FINAL REPORT
2012 UPPER GREEN RIVER OZONE STUDY

Prepared for:

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2012 UPPER GREEN RIVER WINTER OZONE STUDY
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1.0 INTRODUCTION

In a continued effort to protect human health and the environment, the Wyoming Department of Environmental Quality – Air Quality Division (AQD) sponsored the Upper Green Winter Ozone Study (UGWOS) in 2012. 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 exceeding the National Ambient Air Quality Standard which is currently set at a daily maximum eight-hour average of 75 parts per billion (ppb).

In 2012, AQD contracted with Meteorological Solutions Inc. (MSI) and sub-contractor T & B Systems to conduct a scaled-down version of UGWOS. Field operations included a temporary ambient monitoring station in the Jonah Field which provided continuous measurements of ozone (O_3) and oxides of nitrogen (NO_x) as well as additional speciated hydrocarbon sampling during periods when conditions favoring potential elevated ozone episodes were forecast. The Boulder monitoring site was again expanded to include more specialized ozone precursor measurements which included trace level NO_y and "true NO_2".

Quality assurance project plans, data, and reports from previous UGWOS field efforts (2007-2011) are posted on the Monitoring Information Page (AQD website).[1] During each year's field effort, data were collected from a network of long-term air quality monitoring stations, temporary monitoring stations, upper air data from soundings and/or miniSODAR™, and various specialized ozone precursor measurements.

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

Field operations for UGWOS 2012 started on January 15, 2012 and continued through March 31, 2012. Daily weather forecasts were issued by MSI's forecast meteorologist in order to identify periods when ambient ozone concentrations in the UGRB were likely to be elevated and to provide an alert to field personnel so additional measurements could be implemented during these Intensive Operational Periods (IOP's).

This report presents a summary of UGWOS 2012 field operations, quality assurance activities, and the results of the field measurement program. Section 2.0 presents an overview of the ozone and ozone precursor measurements. In addition, this section provides synoptic weather summaries for the intensive operational periods. 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 2012 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 2012, elevated ozone forecasts, and synoptic weather summaries during 2012 IOP's.

2.1 Overview

UGWOS 2012 field operations were scheduled for January 15, 2012 through March 31, 2012. All UGWOS 2012 monitoring sites were installed, calibrated, and ready for operations by January 14, 2012. Problems with the oxides of nitrogen analyzer at the Jonah Field site and its UPS delayed data collection until January 17 and then from January 19-24. Forecasting for elevated ozone conditions started on January 15, 2012 and continued through March 31, 2012 when the field monitoring program ended.

2.1.1 Planning Process

A siting trip was conducted with AQD personnel to locate a suitable substitute for the former Jonah site to monitor ambient conditions in the Jonah Field area. The previous site was removed and access to power was not available at the original location. After investigating several possible alternatives, it was decided that the Luman Road temporary site located at the entrance to the Jonah Field which still had a power drop available was the best option.

AQD-owned VOC sampling systems from the Sublette County Air Toxics Study and the existing VOC canister sampling system at the Boulder site were utilized for the UGWOS 2012 VOC sampling effort. Sampling systems were cleaned, leak-checked and tested for contamination prior to operational use.

Prior to the start of UGWOS 2012, specialized measurements were added to the Boulder site to enhance understanding of ozone precursor mechanisms. These included trace level NO_x with a photolytic converter for true NO_2 and NOy.

2.1.2 Monitoring Sites

All of the currently operating long-term WDEQ-AQD monitoring stations provided meteorological and air quality data for the UGWOS database. A map showing the locations of these stations and the mobile trailer stations active during the UGWOS 2012 program is shown in Figure 2.1. Areas marked on the map with colored shading indicate active industrial (oil and gas) development projects which are potential sources of ozone precursor emissions.

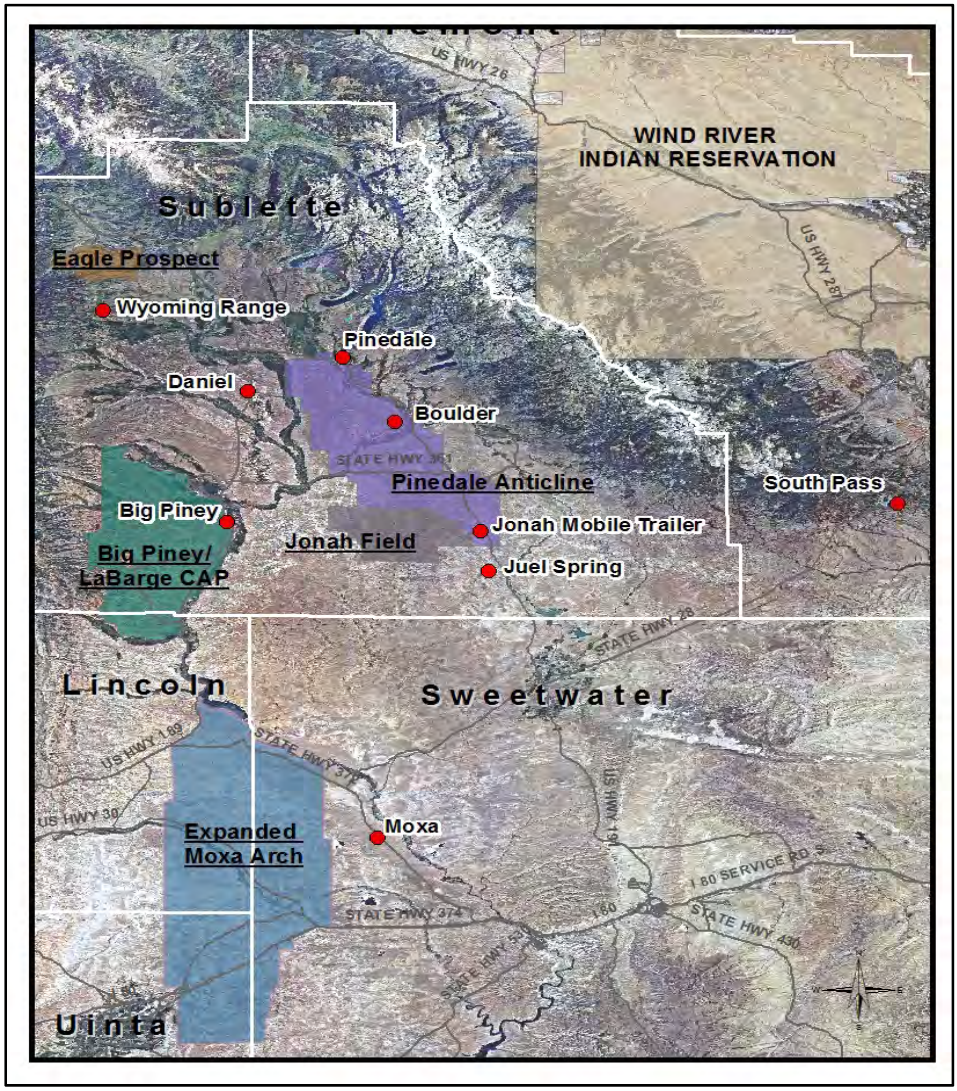

Figure 2.1 Active Monitoring Stations and Industrial Development Areas (Colored Shading) in the UGWOS 2012 Study Domain.

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

Table 2-1

Summary of Measurement Methods during UGWOS 2012

Platform	Measurement	Instrumentation	
		Method	**Model**
Mobile Trailer Big Piney and Jonah Field	Ozone	UV Photometric	T-API 400E
	NO_x	Chemiluminescence	T-API 200E
	Methane/TNMHC	FID	Baseline-Mocon 9000 (Big Piney)
	$PM_{2.5}/PM_{10}$	Beta Attenuation	BAM 1020 (Big Piney)
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	WS, WD, T, RH, BP, Solar Rad., Precip.	Various	Various
Boulder Special Measurements	True NO_2	Chemiluminescence	T-API 200EU w/Photolytic Converter
	NO_y	Chemiluminescence	T-API T200U w/501Y Converter
	Speciated VOC	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	Total UV Radiation	Pyranometer (upward and downward facing)	Eppley TUVR
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	TEOM 1400a (Daniel and Boulder)
		Beta Attenuation	BAM 1020 (Wyoming Range, Moxa)
	Methane/TNMHC	FID	Baseline-Mocon 9000 (Boulder)
	$PM_{2.5}$	Beta Attenuation	BAM 1020 (Wyoming Range, Pinedale)
	Speciated VOC (Juel Springs)	TO-14 Canister w/expanded PAMS list of analytes	GC/FID
	WS, WD, T, RH, BP, Solar Rad., Precipitation	Various	Various

Table 2-1 (Continued)

Summary of Measurement Methods during UGWOS 2012

Platform	Measurement	Instrumentation	
		Method	Model
MiniSODAR™	Upper Level Winds	Doppler Sodar	ASC 4000 miniSODAR™
	Mixing Height	Doppler Sodar	ASC 4000 miniSODAR™
	Surface WS, WD, T, RH, BP and precip. detection	Integrated sonic anemometer, thermistor, RH and pressure sensors with separate precip. detection sensor	Vaisala WXT-510

2.2 Field Measurements

Active measurement stations which provided data for the UGWOS 2012 database included the long-term WDEQ-AQD monitoring stations already operating in the Upper Green River Basin study area, two temporary WDEQ-AQD mobile trailer monitoring sites at Big Piney and the Jonah Field, and the miniSODAR™ located adjacent to the Boulder monitoring station. During the UGWOS operational period, VOC canister samples were collected at four locations - the two mobile trailer sites and at the Boulder and Juel Springs long-term monitoring stations.

2.2.1 WDEQ-AQD Long-Term Monitoring Sites

WDEQ-AQD monitoring stations in and around the UGRB which were actively collecting data during UGWOS 2012 included Wyoming Range, Daniel South, Boulder, Pinedale, Juel Springs, South Pass, and Moxa. These sites were typically measuring wind speed and direction at 10 meters, temperature at 2 and 10 meters, relative humidity, barometric pressure, solar radiation at 2 meters, and precipitation. Air quality parameters measured at these sites included ozone, oxides of nitrogen, and particulate matter. Figure 2.2 presents a photograph of the long-term monitoring station at Boulder. Figures 2.3 and 2.4 show Boulder meteorological sensors and the interior of the air quality monitoring shelter, respectively.

2.2.2 Boulder Monitoring Station Specialized Measurements

During UGWOS 2012, specialized measurements were added to the Boulder monitoring site just prior to the field measurement program. These included continuous analyzers to measure NO_y and trace level oxides of nitrogen using a photolytic converter to measure true NO_2. The existing VOC canister sampling system was operated during IOP's to provide speciated VOC data at the site. Figure 2.5 shows the VOC canister sampling system at the Boulder monitoring station. Data collection at the Boulder station again included total ultra-violet (UV) radiation (incoming and reflected UV).

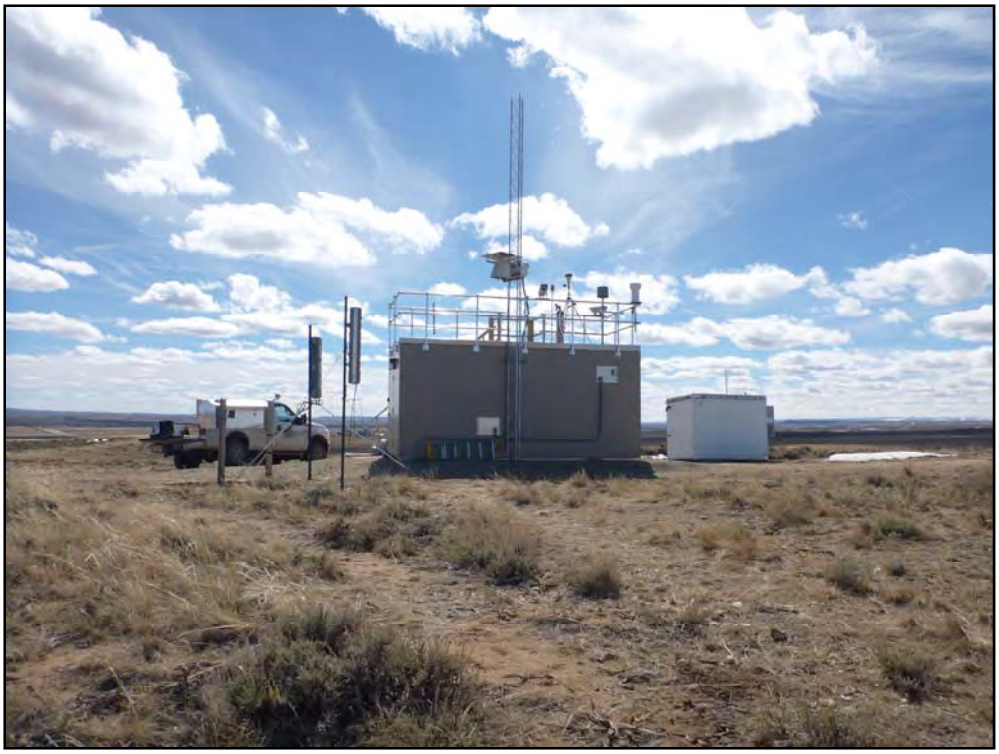

Figure 2.2 Long-term Monitoring Sites Example: Boulder

Figure 2.3 Boulder Meteorological Tower and UV Radiation Sensors

Figure 2.4 Boulder Air Quality Monitoring Shelter

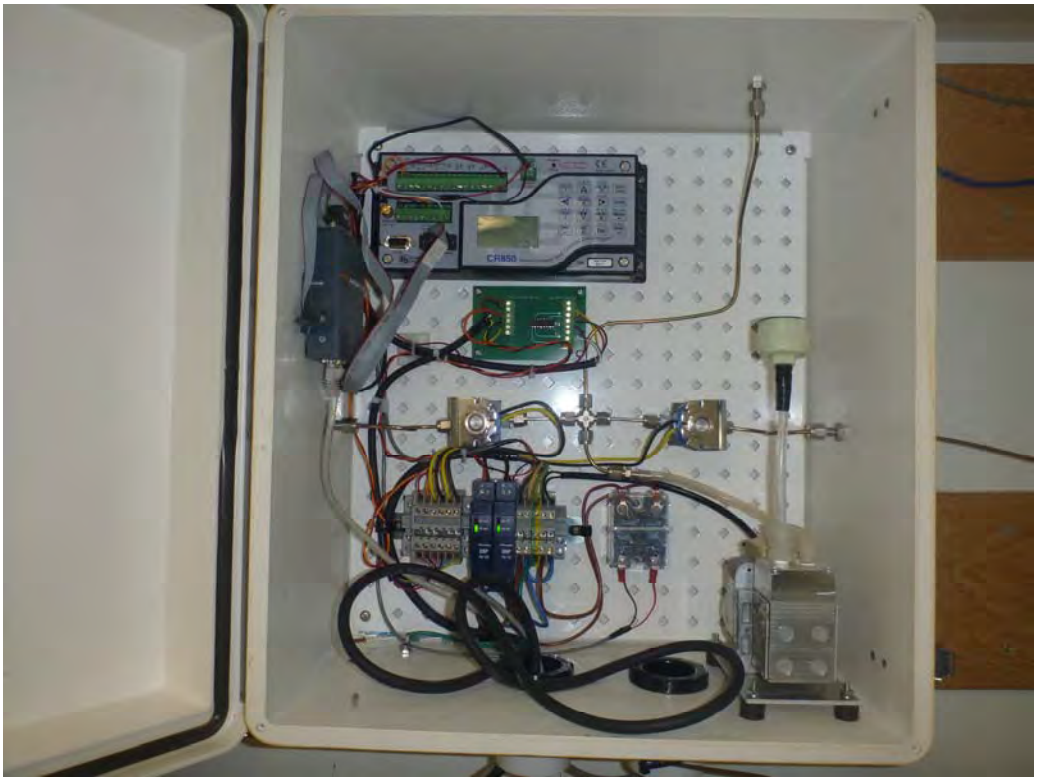

Figure 2.5 Boulder VOC Canister Sampling System

2.2.3 Mobile Trailer Measurements: Big Piney and Jonah Field

One of AQD's mobile monitoring trailers operated by Air Resource Specialists was located just south of the town of Big Piney, Wyoming. This trailer was outfitted with a 10-meter tower mounted to the side of the trailer measuring wind speed, wind direction, temperature, relative humidity, barometric pressure, solar radiation and precipitation. Ozone, oxides of nitrogen, $PM_{2.5}$, PM_{10}, and hydrocarbon analyzers were operating inside the trailer. A VOC canister sampling tripod was operating adjacent to the trailer during IOP's.

A smaller AQD-owned mobile monitoring trailer was located at the entrance to the Jonah Field on the Luman Road. The trailer had wind and temperature sensors at approximately 4 meters height and USEPA FEM analyzers to measure ambient ozone and oxides of nitrogen. A VOC canister sampling system was operating adjacent to the trailer during IOP's. Figures 2.6 and 2.7 present photographs of the mobile trailers operated at Big Piney and Jonah Field, respectively.

Figure 2.6 Big Piney Mobile Monitoring Station with Adjacent Tripod-Mounted VOC Sampling System

Figure 2.7 Jonah Field Mobile Trailer with Adjacent VOC Sampling Tripod

2.2.4 miniSODAR™

The WDEQ Wind Explorer miniSODAR™ was maintained and operated adjacent to the Boulder monitoring station and continuously measured surface and winds aloft and provided mixing height information up to approximately 250 meters. Figure 2.8 shows the miniSODAR™ at its Boulder monitoring site location.

Figure 2.8 miniSODAR™ at the Boulder Location

2.2.5 Other Specialized Measurements: VOC Canister, True NO_2, NO_y, and Total UV Radiation

Speciated VOC measurements were performed using the TO-14 canister sampling method with expanded analyte list at the Boulder, Juel Springs, Big Piney and Jonah Field monitoring stations. Canister samples were collected during forecast IOP's using automated sampling systems that collected three-hour integrated samples typically from 07:00 to 10:00 on IOP days. Figure 2.9 shows an example of the tripod mounted canister sampling system at the Juel Springs site.

Figure 2.9 VOC Canister Sampling System at the Juel Springs Site

True NO_2, measurements were performed at the Boulder monitoring site using a T-API Model 200EU Trace Level Oxides of Nitrogen analyzer with photolytic converter to measure true NO_2. This type of converter allows for better speciation of lower levels of NO_2 than a 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.

2.3 Intensive Operating Periods (IOPs)

This section describes the outlooks that were issued daily during the 2012 UGWOS season. These outlooks were used to provide expected weather conditions for the following week and discuss possible elevated ozone episodes between January 15 and March 31, 2012. This section also provides a summary of the synoptic weather conditions during the six IOP's that occurred in UGWOS 2012. In 2012, an IOP event was defined as a day on which the operation of VOC canister samplers took place. Canister operation occurred during the early morning hours of the IOP day from 0700 to 1000. The outlook provided personnel a time frame of when IOP operations could be expected so that preparation of the sampling canisters could be completed by the time they were needed. The six IOP's that occurred covered a total of nine days.

2.3.1 IOP Weather Conditions

The weather outlooks provided in 2012 used the same format as in 2011. The outlook was broken into four parts, with the first section a synopsis of weather conditions expected over the next seven days. The general weather pattern and how this would evolve over the following week was described.

The second section provided a forecast for the UGWOS area from the day of issuance through day 3. Expected sky conditions, temperatures, winds, and precipitation were described. Additionally a brief discussion of how favorable the expected weather conditions over this period would be for ozone development was provided.

The third section was identical to the second section but covered days 4 through 7.

The fourth section was a brief statement on the possibilities that conditions for an IOP would develop in the upcoming week. If conditions were favorable and an IOP had been declared, then this would be stated. Figure 2.10 presents an example of the Weather Outlook product.

2012 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: **MONDAY FEBRUARY 27, 2012 AT 1000 MST/0900 PDT**

SYNOPSIS

A trough of low pressure covers much of the western US this morning. This storm will consolidate and push through the central Rockies beginning later today into Tuesday. A brief period of high pressure will move in Tuesday night and the next storm will push into Wyoming on Wednesday. A moist northwesterly flow will hold over the state for late Wednesday into Thursday. A breezy period is possible for Friday and Saturday as moderate to strong northwest winds aloft combined with a surface pressure gradient across the state. Sunday should see higher pressure build into the area.

SHORT TERM FORECAST (THRU DAY 3)

Clouds from the incoming storm have overspread the area this morning and the day will continue cloudy. There will be showers developing today with snow continuing tonight which could be moderate at times. Snow will decrease later in the day Tuesday. Wednesday will be partly cloudy early then turn overcast with snow showers developing.

OZONE: No elevated ozone is expected through this period.

LONG RANGE OUTLOOK (DAY 4 TO 7)

Thursday through Saturday will be generally unsettled with mostly to partly cloudy conditions and wind and or snow at times. Sunday will be mostly fair with light winds.

OZONE: Hourly elevated ozone is not expected on Thursday through Saturday. There will be a chance for elevated hourly ozone readings on Sunday.

IOP: Today is an IOP day.

Figure 2.10 Example Weather Outlook

2.3.2 Synoptic Weather Summaries of IOP's

There were six IOP's covering a total of nine days in 2012. There was one IOP event in January, three in February, and two in March. Additionally, canister sampling took place twice in March during periods when there was no snow on the ground.

The first IOP was a one day event on January 29, 2012. High pressure aloft along the coast on January 28 moved inland and covered much of the western United States on the morning of January 29. This ridge almost immediately began to weaken as a storm system moving in from the Pacific rode up and over the ridge. Surface high pressure was centered over southeast Idaho in the morning and moved south through the day in response to the storm moving in from the west. Clear skies early in the day gave way to some cirrus from the incoming storm system. An inversion was likely in the morning as winds were light, there were mostly clear skies overnight, and there was a good snowpack in place with 20 to 30 inches along the rim of the UGRB, 12 to 16 inches in the northern interior part of the UGRB, then decreasing to 4 to 8 inches and less south of La Barge. WDEQ-AQD snow stakes located at the Boulder, Daniel South, Big Piney, and Juel Springs sites indicated 6 to 10 inches with Wyoming Range showing over two feet of snow. Morning temperatures were in the single digits (°F) (positive and negative) range in the northern part of the UGRB with positive teens to the south. By late afternoon, temperatures had warmed into the teens in the north and upper 20's and low 30's (°F) to the south. Figures 2.11 through 2.13[1,2,3] present weather charts and snow depth information for January 29, 2012.

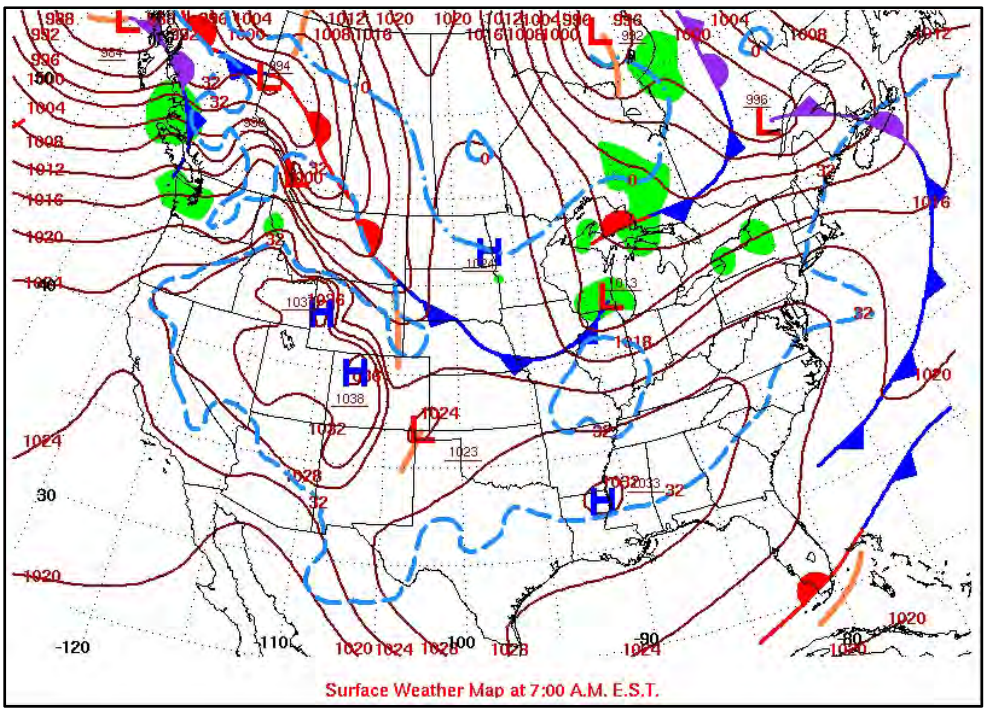

Figure 2.11 Surface Chart for 5 AM MST January 29, 2012

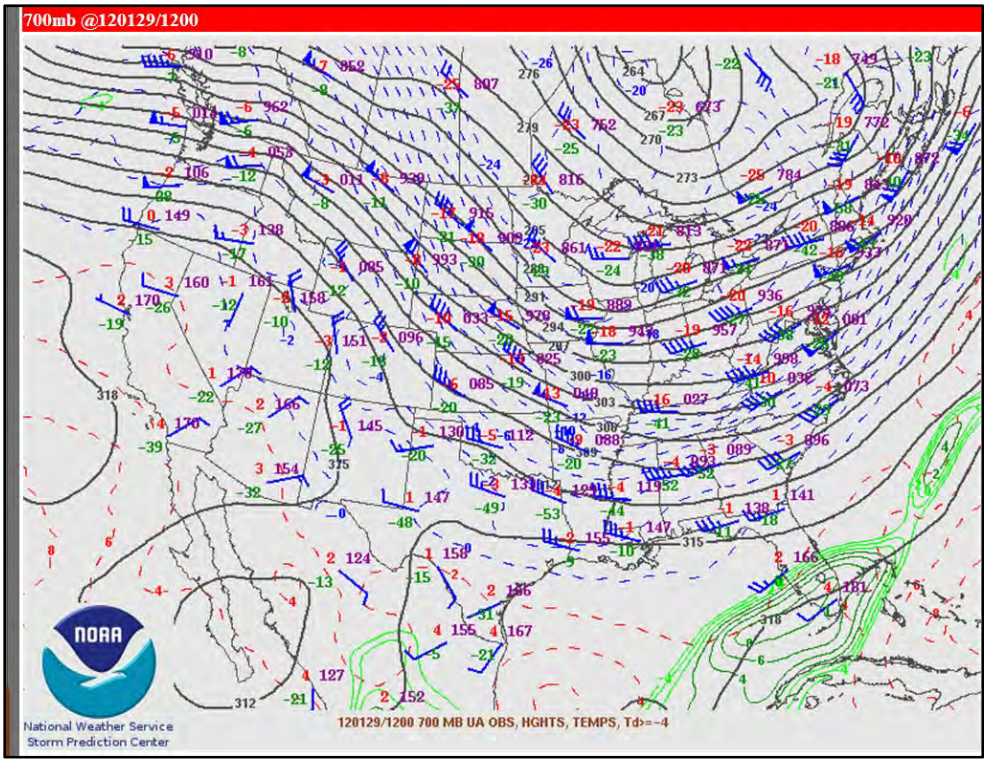

Figure 2.12 700 MB Chart for 5 AM MST January 29, 2012

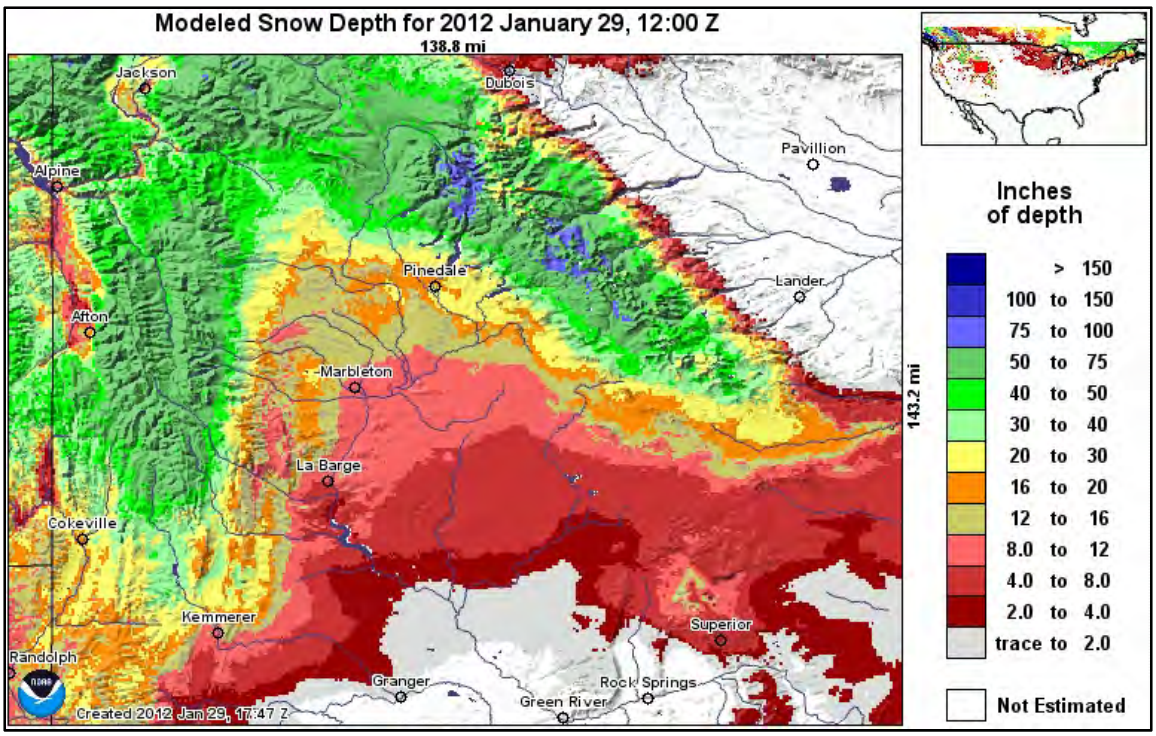

Figure 2.13 Snow Depth Chart for 5 AM MST January 29, 2012

The second IOP occurred on February 5 and 6, 2012. Low pressure in the upper atmosphere over Kansas and Nebraska worked its way east while high pressure built into Wyoming from the west on February 4 and overnight into February 5. At the surface, high pressure lay across Wyoming from a strong center over northeast Colorado and northwest into western Montana on February 5. This high weakened some on February 6 but remained over the state. There were some high clouds February 5 due to wrap around moisture from the low in the Plains, but February 6 was clear. Morning temperatures were cold during this period with lows generally below zero (°F) in all areas of the UGRB warming to the low teens to low 20's (°F) during the day through the UGRB. Winds were light with speeds mostly 10 mph or less. Snow depth was less than the first IOP and ranged from 8 to 16 inches. The WDEQ-AQD snow stakes indicated from less than 6" in most locations to around 2 feet at Wyoming Range. Figures 2.14 through 2.18 provide weather charts for February 5 and 6 and snow depth information for February 6, 2012.

