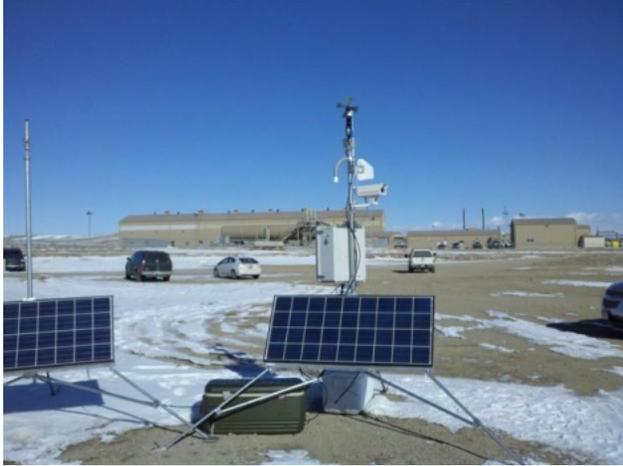


**View to South**



**View to West**

**Jonah 2 Site**



**Monitoring Equipment, View to North**



**View to East**

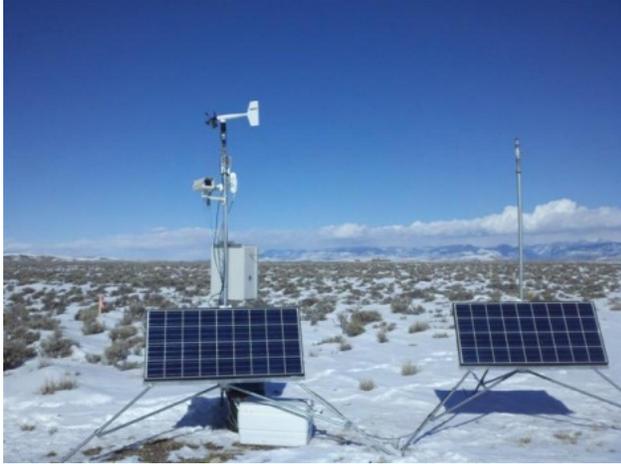


**View to South**



**View to West**

**Paradise Site**



**Monitoring Equipment, View to North**



**View to East**



**View to South**



**View to West**

**Mesa Site**



**Monitoring Equipment, View to North**



**View to East**



**View to South**



**View to West**

**Warbonnet Site**

## **APPENDIX B**

### **STANDARD OPERATING PROCEDURES**

 <p style="text-align: center;"><b>STANDARD OPERATING PROCEDURE</b></p>	Title: 2B Model 202 Ozone Analyzer Calibration Procedures	
	Number: SOP 71	Page: 1 of 2
	Revision Number: 1	Effective Date: 02/19/2013 02/17/2010 (Rev 0)
Approval: Date:		Concurred By:

### Ozone Analyzer Calibration

1. If the analyzer is not already powered on and warmed up, turn it on and allow it to warm up for at least one hour to let internal temperature stabilize.
2. Log onto the data logger and add minutes to the ozone timer so that the channel is flagged. Note the calibration start time in a log book.
3. Position the 2B Model 306 ozone standard near the station analyzer such that the calibration line reaches the sample inlet. Connect the sample inlet to the Teflon calibration line using a "T" with an atmospheric dump.
4. Connect the calibrator's power cord adapter to the inverter that is powered by a 12V battery inside the truck. Turn on the transfer standard and allow it to warm up. The calibrator display will read "warming up..." while doing so. When the indicated delT reading is within 1°C, the display will read "*Temperature Set Press Select*".
5. Adjust the Model 306 transfer standard to produce the zero and four span points. Record raw and adjusted values on a datasheet.
6. The zero and four span points will create a slope and intercept. If the slope and intercept or the % differences have drifted significantly (>5%) from the previous calibration, enter the new slope and intercept into the data logger and recheck the zero and two span points to ensure a successful calibration.
7. Turn off standard and disconnect the sample line from the calibration line.
8. Before leaving the site ensure that the ozone timer minutes do not exceed five minutes.
9. To change the calibration parameters, select **Cfg** from the **Main Menu**:  
**Cfg Menu D/T**  
**Cal I/O Unt** ←  
**Cal Menu Z=-2**  
Use the rotary select switch to select and click on **Cal**. The following submenu with the values of the current calibration parameters will then appear:  
**S=1.01**

Title: 2B Model 202 Ozone Analyzer Calibration Procedures	Number: SOP 71	Revision Number: 1
---	----------------	--------------------

Z is the offset applied (in this case -2 ppbv) and S is the slope applied (in this case 1.01). The value of Z is added to the measured ozone value, and the value of S is then multiplied by the measured ozone value. For UGWOS 2013, all 2B Mesonet analyzers should be configured with a slope of 1.0 and a Z value of +9.

When the **Cal Menu** first appears, the **Z** will be underlined with a cursor. Rotate the Select switch to choose the calibration parameter **S** or **Z**. A single click on **S** or **Z** will select that parameter for change and activate a blinking cursor. Once **S** or **Z** is selected, its value can be changed by rotating the Select switch to the left or right. After choosing the desired value, a single click turns off the blinking cursor and allows you to scroll to the other parameter or to ← to exit the submenu. Once the values of **Z** and **S** are set, clicking on ← will return the display to the **Cfg** menu, and another click on ← will return to the **Main Menu**.

 <b>STANDARD OPERATING PROCEDURE</b>	Title: 2B Model 202 Ozone Analyzer Troubleshooting and Maintenance Procedures	
	Number: SOP 72	Page: 1 of 3
	Revision Number: 0	Effective Date: 01/06/2010
Approval:	Date:	Concurred By:

### Ozone Analyzer Troubleshooting and Maintenance Procedures

The only component that requires routine maintenance on the 2B Ozone analyzer is the ozone scrubber, which should be changed at least once every six months of operation. Other serviceable components include the lamp, air pump, and solenoid valve, all of which are easily replaced should they fail. Also, the inlet filter should be changed as conditions require. If the instrument fails to operate correctly, common problems can be identified and corrected using Table 1. If the problem cannot be corrected, the instrument may be returned to 2B Technologies for service.

**Table 1  
Troubleshooting the Ozone Analyzer**

<b>Problem/Symptom</b>	<b>Likely Cause</b>	<b>Corrective Action</b>
Instrument does not turn on	Power not connected properly or circuit breaker open.  Power cable not connected to circuit board.	Check external power connection for reverse polarity or a short and wait a few minutes for the thermal circuit breaker to reset.  Remove top cover and disconnect and reconnect power cable to circuit board.
Instrument turns on then powers off.	Burned out air pump.	Remove top cover and unplug air pump. Turn instrument on; if it remains running, then the air pump motor is burned out and shorting. Replace air pump.
Display is blank or nonsense	Bad connection of display to circuit board.	Remove top cover and reconnect display to circuit board. Check solder connections to display.
Cell temperature reads low by several 10's of degrees.	Absent or loose connection of temperature probe cable to circuit board.	Remove top cover and reattach connector to circuit board.
Readings are noisy with standard deviations greater than 2.0 ppbv.	Lamp output is weak.  Excessive vibration.	Remove top cover and check lamp connection to circuit board. Run Lamp Test from menu. If photodiode voltage is less than 0.7 V, replace lamp. Provide additional vibration insulation for the instrument such

		as a foam pad.
Title: 2B Model 202 Ozone Analyzer Troubleshooting and Maintenance Procedures	Number: SOP 72	Revision Number: 0

**Table 1 Continued  
Troubleshooting the Ozone Analyzer**

<b>Problem/Symptom</b>	<b>Likely Cause</b>	<b>Corrective Action</b>
Readings are noisy with standard deviations greater than 2.0 ppbv.	Flow path contaminated.	Clean flow path with methanol
Analog output is constant or does not track front display.	Cable not properly connected between analog output BNC and circuit board.  Wrong scaling factor selected in menu.	Remove top cover and reconnect cable between analog output and circuit board.  Check and reset analog output scaling factor in the Menu.
Select switch does not work.	Cable not properly connected between select switch and circuit board.	Remove top cover and reconnect select switch cable to circuit board.
Serial port does not work.	Cable not properly connected between serial port 9-pin connector and circuit board.  Wrong serial cable used.  Wrong baud rate selected.	Remove top cover and reconnect serial port cable to circuit board.  A “straight through” serial cable is provided. Some data collection devices require a “cross over” cable in which pins 1 and 3 are exchanged between the two ends of the cable. Use a “cross over cable or additional connector that switches pins 1 and 3.  Make sure that the baud rate chosen in the menu matches the baud rate setting of your data acquisition program.

Title: 2B Model 202 Ozone Analyzer Troubleshooting and Maintenance Procedures	Number: SOP 72	Revision Number: 0
---	----------------	--------------------

**Table 1 Continued**  
**Troubleshooting the Ozone Analyzer**

<b>Problem/Symptom</b>	<b>Likely Cause</b>	<b>Corrective Action</b>
Required calibration parameters are outside the adjustable range ( $\pm 9$ ppbv offset and/or $\pm 9\%$ slope) when calibrated using a standard ozone source or reliable ozone instrument.	Ozone scrubber is contaminated.	Replace ozone scrubber. Be sure to use an inlet filter to remove particulate matter.
	Flow path is contaminated.	Clean flow path with methanol.
	Solenoid valve is contaminated and not opening and closing properly.	Remove solenoid valve, rinse with methanol, dry with zero air, and replace.
	Air pump is not drawing sufficient flow.	As a first check, hold your finger over the air inlet to determine whether air is being drawn in. If there is flow, measure the flow rate by removing the bottom cover and attaching a high conductance flow meter to the exit port of the pump. Air flow should be greater than 0.7 L/min. If flow is lower, check for leaks. If there are no leaks, replace air pump.
Instrument always reads close to zero for ozone concentration.	Solenoid valve cable is not properly connected to circuit board.	Reattach solenoid valve cable to circuit board.

 <p style="text-align: center;"><b>STANDARD OPERATING PROCEDURE</b></p>	Title: 2B Model 306 Ozone Calibrator Calibration Procedures	
	Number: SOP 73	Page: 1 of 2
	Revision Number: 1	Effective Date: 02/19/2013 02/17/2010 (Rev 0)
Approval: Date:		Concurred By:

### Ozone Calibrator Calibration

1. Turn on the 306 calibrator and allow it to warm up for at least one hour prior to calibration in order to let internal temperature stabilize. The calibrator display will read “warming up...” while doing so. When the indicated delT reading is within 1°C, the display will read “*Temperature Set Press Select*”. The calibration line that is used in the field should also be connected to the calibrator while it is warming up. This will allow the calibration line to be conditioned.
2. Turn on the transfer standard and allow it to warm up for at least one hour with the 306 calibrator.
3. Position the 2B Model 306 ozone standard near the transfer standard. Connect a sample inlet line of approximately three meters long to the sample inlet of the transfer standard. Connect this line to the calibration line using a T. A rotometer should be connected to the third port of the T to ensure sufficient overflow.
4. If sufficient overflow is not achieved, verify that the internal atmospheric dump of the 306 calibrator is capped.
5. Record calibrations start time in the logbook.
6. Adjust the Model 306 calibrator to produce the zero and four span points. Record the values on the datasheet.
7. Enter the new slope and intercept, calculated from the four span points, into the 2B 306 using the directions below.

To change the calibration parameters, select **Cfg** from the **Main Menu**:

**Cfg Menu D/T**

**Cal I/O Unt ←**

Use the rotary select switch to select and click on **Cal**. The following submenu with the values of the current calibration parameters will then appear:

**Cal Menu Z=-2**

**S=1.01**

Z is the offset applied (in this case -2 ppbv) and S is the slope applied (in this case 1.01).

