FINAL REPORT
2014 UPPER GREEN RIVER WINTER OZONE STUDY

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September 2014

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A Trinity Consultants Company

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Appendix

A Monitoring and Quality Assurance Plan
B Microsoft Access Database Description

1.0 INTRODUCTION

The Wyoming Department of Environmental Quality (WDEQ) – Air Quality Division (AQD) sponsored the Upper Green Winter Ozone Study (UGWOS) during the period January 15 to March 31, 2014. This research program has been conducted each year since 2007 to investigate wintertime ozone formation in the Upper Green River Basin (UGRB) leading to concentrations of ambient ozone (O_3) exceeding the National Ambient Air Quality Standard (NAAQS) which is currently set at a daily maximum eight-hour average of 75 parts per billion (ppb). During each year's field effort, data are collected from a network of long-term air quality monitoring stations, 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 (2007-2013) are posted on the Monitoring Information Page of the WDEQ-AQD website.[1]

In 2014, AQD contracted with Meteorological Solutions Inc., a Trinity Consultants company (MSI Trinity) and sub-contractor T&B Systems, to conduct a field measurement program, which focused on the spatial distribution of ozone and ozone precursors. MSI Trinity was responsible for overall project management, 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 was stationed full-time in the project area for the duration of the UGWOS field effort to install and operate six (6) canister and carbonyl sampling sites, perform routine quality control checks on air quality monitoring 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 (3) mesonet sites providing continuous ozone, wind speed and direction, temperature and camera images;

- Installation, calibration, and operation of a temporary ambient air quality monitoring station in the Jonah Field, which provided continuous measurements of O_3 and oxides of nitrogen (NO_x) as well as wind speed, wind direction, temperature and camera images;

- Speciated hydrocarbon sampling using stainless steel canisters and carbonyl cartridges at six (6) 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 also provided secondary ozonesonde instrumentation and operation.

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

[1] http://deq.state.wy.us/aqd/Monitoring%20Data.asp

Field operations for UGWOS 2014 began on January 15, 2014 and continued through March 31, 2014. Daily weather outlooks were issued by MSI Trinity'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, carbonyl, and upper air ozonesonde/radiosonde measurements could be implemented during these Intensive Operational Periods (IOPs). IOP conditions never materialized during the UGWOS 2014 field measurement season; instead, there were six designated volatile organic compound (VOC) sampling days which were forecast and characterized by high pressure, light winds and sunny skies.

This report presents a summary of UGWOS 2014 field operations, quality assurance activities, and the results of the field measurement program. Section 2.0 presents an overview of field measurement operations including the ozone and ozone precursor measurements. This section also provides synoptic weather summaries for the designated VOC sampling days. Section 3.0 describes database management, quality assurance, data validation, and data archiving. Monitoring results are described in Section 4.0. Section 5.0 presents a summary of the findings, conclusions based on the findings, and recommendations. UGWOS 2014 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 2014, operational forecasts, and synoptic weather summaries during 2014 designated VOC sampling periods.

2.1 Overview

UGWOS 2014 field operations were scheduled for January 15 through March 31, 2014. All UGWOS 2014 monitoring sites were installed, calibrated, and ready for operation by January 14, 2014. Forecasting for elevated ozone conditions started on January 15 and continued through March 31, 2014.

2.1.1 Planning Process

Ambient conditions in the Jonah Field area were measured at the same location as the 2013 UGWOS study. The location was determined to be representative of the Jonah field and a suitable replacement for the former Jonah site. The site is located just outside the property line of an energy facility and was considered to be the preferred location, since the facility was willing to allow access to their power.

During UGWOS 2014, three (3) tripod-mounted solar-powered mesonet sites were operated at locations utilized during previous measurement programs. Former mesonet sites – Mesa, Paradise, and Warbonnet from the 2013 study were reactivated for the 2014 study. These sites required clearance for wildlife concerns and Bureau of Land Management (BLM) approval. BLM approval for the three mesonet sites was obtained as part of the UGWOS study on January 7, 2013.

AQD-owned VOC sampling systems were utilized for the UGWOS 2014 VOC sampling effort. Sampling systems were retrieved in December 2013, cleaned, leak-checked, and tested for contamination prior to operational use during UGWOS 2014.

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, and a mobile trailer in the Jonah field provided meteorological and air quality data for the UGWOS 2014 database. A map showing the measurement stations active during the UGWOS 2014 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.

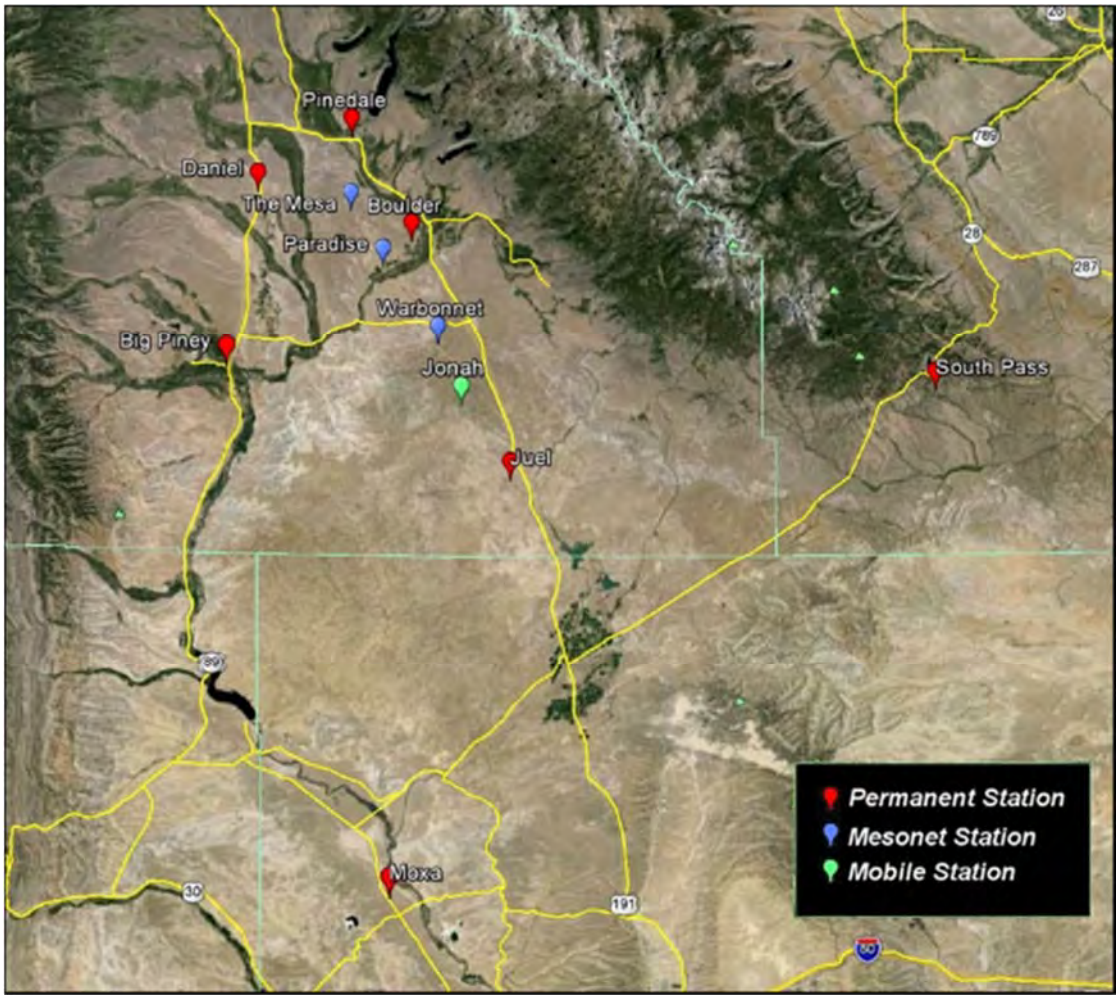


Figure 2.1 Active Monitoring Stations in the UGWOS 2014 Study Domain

Table 2-1 Summary of Measurement Methods Used During UGWOS 2014

Platform	Measurement	Instrumentation	
		Method	Model
Jonah Field Mobile Trailer	Ozone	UV Photometric	Thermo 49i
	NO_x	Chemiluminescence	Thermo 42i
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	Wind speed, wind dir., Temperature	Various	R.M. Young 05305 CSI CS109
Boulder Special Measurements	True NO_2	Chemiluminescence	T-API 200EU w/Photolytic Converter
	NO_y	Chemiluminescence	T-API T200U w/501Y NOy Converter
	Methane/TNMHC	FID	Baseline-Mocon 9000
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID
WDEQ Long-Term Monitoring Sites	Ozone	UV Photometric	T-API 400E/400A
	NO_x	Chemiluminescence	T-API 200E/200A
	PM_{10}	Tapered Element Oscillating Microbalance Beta Attenuation Monitor	TEOM 1400a (Daniel, Boulder, South Pass) BAM 1020 (Moxa)
	$PM_{2.5}$	Beta Attenuation	BAM 1020 (Pinedale)
	SO_2	Pulsed Fluorescence	Thermo 43i (Moxa)
	TUVR	Incoming and reflected short wave radiation	Eppley TUVR (Boulder & Moxa)
	Speciated VOC	TO-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID (Big Piney)
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

Table 2-1 (Continued) Summary of Measurement Methods Used During UGWOS 2014

Platform	Measurement	Instrumentation	
		Method	Model
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-11/TO-14 Canister w/expanded PAMS list of analytes	GC/FID
Tethered 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

For the 2014 field study, the UGWOS website was hosted by MSI Trinity and allowed remote access to near real-time station data for all UGWOS and UGRB long-term monitoring sites. An example of the UGWOS web-site home page with the most current ozone concentrations and web-site menu is presented in Figure 2.2 below. The web-site displayed near real-time ozone and meteorological information for the following stations:

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

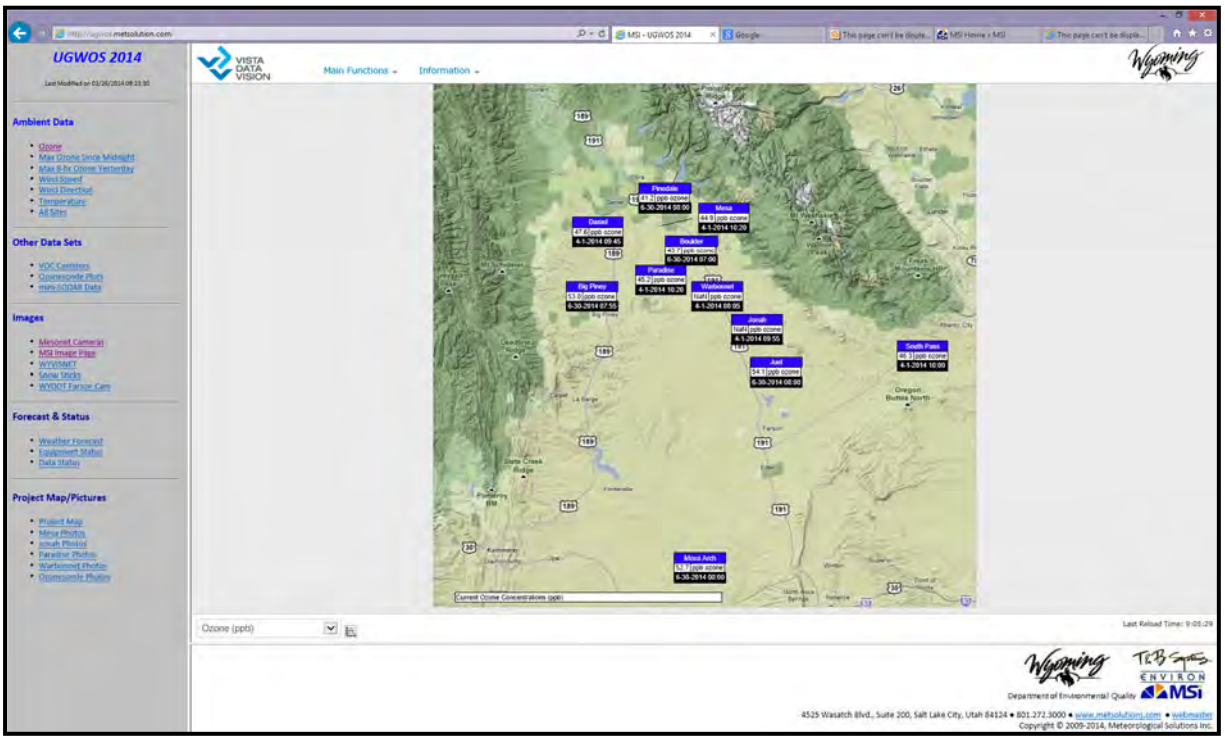


Figure 2.2 Current Ozone Concentrations with Website Menu

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). The project weather and ozone outlook page was updated on a daily basis (Figure 2.5). Camera images from mesonet (Figure 2.6) 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 2.7). A monitoring site data retrieval status table (Figure 2.8) 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.

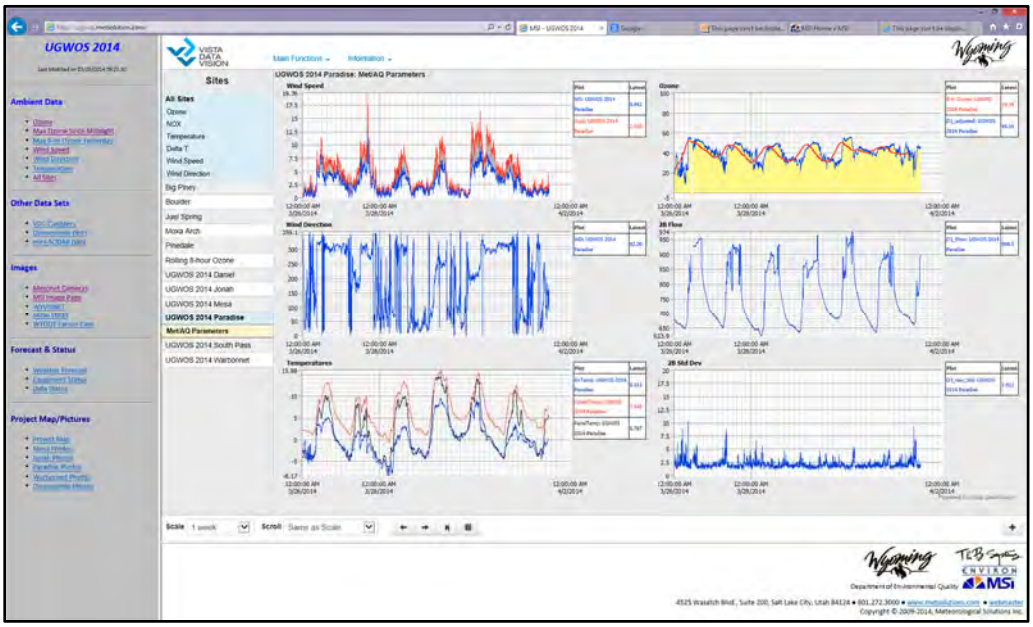


Figure 2.3 Single Station Strip Chart Example

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

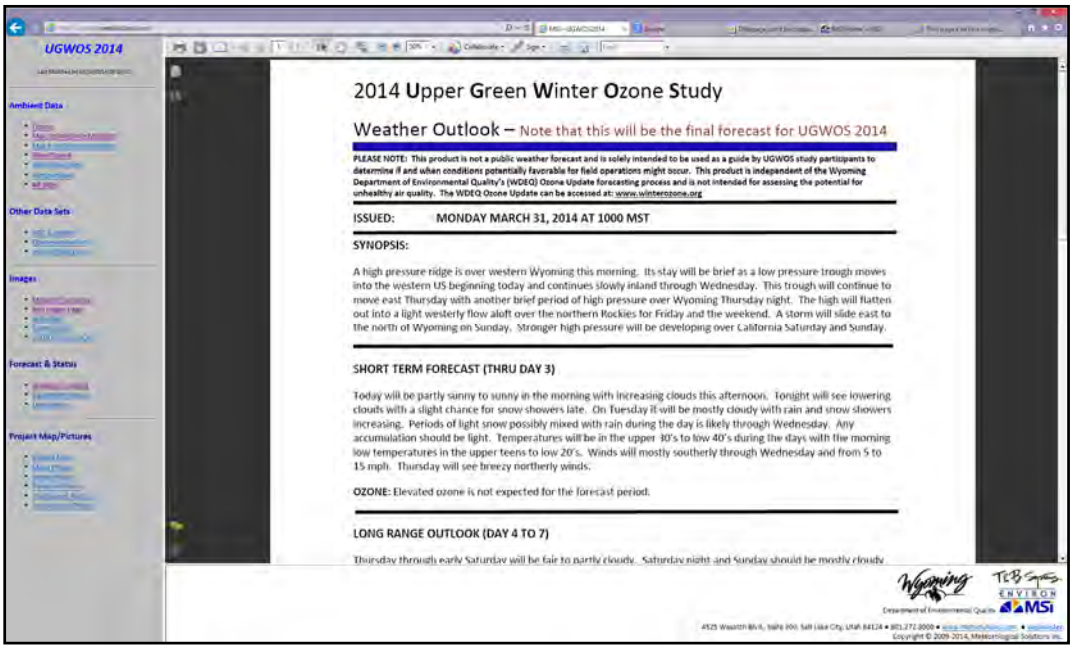


Figure 2.5 Project Weather/Ozone Outlook Example

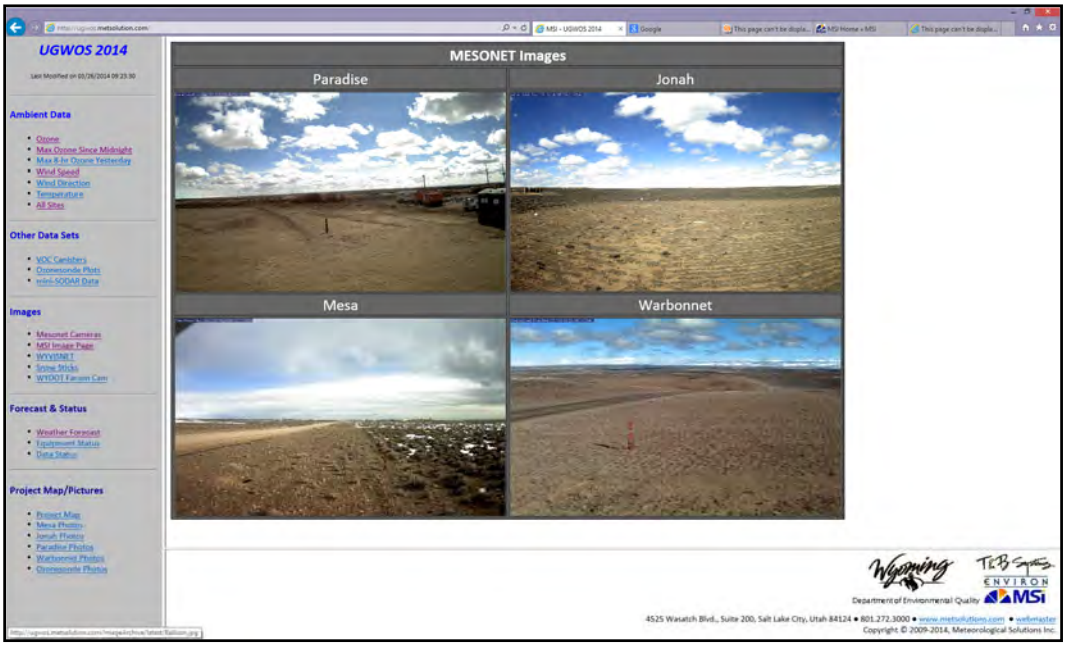


Figure 2.6 Images from Mesonet Site Cameras Updated on the Website Every 15 Minutes

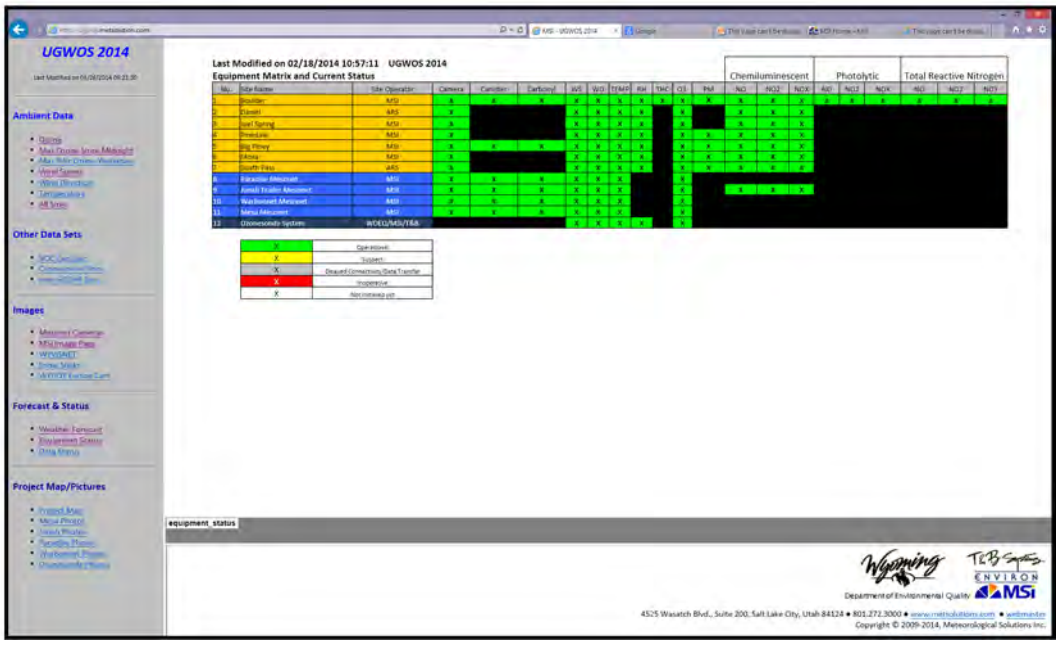


Figure 2.7 Current Equipment Status

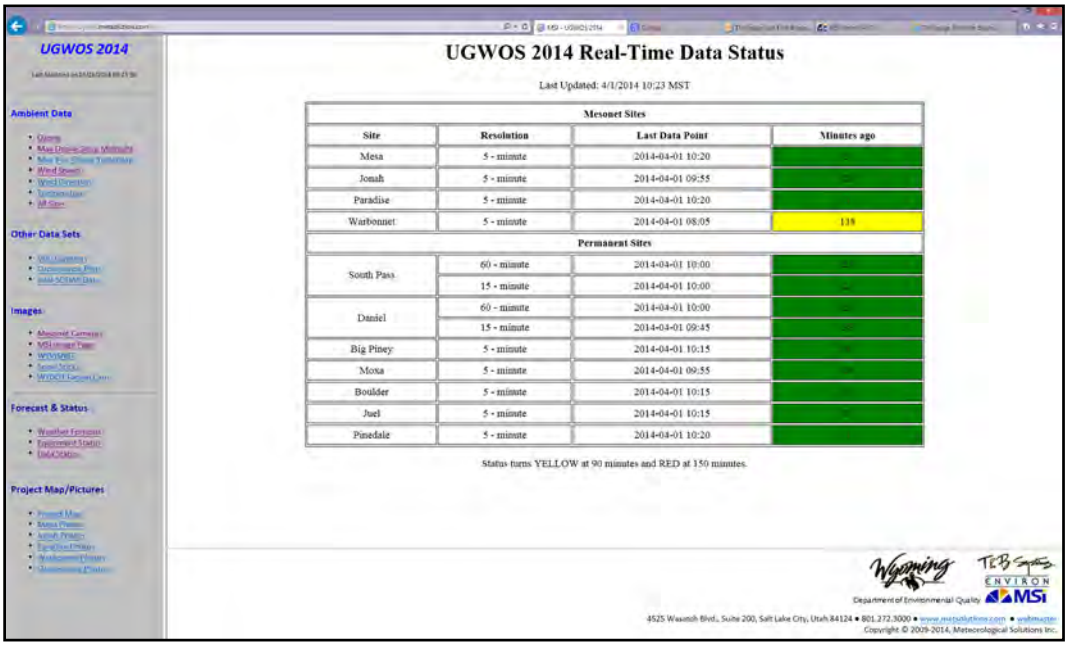


Figure 2.8 UGWOS 2014 Monitoring Site Data Retrieval Status

2.2 Field Measurements

Measurement stations which provided data for the UGWOS 2014 database included the long-term WDEQ-AQD monitoring stations operating in the UGRB study area, a WDEQ mobile trailer monitoring site at 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 2014. During the field measurement season, VOC canister and carbonyl samples were collected on designated days at six locations - Jonah site, the three mesonet sites, and two of the long-term monitoring stations – Boulder and Big Piney.

2.2.1 WDEQ Long-Term Monitoring Sites

WDEQ monitoring stations in the UGRB which were actively collecting data during UGWOS 2014 included Big Piney, Boulder, Daniel South, Juel Springs, Moxa, Pinedale, and South Pass. In late 2013, the Wyoming Range monitoring site was removed from service. The shelter, meteorological, and gaseous air monitoring equipment were moved to the location of the Big Piney mobile trailer to be operated as a long-term site. The Big Piney site will monitor air quality downwind of the Big Piney/La Barge development area and provide air quality data for the west side of the UGWOS domain.

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 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 2.9 presents a photograph of the Big Piney long-term monitoring site. Figures 2.10 and 2.11 show the more extensive long-term monitoring station at Boulder. Figure 2.12 presents a photograph of the Boulder station interior.

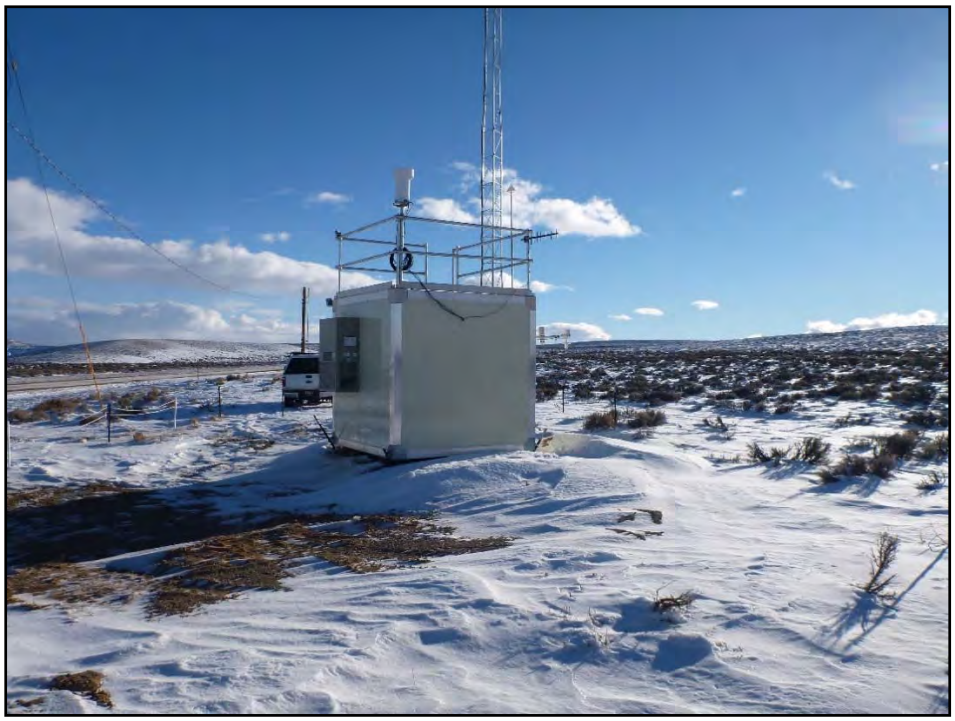


Figure 2.9 Photograph of Big Piney Monitoring Station

Figure 2.10 Boulder Monitoring Site

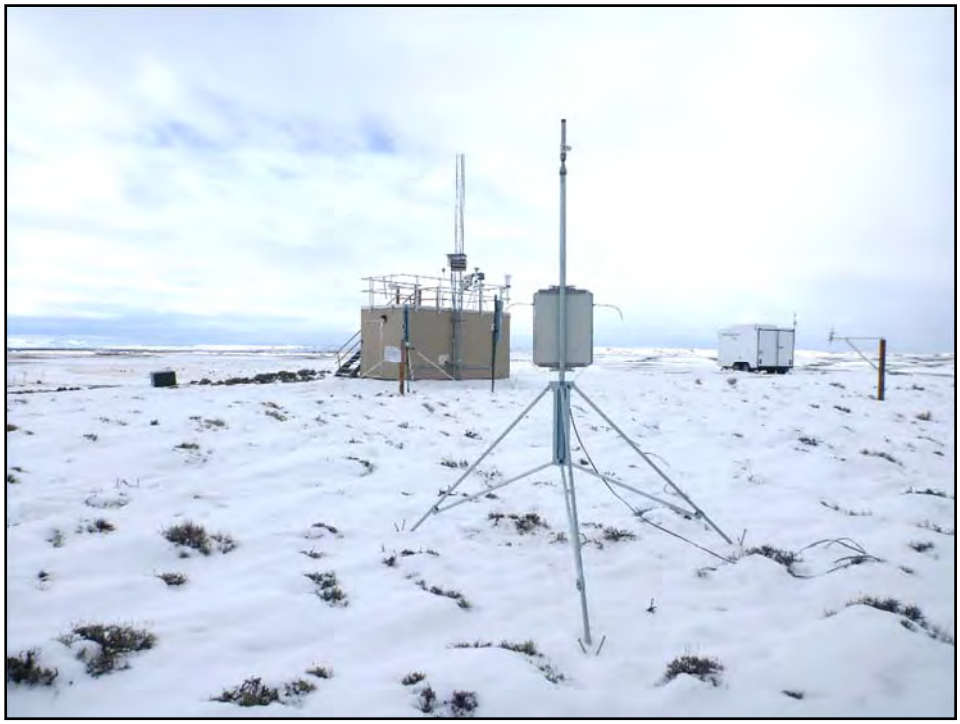


Figure 2.11 Boulder Meteorological Station with TUVR Sensors and UGWOS VOC Sampling Tripod

Figure 2.12 Photograph of Interior of Boulder Monitoring Station

2.2.2 Specialized Measurements at Boulder

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

NO_y 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_2, and other compounds that are too unstable to be measured when brought in through the standard conventional ambient air sample inlet system. Sampling the ambient air directly into the remote converter enables the conversion of labile components of NO_y which might normally be lost in a conventional system with longer transit time between the sample inlet and the converter.

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

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.

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

2.2.3 Mobile Trailer Measurements: Jonah Field

One of AQD's mobile trailers, installed and operated by MSI Trinity, was located in the Jonah Field utilizing electric power from the nearby 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. Figure 2.13 presents a view of the Jonah field monitoring site.

Figure 2.13 Jonah Field Monitoring Site with Adjacent VOC Tripod

2.2.4 Mesonet Monitoring Stations

During 2014, three mesonet stations were operated at Mesa, Paradise, and Warbonnet. These locations were used during previous UGWOS field programs. These 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 2014 program (as low as -20° C with an average temperature of approximately 1.0°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 and carbonyl 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 TO-11 and modified TO-14 methods as described in Section 3.2. Photographs of the three mesonet monitoring stations are shown in Figures 2.14 through 2.16.

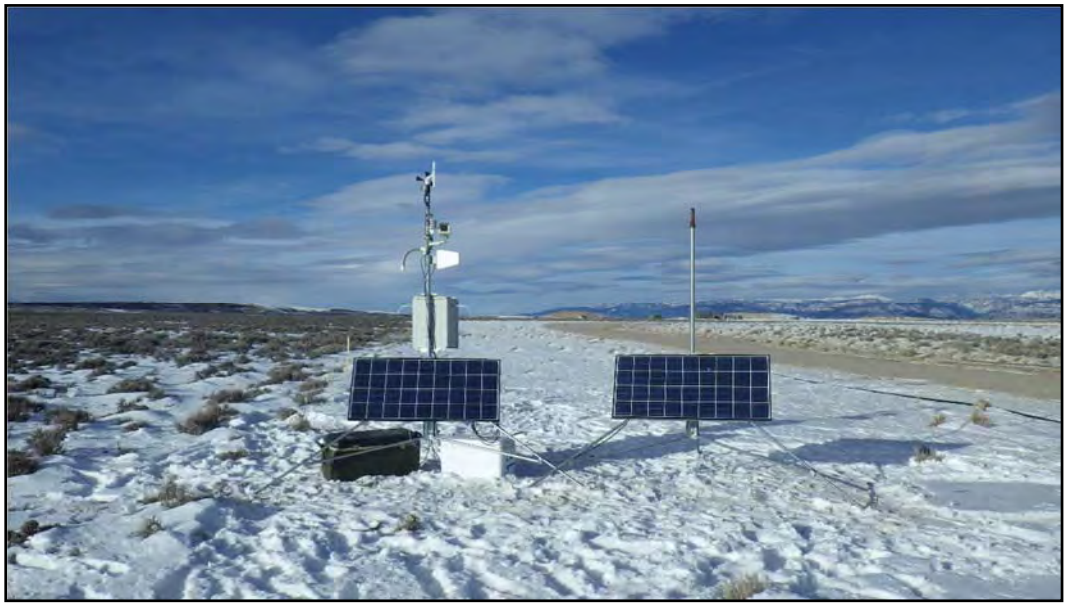


Figure 2.14 Mesa Mesonet Site

Figure 2.15 Warbonnet Mesonet Site

Figure 2.16 Paradise Mesonet Site

2.2.5 VOC Sampling

Ambient air samples were collected in specially prepared stainless steel canisters using the sub-atmospheric sampling method. An adjustable flow controller was used to control the sample flow rate into the canister for a three-hour integrated sample with some negative pressure still remaining in the canister at the end of the period. In addition, Carbonyl samples were collected concurrently with the VOC canisters using DNPH-coated cartridges outfitted with the ozone scrubbers and connected to constant flow pump systems. Canisters and cartridges were typically loaded into each system on the day before a sampling event. The site datalogger activated a solenoid valve and pump system to start the sampling process at the time selected (07:00-10:00 MST) and closed at the end of the period. Canisters and cartridges were retrieved immediately following each event and shipped within a few days to EAS laboratory for modified TO-14 and TO-11 analysis, respectively (description in Section 3.2).

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

VOC canister and carbonyl cartridge sampling systems were set up at Big Piney, Boulder, and Jonah Field as well as at the three mesonet sites at Mesa, Paradise, 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 and carbonyl sampling on designated sampling days from 07:00-10:00 MST.

Measurements of VOC's were originally scheduled to be conducted during designated IOPs. During UGWOS 2014, there were no designated IOPs, i.e. periods when elevated ambient ozone concentrations were expected to develop. There were, however, six designated VOC canister sampling days when conditions were forecast to be high pressure, light winds and sunny skies. VOC samples were collected on the following dates: January 24, February 26, March 5, March 8, March 9, and March 25, 2014.

2.2.6 miniSODAR™

The WDEQ Wind Explorer miniSODAR™ was maintained and operated adjacent to the Boulder monitoring station, continuously measured winds at the surface and aloft and provided mixing height information up to approximately 250 meters. Figure 2.17 shows the miniSODAR at its Boulder monitoring site location.

Figure 2.17 miniSODAR™

2.2.7 Tethered Soundings

During UGWOS 2014, MSI Trinity and T&B Systems were tasked with measuring vertical profiles and aloft measurements of ozone, temperature, and relative humidity using a tethered ozonesonde/radiosonde upper air sounding system. Measurements were arranged to be conducted at the Boulder and Jonah sites.

Soundings were scheduled to begin at 09:00 MST on designated IOP days to characterize the stable period of the diurnal cycle. Review of the data would determine a level of interest in which the sonde would be placed for constant measurements for 30 minutes. This process would repeat on an hourly basis through 16:30 to characterize the daytime boundary layer.

The operational plan called for soundings to be performed during designated IOPs. Since no IOPs were declared during UGWOS 2014, upper air soundings were not conducted.

2.3 Designated VOC Sampling Days

During UGWOS 2014, 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 IOPs when additional field activities, namely VOC sampling at six (6) sites and tethered ozone/radiosonde balloon launches, would take place. Conditions in 2014 were similar enough to 2013 that once again conditions conducive to significant elevated ozone formation never materialized and no IOPs were designated. Instead, in order to provide additional speciated hydrocarbon data for the study domain, VOC sampling days were designated based on a forecast of stable, high pressure conditions with light winds and sunny skies. Cara Keslar from the WDEQ-AQD made the final determination on what days the samples would be collected.

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

2.3.1 Forecasts for IOP/VOC Sampling Events

There were no changes in the way operational forecasts were developed or disseminated in the 2014 season. Forecasts were issued daily from January 15 through March 31, 2014, and were used to assist in the planning of IOP events and other field operations. These forecasts were emailed to all study participants and posted on the UGWOS project web site by 10:00 MST.

The forecast consisted of four sections. The first section provided a synopsis of current weather conditions over the western U.S. and described how the weather pattern would evolve over the following week. The second section provided a three-day forecast for the study area focusing on weather and ozone conditions for the near-term. The third section was a longer range outlook that covered the period from four to seven days. The fourth section provided a brief statement indicating the status of IOPs and/or canister sampling events and what the possibilities of future events were. Figure 2.18 shows an example of a forecast issued in 2014 prior to a sampling event on March 8.

2014 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

ISSUED: THURSDAY MARCH 27, 2014 AT 1000 MST

SYNOPSIS:

The radar and satellite images are showing considerable clouds and shower activity moving across the region. This will continue to be the case into early tomorrow. For Friday and early Saturday a little higher pressure and southwest flow will occur over western Wyoming ahead of the next trough of low pressure that will be developing along the NW coast. Two storm systems will rotate out of this coastal trough with one crossing Wyoming Sunday and the second coming in a couple of pieces early Tuesday through Wednesday of next week.

SHORT TERM FORECAST (THRU DAY 3)

Skies will be generally overcast today with mixed rain and snow showers into tonight. There will be the chance for isolated thunderstorms in the afternoon. Winds will start out west to southwesterly, becoming northwesterly and gusty at times today. Snow accumulation is not likely. On Friday and Saturday skies will be clear to partly cloudy. Today and Friday will be in the lower 40's, while Saturday will be warmer reaching the 40's to low 50's. Morning low temperatures will be in the upper teens to low 20's.

OZONE: Elevated ozone is not expected for the forecast period.

LONG RANGE OUTLOOK (DAY 4 TO 7)

For the Sunday through Wednesday period there will be a chance for showers each day except Monday. Snow accumulation should be minimal due to mild temperatures but showers should be heaviest Sunday afternoon and again during the day on Tuesday.

OZONE: Elevated ozone is not expected for the outlook period.

IOP: An IOP is not planned at this time.

MSI T&B Systems

Figure 2.18 Example Weather Outlook

2.3.2 Synoptic Weather Summaries of Canister Sampling Events

No IOPs were declared during the 2014 study. However, there were six days when VOC canister sampling occurred. The samples were taken in the morning between the hours of 07:00-10:00 MST. Four of the sampling events, on January 24, February 26, March 5, and March 25 occurred during the mornings of a single day. A fifth event occurred on two consecutive days, from March 8 to March 9.

January 24, 2014

During the first day of canister sampling, in the morning, a very narrow ridge of high pressure was centered over the British Columbian Coast and extended south through Washington, Idaho, and Utah. Winds at 700 mb were approximately 8 meters per second (mps) and the wind direction was from the northwest.

At the surface, the high pressure paralleled the ridge aloft with a slight shift to the east. The Mean Sea Level (MSL) pressure over the Upper Green Basin was approximately 1036 millibars (mb). The highest surface pressure was centered over central Idaho. Surface winds were highly variable the morning of January 24 with drainage flows in place. Wind directions ranged from northwest to southerly to easterly. Wind speeds at several locations ranged from 6 to 8 mps, though some locations remained under 2 mps. At 07:00 MST, surface temperatures ranged from -21°C to -6°C. Temperature at 10:00 MST ranged from -16°C to 3°C over the Basin.

Figure 2.19 presents the 700 mb level chart for the morning of January 24. Figure 2.20 presents the surface weather chart, obtained from the National Centers for Environmental Prediction, Hydro meteorological Prediction Center, from the morning of January 24.