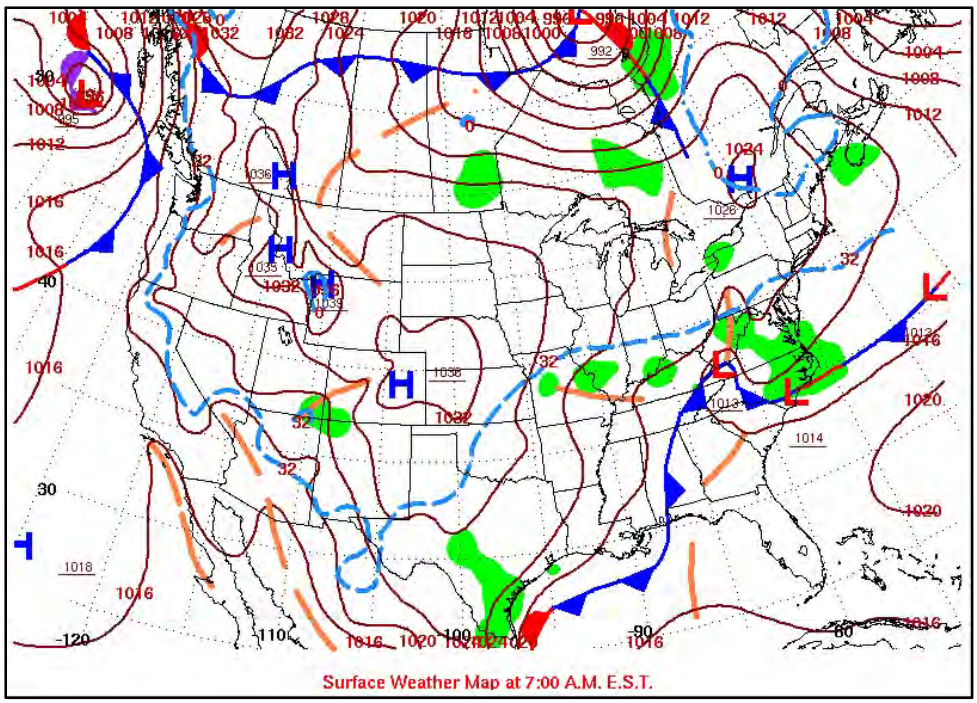

Figure 2.14 Surface Chart for 5 AM MST February 5, 2012

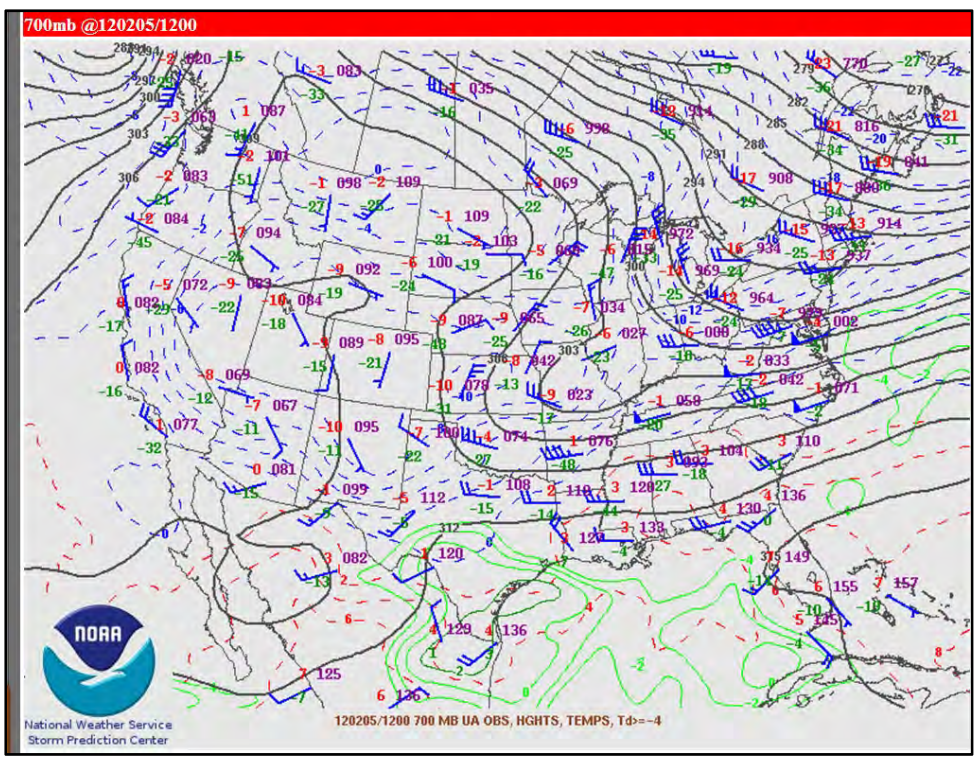

Figure 2.15 700 MB Chart for 5 AM MST February 5, 2012

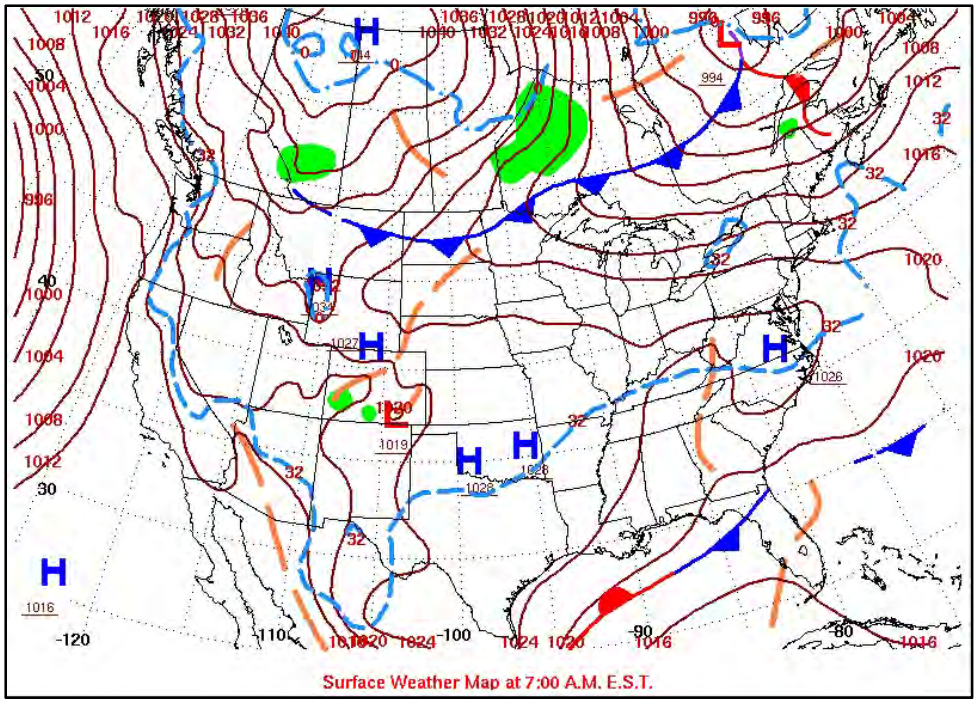

Figure 2.16 Surface Chart for 5 AM MST February 6, 2012

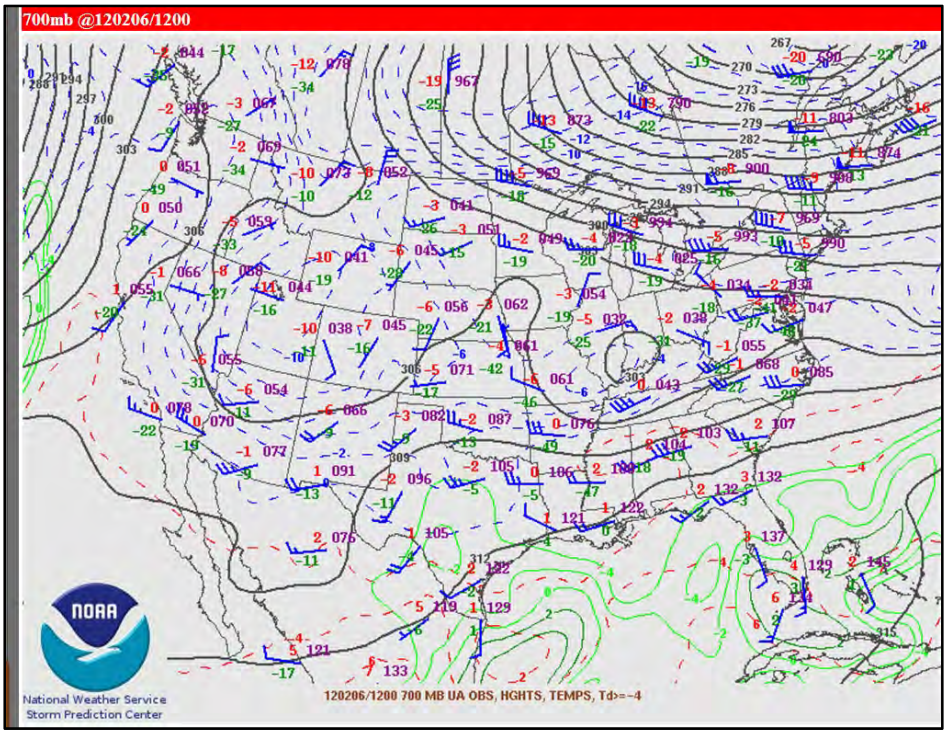

Figure 2.17 700 MB Chart for 5 AM MST February 6, 2012

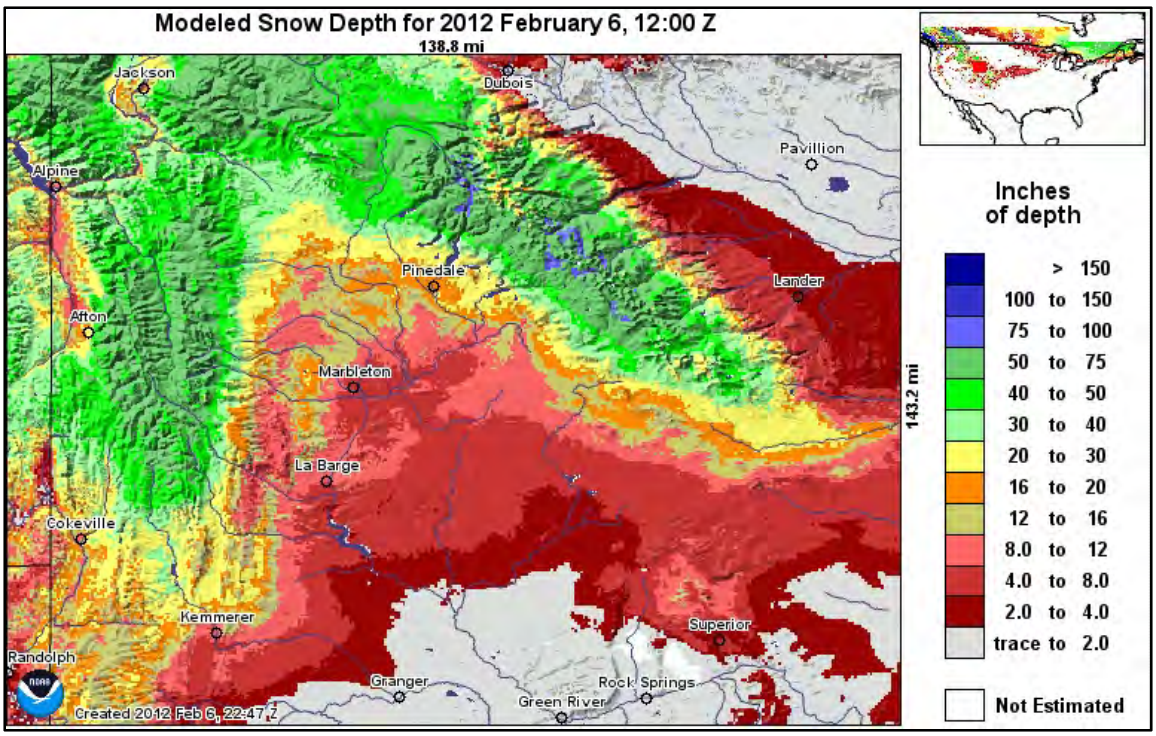

Figure 2.18 Snow Depth Chart for 5 AM MST February 6, 2012

The third IOP occurred on February 16, 2012. At the surface, high pressure lay across Wyoming from northwest to southeast. The upper level winds were light with northwesterly flow to the north and variable wind directions to the south of the UGRB. Temperatures began as cold as the negative teens and climbed into the low 20's in the northern part of the UGRB and into the 30's (°F) to the south. Surface winds were light. Sky conditions were essentially clear, though there were a few high clouds north of the UGRB. Snow stakes at the monitoring sites indicated from less than 6 inches in many locations to over 2 feet at Wyoming Range. Figures 2.19 through 2.21 provide weather charts and snow depth information for February 16, 2012.

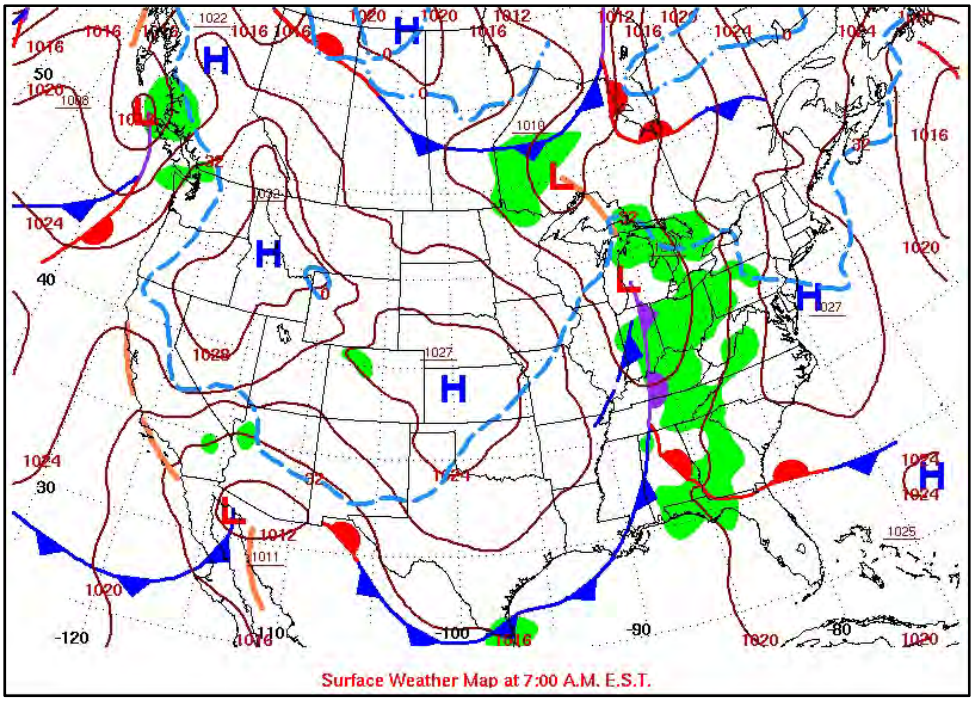

Figure 2.19 Surface Chart for 5 AM MST February 16, 2012

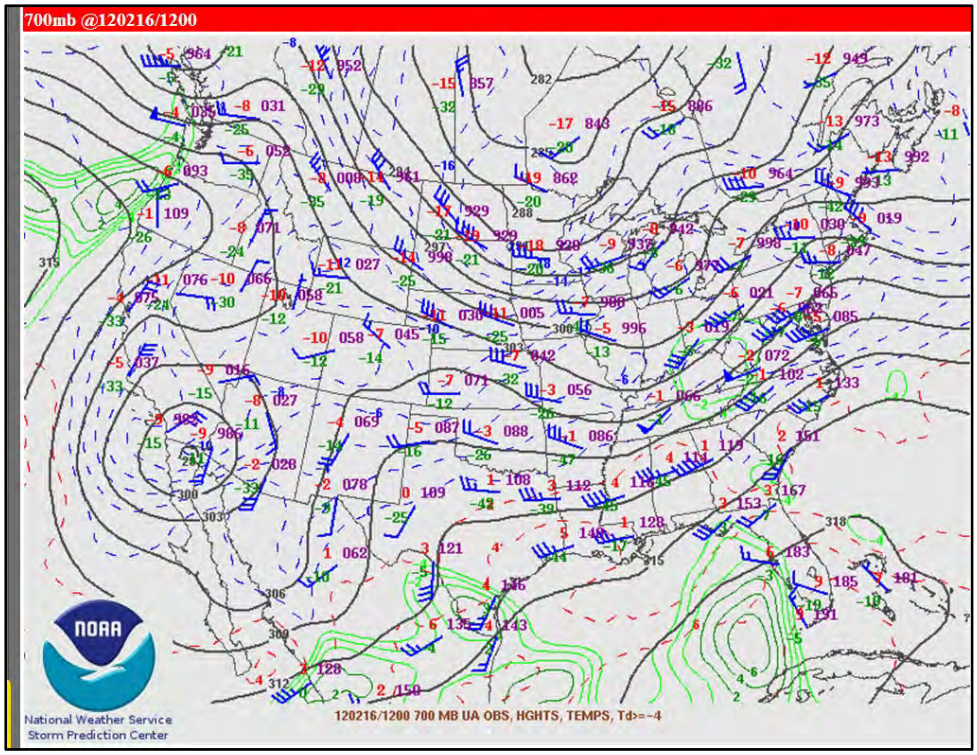

Figure 2.20 700 MB Chart for 5 AM MST February 16, 2012

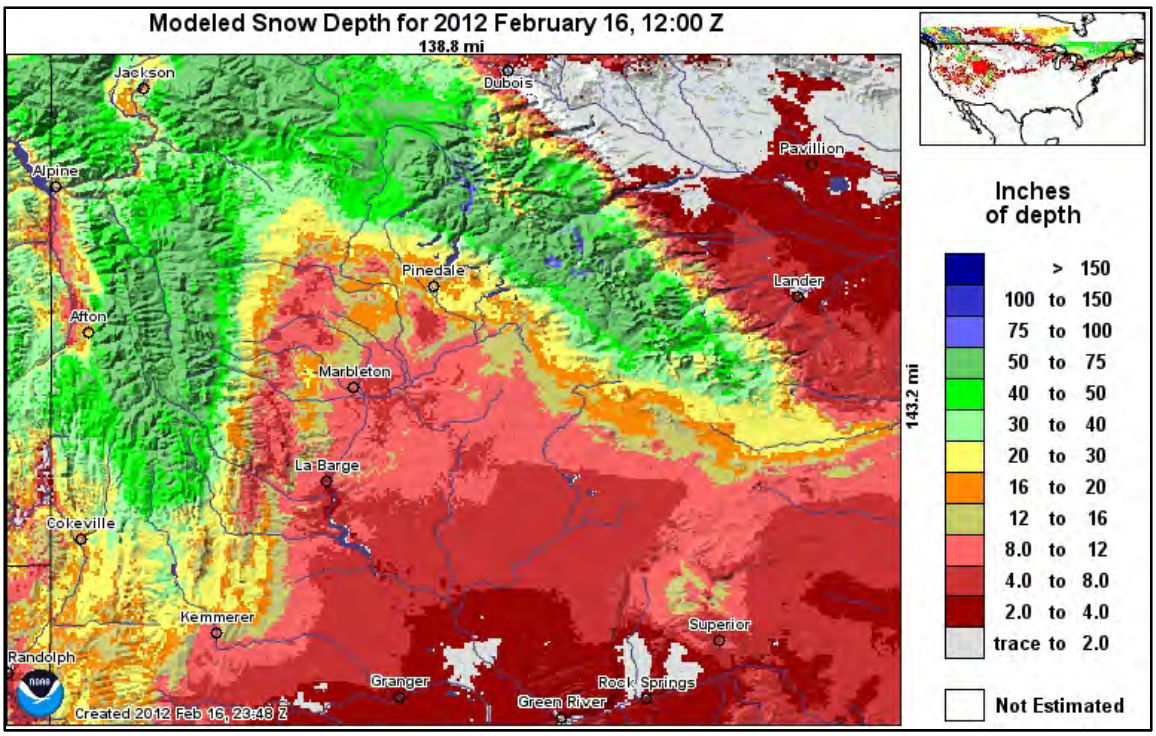

Figure 2.21 Snow Depth Chart for 5 AM MST February 16, 2012

The fourth IOP was another one-day event that occurred on February 27, 2012. The weather pattern this day had a low-pressure system aloft over California with a southwesterly flow at 10,000 feet over western Wyoming. At the surface, a deep low-pressure system was centered over southern Nevada in the morning that moved northeast through southern and central Utah into Colorado by the morning of February 28. This was a cloudy day with snow showers in the higher terrain around the UGRB. Morning temperatures were cold ranging from a few degrees below zero (°F) to the lower teens (°F) throughout the UGRB. By late afternoon it had warmed to near 20°F to the low 30's (°F) in all areas of the UGRB. Surface winds were light and mostly northerly through the day. Figures 2.22 through 2.24 provide weather charts and snow depth information for February 27, 2012.

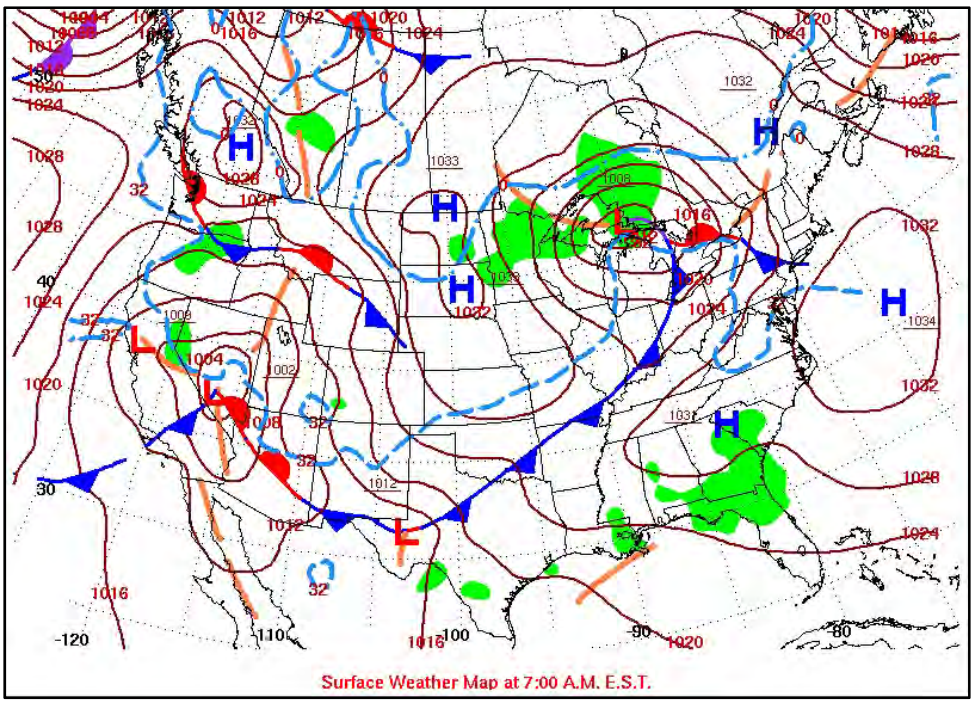

Figure 2.22 Surface Chart for 5 AM MST February 27, 2012

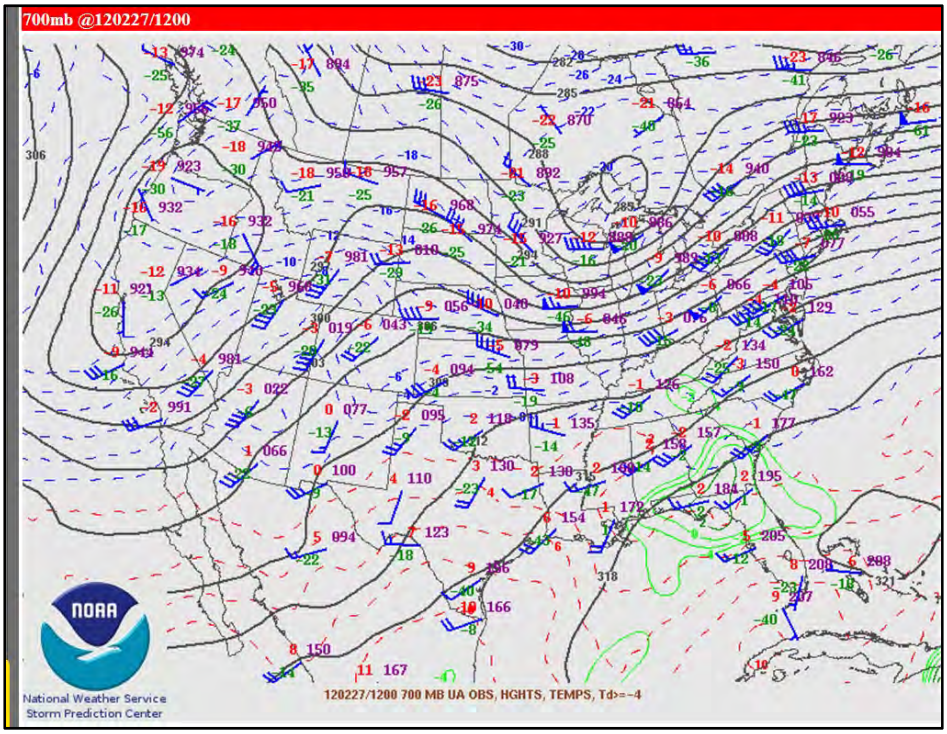

Figure 2.23 700 MB Chart for 5 AM MST February 27, 2012

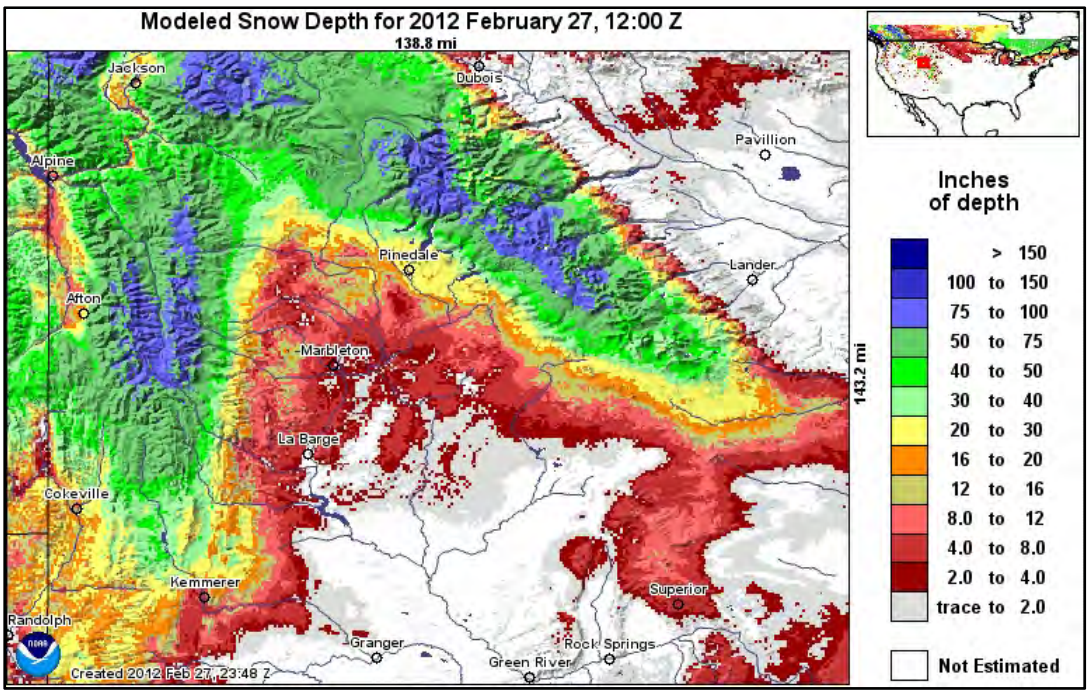

Figure 2.24 Snow Depth Chart for 5 AM MST February 27, 2012

On March 4 and 5, the fifth IOP of the 2012 UGWOS season occurred. High pressure aloft moved into the western U.S. on March 3. This high slowly moved eastward on March 4 and then began flattening on March 5 as another storm approached the Pacific Northwest coast. At the surface, fairly strong high pressure lay from southern Idaho across northern Utah, southwest Wyoming and western Colorado early in the IOP. The high pressure then weakened a little as a surface low developed over the Pacific Northwest. Except for a few cumulus clouds over the mountains and hills, it was a clear and sunny period. Morning low temperatures were in the 20's (°F), warming to the 30's (°F) by late afternoon on March 4 in all areas of the UGRB. On March 5, temperatures started out in the positive single digits (°F) and warmed to the 30's (°F) in the north and 40's (°F) in the south by afternoon. Snow depth was essentially non-existent in the southern part of the basin while 3 to 20 inches was common elsewhere, increasing as you moved north and also east and west into the higher elevations. The Wyoming Range snow stake indicated over 30 inches there. Due to warmer conditions, snow depths had been decreasing, particularly in the southern part of the area. Figure 2.25 through 2.29 provide weather charts for March 4 and 5 and snow depth information for March 5, 2012.

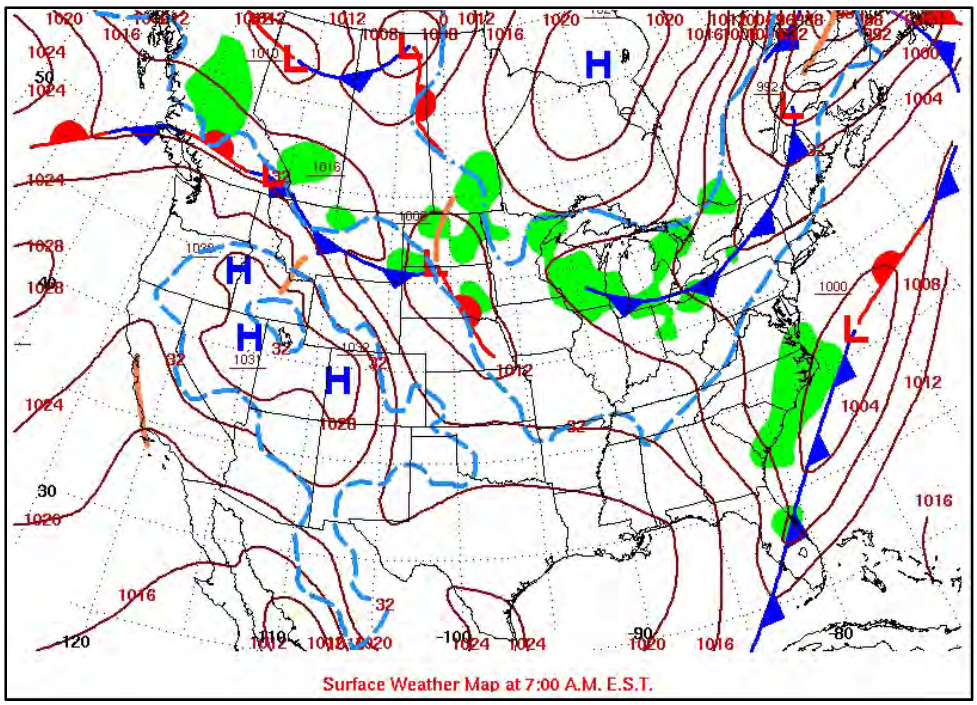

Figure 2.25 Surface Chart for 5 AM MST March 4, 2012

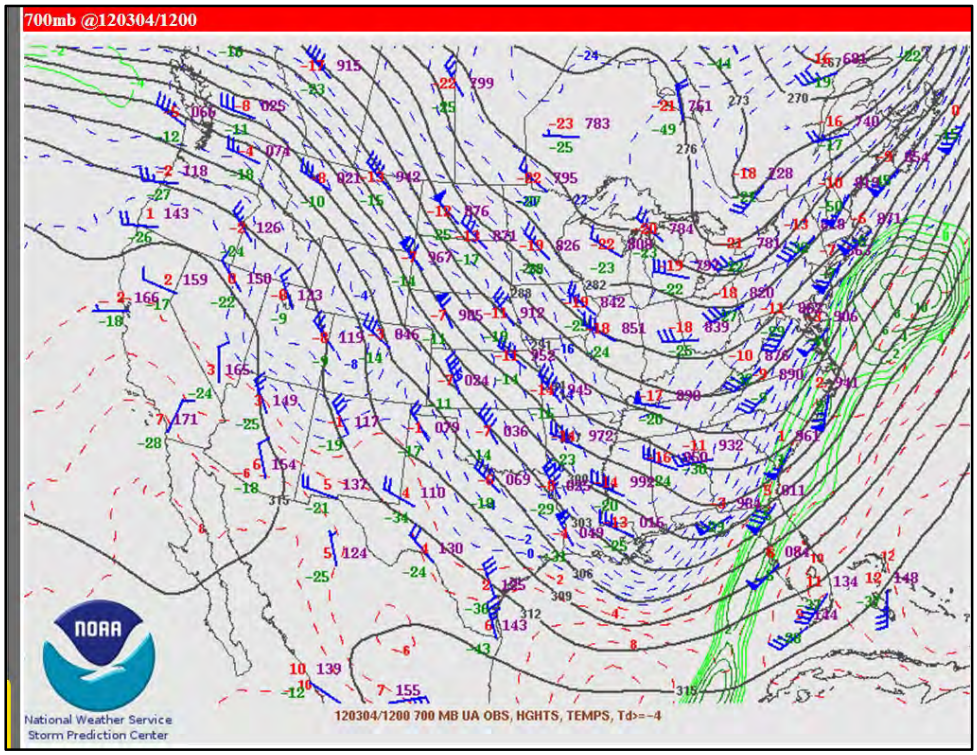

Figure 2.26 700 MB Chart for 5 AM MST March 4, 2012

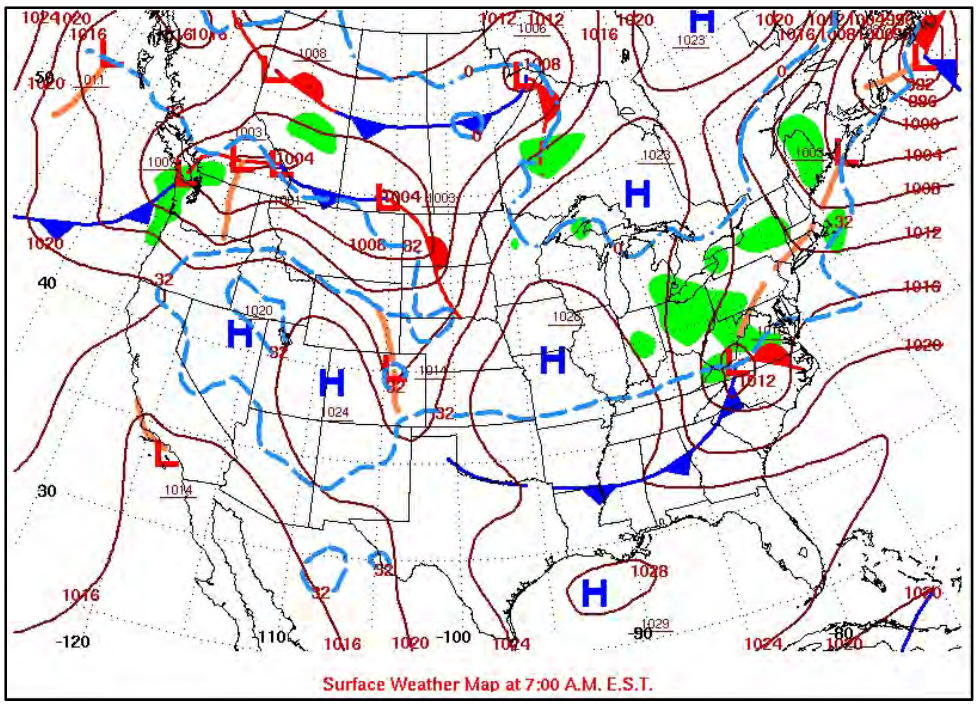

Figure 2.27 Surface Chart for 5 AM MST March 5, 2012

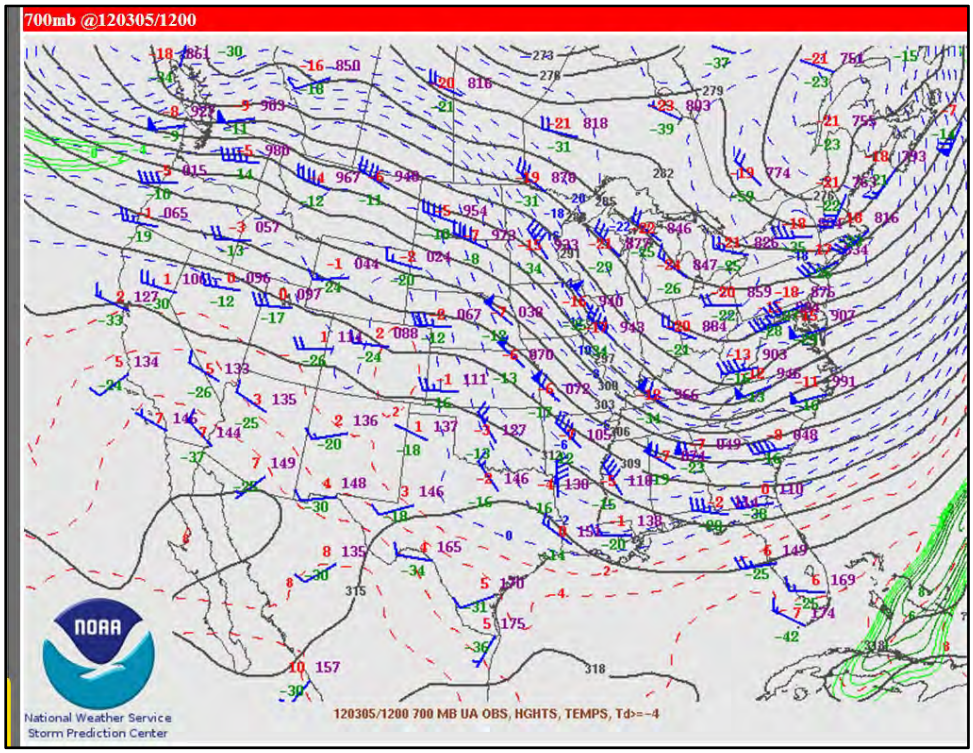

Figure 2.28 700 MB Chart for 5 AM MST March 5, 2012

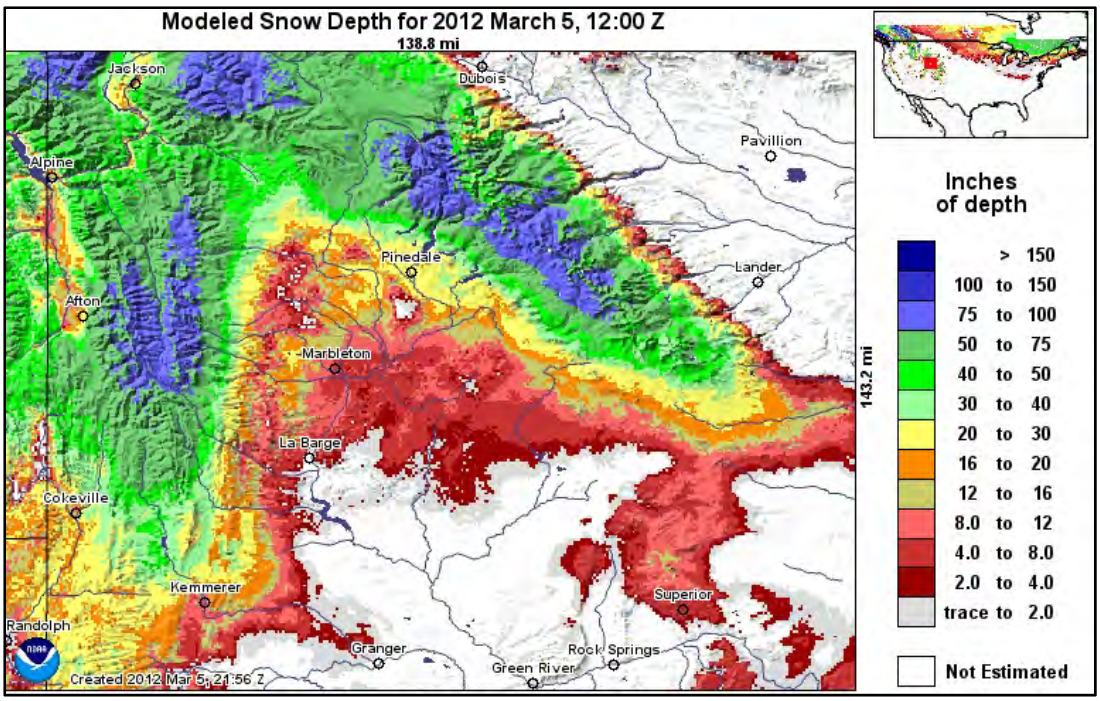

Figure 2.29 Snow Depth Chart for 5 AM MST March 5, 2012

The sixth and final IOP occurred on March 8 and 9, 2012. New snow fell on March 7 in parts of the UGRB, with a couple of inches in some spots. The southern part of the project area remained essentially bare. The Wyoming Range snow stake showed between 24 and 30 inches on the ground. In the atmosphere aloft, a high pressure center pushed in from northern California over the two-day period bringing in warming aloft as well as light winds. At the surface, high pressure held over all of Wyoming and, similar to conditions aloft, temperatures warmed and winds were light. Except for some high clouds during the afternoon of March 8 it was mostly clear during the two days. Temperatures in all parts of the UGRB ranged from the single negative digits to the positive teens (°F) the morning of March 8 with mostly teens the morning of March 9. UGRB afternoon temperatures warmed into the upper 20's and 30's (°F) on March 8 and into the 30's and 40's (°F) on March 9. Figures 2.30 through 2.34 provide weather charts for March 8 and 9 and snow depth information for March 9, 2012.