Title: 2B Model 306 Ozone Calibrator Calibration Procedures	Number: SOP 73	Revision Number: 1
---	----------------	--------------------

The value of **Z** is added to the measured ozone value, and the value of **S** is then multiplied by the measured ozone value. For example, if the instrument reads an average of 3 ppbv with the external scrubber in place, the value of **Z** should be set to -3. If after correction for the zero, the instrument consistently reads 2% low, the value of **S** should be set to 1.02.

When the **Cal Menu** first appears, the **Z** will be underlined with a cursor. Rotate the Select switch to choose the calibration parameter **S** or **Z**. A single click on **S** or **Z** will select that parameter for change and activate a blinking cursor. Once **S** or **Z** is selected, its value can be changed by rotating the Select switch to the left or right. After choosing the desired value, a single click turns off the blinking cursor and allows you to scroll to the other parameter or to ← to exit the submenu. Once the values of **Z** and **S** are set, clicking on ← will return the display to the **Cfg** menu, and another click on ← will return to the **Main Menu**.

8. Record the resultant calibration values on field calibration sheets.
9. If new values were entered into the 2B 306, perform an “as left” verification check starting at Step 6.



**STANDARD  
OPERATING  
PROCEDURE**

Title: Thermo Scientific Model 42i NO/NO <sub>2</sub> /NO <sub>x</sub> Analyzer Calibration	
Number: SOP 77	Page: 1 of 1
Revision Number: 0	Effective Date: 02/22/2013 08/26/2010 (Rev. 0)
Approval: Date:	Concurred By:

The following procedure calibrates the analyzer using the gas phase titrator and zero gas generator. It is suggested that a calibration curve have at least 7 points between the zero and full scale NO concentrations. At a minimum, two points should be located at the zero and 90% levels and the remaining points equally spaced between these values.

NOTE: When the instrument is equipped with internal zero/span and sample valves, the ZERO and SPAN ports should give identical responses to the SAMPLE port when test gases are introduced. The analyzer should be calibrated using the SAMPLE port to introduce zero and span gas sources.

After calibration, the zero and span sources should be plumbed to the appropriate ports on the rear panel of the instrument. The instrument should give identical responses to the test gases whether they are introduced via the SAMPLE port or the ZERO or SPAN ports.

**Calibration Procedure**

1. Assemble the dynamic calibration system.
2. Ensure all flow meters are calibrated under the conditions of use against a reliable standard. All volumetric flow rates should be corrected to 25°C and 760 mmHg.
3. Precautions should be taken to remove O<sub>3</sub> and other contaminants from the NO pressure regulator and delivery system prior to start of the calibration. This problem can be minimized by:
  - A. Carefully evacuating the regulator after the regulator has been connected to the cylinder and before opening the cylinder valve.
  - B. Thoroughly flushing the regulator and delivery system with NO after opening the cylinder valve.
  - C. Not removing the regulator from the cylinder between calibrations.
4. Adjust the instrument gain by:
  - a. Setting the NO and NO<sub>x</sub> backgrounds to zero
  - b. Calibrating the NO channel to the NO calibration gas
  - c. Calibrating the NO<sub>x</sub> channel to the NO<sub>x</sub> calibration gas

Title: Thermo Scientific Model 42i NO/NO <sub>2</sub> /NO <sub>x</sub> Analyzer Calibration	Number: SOP 77	Revision Number: 1
--	----------------	--------------------

5. The NO and NO<sub>x</sub> background concentrations are determined during zero calibration. The background signal is the combination of electrical offsets, PMT dark current, and trace substances undergoing chemiluminescence.
6. To set the NO/NO<sub>x</sub> background:
  - a. The NO channel should be calibrated first and then the NO<sub>x</sub> channel.
    1. Determine the GPT flow conditions required to meet the dynamic parameter specifications.
    2. Adjust the GPT diluents air and O<sub>3</sub> generator air flows to obtain the flows determined in the previous step. The total GPT airflow must exceed the total demand of the analyzer. The Model 42i requires approximately 700 cc/min of sample flow and a total GPT airflow of at least 1.5 liters/min.
      - a. Allow the analyzer to sample zero air until the NO, NO<sub>x</sub>, and NO<sub>2</sub> responses stabilize.
      - b. After the responses have stabilized, from the Main Menu, choose Calibration> **Cal NO Background**.
      - c. Press ← to set the zero concentration reading to zero.
      - d. Press ■ to return to the Calibration menu and repeat this procedure to set the NO and NO<sub>x</sub> background to zero.
      - e. Record the stable zero air responses as ZNO, ZNO<sub>x</sub>, and ZNO<sub>2</sub>.
    3. Adjust the NO flow from the standard NO cylinder to generate a NO concentration that is about 80% of the upper range limit of the NO range. The exact NO calculation is calculated from:

$$[\text{NO}]_{\text{out}} = \frac{FNO \times \text{NOSTD}}{FNO + FO + FD}$$

Where: [NO] out = Diluted NO concentration at the output manifold, ppm

NOSTD = No feed concentration

FNO = No flow

FO = Ozone flow

FD = Dilution flow

### Calibrate the NO Channel to the NO Calibration Gas

Use the following procedure to calibrate the NO channel to the NO calibration gas.

1. Allow the analyzer to sample the NO calibration gas until the NO, NO<sub>2</sub>, and NO<sub>x</sub> readings have stabilized.

Title: Thermo Scientific Model 42i NO/NO <sub>2</sub> /NO <sub>x</sub> Analyzer Calibration	Number: SOP 77	Revision Number: 1
--	----------------	--------------------

- When the responses stabilize, from the Main Menu, choose Calibration > **Cal NO coefficient**. The NO line of the Calibrate NO screen displays the current NO concentration. The SPAN CONC line of the display is where you enter the NO calibration gas concentration. Use ←→ to move the cursor left and right and ↑↓ to increment and decrement the numeric character at the cursor.
- Press ← to calculate and save the new NO coefficient based on the entered span concentration. The NO recorder response will equal:

$$\text{Recorder Response (\% scale)} = \frac{[\text{NO}]_{\text{out}}}{\text{URL}} \times 100 + \text{ZNO}$$

Where: URL = Nominal upper range of the NO channel, ppm

- Record the [NO]<sub>out</sub> concentration and the analyzer NO response as indicated by the recorder response.

### Calibrate the NO<sub>x</sub> Channel to the NO<sub>x</sub> Calibration Gas

Use the following procedure to calibrate the NO<sub>x</sub> channel to the NO<sub>x</sub> calibration gas.

- Press ■ to return to the Calibration menu and choose **Cal NO<sub>x</sub> Coefficient**.
- Verify that the NO<sub>x</sub> calibration gas concentration is the same as the NO calibration gas concentration plus any known NO<sub>2</sub> impurity. The NO<sub>x</sub> line of the Calibrate NO<sub>x</sub> screen displays the current NO<sub>x</sub> concentration. The SPAN CONC line of the display is where you enter the NO<sub>x</sub> calibration gas concentration. Use ←→ to move the cursor left and right and ↑↓ to increment and decrement the numeric character at the cursor.
- Press ← to calculate and save the new NO<sub>x</sub> coefficient based on the entered span concentration.
- Press ► to return to the Run screen. The exact NO<sub>x</sub> concentration is calculated from:

$$[\text{NO}_x]\text{OUT} = \frac{FNO \times [\text{NO}]\text{STD} + [\text{NO}_2]\text{IMP}}{FNO + FO + FD}$$

Where:

[NO<sub>x</sub>]<sub>out</sub> = diluted NO<sub>x</sub> concentration at the output manifold, ppm

[NO<sub>2</sub>]<sub>IMP</sub> = concentration of NO<sub>2</sub> impurity to the NO cylinder, ppm

The NO<sub>x</sub> recorder response will equal:

$$\text{Recorder Response (\% scale)} = \frac{[\text{NO}_x]_{\text{out}}}{\text{URL}} \times 100 + \text{ZNO}_x$$

Title: Thermo Scientific Model 42i NO/NO <sub>2</sub> /NO <sub>x</sub> Analyzer Calibration	Number: SOP 77	Revision Number: 1
--	----------------	--------------------

Where:

URL = Nominal upper range limit of the NO<sub>x</sub> channel, ppm.

- Record the NO<sub>x</sub> concentration and the analyzers NO<sub>x</sub> response.

### Prepare the NO, NO<sub>x</sub>, and NO<sub>2</sub> Calibration Curves

Use the following procedures to prepare the NO, NO<sub>x</sub>, and NO<sub>2</sub> calibration curves.

- Generate several additional NO and NO<sub>x</sub> concentrations by decreasing the FNO or increasing FD.
- For each concentration generated, calculate the exact NO and NO<sub>x</sub> concentrations using the above equations for [NO]OUT and [NO<sub>x</sub>]OUT.
- Record the NO and NO<sub>x</sub> responses.
- Plot the analyzers responses versus the respective calculated NO and Nox concentrations and calculate the respective calibration curve.
- Sample this NO concentration until the NO and NO<sub>x</sub> responses have stabilized, then measure and record the NO concentration as [NO]ORIG.
- Adjust the GPT system to generate a NO concentration near 90% of the URL of the instrument range selected.
- Adjust the O<sub>3</sub> generator in the GPT system to generate sufficient O<sub>3</sub> to produce a decrease in the NO concentration equivalent to about 80% if the URL of the NO<sub>2</sub> range. The decrease must not exceed 90% of the NO concentration as determined in Steps 5 and 6 above.
- When the analyzer responses stabilize, record the resultant NO concentration as [NO]REM.
- From the Main Menu choose Calibration > **Cal NO<sub>2</sub> Coefficient**.
- Set the NO<sub>2</sub> calibration gas concentration to reflect the sum of the following: the NO<sub>2</sub> concentration generated by GPT, ([NO])ORIG-[NO]REM, and any NO<sub>2</sub> impurity. Use ←→ to move the cursor left and right and ↑↓ to increment and decrement the numeric character at the cursor.

$$[NO_2]OUT = ([NO]ORIG - [NO]REM) + FNO \times \frac{[NO_2]IMP}{FNO + FO + FD}$$

Where:

[NO<sub>2</sub>]Out = diluted NO<sub>2</sub> concentration at the output manifold, ppm  
 [NO]ORIG = original NO concentration prior to addition of O<sub>3</sub>, ppm  
 [NO]REM = NO concentration remaining after addition of O<sub>3</sub>, ppm.

Title: Thermo Scientific Model 42i NO/NO <sub>2</sub> /NO <sub>x</sub> Analyzer Calibration	Number: SOP 77	Revision Number: 0
--	----------------	--------------------

11. Press ← to calculate and save the new NO<sub>2</sub> coefficient based on the entered span concentration. The analyzer does a one point NO<sub>2</sub> span coefficient calculation, corrects the NO<sub>2</sub> reading for converter efficiency, and then adds the corrected NO<sub>2</sub> to the NO signal to give a corrected NO<sub>x</sub> signal. If the analyzer calculates a NO<sub>2</sub> span coefficient of less than 0.96, either the entered NO<sub>2</sub> concentration is incorrect, the converter is not being heated to the proper temperature, the instrument needs servicing, or the converter needs replacement.

The recorder response will be as follows:

$$\text{Recorder Response (\% scale)} = \frac{[\text{NO}_2]\text{OUT}}{\text{URL}} \times 100 + Z\text{NO}_2$$

Where:

URL = Nominal upper range limit of the NO<sub>2</sub> channel, ppm

12. Record the NO<sub>2</sub> concentration and the analyzer's NO<sub>2</sub> response.
13. Maintaining the same FNO, FO, FD, adjust the ozone generator to obtain several other concentrations of NO<sub>2</sub> over the NO<sub>2</sub> range.
14. Record the stable responses and plot the analyzer's NO<sub>2</sub> responses versus the corresponding calculated (using the above equation for [NO<sub>2</sub>]OUT) concentrations and draw or calculate the NO<sub>2</sub> calibration curve.