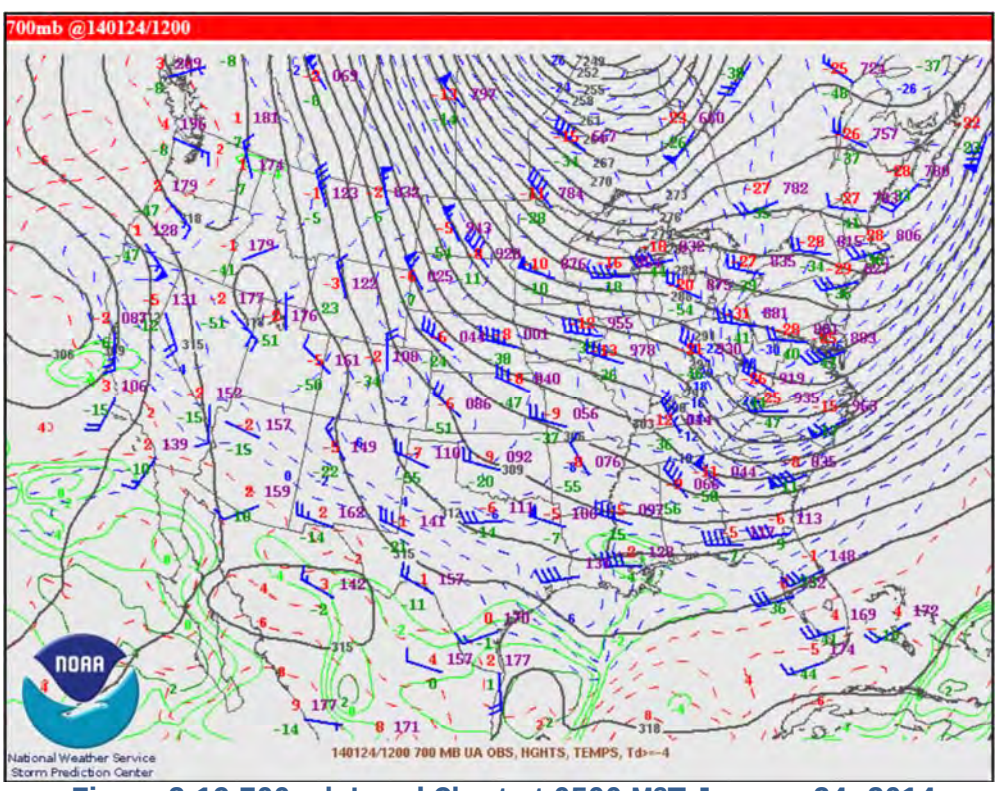


Figure 2.19 700 mb Level Chart at 0500 MST January 24, 2014

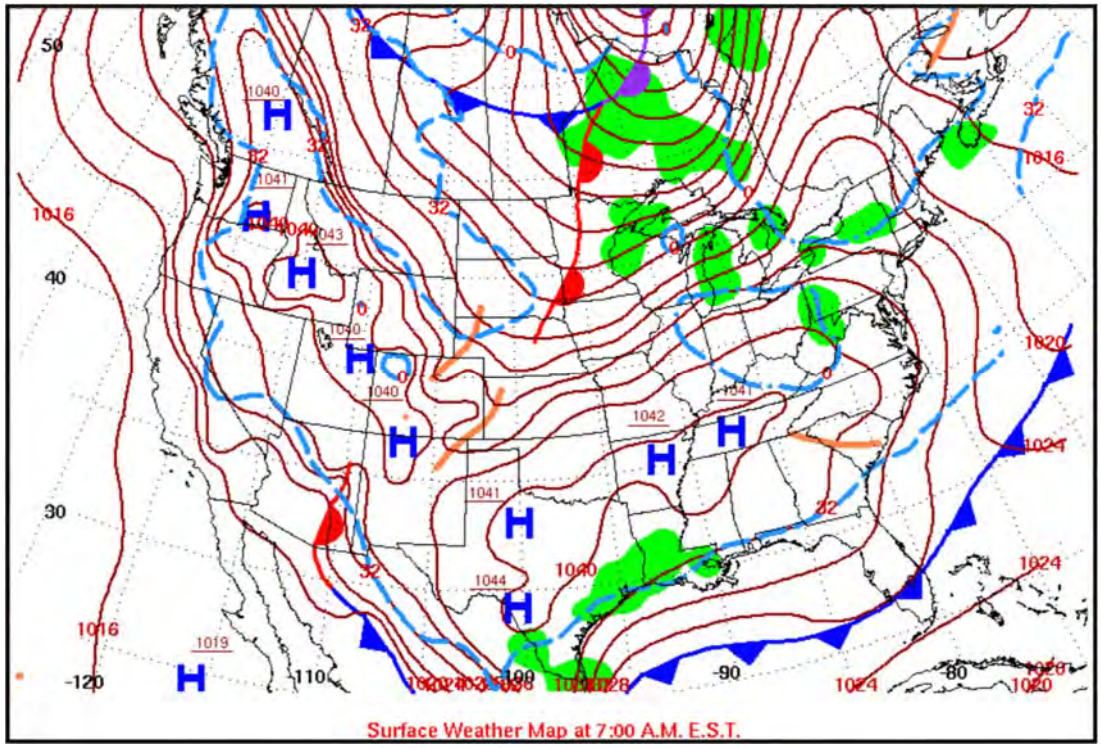


Figure 2.20 Surface Chart at 0500 MST January 24, 2014

February 26, 2014

During the morning of the second sampling period, a broad area of low pressure aloft covered much of the eastern U.S. while the western U.S. was dominated by a high pressure ridge at 700 mb. This western ridge covered the area from the Pacific Northwest southeast into Arizona.

On February 26, winds at 700 mb over western Wyoming were from the northwest during the morning with speeds of approximately 10 mps. Temperatures had warmed strongly the night before and had climbed to approximately -3°C at 700 mb during the morning hours.

At the surface, wind speeds were generally light with predominately a northwesterly wind direction but trended toward the southeast by 10:00 MST. Wind speeds were frequently less than 2 mps with a few sites measuring 3 to 5 mps. Surface high pressure was centered over British Columbia south into western Montana and Wyoming where the study area saw MSL pressures of around 1028 mb during the morning. Temperatures during the sampling period ranged from -19°C to -8°C at 07:00 MST to approximately -14°C to -6°C at 10:00 MST. Figures 2.21 and 2.22 present the 700 mb and surface weather charts, respectively, for the morning of February 26.

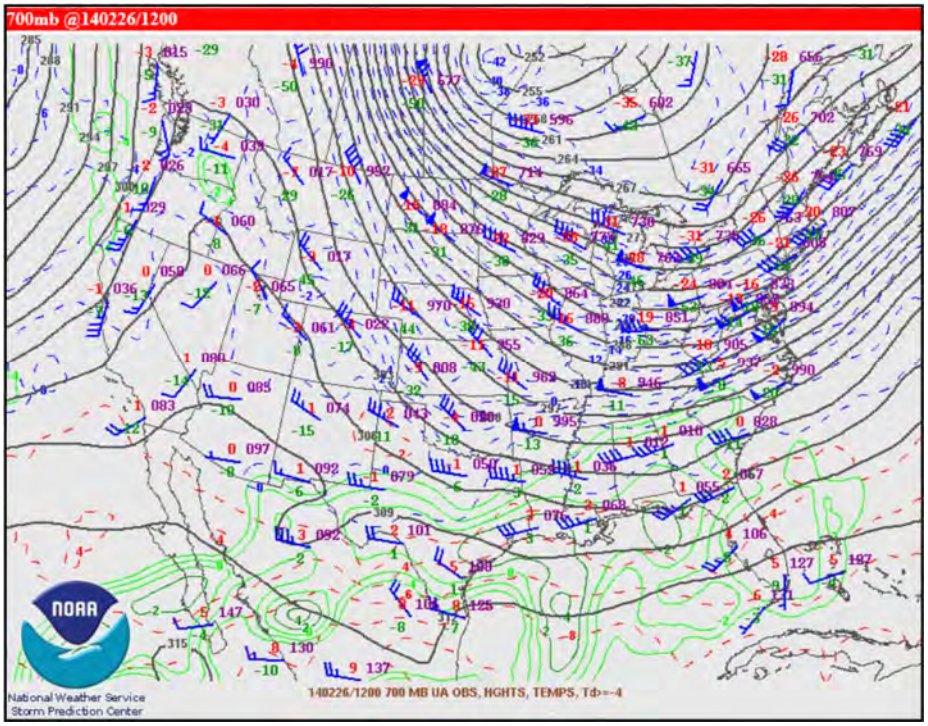


Figure 2.21 700 mb Level Chart at 0500 MST February 26, 2014

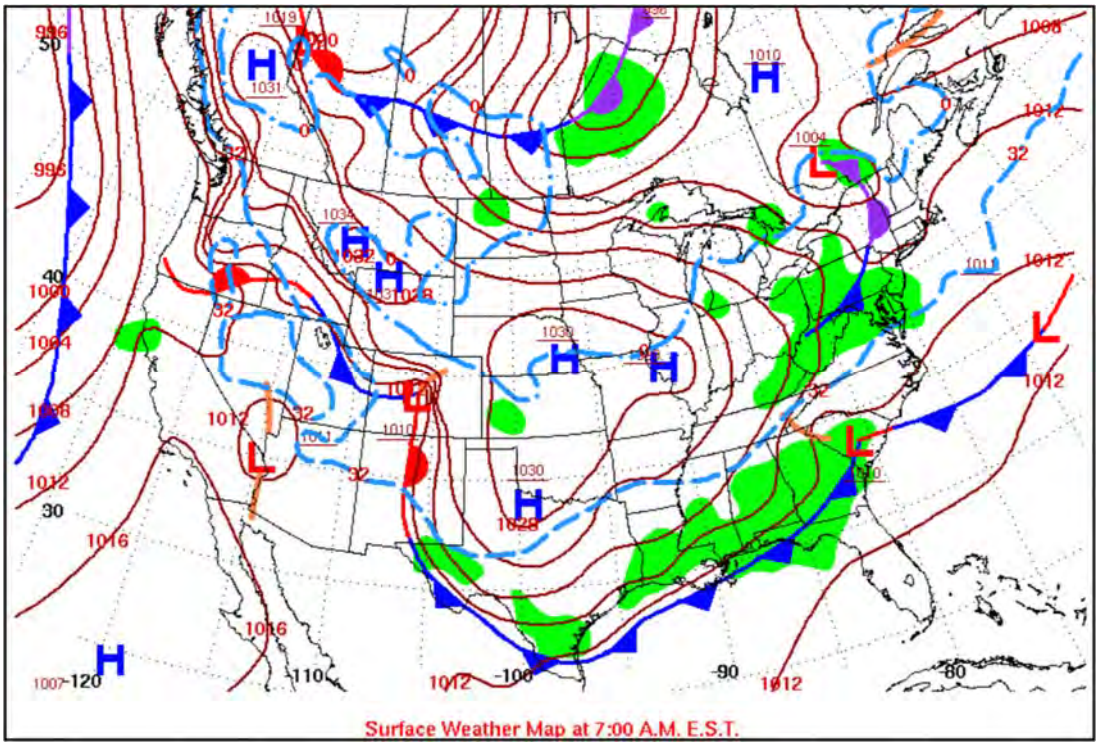


Figure 2.22 Surface Chart at 0500 MST February 26, 2014

March 5, 2014

A ridge of high pressure moved into the Great Basin and Central Rockies with the strongest high pressure over Wyoming around mid-day. This was a relatively weak and short-lived ridge which quickly exited the area as a storm approached the northwest coast late on March 5. At the 700 mb level, the high pressure ridge stretched from Wyoming southwest through Utah, central Nevada and into southern California. The rapidly moving trough of low pressure approaching the northern half of the west coast on March 5 pushed inland early on the March 6. This helped to weaken the ridge and forced the ridge of high pressure to move east of Wyoming. Wind speeds at 700 mb were approximately 5 mps over western Wyoming on the morning of March 5.

Conditions at the surface had high pressure centered over the western part of Wyoming early in the day reaching a MSL pressure of approximately 1022 mb. This high shifted south into southwest Colorado and weakened by early on March 6.

Winds were light at the surface during the sampling period with speeds ranging from 0.5 to 6 mps. Wind directions were generally from the southwest, although the Pinedale area reported a northwesterly direction throughout the sampling period. Temperatures across the study area on March 5 ranged from -11°C to -1°C at 07:00 MST to -5 °C to 4°C by 10:00 MST.

Figure 2.23 presents the 700 mb level chart for the morning of March 5; Figure 2.24 presents the surface weather chart from the morning of March 5.

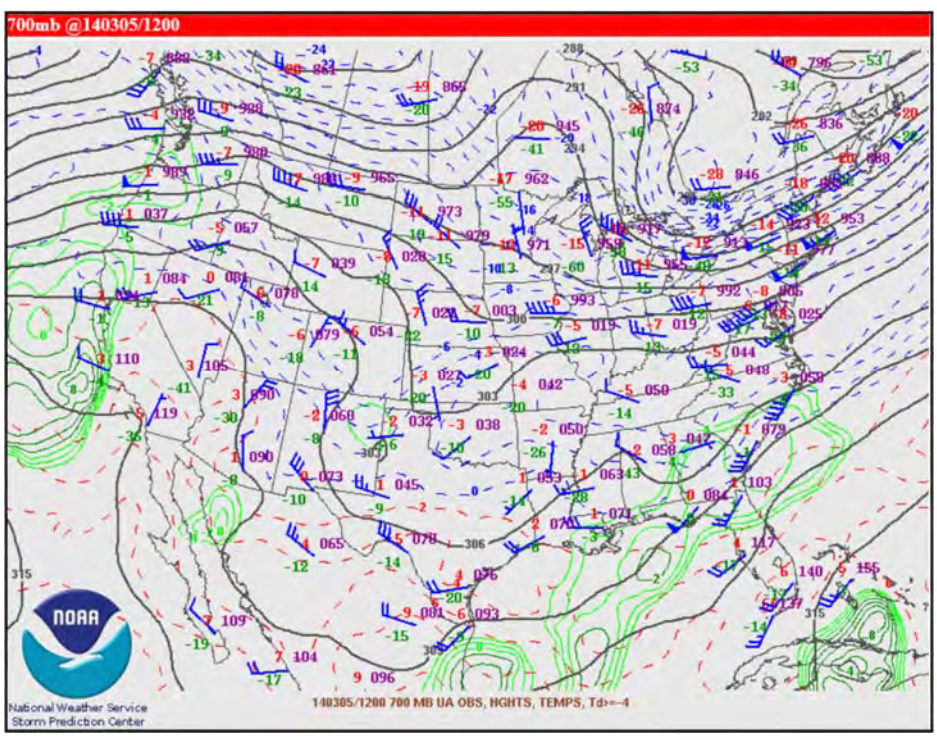


Figure 2.23 700 mb Level Chart at 0500 MST March 5, 2014

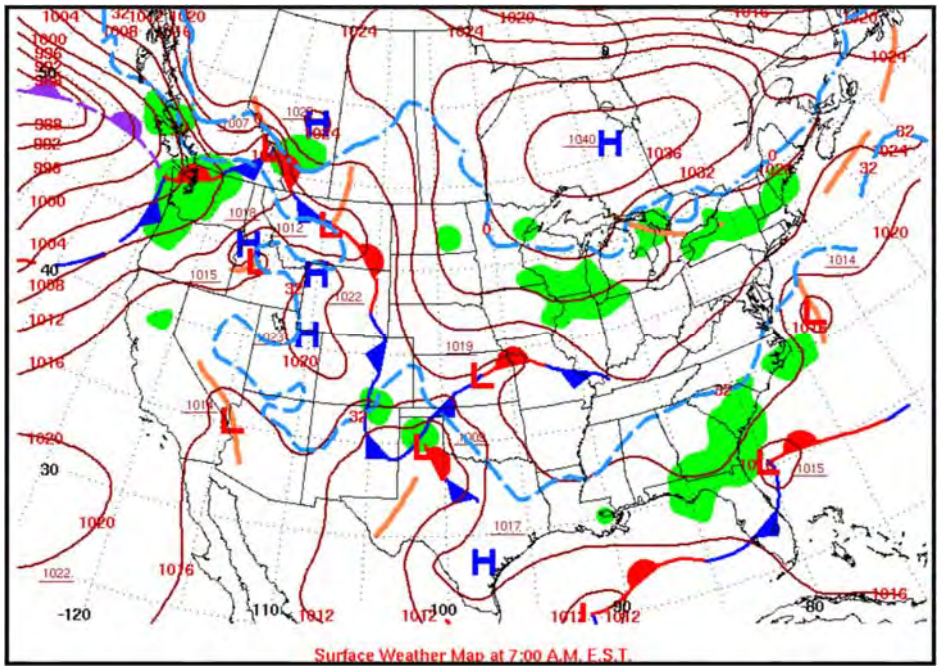


Figure 2.24 Surface Chart at 0500 MST March 5, 2014

March 8-9, 2014

The fourth VOC sampling period occurred on March 8 and 9, 2014. Beginning on March 7, higher pressure began building into Wyoming with a ridge developing that stretched from the northern Rockies southwest into central California. This ridge peaked in strength between the morning of March 8 and the morning of March 9. A storm approaching from the west began weakening the ridge during the day on March 9. At 700 mb, a trough began to move into Wyoming on March 10.

Over western Wyoming westerly winds at 700 mb were present from the morning of March 8 through the afternoon of March 9. Wind speeds at 700 mb on March 8 were less than 3 mps but increased to approximately 18 mps by the morning of March 9 before decreasing to approximately 4 mps the afternoon of March 9. At the surface on March 8, wind speeds were generally out of the northwest and less than 5 mps although some sites had lighter speeds and variable directions that tended to be southerly. Surface high pressure was centered over southwest Montana stretching into Nevada and the MSL pressure was approximately 1026 mb over western Wyoming. Temperatures during the March 8 sampling period ranged from -13°C to -2°C at 07:00 MST to -7°C to +2°C at 10:00 MST. By the morning of March 9, the surface high had settled south into western Colorado although a finger of this higher pressure covered western Wyoming. MSL pressure was approximately 1024 mb over the study area. Morning temperatures during the sampling period on March 9 ranged from -12°C to 0°C at 07:00 MST to -3°C to +4°C by 10:00 MST. Figures 2.25 and 2.26 present the 700 mb and surface weather charts, respectively, for the morning of March 9.

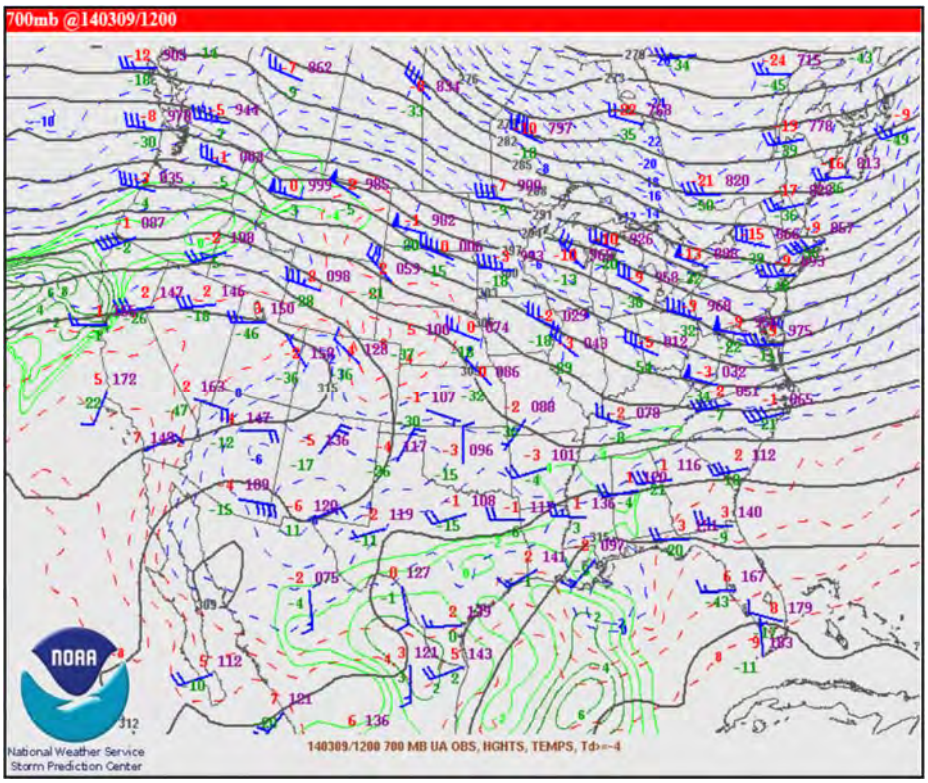


Figure 2.25 700 mb Level Chart at 0500 MST March 9, 2014

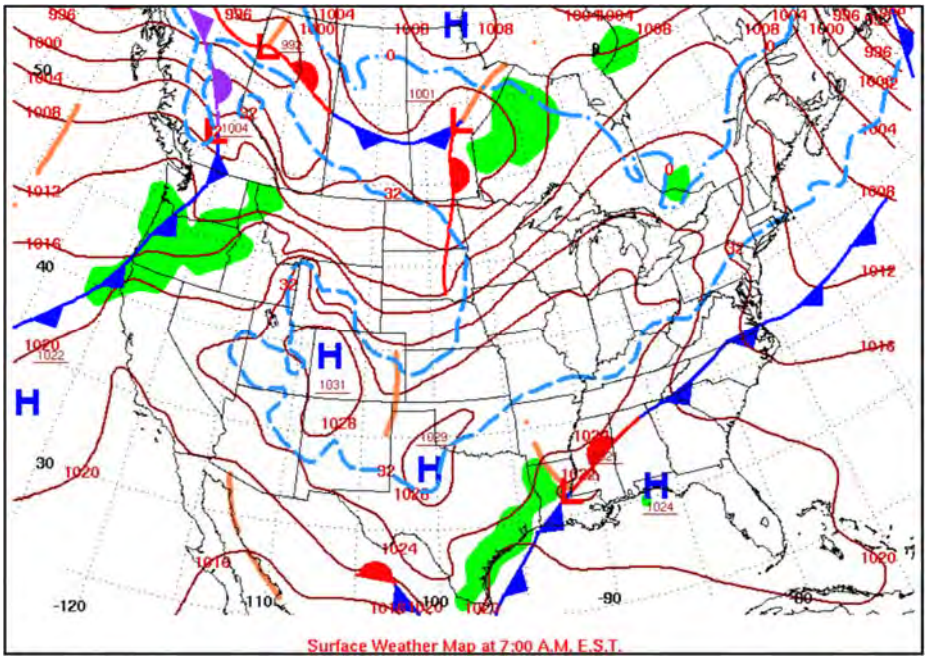


Figure 2.26 Surface Chart at 0500 MST March 9, 2014

March 25, 2014

The final VOC sampling period occurred on March 25, 2014. A high pressure ridge aloft was moving towards Wyoming from the west on March 24. By the morning of March 25, the ridge was just west of Wyoming, stretching from southern British Columbia through Idaho and south into Utah. This ridge pushed through Wyoming during the day. During the morning of March 25, winds at 700 mb were from the west with a speed of approximately 10 mps. Temperature at this level was approximately -2°C.

Conditions at the surface were considerably different than the other sampling days. A strong high pressure system had dropped out of Canada into the Plains states including the eastern parts of Wyoming. Lower pressure covered much of the western US, including western Wyoming. The MSL pressure over the study area was approximately 1020 mb initially during the sampling period but fell through the morning hours. Winds were primarily less than 5 mps and directions were highly variably by location. Temperatures were similar to the other sampling periods with lows ranging from -13°C to 0°C at 07:00 MST to -4°C to 6°C by 10:00 MST. Figure 2.27 presents the 700 mb weather chart for the morning of March 25. Figure 2.28 presents the surface weather chart for the morning of March 25.

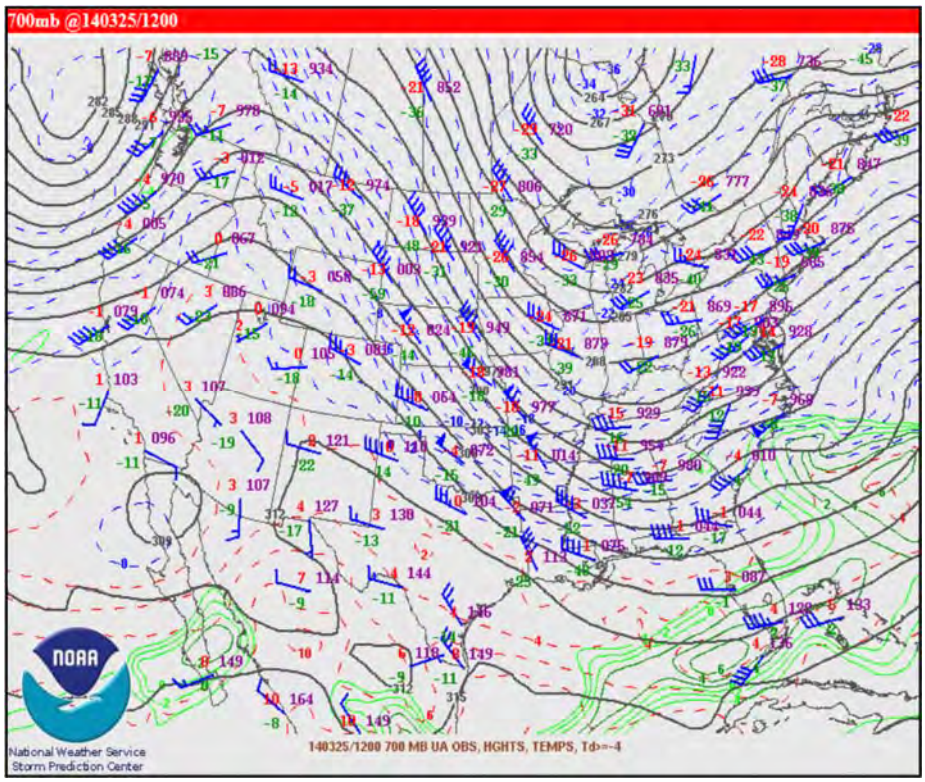


Figure 2.27 700 mb Level Chart at 0500 MST March 25, 2014

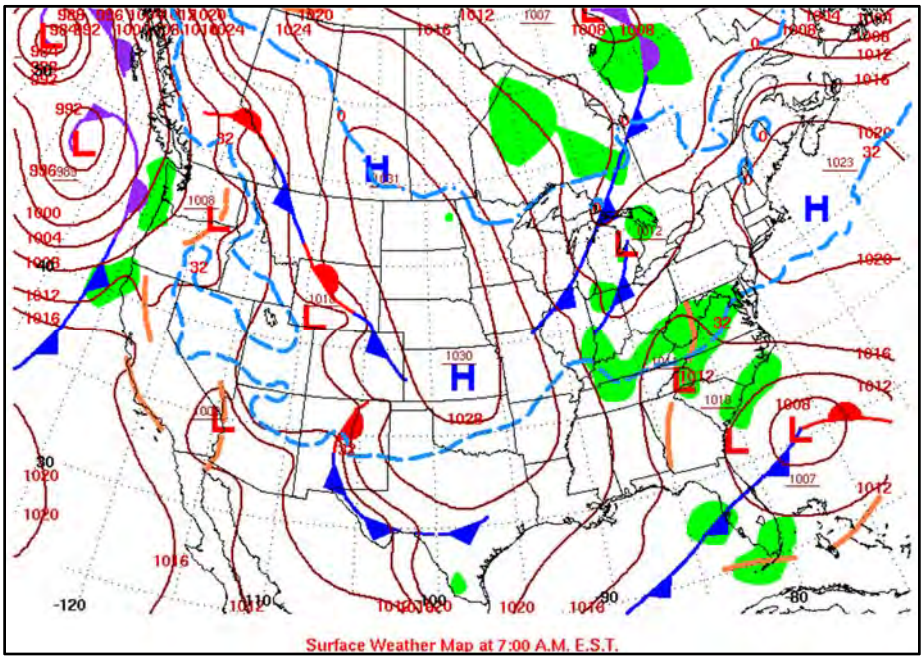


Figure 2.28 Surface Chart at 0500 MST March 25, 2014

3.0 DATA QUALITY ASSURANCE, VALIDATION, AND ARCHIVING

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

3.1 Database Management

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

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

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

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

QC	Description
V	Valid Data
M	Missing Data
I	Invalid Data
S	Suspect Data. Data appears to be a data spike or outside normal data range
U	Data which has not been validated - User is responsible for validation.
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
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

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

QC	Description
B	Below Detection Limit
DA	Aberrant Data (Corrupt Files, Spikes, Shifts)

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

3.2 Quality Assurance Program

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

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

All UGWOS equipment underwent a complete checkout and acceptance prior to the start of monitoring. Standard Operating Procedures (SOPs) for measurements were completed prior to the start of monitoring.

All UGWOS 2014 ozone and oxides of nitrogen analyzers were routinely checked using a traceable transfer standard or reference gas following operating procedures consistent with EPA guidelines. Ozone transfer standards (Level 3) were verified prior to the start of the program and again at the end by checks against a primary (Level 2) ozone standard maintained at MSI Trinity's instrumentation laboratory in Salt Lake City. MSI Trinity's Level 2 ozone standard was last verified to a standard reference photometer (Level 1) by USEPA Region 8 on December 9, 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 Trinity were retrieved remotely at least every 15 minutes. Data from other sites in the UGRB were retrieved hourly. Data updates were posted on the UGWOS website immediately after retrieval and were available to project participants. Data from all sites in the project area were reviewed and inspected daily to confirm normal operation and identify outliers or indications that instrumentation needed attention or repair. MSI Trinity'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.

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

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

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

Table 3-2 Method TO-14 DHA Compound List

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

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

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

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

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

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

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

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

Table 3-3 Method TO-11 HPLC Compound List

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

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

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

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

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

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

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. Temperatures were calibrated using water/ice baths.

Air quality analyzers were calibrated at the start of the UGWOS 2014 study and calibration was verified again at the end. Zero/span/precision 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 1003 PC Level 3 ozone standard that is certified against T&B Systems' Level 2 standard following EPA's guidelines. The Model 1003 PC is an ozone photometer equipped with self-contained zero air and ozone generation and was certified at T&B Systems' instrumentation laboratory in Valencia, CA on January 21, 2014. T&B System's Level 2 ozone standard was last verified to a standard reference photometer (Level 1) by EPA Region 9 on December 22, 2013. For the mesonet audits, the Dasibi Model 1003 PC was operated within the SUV used during the audit. The unit 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 liters per minute (lpm), minimizing residence time within the line.

Gaseous analyzers at the UGWOS Jonah site were audited by WDEQ staff using an Advanced Pollution Instruments (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 API calibrator is also equipped with an integrated photometer which was used as an ozone transfer standard. The API photometer is certified annually against a Standard Reference Photometer (SRP) maintained by EPA Region 8.

Wind speed sensors were audited using an RM 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 RM 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° and 30°C.

Mesonet ozone audit results are summarized in Table 3-5. Note that site readings consist of 5-minute averaged "adjusted" values which take into account results from the most recent performance checks conducted by MSI Trinity. All of the results showed agreement within about 4%, easily meeting the audit criteria of ±10%. Audits of the mesonet meteorological systems revealed that all wind and temperature sensors were operating correctly.

Table 3-5 Mesonet Ozone and Meteorology Audit Results Summary

Site	Date	Max diff (%)	Slope	Intercept (ppm)	Correl
Warbonnet	2/5/2014	2.8	1.0231	0.0000	0.9999
Mesa	2/5/2014	4.5	1.0422	-0.0005	0.9998
Paradise	2/5/2014	3.3	1.0278	0.0004	0.9999

Site	Date	Parameter	Max diff
Warbonnet	2/5/2014	Wind Speed	0.0 m/s
		Wind Direction	-4°
		Ambient Temp.	-0.7°C
Mesa	2/5/2014	Wind Speed	0.0 m/s
		Wind Direction	-2°
		Ambient Temp.	-0.6°C
Paradise	2/5/2014	Wind Speed	0.0 m/s
		Wind Direction	-3°
		Ambient Temp.	-0.6°C

All special study gaseous analyzers at the Jonah Field site trailer easily met the audit criteria, and audits of the meteorological systems at the Jonah site revealed that all wind and temperature sensors were operating correctly. Results of the audit of the gaseous analyzers are presented in Table 3-6.

Table 3-6 Jonah Field Air Quality and Meteorology Audit Results Summary

Site	Date	Parameter	Max diff (%)	Slope	Intercept (ppm)	Correl
Jonah Field	2/5/2014	O_3	-4.3	0.974	-0.001	1.0000
	2/5/2014	NO	10.0	1.062	0.001	0.9998
	2/5/2014	NO_2	3.6	1.044	-0.001	1.0000
	2/5/2014	NO_X	10.0	1.061	0.000	0.9996

Site	Date	Parameter	Max diff
Jonah Field	2/5/2014	Wind Speed	-0.9%
		Wind Direction	2°
		Ambient Temp.	-0.1°C

Tethered Ozonesondes

MSI Trinity personnel were requested to activate an ozonesonde, which was then challenged with ozone concentrations from the audit standard. MSI Trinity then processed the resulting data into files containing concentrations in ppb, which were then reviewed by the auditors. The audit of the MSI Trinity ozonesonde was performed at the Jonah Field site trailer on February 5, 2014 using a Dasibi 1003-PC Level 3 ozone standard. No problems were noted with the setup procedures or the performance evaluation of the ozonesonde. The T&B Systems ozonesonde was verified at the T&B Systems office in Valencia, CA prior to the deployment of the equipment to the UGWOS study area. The verification used an API Model 401 Level 2 photometer. Tethered ozonesonde audit results are summarized in Table 3-7. The audits of these systems revealed no problems.

Table 3-7 Tethered Ozonesonde Audit Results Summary

Ozonesonde S/N	Date	Max diff (%)	Slope	Intercept (ppm)	Correl
MSI-2Z23581	2/5/2014	3.4	1.0351	-0.0016	0.9998
T&B-2Z0664	1/7/2014	-2.5	0.9736	0.0009	0.9998

3.2.2.2 System Audits

A system audit of the field operations was conducted in February 2014 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.

Tethered Ozonesondes

The overall care in the preparation of the sondes appeared to be good. No problems were observed during the preparation process.

MiniSODAR™

The miniSODAR™ has been operational within the UGWOS study area for over four years with good data recovery. Prior to arrival at the Boulder 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_3, NO, NO_2, NO_x, NO_y, and SO_2
- Micrograms per cubic meter for PM_{10} and $PM_{2.5}$
- Parts per million for methane, non-methane hydrocarbons, and total hydrocarbons
- Micrograms per cubic meter, parts per billion by volume, and parts per billion by Carbon for VOC data
- SITE = Alpha-numeric site code identifier
- DATE = (MM/DD/YYYY)
- HOUR= Nearest whole begin hour (HH) (MST)

- TIME = Time stamp of data (HHMM) (MST)
- HEIGHT/LEVEL = 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 2014 field effort.

4.1 Summary of 2014 Meteorological and Air Quality Conditions and Comparison with Prior Years

This section describes meteorological and air quality conditions and measurements recorded during UGWOS 2014 and compares the results to previous UGWOS studies.

4.1.1 700 mb Comparison 2014 versus 2007-2013

2014 is the eighth consecutive winter season that the WDEQ has sponsored the UGWOS project. A comparison of the 700 mb pressure level data during the 2014 UGWOS study with the previous seven study periods is provided below.

Prior to 2007, a study of weather conditions during periods when ozone was elevated at monitoring stations in and near the UGRB was conducted. From this study, a list of objective criteria for forecasting these elevated ozone episodes 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:

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

Averages developed from the 700 mb level parameters for 2014 do not indicate any times when the 700 mb height was at or above 3,060 meters. Figure 4.1 presents 700 mb averages for 2014 and past UGWOS study periods (January 15 through March 31) as well as the average of the seven prior years. Earlier reports used a period covering only February and March to produce these averages.

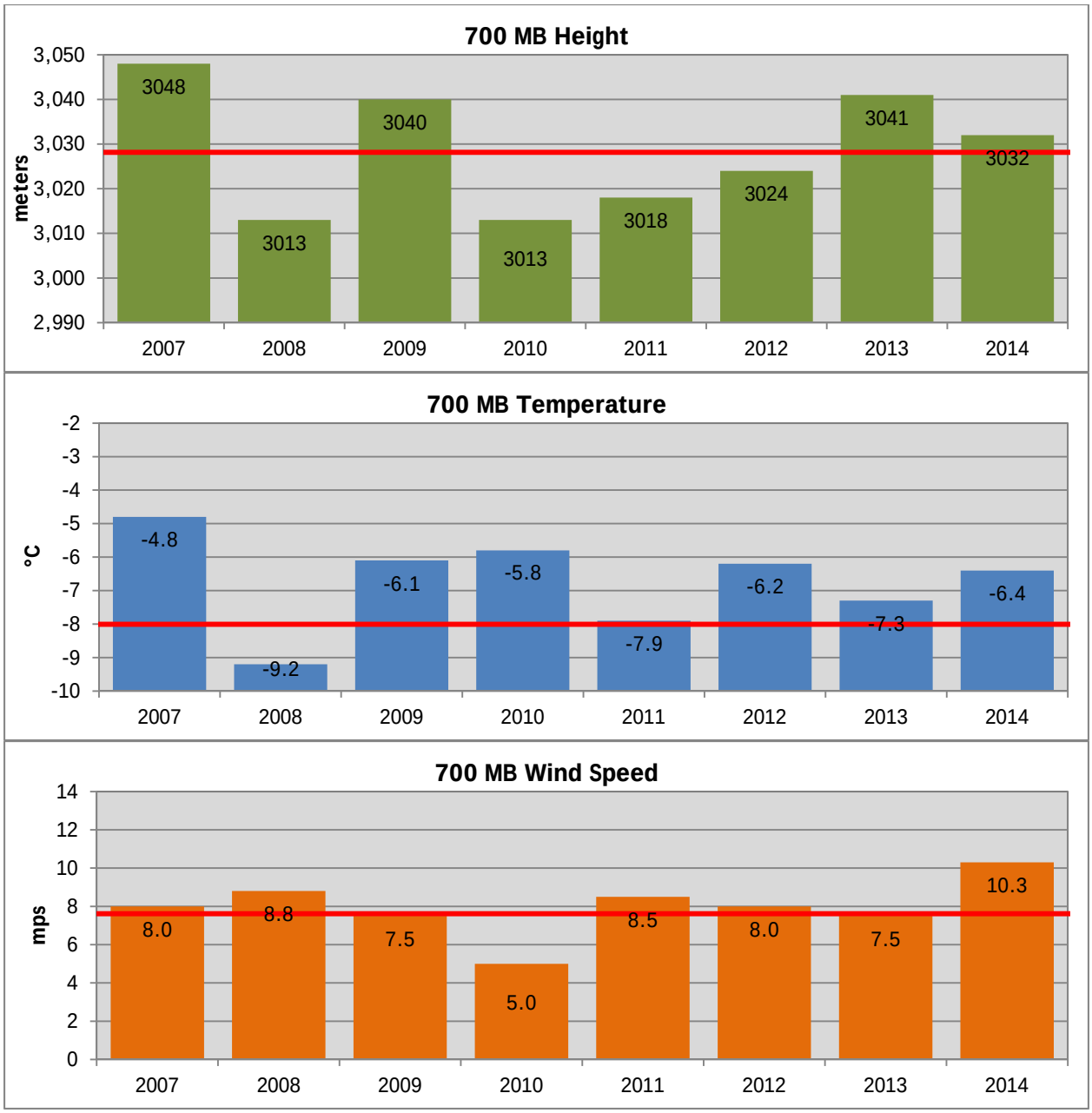


Figure 4.1 700 mb Averages for 2007-2014

During the 2007 through 2014 UGWOS study periods, there were a total of forty-one days when IOPs occurred. Three of these years, 2010, 2013, and 2014 had no declared IOPs. Six out of the eight years had no eight-hour ambient ozone concentrations above 75 ppb. The highest eight-hour ozone concentration was 65 ppb during UGWOS 2014 with a 60 ppb eight-hour period reported as well. Table 4-1 provides the IOP information for each of the project years.

Table 4-1 Intensive Operational Periods by Year

Year	Number of IOPs	Number of IOP Days	Number of Sites with 8-hour Ozone > 75 ppb	IOP dates
2007	1	6	0	March 14-19
2008	3	10	5	February 18 - 21 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	--
2014	0	0	0	--
Total	15	41	--	--

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

For 2014, WDEQ designated six sample dates (January 24, February 26, March 5, March 8, March 9, and March 25) when VOC canister sampling would occur. These days were chosen when high pressure, light winds, and sunny skies were expected. Reanalysis data were also examined for these sample days and found the 700 mb level to have an average height of 3,110 meters, an average temperature of -3.5°C, and an average wind speed of 7.0 mps.

With no IOP days forecast, analysis of the six VOC sampling days were found to meet or exceed the forecast criteria set for ozone formation. Without significant ozone formation measured in 2014, this suggests that a greater emphasis may be placed on overall snow cover for the basin as being a strong variable for ozone formation.

4.1.2 UGWOS Snow Cover in 2012 through 2014

As has been discussed in past UGWOS reports, 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. The 2014 study had a light snow cover at the beginning of the season on January 15. By the end of the month amounts were similar to what was seen at the snow sticks in the previous 2 years, and the remainder of the winter had snow cover that was similar to or deeper than what it was in both 2012 and 2013. The study period had an active storm track that affected western Wyoming. High pressure did not remain in place for very long at any point in the winter, and this type of weather pattern did not allow stagnant conditions (inversions) to develop over a long enough period of time to accumulate, contain and concentrate the precursors necessary for ozone development. Both 2012 and 2013 saw similar weather patterns to 2014 and elevated ozone failed to develop during those two study periods as well.

Due to the lack of measured snow depth information for the UGRB, UGWOS reports prior to 2013 provided a comparison of estimated snow depths by using data provided by NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) web site[2]. In 2012, both NOHRSC data and the snow stick images were used to estimate snow depths and the datasets agreed fairly well. However, in 2013 the comparison did not correlate well and it was decided to use WAQD's images of the snow sticks located at various monitoring sites in the UGRB to provide snow depth comparisons. With possible unknown and undetected bias in the NOHRSC data the 2014 report will again use these snow stick images for comparison. In particular information from the Boulder monitoring site will be emphasized.

As mentioned above and similar to both 2012 and 2013, the 2014 study period was frequented by weather systems pushing across the west and bringing unstable conditions to western Wyoming. The storm systems that moved across the study area provided periodic light precipitation to the UGRB as recorded by monitoring stations operated by the AQD and the Collaborative Community Rain Hail and Snow Network (CoCoRHaS) which has a station located near Pinedale. Measureable precipitation (snow) occurred within the project area on 40 days during the 2014 study. This is nearly the same as the 41 days in 2013, and represents 53 percent of the study days having at least light precipitation.

The snowpack in 2014 was deeper in general than in 2012 and 2013 for most of the study period. Figure 4.2 shows conditions on January 15 at the Boulder site for 2012 through 2014.

[2] http://www.nohrsc.noaa.gov/interactive NOHRSC Interactive Snow Information data provided by NOAA/NWS, Chanhassen, MN, USA. *Accessed Jan-May 2014.*

Figure 4.2 Boulder Site January 15, 2014 (Top), 2013 (Middle), and 2012 (Bottom)

Table 4-2 shows the days when measureable precipitation fell in the study area during 2014. The heaviest snow in 2014 occurred during the period from February 5 through 10 and during the February 27 through March 7 period. Figure 4.3 shows snow conditions at the Boulder site for 2012 through 2014 at the end of March. Figure 4.4 shows the estimated snow depths at the Boulder monitoring site at the beginning and middle of each month. These depths were taken from 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. In 2014 patchy snow lasted through the end of March on the 31st and is still evident in the image on that day.