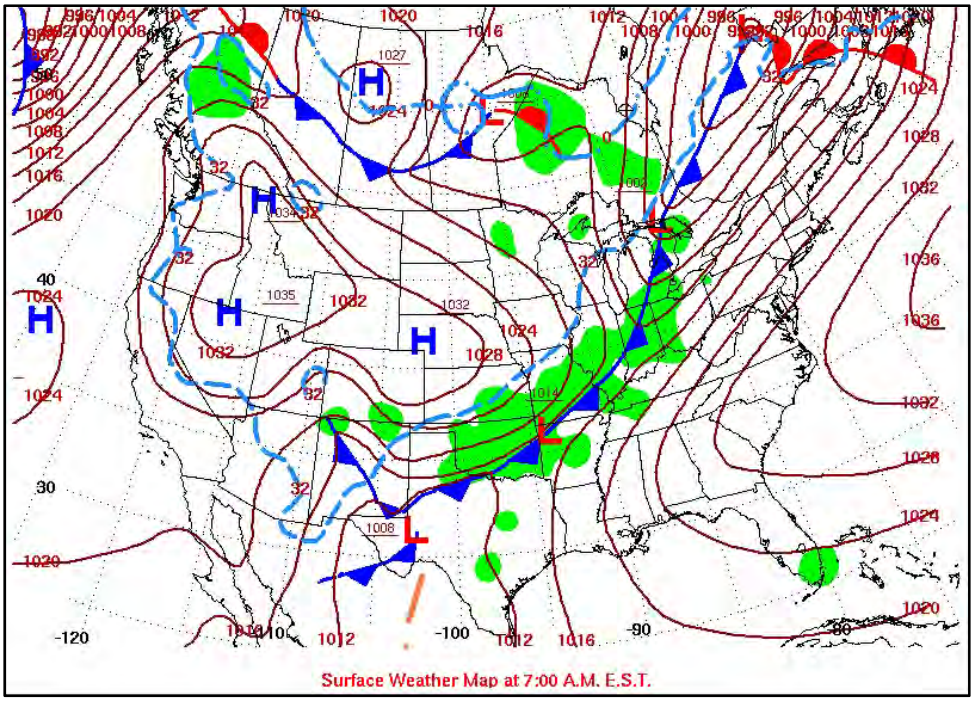

Figure 2.30 Surface Chart for 5 AM MST March 8, 2012

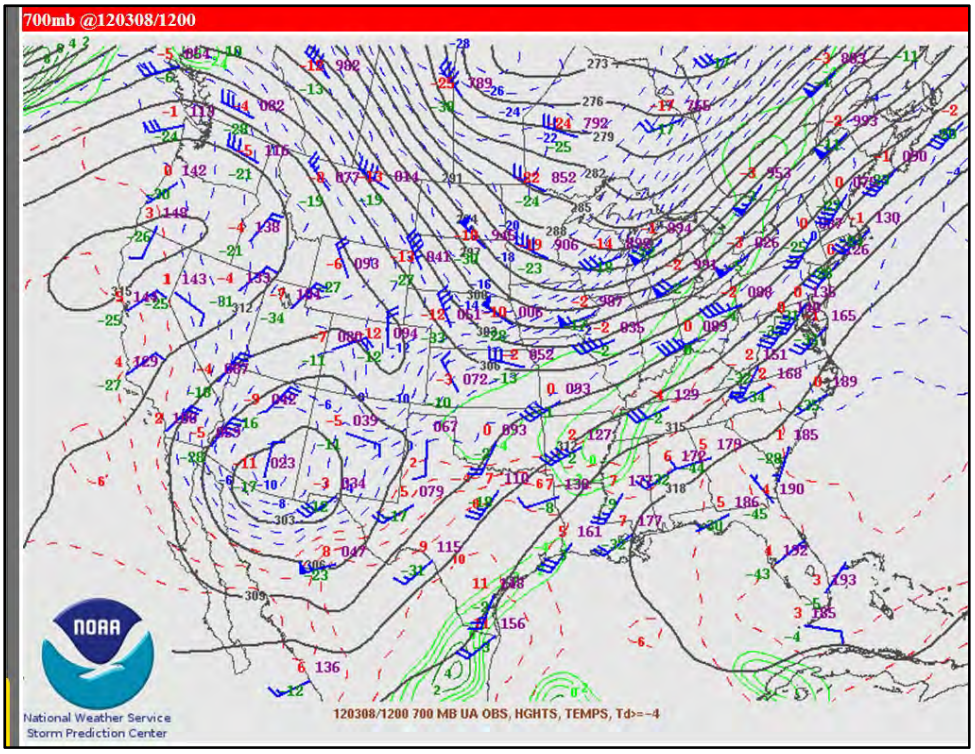

Figure 2.31 700 MB Chart for 5 AM MST March 8, 2012

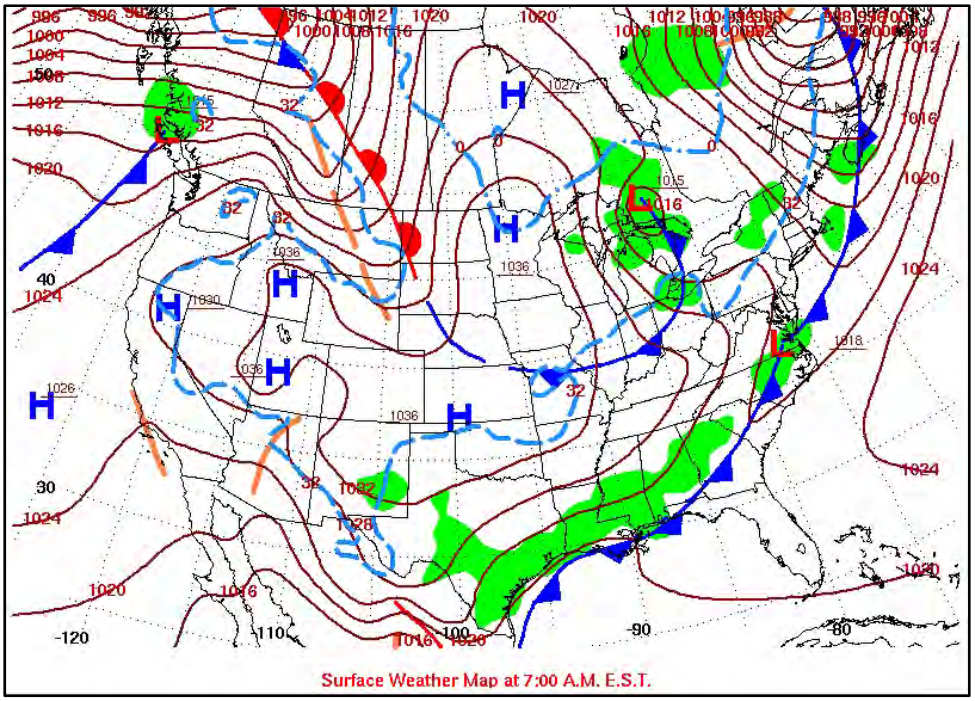

Figure 2.32 Surface Chart for 5 AM MST March 9, 2012

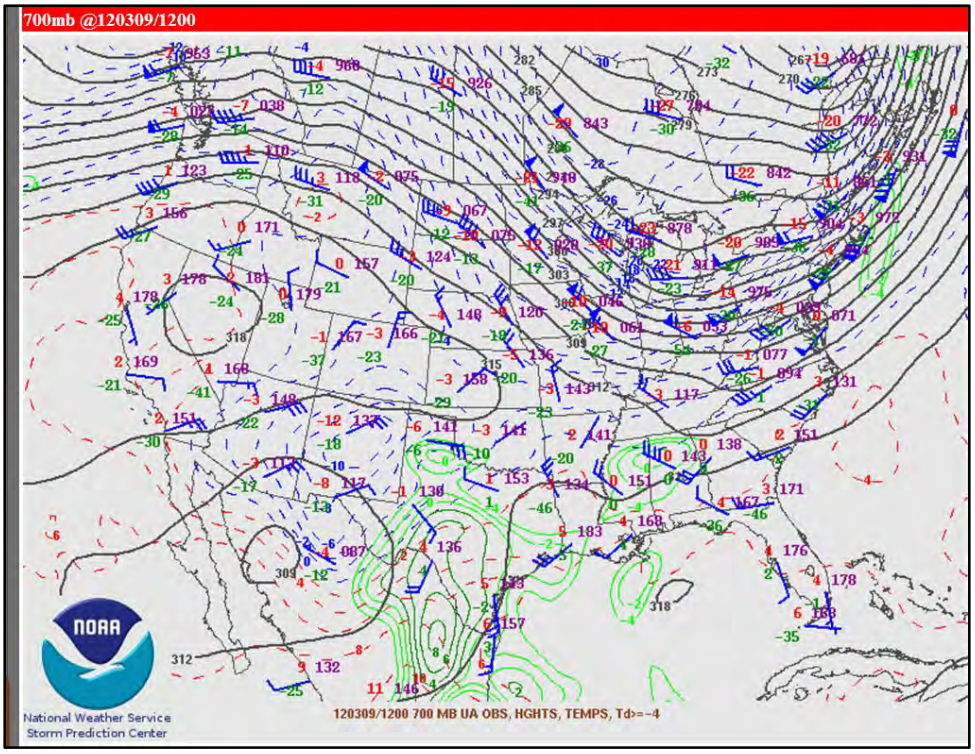

Figure 2.33 700 MB Chart for 5 AM MST March 9, 2012

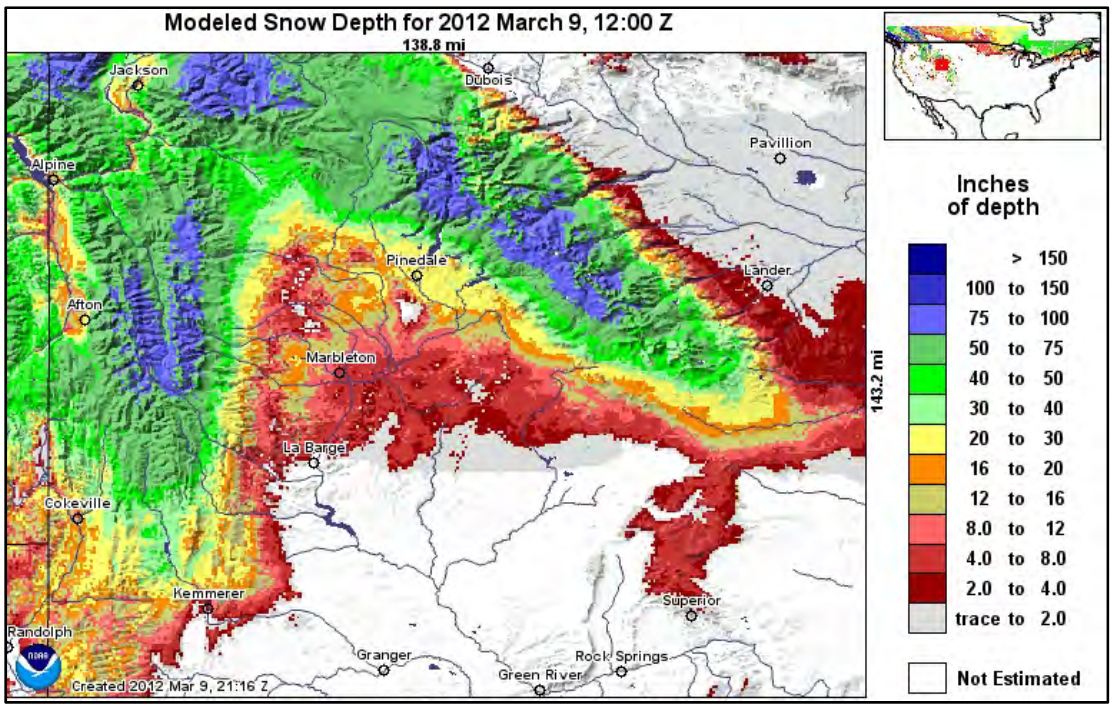

Figure 2.34 Snow Depth Chart for 5 AM MST March 9, 2012

3.0 DATA QUALITY ASSURANCE, VALIDATION AND ARCHIVING

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

3.1 Database Management

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

Each of the participants that provided data was responsible for reviewing and validating their respective data to Level 1 as described in "The Measurement Process: Precision, Accuracy, Validity" (Watson, 2001). 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.

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

Table 3-1 Continued

Data Quality Control Codes Used in UGWOS Database

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

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

3.2 Quality Assurance Program

A Monitoring and Quality Assurance Plan was submitted to the WDEQ-AQD and approved encompassing all aspects of the monitoring program (See Appendix A). This document provides a detailed discussion of the quality assurance program implemented in 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 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 2012 ozone and oxides of nitrogen analyzers were routinely checked using a traceable transfer standard or reference gas following operating procedures consistent with EPA guidelines.

WDEQ tripod-mounted portable VOC sampling systems as well as the canister sampling system inside the air quality shelter at the Boulder monitoring site were leak checked, flushed with ultrapure air and checked for contamination prior to the start of the UGWOS 2012 study. VOC canisters were installed in each system, allowed to sample ultrapure air through the system inlet, and sent to the analytical laboratory for analysis to confirm that systems were free of contamination. A field sample data sheet was generated for each VOC canister indicating sample ID, sample date and time, and canister start and stop pressure. VOC canisters were sent back to the laboratory for analysis following each IOP accompanied by a chain-of-custody form.

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 values and adjusting the instrument to respond properly to those values. The calibration method for each of the air quality and meteorological variables 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 a water bath.

Air quality analyzers were calibrated at the start of the UGWOS 2012 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

Performance audits were conducted during T&B Systems' 1st Quarter 2012 auditing effort for the WDEQ-AQD. Audit procedures and detailed results were included in the T&B Systems' report "First Quarter 2012 Quality Assurance Report for the Wyoming Department of Environmental Quality Air Monitoring Network." A summary of the results for the UGWOS-specific instrumentation is presented in Table 3-2.

Table 3-2

UGWOS 2012 (Jonah Trailer) Performance Audit Results

Site: Jonah Trailer
Project: UGWOS QA Audits
Operator: MSI

AMBIENT AIR QUALITY MONITORS

Audit Date	Parameter	Max Diff. (%)	DAS Slope	DAS Intercept	DAS Correlation
1/30/2012	Ozone	-6.6	0.926	0.002	1.0000
1/30/2012	Nitric Oxide	-4.4	0.957	0.000	1.0000
1/30/2012	Nitrogen Oxides	-6.1	0.938	0.001	1.0000
1/30/2012	Nitrogen Dioxide	-6.6	0.929	0.002	0.9999

Audit Criteria: Max Diff ±15%, Slope 1.000 ± 0.15: Intercept 0 ± 0.015 ppm (THC 0 ± 0.9 ppm); Correlation > 0.9950

METEOROLOGICAL SENSORS

Audit Date	Sensor	Audit Input	DAS Diff.	Audit Criteria
1/30/2012	Wind Speed (5 meters)	m/s	m/s	
		0	0.0	±.25 m/s; ws ≤ 5 m/s
		2.6	0.0	
		m/s	%	
		7.7	0.0	± 5%; ws > 5 m/s
		12.8	0.0	
		23.0	0.0	
		33.3	0.0	
1/30/2012	Wind Direction (5meters)	Deg	Deg	
		43	1	± 5 degrees
		88	1	
		133	1	
		178	-1	
		223	-2	
		268	0	
		313	0	
		358	2	
1/30/2012	Temperature (4 meters)	Deg C	Deg C	
		0.2	-0.2	± 1.0 degree Celsius
		18.4	-0.3	
		39.6	-0.5	

3.2.2.2 System Audits

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

- Siting of the equipment used for the intensive measurements
- Adherence of the field personnel to the Standard Operating Procedures
- 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:

MiniSODAR™

The miniSODAR™ has been operational at the site for over a year with good data recovery. Prior to arrival at the site the data were reviewed for internal consistency. While at the site a review of the level of the antenna was conducted. The results of the reviews are summarized below.

- Prior to the system audit, the operational frequency of the sodar had been adjusted to 4,700 Hz to move the central frequency away from spurious signals noted at 4,700 and 5,000 Hz. This change minimized the influence of the spurious signals.

- It was noted prior to the system audit that there was an apparent heater issue with the miniSODAR™ reflector board heater not melting the accumulated snow. The auditor did help by clearing snow from the board. This clearing was manually performed following each snow event until a suitable fix was implemented.

- In late February a temporary fix was implemented by installing a pair of heating lamps inside the shelter, aimed at the reflector board. These lamps provided adequate heating to melt snow and keep any ice from accumulating. Data during periods where snow was present will need careful review to remove periods of invalid data.
- Two speakers were noted to be not operational. It was decided to not replace the speakers as the effect on operation would be negligible. The replacement would be planned for when the heater system is repaired.
- A review of the miniSODAR™ vista showed an open view in all directions with the exception of the following:
  - 60° - The meteorological tower was located about 33 meters from the miniSODAR™ with the top of the tower at an elevation angle of 30°.
  - 120° - Air quality shelter located about 17 meters from the miniSODAR™ with the top of the structure at a 20° elevation angle.
  - 180° - Air quality shelter located about 13 meters from the miniSODAR™ with the top of the structure at a 10° elevation angle.

Each of the noted obstructions above did not seem to adversely affect the operation of the miniSODAR™.

- 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 44.8°, which is within the expected tolerance of 45° ±0.5°. The level of the antenna was found to be 0.2°, which is within the expected tolerance of 0.0° ±0.5°.

Air Quality Variables

The data collection procedures and siting of the UGWOS specific measurements were reviewed. The results of the reviews are summarized below.

- The NO gas cylinder used for calibration checks at the Jonah Field monitoring station had an expiration date of 12/3/11. The operator indicated that they had performed several comparisons to a cylinder with a current certification date with negligible differences observed.
- The location of the temporary Jonah trailer was near Luman Road, adjacent to the roadway. There is some traffic nearby that could influence the measurements.

3.2.2.3 Processing of the miniSODAR™ data

The processing of the miniSODAR data at the Boulder site was performed using four 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. Using the merged hourly data, periods of known bad data when the miniSODAR™ reflector board heater was not working and the enclosure was known to have snow present were invalidated. Snow on the reflector board will dampen the miniSODAR™ transmit pulse and return echoes, and potentially alter the beam angles. This issue was identified just after the start of the field effort during a significant snowfall.
3. 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.
4. The resulting hourly validated data from the miniSODAR™ database were exported into a comma delimited data set for submission.

As noted above, there were two periods of known invalid data due to reflector board heating pad issues and the resulting accumulation of snow. A summary of these periods is described below:

1/21/12, 1000 through 1/29/12, 1700 – Snow accumulation on the miniSODAR™ reflector board that was manually cleared on 1/29. Changes were made to the miniSODAR™ thermostat to try and rectify the problem.

2/11/12, 2100 through 2/12/12, 1700 – Snow accumulation on the miniSODAR™ reflector board that was manually cleared on 2/12. Infra-red heat lamps were subsequently shipped to the site and installed in late February to alleviate any further snow issues.

3.3 Data Validation

Each study participant was responsible for reviewing and validating their collected data. These data were validated to Level 1 as described by Watson, et. al. (2001)[1] before submittal to the database. This included flagging values for instrument downtime and performance tests, applying any adjustments for calibration deviation, investigating extreme values and applying appropriate flags.

3.4 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

[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.

- 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, START_TIME or END_TIME = Time stamp of data (HHMM) (MST)
- HEIGHT = Elevation in meters above MSL
- QC_CODE, (WS_QC, WD_QC, O3_QC, etc.) = As described in Table 3-1
- NOTES = any additional information

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

4.0 RESULTS

This section discusses the results of meteorological and air quality measurements collected during the UGWOS 2012 field effort.

4.1 Summary of 2012 Meteorological and Air Quality Conditions and Comparison with Prior Years

This section describes meteorological and air quality conditions and measurements recorded during UGWOS 2012 and how they compared with previous UGWOS studies.

4.1.1 700 mb Comparison 2012 versus 2007-2011

This section will look at how the700 mb pressure level data during the 2012 UGWOS study compared with the previous five years of study.

Prior to the first UGWOS study, objective criteria for forecasting elevated ozone episodes were developed based on several weather parameters. These criteria were developed after studying high ozone periods that occurred prior to 2007 and have been used as guidance in forecasting elevated ozone in the UGWOS study area since that time. The 700 mb criteria that have been used for forecasting elevated ozone for the UGWOS study and that are compared in this section are as follows:

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

Table 4-1 contains the average 700 mb criteria for each of the study years (February and March only). These data were taken from maps developed from reanalysis data[2] provided by NOAA's Earth System Research Labs (ESRL).

Table 4-1

Averaged 700 mb Parameters during UGWOS 2007-2012

February/March Period	Average700 mb Height (m)	Average 700 mb Temperature (°C)	Average 700 mb Wind Speed (mps)
2007	3042	-5.1	10.4
2008	3018	-8.2	10.1
2009	3024	-6.5	9.6
2010	3023	-7.0	6.8
2011	3008	-8.2	10.8
2012	3024	-5.7	9.3

The 700 mb level parameters for 2012 shown in Table 4-1 fell well within the range of values that have occurred over the previous five years. The 700 mb temperature during the two-month period was on the warmer side of the range but the average height and wind speed were near the previous five-year average.

During the 2007 through 2012 UGWOS study periods, there were a total of forty one days when IOP's occurred. Four out of the six years had no eight-hour ambient ozone concentrations above 75 ppb. In UGWOS 2012, there were no eight-hour ozone values above 75 ppb and very few hourly ozone values of 70 ppb or greater. Table 4-2 provides the number of IOP's each year.

[2] NCEP Reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, Accessed August 2012, http://www.esrl.noaa.gov/psd/

Table 4-2

Intensive Operational Periods by Year

Year	Number of IOP's	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
Total	15	41	-	-

Using reanalysis data and incorporating only IOP days reveals the following averaged results for the 700mb criteria parameters in Table 4-3.

Table 4-3

Averaged 700mb Parameters during IOP Days 2007-2012

February/March Period	Average700 mb Height (m)	Average 700 mb Temperature (°C)	Average 700 mb Wind Speed (mps)
2007	3061	-1.9	11.2
2008	3064	-7.2	6.5
2009	3104	-4.8	7.7
2010	-	-	-
2011	3053	-9.1	10.7
2012	3075	-5.8	4.4

Although elevated ozone did not develop, the days chosen for the 2012 IOP's did record 700 mb meteorological parameters that fell within the forecast criteria. The pressure height and temperature for 2012 were both nearly equal to the average of the previous years of data (2010 had no IOP's and therefore averages were not available). However, the wind speed was much lower than previous years' IOP days and was only about half (4.4 mps) of the 9.0 mps average of the other years (see Table 4-3).

4.1.2 Snow Cover in 2012 Versus 2007-2011

It is well known[3] that the snow cover that accumulates in the UGRB during the winter and early spring months is an essential element in the development of elevated ozone. However, in 2012 it was also demonstrated that having a significant snow cover does not guarantee that elevated ozone will develop. In conjunction with a significant snow cover, there must be stable atmospheric conditions that will provide a period of stagnation and low level inversions that allow the accumulation and concentration of ozone precursors. In 2012 although there was significant snow cover for much of the study period, no significant elevated ozone was measured.

The general weather pattern was fairly consistent during the 2012 UGWOS season. Storm systems frequently moved onto the west coast and pushed inland with the core of the storms moving across the southern part of the country from California into the southern Rockies. At the latitude of Wyoming these storms were mostly weak and brushed the area causing infrequent snowfall. The beginning of the UGWOS season had little if any snow below 7,500 feet as seen in Figure 4.1. Snow did fall between January 15 and the end of the month with a more vigorous system moving through on January 21. This period produced snowfall amounts up to 4 to 8 inches in the southern part of the study area. The northern, higher elevations ended up with over two feet on the ground as seen in Figure 4.2

[3] *"Comparison of Weather Conditions During the 2011 Upper Green Winter Ozone Study To past Study Seasons", MSI, Pg 2-2 ,October 2011*

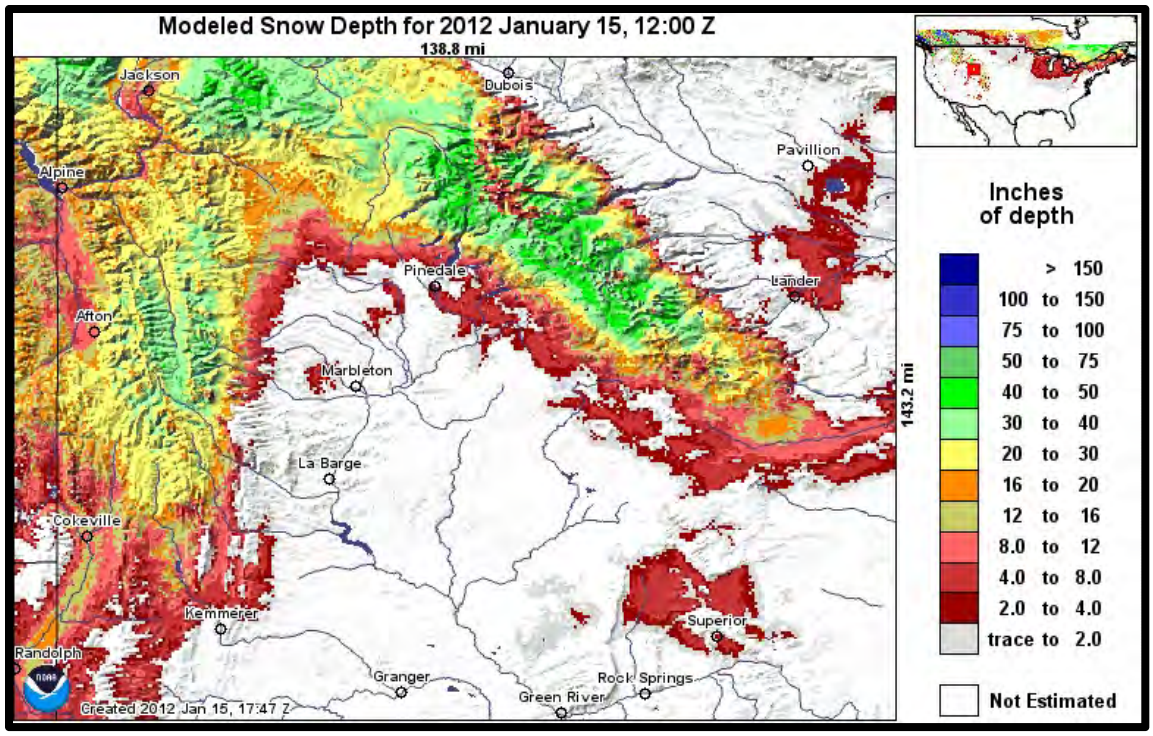

Figure 4.1 Snow Depth in the UGWOS Area on January 15, 2012

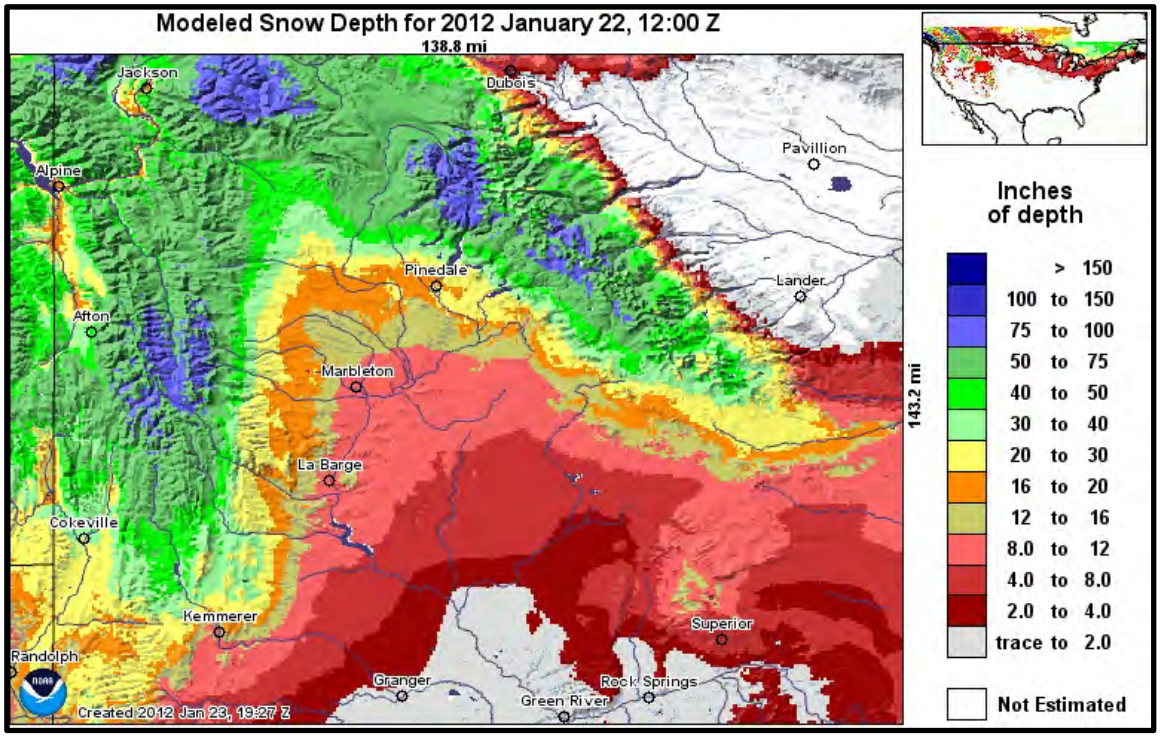

Figure 4.2 Snow Depth in the UGWOS Area on January 22, 2012

Images showing the modeled snow depth over the UGWOS study area at the beginning and middle of the month can be found in Appendix C.

The snow level changed little over the next month following the January 21 storm. Slow melting caused decreasing amounts for elevations below approximately 7,000 feet after February 22 until between February 29 and March 1 when a little more snow fell. The strengthening spring sun slowly melted the snow, particularly at the lower elevations between March 2 and March 18. A weak storm brought light snow to the area on March 19. After this the snow depth continued to drop with snow pack receding in the higher elevations through the end of the month. Figure 4.3 presents the UGWOS area snow cover as of March 31, 2012.

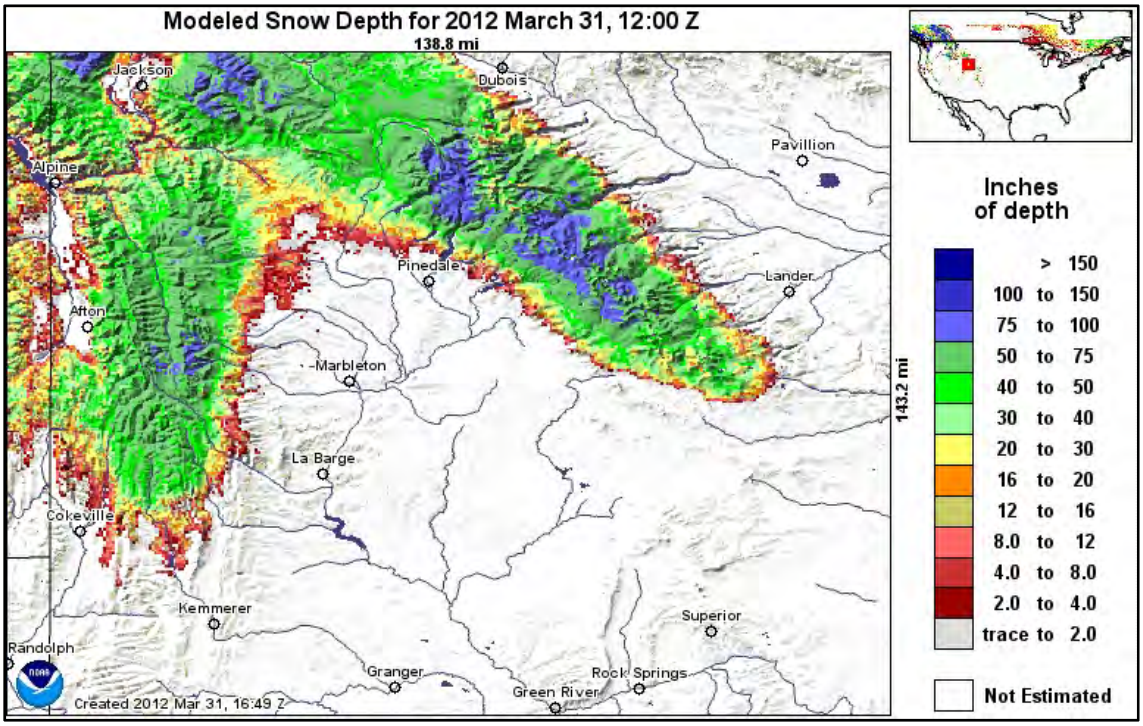

Figure 4.3 Snow Depth in the UGWOS Area on March 31, 2012

The beginning of the UGWOS season in 2012 had the least amount of snow on the ground compared to the previous five years. The beginning of the 2009 season was a close second although it had higher amounts in the foothills, including the Pinedale area. In both 2009 and 2012 there was essentially no snow in the lower basin. However, there was significant new snow accumulation in 2012 during late January.