 <p style="text-align: center;"><b>STANDARD OPERATING PROCEDURE</b></p>	Title: Thermo Scientific Model 49i Ozone Analyzer Calibration	
	Number: SOP 79	Page: 1 of 2
	Revision Number: 0	Effective Date: 12/6/2010
Approval:	Date:	Concurred By:

Connect the Model 49i to the manifold on the output of the ozonator. If an optional sample line filter is used, the calibration must be performed through this filter. Ensure that the flow rate into the output manifold is greater than the total flow required by the calibration photometer, analyzer, and any other flow demand connected to the manifold.

### Zero Adjust

Use the following procedure to adjust zero.

1. Allow sufficient time for the instrument and the calibration photometer to warm up and stabilize.
2. With the zero air supply ON, but the ozonator OFF, allow the instrument to sample zero air until a stable response is obtained.
3. From the Main Menu choose **Calibration**.
4. From the Calibration menu choose **Calibrate Zero**. Press ← to perform a zero calibration. Press ► to return to the Run screen. If a strip chart recorder is used, it is recommended that it be adjusted to obtain a record of zero drift and/or zero noise. This can be achieved by using the zero offset capability of the recorder.
5. Record the stable zero air response as Z.

### Span Adjust

Use the following procedure to adjust span.

1. Generate an ozone concentration standard of approximately 80% of the upper range limit (URL) of the ozone analyzer (such as, 0.4 or 0.8 ppm for the 0.5 and 1.0 ppm ranges respectively).
2. Allow the instrument to sample this ozone concentration standard until a stable response is obtained.
3. From the Main Menu choose Calibration > **Calibrate Span**. Use ↑ and ↓ to increment/decrement the known span gas concentration. Press ← to calibrate the instrument. The recorder response will equal:

Recorder Response (% scale) = \_\_\_\_\_

Where:

URL = Upper range limit of the Model 49i, ppm

Z = Recorder response with zero air, % scale

[O3]out = Ozone concentration as determined by the calibration photometer, ppm

Title: Thermo Scientific Model 49i Ozone Analyzer Calibration	Number: SOP 79	Revision Number: 0
---	----------------	--------------------

4. Record the ozone concentration as determined by the calibration photometer and the corresponding analyzer response.

#### **Additional Concentration Standards**

1. Generate several other ozone concentration standards (at least five others are recommended) over the scale range of the instrument.
2. For each ozone concentration standard, record the ozone concentration as determined by the calibration photometer and record the corresponding Model 49i analyzer response. If a Model 49i Primary Standard is being used as the calibration photometer, use the ozone concentration as determined by the photometer and not the value of the ozone level thumbwheel.

#### **Calibration Curve**

Use the following procedure to plot the calibration curve.

1. Plot the Model 49i Analyzer responses versus the corresponding ozone concentrations.
2. Connect the experimental points by using a straight line, preferably determined by linear regression techniques. Points that lie more than  $\pm 4\%$  from this line are an indication of an error in determining the calibration curve. The error may be due to a malfunction of the calibration photometer, or a malfunction of the analyzer being calibrated. The most likely malfunctions in both the analyzer and calibration photometer which can give non-linear results are leaks, a malfunctioning ozone scrubber, a dirty solenoid, or dirt in the optical system. The calibration curve is used to reduce subsequent ambient data.

**Note:** To generate data of the highest confidence, it is recommended that a multipoint calibration be performed every three months, any time major disassembly of components is performed, or any time the zero or span checks give results outside the limits described in “Periodic Zero and Span Checks” that follow.

 <p>4525 Wasatch Blvd. Suite 200 SLC, UT 84124</p> <p><b>MSI</b></p> <p>Meteorological Solutions Inc. P. 801.272.3000 F. 801.272.3040</p>	<b>STANDARD OPERATING PROCEDURE</b>		Title: Sub-atmospheric Pressure Canister Sampling – Time-Integrated Samples Using Sampling System	
	No: SOP 92	Page: 1 of 3		
	Revision No: 0	Effective Date: 08/07/2012		
Approval: <i>[Signature]</i>		Date: 8/7/2012	Concurred By: <i>[Signature]</i>	

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.

Title: Sub-atmospheric Pressure Canister Sampling – Time-Integrated Samples Using Sampling System	Number: SOP 92	Revision Number: 0
---	----------------	--------------------

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.

# Canister Sampling Field Data Sheet



## A. General Information

Site Location (BOL, JON):

Sampler ID:

Operator:

## B. Sampling Information

Canister ID:

Sample ID Number:

Start Date:

Stop Date:

Start Time:

Stop Time:

Canister Start Pressure: PSI

Canister Stop Pressure: PSI

## C. Additional Notes

 <p style="text-align: center;"><b>STANDARD OPERATING PROCEDURE</b></p>	Title: Ozonesonde Preparation and Deployment Procedures	
	No: SOP 101	Page: 1 of 32
	Revision No: 0	Effective Date: 2/22/2013
Approval:	Date:	Concurred By:

This SOP describes the procedures for the preparation and deployment of ozonesondes.

This SOP is divided according to the following sections:

- 1) Preparing the 2ZV7 Ozonesonde 3 to 7 days before launch day.
- 2) Day of Launch: Preparing the Ozonesonde for flight.
- 3) Day of Launch: iMet-3050 System Setup.
- 4) Day of Launch: Activating the iMet-1 RSB Radiosonde and 2ZV7 ozonesonde for Flight.
- 5) Day of Launch: Starting and operating the Icom IC-PCR1500/2500 and the Internet Ozonesonde Data Acquisition software (O<sub>3</sub> program).
- 6) Day of Launch: Balloon Setup and Configuration.
- 7) Day of Launch: Launching the balloon and computer operations.
- 8) Day of Launch: Terminating Flight and Archiving Flight data.
- 9) Post Processing of Data.

## **OZONE/RAWINSONDES**

To profile ozone concentrations from the surface to the tropopause, we will use balloon-borne ozonesondes, with measurements placed at the Boulder air quality site. The ozonesonde system has three primary components, described below:

### **iMet-3050 403 MHz GPS Upper-Air Sounding System**

The iMet-3050 is an automated sounding system that operates in the 403 MHz meteorological frequency band. Pressure, temperature, and humidity data (PTU) are collected by the radiosonde and transmitted to the ground station by a digitally coded message sent once per second.

### **iMet-1 RSB Radiosondes**

The iMet-1 RSB radiosonde is 9 x 9 x 18 cm, weighs 260 grams, and is powered by an alkaline dry cell battery. The radiosonde transmitter sends its modulated signals in the 403 MHz range. Temperature is measured using a bead thermistor and relative humidity using a capacitive hygistor.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

The iMet-1 RSB incorporates a low-noise integrated circuit GPS receiver. Winds aloft are calculated from the change in balloon position (determined from navaid) with time. Height is obtained directly from GPS positioning and, unlike older systems, pressure is now a derived parameter, calculated from the hydrostatic equation, using measured height, temperature, and humidity.

<b>Accuracy (instrument specifications)</b>	
Horizontal Wind Speed	$\pm 1.0 \text{ ms}^{-1}$
Horizontal Wind Direction	Unknown
Temperature	$\pm 0.2^\circ \text{ C}$
Relative Humidity	$\pm 5.0\%$
<b>Output Resolution</b>	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	$0.1^\circ$
Temperature	$<0.01^\circ \text{ C}$
Relative Humidity	$<0.1\%$

### **EN-SCI Corporation 2ZV7-ECC Ozonesondes**

EN-SCI Corporation KZ-ECC ozonesonde system will be used in conjunction with the radiosonde package described above. Ozone is measured with an electrochemical concentration cell (ECC) ozonesonde coupled through an electronic interface to the radiosonde.

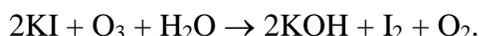
The ECC ozonesonde is of a simple design consisting of a rigid mainframe on which is mounted a motor-driven Teflon/glass air sampling pump, a thermistor for measuring pump temperature, an ozone sensing ECC, and an electronics box containing interface circuitry which couple the ozone sensor to the radiosonde.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

The ozone-sensing cell is made of two bright platinum electrodes immersed in potassium iodide (KI) solutions of different concentrations contained in separate cathode and anode chambers. The chambers are linked with an ion bridge that, in addition to providing an ion pathway, retards mixing of the cathode and anode electrolytes thereby preserving their concentrations. The electrolytes also contain potassium bromide (KBr) and a buffer whose concentrations in each half-cell are the same.

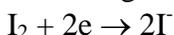
Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

The driving electromotive force for the cell, of approximately 0.13 V, is provided by the difference in potassium iodide concentrations in the two half cells. Sample air is forced through the ECC sensor by means of a non-reactive pump fabricated from TFE Teflon impregnated with glass fibers. The pump is designed to operate without ozone-destroying lubricants. Pumping efficiency for each pump varies from pump to pump and is also dependent on ambient air pressure. The sampling flow rate is calibrated at the factory and checked in the field before launch. The ECC ozone concentration calibration is also determined prior to launch.

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



The cell converts the iodine to iodide according to:



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

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

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

As an integral part of the ozonesonde operations, the ozone analyzer readings at the Boulder site will provide ground-truth data.

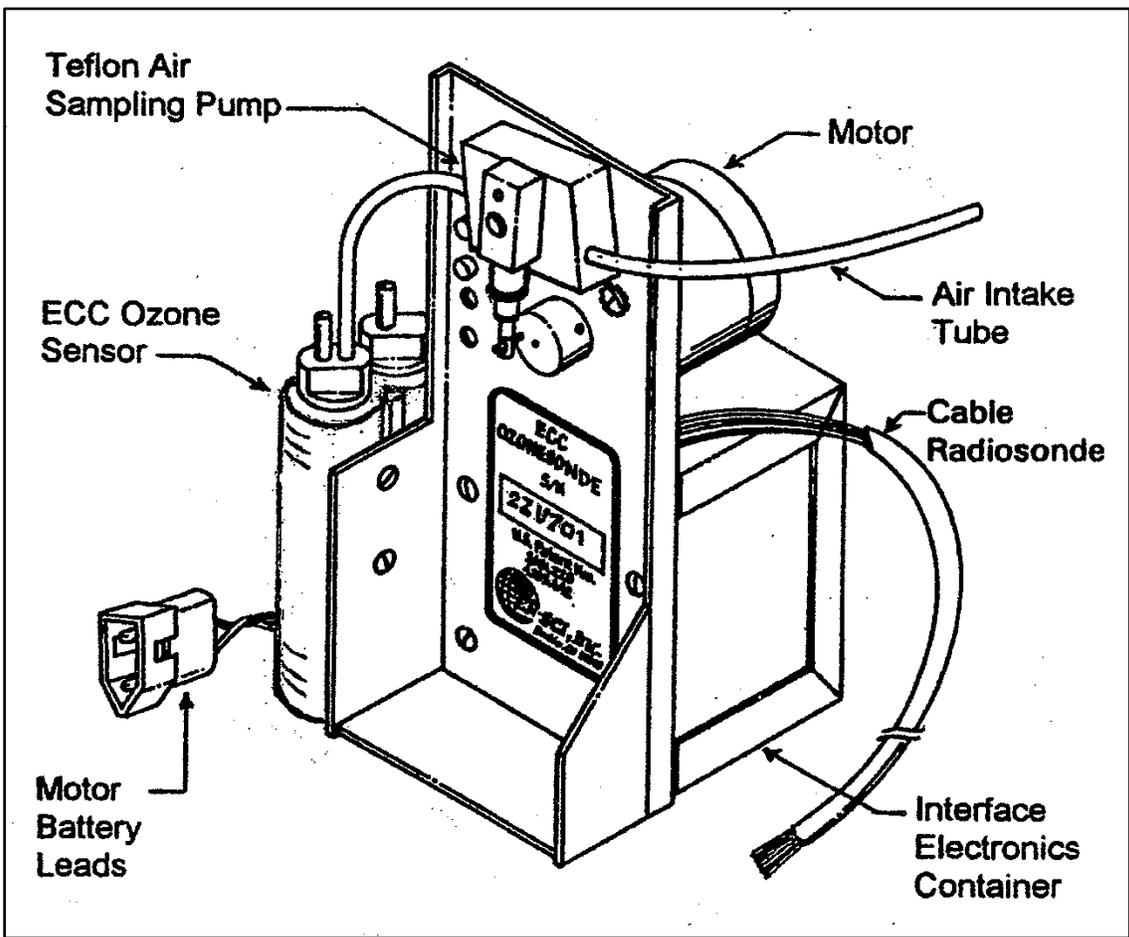
<b>Sensitivity</b>	<b>2-3 ppb by volume ozone in air</b>
Response Time	15 seconds for 67% of change; 60 seconds for 85% of change
Noise	less than 1% of full scale
Estimated Measurement Uncertainty	less than $\pm 10\%$ of indicated value