Table 4-2 Days with Measureable Snow in the Upper Green River Basin in 2014

January	February	March
23, 27, 29	4, 5-17, 19-23, 25, 27-28	1-4, 6-7, 10-11, 16,18, 26-28, 30-31

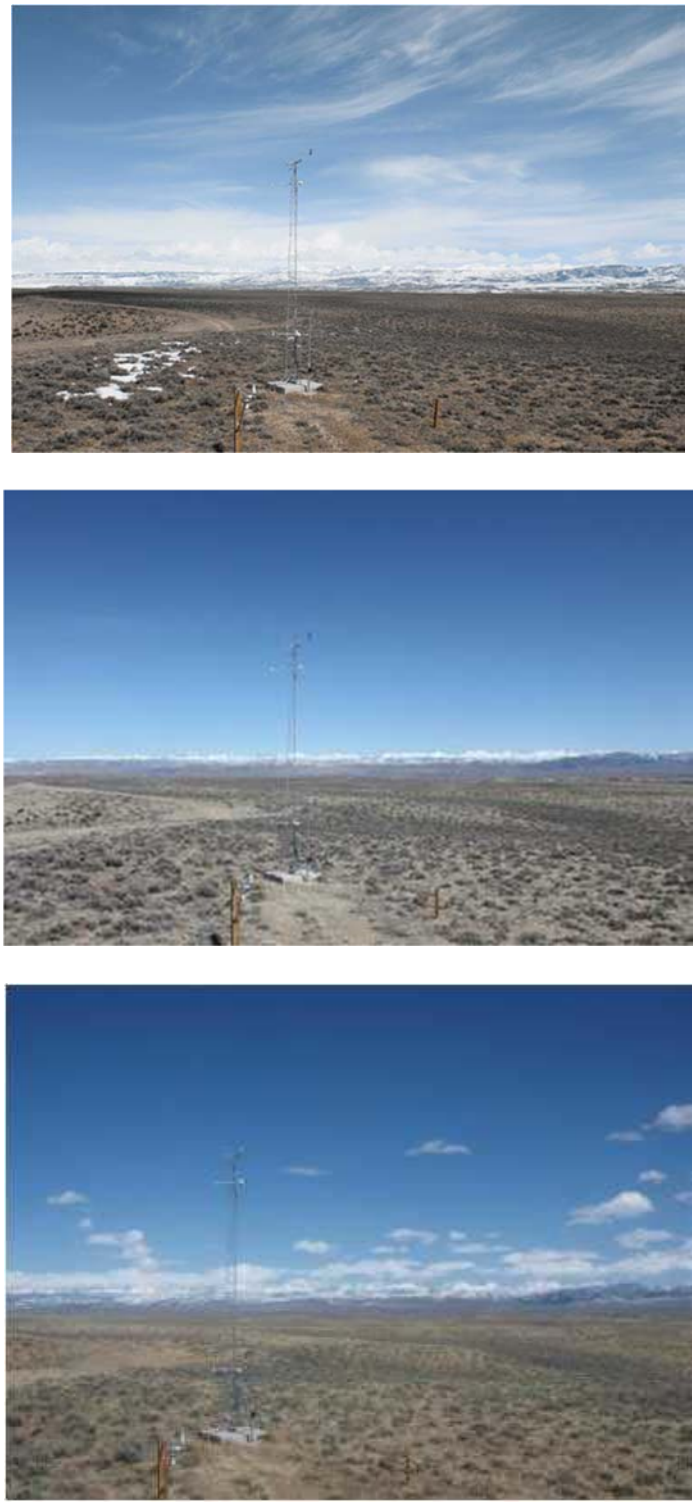


Figure 4.3 Boulder Site Early March 2014 (Top), 2013 (Middle), and 2012 (Bottom)

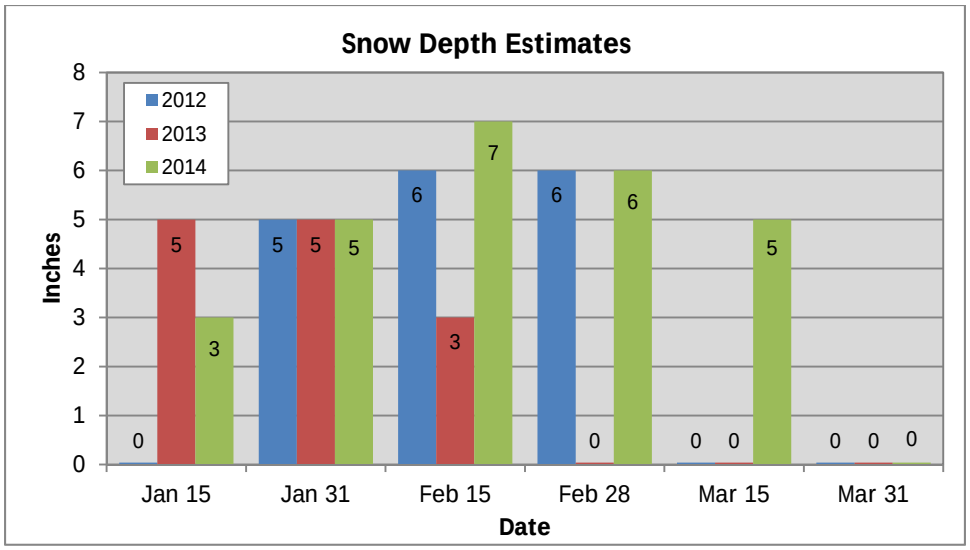


Figure 4.4 Estimated Snow Depth at Boulder Based on Snow Stick Images

4.2 Ozone Spatial and Temporal Distribution

Ozone levels measured during the UGWOS 2014 campaign were low. The highest 8-hour ozone concentration recorded by any of the long-term monitoring sites was 57 ppb, which is well below the U.S. EPA NAAQS of 75 ppb. The second highest 8-hour ozone concentration was 56 ppb and the third highest ozone concentration was 55 ppb. Among the sites that were established and operated specifically for the UGWOS program (hereafter referred to as "mesonet" sites), the highest 8-hour ozone concentration recorded was 65 ppb. The second highest 8-hour ozone concentration recorded by a mesonet site was 60 ppb and the third highest ozone concentration was 57 ppb. The maximum eight-hour and one-hour ozone concentrations at all UGWOS 2014 monitoring sites are presented in Figure 4.5.

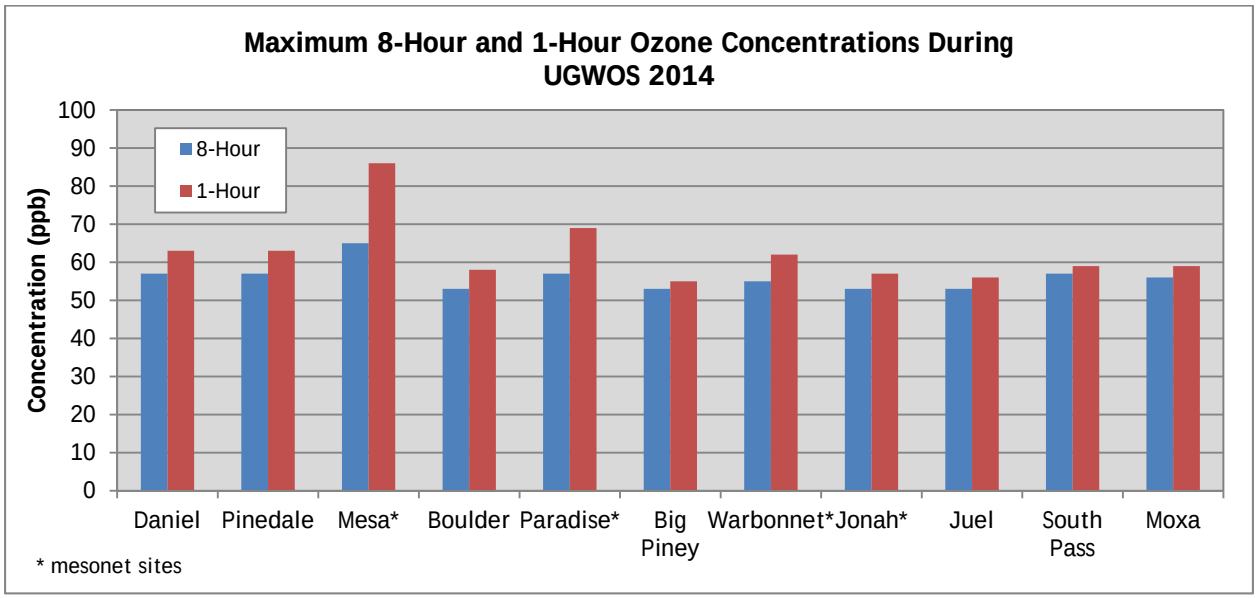


Figure 4.5 Maximum Eight-Hour and One-Hour Average Ozone Concentrations in the UGRB during UGWOS 2014

At an elevation of 2,526 meters, South Pass is approximately 400 meters above the floor of the UGRB and is the highest monitoring site in the study. Ozone levels measured at South Pass were frequently higher and had less variability than those measured at other sites. Its elevation makes it less susceptible to NO_x scavenging and more apt to ventilate with the free atmosphere. Its location at the edge of the study area is less subject to the same air mass as other sites in the study. Thus, South Pass will be omitted from the set of stations studied in this section.

While the Moxa site has a relatively low elevation of 1,919 meters, its location over 60 km to the south of the Juel Spring site is far removed from the central study area. Ozone levels measured at Moxa were often incongruent with those from other sites in the study area, indicating that Moxa was often not sampling the same air mass as other sites in the study area. Thus, Moxa will also be omitted from the set of stations studied in this section.

As seen in previous UGWOS studies, the diurnal distribution of ozone followed a predictable pattern. Ozone concentration minimums often occurred near dawn (07:00 MST), then quickly recover to background levels (35-45 ppb) by noon. Peak ozone concentrations occurred in the early afternoon (13:00 – 15:00 MST), then concentrations slowly decreased during the late afternoon through overnight hours. Figure 4.6 presents the diurnal composite hourly ozone concentrations for all sites during UGWOS 2014. Figure 4.7 presents the running eight-hour average ozone levels for all monitoring sites during UGWOS 2014.

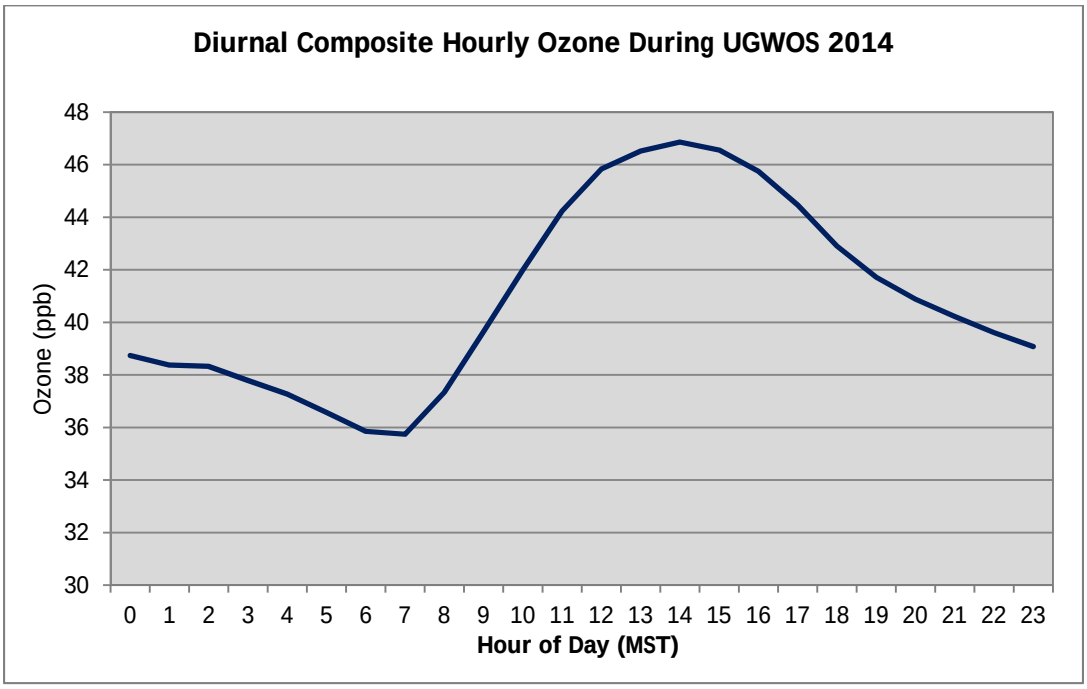
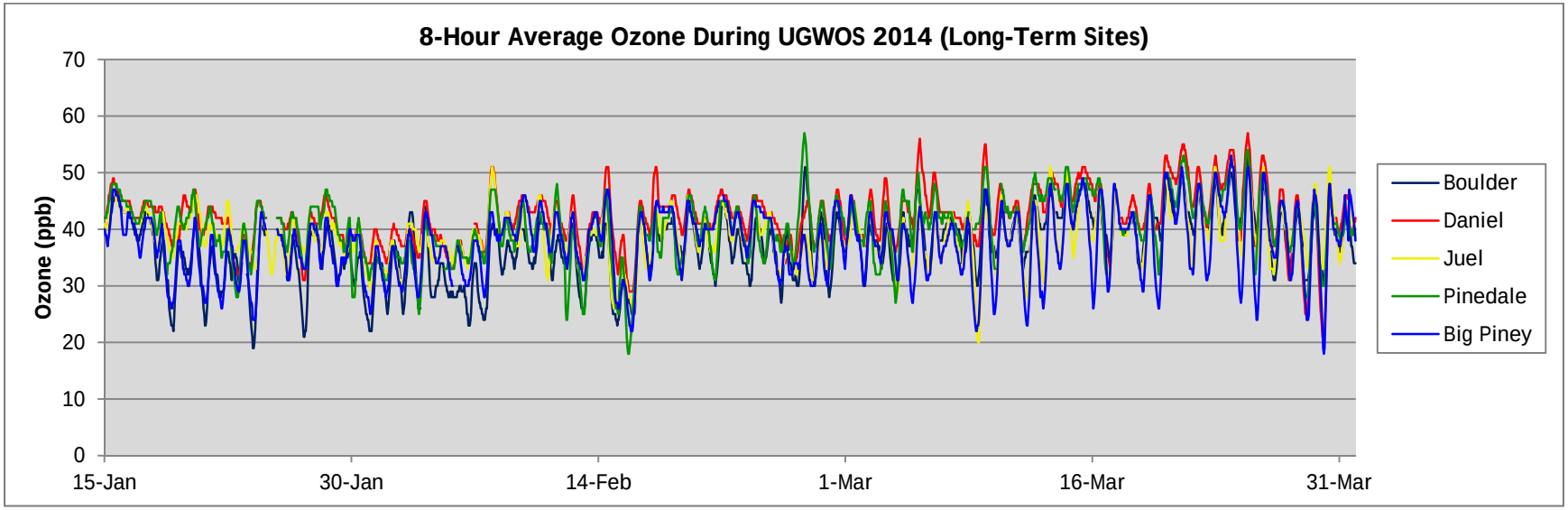


Figure 4.6 Diurnal Composite Hourly Ozone Concentrations for all Sites during UGWOS 2014



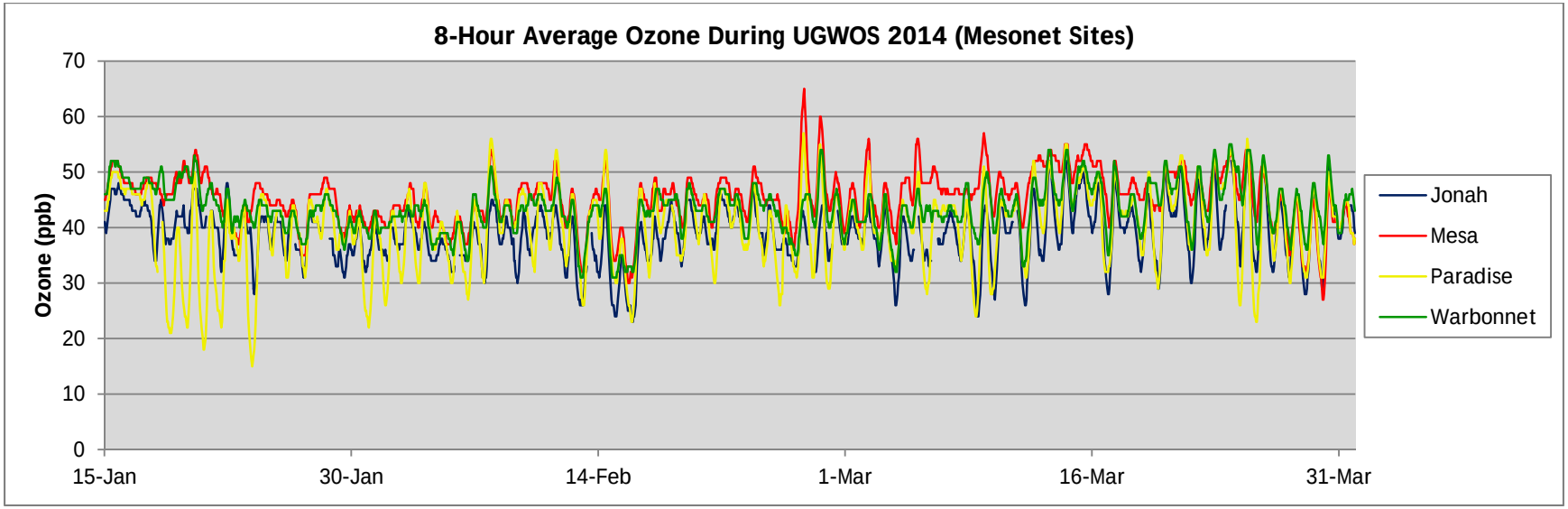


Figure 4.7 Running Eight-Hour Ozone Concentrations during UGWOS 2014

The sites with the highest afternoon ozone concentrations were typically Mesa and Daniel while Boulder, Paradise, Big Piney, and occasionally Jonah typically observed the lowest morning minimum ozone concentrations. NO_x scavenging may contribute to the low morning ozone minimum concentrations at those sites. In previous years, the magnitude of the diurnal ozone cycle increased towards the end of the study period, coincident with higher sun angles and warmer temperatures. This year the increase in the magnitude of the diurnal ozone cycle was modest.

Figure 4.8 presents the daily maximum eight-hour average ozone concentrations for all sites during UGWOS 2014. Mesa and/or Paradise experienced the highest ozone concentrations 80 percent of the time.

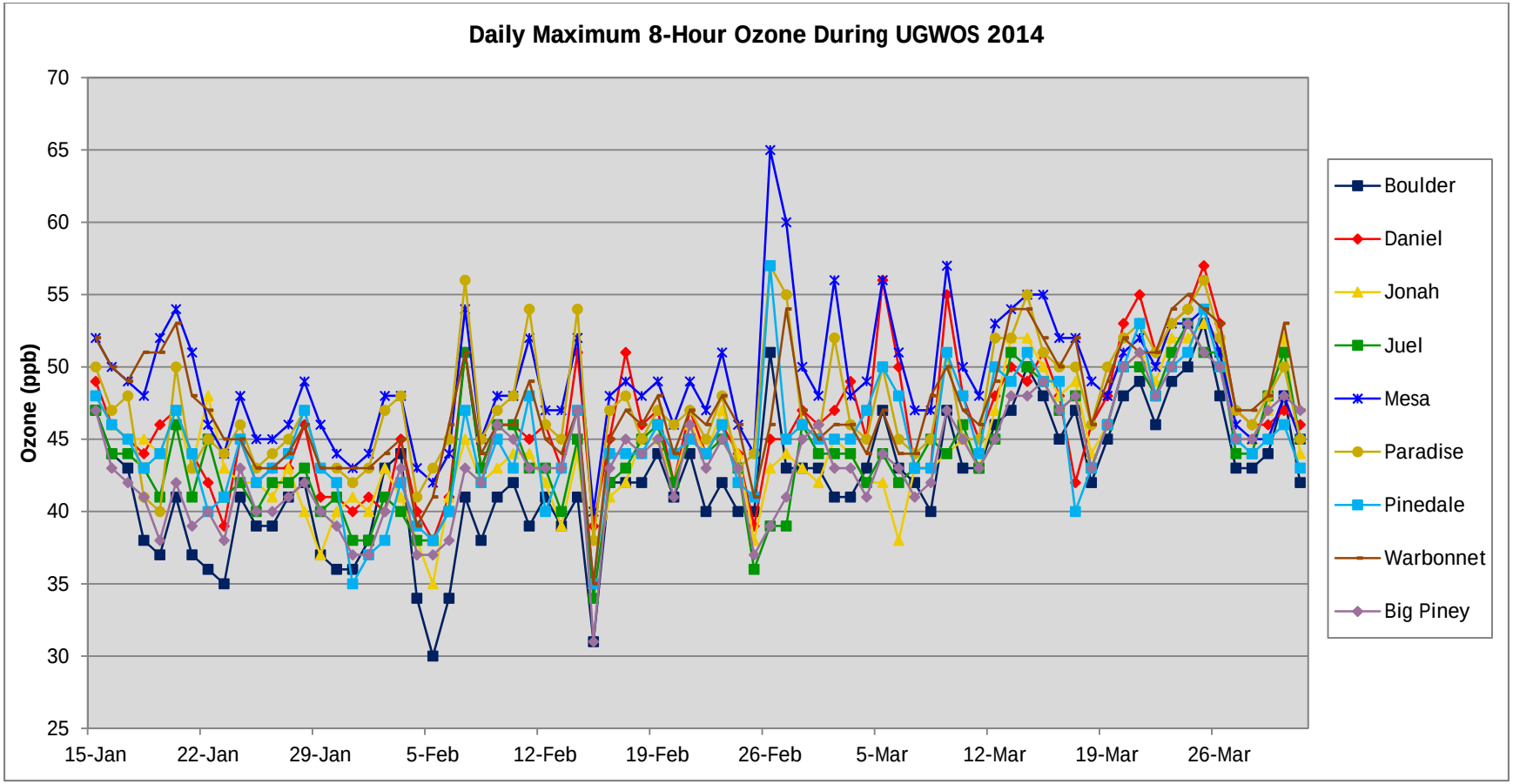


Figure 4.8 Daily Maximum Eight-Hour Ozone Concentrations, UGWOS 2014

Table 4-3 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 4-3 shows that elevated ozone was most commonly observed at Mesa and Paradise.

Table 4-3 Maximum Eight-hour Average Ozone Concentrations (ppb) for Boulder (BD), Daniel (DN), Jonah, Juel Springs (Juel), Mesa, Paradise (PA), Pinedale (PD), Warbonnet (WB), and Big Piney (BP) on Days When at Least One Site Recorded Concentrations > 55 ppb

Station	Boulder	Daniel	Jonah	Juel	Mesa	PA	Pinedale	WB	BP	Network Max
Feb 7	41	51	45	51	54	56	47	51	43	**56**
Feb 26	51	45	43	39	65	57	57	46	39	**65**
Feb 27	43	45	44	39	60	55	45	54	41	**60**
Mar 2	41	47	45	44	56	52	45	46	43	**56**
Mar 5	47	56	42	44	56	50	50	47	44	**56**
Mar 9	47	55	44	44	57	51	51	50	47	**57**
Mar 25	53	57	53	51	54	56	54	54	51	**57**

Values > 55 in Yellow
Values > 60 in Red

4.2.1 Spatial and Temporal Distribution of O_3 during Designated VOC Canister Sampling Periods

There were five designated VOC canister sampling periods (six sample days) during UGWOS 2014: January 24, February 26, March 5, March 8 through March 9, and March 28. VOC canister samples were taken at each mesonet site (Mesa, Warbonnet, and Paradise), at the Jonah Field site, and at the Boulder and Big Piney permanent monitoring 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 24. Mesa observed the highest ozone concentrations, albeit they never rose above 50 ppb. In the morning hours, several sites including Paradise, Boulder, and Big Piney experienced depressed ozone concentrations to varying degrees likely due to NO_x scavenging. Ozone concentrations at higher elevation sites such as Mesa were not depressed during the morning hours. Beyond 14:00 MST, ozone concentrations at all the sites remained clustered between 39 ppb and 48 ppb for the rest of the day. The hourly ozone concentrations for January 24 are presented in Figure 4.9.

The second designated VOC canister sampling period was February 26. Mesa, Paradise, and Pinedale observed elevated afternoon ozone concentrations greater than 55 ppb. Mesa recorded a maximum of 74 ppb for the hour beginning at 15:00 MST, which was the highest ozone reading during any of the VOC canister sampling periods and contributed to the highest 8-hr ozone measurement (65 ppb) of the study. Unlike the first sampling period, morning ozone levels in the UGRB were generally uniform between 30 ppb and 40 ppb with greater variability observed during the afternoon and evening hours. The hourly ozone concentrations for February 26 are presented in Figure 4.10.

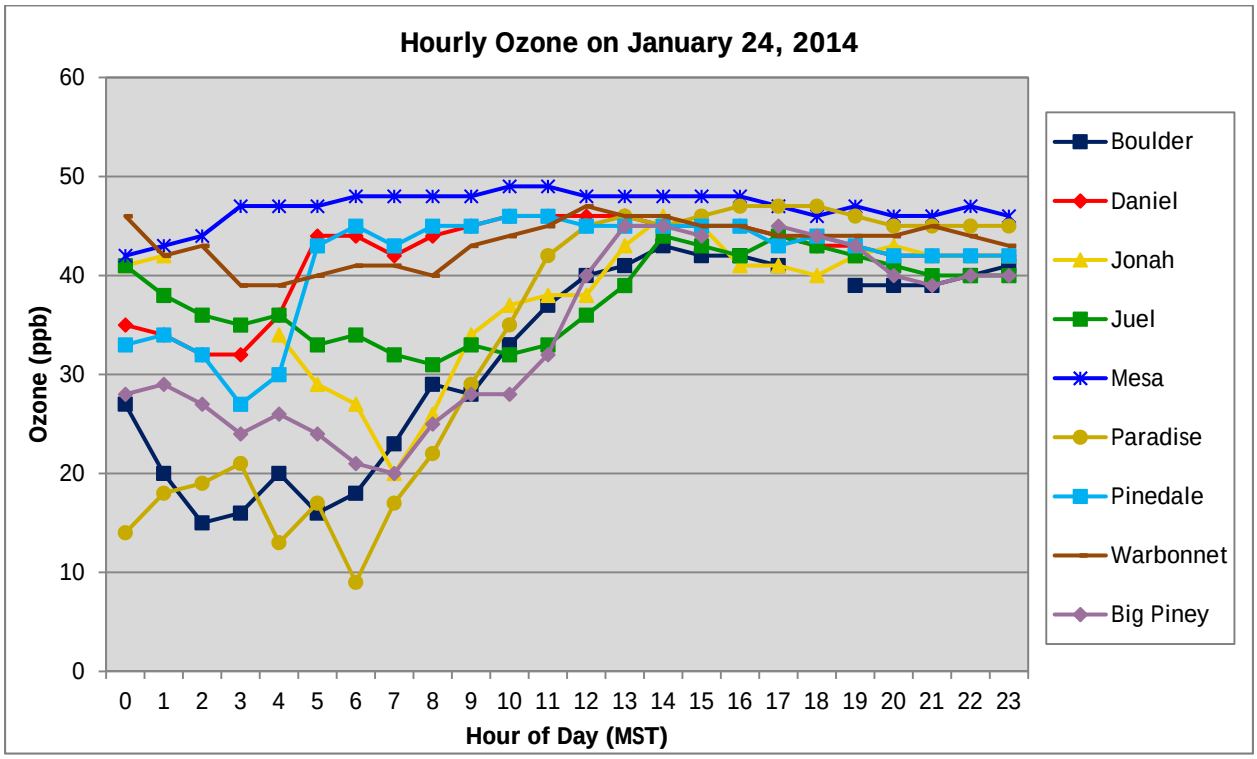


Figure 4.9 One-Hour Average Ozone during Designated VOC Sampling Period 1

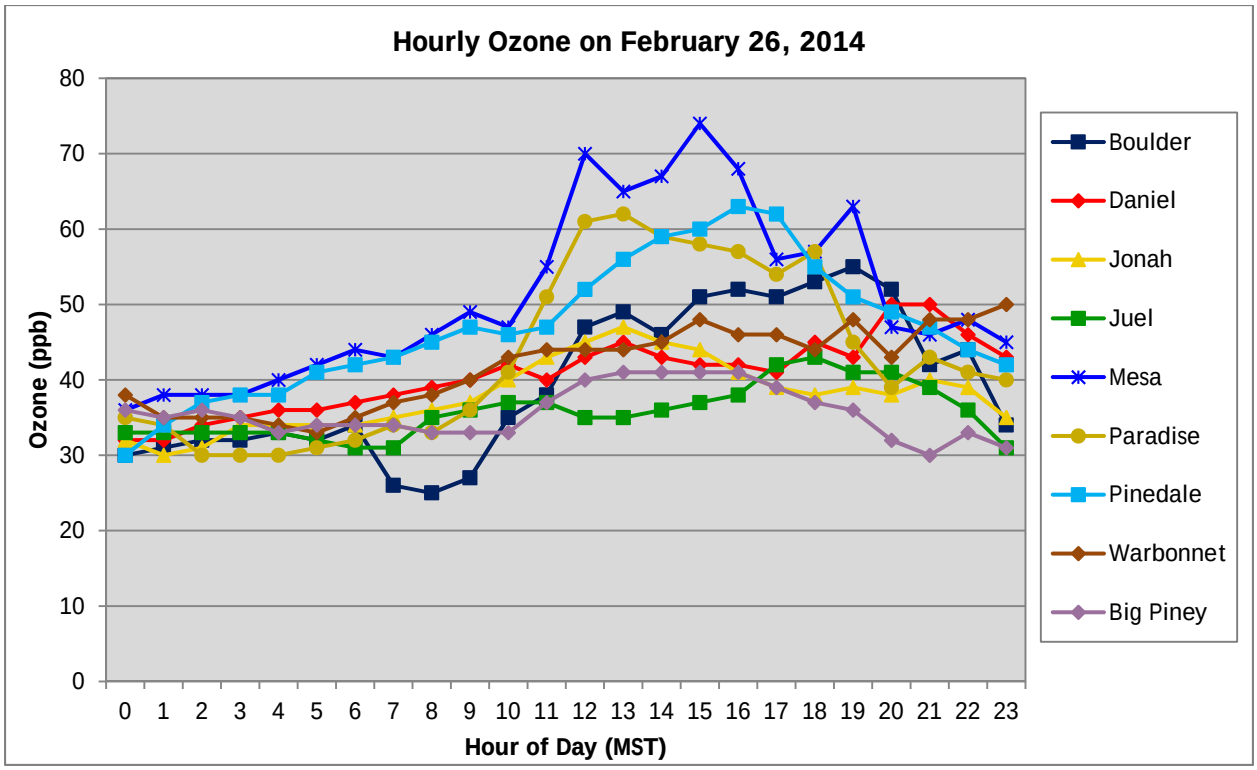


Figure 4.10 One-Hour Average Ozone during Designated VOC Sampling Period 2

The third designated VOC sampling period occurred on March 5. Mesa, Daniel, Paradise, and Pinedale observed elevated afternoon ozone concentrations above 55 ppb. Mesa once again recorded the highest ozone concentration of 64 ppb for the hour beginning at 13:00 MST. Ozone levels varied by about 20 ppb throughout the course of the day with the most elevated readings between 10:00 MST and 15:00 MST. The hourly ozone concentrations for March 5 are presented in Figure 4.11.

The fourth designated VOC sampling period occurred March 8 to March 9. With the exception of Warbonnet, ozone concentrations on March 8 remained below 50 ppb in the UGRB. Ozone levels at Warbonnet were largely below 50 ppb with the exception of the hours beginning at 11:00 and 12:00 MST, measuring concentrations of 58 and 56 ppb, respectively. Morning ozone levels on March 8 varied widely ranging between 25 ppb and 47 ppb with high-elevation sites like Mesa recording the highest and most steady ozone concentrations and low-elevation sites recording the lowest and most variable ozone concentrations. Ozone levels during the overnight hours between March 8 and March 9 were even more varied ranging between 10 and 50 ppb with the same characteristic high elevation/high ozone and low elevation/low ozone pattern discussed previously. On March 9, Mesa and Daniel recorded elevated ozone levels of 62 ppb and 61 ppb, respectively. The hourly ozone concentrations for March 8 and March 9 are presented in Figure 4.12.

The fifth and final designated VOC sampling period occurred March 25. Ozone levels did not exceed 59 ppb the entire day. Morning ozone concentrations prior to 8:00 MST and evening ozone concentrations after 17:00 MST varied widely with low-elevation sites like Paradise and Big Piney recording the lowest ozone levels. The hourly ozone concentrations for March 25 are presented in Figure 4.13.

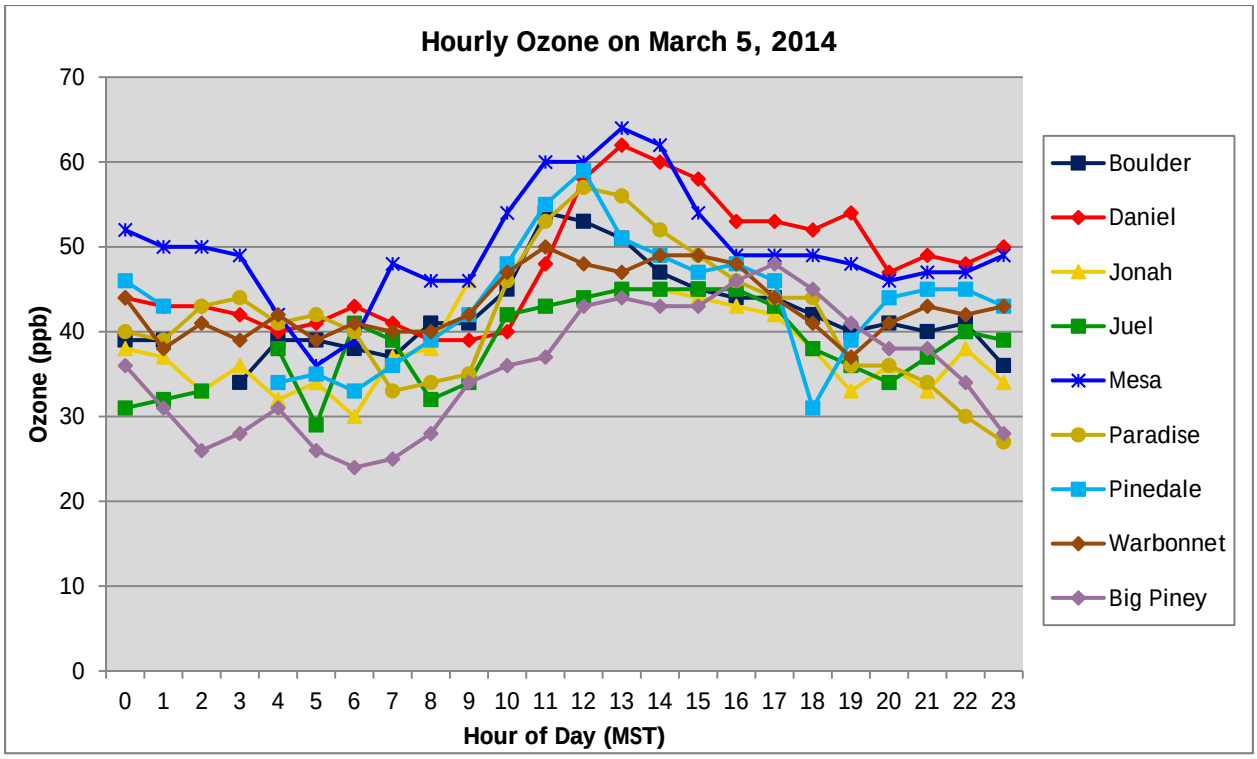


Figure 4.11 One-Hour Average Ozone during Designated VOC Sampling Period 3

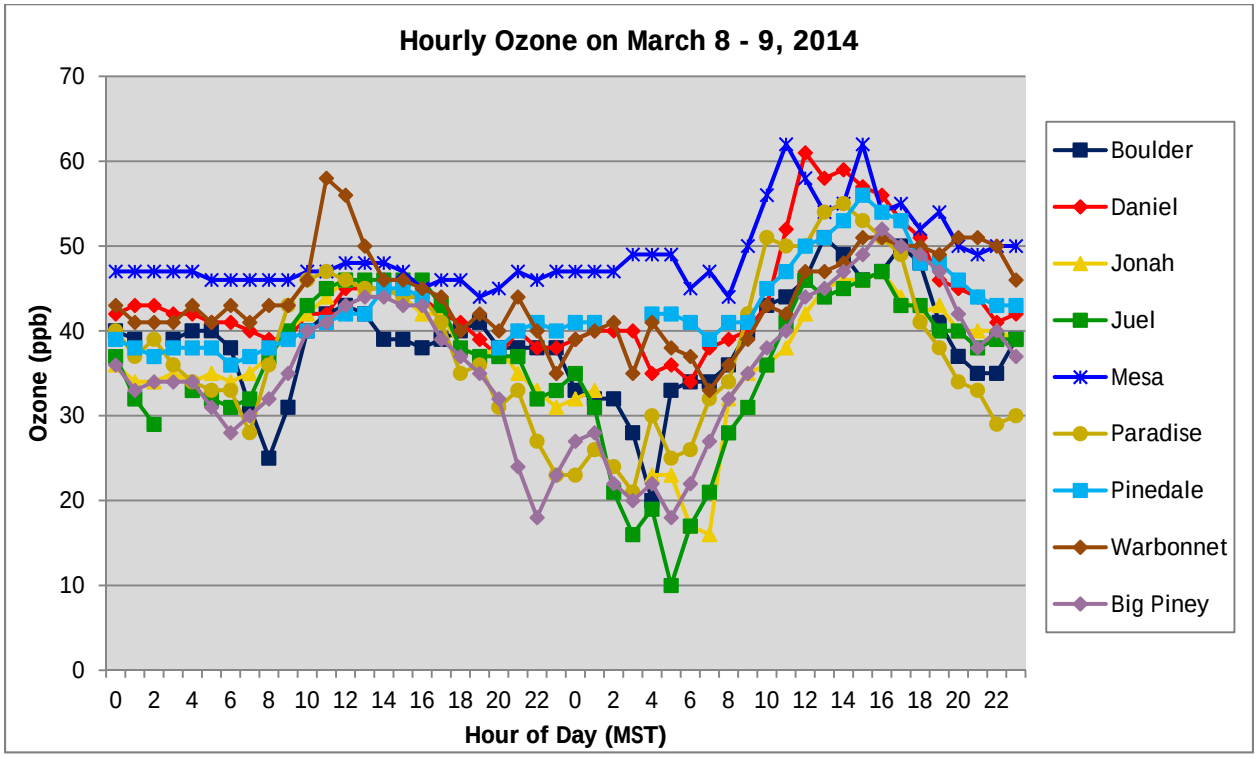


Figure 4.12 One-Hour Average Ozone during Designated VOC Sampling Period 4

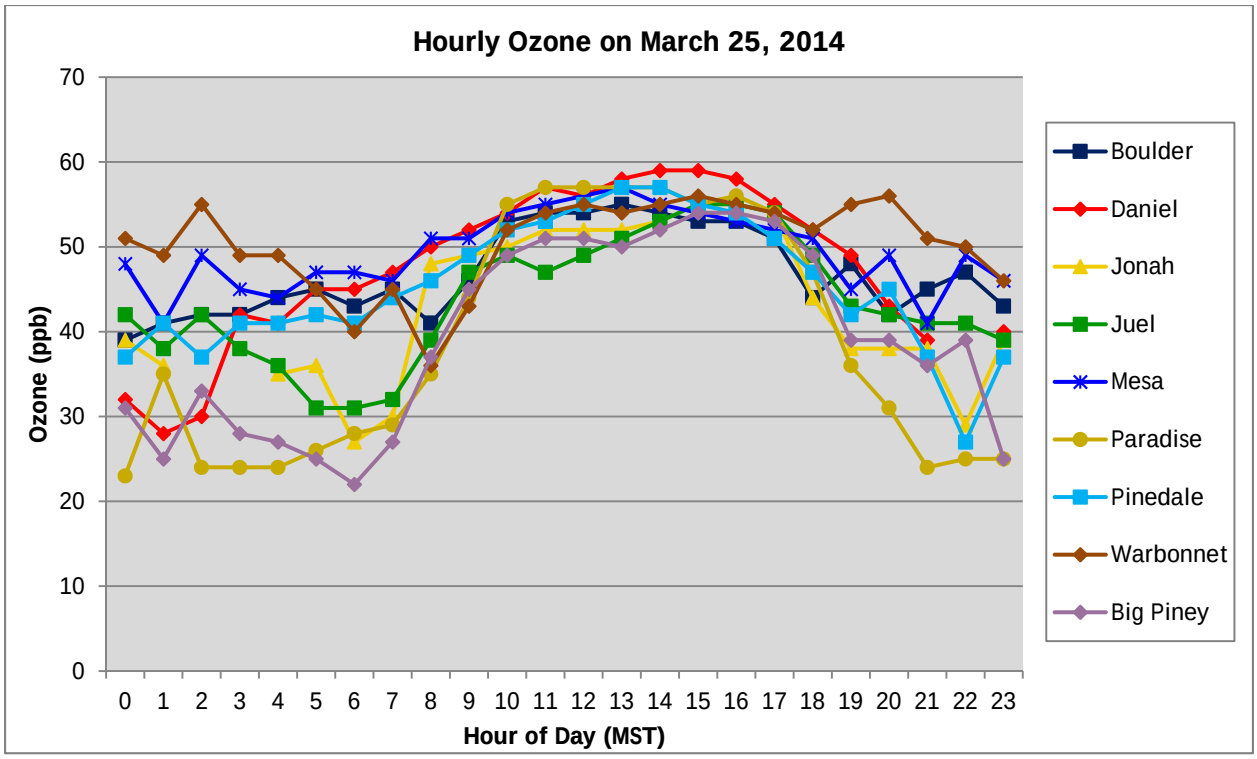


Figure 4.13 One-Hour Average Ozone during Designated VOC Sampling Period 5

Mesa consistently recorded the highest ozone concentrations in the UGRB during designated VOC sampling periods. Other sites that recorded elevated ozone levels include Daniel, Paradise, Warbonnet, and Pinedale. Nocturnal NO_x scavenging was evident during each of the sample periods and appears to have the greatest impact on sites that are low in elevation and close to NO_x sources.

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

There were five VOC sampling periods during UGWOS 2014. This section will focus on the wind patterns that occurred at sites that observed elevated ozone during these periods. Since there was no elevated ozone observed during the first and fifth sampling periods, only the second, third, and fourth 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 meters per second.

The wind at Mesa and Pinedale was generally from the northwest until the late morning of the second VOC sampling period (February 26), during which time the ozone concentrations were slowly rising. Afterward, the wind reversed to the southeast and the highest ozone concentrations of the day were recorded. Beyond the late afternoon, the wind shifted back to northwesterly or northerly during which time ozone concentrations fell. This wind pattern is characteristic of elevated ozone episodes observed at Boulder and Jonah in past UGWOS campaigns. The wind at Paradise during the February 26 VOC sampling period was light and variable and did not follow the characteristic pattern discussed above. Hourly wind and ozone data for Mesa, Pinedale and Paradise during the second sampling period are represented in Figure 4.14.