By the first of February 2012 there was deep snow in the mountains with some locations estimated to have over 75 inches. These amounts surpassed 2008 and were very similar to depths at this time in 2011. In the lower basin, snow depths at this time were some of the highest recorded in any of the study years with 2 to 4 inches as far south as between Farson and Moxa. South of this point the snow depths were not as high as any of the previous five years.

On March 1, 2012 basin snow depths had increased over most parts of the study area although in the far south, the snow had melted. Snow depth was less in the lower basin compared to 2011 but was very similar to amounts in the mountains in that year. In general the study area in 2012 had more snow than 2008 through 2010. The lower basin had similar amounts to 2007, while the mountains in 2007 had considerably less snow than was observed in 2012.

By the end of March 2012, the normal reduction in snow depths in the UGRB due to the warming spring sun were evident. There was no snow on the ground in elevations below approximately 7,500 feet. In the previous five years, 2010 had similar conditions; 2009 and 2011 had lost most snow below approximately 7,000 feet. In 2007 and 2008, there were still large parts of the UGRB which had 2 to 4 inches of snow or more on the ground in late March.

In summary, except at the very beginning and the very end of the 2012 UGWOS season, there was generally a heavier snowpack over much of the study area than in previous years. The biggest exception was 2011 which had the overall highest snow levels during the January 15 through March 31 period when compared with the 2007 through 2012 UGWOS monitoring years.

4.1.3 Comparison of Ozone in 2012 with 2005-2011

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 this year's 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. Eight-hour ozone averages and maxima by month from these sites are presented in Table 4-4.

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
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
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

* Temporary Mesonet site with 2B ozone analyzer prior to long-term site.
† BAM trailer with FEM monitor after long-term site equipment moved to Juel Springs
NA – Data not available

With the exception of Jonah, 2012 established new minimums for the average 8-hour ozone concentration for nearly every month and site. The maximum eight-hour ozone concentration for nearly each month and site in 2012 was lower than any previous year. The highest 8-hour ozone concentration for any site was 64 ppb observed at Boulder.

4.1.4 Comparison of NO_x and PM during UGWOS 2012 with 2006-2011

Average monthly NO and NO_2 concentrations at AQD monitoring sites in the UGRB are presented in Table 4-5. During 2012, concentrations were very light with no sites exceeding a monthly average of 1.3 ppb NO and 4.3 ppb NO_2, respectively. For several sites and months, the monthly average concentration established a new minimum for the site.

Table 4-5

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

Jan.	1-Hour NO (ppb)						1-Hour NO_2 (ppb)					
Year	Jonah/ BAM	BD	DN	PD	Juel	WR	Jonah/ BAM	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
Feb.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
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
Mar.	**1-Hour NO (ppb)**						**1-Hour NO_2 (ppb)**					
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

* January 15-31, 2010
† BAM 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 during 2012 were comparable with those from prior years.

Table 4-6

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

January	**Average PM_{10} (µg/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
February	**Average PM_{10} (µg/m^3)**			**Average $PM_{2.5}$ (µg/m^3)**	
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
March	**Average PM_{10} (µg/m^3)**			**Average $PM_{2.5}$ (µg/m^3)**	
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

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

4.1.5 Comparison of NMHC and THC during UGWOS 2012 with 2010-2011

Methane/THC measurements using a continuous analyzer were made at two locations during UGWOS 2012: Big Piney and the Boulder complex. Of the sites operating during 2012, only the Boulder site made these measurements during years prior to 2012. Average monthly CH_4, NMHC, and THC concentrations at the Boulder monitoring site are presented in Table 4-7.

Methane/THC measurements during 2012 were similar to those during 2010, which was also a low-ozone year. Inspection of the monthly average NMHC concentration (which serves as a proxy for ozone precursors) for the past 3 years yields a distinct pattern in which 2011 was higher than 2010 and 2012, especially in January and March.

Table 4-7

Monthly Average CH_4, NMHC and THC Concentrations by Year at Boulder

January	**Average CH_4 (ppm)**	**Average NMHC (ppm)**	**Average THC (ppm)**
Year	**Boulder**	**Boulder**	**Boulder**
2010	NA	NA	NA
2011	6.76	1.05	7.77
2012	2.10*	0.14*	2.24*
February	**Average CH_4 (ppm)**	**Average NMHC (ppm)**	**Average THC (ppm)**
2010	2.46	0.28	2.75
2011	2.39	0.32	2.70
2012	2.46	0.26	2.72
March	**Average CH_4 (ppm)**	**Average NMHC (ppm)**	**Average THC (ppm)**
2010	2.14	0.13	2.27
2011	2.37	0.31	2.69
2012	2.14	0.15	2.29

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

For each day during UGWOS 2012, the maximum 8-hour ozone concentration and average NMHC concentration were calculated at the Boulder site. These data are presented as a time series in Figure 4.4 and as a scatter plot in Figure 4.5. Figure 4.5 also contains the same parameters for Boulder from UGWOS 2011. Both positive (March 7 - 13) and negative (January 1 - 14) correlations exist during the course of the field study according to Figure 4.4. As a whole, NMHC explains only 29.6 percent of the variance in ozone concentrations, as shown in Figure 4.5. While it is true that the highest ozone concentration measured in 2011 (123 ppb) occurred on the same day as the highest NMHC concentration (1.1 ppm), there are several periods in which NMHC were measured in relatively high concentrations without high ozone concentrations to match. Ozone and NMHC concentrations measured in 2012 were very low when compared to 2011 data. Figure 4.6 presents a scatter plot of NMHC and Ozone Data collected at the Big Piney mobile air quality shelter. In 2012, Big Piney had very little NMHC measured at the site and no correlation between NMHC and ozone is apparent. Thus, NMHC may be a helpful indicator of ozone development when measured within an air shed relatively close to sources of NMHC like the Boulder site.

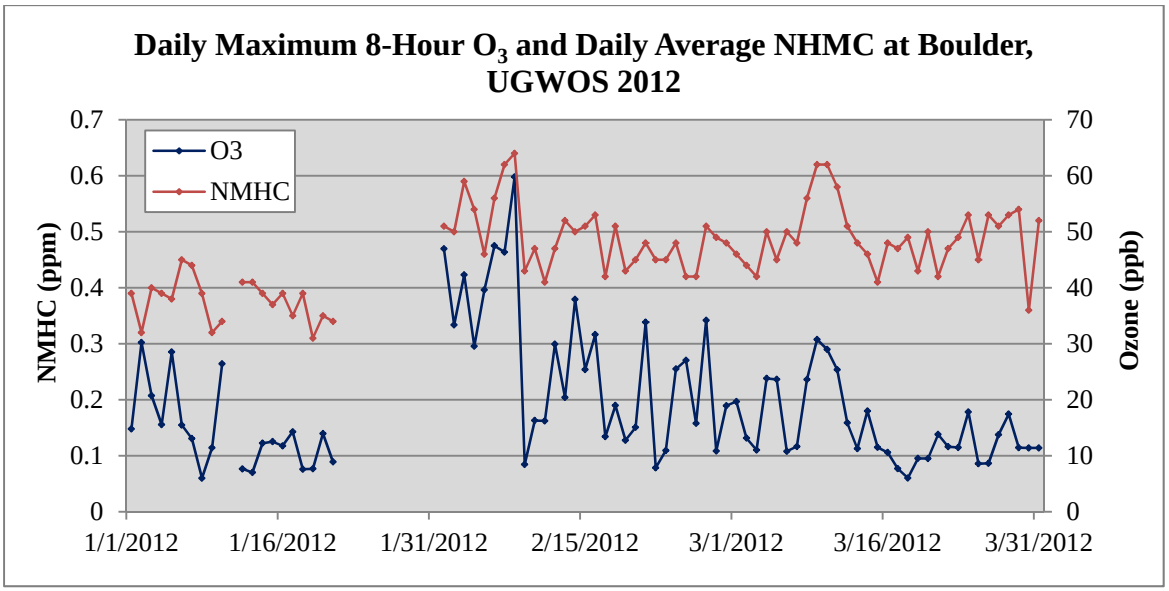

Figure 4.4 Time Series of Maximum 8-hr Ozone and Daily Average NMHC at Boulder

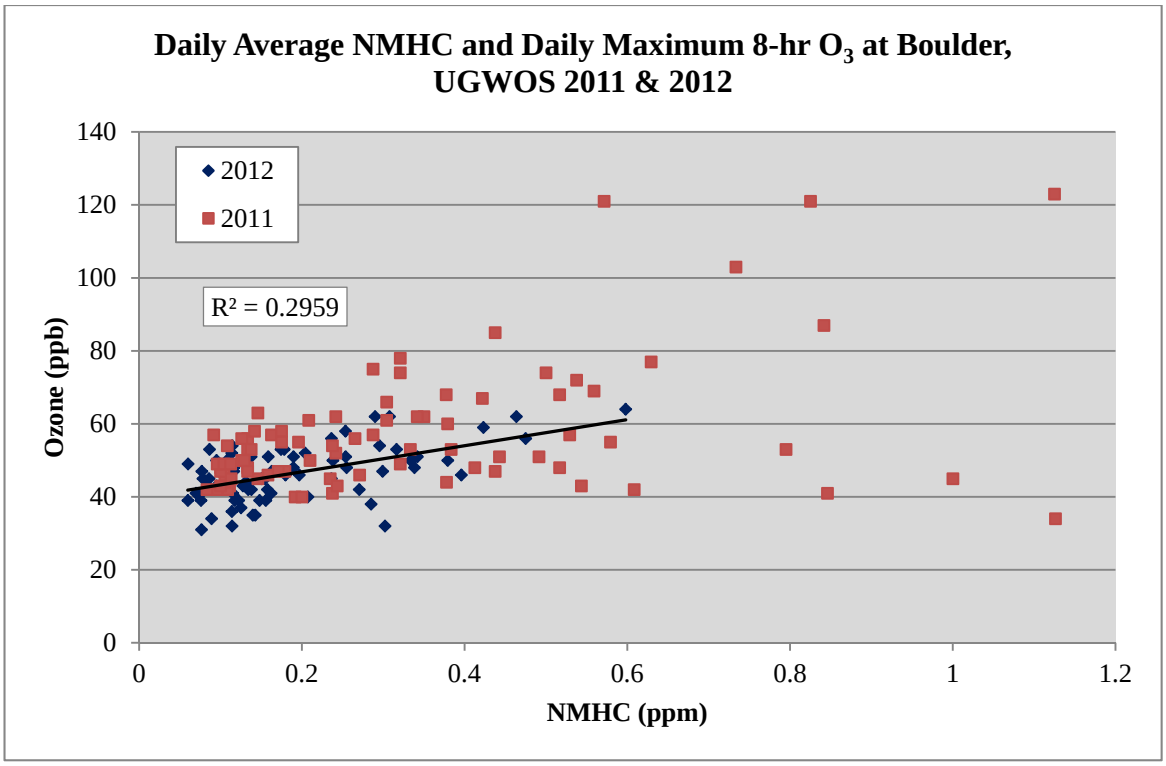

Figure 4.5 Comparison of Maximum 8-hr Ozone and Daily Average NMHC at Boulder for UGWOS 2011 and 2012. Linear regression fit for 2012 data is shown.

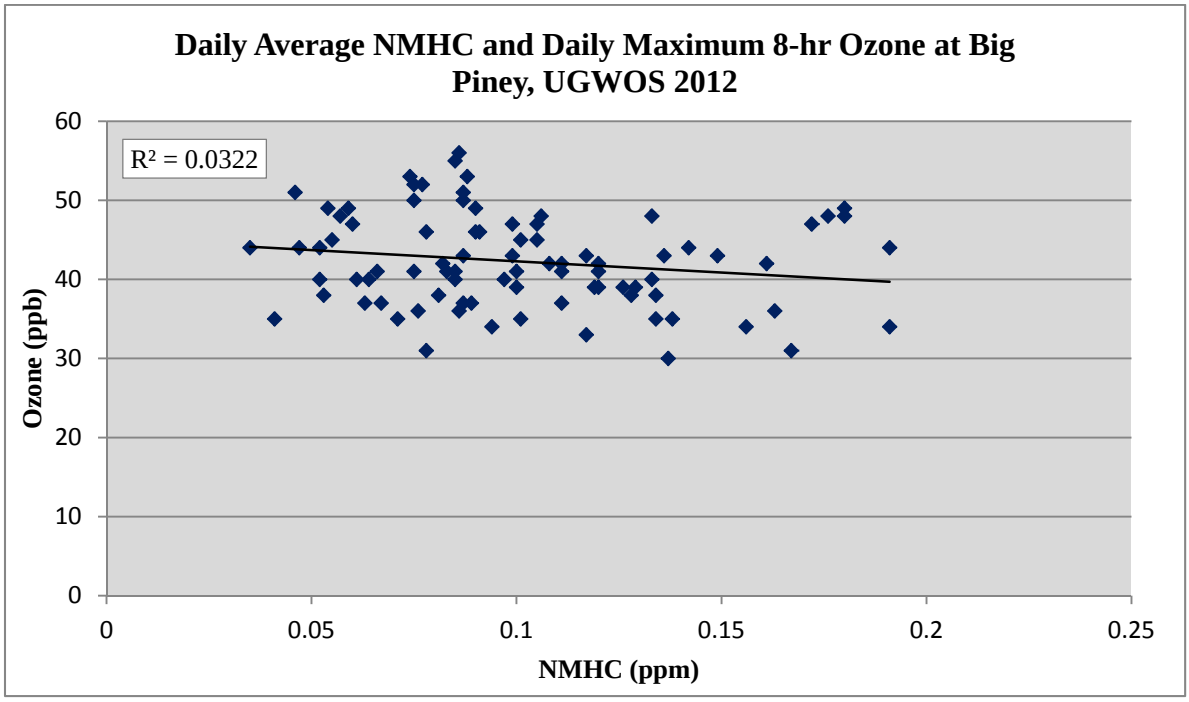

Figure 4.6 Comparison of Maximum 8-hr Ozone and Daily Average NMHC at Big Piney

4.2 Ozone Spatial and Temporal Distribution

The highest 8-hour ozone concentration recorded during the UGWOS 2012 campaign was 64 ppb, which is well below the US EPA NAAQS of 75 ppb. The maximum eight-hour and one-hour ozone concentrations at all UGWOS 2012 monitoring sites are presented in Figure 4.7.

Figure 4.8 presents the rolling eight-hour average ozone levels for all monitoring sites during UGWOS 2012. Elevated ozone concentration afternoon maximums occurred most frequently at Boulder and Jonah while suppressed ozone concentration morning minimums occurred at Big Piney and occasionally at Pinedale. NO_x scavenging may contribute to the suppressed morning ozone minimum concentrations at Big Piney and Pinedale.

Further inspection of Figure 4.8 shows that the magnitude of the diurnal ozone cycle increased after March 3 at Big Piney and Jonah, coincident with a shift toward warmer temperatures. Temperature data indicate that March 3rd marked a pronounced transition from a wintertime regime with daily maximum temperatures near freezing and minimums well below freezing to a springtime regime with daily minimum temperatures just below freezing and maximums well above freezing. Examination of the upper-air patterns during this time indicates that the mean position of the jet stream shifted north, allowing warmer air to penetrate the UGRB.

Figure 4.9 presents the daily maximum eight-hour average ozone concentrations for all sites during UGWOS 2012. Boulder and/or Jonah experienced the highest ozone concentrations 59 percent of the time.

Table 4-8 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 4-8 shows that elevated ozone was most commonly observed at Boulder and Jonah.

Table 4-8

Maximum Eight-hour Average Ozone Concentrations (ppb) for Wyoming Range, Pinedale, Juel Springs, Daniel, Boulder, Big Piney, and Jonah on Days When at Least One Site Recorded Concentrations > 55 ppb

Station	Wyoming Range	Pinedale	Juel Springs	Daniel	Boulder	Big Piney	Jonah	Network Max
Feb 3	37	41	53	40	59	42	48	**59**
Feb 6	38	47	49	48	56	48	45	**56**
Feb 7	37	45	49	44	62	44	48	**62**
Feb 8	39	47	48	45	64	44	48	**64**
Mar 8	47	56	56	51	56	46	61	**61**
Mar 9	48	54	56	51	62	49	59	**62**
Mar 10	50	58	56	51	62	48	60	**62**
Mar 11	50	59	53	58	58	50	56	**59**
Mar 12	50	51	55	50	51	53	56	**56**
Mar 26	49	55	55	54	53	56	55	**56**
Mar 27	46	52	54	53	51	52	57	**57**
Mar 28	48	53	56	54	53	55	58	**58**
Mar 29	48	56	53	54	54	51	56	**56**

Values > 55 in Yellow
Values > 60 in Red

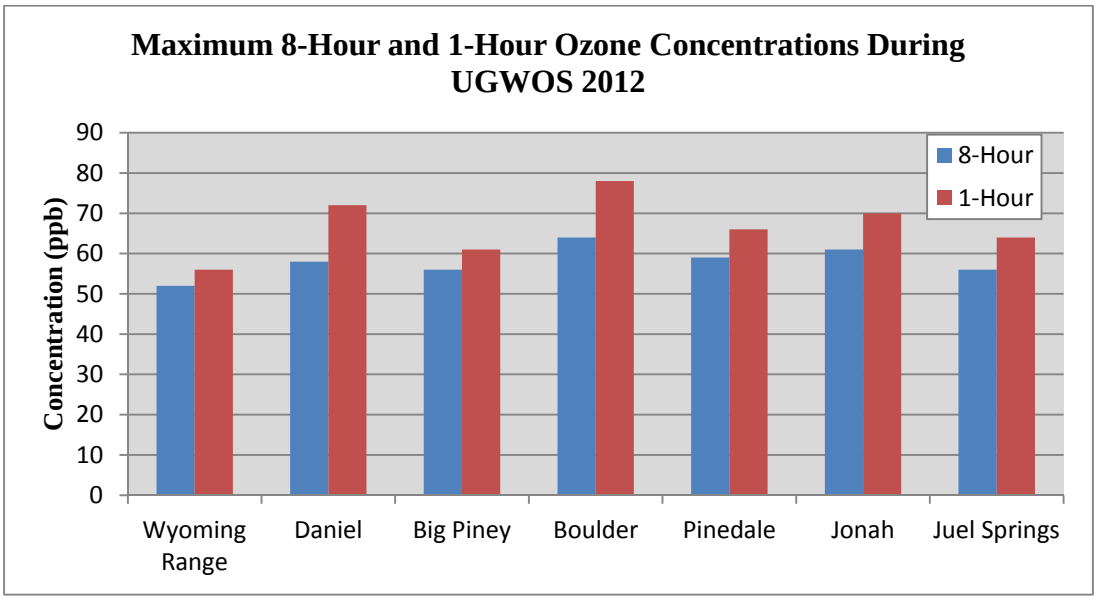

Figure 4.7 Maximum Eight-Hour and One-Hour Average Ozone Concentrations in the UGRB during UGWOS 2012

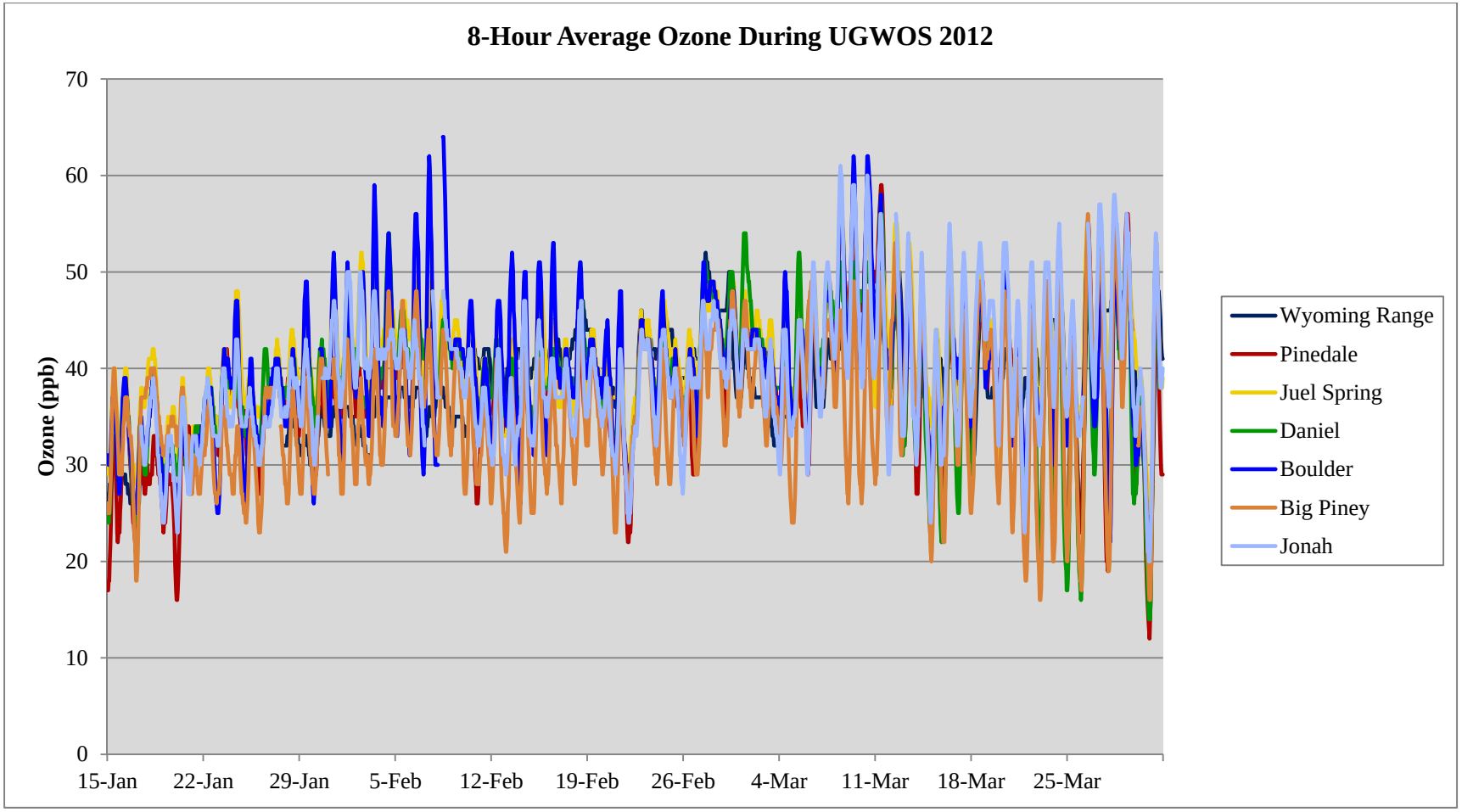

Figure 4.8 Running Eight-Hour Ozone Concentrations during UGWOS 2012

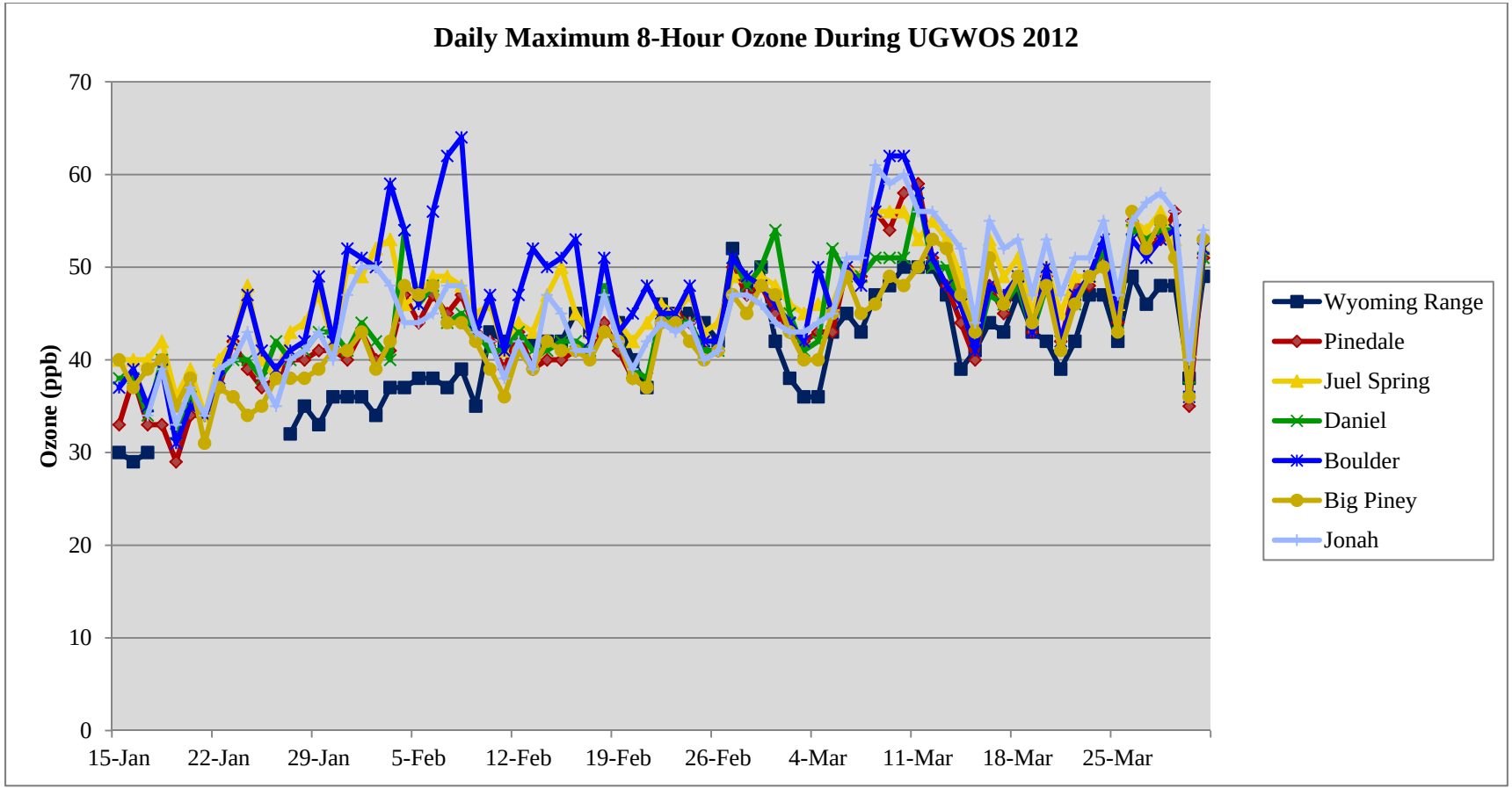

Figure 4.9 Daily Maximum Eight-Hour Ozone Concentrations, UGWOS 2012

4.2.1 Discussion of Spatial and Temporal Distribution of O_3 during Intensive Operational Periods

There were six Intensive Operational Periods (IOPs) during UGWOS 2012, two of which lasted only one day and the remaining four lasted two days. This section will focus only on the IOP days that measured eight-hour ozone above 55 ppb.

The first IOP occurred January 28 to January 29. Hourly ozone concentrations on January 28 remained below 50 ppb. On January 29, ozone concentrations were generally between 30 ppb and 40 ppb through 10:00, with the exception of Big Piney, which observed lower ozone concentrations in the 20 ppb to 30 ppb range, possibly due to NOx scavenging. Ozone levels at all sites except Wyoming Range began to rise after 10:00 and reached a maximum around 15:00 before declining to between 30 ppb and 40 ppb by the end of the day. Boulder and Juel Springs were the only sites that recorded 1-hr ozone concentrations greater than 50 ppb on January 29. The hourly ozone concentrations for January 29 are depicted in Figure 4.10.

IOP 2 occurred February 5 to February 6. Hourly ozone concentrations on February 5 were no higher than 52 ppb. The hourly ozone concentrations for February 6 are depicted in Figure 4.11. Ozone concentrations during the early morning hours of February 6 were generally between 35 ppb and 45 ppb, except for Big Piney and Boulder, which experienced lower concentrations, possibly due to NO_x scavenging. Ozone levels began to rise at 11:00 and reached a maximum around 15:00. All sites peaked between 50 ppb and 55 ppb, except Boulder, which peaked at 65 ppb, and Wyoming Range, which remained below 40 ppb.

IOP 3 occurred on February 16 and hourly ozone concentrations are shown in Figure 4.12. As in IOP 2, early morning concentrations were between 35 ppb and 45 ppb except at Boulder and Big Piney, which were lower, possibly due to NO_x scavenging. The afternoon maximums occurred around 15:00 and were all between 42 ppb and 48 ppb, except for Boulder, which peaked at 60 ppb.

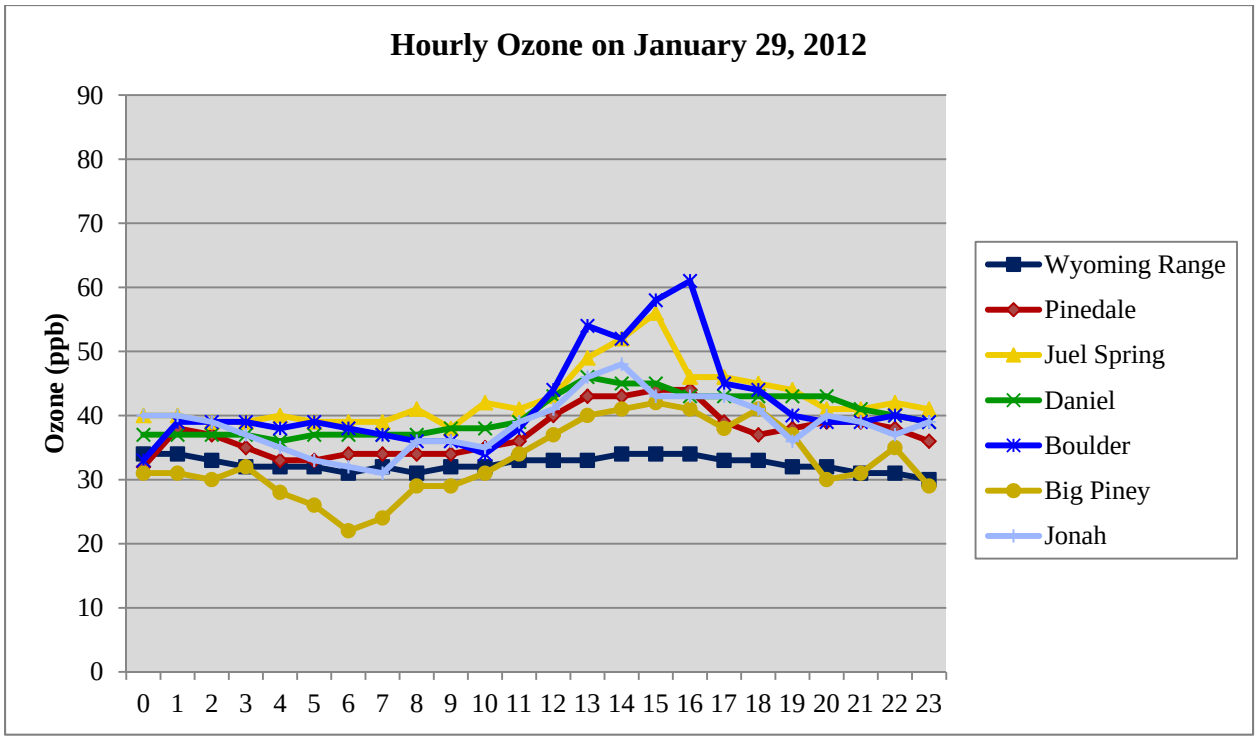

Figure 4.10 One-Hour Average Ozone during IOP 1 (January 29)

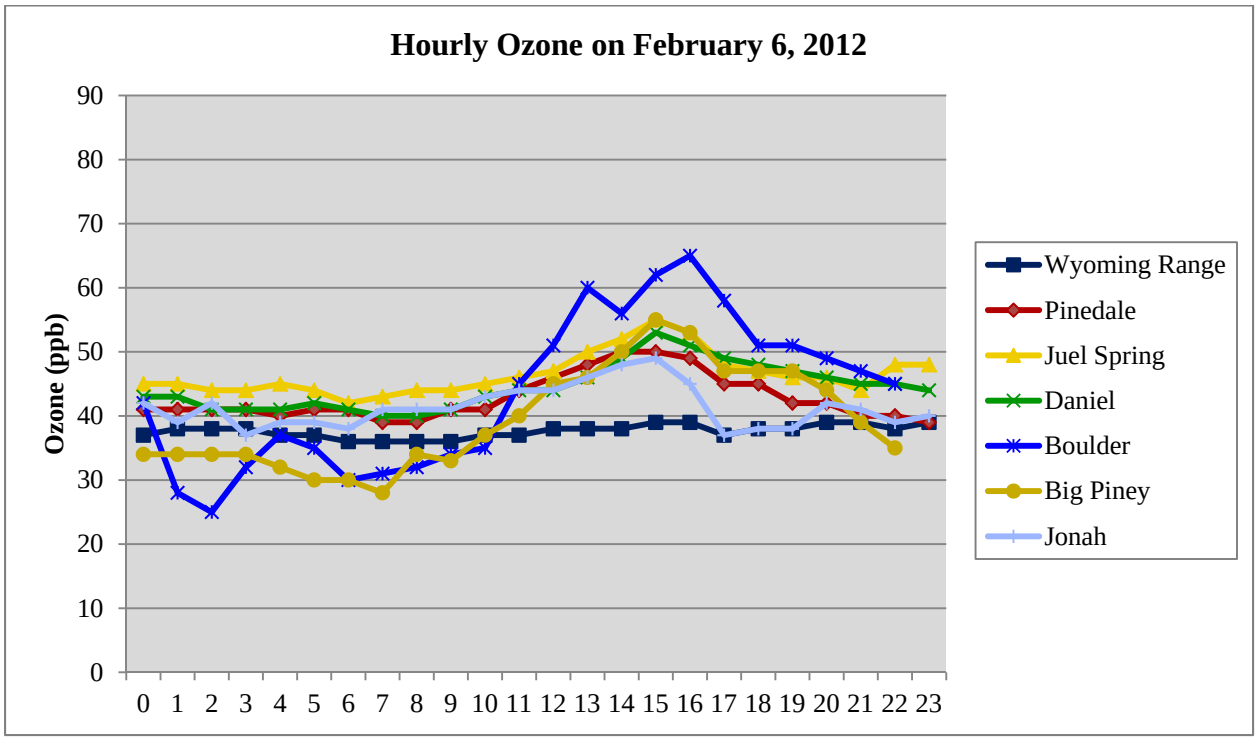

Figure 4.11 One-Hour Average Ozone during IOP 2 (February 6)

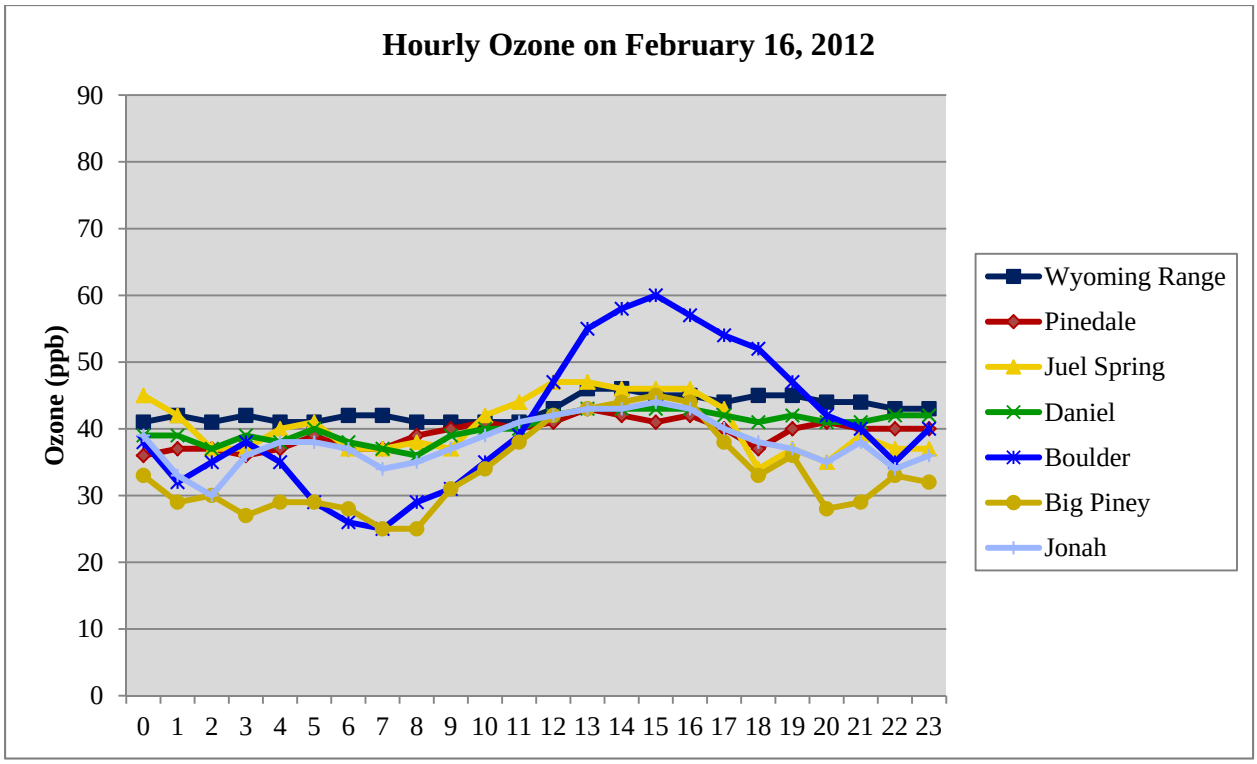

Figure 4.12 One-Hour Average Ozone during IOP 3 (February 16)

IOP 4 occurred on February 27. Hourly ozone concentrations during IOP 4 climbed modestly from around 40 ppb early in the morning to no greater than 55 ppb during the afternoon and evening.