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

**1) PREPARING THE 2ZV7 OZONESONDE 3 TO 7 DAYS BEFORE LAUNCH DAY.**

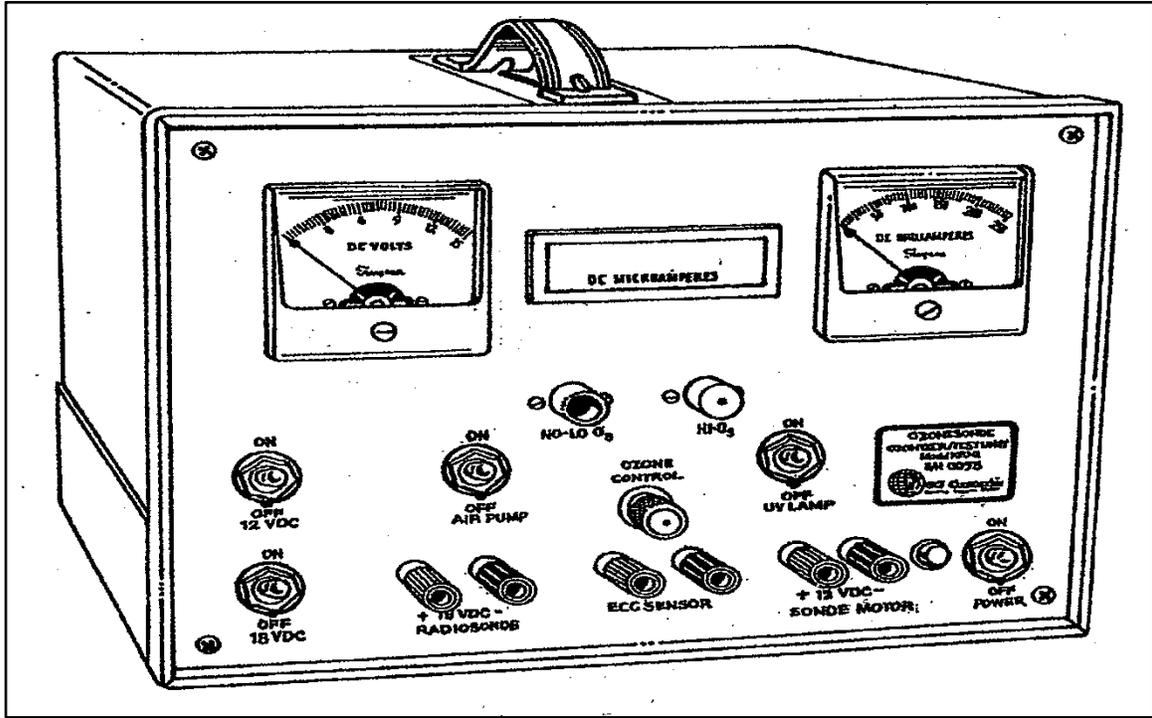
**Note 1.** Preparation of the ozonesonde for flight should always be performed in a clean environment where smoking is prohibited; otherwise the performance of the instrument may be adversely affected.

**Note 2.** Tubing connections to the sonde pump are made with pressure-fitted Teflon tubing. Should the fit appear to be too loose, enlarge the Teflon tube using a clean, awl-shaped tool of outside diameter slightly larger than the inside diameter of the tube. Use small strips of sand paper with which to grasp the Teflon tubing firmly when making or breaking pump connections.



**Balloon-borne Model 2ZV7 ECC (Electrochemical Concentration Cell) Ozonesonde**

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



**Model KTU-2 Ozonizer/Test Unit.**

The first step in preparing the ozonesonde for use is to check the overall performance of the instrument, and to charge the sensor with sensing solution (Initial charging of the sensor should be done 3 days to 1 week before flight time in order to attain a low sensor background current. An EN-SCI Corporation Model KTU-2 ozonizer/test unit is used for checking on the overall sonde performance. The unit consists of a high ozone source for conditioning the sonde air intake tube, pump, and sensor air intake tube with ozone; a variable low ozone source for conditioning the sonde sensor charged with sensing solution, and for checking on the sensor background current and response time; a 12 VDC power supply for operating the sonde motor; electrical meters for use in checking on the sonde motor/sensor characteristics; and an 18 VDC power supply for powering the 403 MHz ground receiving station antenna pre-amplifier during cold weather operation, when necessary.

Proceed as follows in advance preparation of the instrument for use. The preparation should be performed in a clean room at a temperature of 20-25 degrees C. MSI will keep a log book in the laboratory where all of the initial 3 to 7 day preparation will occur and record all serial numbers, pump and sonde characteristics, and all other critical information.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

(a) Remove the sonde from its polystyrene flight box and connect the Teflon air intake tube packed with the instrument to the sonde pump.

(b) Connect the ozonesonde battery power leads to the ozonizer/test unit's 12 VDC output power supply terminals. Pull the ECC sensors' air intake tube away from the pump. Next, insert the pump air intake tube into the NO-LO OZONE port of the unit. With all ozonizer/test unit switches, except the 18 VDC power supply switch and the UV lamp switch, turned ON, operate the sonde pump for 10 minutes (during which time clean, ozone-free air will be passed through the pump. After the 10-minute interval, check the current drawn by the sonde ( pump motor and V7 interface board) at about 12.3 VDC. The current should be less than 100 mA. (The current drawn by the interface board is about 8 mA.) If the current is larger, the fit between the piston and cylinder may be too tight and may cause excessive frictional heating. Continue operating the pump for an additional 20 minutes to see if the current decreases. If it does not, take remedial action as outlined in Appendix C. A properly adjusted pump will draw less than 90 mA of current, and develop at least 50 cm (\*20 inches) of Hg pressure and 45 cm (\*18 inches) of Hg vacuum. Measure the pressure and vacuum developed by the pump with a pressure/vacuum gauge.

(c) With proper pump performance attained, remove the sonde air intake tube from the NO-LO OZONE port of the ozonizer/test unit, and insert it snugly into the HI OZONE port of the unit. (The connection must be snug since the sonde pump draws highly ozonized air from the unit.) Next, remove the top plug with air intake tube from the sensor cathode chamber, and re-connect the air intake tube to the pump. Now turn OFF the AIR PUMP switch, but turn ON the UV LAMP switch, and pull out the OZONE CONTROL tube as far as possible out of the chassis. Conditioning of the sonde Teflon tubing, pump, and sensor air intake tube (but not the sensor cathode chamber) with high ozone now begins. Blue light visible through a hole in the front of the OZONE CONTROL tube indicates that the UV lamp is ON. During the conditioning, avoid direct breathing of the ozonized air coming out of the sensor air intake tube. **Condition with high ozone for 30 minutes.**

(d) After conditioning with high ozone is completed, push the OZONE CONTROL tube as far as possible into the ozonizer/test unit chassis, turn ON the AIR PUMP switch, and withdraw the sonde air intake tube from the HI OZONE port and insert it into the NO-LO OZONE port. Ozone-free air will now be passing through the pump and sensor air intake tube to flush out the ozone. Continue flushing for 3-5 minutes.

(e) Now unplug the sensor leads from the sonde electronic interface board, and plug them into the sensor cable connector of the ozonizer/test unit. Then charge the sensor with sensing solution as follows:

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

The sensor cathode must always be charged first to allow cathode solution to permeate the sensor's ion bridge. Using a Teflon-tipped syringe especially reserved for use with cathode sensing solution, inject 3.0 ml of the solution into the sensor cathode chamber. This is the chamber containing the large platinum screen. When re-installing the top plug of the cathode, make sure that the air intake tube is correctly centered within the cathode chamber by inserting the tube carefully over a thin Teflon rod projecting out of the bottom plug of the sensor cathode chamber. Rinse the syringe with distilled water prior to storage. Note: Do not attempt to fill or empty the sensor cathode through the short air exhaust tube of the cathode chamber top plug; otherwise, the platinum screen may be damaged (distorted), leading to sensor malfunction.

Next, after waiting 2 minutes to allow the cathode sensing solution to permeate the sensor's ion bridge, use a syringe especially reserved for dispensing anode solution to inject 1.5 ml anode sensing solution into the sensor anode chamber. Rinse the syringe with distilled water prior to storage.

**(f)** After charging the sensor with solution, run the sonde on ozone-free air for 5-10 minutes. The sensor current, as observed on the ozonizer/test unit microammeter should be low, 0.5 micro A or less. Now set the ozonizer/test unit OZONE CONTROL tube position for a low ozone output, one that produces a sensor current of 5 micro A. Continue input of ozonized air into the sensor for 10 minutes while periodically adjusting the OZONE CONTROL tube position as needed. At the end of the 10-minute interval, abruptly push the OZONE CONTROL tube as far as possible into the ozonizer/test unit front panel to begin the flow of ozone-free air through the sensor. Read the microammeter current 1 minute later; it should then have decreased from the original value of 5 micro Amps to 1.5 micro Amps or less, indicating satisfactory ECC sensor performance.

**(g)** Continue running the sonde on ozone-free air for 10 minutes. Then turn off all ozonizer/test unit switches, and disconnect the sonde from the unit. Prior to storage of the sonde until flight day, add 2.5 ml cathode sensing solution to the sensor cathode chamber to fill it about 3/4 full. Re-insert the sensor cathode chamber air intake tube into the sensor, and store the sonde in a dark, clean-air environment at a temperature of 20-25deg C until the day of the flight.

**IMPORTANT!** Prior to storage, also, short the ECC sensor leads together with a shorting plug. This will allow a sensor cleaning action to proceed during storage. (Do not re-plug the sensor into the sonde's electronic interface board for storage since the unpowered board's input impedance may be high, and proper sensor cleaning action would not proceed.)

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

## 2) DAY OF LAUNCH: PREPARING THE OZONESONDE FOR FLIGHT.

The preparation should be conducted in a clean room at a temperature of 20-25 degrees Celsius. MSI will keep a log book on-site and record all serial numbers, sonde characteristics, and all other critical information.

(a) Remove the top plug from the sensor cathode chamber and remove all solution from the chamber. Now rinse the chamber by injecting into it 3.0 ml fresh cathode solution, then removing the solution completely from the chamber. Finally, refill the chamber with 3.0 ml cathode solution. (Note: For soundings of duration less than 3-4 hours, made primarily to measure tropospheric ozone, 2.5 ml cathode sensing solution may be used, instead. Sensor response time will then be improved.) Replace the top plug. Next, remove the top plug from the sensor anode chamber and remove all anode solution from the chamber. Re-fill the chamber with 1.5 ml of fresh anode solution. Replace the anode plug.

(b) Connect the ECC sonde motor and sensor leads to the ozonizer/test unit, and insert the sonde air intake tube into the NO-LO OZONE port of the unit to a distance of about 7 cm. Set the controls so that ozone-free air passes through the air pump and sensor. Next, turn on the UV LAMP switch to warm up the lamp. Continue passing ozone-free air through the sensor for a total of 10 minutes. At the end of the 10-minute interval, record the sensor background current (which generally should be less than  $0.05 \mu\text{A}$ ). Save this information as part of your raw data file (e.g.,  $ib1 = 0.05 \mu\text{A}$ ).