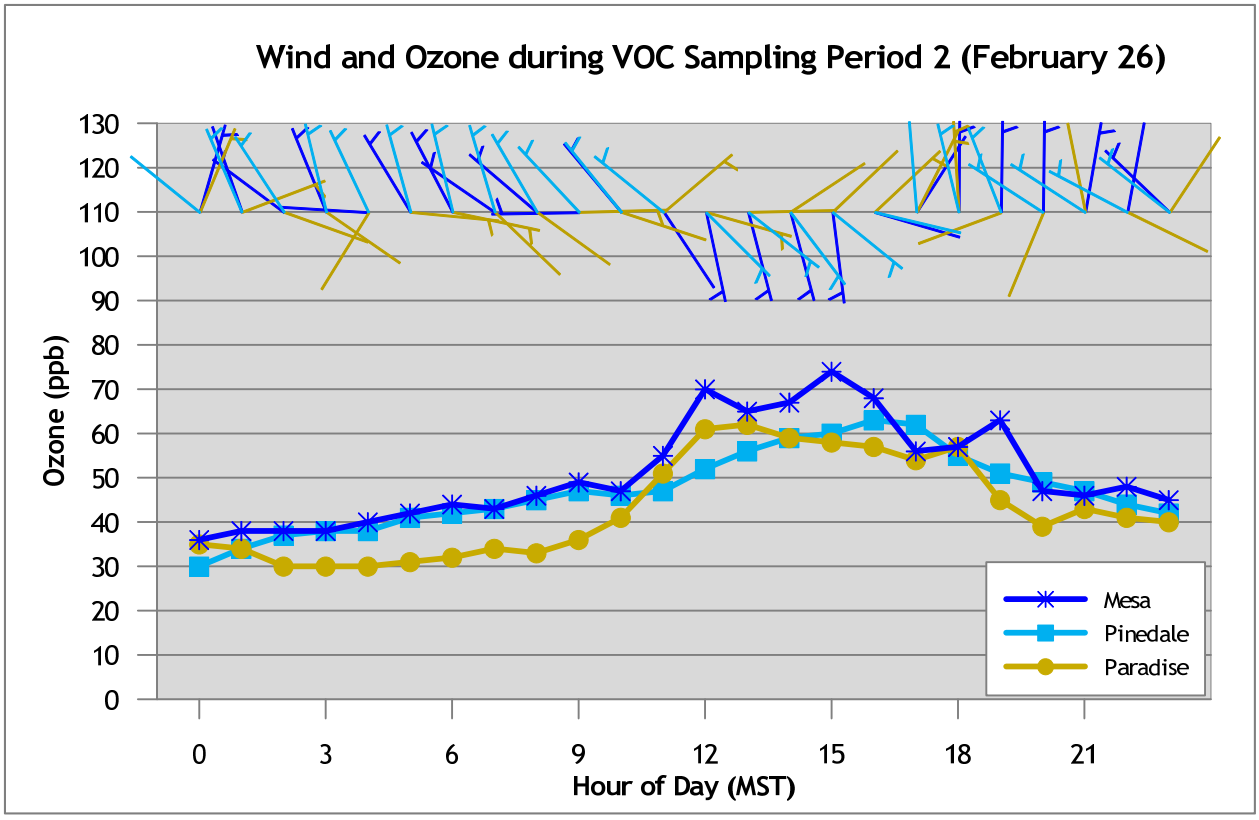


Figure 4.14 One-Hour Average Ozone and Wind at Mesa, Pinedale, and Paradise during VOC Sampling Period 2

The wind during the morning hours of the third VOC sampling period (March 5) was light and varied greatly in direction, although it slightly favored the northwest quadrant. Ozone levels at Mesa, Daniel, Pinedale, and Paradise during this period were stable. During the period of highest ozone (11:00 to 15:00 MST) the wind became steady from the east or northeast. By mid-evening the wind had shifted to the northwest and ozone levels were either steady or falling slightly. Hourly wind and ozone data for Mesa, Daniel, Pinedale, and Paradise during the third VOC sampling period are represented in Figure 4.15.

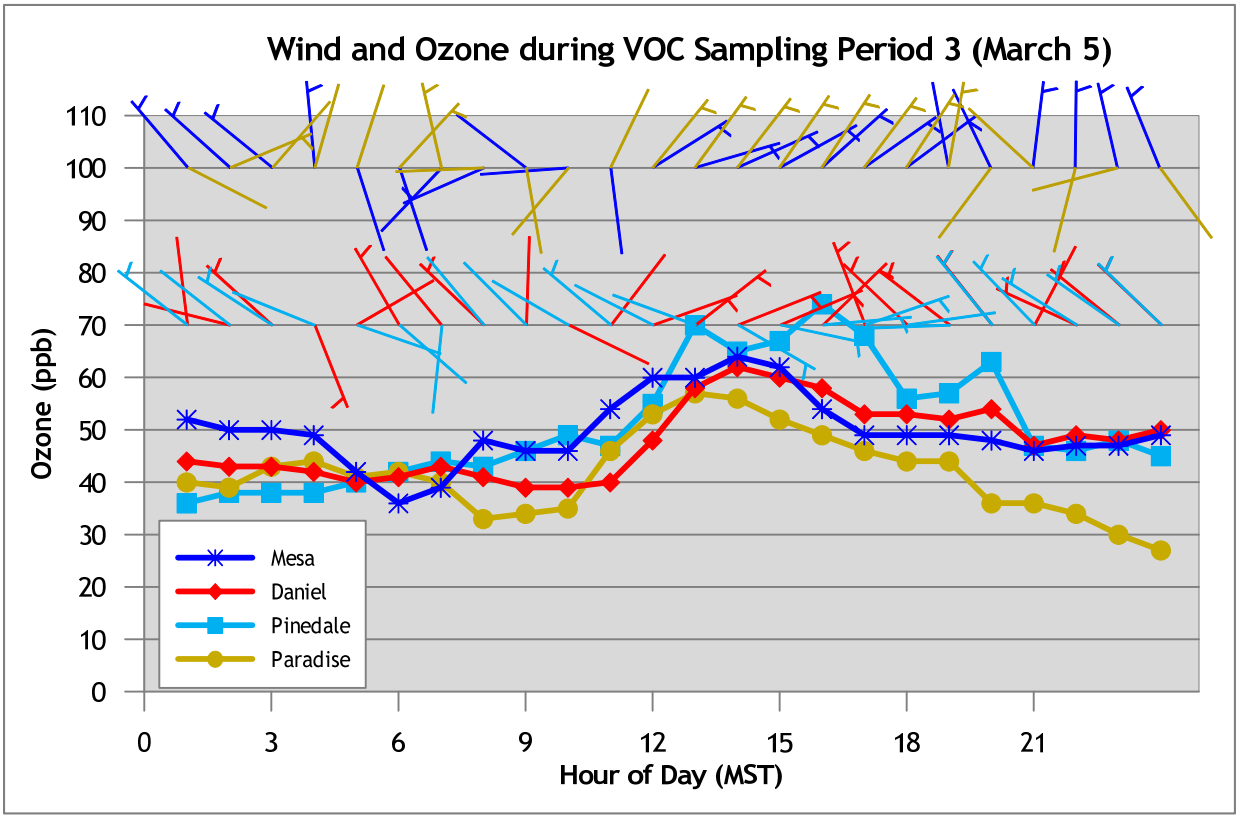


Figure 4.15 One-Hour Average Ozone and Wind at Mesa, Daniel, Paradise and Pinedale during VOC Sampling Period 3

Warbonnet was the only site that observed elevated ozone levels on March 8, the first day of the fourth VOC sampling period. The wind at Warbonnet on March 8 was steady from the northwest before, during, and after the period of elevated ozone. Mesa and Daniel observed elevated ozone levels on March 9, the second day of VOC Sampling Period 4. The wind at Mesa and Daniel on March 9 was light and variable between 6:00 MST and noon, then switched between northeasterly and northwesterly for the remainder of the day. Hourly wind and ozone data for Mesa, Daniel, and Warbonnet during the fourth VOC sampling period are represented in Figure 4.16.

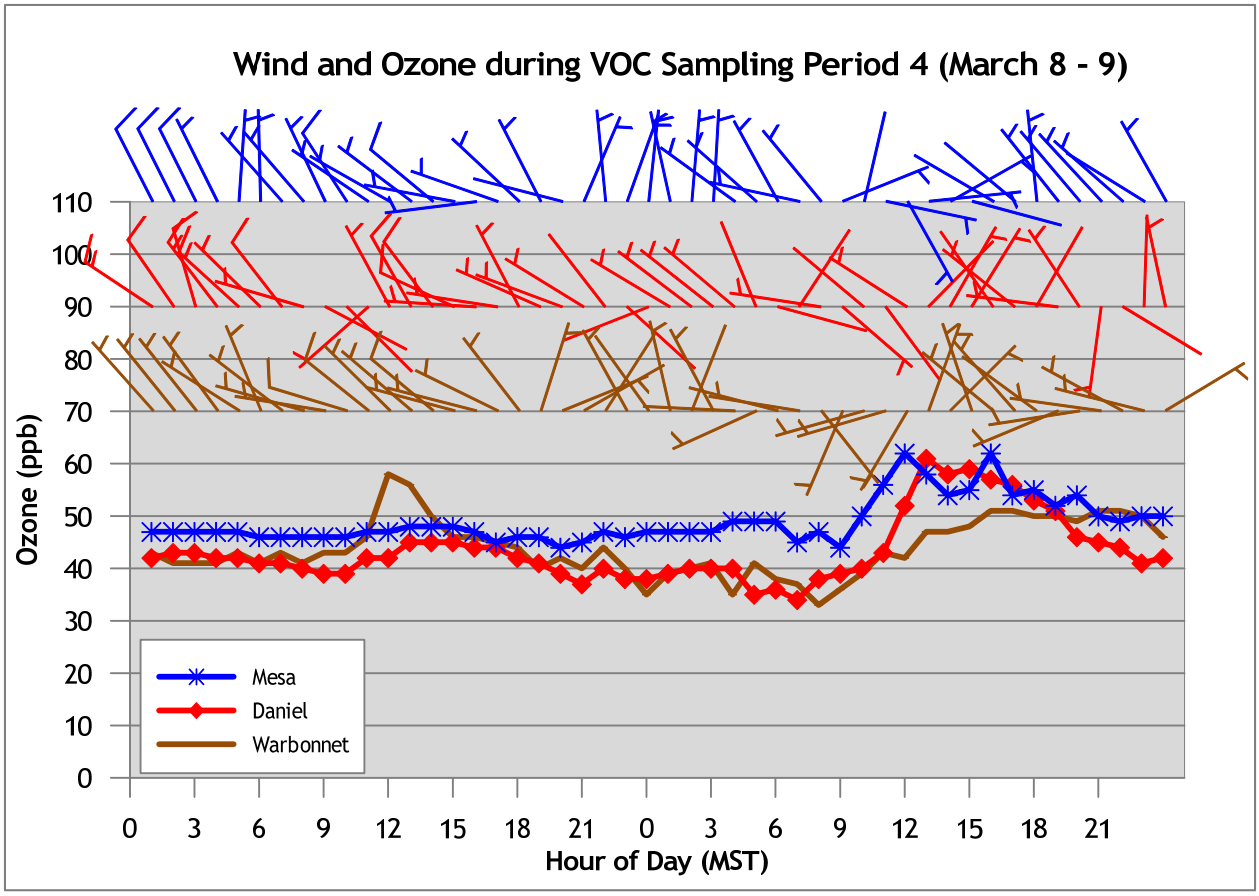


Figure 4.16 One-Hour Average Ozone and Wind at Mesa, Daniel, and Warbonnet during VOC Sampling Period 4

In past UGWOS campaigns, elevated ozone episodes were associated with a characteristic wind shift that recirculated pollutants within the basin. Northwest winds during the night were followed by southeast winds during the day as ozone concentrations climbed. This characteristic wind reversal pattern was observed during VOC Sampling Period 2 (February 26), which recorded the highest ozone levels of this year's study.

4.2.3 Comparison of Ozone in 2014 with 2005-2013

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 the 2013 and 2014 UGWOS campaigns, the WDEQ BAM trailer was located inside the Jonah field, 6.2 kilometers northeast of the former long-term site, where a source of power was available. In 2013, the Wyoming Range site was removed from service and the equipment moved to the location of the Big Piney mobile trailer. Meteorology, ozone, and oxides of nitrogen are currently being monitored at the Big Piney site. Eight-hour ozone averages and maxima by month from these sites are presented in Table 4-4.

Monthly average 8-hour ozone concentrations were generally near average to below average during the 2014 UGWOS campaign. Similarly, maximum eight-hour ozone concentrations were low compared to those of previous years with several sites establishing new monthly low maximums. The highest 8-hour ozone concentrations recorded at the long-term monitoring sites with FEM analyzers were 57 ppb observed at Daniel on March 25 and at Pinedale on February 26.

Table 4-4 Eight-Hour Monthly Average and Maximum Ozone by Year for Jonah, Boulder, Daniel, Pinedale, Juel Springs, and Wyoming Range

January	Average 8-Hour Ozone (ppb)						Maximum 8-Hour Ozone (ppb)					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	39•†	34	40	39	38	NA	48•†	47	49	48	47	NA
February	**Average 8-Hour Ozone (ppb)**						**Maximum 8-Hour Ozone (ppb)**					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	37†	35	40	38	37	NA	47†	51	51	57	51	NA
March	**Average 8-Hour Ozone (ppb)**						**Maximum 8-Hour Ozone (ppb)**					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	39†	40	43	42	40	NA	53†	53	57	54	53	NA

* 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

4.2.4 Comparison of NO_x and PM during UGWOS 2014 with 2006-2013

Average monthly NO and NO_2 concentrations at AQD monitoring sites in the UGRB are presented in Table 4-5. During 2014, concentrations were low with no sites exceeding a monthly average of 1.5 ppb NO and 3.8 ppb NO_2, respectively.

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

Jan.	1-Hour NO (ppb)						1-Hour NO_2 (ppb)					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	1.5*†	0.1	0.03	0.2	0.2	NA	3.1*†	1.4	0.5	2.3	0.7	NA
Feb.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	1.8†	0.2	0.05	0.7	0.2	NA	3.4†	1.8	0.9	3.8	0.6	NA
Mar.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
Year	Jonah	BD	DN	PD	Juel	WR	Jonah	BD	DN	PD	Juel	WR
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
2014	0.7†	0.04	0.03	0.4	0.1	NA	1.6†	0.5	0.7	1.1	0.7	NA

* January 15-31
† WDEQ trailer with FEM monitor after long-term site equipment moved to Juel Springs
NA – Data not available

Average monthly PM_{10} and $PM_{2.5}$ concentrations at AQD monitoring sites in the UGRB are presented in Table 4-6. Monthly average concentrations of PM_{10} during 2014 established new record lows while $PM_{2.5}$ concentrations were near or above average compared to normal.

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

January	Average PM_{10} (µg/m^3)			Average $PM_{2.5}$ (µg/m^3)	
Year	Boulder	Daniel	Wyoming Range	Pinedale	Wyoming Range
2006	7.1	5.0	NA	NA	NA
2007	NA	5.2	NA	NA	NA
2008	6.9	6.4	NA	NA	NA
2009	6.7	4.9	NA	4.1	NA
2010	6.7	4.3	NA	4.1*	NA
2011	6.7	4.4	1.6	4.4	0.8
2012	5.7	4.6	3.7	5.1	0.5
2013	5.5	5.7	1.2	5.3	0.9
2014	4.5	3.8	NA	4.0	NA
February	**Average PM_{10} (µg/m^3)**			**Average $PM_{2.5}$ (µg/m^3)**	
Year	**Boulder**	**Daniel**	**Wyoming Range**	**Pinedale**	**Wyoming Range**
2006	7.4	6.1	NA	NA	NA
2007	5.0	4.8	NA	NA	NA
2008	7.4	5.7	NA	NA	NA
2009	6.9	6.6	NA	3.6	NA
2010	6.3	4.4	NA	2.4	NA
2011	10.3	6.4	4.4	5.1	2.1
2012	6.0	4.5	3.6	4.8	1.2
2013	4.7	4.0	1.8	2.6	1.0
2014	4.5	3.9	NA	6.6	NA
March	**Average PM_{10} (µg/m^3)**			**Average $PM_{2.5}$ (µg/m^3)**	
Year	**Boulder**	**Daniel**	**Wyoming Range**	**Pinedale**	**Wyoming Range**
2006	7.7	6.8	NA	NA	NA
2007	8.5	6.7	NA	NA	NA
2008	7.5	6.7	NA	NA	NA
2009	10.9	11.2	NA	4.3	NA
2010	8.2	6.6	NA	3.0	NA
2011	11.1	7.3†	5.7	5.5	3.1
2012	10.0	9.4	8.4	7.0	2.7
2013	7.6	7.1	7.5	3.0	1.5
2014	5.8	4.1	NA	5.3	NA

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

4.2.5 Comparison of NMHC and THC during UGWOS 2014 with 2010-2013

Average monthly CH_4, NMHC, and THC concentrations at the Boulder and Big Piney monitoring sites are presented in Table 4-7. Methane/THC measurements during 2014 were generally low with several new monthly average minimums established.

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

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

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

Since elevated NMHC periods are typically short-lived and separated by long periods of low NMHC concentrations, it may be more meaningful to summarize NHMC activity by calculating the number of days that the highest 1-hour NMHC concentration surpasses some arbitrary level. Table 4-8 presents the number of days at Boulder and Big Piney that the highest 1-hour NMHC concentration surpassed 2.0 ppm and 4.0 ppm. Using this metric, NMHC activity during 2014 was very low.

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

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

For each day during UGWOS 2014, the maximum 8-hour ozone concentration and average NMHC concentration were calculated at the Boulder site. These data are presented as a scatter plot in Figure 4.17 along with similar data from previous years. 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 in which NMHC concentrations were in the same range as NHMC concentrations that occurred during elevated ozone in 2011, but corresponding elevated ozone concentrations failed to materialize. Since 2014 observed relatively few days with elevated NMHC or elevated ozone, it may be inappropriate to derive any meaningful conclusions regarding the relationship of NMHC and high ozone based on 2014 data alone. The data collected over the past three years, especially those from 2013, would also suggest that there is no correlation between daily average NMHC concentration and daily maximum 8-hour ozone concentration.

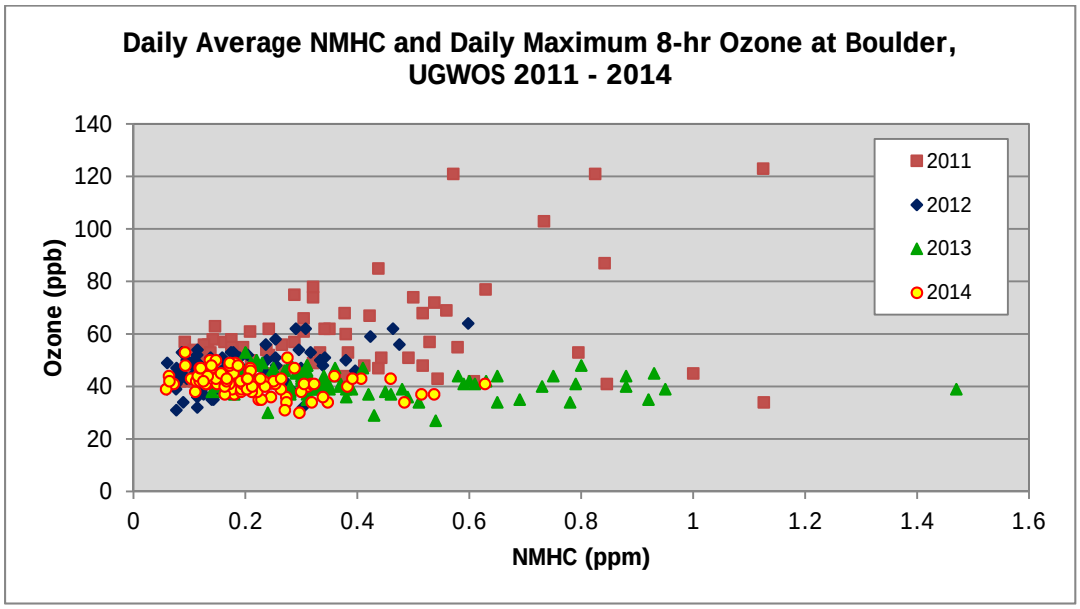


Figure 4.17 Comparison of Maximum 8-hour Ozone and Daily Average NMHC at Boulder for UGWOS 2011 – 2014.

4.3 VOC Sampling

The goal of the UGWOS 2014 VOC sampling stemmed from the UGWOS 2012 study to investigate the spatial distribution of ozone precursor concentrations in and around the gas and oil fields located in the UGRB. To obtain a spatial distribution of precursors, VOC canister and carbonyl canister samples were collected at Boulder and Big Piney monitoring stations as well as the UGWOS-specific Jonah air quality site and three mesonet sites (Paradise, Mesa, and Warbonnet). Although no IOPs were initiated during the 2014 UGWOS study period, six 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.

4.3.1 VOC Canister Sampling

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 4.18 and 4.19 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 six sample locations.

Figures 4.20 and 4.21 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. The March 5 sample at Jonah was not analyzed due to an equipment failure during sampling.

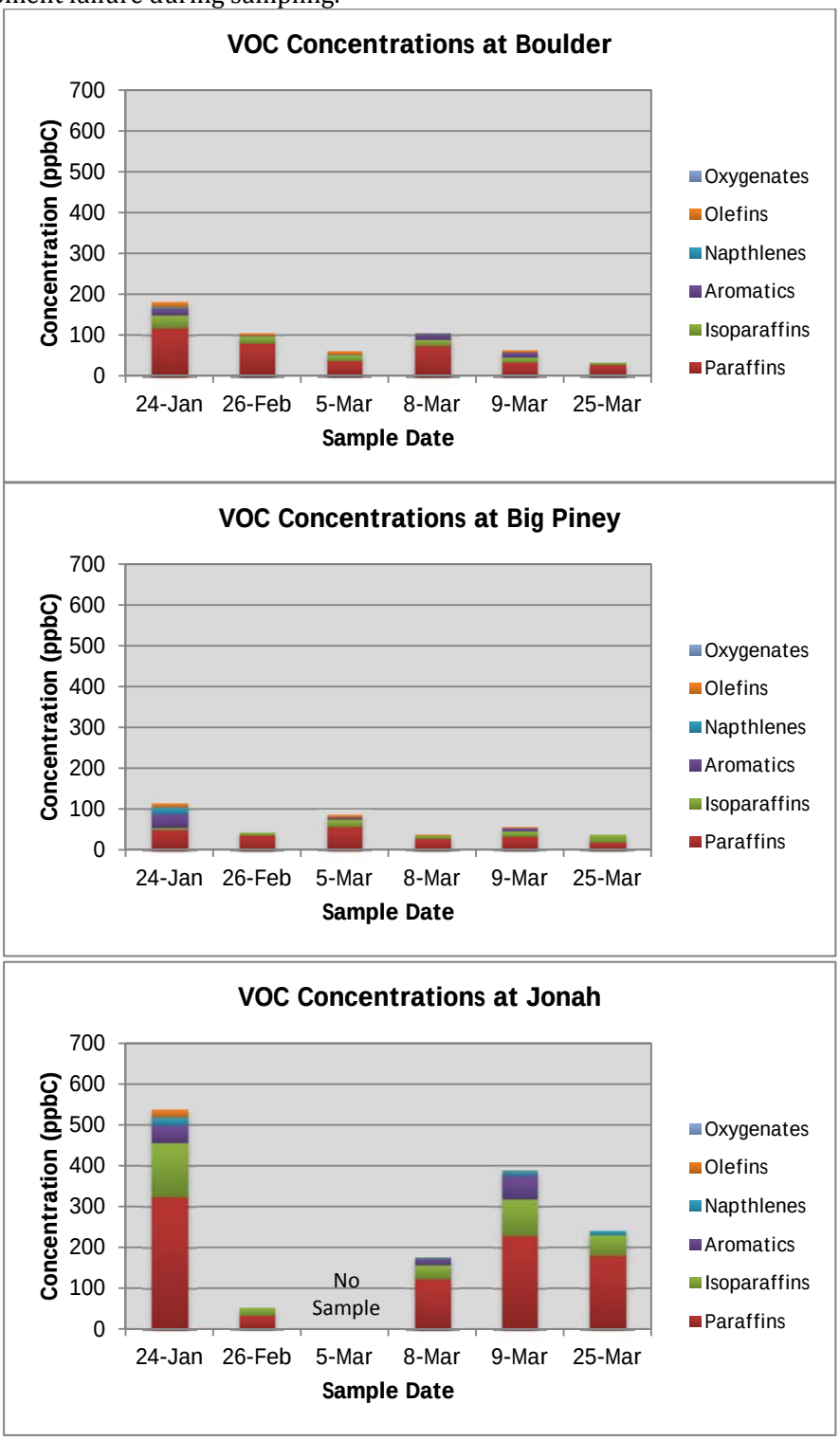
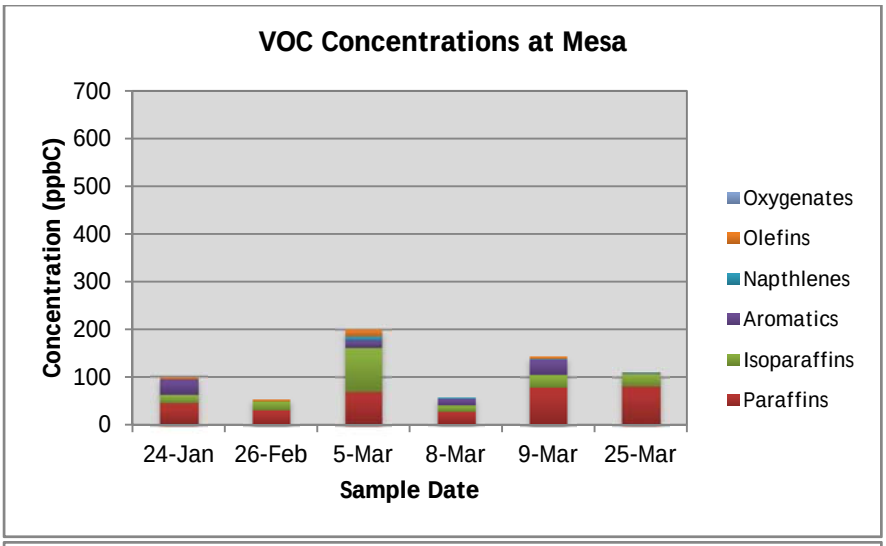
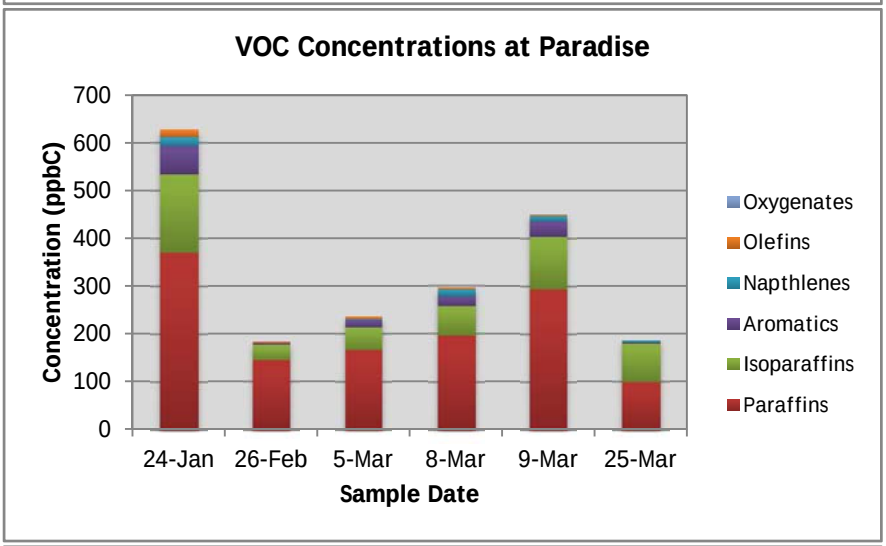


Figure 4.18 VOC Concentrations from Canisters Collected at Boulder, Big Piney, and Jonah





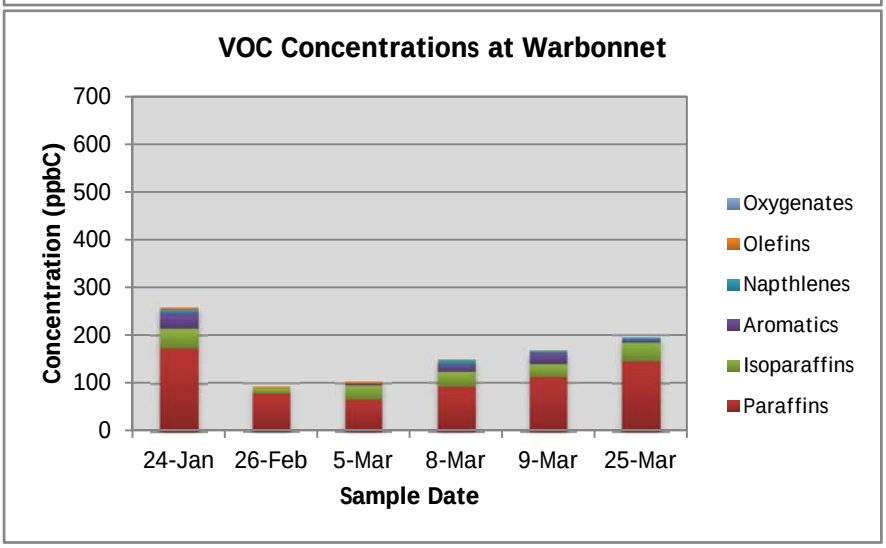


Figure 4.19 VOC Concentrations from Canisters Collected at Mesa, Paradise, and Warbonnet

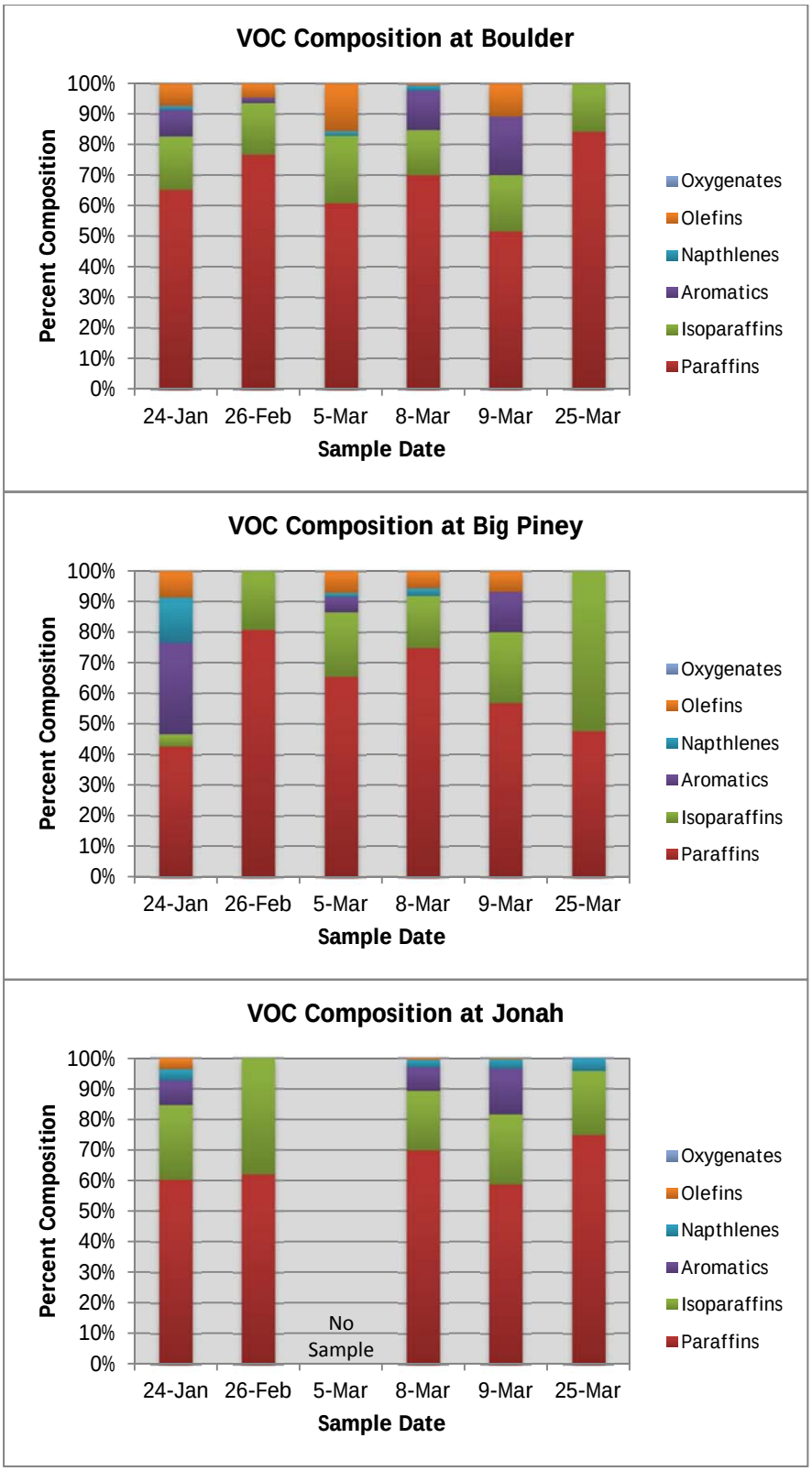


Figure 4.20 Relative Composition from Canisters Collected at Boulder, Big Piney, and Jonah

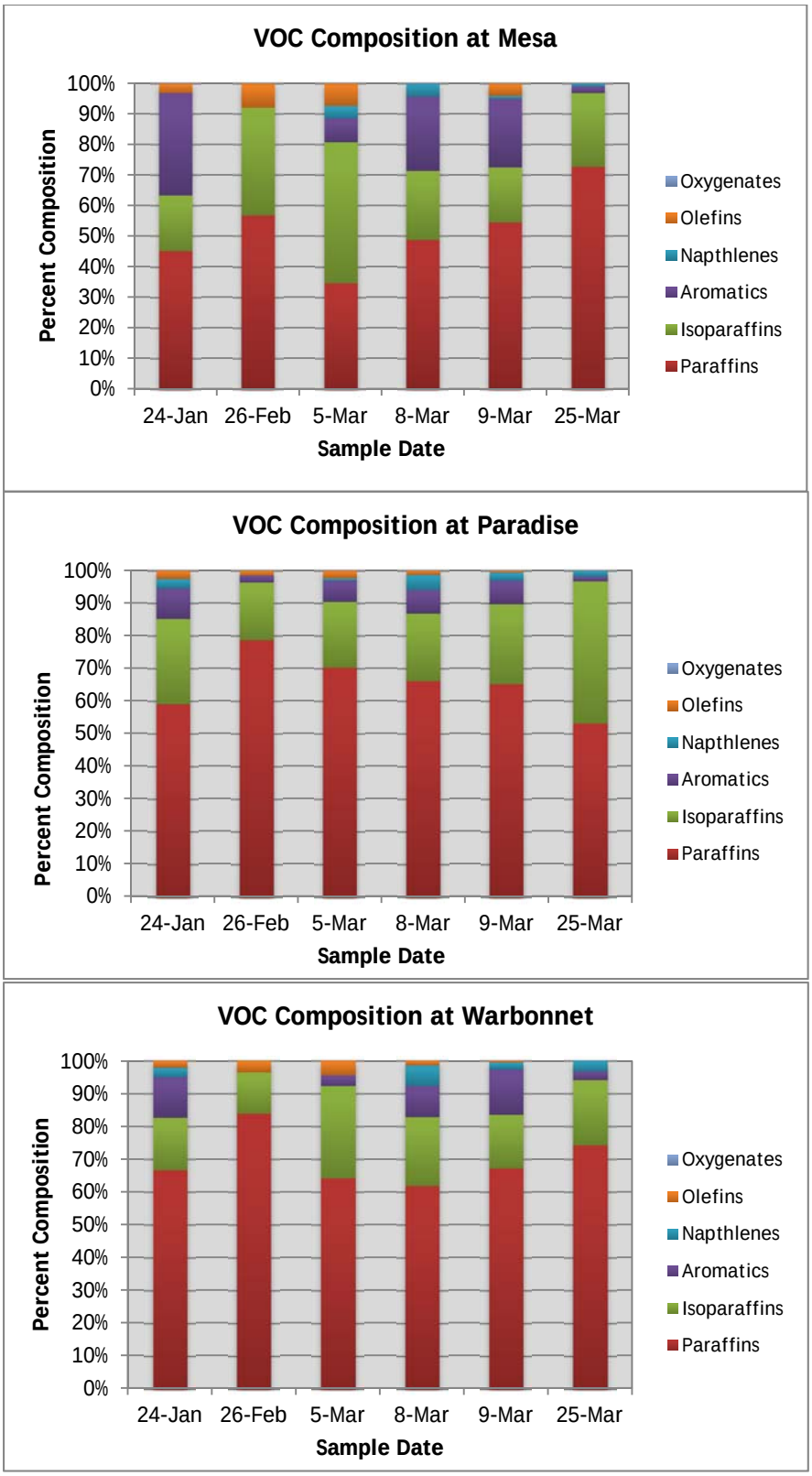


Figure 4.21 Relative Composition from Canisters Collected at Mesa, Paradise, and Warbonnet

VOC concentrations at Paradise were consistently higher than the other five 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 systems). 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 six 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 4-9 presents the maximum and average wind speeds for the study period as well as the 24- hour maximum and average wind speeds for days in which VOC samples were taken.

Table 4-9 Wind Speed (mps) Statistics for VOC Sample Locations

Time Period		WS Stats	Boulder	Big Piney	Jonah	Mesa	Paradise	Warbonnet
Study Period		Maximum	19.4	15.7	12.7	12.5	10.8	13.9
		Average	4.5	3.0	3.4	3.2	2.6	3.5
Sample Days	1/24/2014	Maximum	11.1	2.7	6.6	8.8	8.5	7.9
		Average	4.3	1.6	2.5	6.3	3.6	4.0
	2/26/2014	Maximum	5.9	3.9	4.4	2.2	2.8	3.5
		Average	2.5	2.1	2.1	1.7	1.3	1.8
	3/05/2014	Maximum	4.7	4.8	3.8	3.5	3.1	2.8
		Average	2.5	2.4	2.3	1.7	1.5	1.9
	3/08/2014	Maximum	5.4	3.2	6.3	4.6	5.0	4.5
		Average	3.4	1.8	3.0	3.0	1.8	2.6
	3/09/2014	Maximum	3.3	5.0	4.4	3.7	3.4	2.8
		Average	2.1	2.2	2.1	1.7	1.3	1.6
	3/25/2014	Maximum	4.9	4.9	5.5	2.6	4.0	4.3
		Average	3.3	2.4	2.1	1.6	1.8	1.8
Cumulative Sample Days		Maximum	11.1	5.0	6.6	8.8	8.5	7.9
		Average	3.0	2.1	2.4	2.7	1.9	2.3

4.3.2 Carbonyl Samples

Carbonyl samples were collected using DNPH-coated cartridges outfitted with ozone scrubbers and connected to constant flow pump systems over the same time period as the canisters (07:00-10:00). Figures 4.22 and 4.23 present a summary of the formaldehyde and acetaldehyde concentrations measured at each of the six sample locations. Dates in which samples were taken are shown on the x-axis and are presented in chronological order to compare site concentrations throughout the study period.

Overall concentrations of formaldehyde and acetaldehyde measured in the cartridges were fairly low. Sample concentration trends correlated well with Total Hydrocarbon (THC) concentrations measured in the VOC canisters. Paradise largely had the highest concentrations of acetaldehyde throughout the study while Jonah measured the highest overall concentration of formaldehyde for the study on January 24, 2014. Early in the study, formaldehyde was observed in the cartridges to be the prominent pollutant sampled, particularly at the Paradise and Jonah sample locations. Acetaldehyde was mostly absent in samples collected in January and February, but was shown to be more prominent at all sites in samples taken during the latter portion of the study in March.