IOP 5 occurred on March 3 and March 4. Hourly ozone concentrations on March 3 remained below 50 ppb. Hourly ozone concentrations on March 4 are portrayed in Figure 4.13. Ozone concentrations were below 40 ppb during the early morning hours of March 4 and began to rise at 10:00, reaching a plateau that persisted from about 12:00 to 17:00. Afternoon ozone concentrations were around 45 ppb except for Boulder which peaked at 57 ppb and Wyoming Range, which remained around 36 ppb.

IOP 6 occurred on March 8 and March 9. Hourly ozone concentrations during IOP 6 are portrayed in Figure 4.14. IOP 6 was the only one of the four two-day IOPs where both days exceeded 55 ppb. The four sites that exceeded 55 ppb for multiple hours were Pinedale, Boulder, Jonah, and Juel Springs, all of which are on the eastern side of the UGWOS domain. Jonah recorded the highest hourly ozone concentration on March 8, which was 70 ppb and Boulder recorded the highest hourly ozone concentration on March 9, which was 77 ppb. Big Piney likely experienced NO_x scavenging the morning of March 9. Wyoming Range was largely unaffected during the entire IOP.

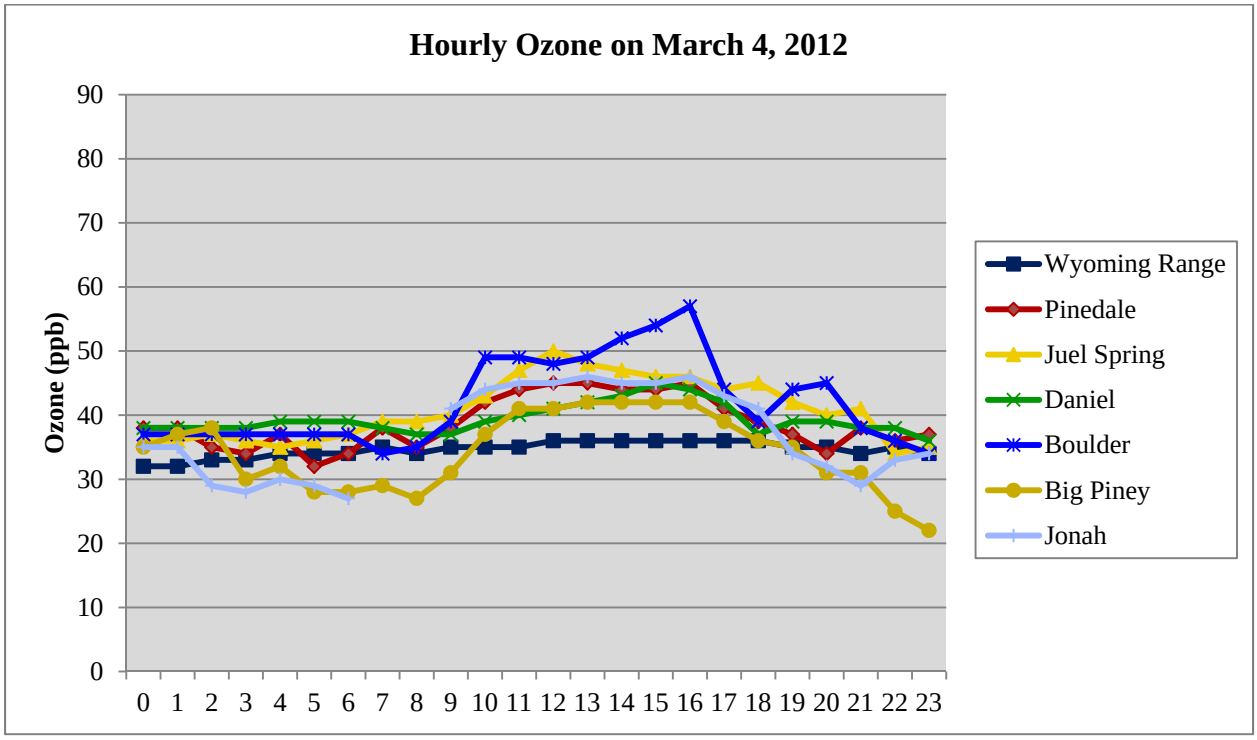

Figure 4.13 One-Hour Average Ozone during IOP 5 (March 4)

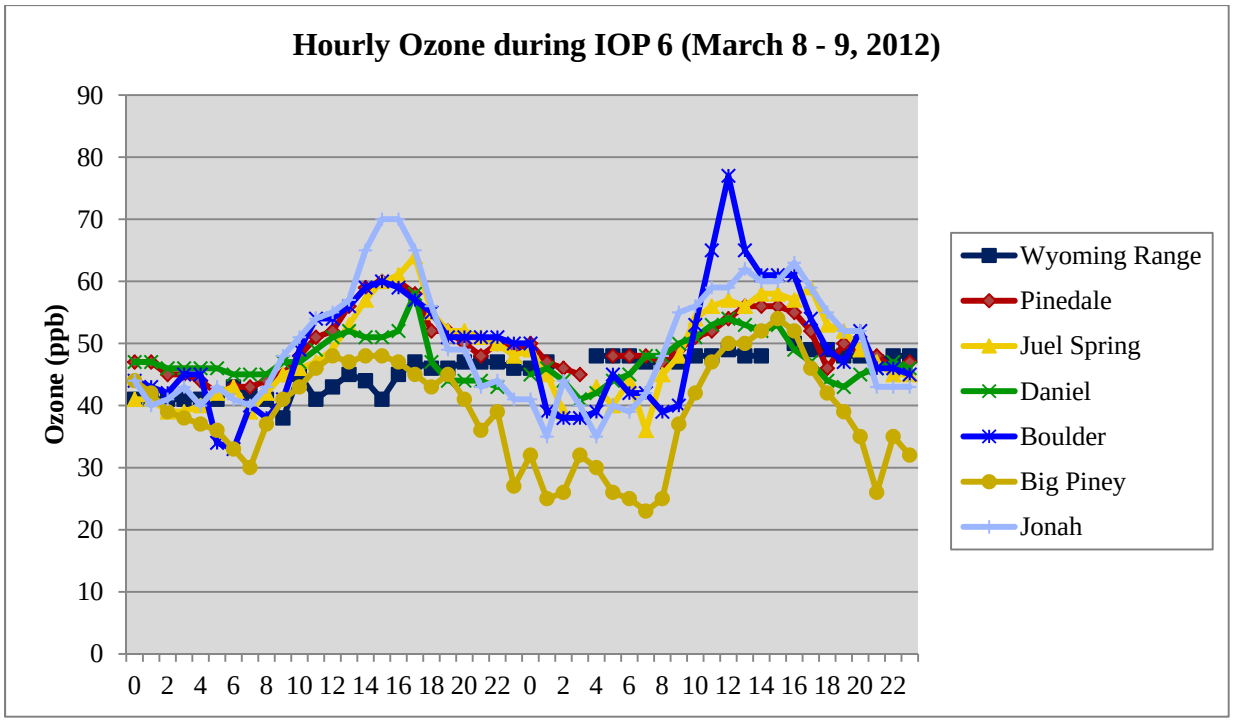

Figure 4.14 One-Hour Average Ozone during IOP 6 (March 8 - March 9)

4.3 Surface Wind Patterns during Intensive Operational Periods

There were six IOPs during UGWOS 2012. This section will focus on the wind patterns that occurred at sites that observed elevated ozone during IOPs. For each case, 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 IOPs are usually low, a full barb will represent a wind speed of 5 m/s.

Boulder and Juel Springs were the only two sites that observed 1-hr ozone concentrations in excess of 50 ppb during IOP 1. Hourly wind and ozone for Boulder and Juel Springs during IOP 1 are represented in Figure 4.15. After several hours of initially sustained northwest wind at Juel Springs, winds were generally light at both sites during IOP 1. The direction of the flow was generally northerly, though considerable variation was observed, especially at Juel Springs.

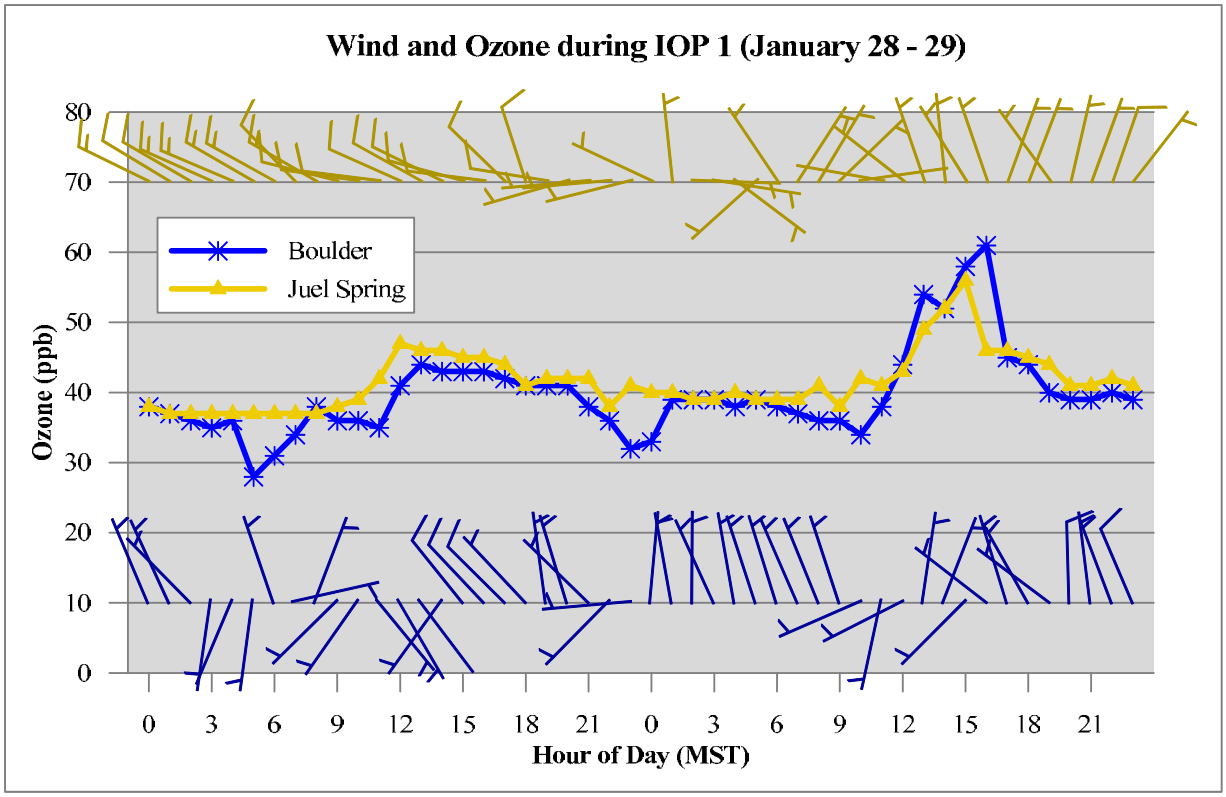

Figure 4.15 One-Hour Average Ozone and Wind at Boulder and Juel Springs during IOP 1

While IOP 2 occurred on February 5 and February 6, elevated ozone was observed only on the second day of the IOP. Boulder was the only site that observed hourly ozone concentrations in excess of 55 ppb. Hourly wind and ozone for Boulder during IOP 2 are represented in Figure 4.16. Winds throughout the IOP were light and very consistently out of the north to northeast, showing an absence of any diurnal wind pattern or wind shift coincident with the onset of higher ozone concentrations.

Boulder was the only site that observed hourly ozone concentrations in excess of 50 ppb during IOP 3, which occurred on February 16. Hourly wind and ozone for Boulder during IOP 3 are represented in Figure 4.17. As in IOP 2, the wind at Boulder was very consistently out of the northeast at a speed generally less than 5 m/s and did not show any diurnal pattern or wind shift coincident with the onset or decrease of elevated ozone concentrations.

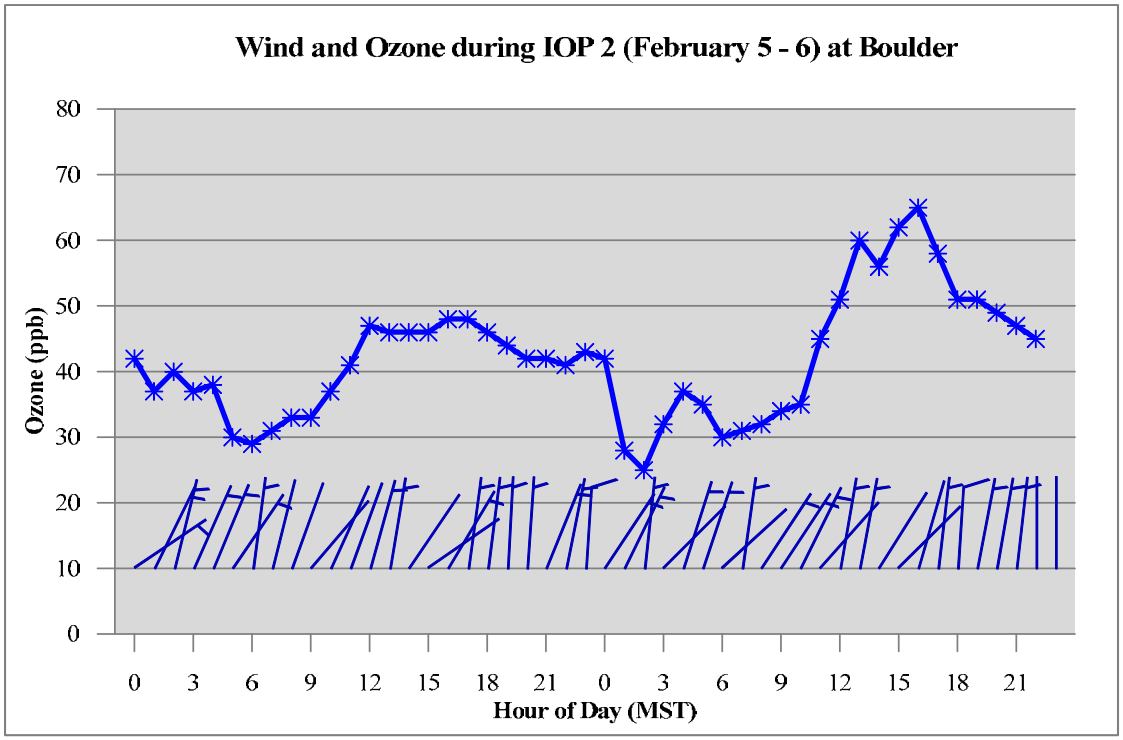

Figure 4.16 One-Hour Average Ozone and Wind at Boulder during IOP 2

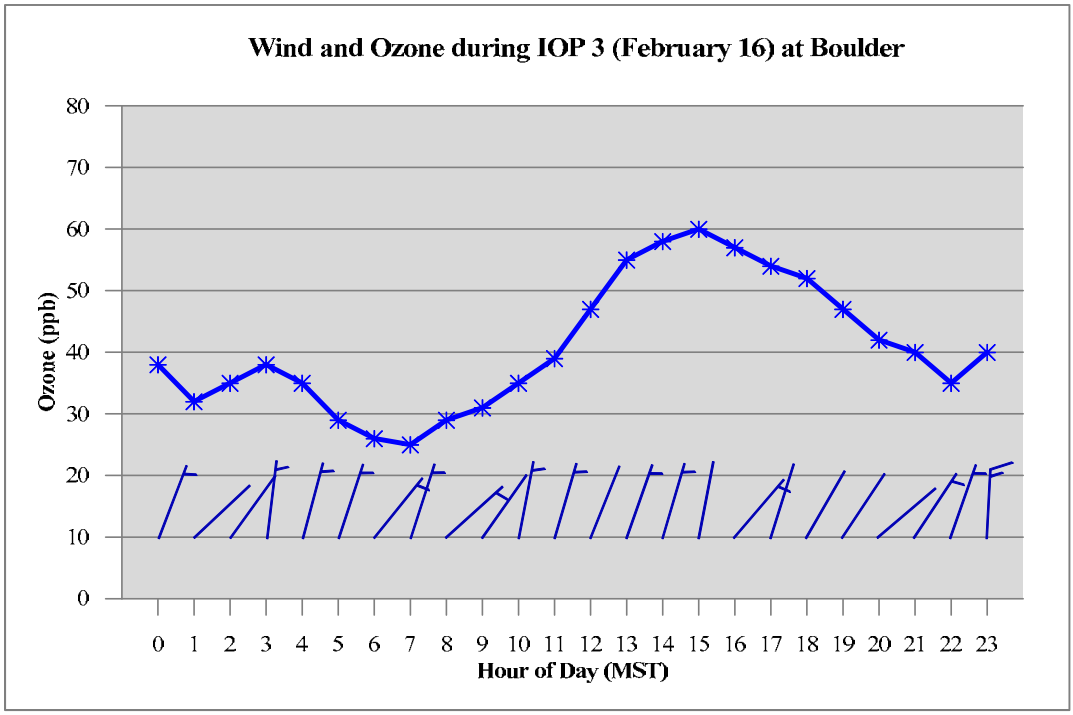

Figure 4.17 One-Hour Average Ozone and Wind at Boulder during IOP 3

IOP 4 occurred on February 27. But, due to the lack of elevated ozone concentrations on this day, no wind analysis was performed.

While IOP 5 occurred on March 3 and March 4, elevated ozone was observed only on the second day of the IOP. Boulder and Juel Springs were the only sites that observed hourly ozone concentrations at or above 50 ppb. Hourly wind and ozone for Boulder and Juel Springs during IOP 5 are represented in Figure 4.18. Wind speeds during the first day of the IOP were generally elevated between 5 m/s and 10 m/s, with a north wind at Boulder and a northwest wind at Juel Springs. Wind speeds on the second day of the IOP were generally lighter between 2.5 m/s and 5 m/s, with a northeast wind at Boulder and a north wind at Juel Springs.

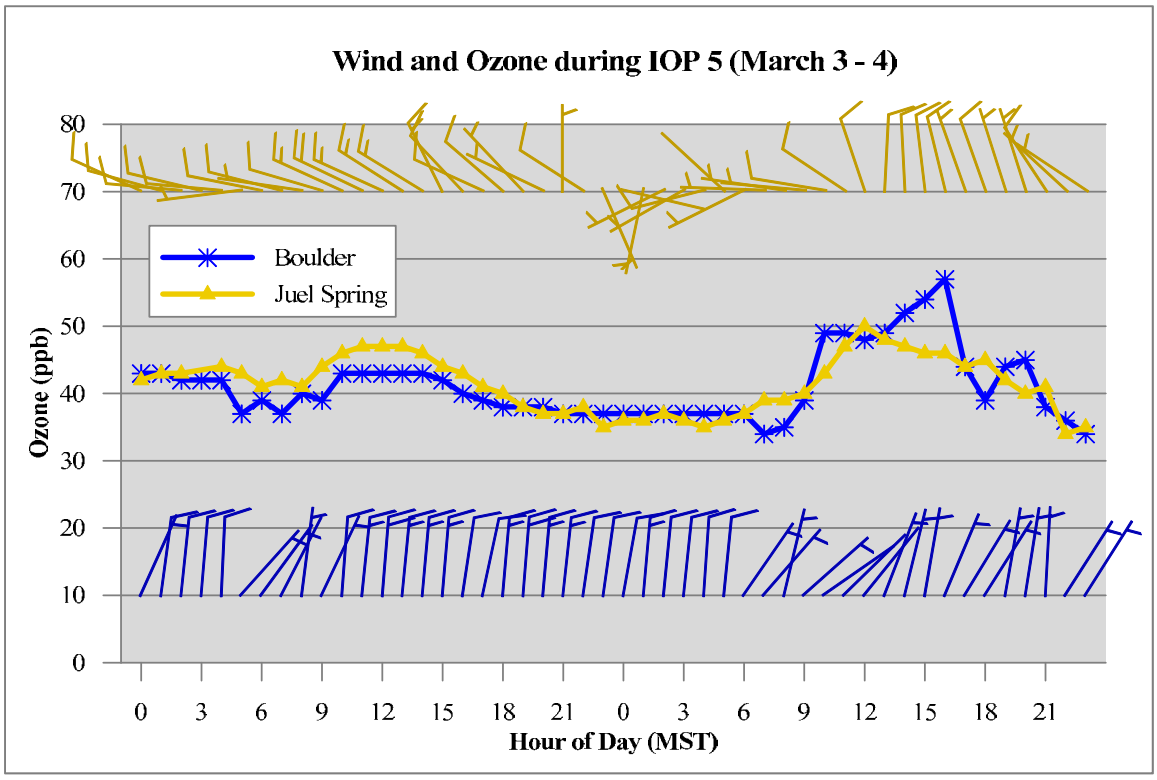

Figure 4.18 One-Hour Average Ozone and Wind at Boulder and Juel Springs during IOP 5

Ozone concentrations at Boulder, Juel Springs, Jonah, and Pinedale were at or above 60 ppb during IOP 6, which occurred March 5 and March 6. Wind speeds were generally light (5 m/s or less) and wind directions were generally northerly. Boulder's wind direction prior to and during elevated ozone shifted slightly to northeast. Wind direction at Juel Springs shows somewhat of a clockwise progression prior to and during elevated ozone. Jonah's wind direction was quite variable on March 8 when ozone concentrations reached 70 ppb and the wind direction was northwesterly on March 9. Pinedale's wind direction was northwesterly during the entire IOP except for a brief shift to southeast on March 8 during the period of increasing ozone. Hourly wind and ozone for Boulder, Juel Springs, Jonah, and Pinedale during IOP 6 are represented in Figure 4.19.

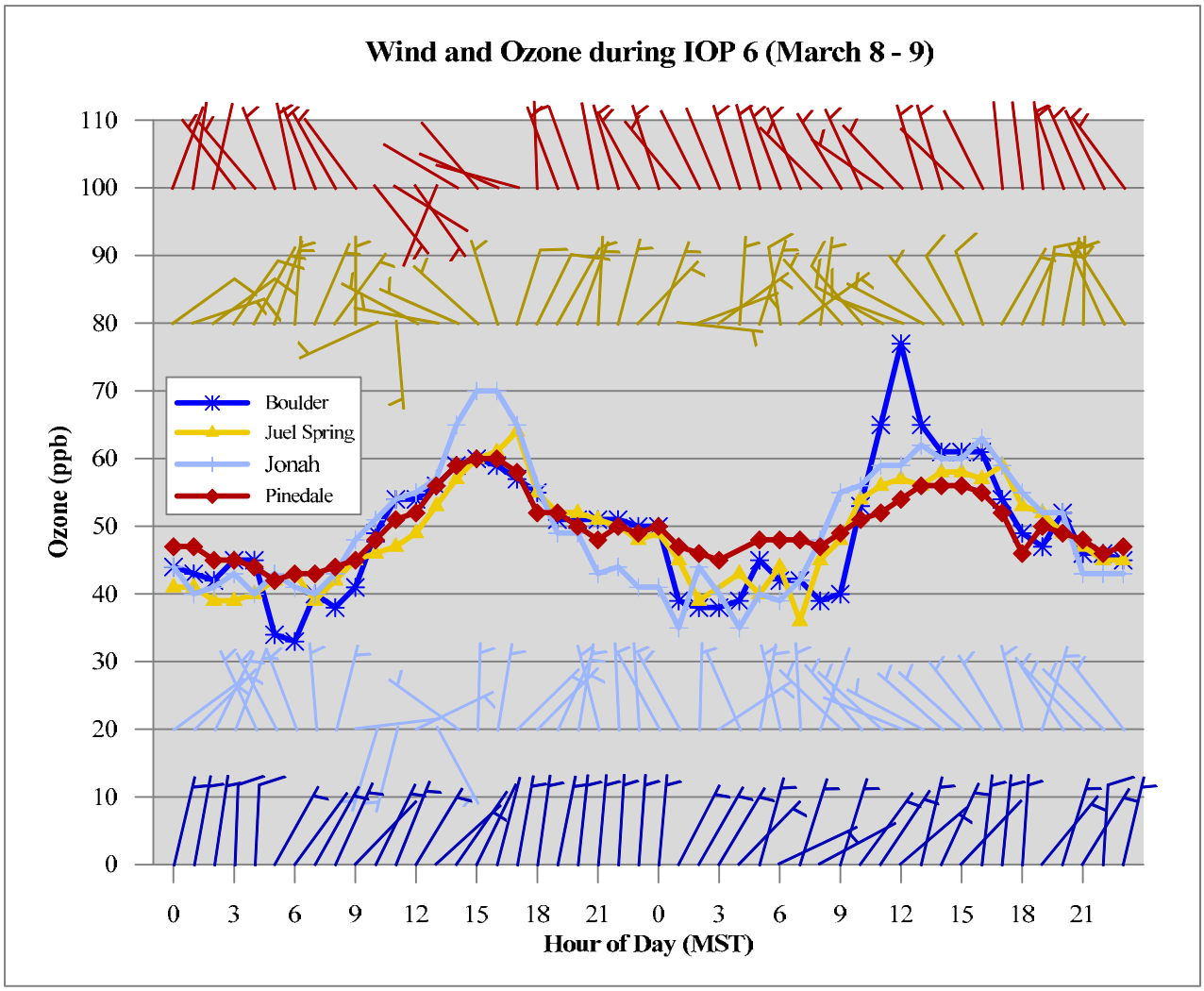

Figure 4.19 One-Hour Average Ozone and Wind at Boulder, Juel Springs, Jonah, and Pinedale during IOP 6

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 did not manifest itself during this year's IOPs.

4.4 miniSODAR™ Data

As with the previous UGWOS studies, the most relevant data obtained from the miniSODAR™ (Sodar) were the mixing heights estimated from the Sodar's facsimile data. Table 4-9 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 winds – Wind speeds measured by the Sodar at 30 meters are presented as being representative of 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.
- Peak 1-hr and 8-hr average ozone reported from the Boulder site.

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 highlights in orange.

Key conditions common with periods of higher ozone concentrations are consistent with those presented in previous UGWOS reports, which included the following:

- Median morning (AM) mixing heights are less than or equal to 70 meters, indicating stable conditions that trap surface emissions during the morning.
- Definable tops to the mixing heights persist into the afternoon and PM periods, though some afternoon mixing is frequently associated with higher concentrations.
- Surface wind speeds 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.
- Reflected UV radiation is at least 50% of the incoming UV radiation - a direct result of the amount of snow on the surface.

Review of Table 4-9 shows that days showing ozone development consistently meet the above conditions. In reviewing individual days, most days that meet these conditions show some degree of ozone development, with peak hourly averages of at least 55 ppb. The only unusual day is February 5, when little ozone development is noted despite what looks like favorable conditions. Sodar data for this day look very similar to that for the several days preceding and following this day, during which some degree of ozone development occurred. February 5 was a Sunday, when there may be a possibility of scaled back gas field operations, and consequently reduced emissions. Also, the total available UV (incoming plus outgoing) is somewhat lower on this day than during surrounding days, though February 1 had similar UV radiation values coupled with ozone development. It is worth noting that Sunday February 26 also does not show any ozone development, though conditions as defined by the Sodar data are not particularly unfavorable, as outlined above.

Table 4-9 MiniSODAR™ Metrics

	Median Mixing Height (m)				30-m Vector Winds (m/s)		UV (W-hr/m^2)		Peak Ozone (ppb)	
Date	AM	Mornng	PM	Afternoon	Morning WS	After. WS	Incoming	Outgoing	1-hr avg	8-hr avg
1/15/2012	130	135	200	200	2.95	8.92	123	8	42	37
1/16/2012	200	200	200	200	9.28	9.34	118	7	42	39
1/17/2012	143	83	200	200	1.09	3.66	132	9	38	35
1/18/2012	200	200	200	200	4.53	2.94	84	47	41	39
1/19/2012	200	200	200	200	4.21	1.91	104	72	34	31
1/20/2012	130	53	200	200	1.44	3.76	123	65	38	35
1/21/2012	200	200	-999	-999	-999.00	-999.00	85	76	35	34
1/22/2012	-999	-999	-999	-999	-999.00	-999.00	192	170	39	38
1/23/2012	-999	-999	-999	-999	-999.00	-999.00	141	125	46	42
1/24/2012	-999	-999	-999	-999	-999.00	-999.00	196	173	58	47
1/25/2012	-999	-999	-999	-999	-999.00	-999.00	163	141	47	41
1/26/2012	-999	-999	-999	-999	-999.00	-999.00	125	132	39	39
1/27/2012	-999	-999	-999	-999	-999.00	-999.00	196	182	42	41
1/28/2012	-999	-999	-999	-999	-999.00	-999.00	207	181	44	42
1/29/2012	-999	-999	58	28	-999.00	-999.00	183	156	61	49
1/30/2012	55	30	200	125	0.73	2.74	162	139	44	42
1/31/2012	60	60	50	50	0.76	0.72	203	180	63	52
2/1/2012	68	50	48	48	1.15	1.34	189	169	62	51
2/2/2012	43	50	63	40	0.81	-999.00	-999	-999	76	50
2/3/2012	33	50	38	125	0.86	0.34	213	190	69	59
2/4/2012	63	58	88	120	0.81	1.12	217	196	58	54
2/5/2012	35	45	53	55	0.42	1.03	195	168	48	46
2/6/2012	65	43	75	200	0.65	-999.00	227	199	65	56
2/7/2012	50	63	73	200	0.85	-999.00	231	202	73	62
2/8/2012	65	65	200	123	0.73	0.31	216	193	70	64
2/9/2012	200	200	200	200	10.54	10.61	242	208	44	43
2/10/2012	200	200	53	200	2.42	0.67	196	166	53	47
2/11/2012	125	50	-999	200	0.34	0.60	173	151	43	41
2/12/2012	-999	-999	-999	-999	-999.00	-999.00	156	165	54	47
2/13/2012	48	50	45	45	2.69	0.48	244	230	69	52
2/14/2012	38	43	50	125	0.96	1.78	242	223	66	50
2/15/2012	58	65	75	200	1.94	1.31	249	222	71	51
2/16/2012	110	100	65	73	0.90	0.65	253	234	60	53
2/17/2012	200	200	200	200	3.83	10.49	258	227	43	42
2/18/2012	75	65	60	200	0.37	2.30	261	232	58	51
2/19/2012	120	38	200	200	-999.00	11.25	255	224	45	43
2/20/2012	135	200	140	200	2.27	-999.00	267	230	53	45
2/21/2012	45	38	200	200	0.25	5.97	250	221	74	48
2/22/2012	200	50	200	200	9.41	8.58	213	174	46	45
2/23/2012	200	200	200	200	8.47	8.97	300	244	48	45
2/24/2012	50	45	73	200	0.52	1.83	293	244	57	48
2/25/2012	58	50	200	200	-999.00	-999.00	267	217	48	42
2/26/2012	55	53	138	200	0.07	1.23	299	239	44	42
2/27/2012	200	200	200	200	0.56	2.34	266	205	53	51
2/28/2012	200	200	200	200	5.60	9.76	279	249	51	49
2/29/2012	63	40	200	200	1.80	4.70	252	224	51	48
3/1/2012	53	50	128	200	1.06	-999.00	325	281	47	46
3/2/2012	200	200	200	200	11.27	11.30	341	295	46	44
3/3/2012	200	78	200	200	4.09	7.16	315	269	43	42
3/4/2012	50	133	55	128	0.55	1.59	327	264	57	50
3/5/2012	58	55	200	130	0.82	-999.00	321	252	47	45
3/6/2012	58	63	200	200	2.19	-999.00	248	174	53	50
3/7/2012	60	60	200	200	2.40	6.80	334	269	49	48
3/8/2012	53	50	200	200	0.98	0.50	339	257	60	56
3/9/2012	60	48	128	200	0.83	0.70	335	238	77	62
3/10/2012	70	70	78	120	1.85	1.14	337	211	78	62
3/11/2012	70	78	200	200	0.64	1.54	325	175	62	58
3/12/2012	53	58	143	200	2.42	3.53	284	107	54	51
3/13/2012	200	138	200	200	3.91	5.07	202	51	52	48
3/14/2012	143	83	200	200	0.88	5.30	213	40	48	46
3/15/2012	58	53	200	200	1.17	-999.00	227	27	45	41
3/16/2012	200	200	200	200	3.09	3.20	167	12	50	48
3/17/2012	200	200	200	200	6.45	9.41	149	8	49	47
3/18/2012	200	200	200	200	9.87	7.60	202	10	52	49
3/19/2012	200	200	200	200	3.72	9.43	228	42	51	43
3/20/2012	200	70	65	200	2.94	3.09	319	19	52	50
3/21/2012	200	200	200	200	0.29	3.98	287	16	44	42
3/22/2012	200	63	65	200	1.55	1.84	330	18	51	47
3/23/2012	200	53	200	200	3.03	8.31	300	16	53	49
3/24/2012	158	68	200	200	1.55	3.70	302	16	56	53
3/25/2012	200	80	200	200	2.10	4.36	221	13	48	45
3/26/2012	200	200	200	200	7.05	-999.00	165	42	59	53
3/27/2012	128	53	200	200	1.42	1.87	313	71	52	51
3/28/2012	100	50	200	200	0.21	-999.00	188	11	56	53
3/29/2012	138	200	200	200	0.94	0.90	245	27	57	54
3/30/2012	200	53	200	200	0.27	2.46	173	8	38	36
3/31/2012	200	68	200	200	3.25	8.19	344	20	56	52

Conversely, conditions on March 11 show somewhat elevated ozone concentrations under higher mixing heights than normally noted for ozone development, along with a rapidly depleting snow cover that approaches the 50% criteria described above. Interestingly, March 11 is also a Sunday. However, both March 9 and March 10 showed notable ozone development, and consistent light winds through the period potentially allowed for some carryover of ozone concentrations, contributing to the somewhat above background concentrations measured on March 11.