(c) Pull the OZONE CONTROL tube out of the ozonizer/test unit a distance such that, after several minutes, the sonde sensor output current becomes approximately  $5 \mu\text{A}$ . Continue passing an equivalent of  $5 \mu\text{A}$  ozone current through the sensor for a total of 10 minutes. Periodically adjust the position of the OZONE CONTROL tube so that at the end of the 10-minute interval the ECC sensor current is exactly  $5.0 \mu\text{A}$ .

(d) Check the ECC sensor response time as follows: Using a stopwatch, at time  $t = 0$  quickly push the ozonizer/test unit OZONE CONTROL tube all the way into the instrument chassis and turn the UV LAMP switch OFF. As the ECC sensor current continues to fall, record the current for times  $t = 0, 0.5, 1, 3, 5$  and 10 minutes as shown in the example on the following page giving typical measurement results at  $20^\circ\text{C}$ . Record also the room temperature at which this test was performed. Save all the information as part of the raw data file.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

Sensor response time R, is satisfactory if:

$$R = 100[(i_m(t = 0) - i_m(t = 1))/i_m(t = 0)] \geq 80\%.$$

t	Sensor Current,
0 min.	5.00 $\mu$ A
0.5	1.61
1	0.82
3	0.25
5	0.20
10	0.10

For the above example, R = 83.6%. Sensor response time becomes faster as sensor temperature increases.

(e) After the sensor response time check is completed, continue running the ozonesonde on ozone-free air for another 10-15 minutes. During this time, re-connect the ECC sensor leads to the V7 interface board. Connect the ozonesonde to the InterMet radiosonde. Activate your data acquisition system for operation in the "Calibration" mode to begin receiving and recording the radiosonde and ozonesonde data by computer. (See Appendix E for configuration of the data acquisition system). This procedure will enable you to check for satisfactory performance of the ozone-radiosonde instrument package as a whole. At this stage, the ozonesonde should still be operated without its flight box at a room temperature of 20-25 deg C, and powered by the ozonizer/test unit's 12 VDC power supply.

Power the InterMet radiosonde with an auxiliary 6 V battery power supply. As the sonde is continuing to be run on ozone-free air, perform a sonde pump air flow rate according to instructions given in Appendix D (**Due to a miscalibrated bubble meter device, this Appendix in the manual will not be followed. MSI will use a certified Alltech mass flow meter to check the pump flow rate**). Check to insure that the pump motor voltage is about 12.3 volts.

Record the pump motor voltage and current (which should be less than about 110 mA).

Record also the pump air flow rate and the room temperature, and save all information as part of the raw data file. Now enter into your computer raw data file all pertinent ozonesonde and radiosonde calibration data, instrument serial numbers, station name, release date, etc. At the end of the final 10-minute ozone-zero air conditioning period, record in the raw data file, also, the ECC sensor background current (ib2) which should generally be less than about 0.1 micro A.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

(f) Turn off power to the ozonizer/test unit. (By this time, inflation of the flight balloon and preparation of the flight train should have been completed.) Install the ECC sonde into its flight box together with the sonde pump motor battery, but do not activate the battery. Activate the radiosonde by plugging the leads connector of the 2-cell lithium battery pack, located within the radiosonde, into its mating connector mounted on the radiosonde electronics board. Tape the radiosonde to the ozone instrument flight box (see Appendix F for configuring the instrument package for flight). Affix a return address/reward notice to the cover so that the instrument could be returned to your laboratory should someone recover it.

(g) Carry the ozonesonde package outdoors, and suspend it from a pole (or set it on a platform) at a height of about 1.5 meters above the ground, with the sonde air intake tube pointing into the wind. Connect the sonde pump motor battery leads to begin ECC ozonesonde operation. Activate the 403 MHz ground receiving equipment for operation in the “Surface Ozone Measurement” mode to measure and record surface ozone data for 10 minutes.

In very warm weather, the surface ozone measurement should be made with the cover off the sonde weatherproof box to prevent excessive heat build-up within the box. Tape the cover on to the box prior to instrument release.

### 3) DAY OF LAUNCH: IMET-3050 SYSTEM SETUP.

#### The iMet-3050 403 MHz GPS Upper-Air Sounding System Components

Item	Description	InterMet Part Number
N/S	CD with Software, Drivers, and Documentation	693,050
1	403 MHz Antenna with Base and Tripod	100,244
2	LNA to 403 MHz Antenna Cable	597,426
3	403 MHz LNA	900,002
4	403 MHz Cable	597,444
5	GPS Cable (Optional)	597,443
6	AC Power Cable	Varies
7	DC Power Supply	501,046
8	GPS Re-Radiator (Optional)	100,185
9	GPS Re-Radiator Cable (Optional)	597,422
10	iMet-3050 Meteorological Processor	100,413
11	USB Cable	597,049
12	System Computer Power Cord	Optional / Varies
13	System Computer	Optional / Varies
N/S	Cable Reel for 403 MHz Cable / GPS Cable	490,005

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

**The iMet-3050 403 MHz GPS Upper-Air Sounding System Components – (Continued)**

Item	Description	InterMet Part Number
N/S	UPS	Optional / Varies
N/S	Transportation Case for System Cables (Optional)	300,020
N/S	Transportation Case for System, Re-Rad, LNA (Optional)	300,021
N/S	Transportation Case for Tripod Unit (Optional)	300,022
N/S	Balloon Inflation Kit	100,438

**a) Setup Antenna Unit outside**

- Tripod may be placed up to 30 m away from iMet-3050 MP location
- High and clear areas provide for the best reception of radiosonde data
- Avoid valleys, buildings, trucks, and electrical wires
- Adjust tripod legs to orientate the 403 MHz Antenna to approximately vertical



**M403 MHz Antenna Unit with Cables attached.**

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



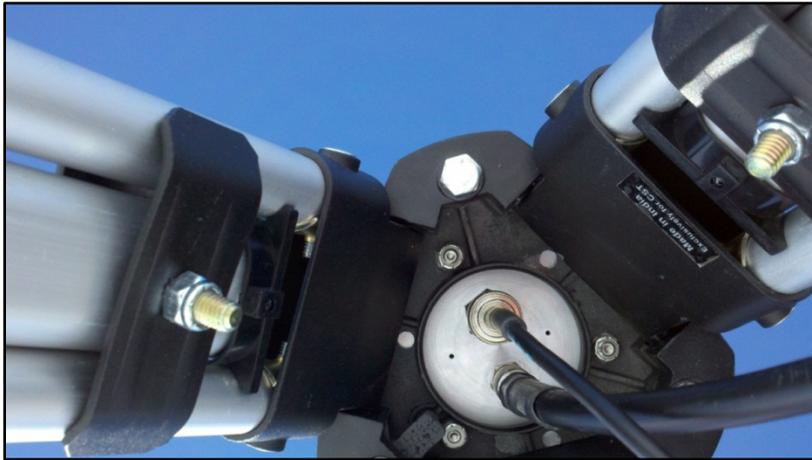
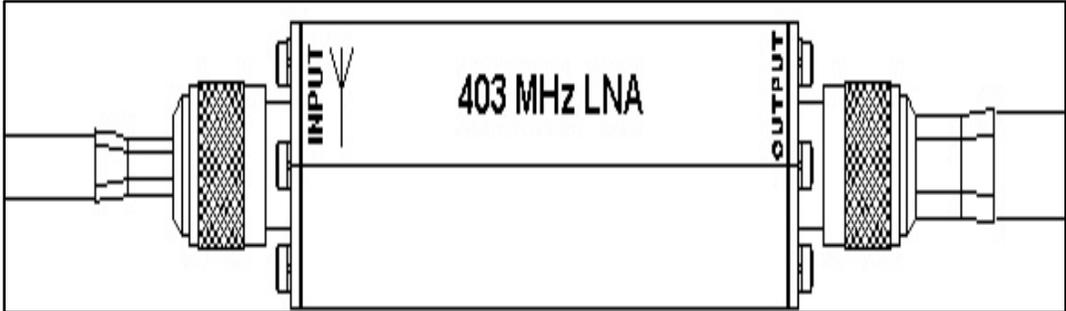
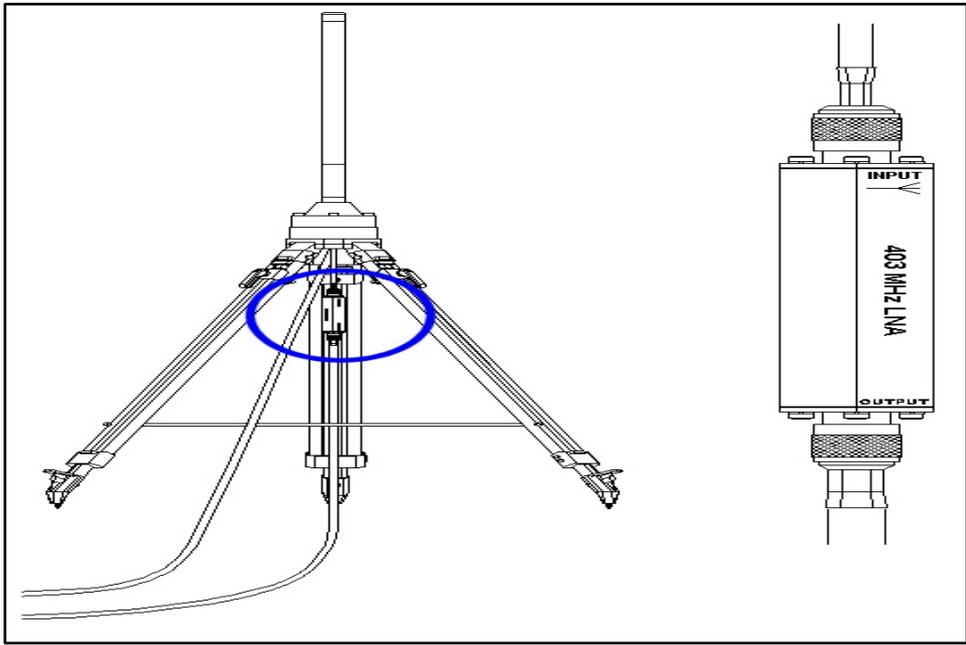
**b) Connect iMet-3050 Cables to MP**

- GPS Cable
- 403 MHz Cable
- USB Cable
- Power Cable
- GPS Re-radiator Cable

**c) Connect the Input side of the 403 MHz LNA to the 403 MHz Antenna base (see next page)**

- The input side is labeled with the schematic symbol for an antenna
- It looks like an upside down tripod
- Connect the GPS Cable to the Antenna base

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

**d) Power On System Laptop.**

e) Connect the iMet-3050 to the System Computer with the USB Cable (**Plug into the USB port on the right side of the laptop labeled “Use This” ...second port facing the user...the system will not operate correctly unless the USB cord is plugged into the correct port**) at any time.

f) Once the USB cable is plugged in, wait a few moments before turning on the iMet-3050.

g) Turn on the iMet-3050 MP.

**4) DAY OF LAUNCH: ACTIVATING THE IMET-1 RSB RADIOSONDE AND 2ZV7 OZONESONDE FOR FLIGHT.**

1. Being careful not to tear the box, open the tip of the carton, and slide up the Styrofoam panel on the side of the radiosonde.



Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

2. Plug in the battery quick connect (black lead down) and select the frequency for the radiosonde to transmitter using the switch above the battery plug in. Select a different frequency than the last frequency used.