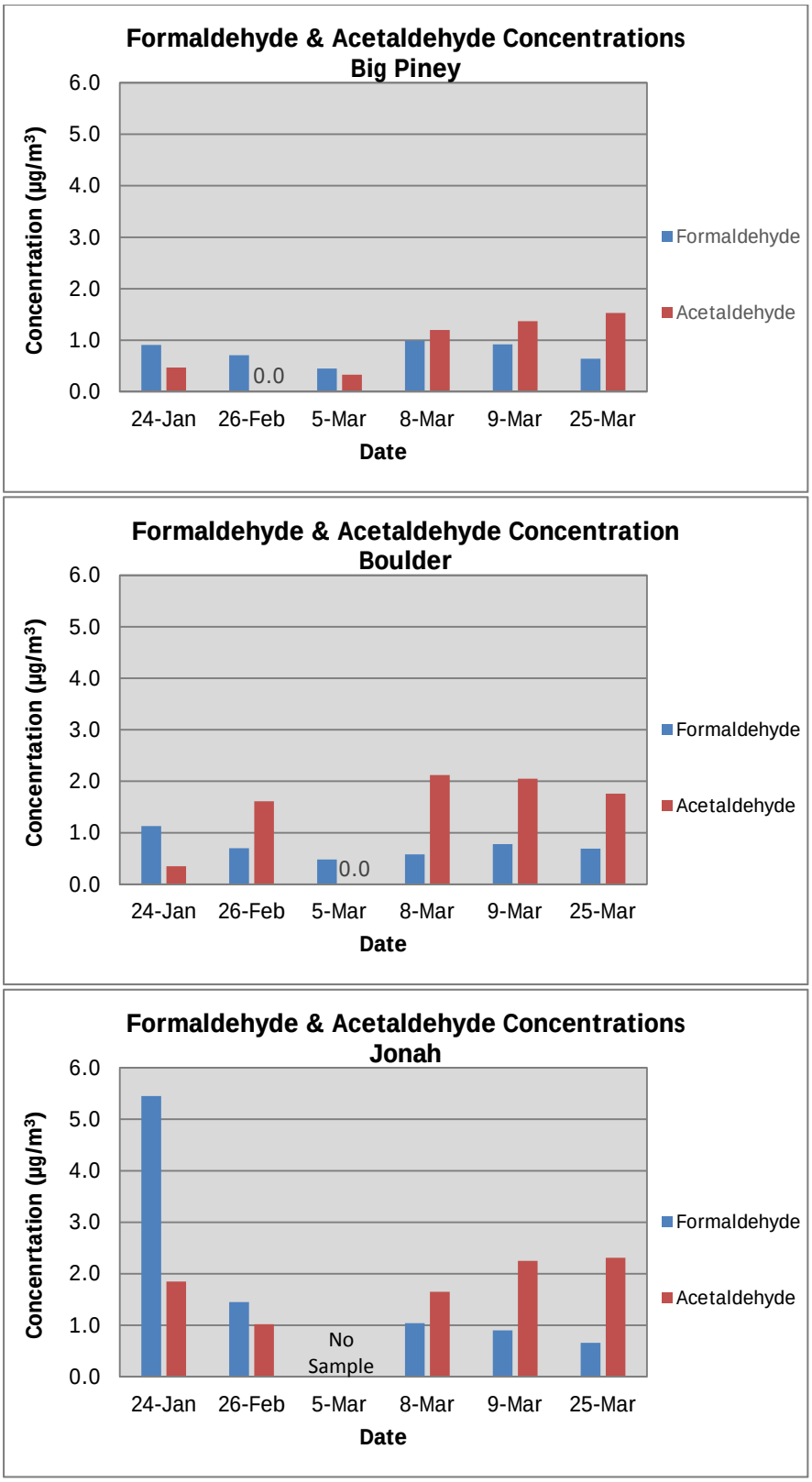


Figure 4.22 Formaldehyde and Acetaldehyde Concentrations at Big Piney, Boulder, and Jonah

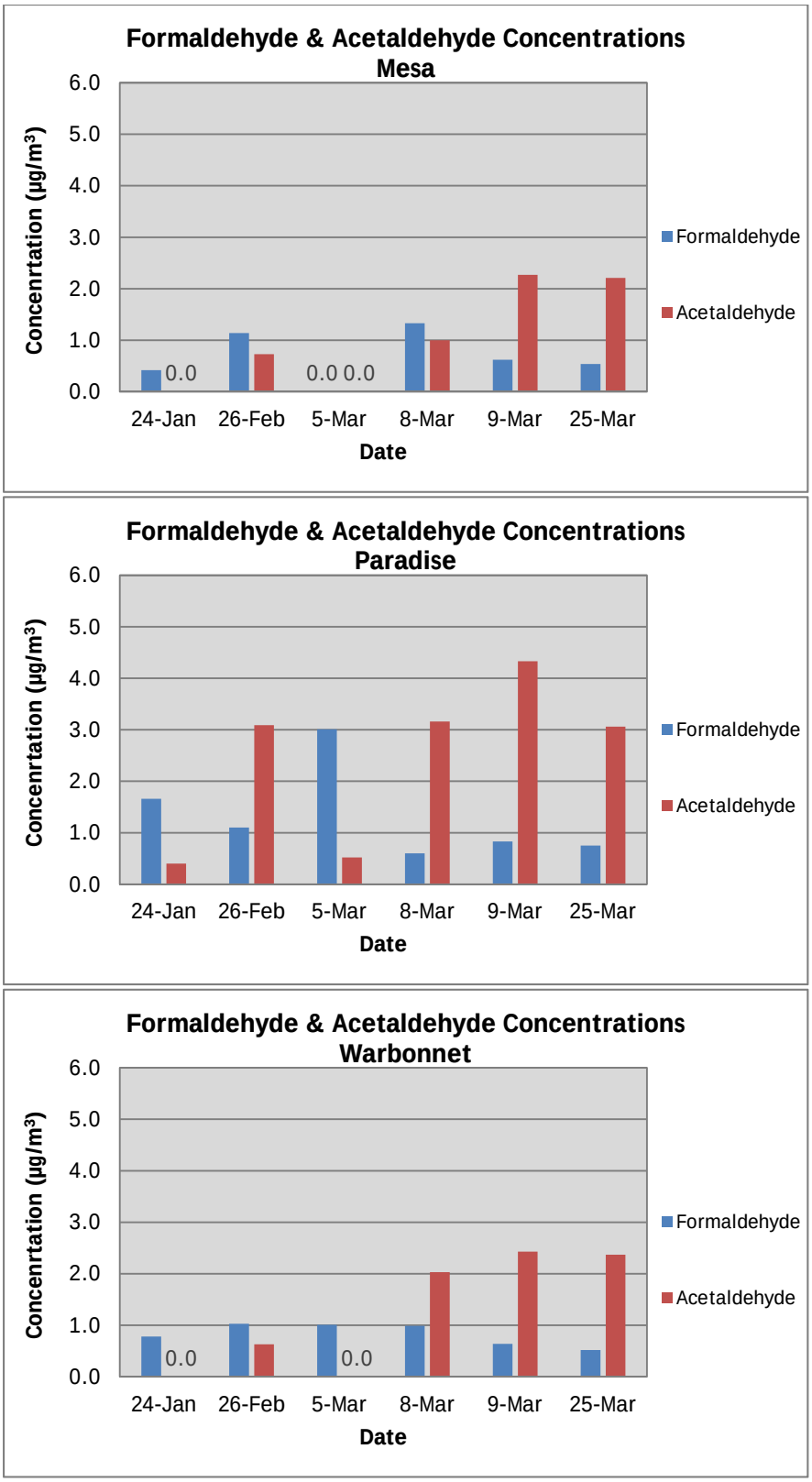


Figure 4.23 Formaldehyde and Acetaldehyde Concentrations at Mesa, Paradise, and Warbonnet

4.3.3 Comparison of VOC Measurements to Previous Study Years

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

There were six (6) designated sample days in 2014. Eleven (11) samples were taken at four sites in 2012 and five samples were taken at eight sample locations in 2013. The average value for each of the five hydrocarbon categories (paraffins, isoparaffins, aromatics, napthlenes, and olefins) and oxygenates was evaluated. VOC samples were scheduled based on forecast conditions as described in Section 2.3. The average value of each hydrocarbon category considered to be a representative distribution of VOCs by study year when predefined forecast conditions were met. Figures 4.24 through 4.29 present distribution of VOCs, by year, for 2012, 2013, and 2014 at each sampling site. (Note: concentration scales differ by plot to improve readability.)

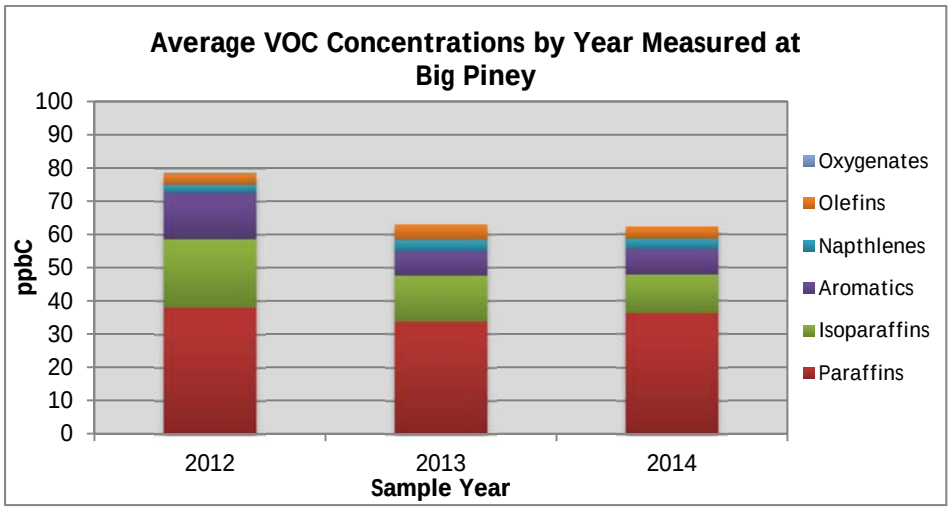


Figure 4.24 VOC Distribution by Study Year at Big Piney

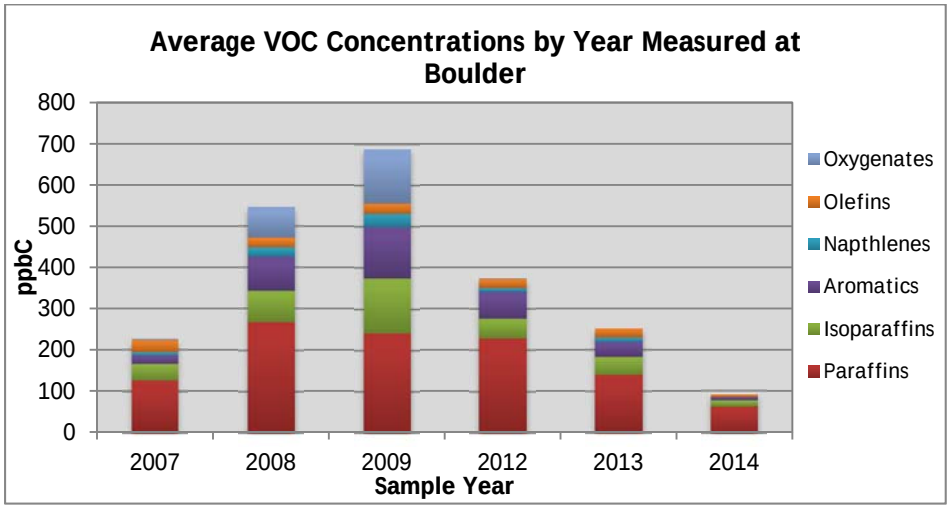


Figure 4.25 VOC Distribution by Study Year at Boulder

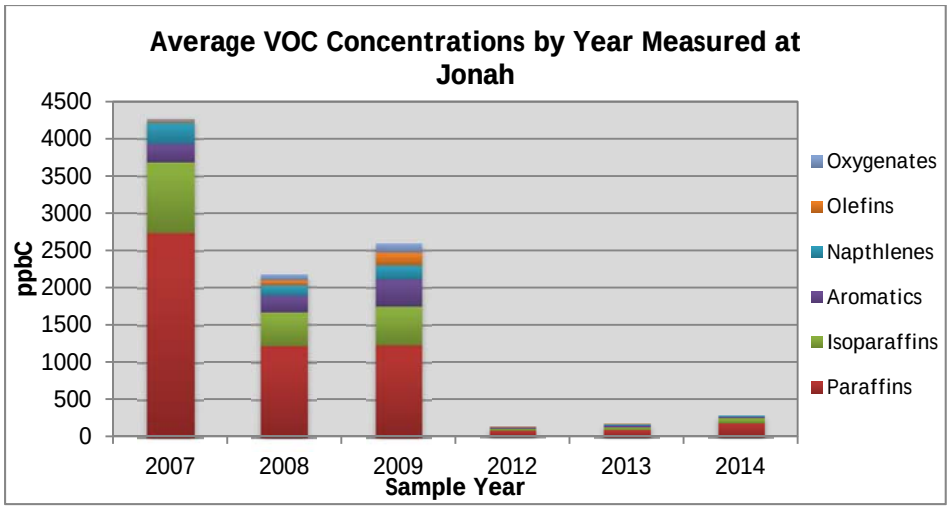


Figure 4.26 VOC Distribution by Study Year at Jonah

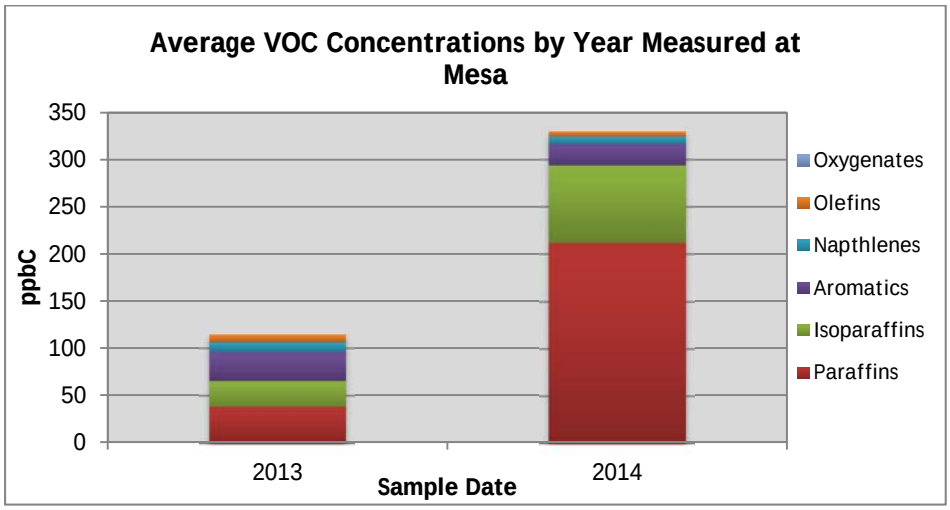


Figure 4.27 VOC Distribution by Study Year at Mesa

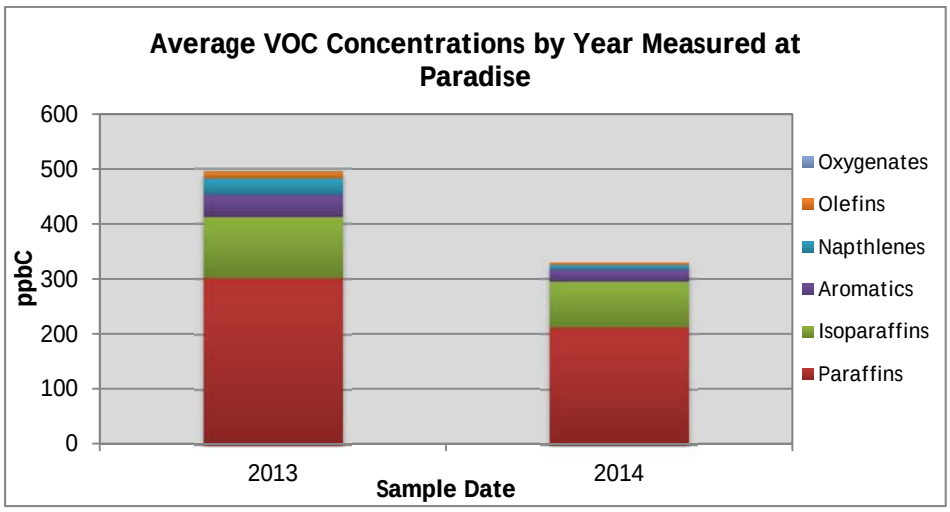


Figure 4.28 VOC Distribution by Study Year at Paradise

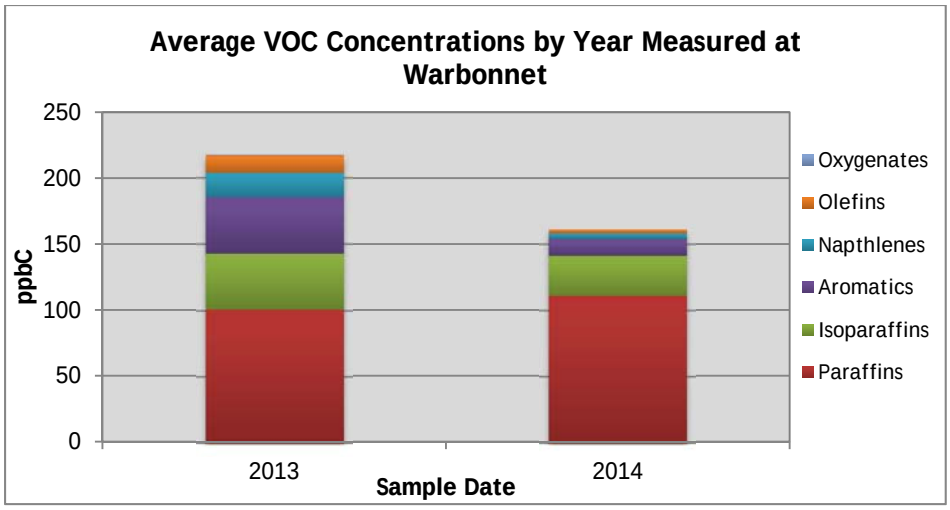


Figure 4.29 VOC Distribution by Study Year at Warbonnet

Overall, the distribution of VOC concentrations in 2014 were low at each station relative to measurements made in 2007-2009. Most sites saw an overall decrease in VOCs while Jonah and Mesa were the only stations with a year over year increase in VOC concentrations. Sample concentrations at Big Piney have historically been very low when compared to stations located in the northeastern portion of the basin. Paradise, located in the heart of the oil and gas operations, measured the highest concentrations of VOCs during the 2013 and 2014 studies. The distribution of olefins, napthlenes, and aromatics decreased at each site while paraffins showed an overall increase in contribution and was the primary category leading to an overall increase in VOC concentrations measured at Mesa and Jonah.

There is relatively 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). However, oxygenates have been absent in the last three study campaigns and were prominent in both 2008 and 2009. Figure 4.30 presents the average percent contribution, by year, of each composition classification as measured at Boulder. The figure shows the increase in paraffin composition with remaining categories showing an overall decrease in contribution.

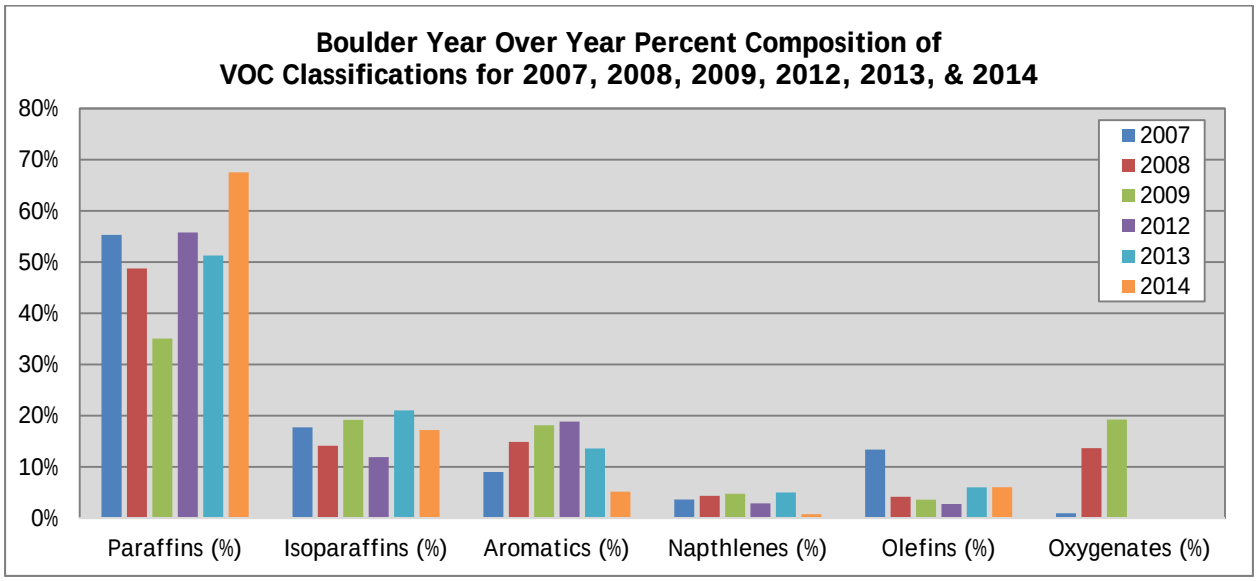


Figure 4.30 Percent Composition of VOC Classifications by Study Year at Boulder

4.3.4 Comparison of Carbonyl Samples to Previous Study Years

In addition to the 2014 study, carbonyl samples were also collected at the Boulder site and in the Jonah Field in 2007, 2008, and 2009. As previously noted, due to site power availability the Jonah site changed locations between the 2012 and 2013 campaigns and was moved approximately 3.75 miles west from the 2012 location which was the same location as the 2007-2009 campaigns. This section compares concentrations of formaldehyde and acetaldehyde measured in 2007, 2008, 2009, and 2014.

During the 2007 study, there were five sample days (March 15, March 16, March 17, March 18, and March 19) scheduled to be taken at 04:00, 09:00, and 14:00. There was only one sample collected on March 15 at 14:00 at both the Boulder and Jonah sites for a total of 12 samples collected at the Boulder site and 13 samples collected at the Jonah Site. The 2008 study had 11 designated sampling days with 31 samples collected at the Boulder site and 12 designated sampling days with 32 samples collected at the Jonah site. To match the 2007 study, three-hour samples were scheduled to begin at 04:00, 09:00, and 14:00. In 2009, the Boulder site had nine designated sampling days with a total of 17 samples collected and the Jonah site had seven designated sampling days with a total of 13 samples collected. Three-hour samples were scheduled to be collected at 06:00 and 13:00 on designated sampling days. In 2014, there were six designated sampling days with three-hour samples being collected at 07:00, Figures 4.31 and 4.32 present the average concentrations of formaldehyde and acetaldehyde by study year measured at the Boulder and Jonah sites.

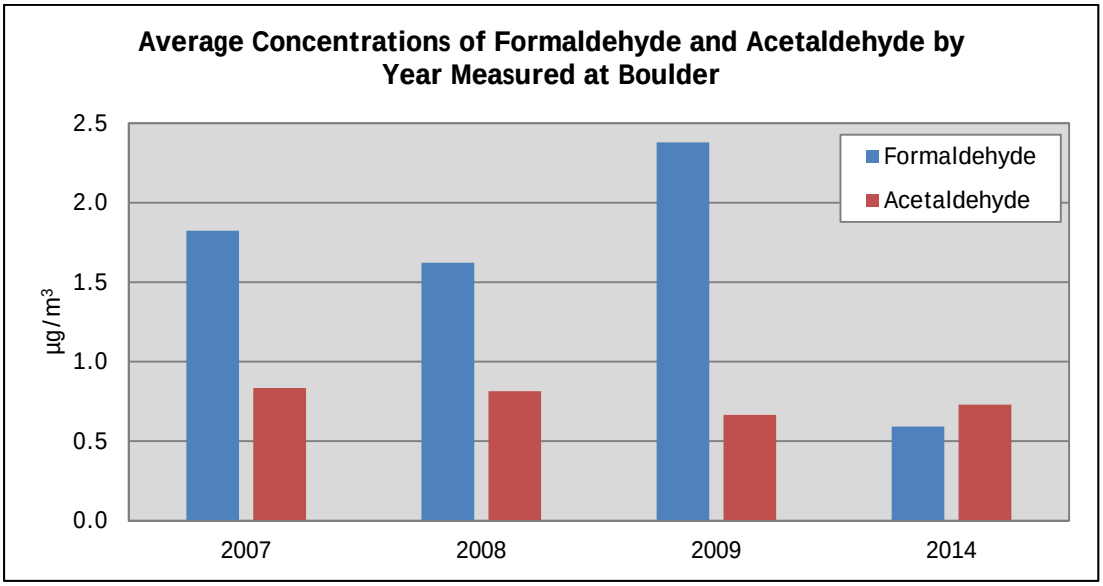


Figure 4.31 Average Formaldehyde and Acetaldehyde by Year at Boulder

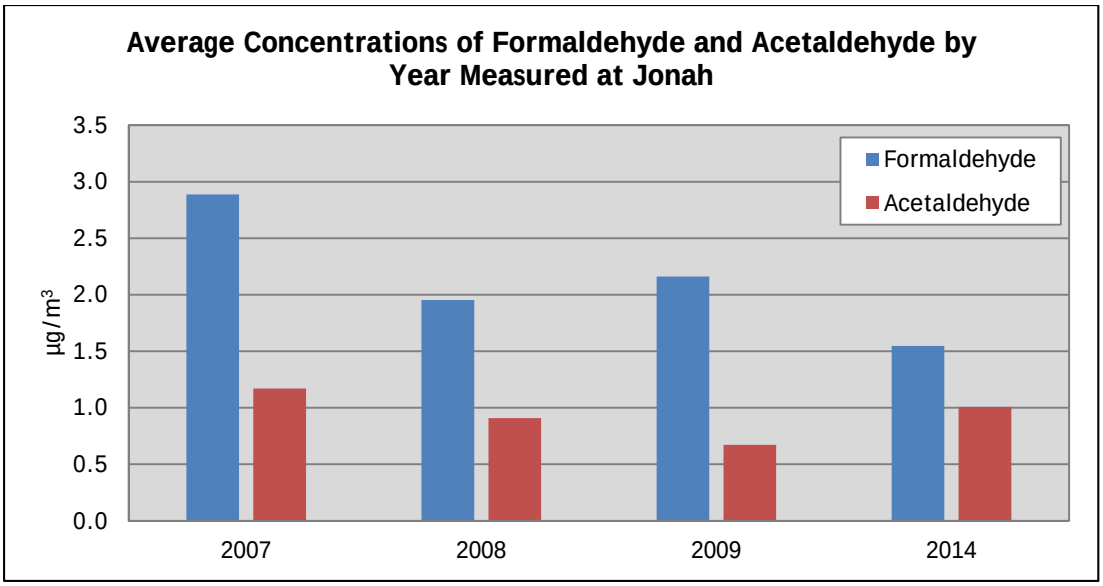


Figure 4.32 Average Formaldehyde and Acetaldehyde by Year at Jonah

4.3.5 VOC Maximum Incremental Reactivity Analysis

In addition to the relatively low measurements of Total NMHC for 2012 through 2014, there was very little ozone development throughout the basin 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.

On February 26, 2014, Mesa measured the high eight hour average ozone concentration for the study at 65 ppb with Paradise and Pinedale also measuring eight-hour ozone concentrations above 55 ppb. Figure 4.33 presents the relationship of the actual Total NMHC and MIR enhanced Total NMHC concentrations measured at each of the VOC sites on February 26. Mesa, Jonah, and Warbonnet were the only site to measure compounds which increased the potential for ozone formation and Paradise measured the highest concentration of compounds conducive to ozone formation.

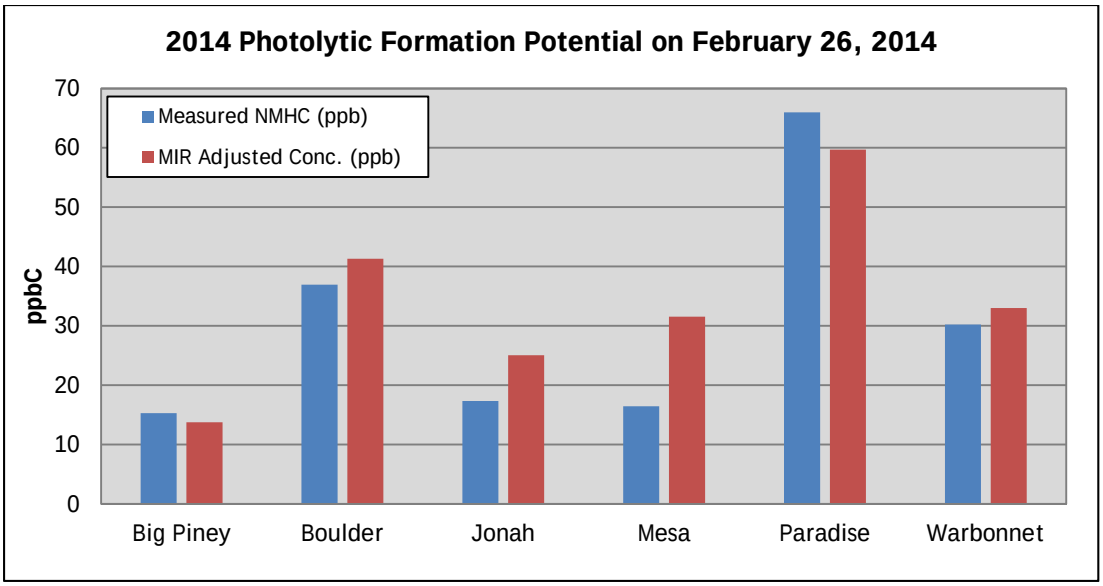


Figure 4.33 Actual and MIR Adjusted Total NMHC

The ratio of 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. An analysis was conducted to determine which measured compounds (including formaldehyde and acetaldehyde) were the most abundant in the basin during the 2014 study based on the potential for ozone formation. Figures 4.34 through 4.39 present the top ten average compound concentrations detected in at least three samples (50% of samples) and adjusted for reactivity for each sampling site. Table 4-10 presents the top 15 compounds as a comprehensive average at all sites throughout the basin as well as the top 15 compounds adjusted for reactivity. It was found that on average throughout the basin ethane was the most abundant compound measured while 1-butene was the most available compound conducive to ozone production.

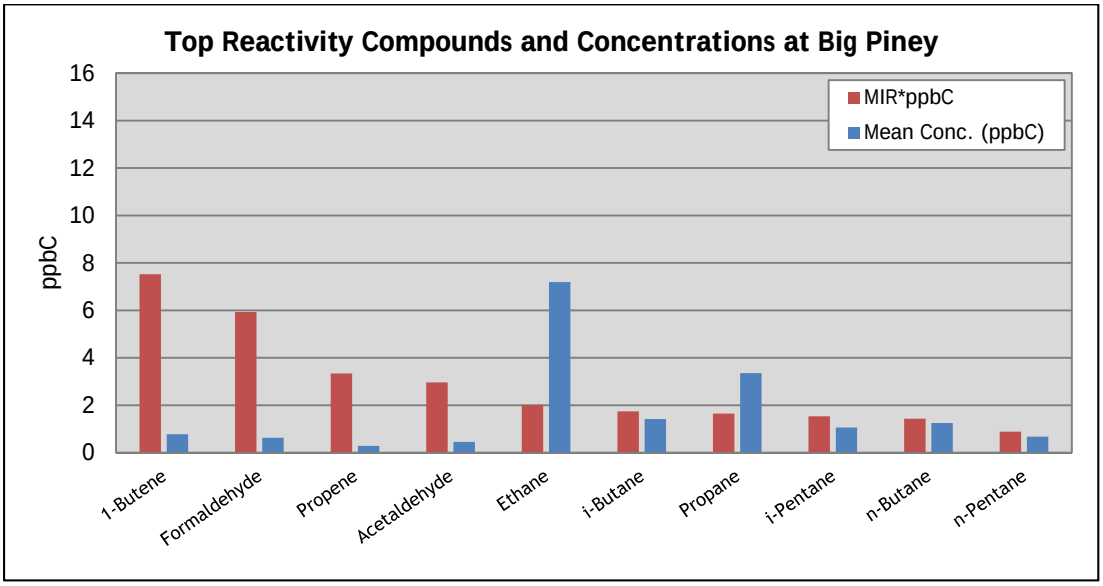


Figure 4.34 Top 10 Average VOC Compounds by Reactivity at Big Piney

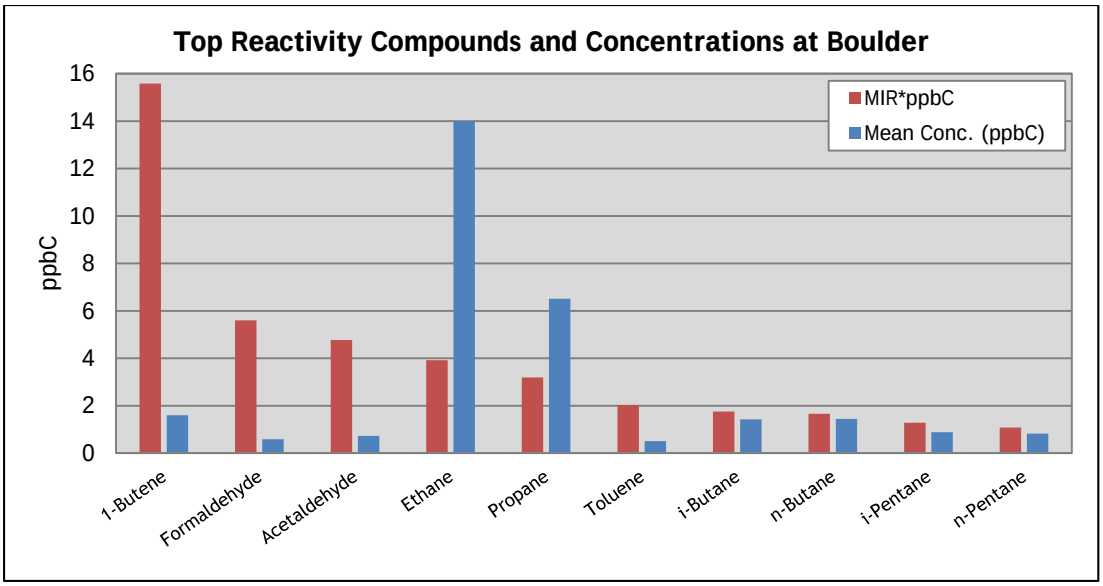


Figure 4.35 Top 10 Average VOC Compounds by Reactivity at Boulder

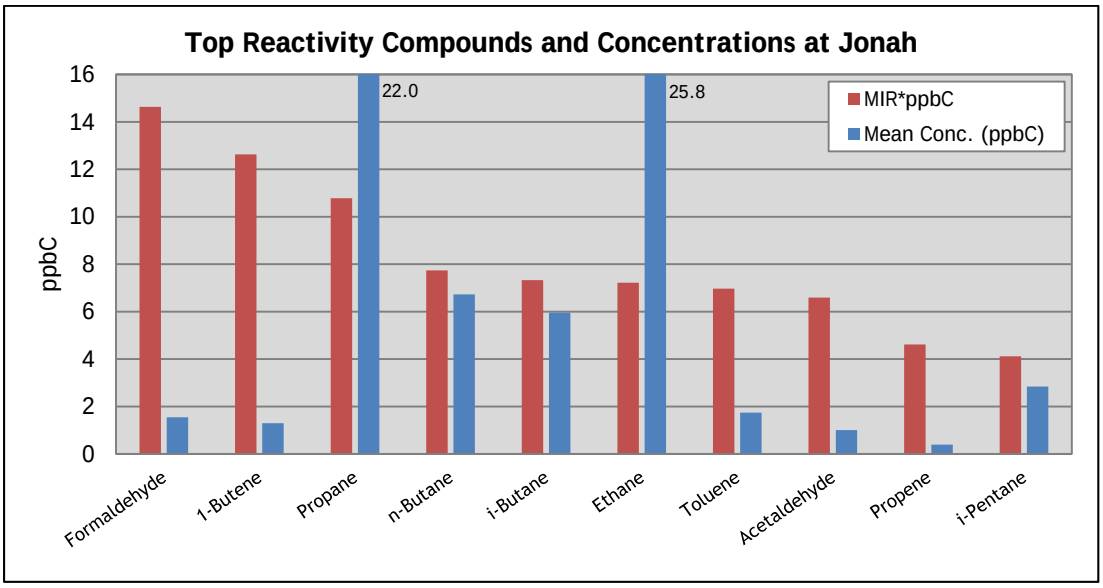


Figure 4.36 Top 10 Average VOC Compounds by Reactivity at Jonah

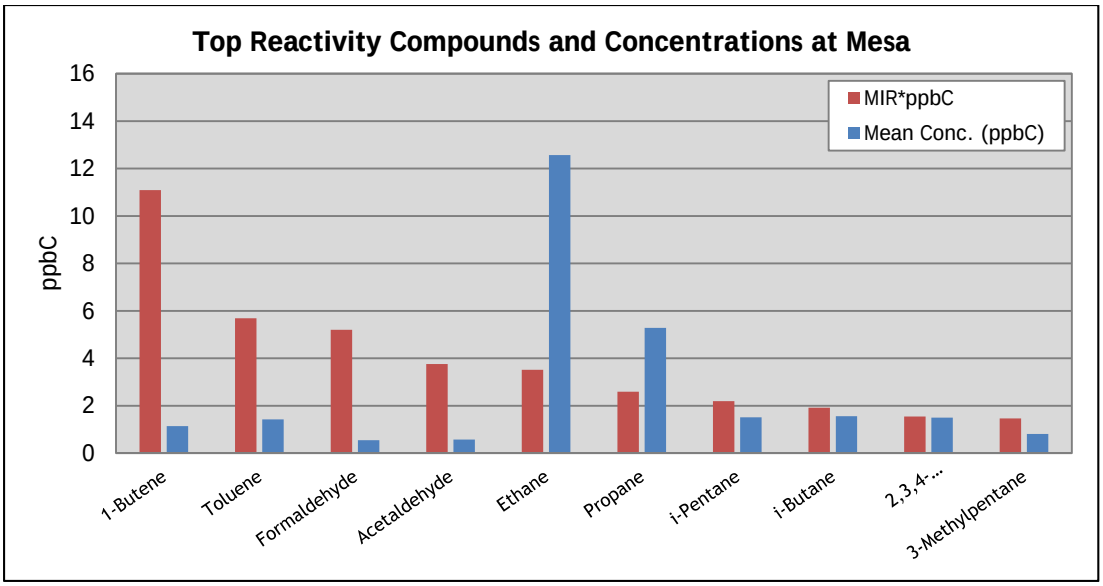


Figure 4.37 Top 10 Average VOC Compounds by Reactivity at Mesa

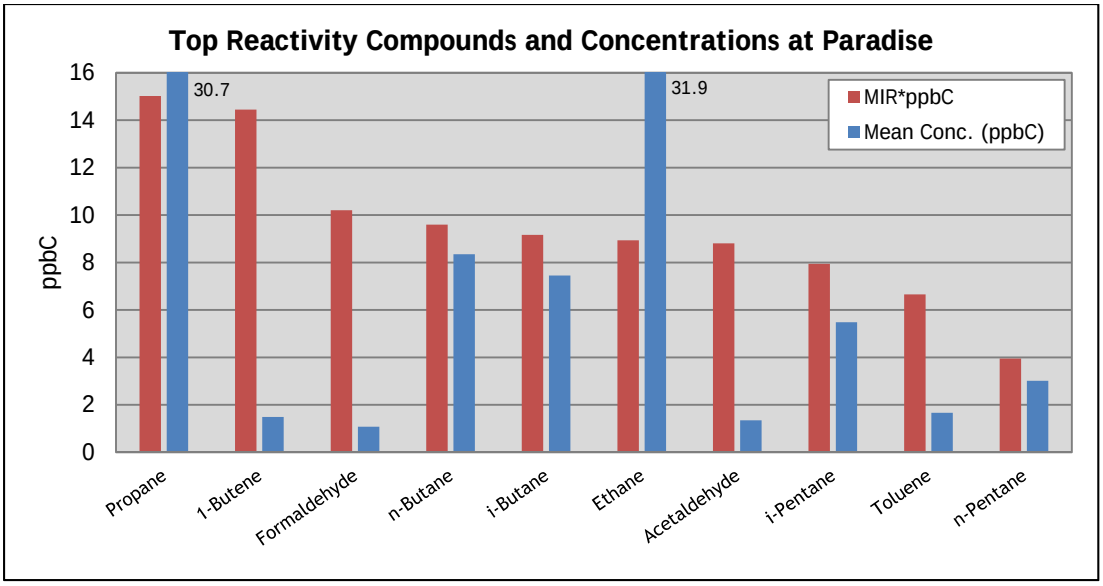


Figure 4.38 Top 10 Average VOC Compounds by Reactivity at Paradise

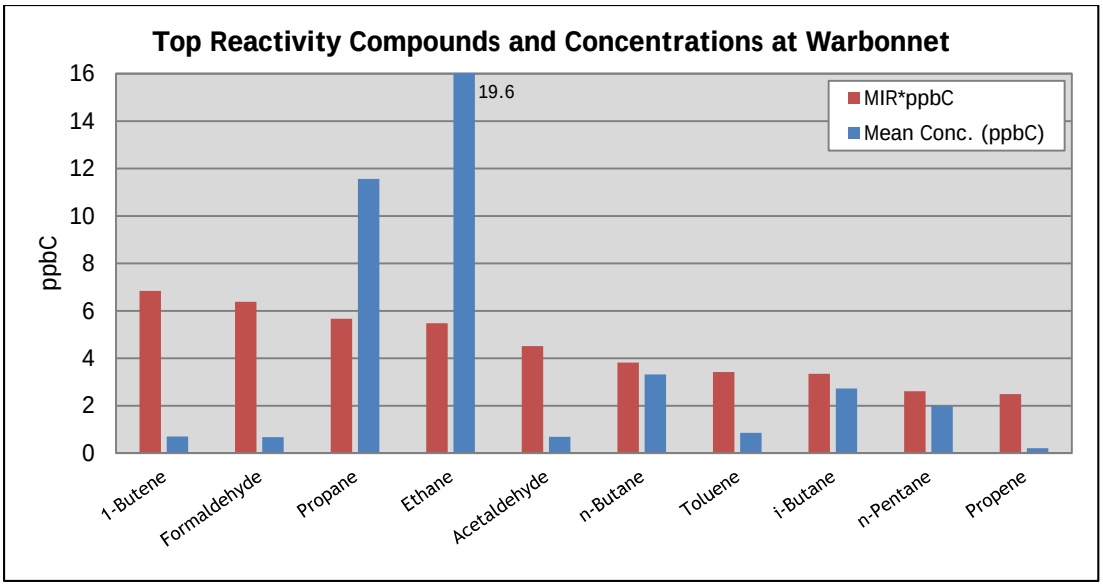


Figure 4.39 Top 10 Average VOC Compounds by Reactivity at Warbonnet

Table 4-10 Top Compounds by Concentration and Reactivity

Rank	Top 15 Compounds by Concentration	Top 15 Compounds by Reactivity (MIR)
1	Ethane	1-Butene
2	Propane	Formaldehyde
3	n-Butane	Toluene
4	i-Butane	Propane
5	i-Pentane	m,p-xylene
6	Toluene	Acetaldehyde
7	2,3,4-Trimethylpentane	Propene
8	n-Pentane	Ethane
9	1-Butene	n-Butane
10	Acetylene	o-xylene
11	Benzene	i-Butane
12	Cyclopentane	i-Pentane
13	n-Heptane	Cyclopentane
14	Acetaldehyde	1,3,5-Trimethylbenzene
15	n-Hexane	n-Pentane

4.3.6 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 five different VOC canister sites (Big Piney, Boulder, Jonah, Paradise, and Warbonnet) once during the study period. Figures 4.40 through 4.44 present summaries of the collocated sample results collected on January 24 at Boulder, February 26 at Big Piney, March 5 at Warbonnet, March 9 at Jonah, and March 25 at Paradise. The results of the collocated canisters show differences in Total NMHC of 68.5%, -27.0%, 2.2%, 9.7%, and -9.0, respectively. The high percent differences are a result of low concentrations measured throughout the study period and a discrepancy in measured aromatics in the case for Boulder. For such low concentrations, the agreement between the collocated samples was relatively good and with the exception of the Boulder aromatics, there were few major outliers.