As noted previously in other sections of this report, the winter of 2012 was characterized by relatively low ozone concentrations, particularly compared with those recorded in 2011. The 2012 winter ozone season is very similar to that observed in 2010, and the Sodar data obtained during 2012 can be compared directly to Sodar data obtained in 2010. Furthermore, though the Sodar was sited in a different location in 2009, much of the data is comparable to the 2009 data, as discussed in detail in the 2010 UGWOS report. Table 4-10 summarizes and compares key metrics for 2009, 2010, and 2012. Note that since the 2011 study concentrated on two specific episodes, mixing heights were not estimated for the entire winter period, and 2011 consequently is not included in the table.

Table 4-10

Comparisons with Previous Year's

	2009	2010	2012
Percentage of hours with reported mixing height <200 m	44	46	45
Percentage of afternoon hours with reported mixing heights (m)	27	9	19
Overall average of reported mixing heights (m)	[1]	47	55
Days with low mixing heights through afternoon	11	3	5
Boulder 8-hour peak ozone > 60 ppb	9	3	4
Boulder 1-hour peak ozone > 60 ppb	16	17	15
Boulder highest 8-hour average ozone (ppb)	70	71	64

[1]In 2009, the miniSODAR was in a different location and about 30 meters lower in elevation, so the average reported mixing height is not directly comparable to 2010 and 2012.

Review of Table 4-10` shows the following:

- The percentage of hours during which a measured mixing height was detected was essentially the same for all three years, with the Sodar identifying a defined top to the mixing layer about 45% of the time.

- In contrast, the percentage of hours from noon to early afternoon period (hours 11 – 15) during which a measured mixing height was estimated is notably different for the three years. Relatively stable conditions during this period continue to appear necessary for the formation of higher ozone concentrations, as noted in previous reports. While the number of days with peak 1-hr average ozone concentrations exceeding 60 ppb is essentially the same for all three years, the higher frequency of peak 8-hr average concentrations in 2009 is consistent with somewhat more stable conditions overall during that year.

- The number of days when afternoon mixing heights remained low also appears to be an indication of overall stability for the winter season, with again 2009 having a notable larger number of days when the mixing height remained low throughout the afternoon. For comparison, while mixing heights were only estimated in 2011 for the seven episodic days, all seven days maintained low mixing heights throughout the afternoon.

In summary, the Sodar data for 2012 are consistent with the lack of significant ozone development during the study period, and are similar to other low ozone years. Conclusions made in previous UGWOS reports remain valid during UGWOS 2012, with no significant revisions to the conceptual model for ozone development. The possibility of reduced emissions and consequently lower ozone development on Sundays should be explored further.

4.5 VOC Canisters

The overall goal of the 2012 VOC sampling was to investigate the spatial distribution of precursor concentrations during IOPs. To obtain a spatial distribution of precursors, VOC canister samples were collected at Boulder, Jonah, Juel Springs, and Big Piney monitoring stations. Eleven samples were taken at each station throughout the 2012 UGWOS study period. Late in the study, snow cover in the basin diminished and forecasts showed that favorable conditions for ozone formation were unlikely to develop. The AQD project manager made the decision to complete the canister sampling effort with conditions in which there was no snow on the ground.

Figure 4.20 summarizes analytical results for each of the canister samples, for each of the four sample locations, broken down by species groups. Figure 4.21 presents the same data as Figure 4.20 but rescaled to show the relationship of the lower sample concentrations with the Juel March 8 sample going off the scale. Figure 4.22 presents the relative contribution of each species group. Samples were collected from 7:00 to 10:00 a.m. MST on the dates shown on the x-axis and are presented in chronological order to compare site concentrations throughout the study period.

As can be seen in Figure 4.20 and 4.21, total VOC concentrations at Boulder were consistently higher than the other three sample locations with the exception of Juel Springs on March 8. This is to be expected since the Boulder station is closer to field operations (primarily well production and Liquid Gathering System). Figure 4.22 shows several samples taken have a high percentage of unidentified compounds. EAS provided a technical memorandum dated September 28, 2012 titled “Evaluation of the Samples for Low Percent Identification”. The memorandum confirmed that the ozone precursor target list is based on auto exhaust and that samples with a low percentage of identification for the most part show they are being impacted by sources other than auto exhaust. In addition, samples with a low concentration of total hydrocarbons can have a significant impact on the percentage of unidentified compound when the sample has only a few peaks. The technical memorandum is provided in Appendix D.

The March 8 sample at Juel Springs is suspected of being an outlier since the concentrations are four times higher than any other concentration measured throughout the study period. However, field and lab documentation give no reason to invalidate the data. EAS laboratory initially re-ran the sample using GC-MS to qualitatively confirm the contents of the sample. Lab QC sample reports appear to rule out contamination at the laboratory. EAS stated that currently and at the time of the analysis, no methanol or acetone was present in their laboratory. Examination of field notes and field sample data sheets revealed no abnormalities in sampling conditions, equipment, or procedures. Sample results for VOC canisters collected before (March 5) and after (March 9) the March 8 sample show no indication of contamination. Methanol and acetone were not detected in either of these canister samples which were collected with the same sampling equipment as the March 8 sample. The meteorological data collected at Juel Springs also showed no evidence of a strong surface-based inversion on March 8. During most of the sampling period on that date, winds were light and northeasterly.

The nearest potential pollution source is the propane-powered backup power generator affiliated with the Union Wireless tower installation approximately 40 meters south of the VOC canister sampling site. The power generator is operated every Wednesday at 14:30 for approximately 30 minutes as a test. The test day closest to the sample day in question was Wednesday March 7. Union Wireless site maintenance records show nothing unusual for the March 8 sample period. There are no records of the propane tank being filled during this period and annual maintenance on the back-up power system did not occur until May 2012.

Samples taken on March 22 and March 23 were collected during a synoptic ridge of high pressure when there was no snow cover on the ground and showed similar diversity of hydrocarbons to samples taken earlier in the study period. With relatively low VOC concentrations and with limited ozone development throughout the study period, it is difficult to draw any conclusions about how the “no snow” samples compare to periods in which ozone formation occurs.

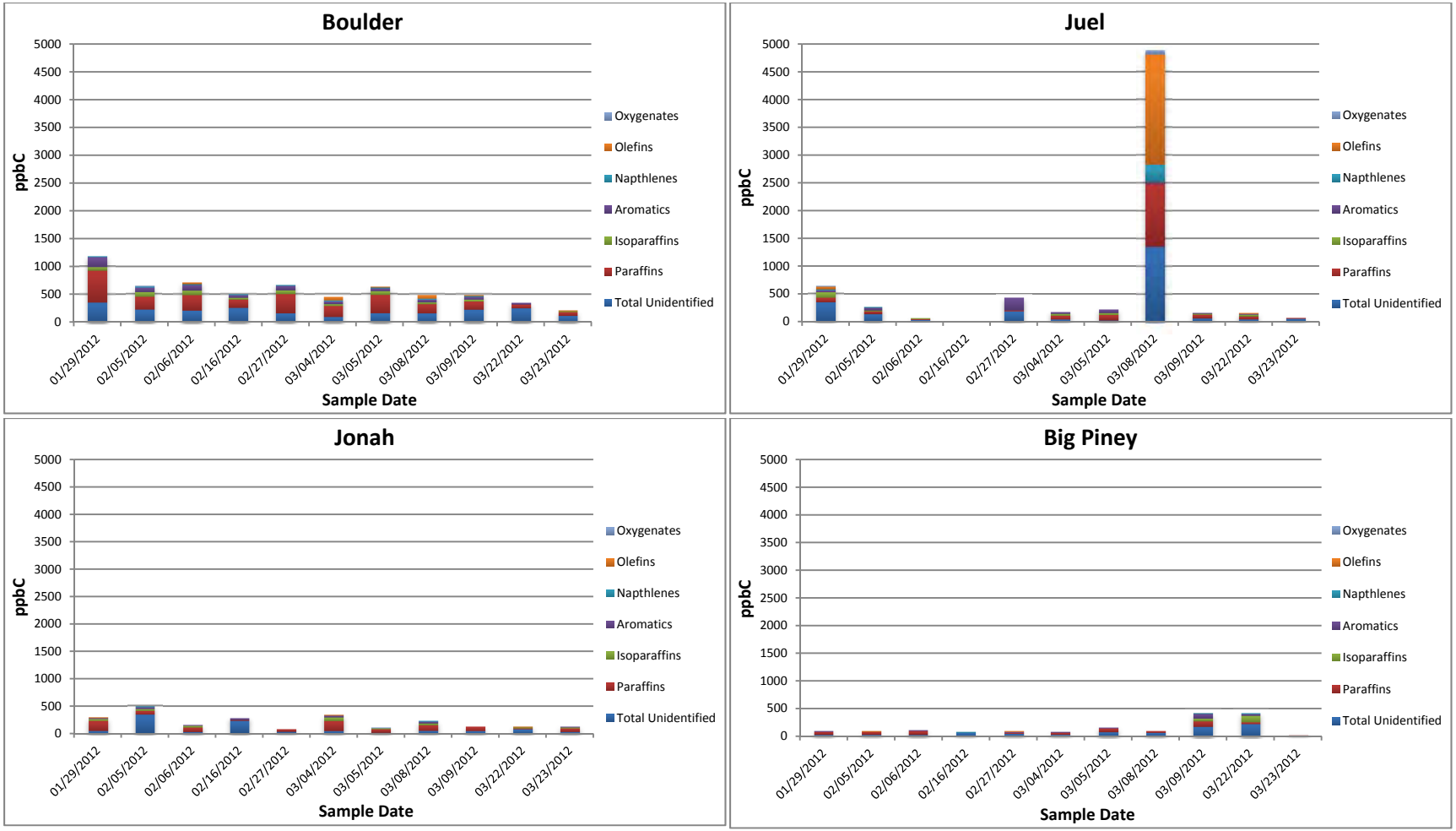

Figure 4.20 VOC Concentrations from Canisters Collected at Sample Locations

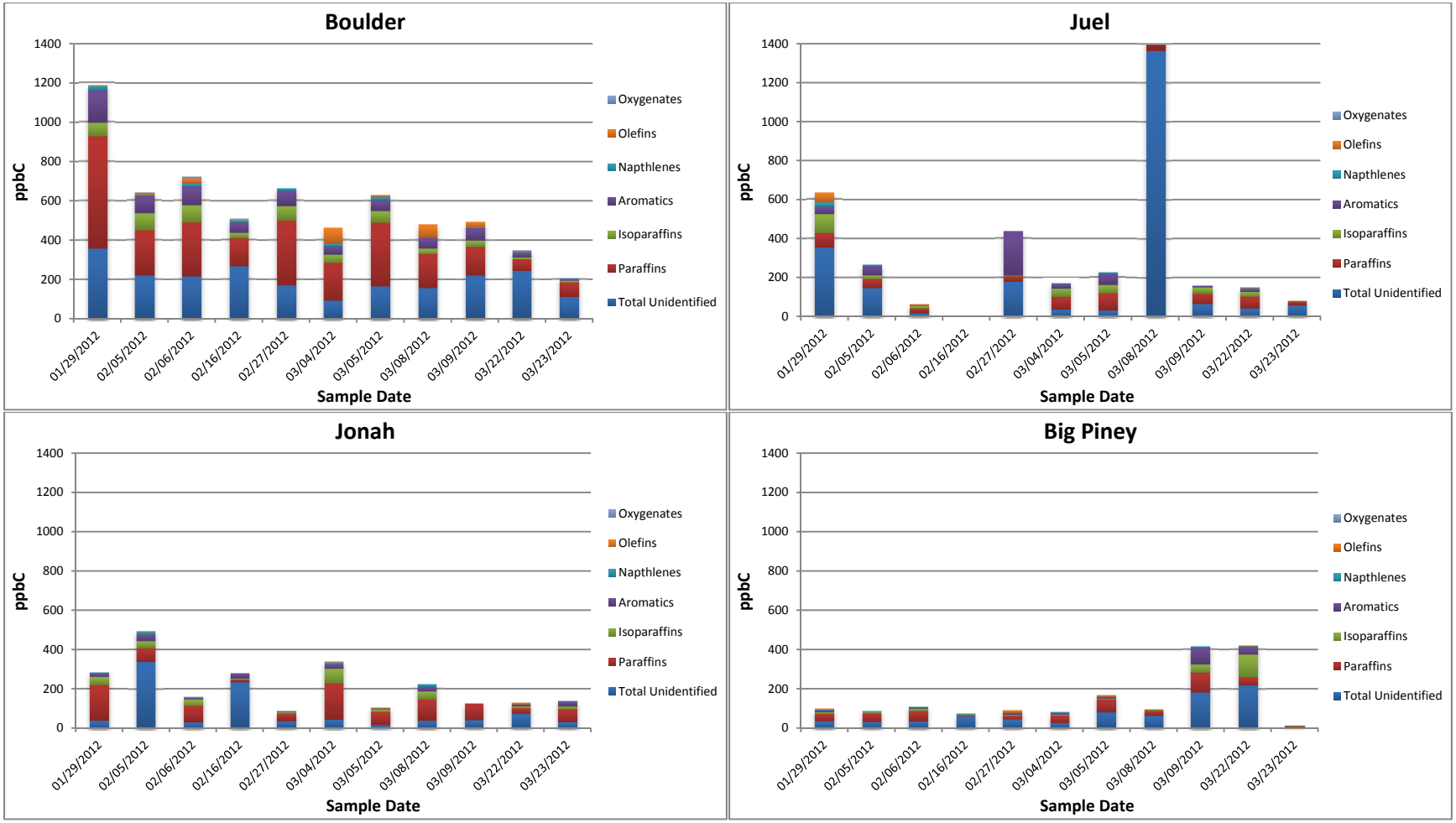

Figure 4.21 VOC Concentrations from Canisters Collected at Sample Locations (Rescaled)

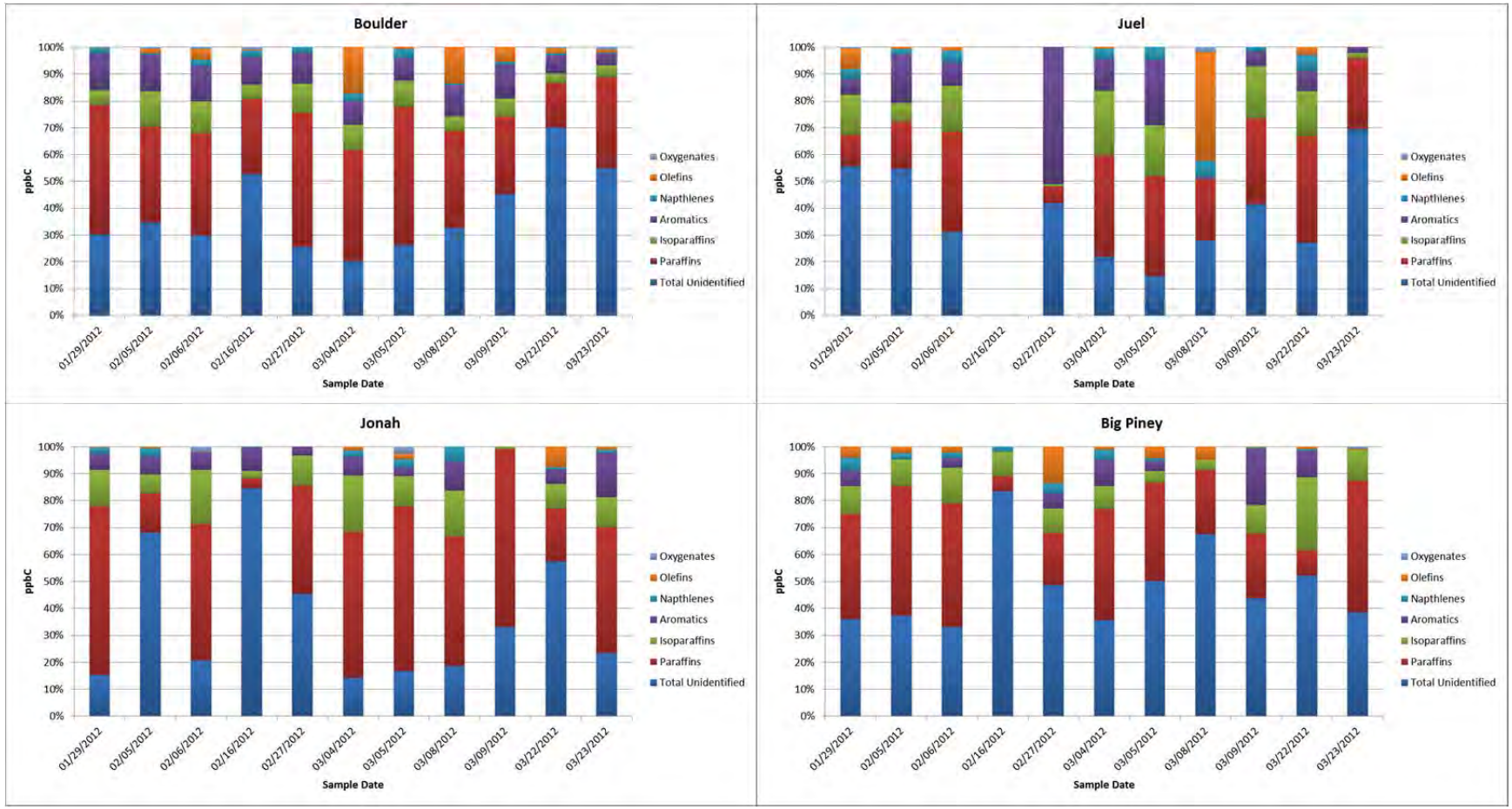

Figure 4.22 Relative Composition of Canisters Collected at Sample Locations

Non-methane organic compounds (NMOC) species vary greatly in the degree to which they participate in photochemical reactions. Figure 4.23 presents a comparison of average concentrations with reactivity weighted concentrations using maximum incremental reactivity (MIR) weighted concentrations (Carter, 2010) for the most common NMOC species observed at Boulder. It should be noted that the MIR values utilized in this analysis were developed for typical summer urban conditions and not winter UGWOS conditions. Compounds presented in Figure 4.23 are those detected in at least 50% of all samples collected at Boulder during UGWOS 2012. Toluene is the most abundant species on a reactivity weighted basis although concentrations are low relative to the less reactive light alkanes.

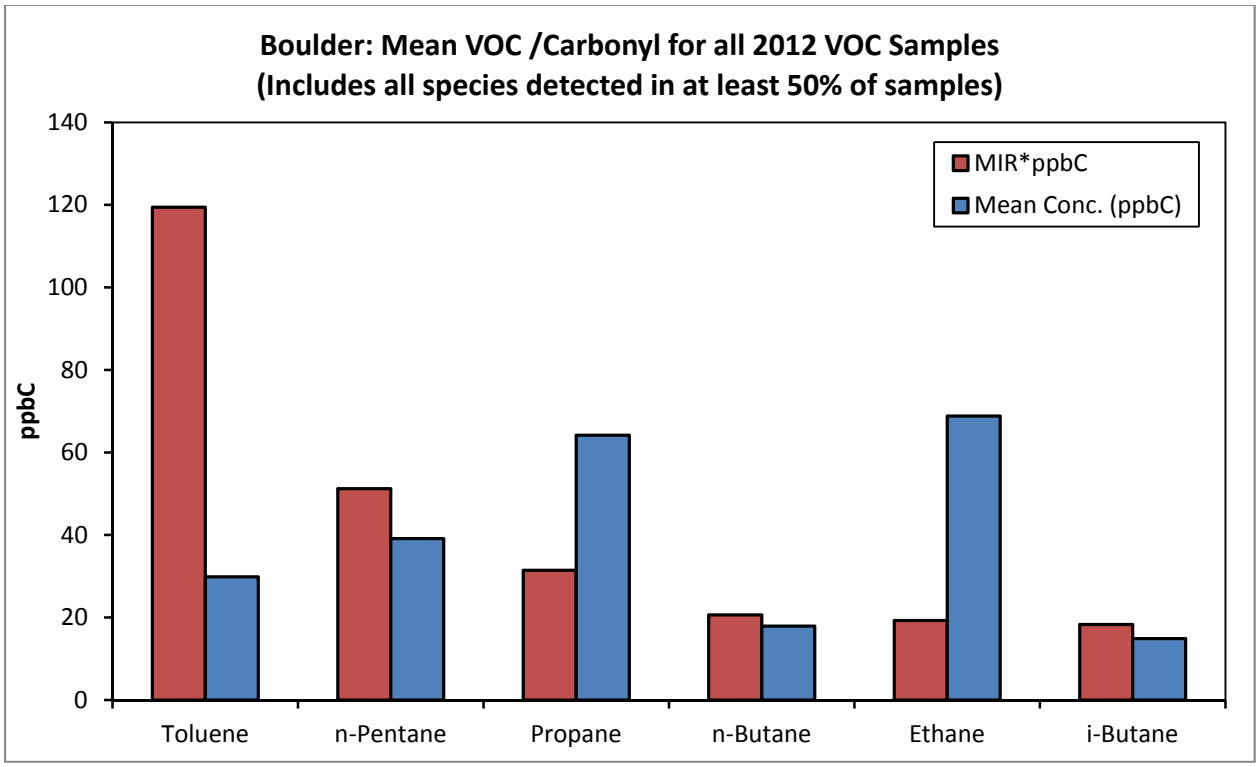

Figure 4.23 Comparison of Average Concentrations and Average MIR Weighted Concentrations

5.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Presented below is a summary of the UGWOS 2012 field campaign (January 15 through March 31, 2012), 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 ozone formation in Wyoming's Upper Green River Basin. Ozone formation mechanisms were the focus during the 2007-2009 studies. The 2010 study focused on monitoring spatial and temporal patterns of ozone and meteorology. Investigation of the vertical distribution of ozone and ozone precursors was the main thrust of the 2011 effort. The 2012 field measurement campaign focused again on the spatial distribution of ozone and ozone precursors using existing long-term monitoring stations and added mobile trailers at Big Piney and Jonah Field.

During UGWOS 2012, the synoptic weather pattern was fairly consistent. Weak storms frequently brushed the area with considerable atmospheric mixing and little substantial snowfall. There were no extended periods of persistent high pressure. During the UGWOS 2012 field season, there were no days when 8-hour ozone concentrations above the current EPA standard of 75 ppb were observed at monitoring stations in the UGRB. The maximum 8-hour ozone concentration for nearly every month and monitoring site in UGWOS 2012 was lower than any previous year. The highest 8-hour ozone concentration for any site was 64 ppb observed at Boulder on February 8, 2012.

5.1.1 UGWOS 2012 Field Operations

During UGWOS 2012, forecasts were issued daily to alert project managers and field personnel when elevated ozone episodes were expected so they could prepare for more intensive measurement operations. UGWOS field operations in 2012 included a temporary ambient monitoring station in the Jonah Field which provided continuous measurements of meteorology, O_3 and NO_x as well as additional speciated hydrocarbon sampling during periods when conditions favoring potential elevated ozone episodes were forecast. During UGWOS 2012, six (6) IOP's were declared during the two and one half month field study. VOC canister samples were collected at four sites – Boulder, Big Piney, Jonah Field and Juel Springs during the IOP's. In addition to the six IOP's, VOC canister samples were also collected on two days in the latter part of March when there was no snow cover in the area. A dedicated air quality technician was stationed in the project area to operate VOC sampling equipment and provide fast response to repair any instrument failures.

Seven WDEQ-AQD long-term stations provided surface air quality and meteorological measurements during the UGWOS field effort including Boulder, Daniel, Pinedale, Wyoming Range, Juel Spring, South Pass, and Moxa. The Boulder monitoring site was outfitted with more extensive specialized measurements to further characterize the role of ozone precursors during ozone formation. Specialized measurements 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 study period. One of AQD's mobile monitoring trailers was located at Big Piney to monitor air quality downwind of Big Piney/La Barge development and it provided air quality data for the west side of the UGWOS domain. Another mobile monitoring trailer was located at the entrance to the Jonah Field and measured ozone, oxides of nitrogen, wind and temperature.

5.2 Conclusions/Observations

The following conclusions/observations are made based on an analysis of the UGWOS 2012 field study results:

- Meteorology once again appeared to be the determining factor in whether or not elevated ozone concentrations developed in the study area. There was significant snow cover present over most of the study area especially during the one-month period following the January 21 storm event. However, persistent high pressure never developed over the study area and there were only five days when low mixing heights measured by the miniSodar persisted through the afternoon of past elevated ozone episodes.

- Although maximum 8-hour ambient ozone concentrations during IOP's were lower than during any previous UGWOS year, typical diurnal ozone patterns were observed at all of the monitoring sites except Wyoming Range. Wyoming Range recorded either only very slight increases or no increase in ozone concentration during IOP afternoons.

- With the exception of one outlier, VOC canister sample results showed relatively low concentrations as might be expected during a measurement season when no significant elevated ozone developed. Although the overall VOC sample concentrations were considerably less during 2012, the relative composition of VOC groups (paraffins, oxygenates, etc.) was similar to samples collected during previous UGWOS years.

- NO_x scavenging of ozone is a well-known process which occurs as NO_x moves through an area containing ozone, either transported by wind or by lowland drainage at night. This phenomenon was observed in the 2012 study at WDEQ's mobile monitoring site at Big Piney and possibly other sites as well. Inspection of Figures 4.10 through 4.14 consistently shows a decrease in ozone concentrations recorded during the early morning hours during each IOP at the Big Piney monitoring site. Further investigation into this scavenging would help in understanding this transport process.

5.3 Recommendations

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

5.3.1 Ozonesonde/Rawinsonde System

We would assign a high priority to conducting a rawinsonde balloon release each morning to document atmospheric profiles above the study area. Because AQD already owns a rawinsonde system, the expense of this effort would be reduced to the cost of the sondes and an operator. With proper organization, this system could be set up to be operated daily by the technician dedicated to field operations full-time. These data would not only be valuable for health alert and IOP forecasting purposes but also for regional modeling efforts and associated model validation efforts.

5.3.2 Tall Tower Measurements

We again recommend considering the installation of a long-term 100-meter tower, instrumented with meteorological sensors to be operated continuously year round. In the past, we recommended placing the tower at the Boulder air quality site with multi-level air quality monitoring capability. We realize that this involves considerably more effort and funding. Unlike air quality measurements which are more site specific, meteorological measurements on a tall tower are more likely to be representative of a larger portion of the study area domain.

For this reason, AQD may want to consider other locations with simpler logistics than the Boulder site if a meteorological-only tower to characterize atmospheric structure is desired. This type of a tower could be operated using solar power. Potential locations might include the area bordered by Highway 351 on the south, Highway 191 on the northeast side, and the Paradise Road/New Fork River on the northwest. Within this triangle-shaped area there are three sections of state land with generally open terrain. They include the following:

- T31N, R109W, Section 36
- T31N, R108W, Section 16
- T31N, R108W, Section 36

These locations are 5-8 miles south of the Boulder monitoring site and are at about the same elevation or somewhat higher.

5.3.3 Expansion of Surface-Based Monitoring Network during UGWOS Using WDEQ-Owned Mesonet Equipment

Since AQD already owns four sets of ozone mesonet monitoring equipment, it might be cost effective to consider deploying these stations again in locations where AQD modelers feel more data are needed. Additionally, this mesonet equipment could be used in sites that would allow further investigation into NO_x scavenging that appears to occur during nocturnal drainage flow (see 5.3.6).

5.3.4 Radiometer or Ceilometer

The use of a radiometer and/or a ceilometer to assist in identifying atmospheric structure could be very beneficial. In particular, a radiometer has the potential to provide continuous temperature profile data with sufficient resolution to identify vertical structure characteristics such as the base of elevated inversions and inversion strength, both of which likely play a part in the development of ozone episodes and provide quantitative data inputs into models.

The ceilometer provides a more interpretive analysis of mixing, similar to a sodar, but uses the backscatter from aerosols in the mixed layer. As evidenced by field observations during episode events, there are adequate aerosols present to provide a strong backscatter profile within the trapped layers.

Currently, a 25 meter vertical resolution is possible using radiometers and collection of data in climates and environments similar to wintertime conditions in the UGRB will be needed to confirm this potential. Another cold climate study using a single channel radiometer demonstrated the ability to detect low level inversions, but had some issues with the structure above the surface layer. There is still a question if the issues noted were related to the specific instrument, or to the measurement technology as a whole.

For either of the instruments we recommend that the AQD lease a unit(s) to verify the performance relative to forecasting and modeling goals. Performance of either system can be quantified by comparison with rawinsonde releases using AQD equipment and personnel or T&B System's equipment and personnel. For at least the radiometer, leasing plans do exist that will allow a large portion of the lease amount to be applied to a purchase of the equipment once performance is verified. Similar programs may be available for the ceilometer. Again, it is important that the temperature data be collocated with continuous wind data, such as that provided by a SODAR.

5.3.5 Mobile Measurement Verification of Precursor Locations

The area around the Boulder site has historically had the highest concentrations of ozone and precursors. However, in the last couple of years there have been significant changes in the locations of drilling and related activities such that it is not known if potentially higher values of ozone and precursors may be present in other regions. Observations from aircraft platforms in prior studies have shown that the areas of maximum concentrations can migrate around the region, and with the primary sources now in other locations it would be expected that changes in the areas of maximum concentrations may have occurred.

We recommend either airborne or surface mobile measurements be made during episodic conditions to help map these regions and verify that existing network of stations is still adequate to capture a true picture of the pollutant distribution throughout the UGWOS domain. Mobile observations might also be used to further investigate NO_x scavenging that occurs during nocturnal drainage flow (see 5.3.6).

5.3.6 Nocturnal Transport of NO_x along Drainage Basins

Previous UGWOS studies have not comprehensively sampled conditions along the very bottom of local drainage basins, adjacent to rivers and streams. The drainages created by the Green River and its tributaries may serve as a conduit for significant nocturnal transport of NO_x and other pollutants. A number of prospective locations along the Green River system have been identified as possible temporary measurement sites for future UGWOS campaigns. A list of these prospective sites includes:

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

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

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

The transect data combined with low level meteorological measurement would give an indication of the transport and dispersion of the elevated NO_x air masses along the drainage basins and could provide valuable input data for subsequent dispersion modeling efforts.

6.0 ACKNOWLEDGEMENTS

Many individuals and groups in addition to the staff of Meteorological Solutions, Inc. (MSI) and T&B Systems contributed to the successful completion of the 2011Upper Green River Winter Ozone Study and its presentation in this report. Cara Keslar, serving as Project Manager for the Wyoming Department of Environmental Quality (WDEQ) arranged funding, interfaced with Federal and State agencies and other WDEQ contractors, managed contracting details, and provided helpful direction, guidance and comments throughout the study. Jennifer Frazier, WDEQ's Jonah Interagency Office representative, continued to provide field support facilitating project logistics and field measurements. Many other WDEQ personnel provided assistance and were helpful in making 2012 a successful study. Air Resource Specialists (ARS) provided meteorological and air quality data they were collecting at the Boulder and Big Piney sites. Intermountain Laboratories provided data from the Daniel site.

7.0 REFERENCES

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Appendix A
Monitoring and Quality Assurance Plan

MONITORING AND QUALITY ASSURANCE PLAN

for the

UPPER GREEN RIVER WINTER OZONE STUDY - 2012

Prepared for

State of Wyoming
Department of Environmental Quality, Air Quality Division
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January 15, 2012

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UGWOS 2012 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 2012, sponsored by the Wyoming Department of Environmental Quality (WDEQ). While research in nature, the monitoring methods and objectives described in this plan are consistent whenever possible with EPA quality assurance guidance for the collection of air quality and meteorological data (US EPA 2008a and 2008b) and the most recent guidance for the collection of meteorological data for regulatory modeling applications (US EPA, 2000).