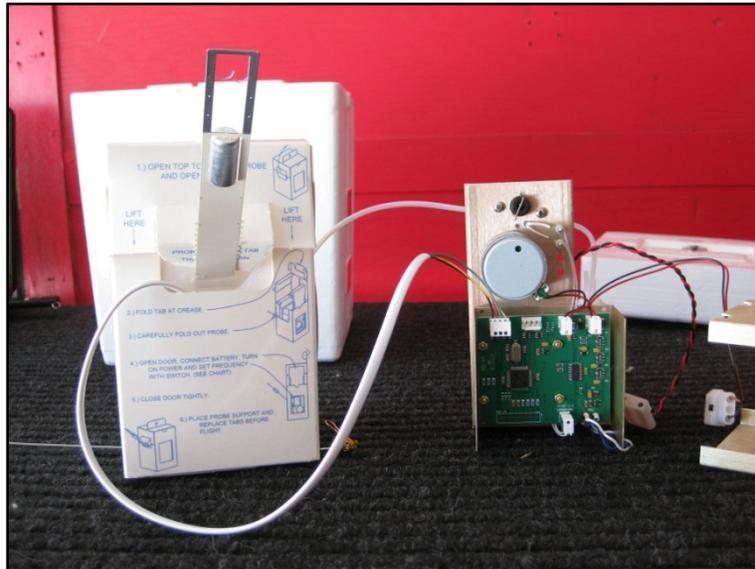
3. Once the signal has been found by the receiver close the foam door on the side of the radiosonde, fold out the sensor assembly and close the top of the box back up per the instructions on the side of the box.



4. Open the top of the ozone sonde and remove the aluminum sensor setup from the box. Often, the inlet tube is loose in the box. Do not lose this piece.

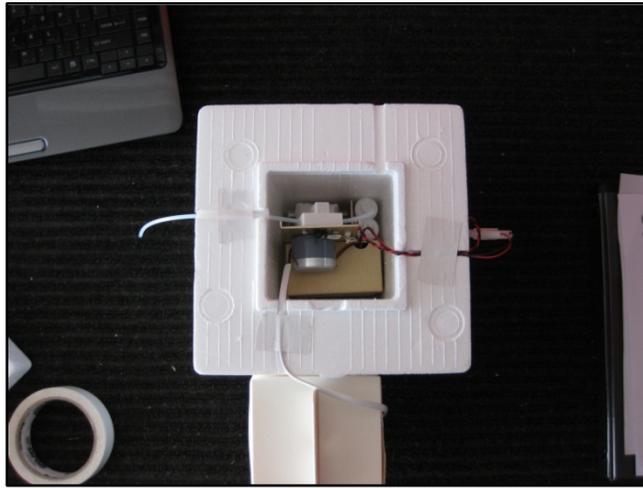
Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

5. Open the cover plate for the circuit board and remove the clip shorting out the two sensor leads. Plug the blue lead into the hole marked blue, white into white.
6. Connect the radiosonde cable to the 4-pin connector on the ozonesonde. This is labeled “radiosonde” on the circuit board.

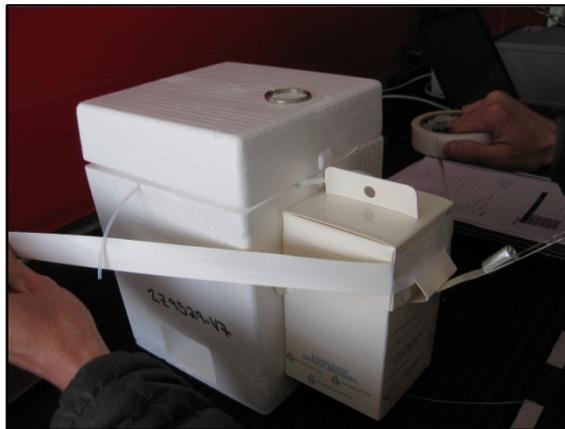


7. Remove the battery from the side of the box and use the adhesive strip to attach it to the sensor assembly in the spot provided.
8. Plug in the battery to the lead on the sensor. The pump should start working. Install the inlet tube in the hole in the side of the pump assembly, being careful not to crimp the tubing.
9. Replace the cover on the sensor assembly and circuit board. Do not crimp the wires.
10. Place the sensor assembly in the Styrofoam box. Note the location of the two adhesive strips on the sonde box and the orientation of the inlet, data cable and battery leads; use a small piece of tape to hold the three in place.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

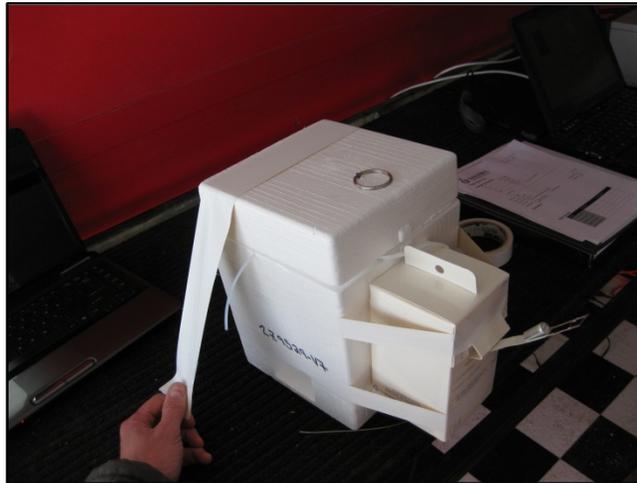


11. Using the two adhesive tabs on the front of the ozonesonde box, attach the radio sonde (antenna out) to the ozonesonde, making sure to center the radio sonde and keep the cable routed in the appropriate channel. Use two strips of thin white tape all the way around the two sondes to ensure they stay together.



12. Attach the lid to the ozone sonde (ring goes closest to the radiosonde) with two strips of white tape all the way around the Styrofoam box. Do not invert the Styrofoam box; do not dislodge the inlet tubing. Make sure the battery leads, inlet tube and data cable are sticking out of the box.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



13. Place the sondes outside prior to launch on a clean, level spot.

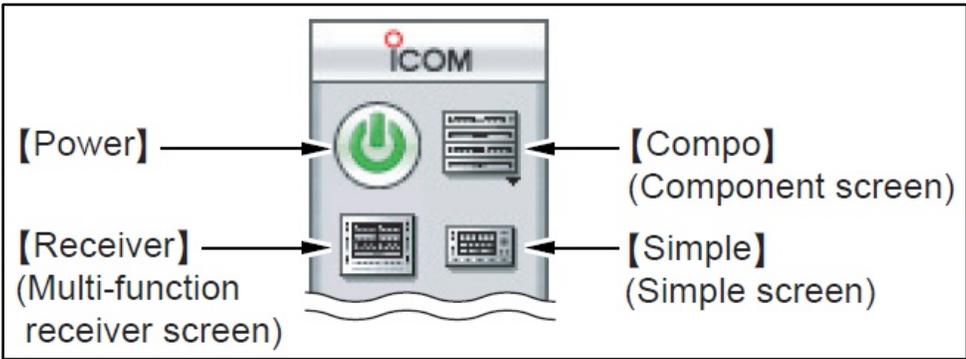
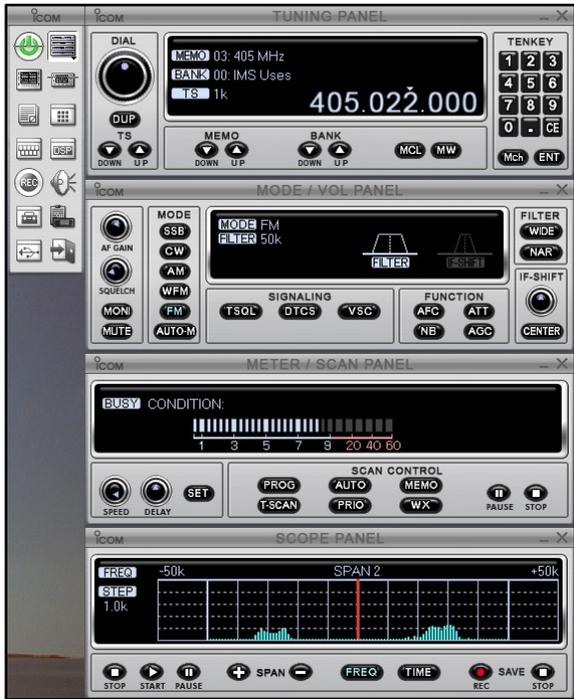
14. Verify that the data the sondes are collecting is being received by the base station.

**5) DAY OF LAUNCH: STARTING AND OPERATING THE ICOM IC-PCR1500/2500 AND THE INTERNET OZONESONDE DATA ACQUISITION SOFTWARE (O3 PROGRAM).**

The Icom IC-PCR1500/2500 software is required to control the receiver within the iMet-3050.

- a. Start the Icom PC-PCR1500/2500 software by using the desktop icon.
- b. Once the software has initialized, the Icom Toolbar will open and display.

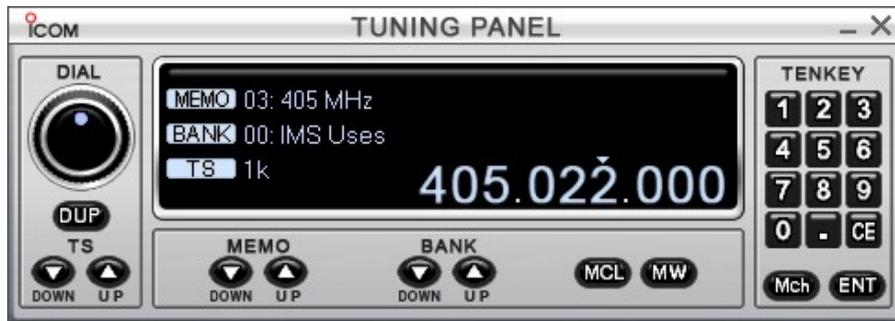
Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



Icom Toolbar Top

- c. Click the [Power] icon on the Toolbar to connect the control software and the receiver.
- d. Click the [Compo] button to open the Component Screen.
- e. In the Tuning Panel window, press the Bank [Up]/[Down] buttons until the Bank reads “00: IMS Uses”.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



**Tuning Panel**

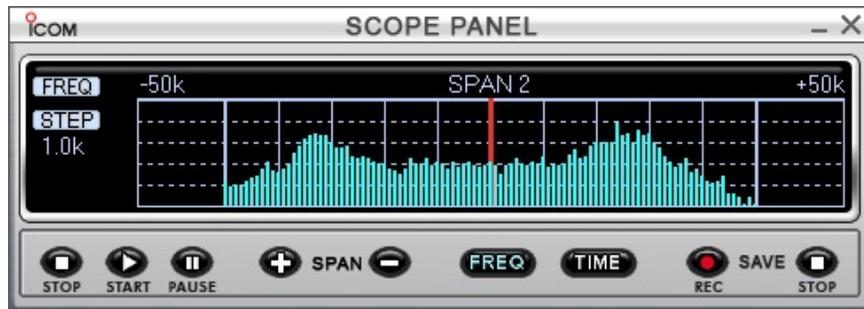
- f. In the Tuning Panel window, press the Memo [Up]/[Down] buttons until the radiosonde frequency is reached.
- g. Adjust the audio volume as desired by [Left] or [Right] clicking the “AF Gain” knob in the Mode / Vol Panel.
- h. Adjust the squelch to its lowest level by [Left] clicking the “Squelch” knob in the Mode / Vol Panel.



**Mode / Vol Panel**

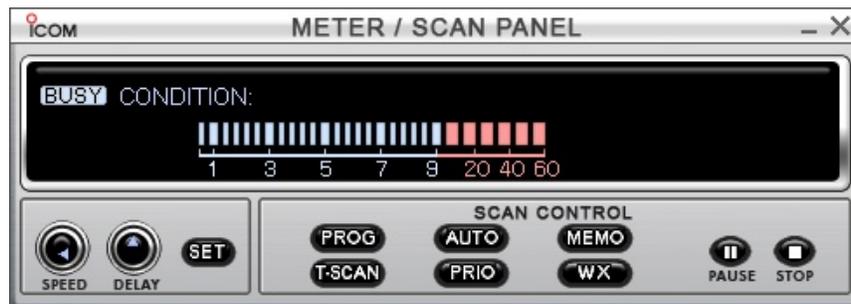
- i. While paying attention to the signal strength in the Meter/Scan Panel, press the Memo [Up]/[Down] buttons in the Tuning Panel window. Scan the four radiosonde frequencies and identify which frequency has the lowest signal strength (lowest amount of interference). Use this frequency when preparing the radiosonde.
- j. In the Scope Panel, use the [+] and [-] Span buttons to adjust the span until -50k and +50k are displayed on either side and SPAN 2 is displayed in the center.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



**Scope Panel**

- k. Using the Dial in the Tuning Panel, [Left] or [Right] click to fine-tune the receiver frequency such that the Red line in the Scope Panel is approximately centered between the twin peaks.
- l. The signal strength in the Meter/Scan panel should now show full signal strength. If it does not, re-check the security of all the RF connectors. Also, verify that the LNA feels warmer to the touch.