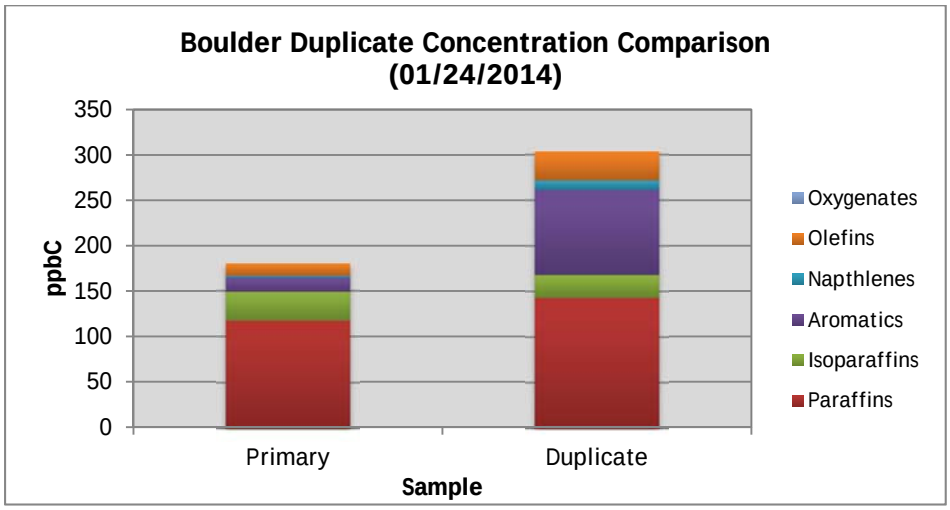


Figure 4.40 Collocated Sample Comparison from Boulder

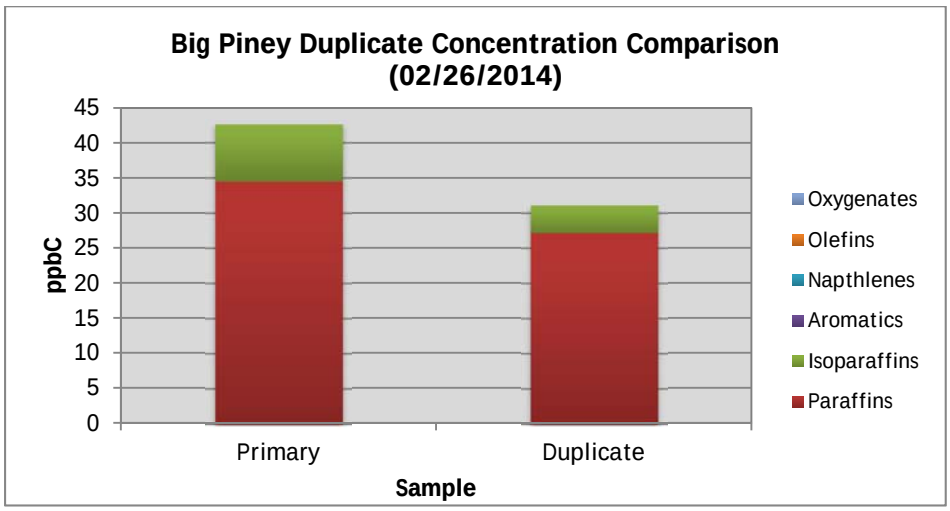


Figure 4.41 Collocated Sample Comparison from Big Piney

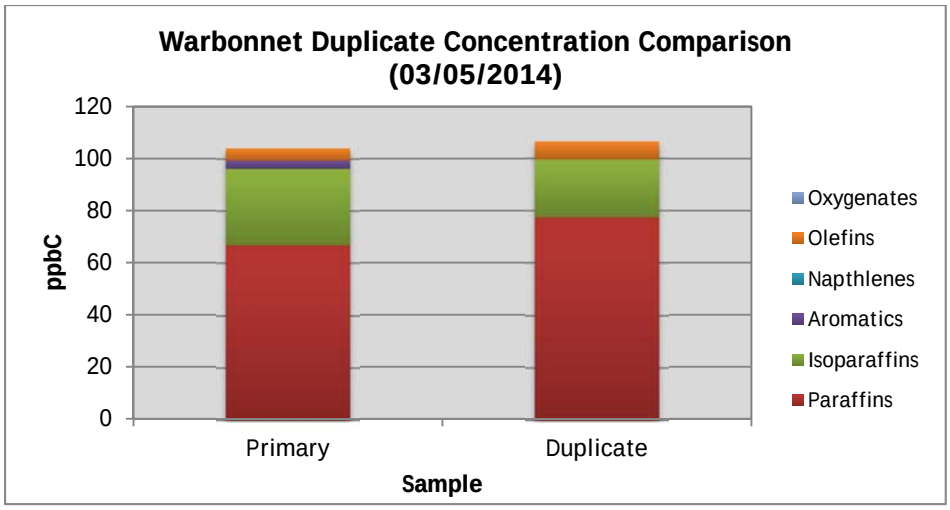


Figure 4.42 Collocated Sample Comparison from Warbonnet

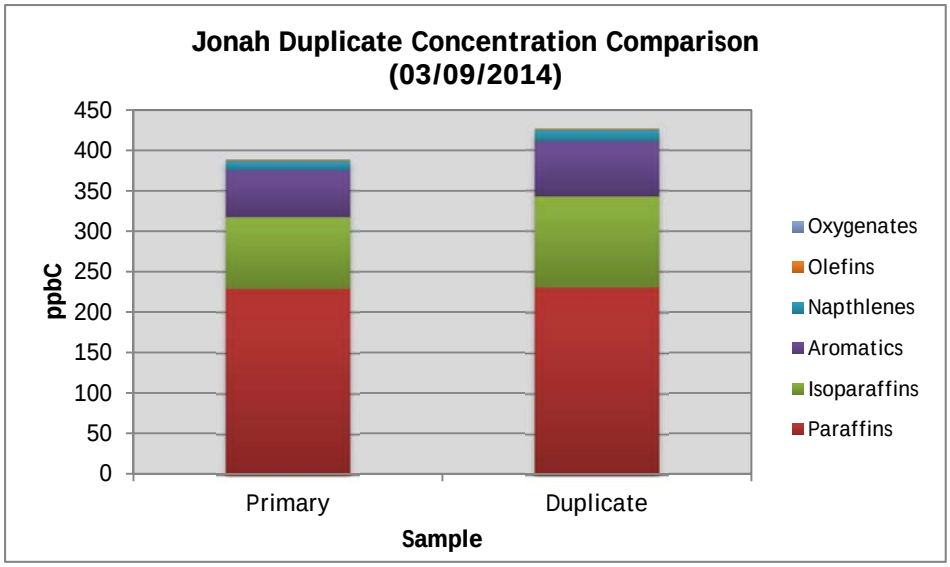


Figure 4.43 Collocated Sample Comparison from Jonah

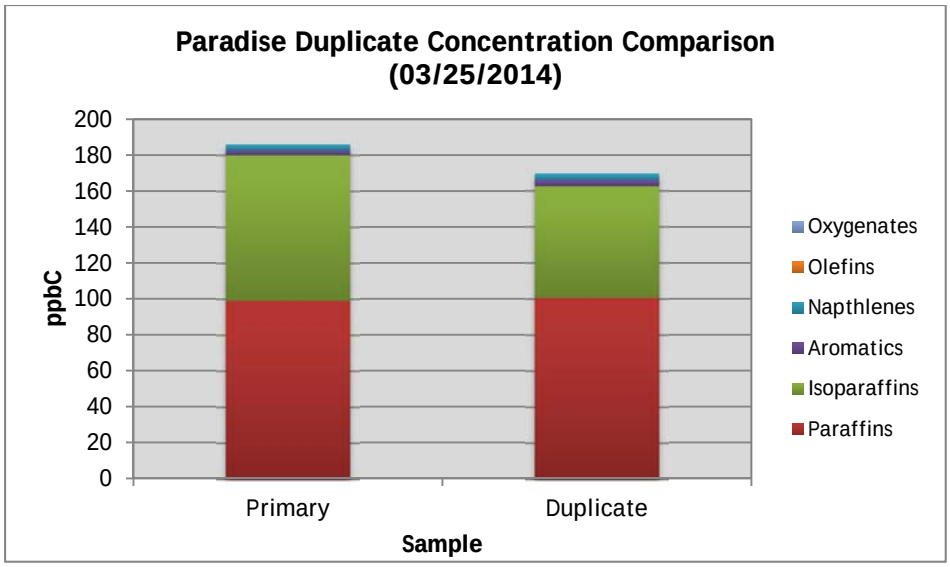


Figure 4.44 Collocated Sample Comparison from Paradise

4.4 miniSODAR™ Data

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

1. The raw 10-minute miniSODAR™ wind records were loaded into the PADS_db database and reviewed for internal consistency in the vertical profile and temporal consistency throughout the diurnal cycle. Data were plotted in time-height cross sections, with all reported data reviewed for consistency. Those data not meeting the internal consistency checks were flagged and removed from the 10-minute database. The review was performed by a trained meteorologist.

2. The validated 10-minute database was then processed to form hourly vector averages based on at least three intervals within the hour having valid wind data. Following the merging, all data were again reviewed for internal consistency using the time-height cross section process.
3. The resulting hourly validated data from the miniSODAR™ database were exported into a comma delimited data set for submission.

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. In addition, several other Sodar metrics were reviewed to assist in the interpretation of the facsimile charts:

- The Sodar data header was reviewed for indications of precipitation, which affects the appearance of the facsimile, making identification of a mixing height difficult. This information comes from the rain and snow sensors on the Sodar. Periods in which precipitation was measured were reported as "no mixing height identified," which normally indicates good mixing conditions.
- Vertical wind speed was reviewed, concentrating on the direction. Negative (downward) vertical wind speeds are consistent with subsidence and a stable layer, whereas positive (upward) vertical wind speeds indicate likely convection and a well-mixed atmosphere. A large negative vertical

wind speed relative to the horizontal wind speed usually is an indication of precipitation, which again impacts the ability to estimate the mixing height.

- Wind shear, as identified by notable changes in horizontal wind speed and direction in the vertical profile, are often good indications of the boundary defining the mixing height. This year, the vertical wind speed was also reviewed, with a change from negative to positive values providing additional evidence regarding the likely top of the stable layer.

All of the above were used to refine and confirm estimates of mixing heights. However, the process remains subjective. Temperature profile data provides a much more definitive indication of a mixing layer top, and a detailed review of the facsimile charts against temperature profile data would be useful to confirm the accuracy of the mixing heights derived from the Sodar data. A scanning radiometer would provide a good source of continuous temperature profile data under a wide range of conditions that could be used for such a comparison.

Table 4-11 summarizes key metrics obtained from the Sodar data relevant to conditions leading to high ozone. These metrics include the following:

- Median mixing height – The median mixing height is reported for four periods: "AM" referring to midnight to noon, "Morning" referring to hour 0600 to 1100, "PM" referring to noon to midnight, and "Afternoon", referring to hours 1200 to 1700. Each of these periods can potentially play a role in determining the occurrence and duration of an ozone event. Because reported mixing heights of 200m actually mean greater than 200m, it is more appropriate to look at the median rather than the mean when summarizing the mixing heights.
- 30-meter vector winds – Wind speeds measured by the Sodar at 30 meters are presented as being representative conditions within the mixed layer, while still being largely unaffected by the surface terrain. Winds are presented for two periods: 0600 – 1200 (morning) during which ozone precursors are likely accumulating, and 1200 – 1800 (afternoon), the period when higher concentrations were typically observed.
- UV radiation – UV radiation reported from the Boulder site is presented due to its role in creating ozone and its relationship with the reported mixing height. Total Watt-hours per meter squared are presented for both incoming and outgoing (reflected) radiation. Note that the readings during the first half of February were problematic, with frequent missing data, making calculations of daily values not possible.

- Peak 1-hr and 8-hr average ozone reported from the Mesa site. The Mesa site consistently showed the highest concentrations in the UGWOS network, and are therefore of most interest. Within the table, days of higher ozone concentration have been highlighted, with hourly averages greater than 60 ppb highlighted in yellow and 8-hour averages greater than 60 ppb highlighted in orange.

In reviewing Table 4-11, the importance of the mixing height is readily noted. Of the 27 days where the mixing height was estimated, only nine days had low mixing heights prevailing through the entire day (no 200m mixing heights in Table 4-11 for any part of the day). All six of the days showing notable ozone development fell within these nine days. Key conditions common with periods of higher ozone concentrations are consistent with those presented in previous UGWOS reports, as summarized below:

- Median morning (AM) mixing heights are less than or equal to 75 meters, indicating stable conditions that trap surface emissions during the morning.
- Definable tops to the mixing heights persist into the afternoon and PM periods.
- Wind speeds within the surface layer are less than 2 m/s, typically both in the morning and the afternoon – a further indication of the stable, stagnant conditions necessary for keeping precursor emissions within the area. The days with the three highest peak ozone concentrations had average morning wind speeds less than 1 m/s.

- Reflected UV radiation is at least 50% of the incoming UV radiation - a direct result of the amount of snow on the surface. Note that for the periods in question, reflected UV radiation was at least 75% of the incoming UV radiation on all marked ozone development days, with such conditions lasting through March 9.

In summary, results are similar to those obtained during other low ozone years (2009, 2010, 2012, and 2013). Low mixing heights and low wind speeds within the mixed layer played an important role for the development of higher ozone concentrations, though the very stable conditions associated with exceedances of the ozone standard did not occur in 2014. For comparison, median mixing heights during the major ozone episodes in 2011 were 30 to 40 meters lower than those recorded on the elevated ozone days in 2014.

Table 4-11 Summary of Sodar Metrics

Date	Median Mixing Height (m)				30-m Vector Winds (m/s)				UV (W-hr/m^2)		Peak Ozone (ppb)	
	AM	Morning	Afternoon	PM	Morning WS	Morning WD	After. WS	After. WD	Incoming	Outgoing	1-hr avg	8-hr avg
2/5/2014	50	40	77.5	45	1.01	341	1.21	301			44	42
2/6/2014	37.5	45	80	25	0.42	270	1.42	214			46	44
2/7/2014	35	55	75	67.5	0.79	198	1.03	203			61	54
2/8/2014	200	200	200	200	1.07	209	5.7	259			47	45
2/9/2014	200	200	200	60	8.42	278	3.73	271			49	48
2/10/2014	60	137.5	200	200	2.99	321	8.36	305			49	48
2/11/2014	200	200	70	150	0.27	47	2.35	275			59	52
2/12/2014	62.5	200	200	200	3.11	85	3.65	92			49	47
2/13/2014	67.5	137.5	200	200	0.15	300	8.98	271			47	47
2/14/2014	60	55	77.5	200	0.92	307	1.6	74			56	52
2/15/2014	200	200	200	85	0.4	268	2.47	62			44	40
2/25/2014	75	75	200	200	0.64	270	6.46	320	282.1	250.9	48	43
2/26/2014	72.5	72.5	85	55	0.57	229	1.45	63	287.4	257.7	74	65
2/27/2014	75	75	70	72.5	0.96	338	1.69	347	241.1	210.7	69	60
2/28/2014	60	75	200	200	0.74	99	4.24	230	255	218.5	52	50
3/1/2014	200	200	200	137.5	11.3	150	6	138	217.4	195.9	50	48
3/2/2014	75	67.5	70	72.5	0.13	308	1.68	66	298.5	274.6	86	56
3/3/2014	75	67.5	35	62.5	1.26	93	1.51	39	285.1	249.5	51	48
3/4/2014	67.5	82.5	200	200	1.08	322	6.23	312	228.4	194.6	51	49
3/5/2014	60	60	60	67.5	1.98	19	2.83	50	292.3	254.7	64	56
3/6/2014	75	85	200	200	1.73	27	5.17	115	202.2	169.6	54	51
3/7/2014	200	200	200	200	11.41	313	11.06	315	329.5	267	48	47
3/8/2014	100	100	80	72.5	2.29	326	2.34	303	329.2	259.6	48	47
3/9/2014	80	75	62.5	60	2.12	356	1.75	28	292.8	222.5	62	57
3/10/2014	72.5	92.5	150	200	1.35	123	4.55	296	282.3	193.7	53	50
3/11/2014	200	200	200	200	6.05	351	4.72	67	268.5	162.6	50	48
3/12/2014	87.5	97.5	200	200	0.82	19	1.77	62	332.1	199.9	55	53

5.0 SUMMARY AND CONCLUSIONS

This section provides a summary of the UGWOS 2014 field measurement effort (January 15 through March 31, 2014), 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 and 2013 field measurement campaigns focused on the spatial distribution of ozone and ozone precursors using existing long-term monitoring stations, mobile trailers at Big Piney and Jonah Field with the addition of three mesonet sites and speciated VOC canister sampling systems at eight of the monitoring sites in 2013. The 2014 campaign largely mirrored the 2013 campaign's spatial distribution of ozone and ozone precursors with the utilization of three mesonet sites. At six sites, speciated VOC canister samples as well as carbonyl samples for measurement of formaldehyde and acetaldehyde were collected. Prior to the 2014 study, meteorological and gaseous pollutant equipment at the Wyoming Range monitoring station was removed from service and relocated to Big Piney which will be managed as a long-term site. The long-term Big Piney site monitors air quality downwind of Big Piney/La Barge oil and gas field development area and it provided air quality data for the west side of the UGWOS domain.

The synoptic weather pattern during UGWOS 2014 was dominated by a trough over the eastern U.S. which brought frequent storms and very cold temperatures to that part of the country. In the western U.S. and eastern Pacific, high pressure was the more common pattern keeping much of southern and central portions of the west coast very dry. Resultant flow experienced in western Wyoming from this pattern was generally from the west to northwest, with storms mostly brushing the area from the north as they traveled up and over the high pressure system and dropped southward into the low pressure to the east. The synoptic weather pattern, over the two and one-half month study period, aligned the jet stream near the study area resulting in a dynamic atmosphere where high pressure rarely remained over the area for more than 24 hours.

During the UGWOS 2014 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 65 ppb, which was observed at the Mesa mesonet site on February 26, 2014.

5.1.1 UGWOS 2014 Field Operations

As in previous years, weather and ozone outlook forecasts were issued daily during UGWOS 2014 to alert AQD and contractor personnel when conditions favoring elevated ozone events were expected. Daily forecasts provided sufficient time for MSI Trinity's air quality field technicians to activate additional measurements during IOPs including a network of speciated VOC samplers and a tethered balloon ozonesonde/radiosonde 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, and current equipment and data collection status.

UGWOS field operations in 2014 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 located at sites utilized for measurements during previous UGWOS programs (Mesa, Paradise, and Warbonnet) provided continuous ozone and meteorological measurements as well as camera images. 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 Big Piney, Boulder, and 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 tethered air sounding system utilizing radiosondes and ozonesondes was assembled, tested, and placed in a state of readiness for daily operation by MSI Trinity field technicians during IOPs from the Jonah and Boulder sites.

Existing WDEQ-AQD long-term monitoring stations (Big Piney, Boulder, Daniel, Pinedale, Juel Springs, South Pass, and Moxa) provided surface air quality and meteorological measurements during the UGWOS field effort. 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 NO_y and "true NO_2." The NO_y analyzer is designed to measure oxides of nitrogen compounds that are too unstable to be measured when brought in through a conventional air sampling inlet system. The "true NO_2" measurements utilize a highly selective photolytic converter which allows for better speciation of lower levels of NO_2 than conventional oxides of nitrogen analyzers. The WDEQ-AQD Wind Explorer mini-SODAR continued to operate adjacent to the Boulder monitoring station for the duration of the UGWOS 2014 study period.

During UGWOS 2014, conditions which favor elevated ambient ozone concentrations never materialized and no IOPs 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 2014 field study data:

- A dominant high pressure system located over the Pacific coast kept the jet stream centered north of the study area. This pattern allowed for frequent weather systems suppressing the formation of significant temperature inversions and periodic snowfall.
- There were no designated IOPs during the 2014 study period. This is the third year in which this has occurred. There were no IOPs declared during UGWOS 2010 or UGWOS 2013.
- There was light snow throughout the basin at the beginning of the study. Snow cover throughout the period was similar or slightly deeper than either 2012 or 2013 campaigns.
- 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 2014 study was 65 ppb which is well below the current U.S. EPA NAAQS of 75 ppb.

- Measured VOC concentrations were consistently higher at the Paradise site than at the other monitoring/sampling locations. These higher concentrations are likely due to the Paradise sites 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 (generally lower than measurements taken in 2013) as might be expected during a measurement season where conditions were not favorable for significant elevated ozone development. 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 2014 than in previous UGWOS studies. This is consistent with the diminished snow cover during 2014 and implies that less UV radiation would be available for photolytic ozone production.

6.0 ACKNOWLEDGMENTS

Many individuals and groups in addition to the staff of Meteorological Solutions Inc. A Trinity Consultants Company and T&B Systems contributed to the successful completion of the 2014 Upper Green River Winter Ozone Study and its presentation in this report. Cara Keslar, serving as Project Manager for the WDEQ arranged funding, interfaced with Federal and State agencies and other WDEQ contractors, managed contracting details, and provided helpful direction, guidance and comments throughout the study. Many other WDEQ personnel provided assistance and were helpful in making 2014 a successful study. ARS provided meteorological and air quality data they were collecting for the WDEQ at the Daniel and South Pass sites.

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APPENDIX A

Monitoring and Quality Assurance Plan

QUALITY ASSURANCE PROJECT PLAN

for the

UPPER GREEN RIVER WINTER OZONE STUDY - 2014

Prepared for

State of Wyoming
Department of Environmental Quality, Air Quality Division
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January 28, 2014

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UGWOS 2014 QAPP APPROVAL

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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 2014, 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).

High ozone events observed in this area over the past several years 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 2013. While meteorological conditions unfavorable to ozone formation encountered during the 2007 study period resulted in only limited monitoring, more favorable meteorological conditions during 2008 and 2011, and to a lesser degree during 2009, 2010, 2012 and 2013 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 2014. This QA plan addresses the 2014 monitoring effort.

Similar to past years, data from the 2014 study will continue to be used to refine a conceptual model of ozone formation developed on the basis of prior year's studies of ozone formation. The conceptual model will be used along with the field data to develop accurate meteorological and air quality numerical simulations of the ozone events. Both the conceptual and numerical models will in turn be used to develop effective air quality management strategies needed to adequately protect public health and the environment in accordance with applicable State and Federal laws.

SECTION 2

SAMPLING PROGRAM DESCRIPTION

The sampling period for UGWOS 2014 will run from January 15, 2014 through March 31, 2014. Sampling that will be conducted for UGWOS during this period is described below.

2.1 FORECASTING PROTOCOL

The UGWOS effort for 2014 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) 2014 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.

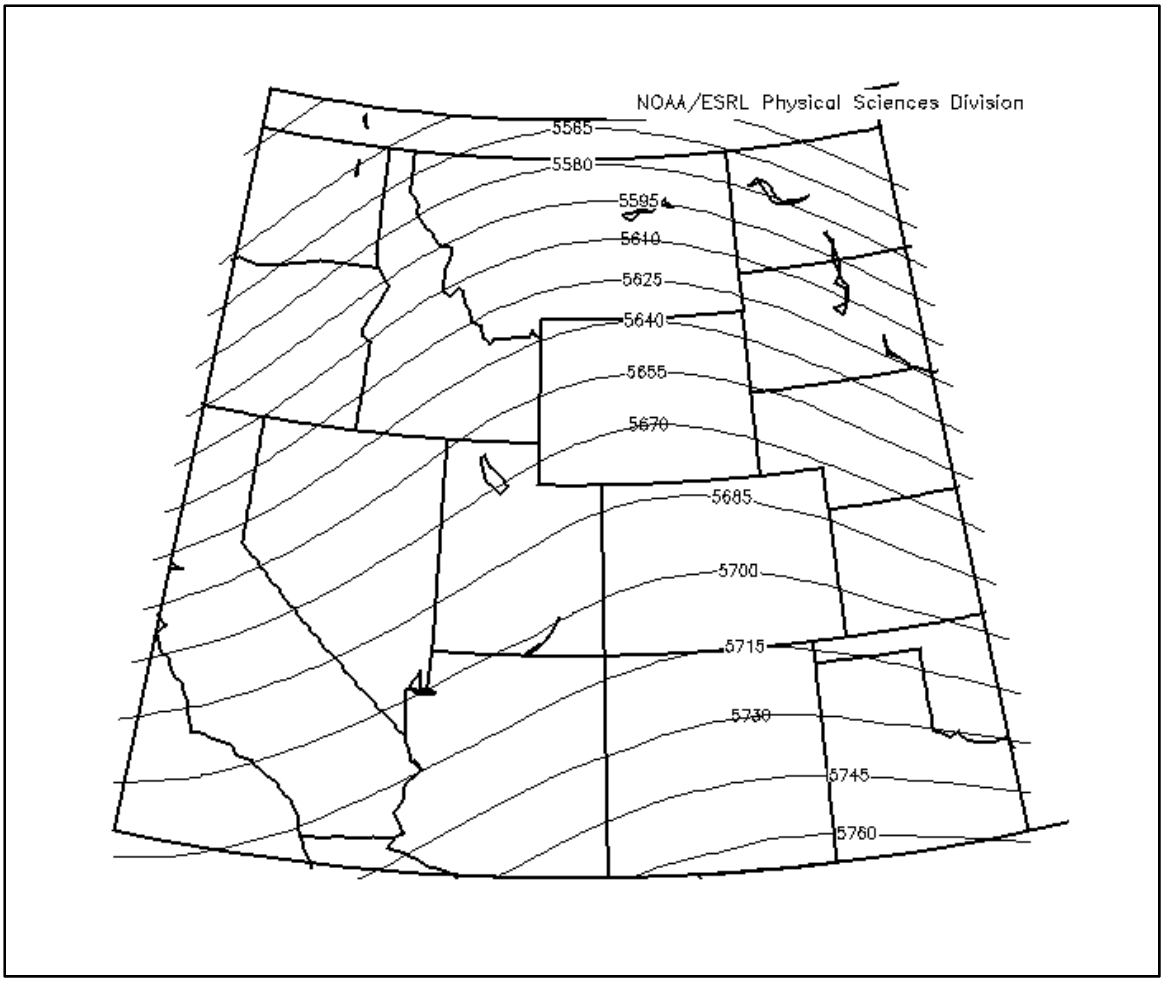


Figure 2.1 Composite 500 mb Heights During High Ozone Periods

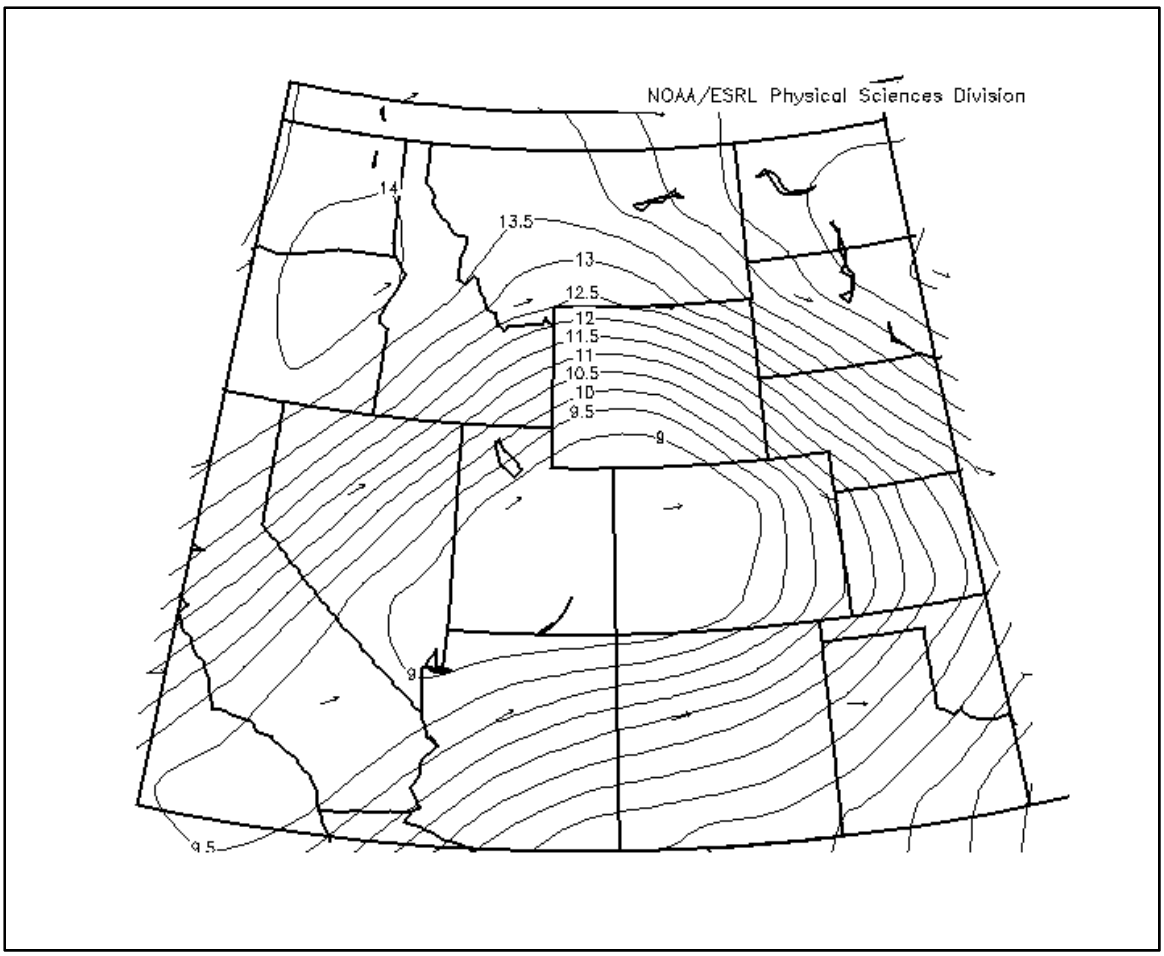


Figure 2.2 Composite 500 mb Winds During High Ozone Periods

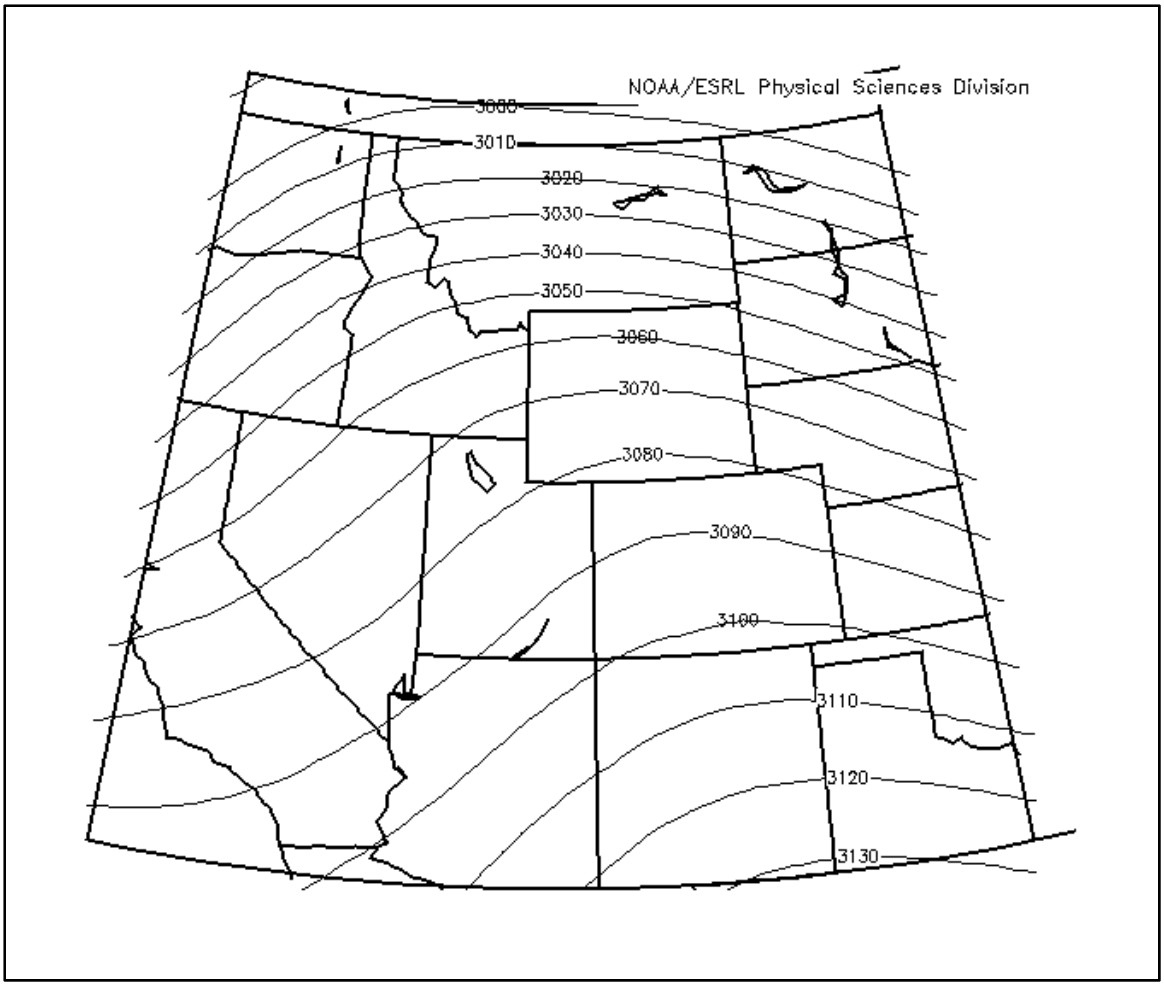


Figure 2.3 Composite 700 mb Heights During High Ozone Periods

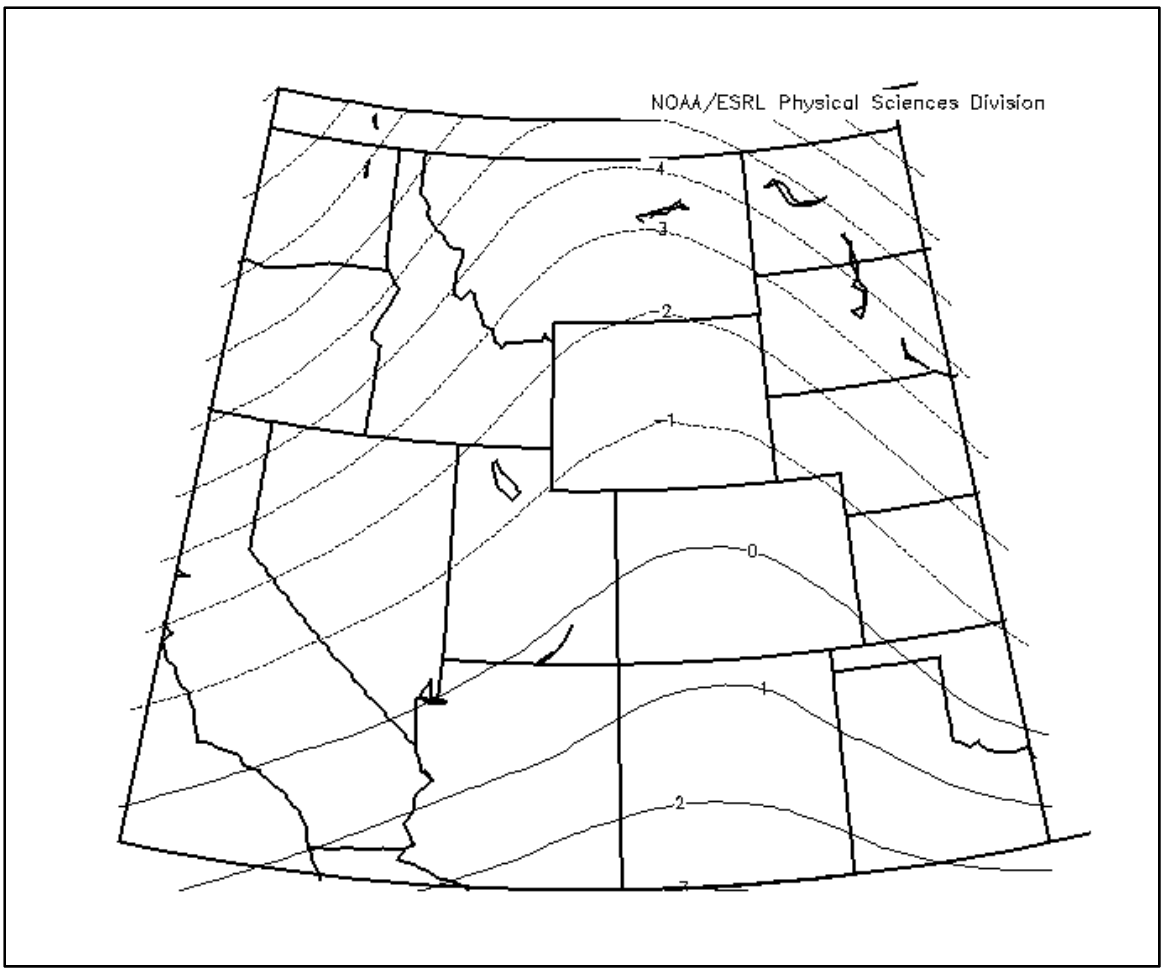


Figure 2.4 Composite 700 mb Temperature During High Ozone Periods

2.2 CONTINUOUS MEASUREMENTS

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

2.2.1 Super Mesonet Measurements

Surface ozone, wind speed, wind direction, and temperature measurements will be taken from a 3-site super mesonetwork (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. A snow stick will be installed at each site to give an estimate of snow depth at each of the sites. The snow sticks will be in prominent view of each of the camera locations.

The mesonet 2B 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 a 2B ozone generator and zero-scrubber, with 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 Spring, Big Piney, Boulder and mesonet sites (see below). He will also be available to troubleshoot issues at all AQD sites in the study area (Daniel, Boulder, Pinedale, Juel Spring, Big Piney, South Pass and Farson meteorological tower). The field technician will also be available to assist with UGWOS and AQD audits during the study period.

2.2.2 Ozone and NO/NO_x 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 trailer 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. The site will be polled every 15 minutes to update data and post to project website. A snow stick will be installed to give an estimate of snow depth in the monitoring area. 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 2014 monitoring effort, the WDEQ MiniSodar (Sodar) will be maintained at the existing WDEQ monitoring site at Boulder. Both surface winds 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 evaluate the collected data during the field effort, both in real-time and after the program is over. This additional evaluation is being conducted to determine what can be learned from measured parameters such as the vertical wind speed (W) and sigma-W, and how this information can be used to both help forecast the events and to help understand the mechanisms that control the mixing out of the shallow mixed layer.

2.3 INTENSIVE MEASUREMENTS

During periods when high ozone levels are forecast, additional intensive measurements will be initiated. Up to 10 IOP days over the course of two IOP periods 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 and carbonyl samples, as described below.

2.3.3 Tethered Sounding Operations

Vertical profiles and aloft measurements of ozone, temperature and relative humidity will be initiated daily during IOPs at 2 sites (Boulder and Jonah). Additional soundings may be considered at Big Piney based on review of data within the study area. The first sounding will be taken at 9:00 to characterize the stable period of the diurnal cycle. Measurements will be ongoing thereafter through 16:30 to characterize the daytime boundary layer. The anticipated schedule is as follows:

- 0900 – 0930 Up/down sounding
- 0930 – 0945 Review data from sounding
- 0945 – 1015 Maintain balloon at constant level of interest, based on review
- 1015 – 1030 Up/down sounding
- 1030 – 1045 Review data from sounding

- 1045 – 1115 Maintain balloon at constant level of interest, based on review
- Repeat pattern until . . .
- 1615 – 1630 Complete day's operation with final up/down sounding

The EC-cell ozone sampler will be compared with the EPA designated equivalent analyzer, which will be simultaneously operating at each sounding site each time the balloon is elevated and retrieved. Balloon tethering height will be determined using the recorded altitude in the sonde GPS system for the MSI system and will be calculated using an onboard pressure sensor in the T&B Systems tethersonde.

It should be noted that on the first day of an IOP, there will be preparation time required to prepare the balloon and line assembly. Thus, the first sounding will be delayed until midmorning. At the completion of each sampling day, the balloons will be tethered at the ground.

It will be up to the tether balloon operator to determine when flying conditions become impractical due to higher winds. In these conditions, the balloon will be brought to the ground and secured until lower wind speeds allow further flights.

Tethered sounding sites will be manned by MSI and T&B Systems.

2.3.3 VOC Sampling

VOC sampling will be conducted at the Boulder, and Big Piney sites, as well as at the UGWOS-specific Jonah air quality site and the three mesonet 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. Carbonyl samples will be collected using DNPH-coated cartridges outfitted with ozone scrubbers and connected to constant flow pump systems over the same time period as the canisters. Samples will be collected on IOP days from 0700-1000. Thus, up to 10 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, 2014 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 latitude/longitude 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 two 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 Trinity Consultants. 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 in the study region.

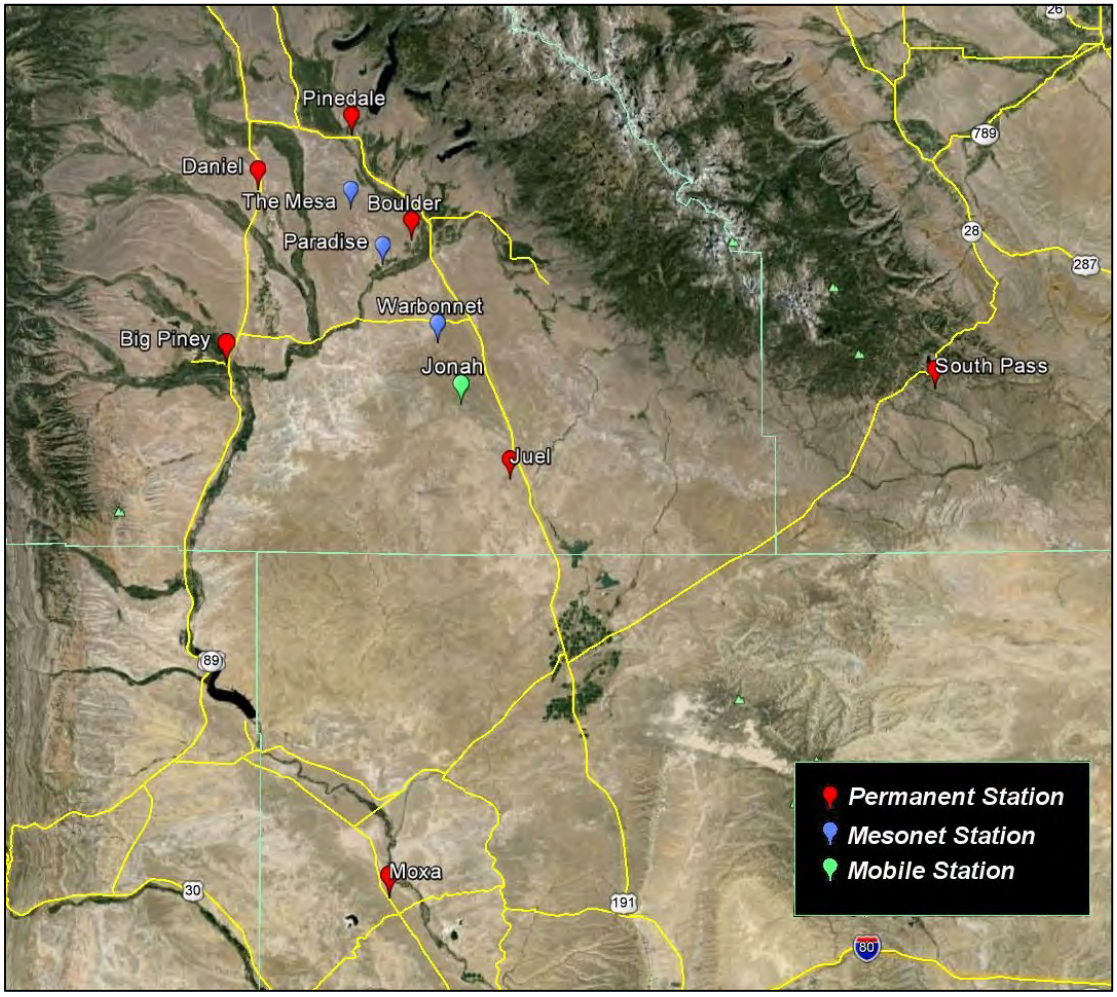


Figure 3.1. Map of UGWOS and Additional Ozone Monitoring Site Locations

Table 3-1. Monitoring Locations

Site	Latitude	Longitude	Elev.
	SODAR SITE		
Boulder	42.7188	-109.7529	7078’
	MESONET SITES		
Mesa	42.7774	-109.8829	7522’
Paradise	42.6825	-109.8090	6966’
Warbonnet	42.5703	-109.7022	7414’
	JONAH AREA SITE		
Jonah (2014)	42.4736	-109.6497	7259’
	EXISTING MONITORING SITES OF INTEREST		
Big Piney	42.4870	-110.0995	6823’
Daniel	42.7910	-110.0650	7084’
Farson	42.1184	-109.4541	6619’
Pinedale	42.8698	-109.8707	7186’
Juel Spring	42.3735	-109.5605	7020’
South Pass	42.528	-108.720	8287’
Moxa	41.750	-109.788	6460’

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 with an Option Wireless Technology - Globesurfer III™ cellular IP router 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 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 a professional transit adjusted for local declination, solar alignment.