Recent high ozone events observed in this area have raised concerns regarding potential adverse health and ecological effects associated with monitored concentrations greater than the U.S. Environmental Protection Agency's ozone standard (currently set at an 8-hour average concentration of 0.075 ppm). Ozone formation in the Upper Green River Basin is unusual in that the highest concentrations have been recorded during the late winter and early spring (February to April) when sun angles are relatively low and temperatures are generally below freezing. This is in stark contrast to ozone exceedances in other areas, which occur during the warm summer months when abundant solar radiation and high temperatures act to increase precursor emissions and enhance the atmospheric reactions that result in ozone formation near the earth's surface (i.e., within the planetary boundary layer). Due to the pressing need to manage ozone air quality in the Upper Green River Basin and the limited amount of information currently available about the nature and causes of these unusual events, the WDEQ funded a comprehensive field study (the Upper Green Winter Ozone Study or UGWOS) which was conducted during the late winter – early spring seasons of 2007 through 2011. 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 and 2010, 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 2012. This QA plan addresses the 2012 monitoring effort.

Data from the 2012 study will be used to refine a conceptual model of ozone formation developed on the basis of prior year's studies of ozone formation. The conceptual model will be used along with the field data to develop accurate meteorological and air quality numerical simulations of the ozone events. Both the conceptual and numerical models will in turn be used to develop effective air quality management strategies needed to adequately protect public health and the environment in accordance with applicable State and Federal laws.

SECTION 2

SAMPLING PROGRAM DESCRIPTION

The sampling period for UGWOS 2012 will run from January 15, 2012 through March 31, 2012. Sampling that will be conducted for UGWOS during this period is described below.

2.1 FORECASTING PROTOCOL

The UGWOS effort for 2012 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) 2012 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.

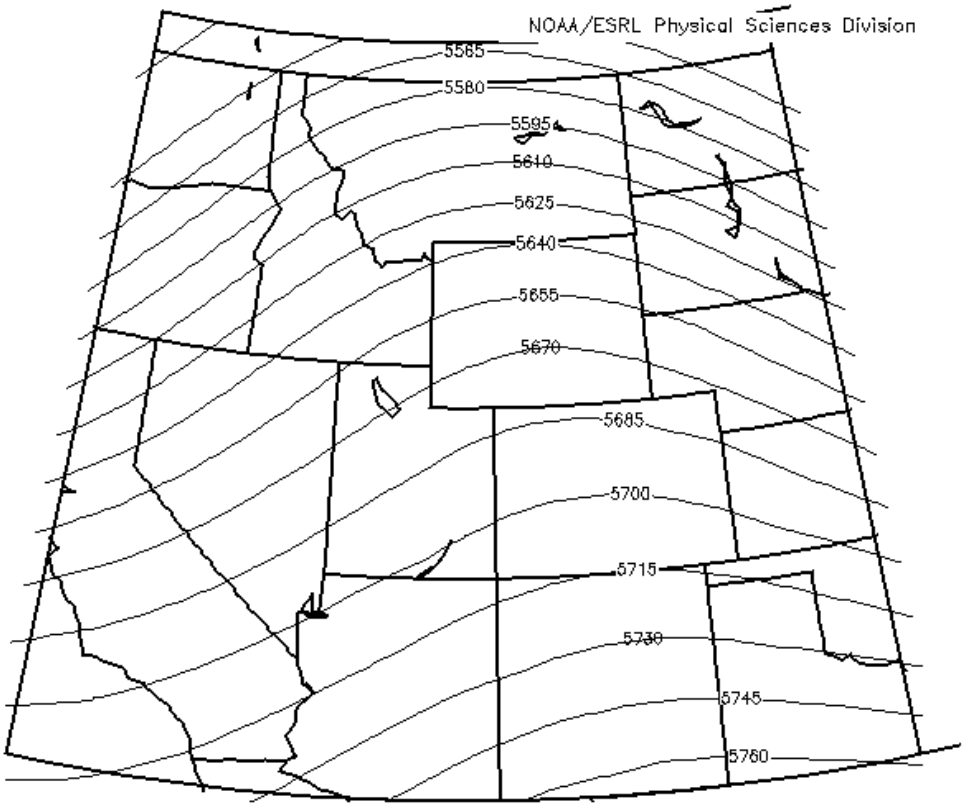


Figure 2-1 Composite 500 mb Heights During High Ozone Periods

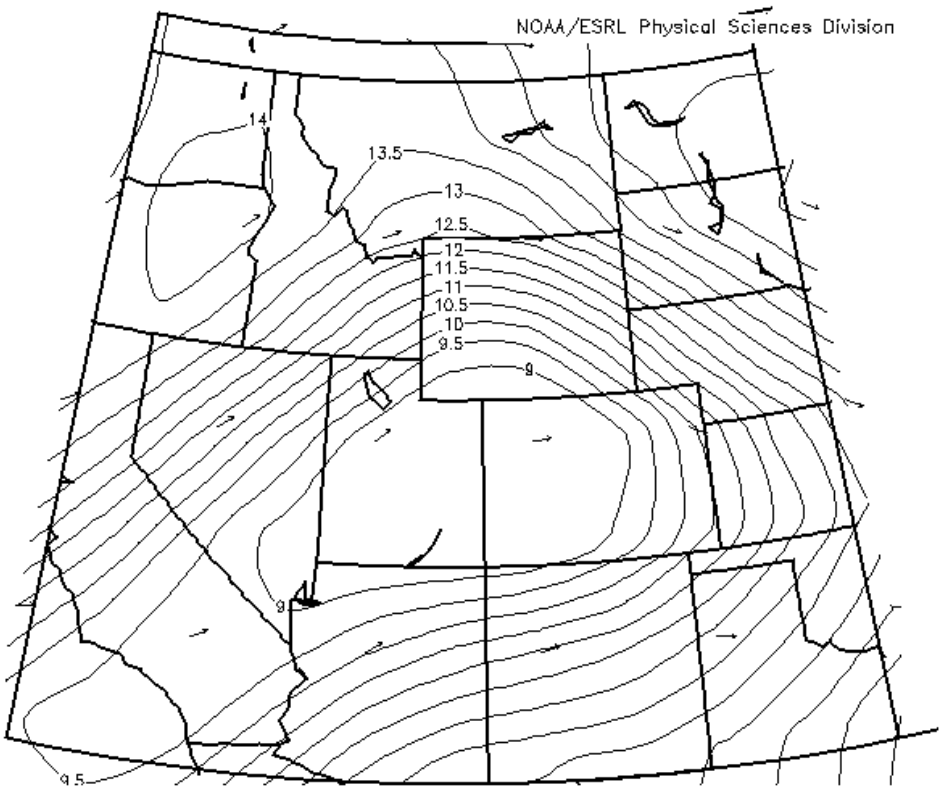


Figure 2-2 Composite 500 mb Winds During High Ozone Periods

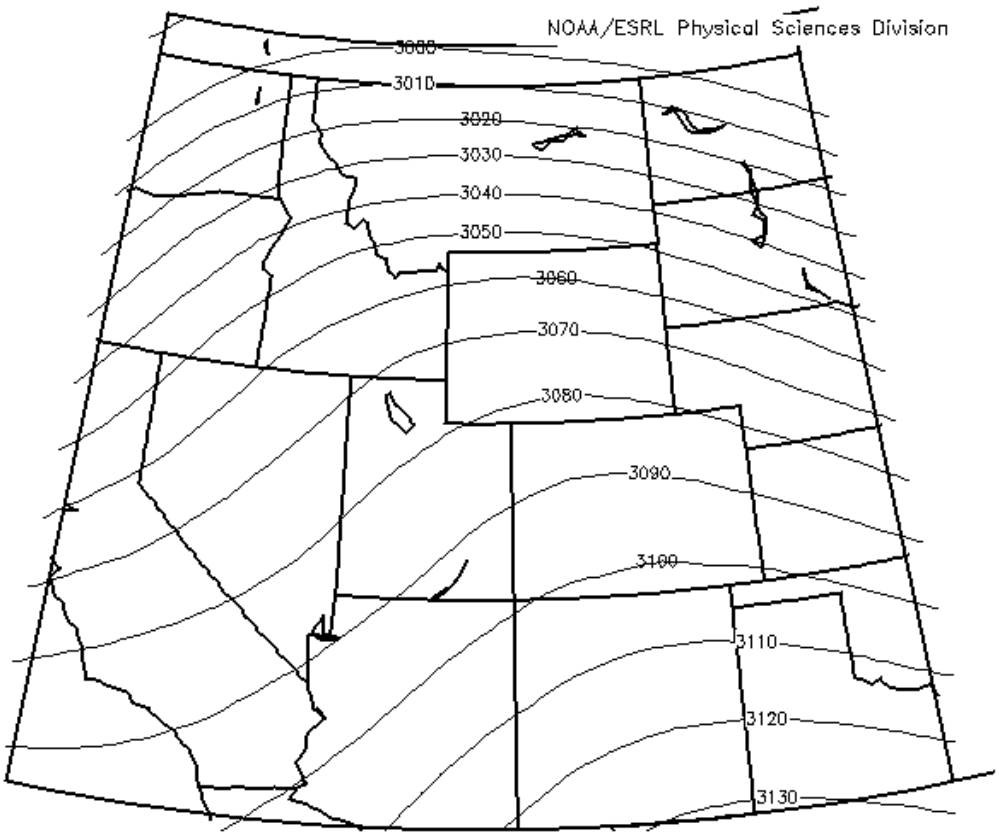


Figure 2-3 Composite 700 mb Heights During High Ozone Periods

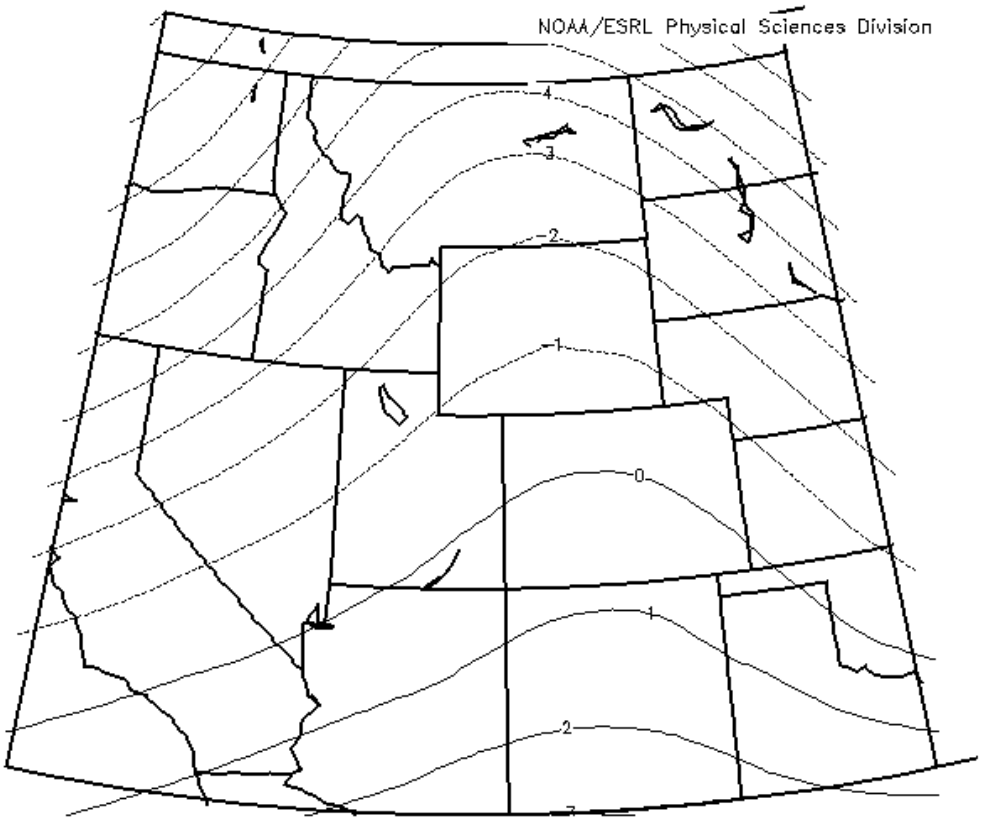


Figure 2-4 Composite 700 mb Temperature During High Ozone Periods

2.2 CONTINUOUS MEASUREMENTS

Project-specific measurements to be continuously obtained over the complete field program period are presented below. As in the last three 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 Jonah monitoring measurements, and deploy/retrieve VOC samples at the Jonah, Juel Springs, Big Piney and Boulder sites. He will also be available to troubleshoot issues at all AQD sites in the study area (Wyoming Range, Daniel, Boulder, Pinedale, Juel Springs, Big Piney and Farson meteorological tower). The field technician will also be available to assist with AQD contracted audits during the study period.

2.2.1 Ozone and NO/NOx Measurements in the Jonah Area

Continuous ozone and oxides of nitrogen will be performed at the entrance to the Jonah Field on Luman Road utilizing WDEQ's BAM trailer. In addition, sampling at the Jonah site will include VOC sampling (25 canisters plus five quality control samples – see below). Wind speed, wind direction, temperature and pressure will also be deployed at this site. A datalogger and cellular telemetry will be supplied to retrieve data from the site on an hourly basis.

MSI will be responsible for the air quality and meteorological measurements, including routine checks, data validation, and database management.

2.2.2 SODAR Upper Level Winds

For the 2012 monitoring effort, the WDEQ MiniSodar (sodar) will be maintained at the existing WDEQ monitoring site at Boulder. Both surface and winds aloft will be measured continuously. The sodar is equipped with a battery bank, solar panels and a backup generator, providing continuous measurements without the need of AC power. However, the chosen site for operations does include available AC power. Remote communications is made possible with a cellular modem. All data will be posted in near real-time on a web page as well as archived data posted automatically on a FTP server. These sodar data can be reviewed remotely, as necessary.

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

2.3 INTENSIVE MEASUREMENTS

During periods when high ozone levels are forecast, additional intensive measurements will be initiated. The key component of the IOPs is the collection of VOC samples, as described below.

2.3.1 VOC Measurements

VOC measurements will be conducted at the Boulder, Big Piney, and Juel Springs sites, as well as at the UGWOS-specific Jonah site. The VOC measurements will be sampled as integrated 3-hour samples. IOP days will be identified using forecast information and consultation with WDEQ AQD. Canisters will be sampled on IOP days from 0700-1000. Up to 25 samples will be taken at each of the sites. In addition, five (5) quality control samples will be collected at each site, including zero air contamination samples, duplicates, and field blank samples.

VOC measurements will be made 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.

2.4 SUPPLEMENTAL MONITORING AND DATA COLLECTION

Archiving of NOAA Products

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

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

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

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

SECTION 3

MONITORING SITE DESCRIPTIONS

Figure 3-1 presents a map of the UGWOS site locations. Table 3-1 presents coordinates for each of the sites. Photographs of the sites can be found in Appendix A.

Also included in Figure 3-1 and Table 3-1 are the locations of additional ozone monitoring sites, both past and present, in the study region.

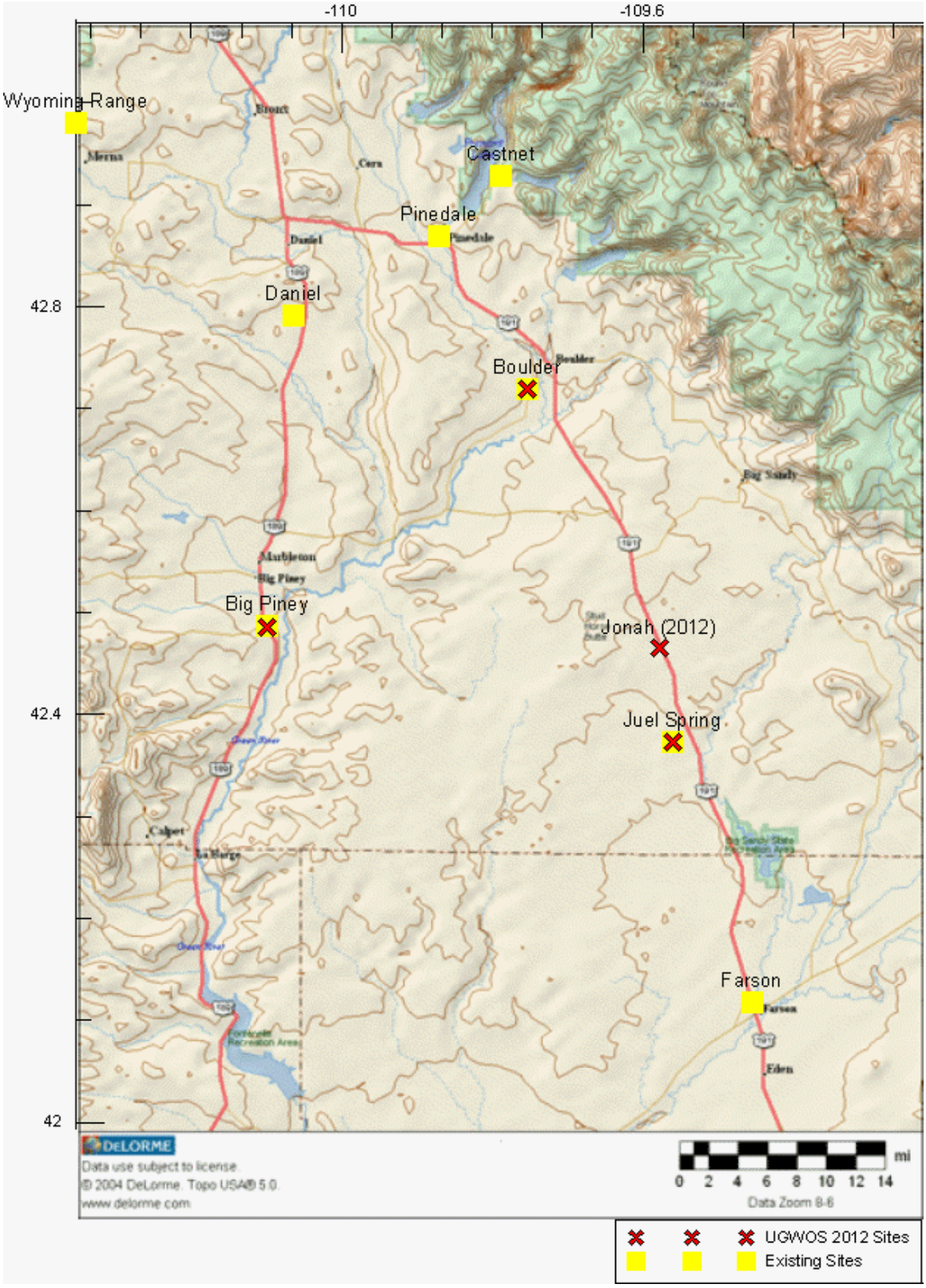


Figure 3-1. Map of UGWOS and Additional Ozone Monitoring Site Locations

Table 3-1. Monitoring Locations

	Latitude	Longitude	Elev.
SODAR SITE			
Boulder	42.7188	-109.7529	7078’
JONAH AREA SITE			
Jonah (2012)	42.4654	-109.5771	7155’
EXISTING MONITORING SITES OF INTEREST			
Big Piney	42.4870	-110.0995	6823’
Daniel	42.7910	-110.0650	7084’
Castnet	42.9284	-109.7880	7853’
Farson	42.1184	-109.4541	6619’
Pinedale	42.8698	-109.8707	7186’
Juel Spring	42.3735	-109.5605	7020’
Wyoming Range	42.9801	-110.3530	8123’

SECTION 4

MONITORING EQUIPMENT DESCRIPTION

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

4.1 JONAH MONITORING SITE – AIR QUALITY

Air quality parameters will be monitored using the following equipment:

Teledyne/API Model 200E $NO/NO_2/NOx$ Analyzer – EPA Approval RFNA-1194-099

The Model 200E 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. Stability is enhanced by an Auto-Zero circuit that continuously provides a true zero reference.

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

Teledyne/API Model 400E Ozone Analyzer – EPA Approval EQOA-0992-087

The Model 400E UV Absorption 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. A 254 nm UV light signal is passed through the sample cell where it is absorbed in proportion to the amount of ozone present. Every three seconds, a switching valve alternates measurement between the sample stream and a sample that has been scrubbed of ozone. The result is a true, stable ozone measurement.

Accuracy	±5%
Precision	±5%
Resolution	1 ppb

Lower Quantifiable Limit	2 ppb

Teledyne/API Model 700 Calibrator

The Model 700 is a microprocessor based calibrator for precision gas analyzers. Using a combination of highly accurate mass flow controllers and compressed sources of standard gases, calibration standards are provided for multipoint span and zero checks. Up to 4 gas sources may be used. In addition, the Model 700 is equipped with an optional built-in, programmable ozone generator for accurate, dependable ozone calibrations and to produce NO_2 when blended with NO gas in the internal GPT chamber. As many as 50 independent calibration sequences may be programmed into the M700, covering time periods of up to one year. These sequences may be actuated manually, automatically, or by a remote signal. Dilution air is supplied to the calibrator using an API Model 701 zero air system.

4.2 JONAH MONITORING SITE – METEOROLOGY

RM Young Model 05305 Wind Monitor AQ

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

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

Campbell Scientific 107 Temperature Sensor

The temperature will be measured using a Campbell Scientific model 107 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 4-1**. 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

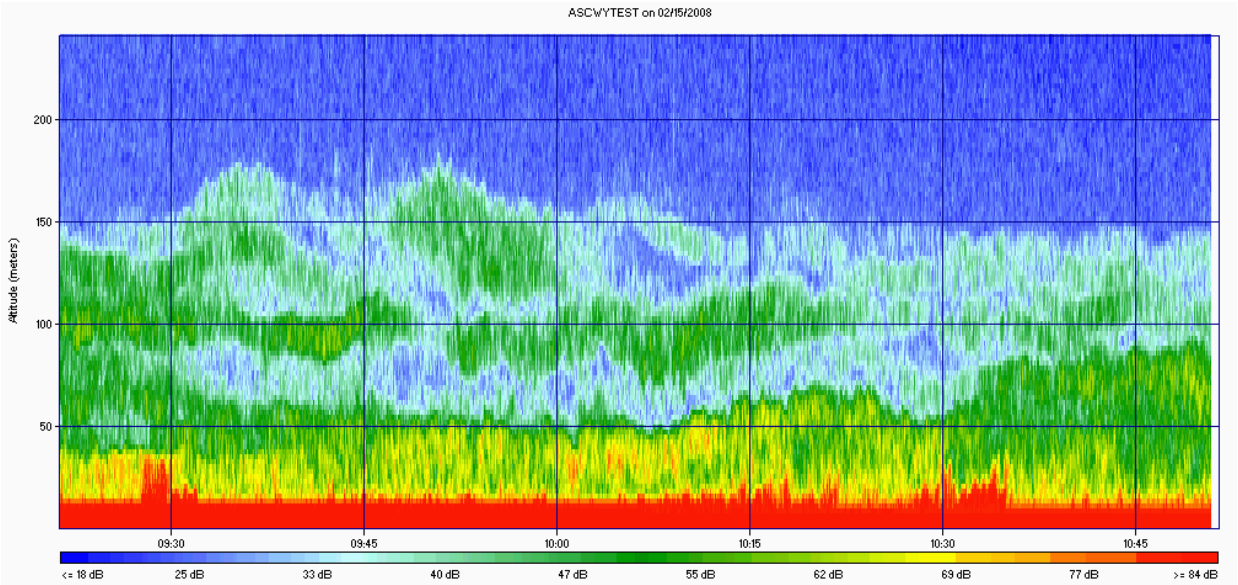


Figure 4-1. Example of sodar backscatter data capturing the daytime mixing height layers under cold wintertime conditions.

4.4 VOC SAMPLING

WDEQ-owned samplers will be retrieved by MSI and bench checked prior to deployment. Figure 4-2 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 Teflon sample tube, with the inlet positioned approximately two meters above ground level. Note that these samplers, which were originally used in 2009/2010 for the Pinedale air toxics study, are designed for obtaining both canister and sorbent tube samples. Only the canister sampling portion of the sampler will be used.

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

VOC samples will be analyzed using Method TO-14 with an expanded PAMS list of compounds (see Table 4-1). Analysis will be performed by Environmental Analytical Services, Inc., San Luis Obispo, CA.

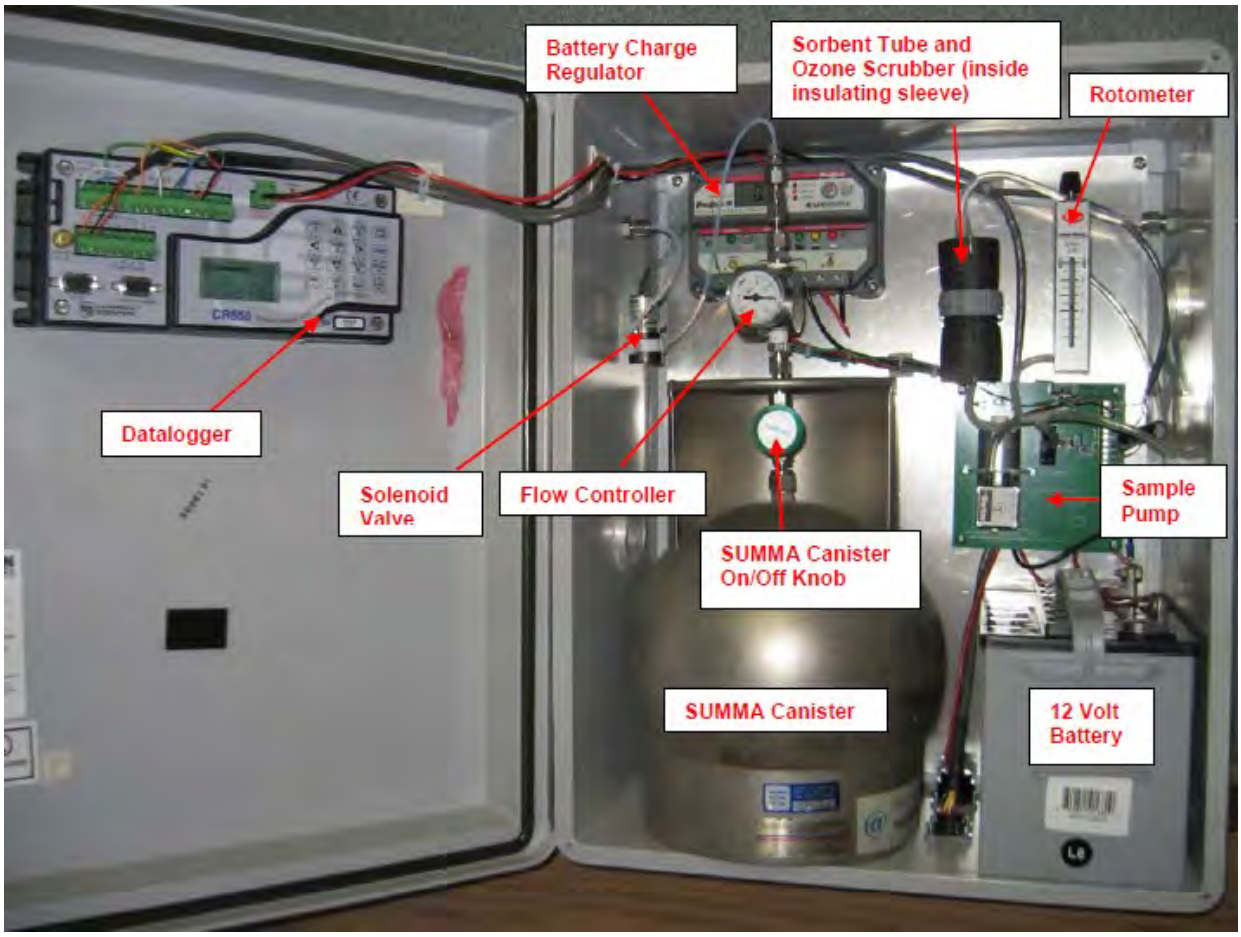


Figure 4-3. Canister Sampler. Only those components associated with the SUMMA canister will be employed.

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

Ethene	Cyclohexane	Total Petroleum Hydrocarbons:
Acetylene	2-Methylhexane	Total Non-Methane Hydrocarbons
Ethane	2,3-Dimethylpentane	Total Gas Non-Methane Organics
Propene	3-Methylhexane	Total Volatile Organic Compounds
Propane	2-Methyl-1hexene	TPH (gasoline)
i-Butane	Tert amyl methyl ether	TPH (diesel)
Methanol	2,2,4-Trimethylpentane	TPH (hexane)
1-Butene	n-Heptane	TPH (toluene)
1,3-Butadiene	Methylcyclohexane	TPH (methane)
n-Butane	2,5-Dimethylhexane	TPH (Jet A Fuel)
t-2-Butene	2,4-Dimethylhexane	TPH (Mineral Spirits)
c-2-Butene	2,3,4-Trimethylpentane	c6+ (hexane)
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	Carbon Ranges:
t-2-Pentene	m,p-xylene	C2 (ethane)
c-2-Pentene	Styrene	C3 (propane)
Tert butyl alcohol	o-xylene	C4 (Butane)
2-Methyl-2-butene	1-Nonene	C5 (Pentane)
2,2-Dimethylbutane	n-Nonane	C6 (Hexane)
Cyclopentene	i-Propylbenzene	C7 (Heptane)
n-Propanol	n-propylbenzene	C8 (Octane)
Cyclopentane	a-Pinene	C9 (Nonane)
Methyl tert butyl ether	3-Ethyltoluene	C10 (Decane)
2,3-Dimethylbutane	4-Ethyltoluene	C11+ (Undecane)
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	
	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	
	Dodecane	

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 Jonah measurements remotely on at least an hourly basis. Both sub-hourly and hourly averages will be collected. The data loggers are all equipped with internal memory that can store data. 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.

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 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.

Table 5-1. Data Quality Control Codes.

0

Flag	Description
BE	Building/site repair
BF	Precision/zero/span
BG	Missing ozone data not likely to exceed level of standard
BH	Interference/co-elution/misidentification
BI	Lost or damaged in transit
BJ	Operator error
BK	Site computer/data logger down
BL	QA audit
BM	Accuracy check
BN	Sample value exceeds media limit
B	Below detection limit

Once the data have been validated to Level 1, the data will be prepared for submittal to the database in a form that clearly defines the time reference, averaging period, parameter names and units. The time reference for the database is **local standard time (Mountain Standard Time)** and the averaging period reference will be standardized to **hour beginning (0 – 23)**. The data will be submitted as ASCII comma delimited text files or excel spreadsheet files, with data columns well defined to clarify site identification, parameters, instrumentation, units, and time reference.

Data will be submitted in a format similar to that of the final database structure, as outlined below. This basically has a second column for each measured value for an accompanying QC code. QC codes include simple validation codes as well as AQS null codes developed by the EPA.

Database Management Design

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

The following describes the design for the database, which was similarly implemented during the 2007, 2008, 2009 and 2010 field studies. The database includes an inventory spreadsheet file to help users track and ensure that all of the data were submitted and processed in a timely and consistent manner. All data files submitted will be examined to verify unique names for all sites, instruments, and parameters so that no orphan or

duplicate records exist in any of the tables. A system is in place for identifying the version and or modification date of all data files. All files are backed up daily.

The data have the following flat format:

Surface Hourly Meteorological Data

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

Ozone 8-hour averaged:

SITE, DATE, HOUR, O3_8HR, O38HR_QC

Hourly Surface Air Quality:

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

Upper level meteorological and air quality data

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

SITE, DATE, HOUR, TIME, HEIGHT, WS, WS_QC, WD, WD_QC

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

- Parts per billion (ppb) for O3, NO, NO_2, and NOx
- 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, 2012.

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

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

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

A final report will be prepared presenting:

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

A draft version of the report will be provided to WDEQ by June 1, 2012. Voluminous tables and figures will be incorporated into electronic appendices as appropriate. All report materials will be made available via a secure FTP transfer site.

SECTION 6

QUALITY ASSURANCE PROGRAM

6.1 PROJECT MANAGEMENT

Mr. George Wilkerson will serve as overall project manager. Mr. Bill Hauze will serve as the Field Operations Manager for the study. He will be responsible for coordinating and verifying corrective action for any measurement-related problems.

An organizational chart for UGWOS 2012 is provided in **Figure 6-1**. Study personnel responsibilities and contact information are presented in **Table 6-1**.

While it is not anticipated that the scope of the monitoring effort will change over the relatively short duration of the effort, any changes will result in a revised version of this QAPP. Mr. David Bush is responsible for the writing and distribution of the QAPP. Revisions will be distributed based on the distribution list at the beginning of this document.

6.2 DATA QUALITY OBJECTIVES

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

Air quality data: 80% of the possible data

Meteorological data: 90% of the possible data

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

6.3 ASSESSMENT AND OVERSIGHT

QUALITY CONTROL PROCEDURES

As part of the quality assurance program, detailed quality control procedures have been implemented to assess and maintain control of the quality of the data collected. All equipment will undergo complete checkout and acceptance prior to the start of monitoring on January 15, 2012. This checkout will occur during the week prior to the start of monitoring, as well as during setup and installation of the equipment. Standard operating procedures (SOPs) for measurements will be developed for key monitoring activities. SOPs can be found in Appendix B.

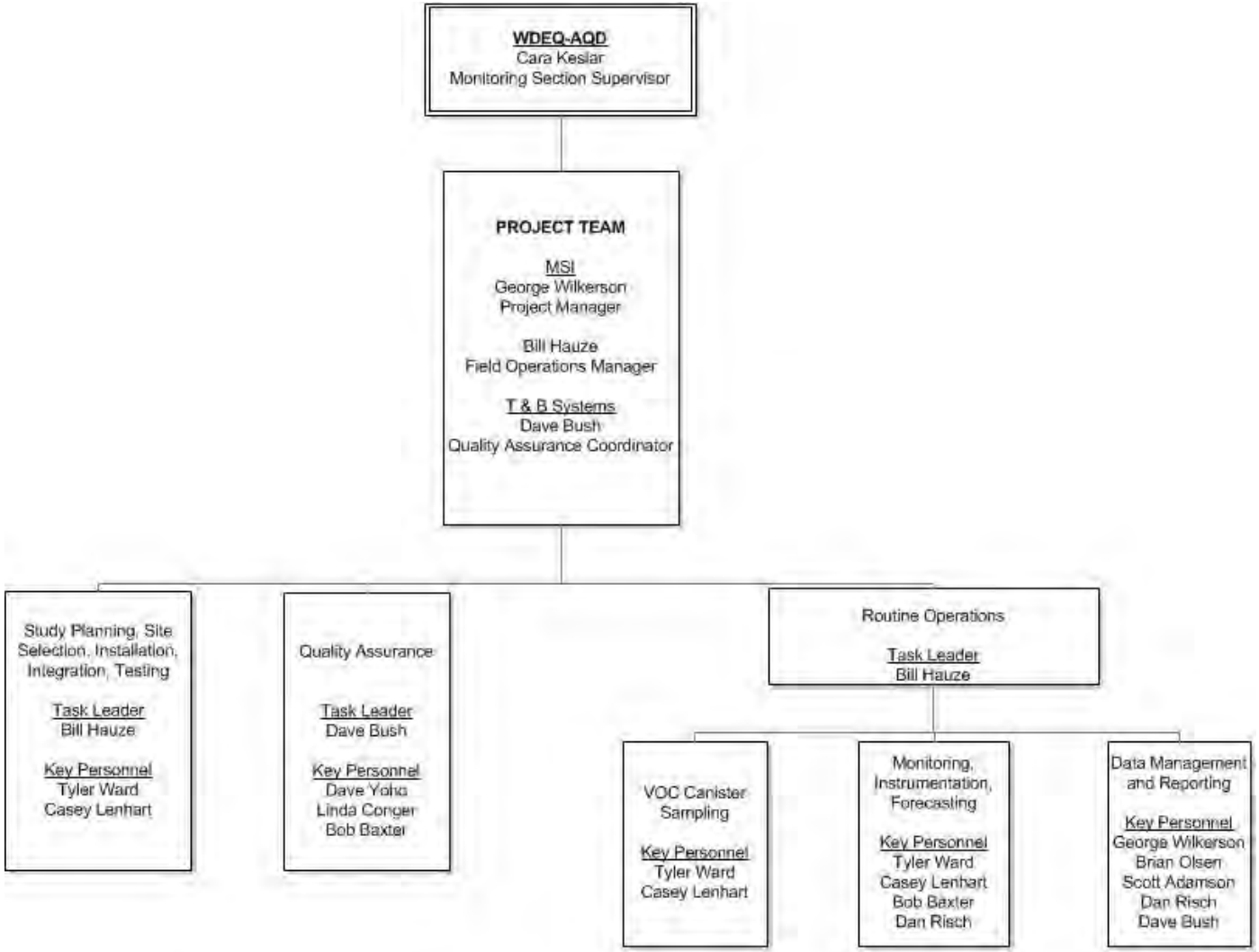


Figure 6-1. Project organization.