**Meter / Scan Panel**

Setup of the Icom IC-PCR1500/2500 is complete.

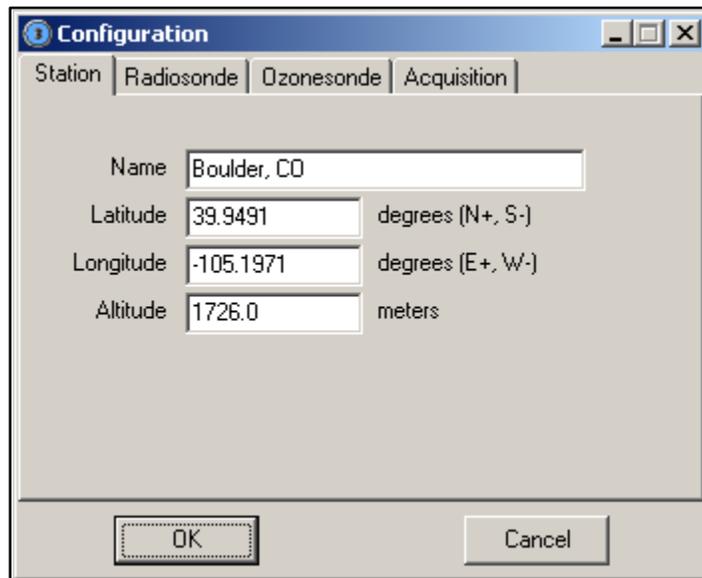
### **InterMet Ozonesonde Data Acquisition software (O<sub>3</sub> program)**

- 1) Open the “O3” program.

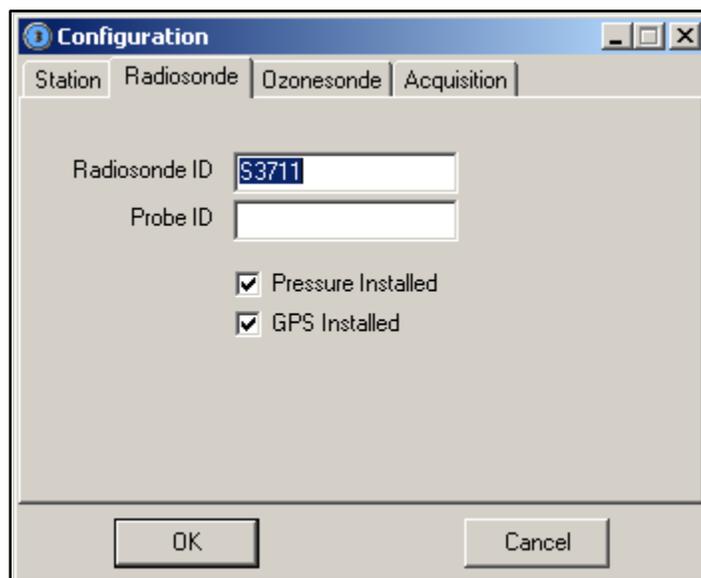


Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

2) Press “Start” and enter Station data in the Station tab as shown below.

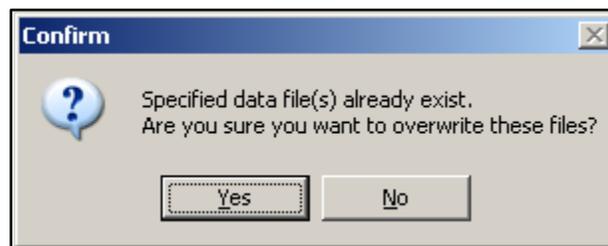
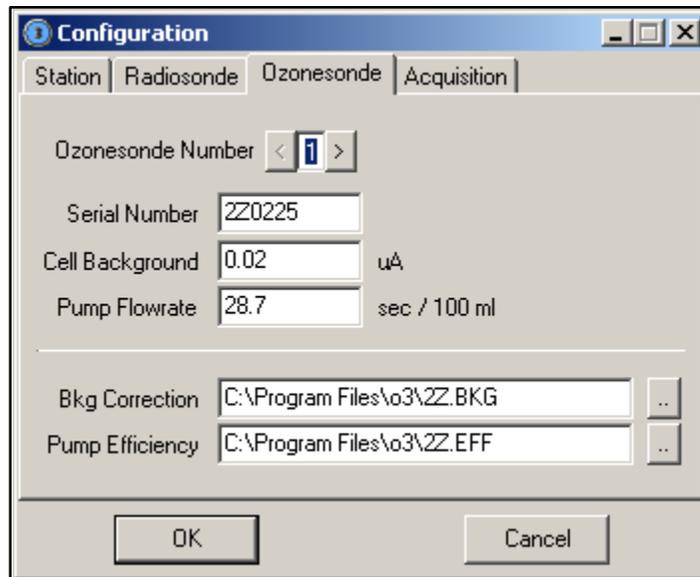


3) Enter the radiosonde ID and ensure that the “Pressure Installed” and “GPS Installed” boxes are checked as shown below.

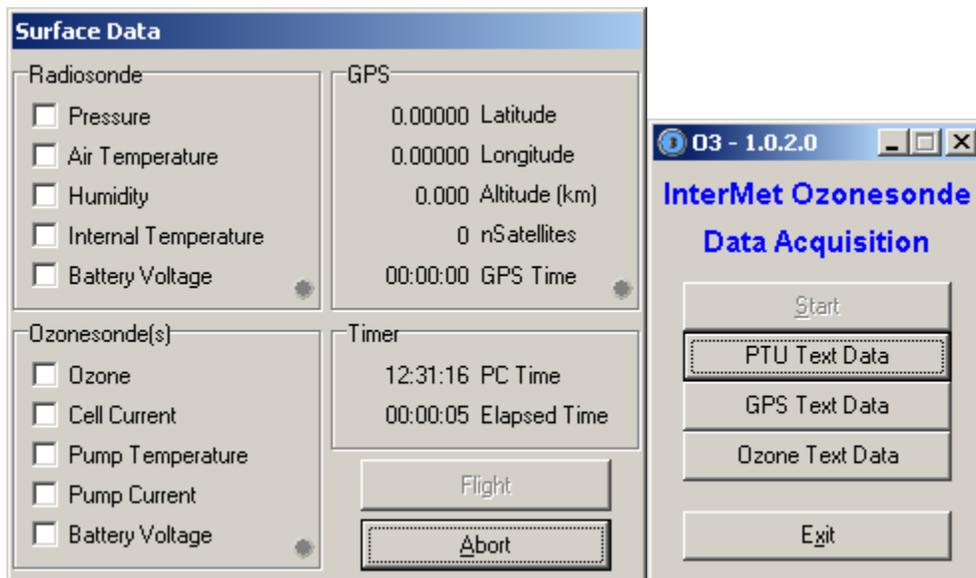


4) Enter ozonesonde information (taken from the “day of flight” ozonesonde prep. check sheet) then press “Ok” and “Yes”, and leave the program window open as shown below.

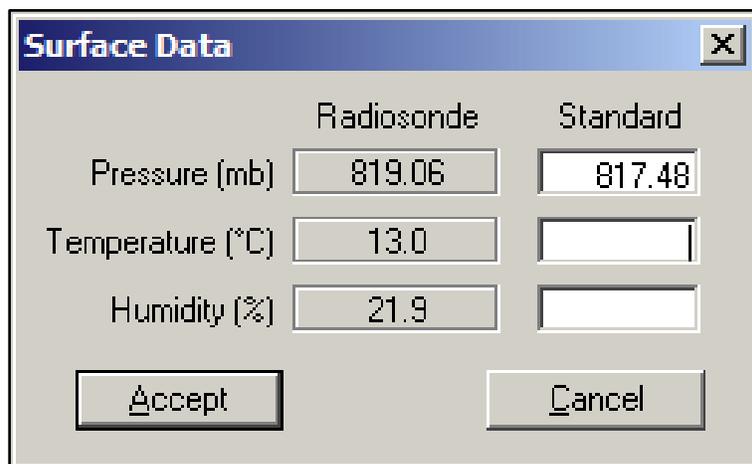
Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



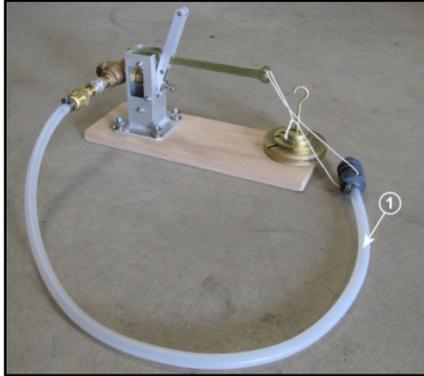
- 5) The “O3” software will show signals being received from not only the Ozonesonde but also the radiosonde by blinking green lights in the lower right hand corners of the “Radiosonde”, “GPS”, and “Ozonesonde” labels under the “Surface Data” screen.



- 6) Once sufficient time has elapsed, you will be able to click the “Flight” button. You will be asked to enter ground truth data for comparison with the radiosonde’s PTU data which will be obtained from the WDEQ Boulder site’s Met Tower. With the sonde package collocated near the Boulder site’s Ozone gas analyzer inlet, a one point ground truth Ozone reference will also be recorded at this time in the station logbook. The O3 software will automatically recognize when the balloon is released from the change in pressure.



**6) DAY OF LAUNCH: BALLOON SETUP AND CONFIGURATION**

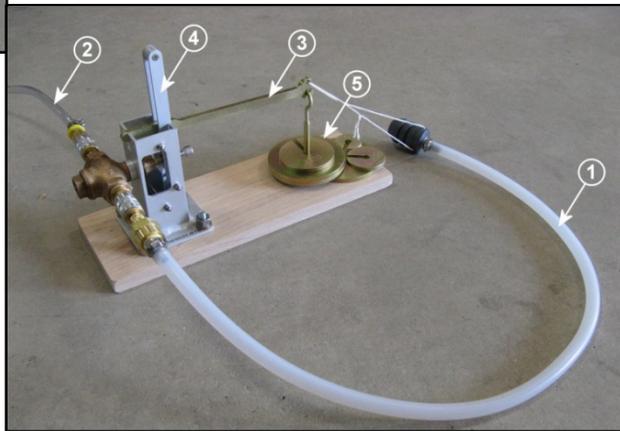


1. Remove the inflation kit from the transportation case.
2. Connect the balloon nozzle and hose (1) to the output side of the shut-off valve.
3. Connect the input hose (2) to the input side of the shut-off valve.

4. Connect the regulator assembly to Helium tank, then connect the input hose to the output of the regulator.

**CAUTION**

Do not exceed 45 PSI output pressure.



5. Lift the weight lever arm (3).
6. Pull back on the vertical valve control arm (4) and allow the weight lever arm to fall.

Condition/Option	Add'l Weight
<b>Rain</b>	
Light	+100 gm
Moderate	+200 gm
Heavy	+300 gm
<b>Icing</b>	
Moderate	+300 gm
Severe	+500 gm
<b>High Surface Wind</b>	
>25 kts (>12.5 m/s)	+100 gm
>40 kts (>20.5 m/s)	+200-300 gm
<b>Parachute</b>	70 gm
<b>De-Reeler</b>	50 gm

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

7. Select the amount of weight (5) appropriate for the flight. Options include parachutes, pibal lights, and de-reelers. The iMet-1 radiosonde weighs approximately 260 gm. During the 2011 IOPs, a 350g balloon with parachute, de-reeler radio and met sondes were launched with 1250g of He. This worked well, provided the inflation took place <20 minutes from the release time. Longer time periods had slower ascent times, likely due to loss of gas from the balloon.