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

Campbell Scientific 109-L Temperature Probe

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

Accuracy (performance checks)	±0.5°C
Precision (performance checks)	±0.2°C
Resolution	0.1°C

Campbell Scientific CR850 Data Loggers

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

StarDot Video Cameras

StarDot video cameras will be used to automatically obtain high resolution images from each of the sites every 15 minutes.

4.2 JONAH MONITORING SITE

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

Thermo Scientific Model 42*i* $NO/NO_2/NO_x$ Analyzer – EPA Approval RFNA-1289-074

The Model 42*i* 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 49*i* Ozone Analyzer – EPA Approval EQOA-0880-047

The Model 49*i* 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 700EU Calibrator

The Model 700EU 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 700EU is equipped with an optional built-in, programmable ozone generator for accurate, dependable ozone calibrations and to produce NO_2 when blended with NO gas in the internal GPT chamber. As many as 50 independent calibration sequences may be programmed into the M700EU, 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 701H zero air system.

RM Young Model 05305 Wind Monitor AQ

For monitoring of wind speed and wind direction an 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	±0.5°C
Precision	±0.2°C
Resolution	0.1°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	±5°
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

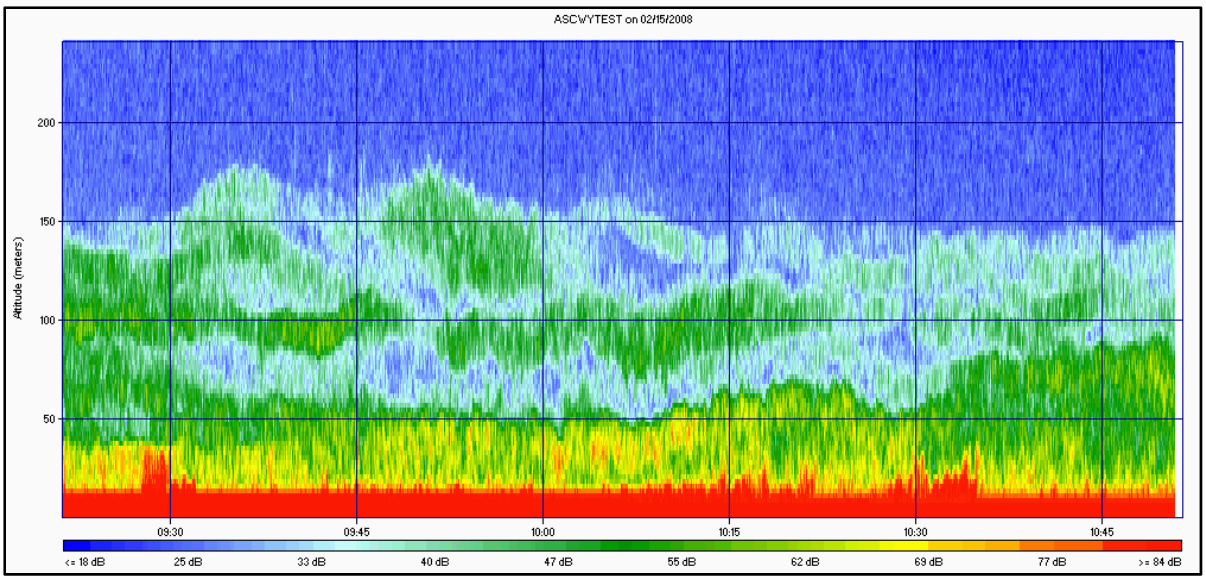


Figure 4.2. Example of Sodar Backscatter Data Capturing the Daytime Mixing Height Layers Under Cold Wintertime Conditions.

4.4 TETHERED SOUNDINGS

Tethersondes will be used to make vertical measurements of ozone, temperature and relative humidity at up to three locations (Boulder, Jonah and Big Piney). The T&B Systems' tethersonde packages will be simple, cost-effective balloon borne instruments and will use the portable ozone saturation sampler developed by T&B Systems. Unlike the MSI tethersonde system, the T&B Systems tethersonde will rely on an onboard datalogger to store data from the measurement platform, which includes ozone (partial pressure) from an EN-SCI Corporation 2ZV7-ECC ozonesonde, ozone cell temperature, ambient temperature and barometric pressure. Barometric pressure and cell temperature will be used to calculate ozone concentration. A secondary onboard data logger will be used to telemeter data to ground level to allow the operator to review data and will also collect and store relative humidity values. Figure 4.2 shows an example of data collected with 5-minute average values at 30-minute intervals, along with the hourly average data from the local ozone monitor. Data were measured and compared at the Santa Clarita, CA SCAQMD monitoring station.

The MSI tethersonde will use the WDEQ iMet-3050 403 MHz GPS Upper-Air Sounding System in a modified configuration to measure and record data using a iMet-1 RSB radiosonde attached to the EN-SCI Corporation 2ZV7-ECC ozonesonde to telemeter data to ground level.

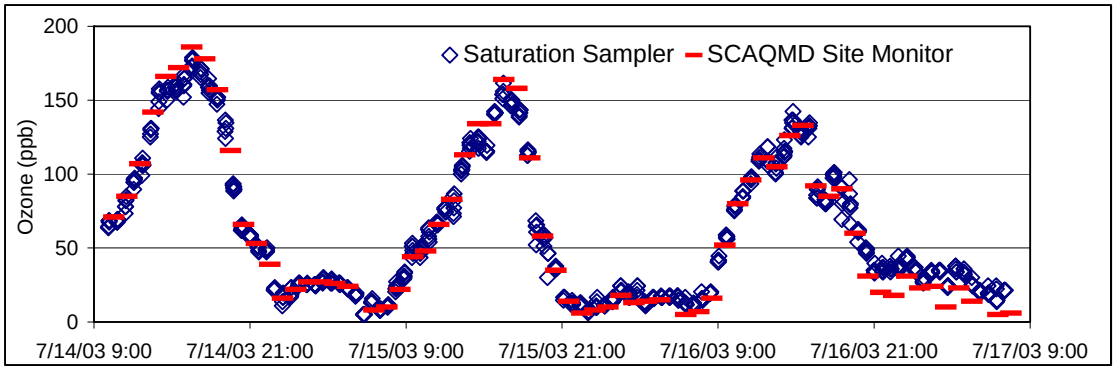


Figure 4.2. Comparison of Saturation Sampler Versus SCAQMD Ozone Data at the Santa Clarita Site in 2003.

The tethersondes with integral ozone measurements operated by T&B Systems and MSI are based on the potassium iodide (KI) bubbler detection principle is described below.

<u>EN-SCI Corporation 2ZV7-ECC Theory of Operation</u>

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:

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2.$$

The cell converts the iodine to iodide according to:

$$I_2 + 2e \rightarrow 2I^-$$

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. Below are the ozone sensor specifications and project data accuracy goals.

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

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

4.4 VOC SAMPLING

WDEQ-owned VOC 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 ⅛" Teflon sample tube connected to a ¼ " 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.

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

MSI's field technician will be responsible for loading and retrieving canisters and carbonyl cartridges into the samplers at each site, confirming sample run times, removing samples and filling out the affiliated documentation. Exposed sample media at the monitoring sites will be collected at the end of each intensive study day and 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 SUMMA canister samples will be analyzed using Method TO-14 with an expanded PAMS list of compounds listed in Table 4-1. Carbonyl samples will be analyzed using Method TO-11 for the compounds listed in Table 4-2. Analysis will be performed by Environmental Analytical Services, Inc., San Luis Obispo, CA.

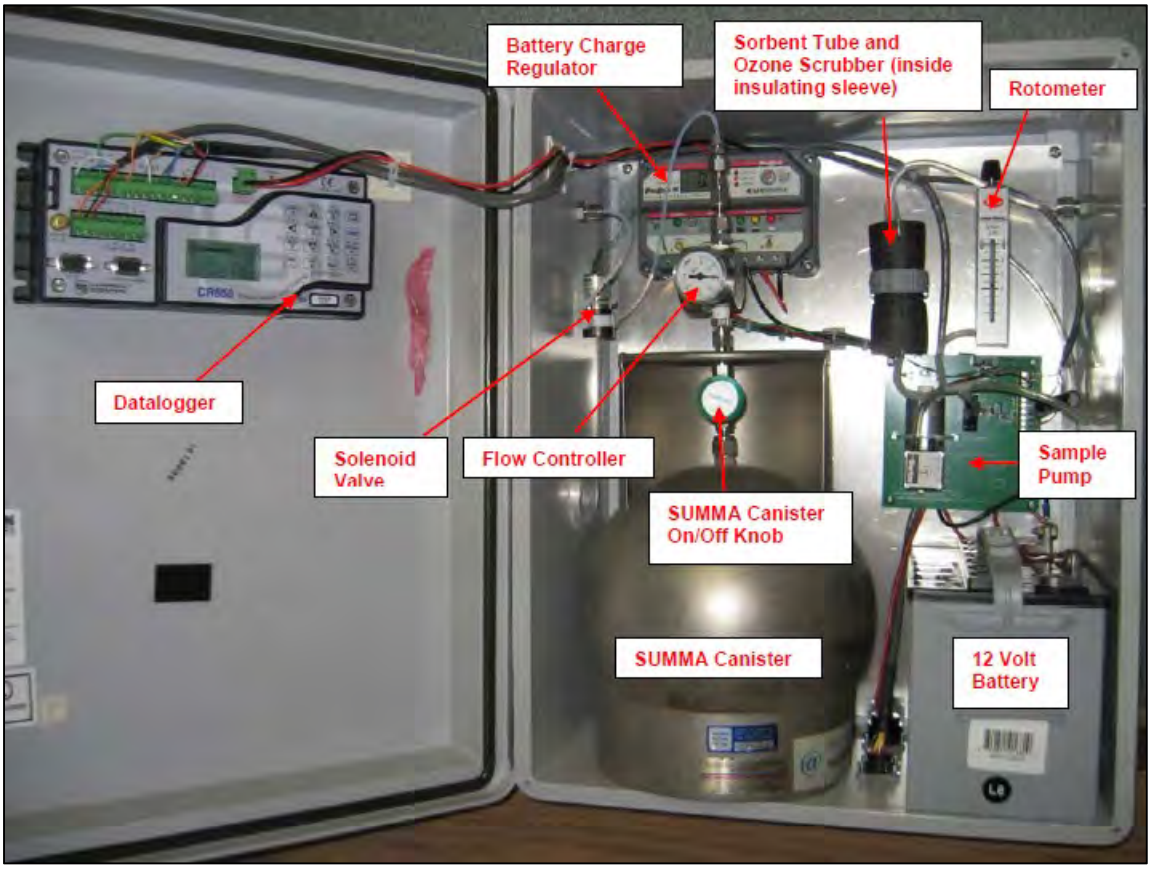


Figure 4.3. Canister Sampler

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	

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

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

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

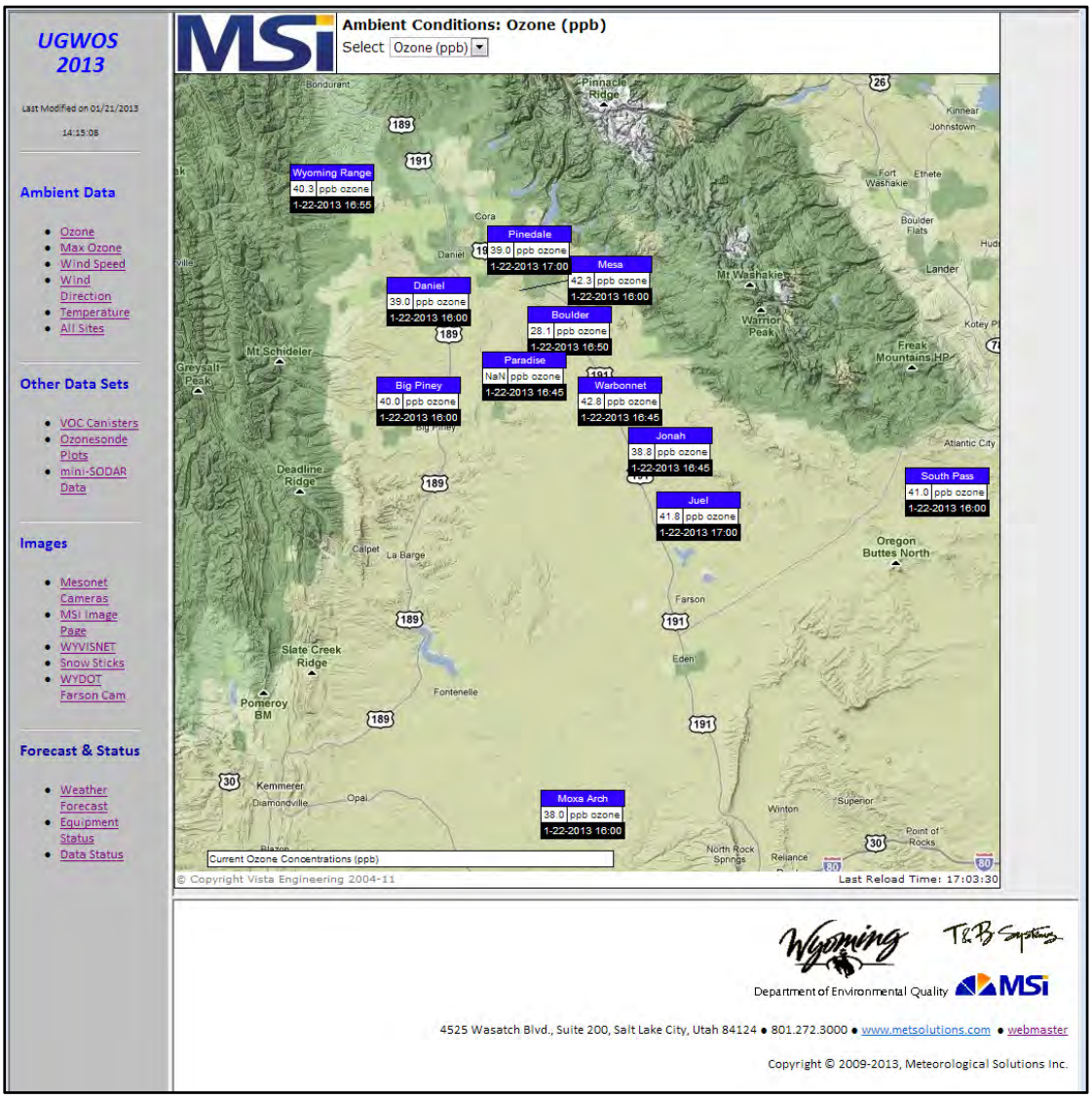


Figure 5.2. Equipment Status

Last Modified on 01/28/2014 10:12:02 UGWOS 2014

Equipment Matrix and Current Status

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

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

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. Data Quality Control Codes

Flag	Description
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 UGWOS 2007 - 2013 field studies. The database includes an inventory spreadsheet file to help users track and ensure that all of the data were submitted and processed in a timely and consistent manner. All data files submitted will be examined to verify unique names for all sites, instruments, and parameters so that no orphan or duplicate records exist in any of the tables. A system is in place for identifying the version and or modification date of all data files. All files are backed up daily.

The data have the following file format:

<u>Surface Hourly Meteorological Data</u>

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

<u>Ozone 8-hour averaged data</u>

SITE, DATE, HOUR, O3_8HR, O38HR_QC

<u>Hourly Surface Air Quality data</u>

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.

<u>Upper level meteorological and air quality data</u>

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

Tethered Sounding Data

Tethersonde data will also be collected during IOPs. The tethersonde database will be developed and refined as the program evolves.

VOC Data

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

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

- Parts per billion (ppb) for O_3, NO, NO_2, and NO_x
- Meters per second for wind speed (as a general rule, metric units will be used)
- Degrees Celsius for ambient temperature
- Watts/m^2 for radiation
- Micrograms per cubic meter, parts per billion by volume, and parts per billion by Carbon for VOC canister data
- SITE = Alpha-numeric site code identifier
- DATE = (MM/DD/YY)
- HOUR= Nearest whole begin hour (HH) (MST)
- TIME, START_TIME or END_TIME = Time stamp of data (HH:MM:SS) (MST)
- HEIGHT = Elevation in meters above MSL
- QC_CODE, WS_QC, WD_QC, O3_QC, etc =
  "V" (valid), "M" (missing), "I" (invalid), "S" (secondary MQOs)
- NOTES = any additional information

The Level 1 data files along with the documentation files will be available for download on an FTP server.

5.2 DATA REPORTING

Files of all data collected during the study will be transmitted to WDEQ by June 1, 2014.

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 from the Sodar;
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, 2014. 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. Casey Lenhart will serve as the Field Operations Manager for the study. He will be responsible for coordinating and verifying corrective action for any measurement-related problems.

An organizational chart for UGWOS 2014 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 Yoho 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, 2014. 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.

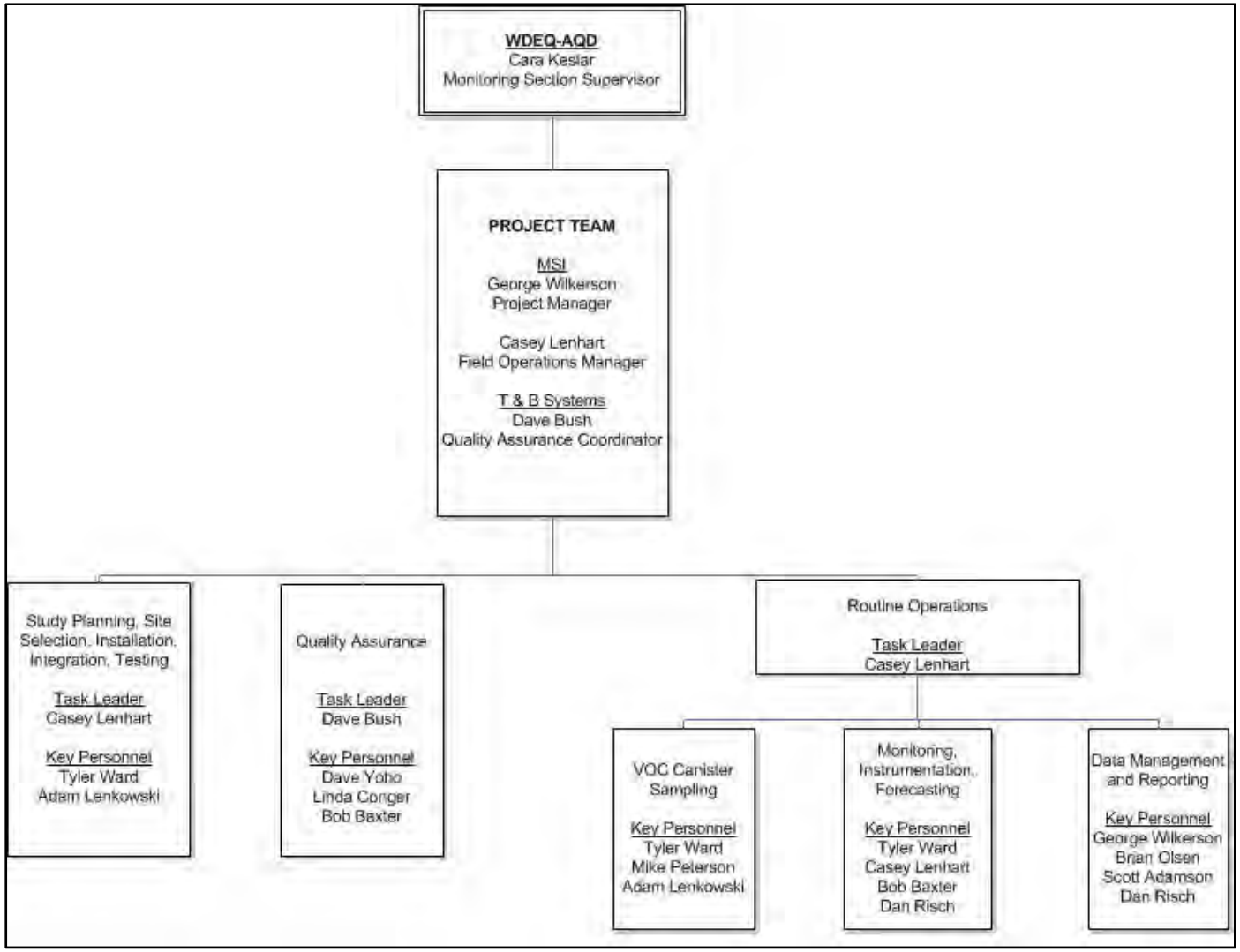


Figure 6.1. Project Organization.

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)
Adam Deppe	Wyoming DEQ	Forecasting	(307) 777-8754
Steve Mugg	Wyoming DEQ	Quality Assurance Audits	(307) 777-7352
George Wilkerson	MSI	Project Manager	(801) 272-3000 Ext. 304
Dan Risch	MSI	Forecasting	(801) 272-3000 Ext. 306
Casey Lenhart	MSI	Field Manager, Reporting	(801) 272-3000 Ext. 307 (801) 979-7874 (cell)
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
Mike Peterson	MSI	VOC Canister Sampling	(801)-272-3000 Ext. 310 (801)-450-8706 (cell)
Adam Lenkowski	MSI	VOC Canister Sampling	(801)-272-3000 Ext. 309 (801)-419-2882 (cell)
Tyler Ward	MSI	Full-time onsite field technician	(928) 814-3926 (cell)
David Bush	T&B Systems	T&B System's QA Coordinator	(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, QAPP, IOP field technician	(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 2014 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 2014 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 2014 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.

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/NO_x 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/NO_x 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_2 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_3)	Multipoint comparison of ozone concentrations with ozone transfer standard
NO/NO_x	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 Yoho will conduct the systems audits of the UGWOS-specific operations. With the exception of tethersonde operations, Mr. Yoho is independent of all UGWOS 2014 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 45° 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 Level 2 standard maintained following EPA's guidelines at their office in Valencia, CA.

Performance audits of the measurements at the Jonah site and the WDEQ sites specific to the UGWOS study area will be conducted by Mr. Steve Mugg. 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 EPA Region 8's standard reference photometer. The gaseous analyzers will be audited using a certified dilution system and a certified cylinder of EPA protocol blended gas.

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. Yoho and Mr. Mugg will work with Mr. Lenhart 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.

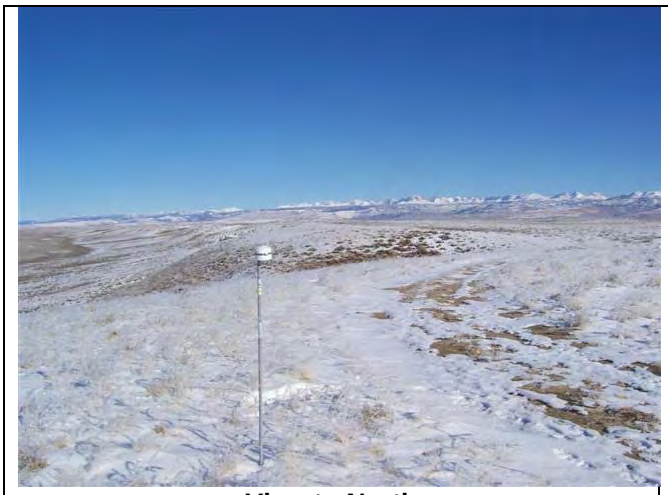
United States Environmental Protection Agency (1999): EPA Requirements for Quality Assurance Project Plans. Document EPA QA/R-5. U.S. EPA Quality Staff Interim Final Report, Research Triangle Park, North Carolina. November.

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.

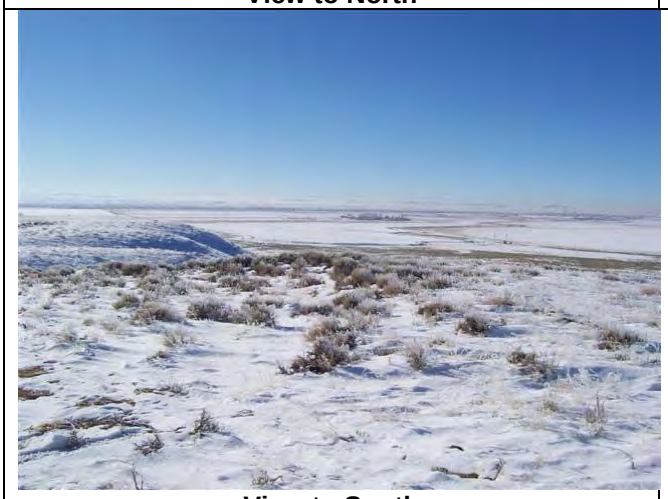
APPENDIX A

SITE PHOTOS

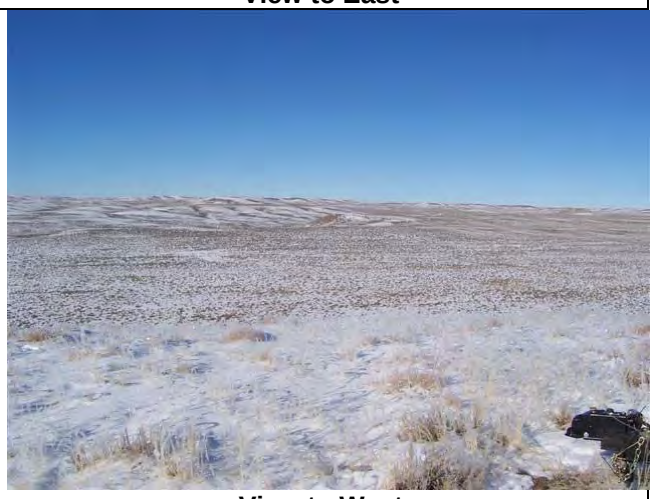


View to North

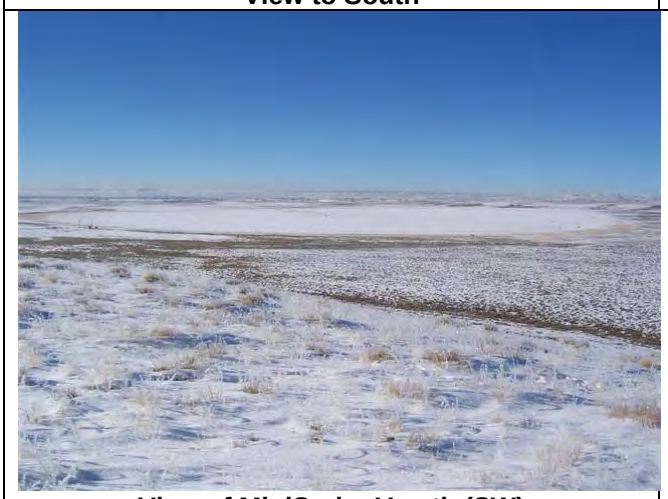
View to East



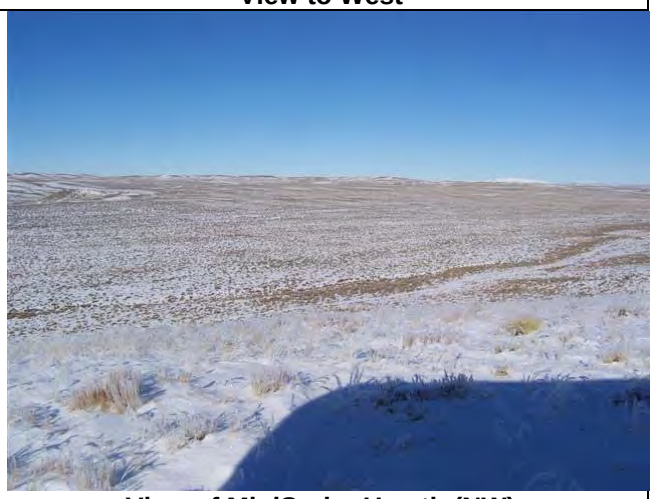
View to South



View to West



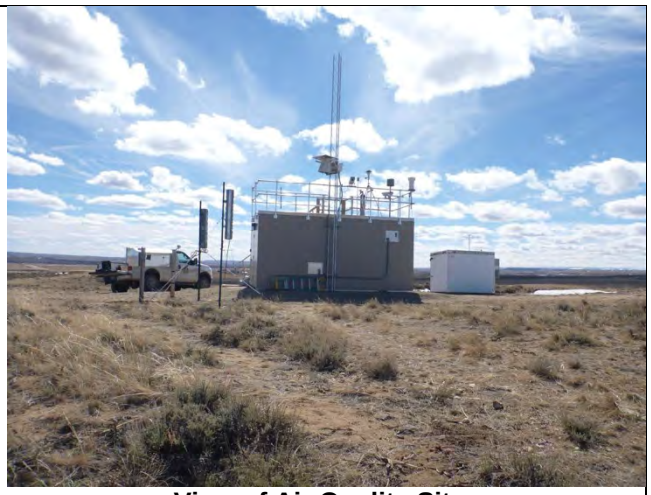
View of MiniSodar V path (SW)



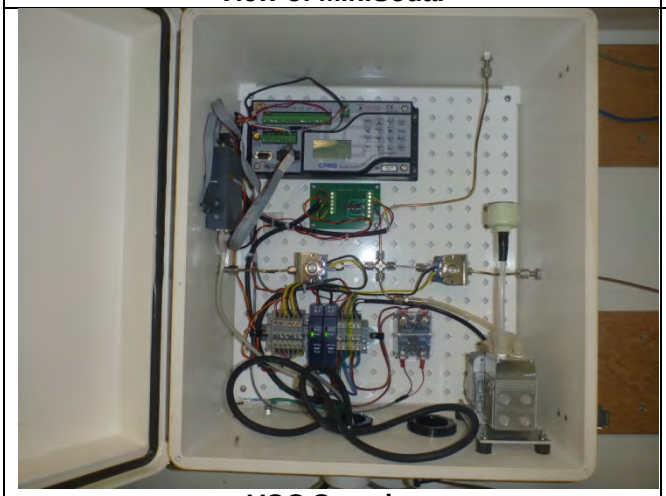
View of MiniSodar U path (NW)

Boulder Site

View of MiniSodar



View of Air Quality Site

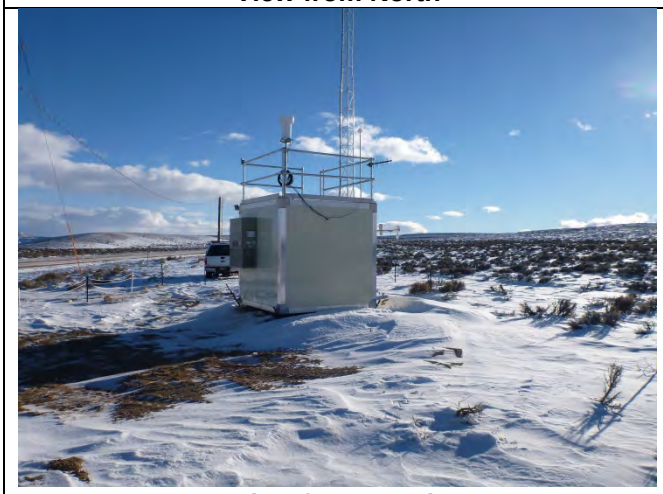


VOC Sampler

Boulder Site

View from North

View from East



View from South

View from West

Big Piney VOC Sampling

View from Jonah to North

View from Jonah to East

View from Jonah to South

View from Jonah to West

Air Quality Analyzers

Jonah Site

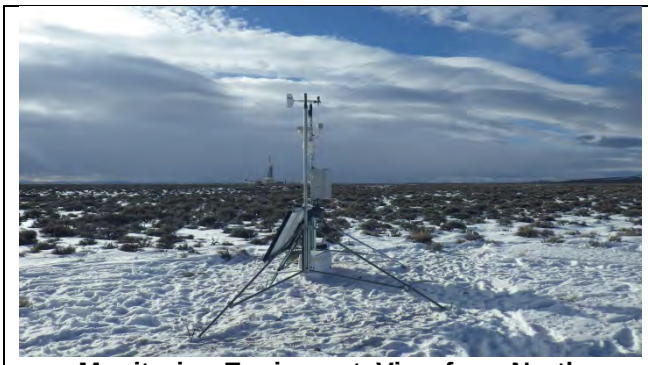
Monitoring Equipment, View from North

View from East

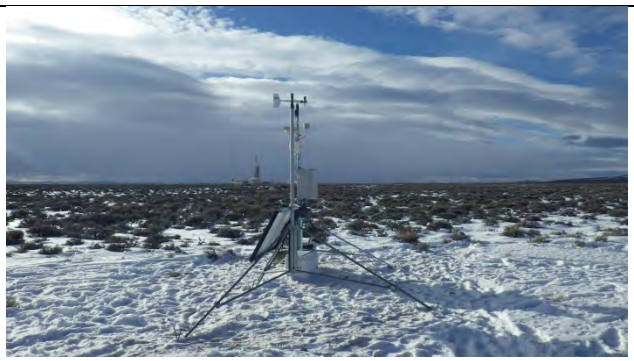
View from South

View from West

Paradise Site



Monitoring Equipment, View from North

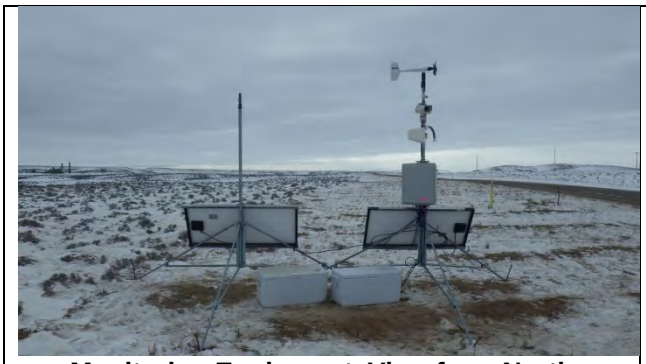


View from East

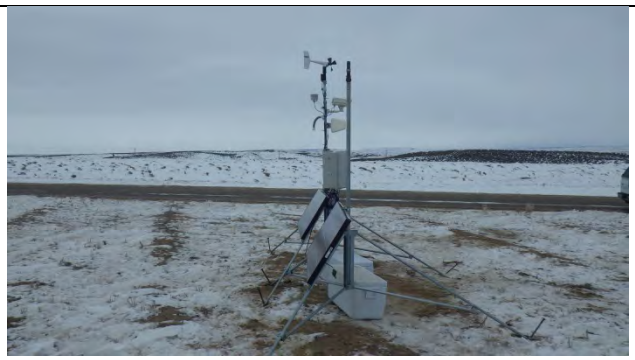
View from South

View from West

Mesa Site

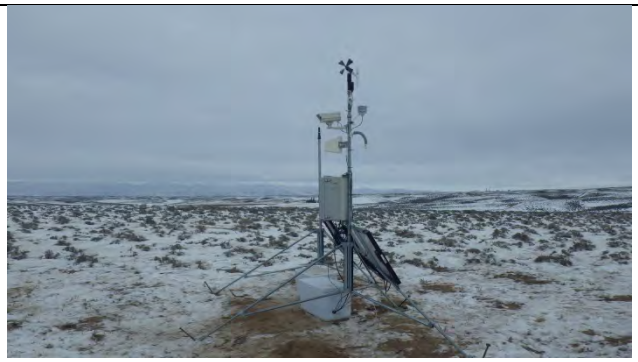


Monitoring Equipment, View from North



View from East

View from South



View from West

Warbonnet Site

APPENDIX B

STANDARD OPERATING PROCEDURES

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 1ºC, 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

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**.

4525 Wasatch Blvd. Suite 200 SLC, UT 84124 MSI Meteorological Solutions Inc. P: 801.272.3000 F: 801.272.3040	**STANDARD OPERATING PROCEDURE**	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

Problem/Symptom	Likely Cause	Corrective Action
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.

Table 1 Continued
Troubleshooting the Ozone Analyzer

Problem/Symptom	Likely Cause	Corrective Action
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.

Table 1 Continued
Troubleshooting the Ozone Analyzer

Problem/Symptom	Likely Cause	Corrective Action
Required calibration parameters are outside the adjustable range (±9 ppbv offset and/or ±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 conncentration.	Solenoid valve cable is not properly connected to circuit board.	Reattach solenoid valve cable to circuit board.

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 1ºC, 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).

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.

4525 Wasatch Blvd. Suite 200 SLC, UT 84124 MSI Meteorological Solutions Inc. P: 801.272.3000 F: 801.272.3040	**STANDARD OPERATING PROCEDURE**	Title: Thermo Scientific Model 42i $NO/NO_2/NO_x$ Analyzer Calibration	
		Number: SOP 77	Page: 1 of 1
		Revision Number: 1	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 25ºC and 760 mmHg.
3. Precautions should be taken to remove O_3 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_x backgrounds to zero
   b. Calibrating the NO channel to the NO calibration gas
   c. Calibrating the NO_x channel to the NO_x calibration gas

5. The NO and NO_x 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_x background:
    a. The NO channel should be calibrated first and then the NO_x channel.
        1. Determine the GPT flow conditions required to meet the dynamic parameter specifications.
        2. Adjust the GPT diluents air and O_3 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_x, and NO_2 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_x background to zero.
            e. Record the stable zero air responses as ZNO, ZNO_x, and ZNO_2.
        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:

$$[NO]out = \frac{FNO\ X\ NOSTD}{FNO+FO+FD}$$

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_2, and NO_x readings have stabilized.

2. 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.
3. Press ← to calculate and save the new NO coefficient based on the entered span concentration. The NO recorder response will equal:

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

   Where: URL = Nominal upper range of the NO channel, ppm
4. Record the [NO]out concentration and the analyzer NO response as indicated by the recorder response.

Calibrate the NO_x Channel to the NO_x Calibration Gas

Use the following procedure to calibrate the NO_x channel to the NO_x calibration gas.

1. Press ■ to return to the Calibration menu and choose **Cal NO_x Coefficient**.
2. Verify that the NO_x calibration gas concentration is the same as the NO calibration gas concentration plus any known NO_2 impurity. The NO_x line of the Calibrate NO_x screen displays the current NO_x concentration. The SPAN CONC line of the display is where you enter the NO_x calibration gas concentration. Use ←→ to move the cursor left and right and ↑↓ to increment and decrement the numeric character at the cursor.
3. Press ← to calculate and save the new NO_x coefficient based on the entered span concentration.
4. Press ► to return to the Run screen. The exact NO_x concentration is calculated from:

   [NOx]OUT = $\frac{FNO\ X\ [NO]STD+[NO2]IMP}{FNO+FO+FD}$

   Where:

   [NOx]out = diluted NOx concentration at the output manifold, ppm

   $[NO_2]$IMP = concentration of NO_2 impurity to the NO cylinder, ppm

The NO_x recorder response will equal:

Recorder Response (% scale) = $\frac{[NOx]out}{URL}\ x\ 100 + ZNOx$

Where:

URL = Nominal upper range limit of the NO_x channel, ppm.

5. Record the NO_x concentration and the analyzers NO_x response.

Prepare the NO, NO_x, and NO_2 Calibration Curves

Use the following procedures to prepare the NO, NO_x, and NO_2 calibration curves.

1. Generate several additional NO and NO_x concentrations by decreasing the FNO or increasing FD.
2. For each concentration generated, calculate the exact NO and NO_x concentrations using the above equations for [NO]OUT and [NOx]OUT.
3. Record the NO and NO_x responses.
4. Plot the analyzers responses versus the respective calculated NO and Nox concentrations and calculate the respective calibration curve.
5. Sample this NO concentration until the NO and NOx responses have stabilized, then measure and record the NO concentration as [NO]ORIG.
6. Adjust the GPT system to generate a NO concentration near 90% of the URL of the instrument range selected.
7. Adjust the O_3 generator in the GPT system to generate sufficient O_3 to produce a decrease in the NO concentration equivalent to about 80% if the URL of the NO_2 range. The decrease must not exceed 90% of the NO concentration as determined in Steps 5 and 6 above.
8. When the analyzer responses stabilize, record the resultant NO concentration as [NO]REM.
9. From the Main Menu choose Calibration > **Cal NO_2 Coefficient**.
10. Set the NO_2 calibration gas concentration to reflect the sum of the following: the NO_2 concentration generated by GPT, ([NO])ORIG-[NO]REM, and any NO_2 impurity. Use ←→ to move the cursor left and right and ↑↓ to increment and decrement the numeric character at the cursor.

[NO2]OUT = ([NO]ORIG – [NO]REM) $+FNO\ X\ \frac{[NO2]IMP}{FNO+FO+FD}$

Where:
[NO2]Out = diluted NO_2 concentration at the output manifold, ppm
[NO]ORIG = original NO concentration prior to addition of O_3, ppm
[NO]REM = NO concentration remaining after addition of O_3, ppm.

11. Press ← to calculate and save the new NO_2 coefficient based on the entered span concentration. The analyzer does a one point NO_2 span coefficient calculation, corrects the NO_2 reading for converter efficiency, and then adds the corrected NO_2 to the NO signal to give a corrected NO_x signal. If the analyzer calculates a NO_2 span coefficient of less than 0.96, either the entered NO_2 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:

Recorder Response (% scale) = $\frac{[NO2]OUT}{URL}\ X\ 100 + ZNO2$
Where:
URL = Nominal upper range limit of the NO_2 channel, ppm

12. Record the NO_2 concentration and the analyzer's NO_2 response.
13. Maintaining the same FNO, FO, FD, adjust the ozone generator to obtain several other concentrations of NO_2 over the NO_2 range.
14. Record the stable responses and plot the analyzer's NO_2 responses versus the corresponding calculated (using the above equation for [NO2]OUT) concentrations and draw or calculate the NO_2 calibration curve.

Connect the Model 49*i* 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) = $\frac{(O3)OUT}{URL} X\ 100 + Z$

   Where:
   URL = Upper range limit of the Model 49*i*, ppm
   Z = Recorder response with zero air, % scale
   [O3]out = Ozone concentration as determined by the calibration photometer, ppm

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 49*i* analyzer response. If a Model 49*i* 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 49*i* 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 ±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.