Table 6-2. Project responsibilities and contacts

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

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

Station Checks

Performance of all UGWOS 2012 Jonah monitoring site equipment will be checked daily via remote polling, with site visits occurring at least weekly.

Ozone, NO/NOx, Analyzers

Analyzers for the UGWOS 2012 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 approximately every 14 days.

VOC Canister Sampling Systems

Tripod mounted portable VOC canister sampling systems as well as the canister sampling system inside the air quality shelter at the Boulder monitoring site will flushed with ultrapure air and checked for contamination prior to the start of the UGWOS 2012 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/NOx analyzer will be performed upon initial installation and at the end of the study period. Additional calibrations will be performed on an as-needed basis in the event of equipment repair or replacement. All calibrations will be performed in accordance with manufacturers' recommendations and consistent with USEPA guidance (USEPA, 1994, 1995, 2000).

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

The NO/NOx analyzer will be calibrated using a certified dilution calibrator and a certified gas standard. Standard gas phase titration (GPT) methodologies will be used for calibration of NO_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/NOx	Multipoint comparison of concentrations against a dilution of a certified gas standard
Wind Speed	Rotational rate using a selectable speed anemometer drive
Wind Direction	Alignment using true north and linearity with a directional protractor
Temperature	Water bath comparisons to a certified transfer standard

INDEPENDENT AUDITS

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

System audits will be conducted of all data collection operations, including the Jonah monitoring effort, the MiniSodar setup, and the VOC sampling. 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 system audits. Mr. Yoho is independent of all UGWOS 2012 measurements. He will conduct the audits during his routine audit visit to the area in January 2012.

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

Mr. David Yoho will conduct the performance audits of all measurement platforms. These audits will be conducted near the beginning of the study, after the continuous measurements have become operational. Comments and recommendations resulting

from the audits will be discussed with measurement personnel at the time of the audit, with a written memo report provided to study management within 48 hours of the audit. Mr. Bush will work with Mr. Hauze to verify that any deficiencies noted during the audit are addressed.

6.4 DATA VALIDATION

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

SECTION 7

REFERENCES

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

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

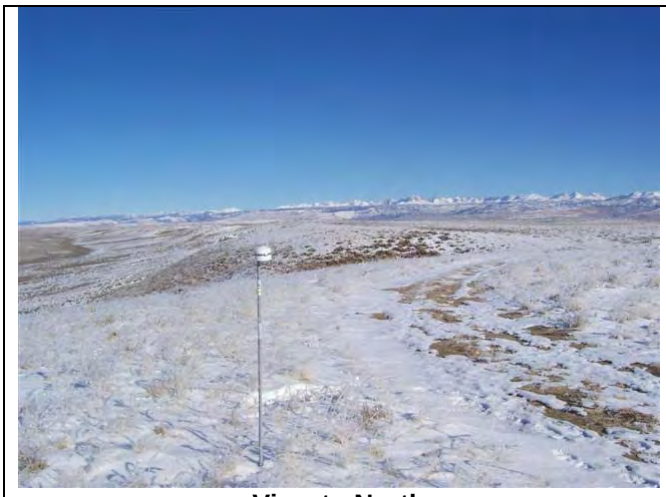
United States Environmental Protection Agency (1999): EPA Requirements for Quality Assurance Project Plans. Document EPA QA/R-5. U.S. EPA Quality Staff Interim Final Report, Research Triangle Park, North Carolina. November.

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

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

APPENDIX A

SITE PHOTOS

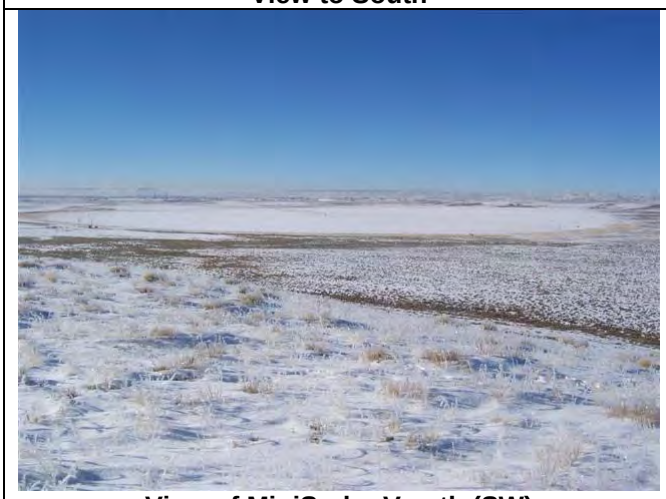


View to North

View to East

View to South

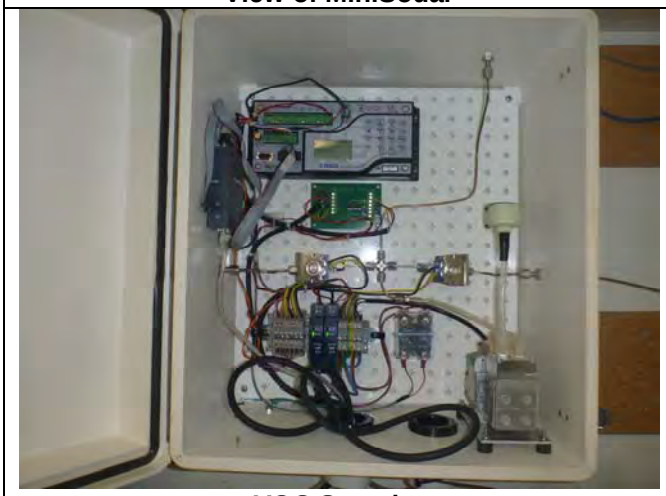
View to West



View of MiniSodar V path (SW)

View of MiniSodar U path (NW)

Boulder Site

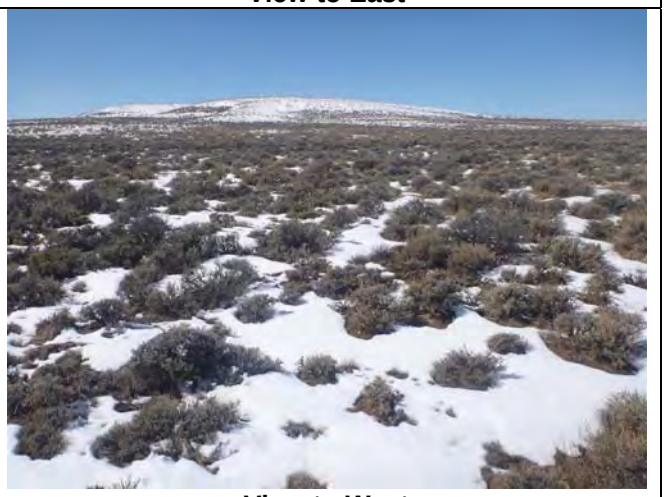
 View of MiniSodar	 **View of Air Quality Site**
 **VOC Sampler**	

Boulder Site

View to North

View to East

View to South

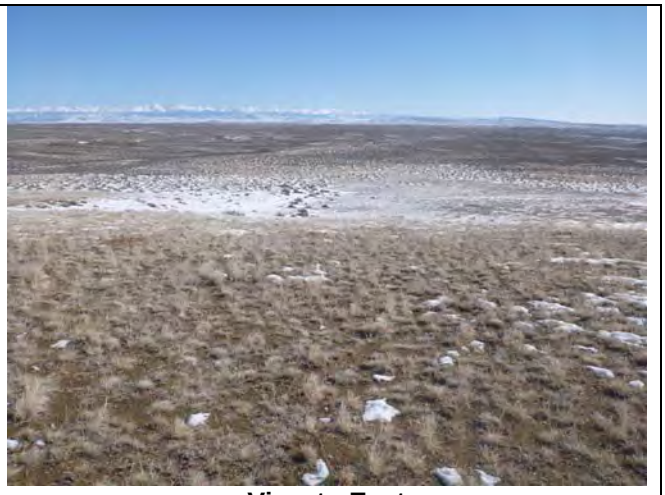


View to West

View of Air Quality Site

Big Piney VOC Sampling

View to North



View to East

View to South

View to West

VOC Sampler

Juel Springs VOC Sampling

View to North

View to East

View to South

View to West

Air Quality Analyzers

Jonah Site

APPENDIX B

STANDARD OPERATING PROCEDURES

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: 8/7/2012	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

Appendix B
Microsoft Access Database Description

The Upper Green Winter Ozone Study (UGWOS) 2012 Database

1. Introduction

This document describes the Upper Green Winter Ozone Study (UGWOS) database for 2012. Included are a review of the study measurements and descriptions of the key data reporting elements such as naming conventions, time reference and units. This document describes the overall structure of the database with a description of the data tables and file formats.

2. Overview of Measurements and Field Study Participants

The 2012 UGWOS field study included hourly measurements of surface air quality and meteorological data during the period of January through March 2012 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 four locations (Boulder, Juel Springs, Jonah, 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 2012 were located in or near Sublette County in southwestern Wyoming. The stations include:
    - Boulder (including 1-minute and 1-hour data collection),
    - Big Piney,
    - Campbell County,
    - Cheyenne,
    - Cloud Peak,
    - Daniel,
    - Jonah,
    - Juel Springs,
    - Moxa,
    - Murphy Ridge,
    - Pinedale,
    - South Pass,
    - Thunder Basin,
    - Wamsutter, and
    - Wyoming Range.

- 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
    - 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.</u>

- Canister Data
    - VOCs

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

Each contracted organization reviewed and validated their collected data to Level 1 before the data set was submitted to the database. The data were examined and any adjustments for calibration deviations were applied. Appropriate flags were assigned for extreme values, instrument downtime and performance tests. A description of the Quality Control (QC) codes used are given in Table 1 and also listed in the table **QC_flags** in the UGWOS 2012 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

3. UGWOS Database Design

Meteorological Solutions Inc. assimilated the submitted data into an Access 2010 database called UGWOS_2012_Database_Version?.?.mdb (where ?.? indicates version number). The database consists of both information and data files. It has a simple straightforward design. The **Sites** table contains all of the site information (site name, site identification code used in all of the data tables, site location including latitude, longitude, elevation, and a tabular list of what parameters were measured at each site and the organization responsible). The **Parameters** table lists parameter codes used in the data tables. The table named **Updates** lists all information pertaining to modifications and versions of the data as well as dates of said modifications. The name of the database includes a version number to help users identify the most current version of the database.

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

The **Hourly Air Quality** table includes hourly average data of criteria pollutants (ozone, oxides of nitrogen, particulate matter) measured at each of the sites. Other pollutants such as methane, non-methane hydrocarbons and total hydrocarbons are also included in the Hourly Air Quality Table. One minute air quality data were collected at the Boulder site. These data are presented in the **1-minute Air Quality** data table. Boulder data went through quality assurance with valid data marked with a "V" in the QC flag field.

Data included in the **Hourly Meteorology** table represent hourly averages of meteorological data parameters such as wind speed, wind direction, standard deviation of the wind direction, and temperature. Select sites have additional meteorological parameters such as relative humidity, solar radiation, barometric

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

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

The data from the SODAR is included in the **Sodar** and the **Mixing Height** data tables.

Surface VOC data collected during IOPs at the Boulder, Juel Springs, Jonah, and Big Piney sites are presented in the **VOC** table. A summary of the canister data collected at the VOC sites are available in **VOC Summary** table.

The data tables all have a flat format with the identifying information in the starting columns. The most common parameters are listed first. An empty data column and quality control flag indicates no measurements obtained at the site for that parameter. Additional documentation that includes a complete description of the data column, units, etc. is provided by Access 2010 in the information bar at the bottom of the Access window screen when the user is accessing the column. All data tables include a Record Number column at the end of the table, this column is intended to keep data sorted in chronological order by site to match the Sites table. With this option, a user can sort the table any way he or she chooses and have the capability of sorting the table into its original format.

The data have the following general unit configurations:

- Parts per billion for O3, 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 2012 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, 2012 and March 31, 2012. Next the user will be asked for an hour beginning and an hour ending, the data are in hour beginning format (0-23). Data not between the specified beginning and ending hours will be removed for all days between the starting and ending dates.

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

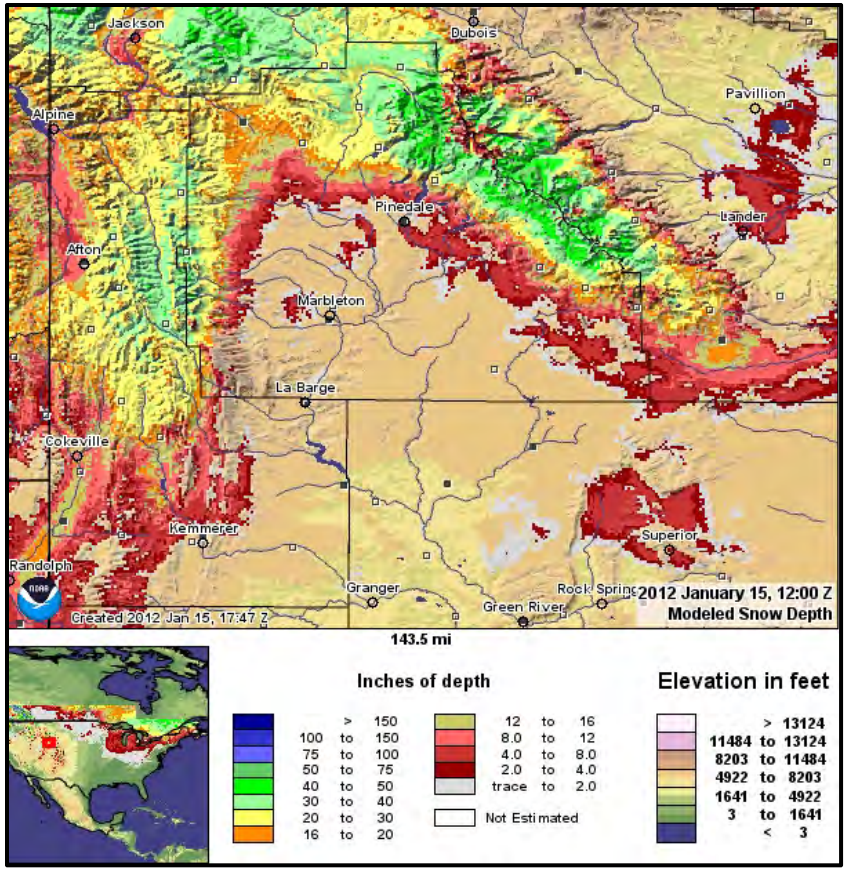
Sort 1-hour Ozone Data- the purpose of this query and the **Sort 8-hour Ozone Data** query are to sort any data above a user specified threshold. The user will be asked to provide a level of which no data records with an ozone level below that threshold will be displayed. Common parameters are displayed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

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

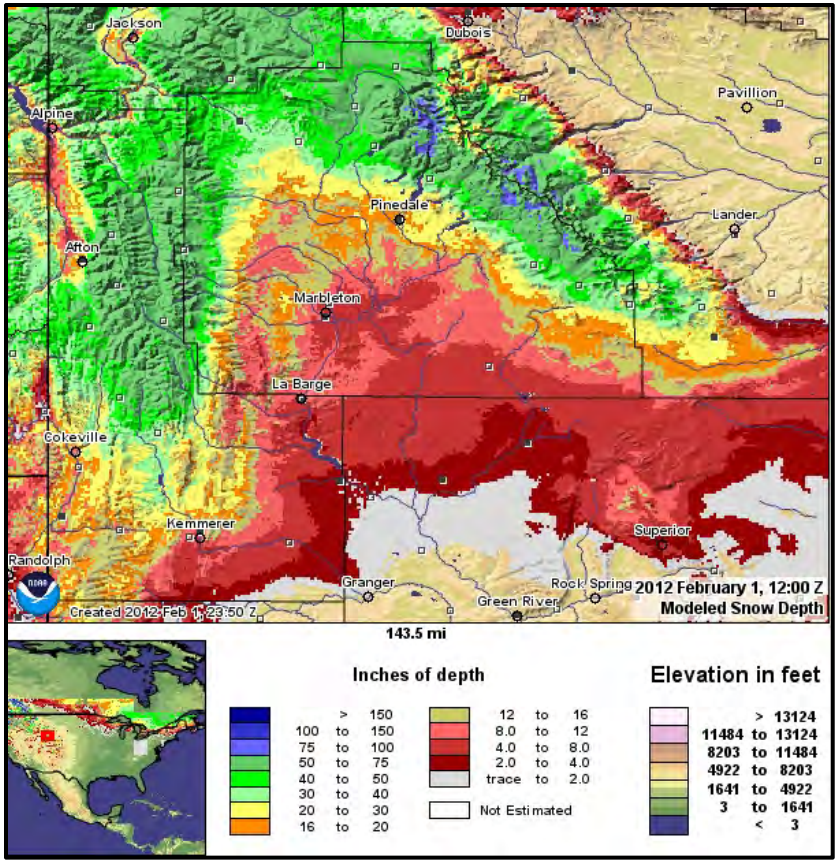
4. Summary

This document describes the 2012 UGWOS database. Feedback from study participants concerning this document and the database is requested and any suggestions for improvement are highly encouraged and appreciated.

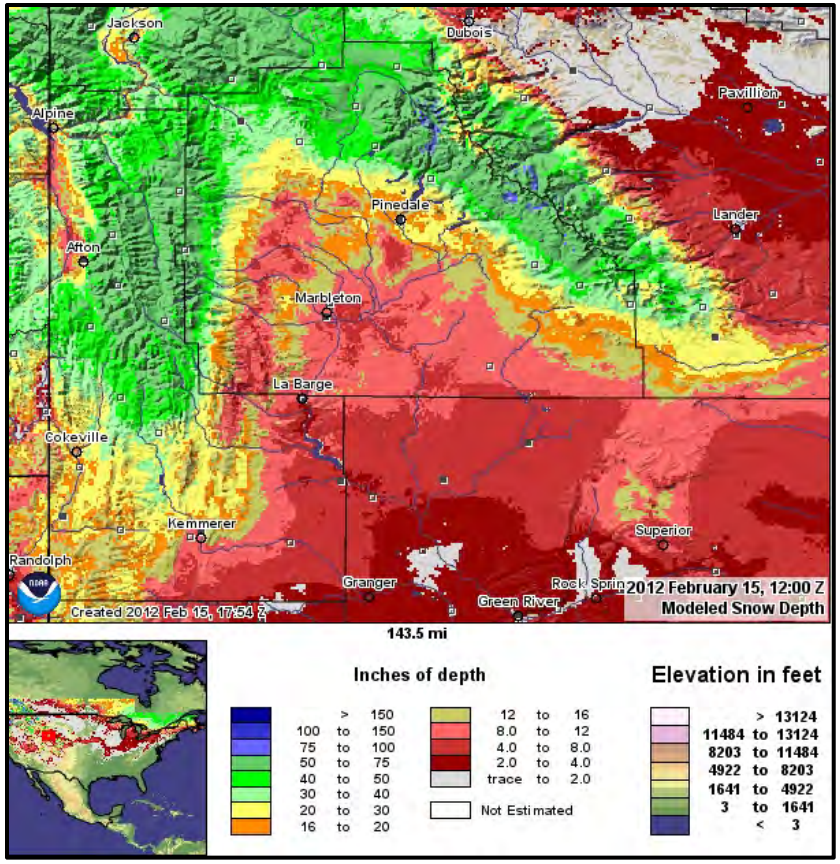
Appendix C
Modeled Snow Depth



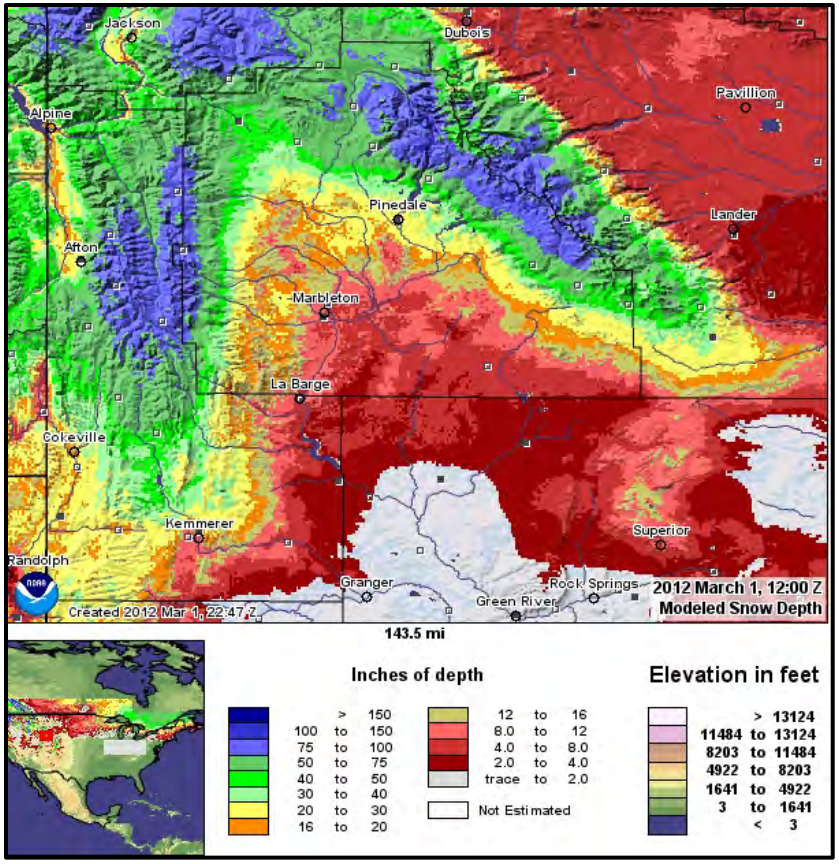
January 15, 2012 Modeled Snow Depth



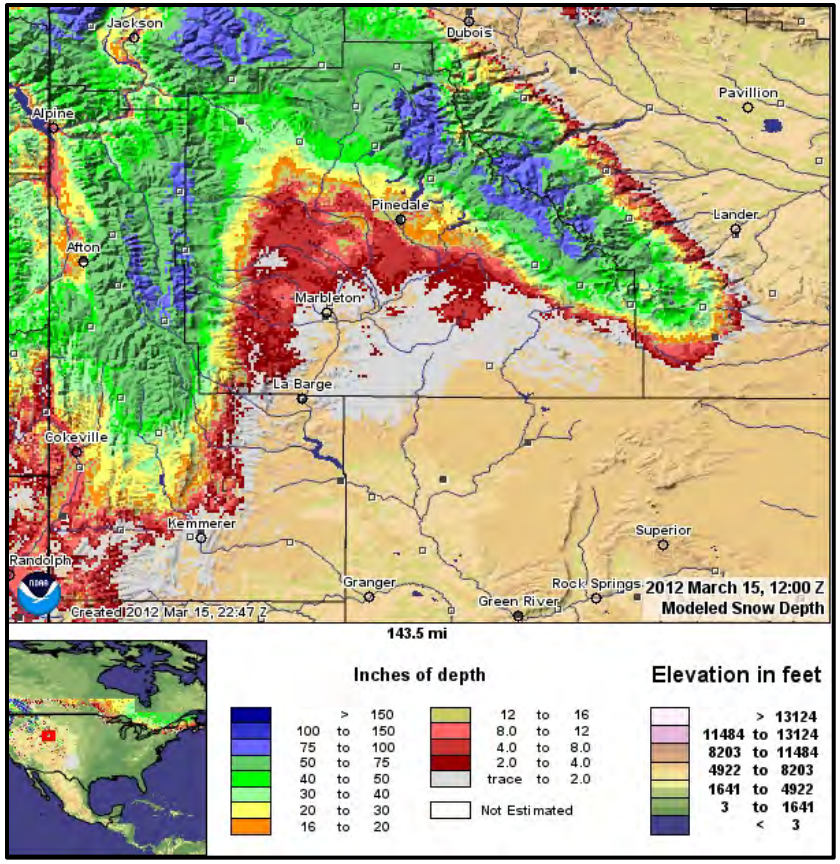
February 1, 2012 Modeled Snow Depth



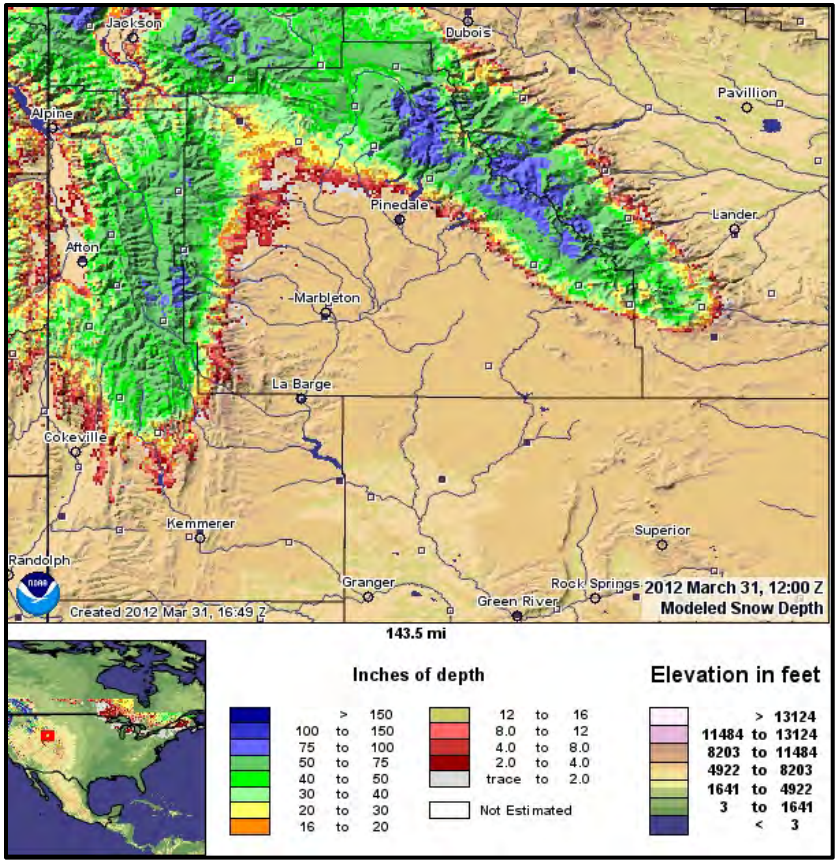
February 15, 2012 Modeled Snow Depth



March 1, 2012 Modeled Snow Depth



March 15, 2012 Modeled Snow Depth



March 31, 2012 Modeled Snow Depth

Appendix D
EAS Technical Memorandum

Environmental Analytical Service
Technical Memorandum

Meteorological Solutions Inc.
Wyoming Project

September 28, 2012

Evaluation of the Samples for Low Percent Identification.

In the winter of 2012 samples were collected for hydrocarbon speciation analysis to identify the ozone precursor hydrocarbons present at several sites. An analysis of the data set was done and reported in the Technical Memorandum of December 23, 2008 "Additional Data Analysis of Samples Analyzed by EPA TO-14 for Hydrocarbon Speciation following the EPA Ozone Precursor Method."

The conclusion of the Technical Memorandum from winter 2008 was that the percentage identified could by improved by adding in the total the "anomalous peaks" found in some of the samples and the unidentified organic compounds in the C8 to C10+ hydrocarbon range. The anomalous peaks did not appear this season.

One of the findings reported in the June 4, 2009 Technical Memorandum was that Rei Rasmussen of the Oregon Health Science Center (formerly called the Oregon Graduate Institute) had observed abundant low hydrocarbons in the C8 to C11 region of the GC/FID chromatograms that were not identifiable using the normal ozone precursor target list. Several years ago he had done work on identifying this hydrocarbon material because it could account for about 10 to 15% of the total hydrocarbon mass in the sample. By collecting large volumes of air they were able to analyze this material by GC/MS. In a personal communication with Professor Rasmussen he provided the following information.

He said that the C8 to C11 unidentified hydrocarbon mass that they have seen at OGI and may be what we are seeing in our samples is generally branched and substituted aromatics with very little oxygen or alkane content. This aromatic mass is very reactive and could be potentially responsible for much of the ozone formation in the region. He said that this material is common around oil production fields and is likely from the wells or seepage.

Evaluation of 2012 Data

The data collected in the 2012 winter season followed the same patterns as the earlier seasons where there were samples with the Percent Identification of the Total Non-Methane Hydrocarbons (TNMH) lower then 70%. The causes are the same as in the earlier season reports. Since the Ozone-Precursor target list is based on auto exhaust, the

samples that have low percentage identification for the most part show that they are being impacted by sources other then auto exhaust. Some of the causes of low TNMH are:

1) Sample whose composition is dominated by sources other then auto-exhaust.
2) Samples that have TNMH below 50 ppbv and have very few peaks. If there is no significant contribution from the C2 and C3 hydrocarbons, the unknown peaks will make a higher contribution to the TNMH resulting in low percentage identification.
3) Samples that have a high amount of hydrocarbon material in the C8 to C11 region. This was discussed above and in earlier memorandums. These compounds in this region are from sources other then auto exhaust. It has been suggested that these compounds are common around oil fields.

Some Examples are Discussed Below:

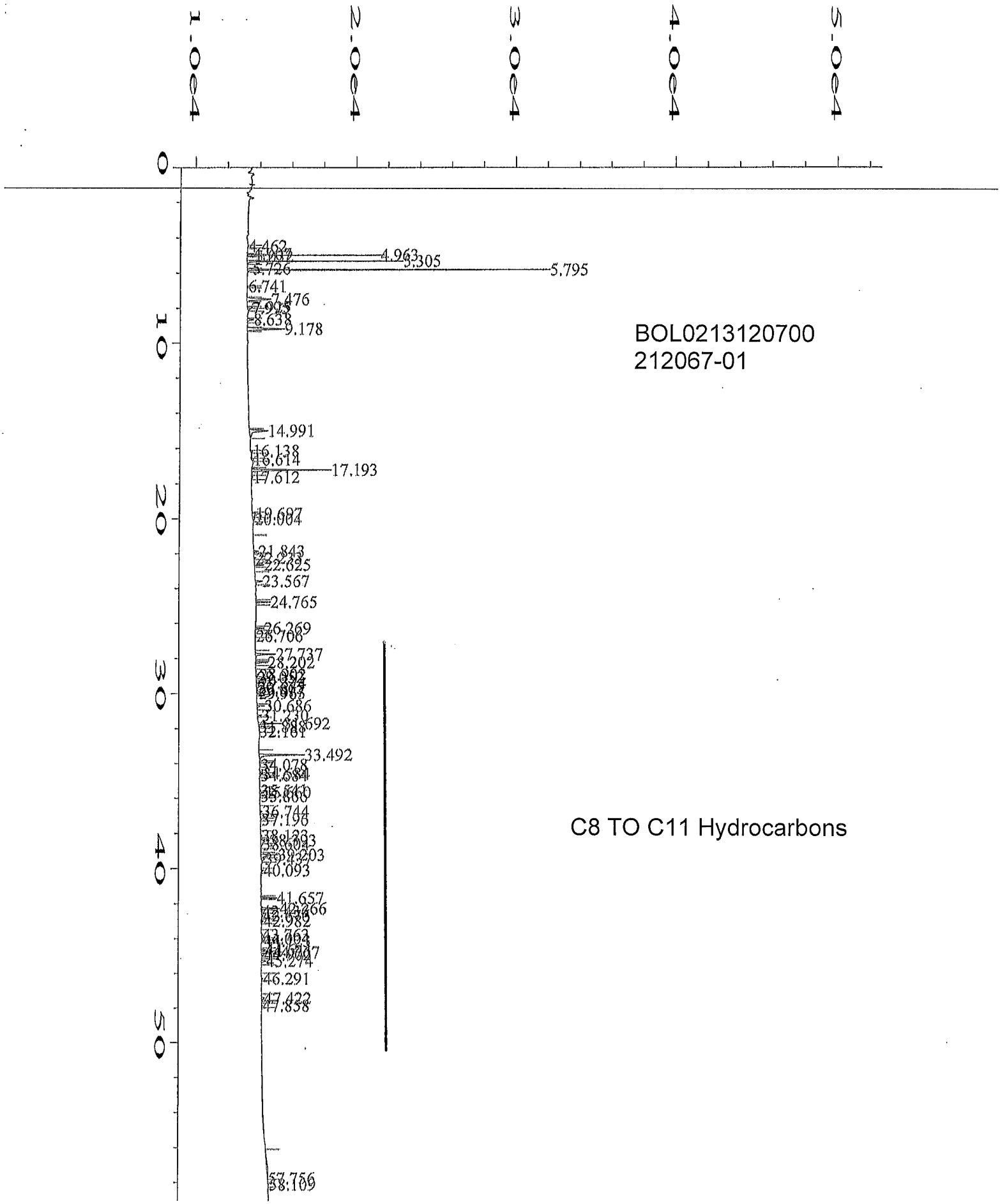
JUL0305120700 SDG 212095-08: This sample had low TNMH but the sample showed primarily an auto exhaust pattern, and the percent identified is 85%.

BOL0206120700 SDG 212051-11: This sample had a TNMH of 120 ppbv, but the compounds were predominately from auto sources, with only a small contribution of the C8 to C11 hydrocarbons. The percentage identification was 70%.

BOL0213120700 SDG212067-01: This sample had a TNMH of 84 ppbv, but the percent identified was only 47%. From the chromatogram it can be seen that there is a large amount of the C8 to C11 hydrocarbons.

C:\HPCHEM\1\DATA\03212GCK\12095C

C:\HPCHEM\1\DATA\02272GCK\12051.



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