MSI will try to attain ascent rates of around 150 meters per minute. From previous test flights, the proper amount of weight to reach this is somewhere around 1200 grams of weight.

Attach the balloon to the nozzle and begin inflation by opening the gas valve on the tank. Adjust the output pressure to 10-12 PSI and lock adjusting knob. We were inflating with the regulator set at 20 psi and noted no problems. Attaching the balloon to the inflation inlet with a piece of string during inflation is recommended. Use the same knot you would use for tying your shoes.

**NOTE**

If used outdoors, wind may cause the weights to be lifted, stopping inflation prematurely. If this happens, reset the arm so gas continues to fill the balloon. You can test the system without resetting the arm by checking to see if the weights pull the balloon back down (need more gas) or if the weights float (enough gas).



Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

8. Once the balloon reaches the appropriate lift, the balloon will lift the weight lever arm, shutting off the gas supply to the balloon.
9. Close the gas valve on the tank. Briefly pull back the vertical valve control arm (4) to relieve the pressure in the inflation system.
10. Cut a piece of string about 4' long, double it and tie a loop large enough to easily fit your hook/ carabiner through it.



11. Tie a series of wraps and knots to hold the neck of the balloon closed, alternating one wrap and one knot and moving down the balloon. After 1/4" of wraps and knots have built up on the balloon, finish with two overhands in a row.



Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

- Clip the grab loop of the string to the BLP4000 (Balloon Launching Platform) and untie the bow holding the holding the balloon on the filling nozzle.



- Finish the tie off by folding the neck of the balloon upward and tying the same series of knots you used in step 11.
- Tie the top of the parachute to the grab loop (the shortest loop in the picture above) on the balloon.
- Attach the de-reeler to the elastic on the bottom of the parachute hub. MSI will be using a metal ratchet type de-reeler (not pictured).



Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

16. Attach the de-reeler to the sondes by running the zip tie through the ring on the top of the ozone sonde and down to the radio sonde's loop.



**Parachute, de-reeler, ozonesonde/radiosonde ready for launch.**

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

## 7) DAY OF LAUNCH: LAUNCHING THE BALLOON AND COMPUTER OPERATIONS.

The 403 MHz Antenna is an omni-directional antenna. There are no restrictions for minimum launch distance between the sonde and the 403 MHz antenna. The radiosonde can be launched from directly next to the antenna as long as precautions are taken to not allow the radiosonde, string, or balloon to contact the antenna or become entangled.

The radiosonde shall be held such that the body does not block the reception of GPS signals. Hold the radiosonde midway up the side of the radiosonde case.

### [ CAUTION ]

When handling the radiosonde, take care not to damage the sensor probe.

- 1) On the “O3” program, ensure that the “Flight” button is highlighted (after first detecting the ozonesonde signal, there will be about a 3-5 minute delay before the “Flight” is highlighted).
- 2) **RELEASE THE BALLOON.** Release the radiosonde as soon as the balloon tries to pull the radiosonde up.
- 3) Tracking the Radiosonde

Occasionally (at least every 15 minutes), double check that the receiver is accurately tuned to the radiosonde. Adjust the frequency, as necessary, such that the red line in the Scope Panel is centered between the twin peaks.

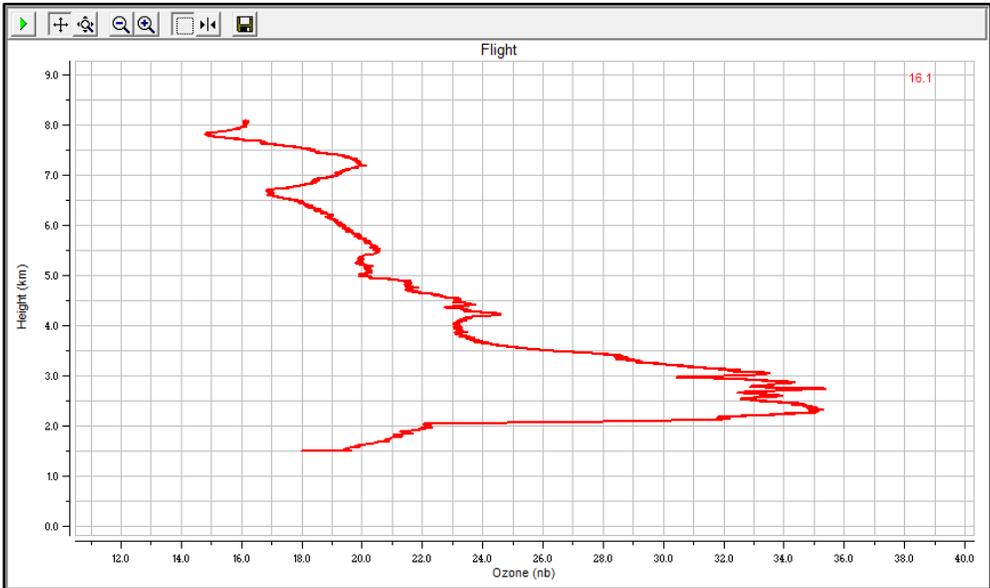
Real time graphs are available to look at in the O3 software during flight, and should be monitored as well. There are also data tables that are updated secondly and can be viewed.

#### Note

Towards the end of the flight, the signal strength will be too weak to be displayed on the Scope Panel. However, by this point in the time, the radiosonde frequency will not change enough to impair performance.

The iMet-1 radiosonde transmits data at a rate of one record per second. Moderate amounts of data loss will not prevent a successful flight and should not result in early termination unless something is clearly wrong. Data loss is more likely at the end of a flight or during periods when the sonde is directly overhead.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------



**Real time graph of Ozone vs Height.**

**8) DAY OF LAUNCH: TERMINATING FLIGHT AND ARCHIVING FLIGHT DATA.**

In the “O3” software, to terminate the flight, press “End” on the “O3” software, and “Yes”. MSI will wait at least until the sonde package has reached 500 mb (~18,000 ft), but in most cases will wait until it reaches 300 mb (~ 30,000 ft) before terminating the flight.

**Once a flight has been terminated, the user cannot resume the flight.**

The Icom IC-PCR1500/2500 software may be closed. Push the [Power] button on the Toolbar to shut down the receiver and [Exit] to close the software. Turn off the MP and unplug the USB cable from the laptop.

The InterMet O3 software outputs a series of files from each flight including separate files for GPS, Wind, PTU, Ozone, config file, and a coded Raw file. After a balloon flight is completed, the operator will connect to the network at the Boulder site and email the flight files to the MSI office for review and post processing.

Title: Ozonesonde Preparation and Deployment Procedures	Number: SOP 101	Rev. Number: 0
---	-----------------	----------------

## **9) REVIEW AND POST PROCESSING OF FLIGHT DATA.**

Once sonde data are received by email at MSI offices, the data are downloaded and imported into the EN-SCI ozonesonde processing software PV7. Before exporting the data, default options on the Preferences tab are changed to reduce data filtration and manipulation. These changes include the “Ozone low-pass filter” is set to 0.0 seconds and the “Show All Data” is selected. Data are then exported (as a .csv file) using the “Export All” option under the “File” dropdown menu and are ready to be plotted using RAOB.

RAOB version 6.2 is used to plot ozonesonde data. To import the ozonesonde data, from the “File” dropdown menu select “Open Sounding” navigate to the .csv file created using PV7. RAOB automatically plots the temperature and wind data. Ozone data can be plotted by clicking the “Analyze” dropdown menu, a window will appear where the user selects “Ozone”. Images are then saved as a .png image to be displayed on the website by selecting “File” then “Save Image to File...”.

**Appendix B**  
**Microsoft Access Database Description**

# The Upper Green Winter Ozone Study (UGWOS) 2013 Database

## 1. Introduction

This document describes the Upper Green Winter Ozone Study (UGWOS) database for 2013. 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 2013 UGWOS field study included hourly measurements of surface and upper air meteorological and air quality data during the period of January through March 2013 in the upper Green River Basin region of southwestern Wyoming. Winds aloft were measured by a mini-SODAR and are reported on an hourly basis for the duration of the study. VOC data were collected at eight locations (Boulder, Juel Springs, Jonah, Jonah2, Paradise, Mesa, Warbonnet, and Big Piney) to determine spatial distribution of VOCs.

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

### Wyoming Department of Environmental Quality:

- WDEQ runs an ambient air quality network throughout the state of Wyoming. Air Quality sites included in UGWOS 2013 were located in or near Sublette County in southwestern Wyoming. The stations include:
  - Boulder (including 1-minute and 1-hour data collection),
  - Big Piney,
  - Daniel South,
  - Farson (Met Only)
  - Jonah,
  - Jonah2 (Winds and VOC only),
  - Juel Springs,
  - Hiawatha,
  - Mesa,
  - Moxa,
  - Murphy Ridge,
  - Paradise,
  - Pinedale,
  - South Pass,
  - Thunder Basin,
  - Wamsutter,
  - Warbonnet, and
  - Wyoming Range.

- The WDEQ Monitoring network data consisting of some or all of the parameters presented below:
  - Ozone
  - PM<sub>10</sub>
  - PM<sub>2.5</sub>
  - NO/NO<sub>2</sub>/NO<sub>x</sub> or NO<sub>y</sub>
  - SO<sub>2</sub>
  - 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
  - Carbon Monoxide
  - Sulfur Dioxide

#### T&B Systems

- SODAR measurements (Boulder site)
  - Wind speed
  - Wind direction
  - Mixing heights

#### Meteorological Solutions, Inc.

- Canister Data
  - VOCs
- Rawinsonde and Ozonesonde Data

Supplemental data included hourly surface ozone and meteorological data from three CASTNET (Clean Air Status and Trends Network) sites, located in or near the Upper Green River Basin.

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 2013 database.

**Table 1 - Data Flags**

<b>QC</b>	<b>Description</b>
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
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

**Table 1 Continued - Data Flags**

<b>QC</b>	<b>Description</b>
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 2010 database called UGWOS\_2013\_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) 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. One minute air quality data were collected at the Boulder site. These data are presented in the **1-minute Air Quality** data table. Boulder data went through quality assurance with valid data marked with a "V" in the QC flag field.

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. One minute meteorological data were collected at the Boulder and Mobile trailer sites. These data are presented in the **1-minute Meteorology** data table. Boulder data went through quality assurance. The Mobile Trailer did not get validated and the data has a QC flag of “U” as specified in Table 1 as data which has not been validated.

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

Upper air data including the data from the SODAR is provided in the **Sodar** and the **Mixing Height** data tables. Radiosonde and Ozonesonde data are presented in **Sonde Data (Met Only)** and **Sonde Data (Ozone)** tables.

Surface VOC data collected during IOPs at the Boulder, Juel Springs, Jonah, and Big Piney sites are presented in the **VOC** table. A summary of the canister data collected at the VOC sites are available in **VOC Summary** 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 2010 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<sub>3</sub>, NO, NO<sub>2</sub>, NO<sub>X</sub>, NO<sub>Y</sub>, and SO<sub>2</sub>
- Micrograms per cubic meter for PM<sub>10</sub> and PM<sub>2.5</sub>
- 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

The 2013 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 Data, Individual Site Data, Sort 1-hour Ozone Data, and Sort 8-hour Ozone Data). Once a user opens the query he or she 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, 2013 and March 31, 2013. 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](mailto:scott.adamson@metsolution.com).

#### 4. Summary

This document describes the 2013 UGWOS database. Feedback from study participants concerning this document and the database is requested and any suggestions for improvement are highly encouraged and appreciated.