4525 Wasatch Blvd. Suite 200 SLC, UT 84124 MSI Meteorological Solutions Inc. P: 801.272.3000 F: 801.272.3040	**STANDARD OPERATING PROCEDURE**	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:		Date:	Concurred By:

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

Equipment

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

Sampling Procedure

1. Ensure the canister valve is closed.

2. Remove the brass, screw-on cap from the upper valve of the stainless steel canister.

3. Connect the pressure gauge to the canister, open the canister valve, record the start pressure, and shut the valve.

4. Place canister inside sampling unit and connect the flow controller to it.

5. Connect the 1/8-inch sampling tube in the sampling system to the flow controller.

6. Open the upper valve of the clean evacuated canister by turning counter-clockwise.

7. Allow the data logger-controlled solenoid to start the sampler at the prescribed time (0700 MST).

8. Record the information on the form below. Any abnormalities surrounding the sample collection event should be recorded on the form.

9. The datalogger-controlled solenoid will stop the sample at the prescribed time (1000 MST).

10. After the sample has stopped, retrieve the canister from the system. First, close the canister valve by turning clockwise and remove the flow controller.

11. Connect the pressure gauge to the canister, open the valve, record the stop pressure, close the valve, and remove the pressure gauge.

12. Replace the brass, screw-on cap onto the upper valve of the stainless steel canister.

13. Put the stainless steel canister back into the shipping carton.

14. Put the sample collection form into the shipping carton.

15. Bring the canister back to the Pinedale project base for shipment to the analytical laboratory.

16. Ship to the analytical laboratory with chain-of-custody documentation.

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

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 Intermet Ozonesonde Data Acquisition software (O_3 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 hygristor.

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.

Accuracy (instrument specifications)	
Horizontal Wind Speed	± 1.0 ms^{-1}
Horizontal Wind Direction	Unknown
Temperature	± 0.2° C
Relative Humidity	±5.0%
Output Resolution	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	0.1°
Temperature	<0.01° 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:

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2.$$

The cell converts the iodine to iodide according to:

$$I_2 + 2e \rightarrow 2I^-$$

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.

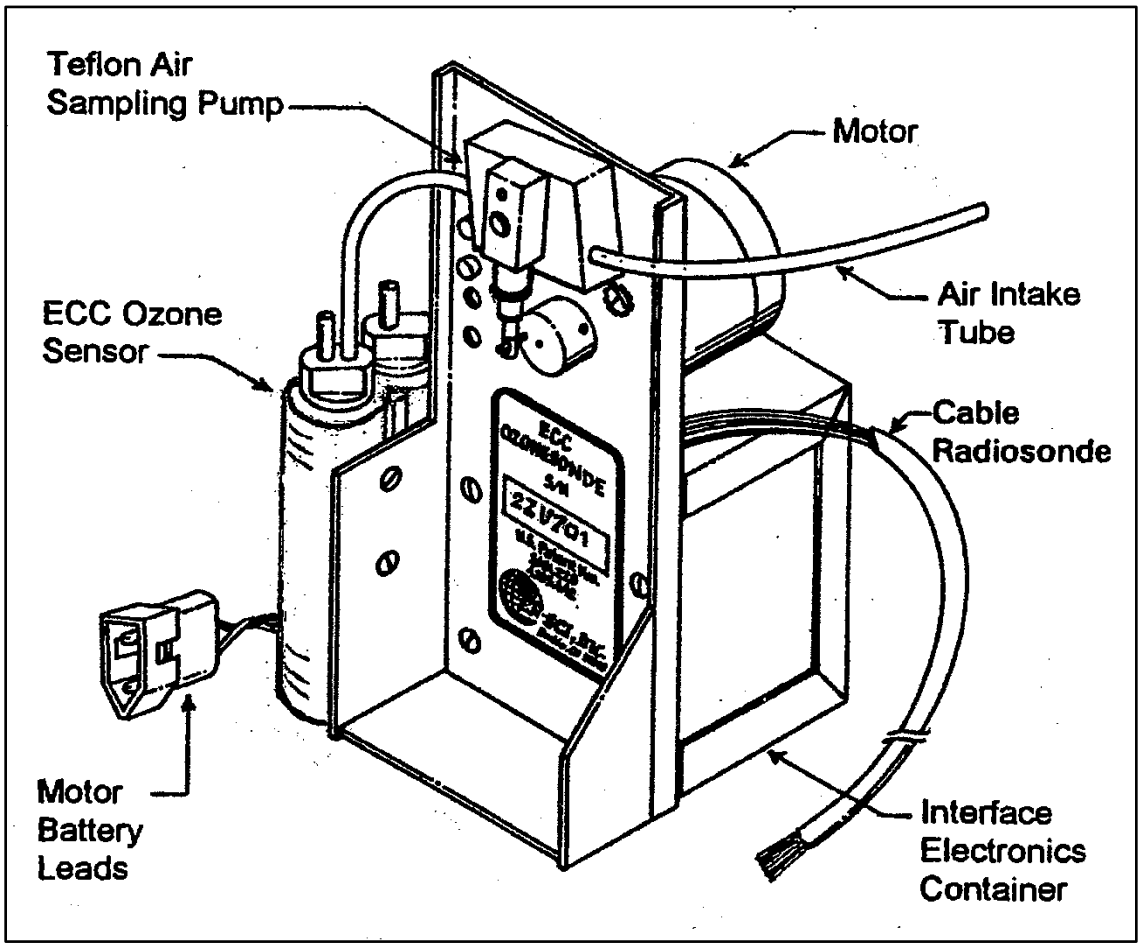
As an integral part of the ozonesonde operations, the ozone analyzer readings at the Boulder site will provide ground-truth data.

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 ± 10% of indicated value

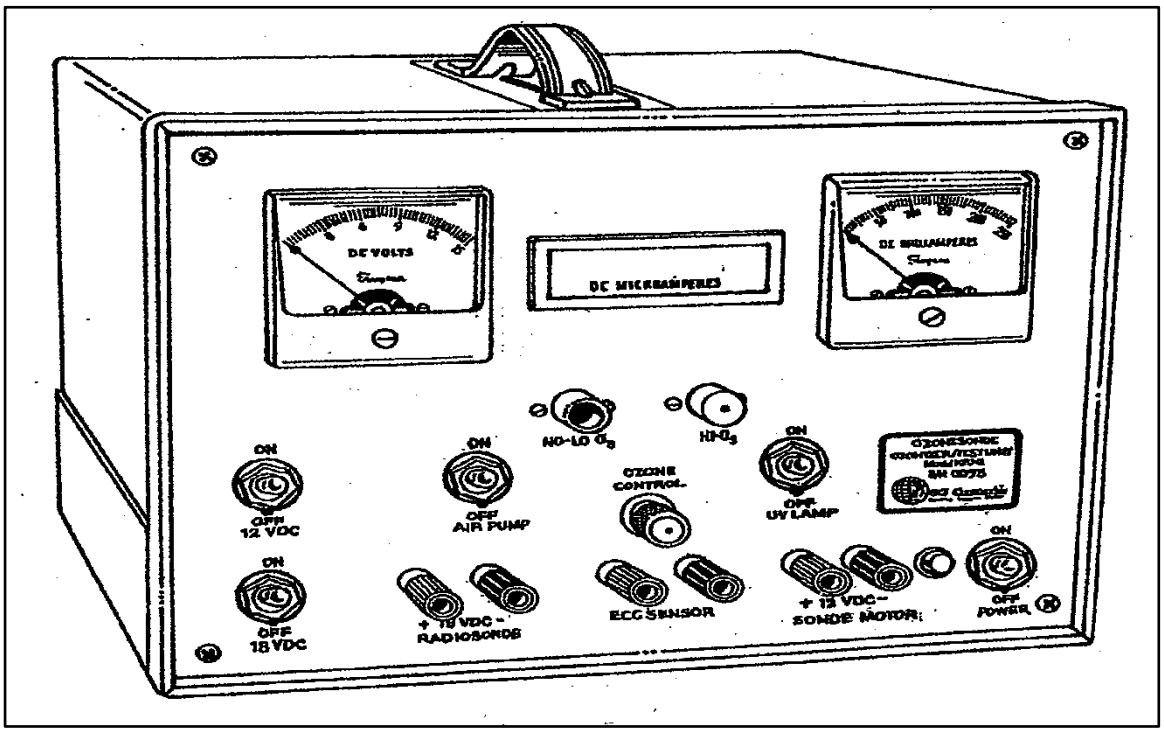
1) PREPARING THE 2ZV7 OZONESONDE 3 TO 7 DAYS BEFORE LAUNCH DAY.

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



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.

(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:

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.)

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 µA). Save this information as part of your raw data file (e.g., ib1 = 0.05 µA).

(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 µA. Continue passing an equivalent of 5 µA 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 µA.

(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°C. Record also the room temperature at which this test was performed. Save all the information as part of the raw data file.

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 μA
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.

(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.

<u>The iMet-3050 403 MHz GPS Upper-Air Sounding System Components</u>

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

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

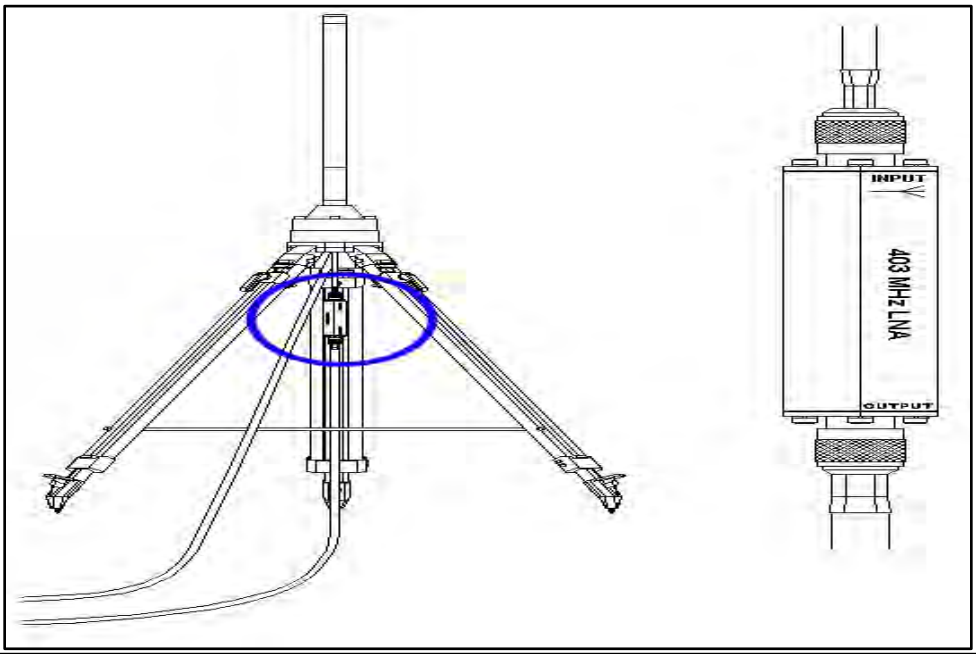
M403 MHz Antenna Unit with Cables attached.

b) Connect iMet-3050 Cables to MP

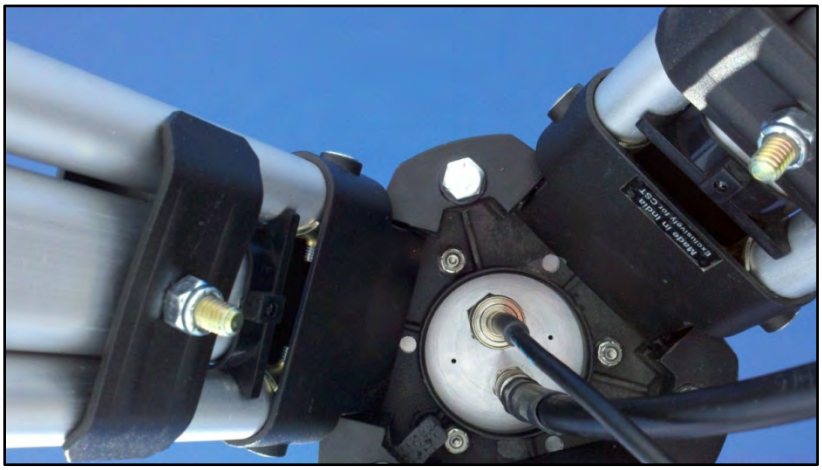
- GPS Cable
- 403 MHz Cable
- USB Cable
- Power Cable
- GPS Re-radiator Cable

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


INPUT
403 MHz LNA
OUTPUT

INPUT
403 MHz LNA
OUTPUT



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.

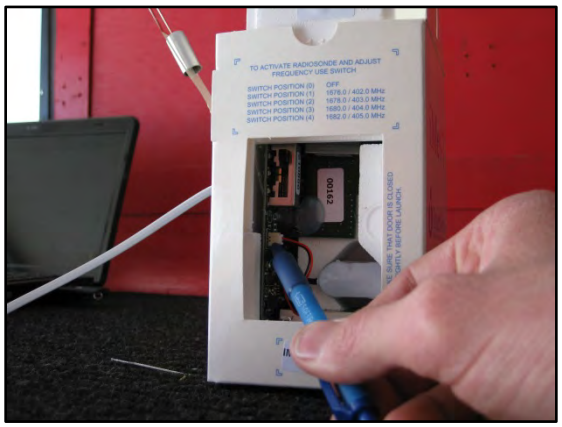
f) Once the USB cable is plugged in, wait a few moments before turning on the iMet-3050.

g) Turn on the iMet-3050 MP.

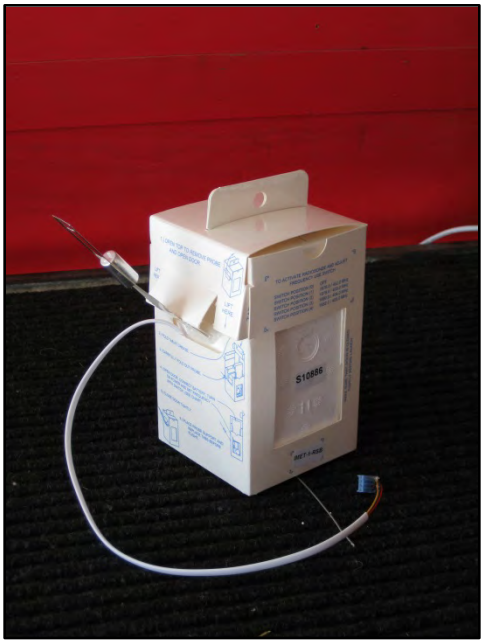
4) DAY OF LAUNCH: ACTIVATING THE IMET-1 RSB RADIOSONDE AND 2ZV7 OZONESONDE FOR FLIGHT.

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.

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.



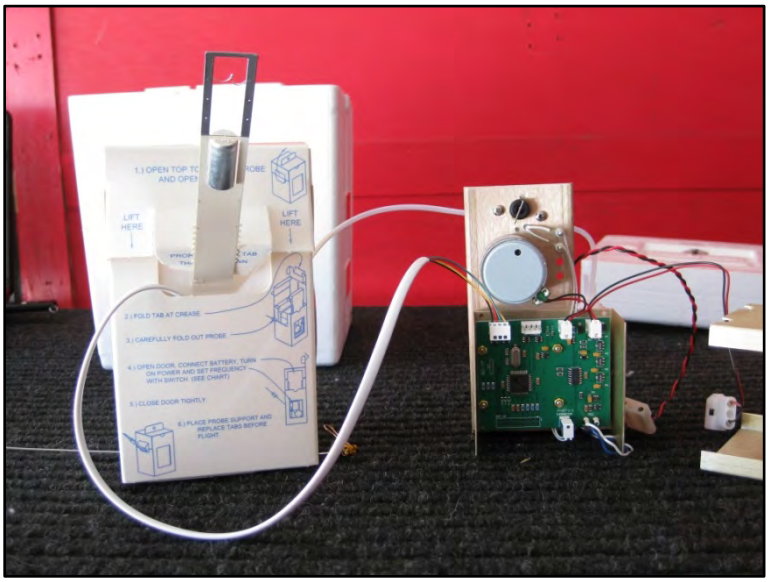
3. Once the signal has been found by the receiver close the foam door on the side of the radiosonde, fold out the sensor assembly and close the top of the box back up per the instructions on the side of the box.



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.

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.

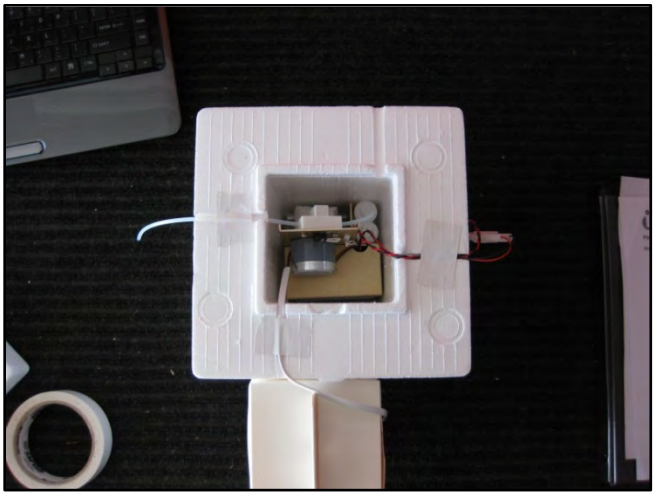


7. Remove the battery from the side of the box and use the adhesive strip to attach it to the sensor assembly in the spot provided.

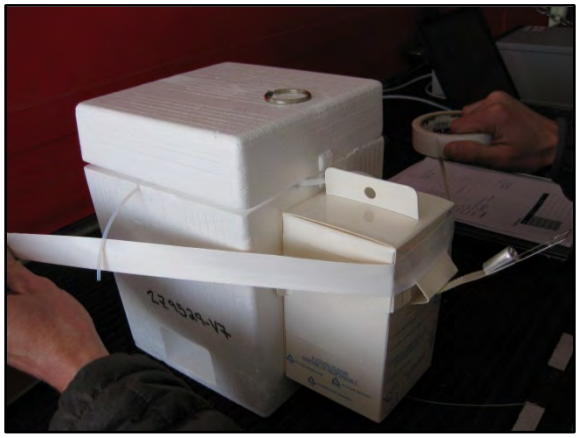
8. Plug in the battery to the lead on the sensor. The pump should start working. Install the inlet tube in the hole in the side of the pump assembly, being careful not to crimp the tubing.

9. Replace the cover on the sensor assembly and circuit board. Do not crimp the wires.

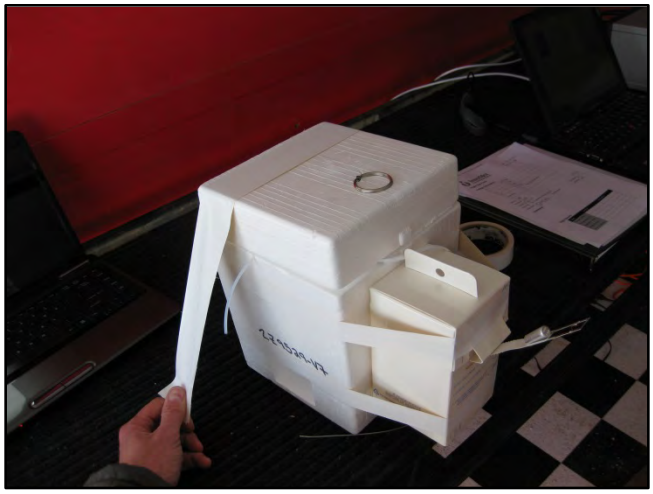
10. Place the sensor assembly in the Styrofoam box. Note the location of the two adhesive strips on the sonde box and the orientation of the inlet, data cable and battery leads; use a small piece of tape to hold the three in place.



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.



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

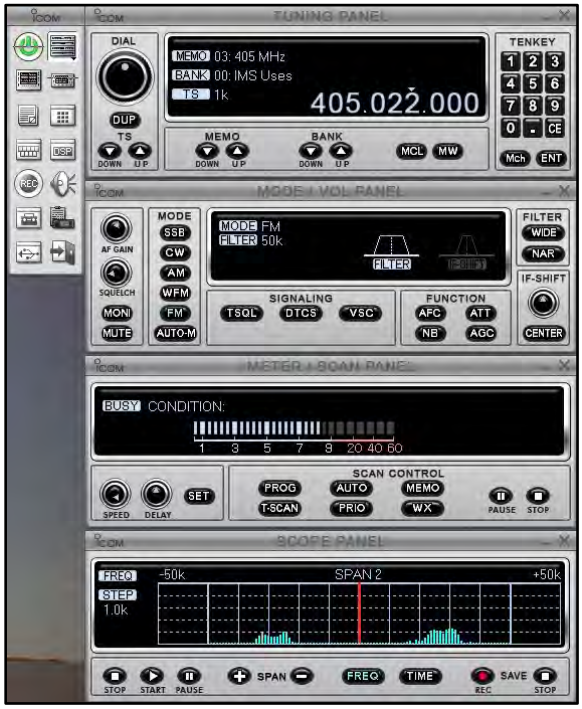
14. Verify that the data the sondes are collecting is being received by the base station.

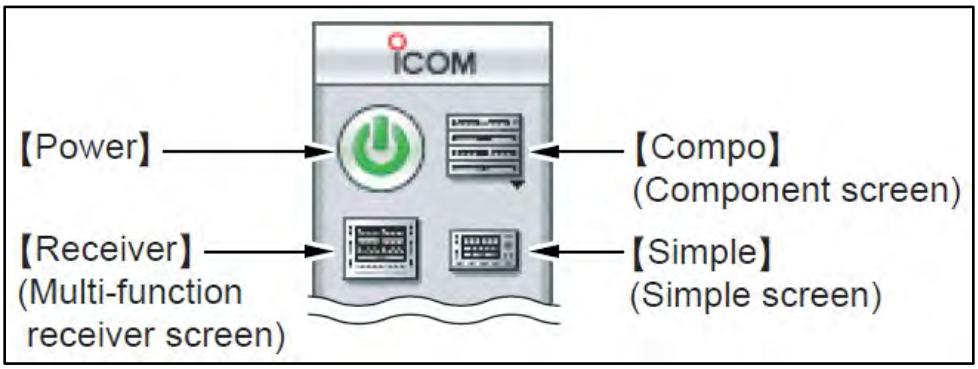
5) DAY OF LAUNCH: STARTING AND OPERATING THE ICOM IC-PCR1500/2500 AND THE INTERMET OZONESONDE DATA ACQUISITION SOFTWARE (O3 PROGRAM).

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.



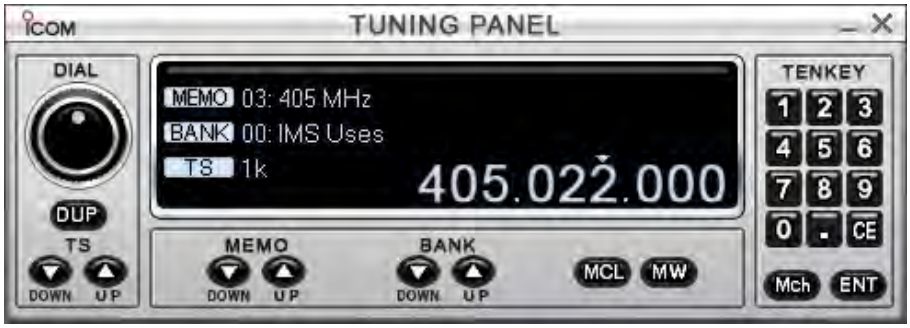


Icom Toolbar Top

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”.



Tuning Panel

f. In the Tuning Panel window, press the Memo [Up]/[Down] buttons until the radiosonde frequency is reached.

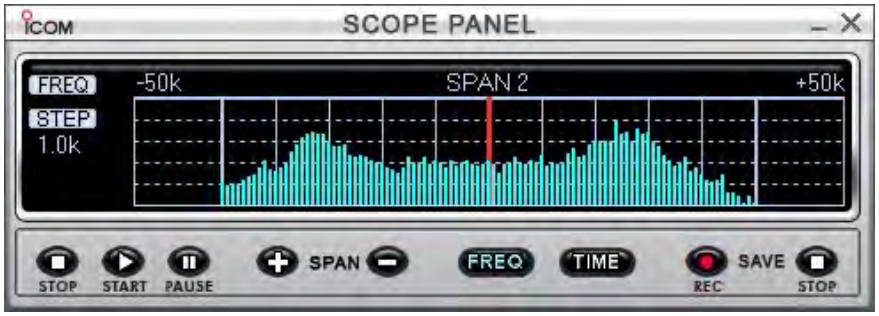
g. Adjust the audio volume as desired by [Left] or [Right] clicking the “AF Gain” knob in the Mode / Vol Panel.

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.

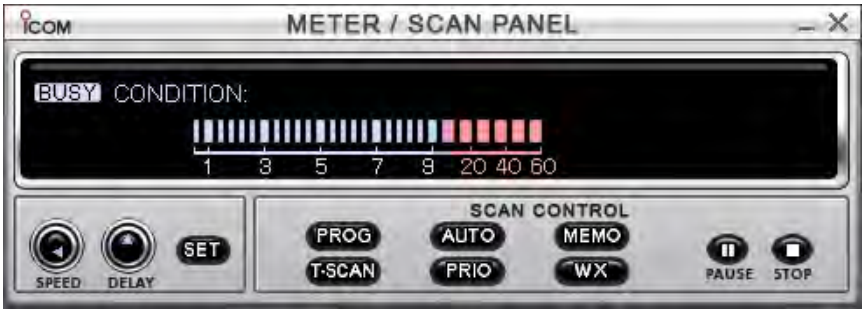
j. In the Scope Panel, use the [+] and [-] Span buttons to adjust the span until -50k and +50k are displayed on either side and SPAN 2 is displayed in the center.



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.



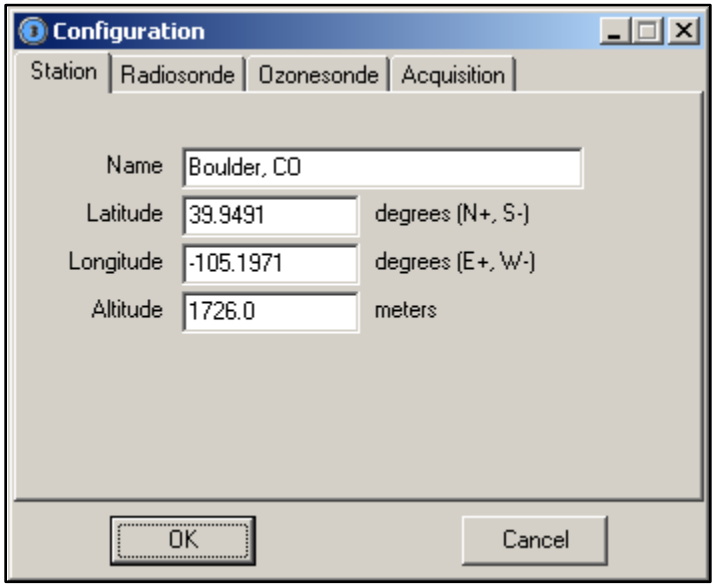
Meter / Scan Panel

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

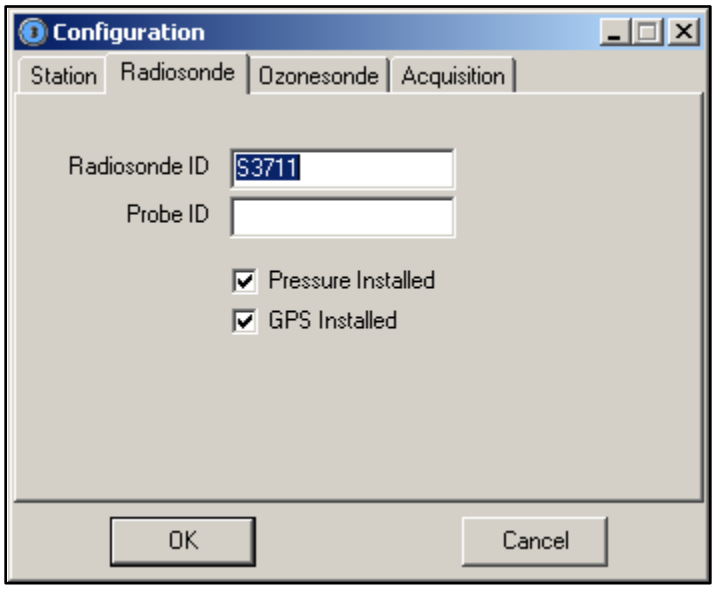
InterMet Ozonesonde Data Acquisition software (O_3 program)

1) Open the "O3" program.

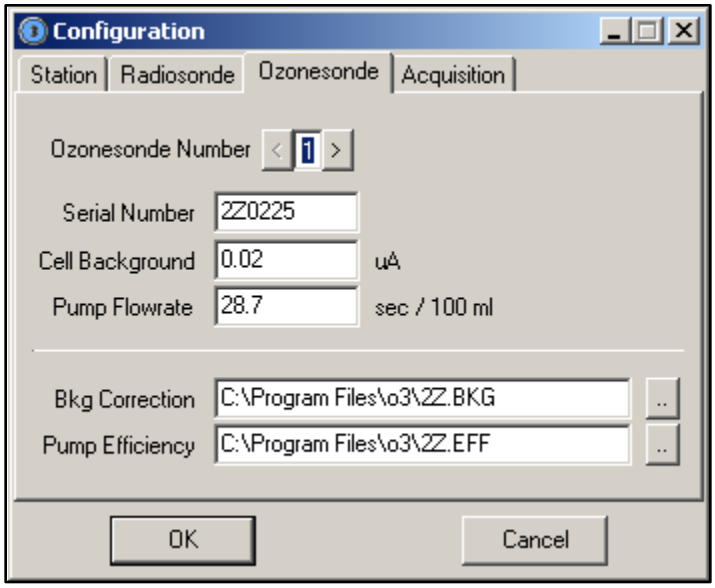
2) Press “Start” and enter Station data in the Station tab as shown below.

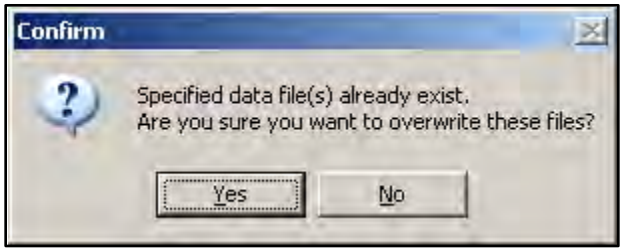


3) Enter the radiosonde ID and ensure that the “Pressure Installed” and “GPS Installed” boxes are checked as shown below.

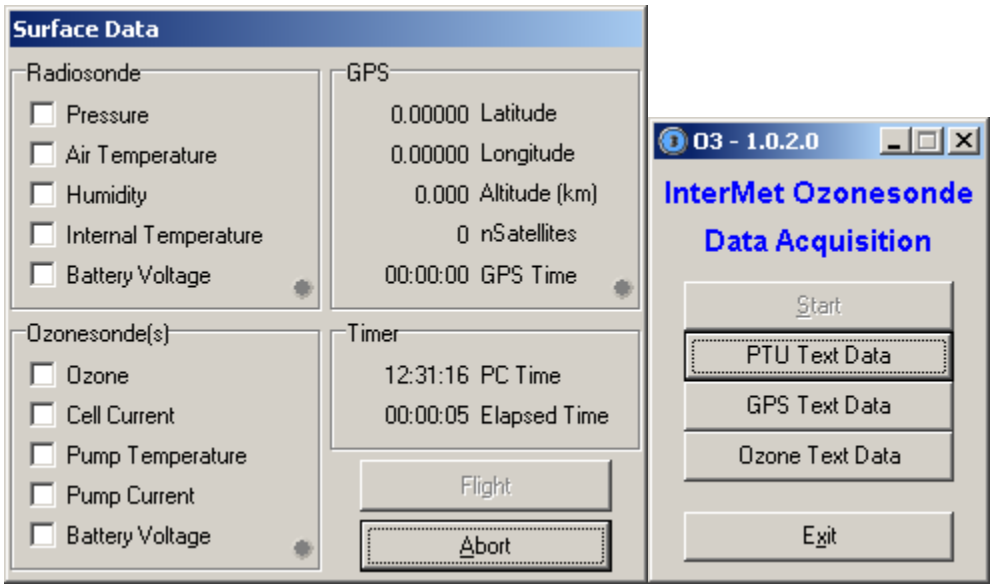


4) Enter ozonesonde information (taken from the “day of flight” ozonesonde prep. check sheet) then press “Ok” and “Yes”, and leave the program window open as shown below.

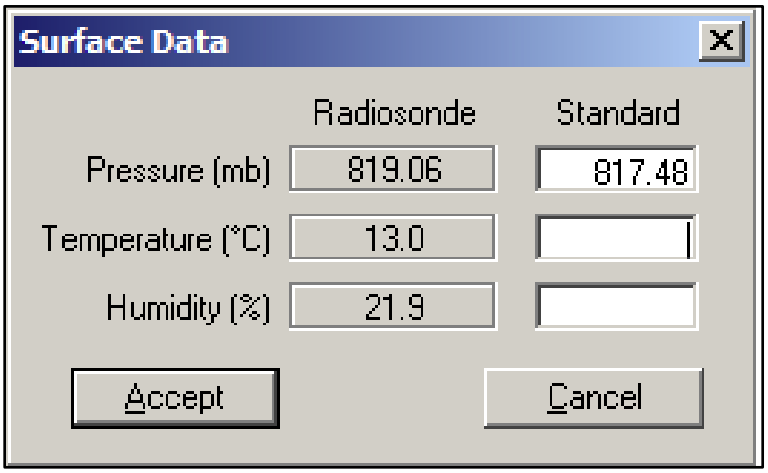




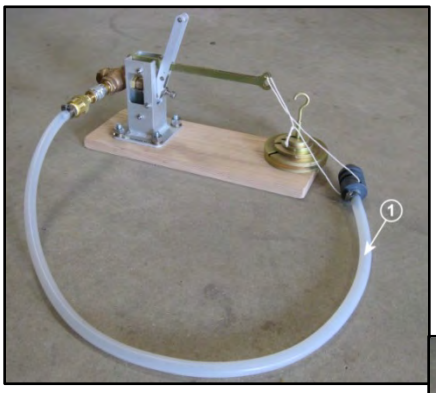
5) The “O3” software will show signals being received from not only the Ozonesonde but also the radiosonde by blinking green lights in the lower right hand corners of the “Radiosonde”, “GPS”, and “Ozonesonde” labels under the “Surface Data” screen.



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.



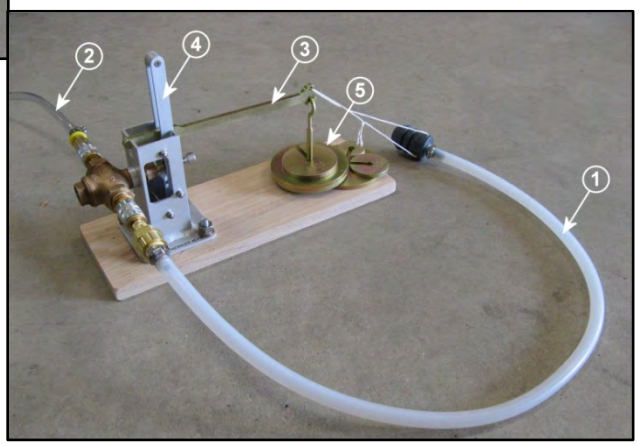
6) DAY OF LAUNCH: BALLOON SETUP AND CONFIGURATION



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**
Rain	
Light	+100 gm
Moderate	+200 gm
Heavy	+300 gm
Icing	
Moderate	+300 gm
Severe	+500 gm
High Surface Wind	
>25 kts (>12.5 m/s)	+100 gm
>40 kts (>20.5 m/s)	+200-300 gm
Parachute	70 gm
De-Reeler	50 gm

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.

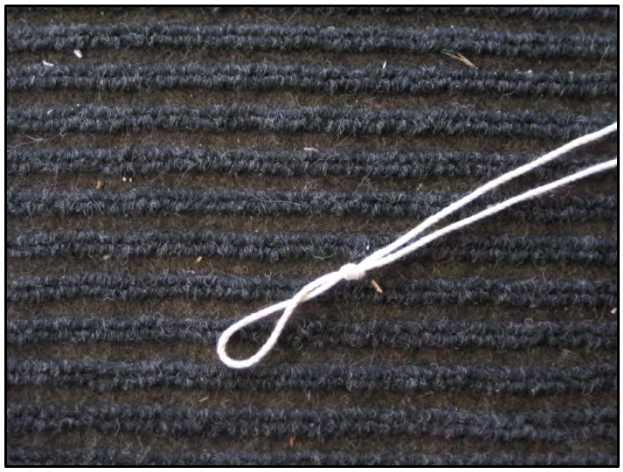
NOTE

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).

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 ¼" of wraps and knots have built up on the balloon, finish with two overhands in a row.

12. 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.

13. Finish the tie off by folding the neck of the balloon upward and tying the same series of knots you used in step 11.

14. Tie the top of the parachute to the grab loop (the shortest loop in the picture above) on the balloon.

15. 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).

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.

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

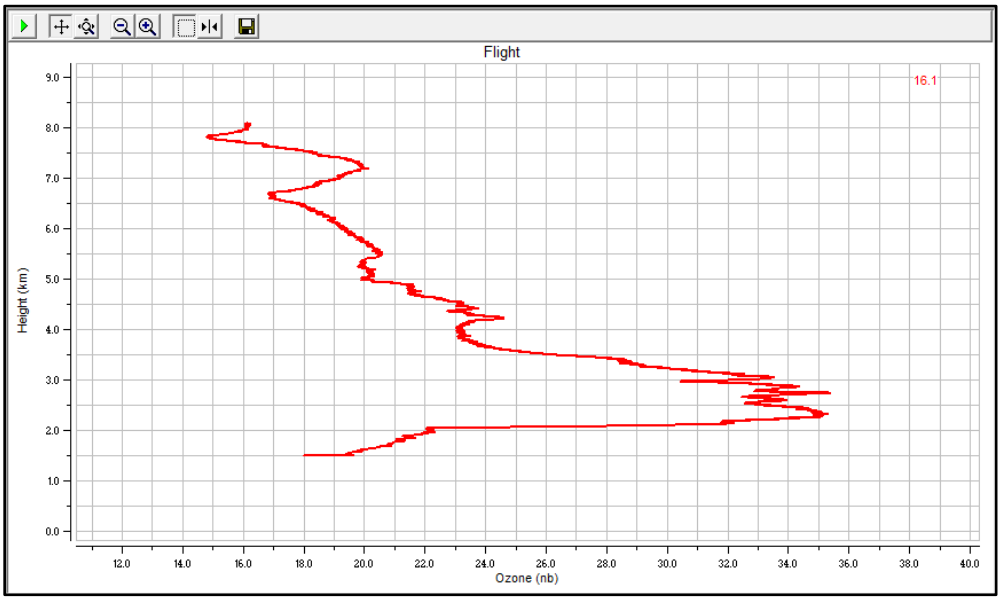
Occasionally (at least every 15 minutes), double check that the receiver is accurately tuned to the radiosonde. Adjust the frequency, as necessary, such that the red line in the Scope Panel is centered between the twin peaks.

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.



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.

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…”.

4525 Wasatch Blvd. Suite 200 SLC, UT 84124 MSI Meteorological Solutions Inc. P: 801.272.3000 F: 801.272.3040	**STANDARD OPERATING PROCEDURE**	Title: Carbonyl Sampling - Three Hour	
		Number: SOP 131	Page: 1 of 2
		Revision No: 1	Effective Date: 12/31/2014 12/29/2013 (Rev 0)
Approval:		Date:	Concurred By:

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

Equipment

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

Sampling Procedure

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

11. Place the completed sampling form and sealed cartridge envelope in a plastic bag and place in the cooler with blue ice.
12. Transport carbonyl samples in the cooler on ice for shipment to the analytical laboratory. Store in a refrigerator until ready to ship.
13. Ship to the analytical laboratory in a cooler with ice and chain-of-custody documentation.

Carbonyl Sampling Form

A. General Information

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

B. Sampling Information

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

APPENDIX B

Microsoft Access Database Description

The Upper Green Winter Ozone Study (UGWOS) 2014 Database

Introduction

This document describes the Upper Green Winter Ozone Study (UGWOS) database for 2014. 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.

Overview of Measurements and Field Study Participants

The 2014 UGWOS field study included hourly measurements of surface and upper air meteorological and air quality data during the period of January through March 2014 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:

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

- WDEQ runs an ambient air quality network throughout the state of Wyoming. Air Quality sites included in UGWOS 2014 were located in or near Sublette County in southwestern Wyoming. The stations include:
    - Boulder (including 5-minute and 1-hour data collection),
    - Big Piney,
    - Campbell County,
    - Casper,
    - Cheyenne,
    - Converse County,
    - Daniel South,
    - Farson (Met Only),
    - Hiawatha,
    - Jonah,
    - Juel Springs,
    - Mesa,
    - Moxa Arch,
    - Murphy Ridge,
    - Paradise,
    - Pinedale,
    - Rock Springs
    - Sinclair
    - South Pass,
    - Thunder Basin, and
    - Wamsutter.

- The WDEQ Monitoring network data consisting of some or all of the parameters presented below:
    - Ozone
    - PM_{10}
    - $PM_{2.5}$
    - $NO/NO_2/NO_x$ or NO_Y
    - SO_2
    - 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

<u>T&B Systems</u>

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

<u>Meteorological Solutions, Inc. A Trinity Consultants Company</u>

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

Each contracted organization reviewed and validated their collected data to Level 1 before the data set was submitted to the database. The data were examined and any adjustments for calibration deviations were applied. Appropriate flags were assigned for extreme values, instrument downtime and performance tests. A description of the Quality Control (QC) codes used are given in Table 1 and also listed in the table **QC_flags** in the UGWOS 2014 database.

Table 1 - Data Flags

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

QC	Description
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

UGWOS Database Design

Meteorological Solutions Inc. A Trinity Consultants Company assimilated the submitted data into an Access 2010 database called UGWOS_2014_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. Five-minute data from the Boulder site were quality assured and reported. These data are presented in the **5-minute Boulder Data** table.

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

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, Jonah, and Big Piney, Mesa, Paradise, and Warbonnet 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 2013 in the information bar at the bottom of the Access window screen when the user is accessing the column. All data tables include a Record Number column at the end of the table, this column is intended to keep data sorted in chronological order by site to match the Sites table. With this option, a user can sort the table any way he or she chooses and have the capability of sorting the table into its original format.

The data have the following general unit configurations:

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

The 2014 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, 2014 and March 31, 2014. 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 or sadamson@trinityconsultants.com.

Summary

This document describes the 2014 UGWOS database. Feedback from study participants concerning this document and the database is requested and any suggestions for improvement are highly encouraged and appreciated.