DAVE FREUDENTHAL
GOVERNOR

THE STATE OF WYOMING

STATE CAPITOL
CHEYENNE, WY 82002

Office of the Governor

March 12, 2009

Ms. Carol Rushin
Acting Regional Administrator
USEPA Region 8
Mail Code: 8P-AR
1595 Wynkoop Street
Denver, CO 80202-1129

RE: Wyoming 8-Hour Ozone Designation Recommendation

Dear Ms. Rushin:

This letter transmits my recommendations, as allowed for under Section 107(d)(1) of the Clean Air Act, for Wyoming area designations and nonattainment area boundaries for the new eight-hour ozone National Ambient Air Quality Standards. These recommendations are based on a Wyoming Department of Environmental Quality (WDEQ) staff analysis which follows EPA's guidance dated December 4, 2008, "Area Designations for the 2008 Revised Ozone National Ambient Air Quality Standards."

At this time, I am recommending that all areas of the State of Wyoming be designated as attainment/unclassifiable with respect to the 8-hour ozone standard except for Sublette County and partial sections of Sweetwater and Lincoln counties. Enclosed with this letter is a table listing all specific areas of the state with their corresponding recommended designations, along with a figure showing the boundary of the nonattainment area, and ozone monitoring data collected through 2008.[1] The technical support document, which includes a 9-Factor Analysis, is being sent by the Director of the Department of Environmental Quality under separate cover.

Elevated ozone in a truly rural environment when temperatures are well below freezing is an uncommon event. As we move forward to solve this problem, we are uniquely challenged by the lack of tools available to understand and predict ozone formation in the winter in a valley flanked by the Wind River Mountains.

The State of Wyoming is also challenged by the need to reduce emissions from the natural gas industry which has not traditionally been regulated for ozone nonattainment problems. While the EPA has a long list of control strategies to apply in nonattainment areas, very few of them will

[1] The recommendation does not extend to lands under the jurisdiction of Tribal Authority.

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help to reduce ozone in Sublette County. Lowest Achievable Emissions Rate (LAER), Reasonably Available Control Technology (RACT), major source offsets, transportation control measures, and clean fuels programs are designed to reduce emissions from very large industrial sources and urban traffic which are not present in rural Wyoming. Therefore, the WDEQ has already identified the sources that require controls such as drill rigs, pneumatic pumps, dehydration units, and small heaters.

The State is not waiting for the nonattainment process to unfold to tackle the problem, but is addressing the issue on several fronts:

- Several significant field studies have been initiated to understand the processes leading to the occurrence of high ozone levels and to precisely define meteorological conditions that exist when these ozone events occur. These field operations began in 2007 and have continued through the winter of 2009.

- The AQD has deployed more Federal Reference Monitors in southwest Wyoming.

- DEQ is working with contractors to develop models to replicate the high wintertime ozone concentrations observed in the Upper Green.

- The University of Wyoming is conducting an ozone and precursor sampling program in 2009 to provide an independent perspective and further information on spatial variability of ozone in the Basin.

- The DEQ, the Wyoming Department of Health and the Sublette County Commissioners are working together to assess public health risks posed by air toxics associated with natural gas development. A study is now underway.

- The Air Quality Division has moved aggressively to reduce air pollution by applying BACT to all well sites in the Jonah and Pinedale Anticline gas fields, as well as a minor source offset permitting program. To my knowledge, there isn't another place in the world with this much attention given to permitting natural gas emission points.

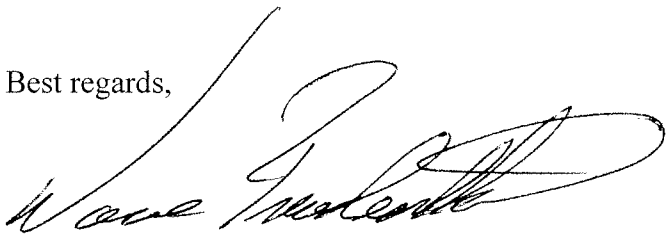
I share the outline of our aggressive program for two reasons. First, we believe that the area designations should be based on the technical information painstakingly developed by the DEQ for a unique ozone nonattainment problem. If the EPA uses standard analytic tools appropriate for summertime ozone formation in large metropolitan areas, EPA will reach the wrong conclusions about what causes ozone in Sublette County and how to fix it.

Secondly, I understand that a nonattainment designation includes requirements to reduce air pollution from existing sources. Many local gas producers, working in cooperation with our DEQ, have aggressively reduced air emissions and those reductions will continue even as our natural gas resources continue to be developed. These air emission reductions have occurred

because of the application of Wyoming's stringent air pollution permitting requirements; because of industry response to our calls for voluntary emission reductions; and because of Wyoming's insistence on stringent air pollution mitigation requirements in the Jonah Infill and Pinedale Anticline Records of Decision. We have not waited for the federal declaration of nonattainment to solve our air pollution problems, and I do not want a nonattainment designation by EPA to penalize the State for instituting early emission reductions.

While we have submitted recommendations as required under the Act, I envision that much work remains. I would like to propose that my staff at DEQ work with US EPA Region 8 to formalize an approach to share technical information and consult over choices of the baseline EI, the size of the nonattainment area and the resulting classification. Should you have any questions or concerns regarding this matter, please contact Mr. John Corra (307-777-7192) or Mr. Dave Finley (307-777-3746).

Best regards,



Dave Freudenthal
Governor

Enclosures: Attachment 1 - Designation Areas
Attachment 2 - Boundary of Designation Area (Figure)
Attachment 3 - Ozone Monitoring Data

cc: John Corra, DEQ Director
David Finley, AQD Administrator
Lori Bocchino, AQD
Christine Anderson, AQD
Callie Videtich, Director, Air and Radiation Program, EPA Region 8 w/ Enclosures
Monica Morales, EPA Region 8 w/ Enclosures
Kerri Fiedler, EPA Region 8 w/ Enclosures

Attachment 1

2008 Primary and Secondary NAAQS 8-hour Primary and Secondary Ozone Standard
Wyoming Recommendations for Ozone Designations
For areas not under the jurisdiction of Tribal Authority

Region	8-hour Ozone Designation
Casper, WY: Natrona County (part)..... The portion within the City of Casper	Attainment/Unclassifiable
Cheyenne, WY: Laramie County (part) ..... The portion within the City of Cheyenne	Attainment/Unclassifiable
Evanston, WY: Uinta County (part)..... The portion within the City of Evanston	Attainment/Unclassifiable
Gillette, WY: Campbell County (part) ..... The portion within the City of Gillette	Attainment/Unclassifiable
Jackson, WY: Teton County (part) ..... The portion within the City of Jackson	Attainment/Unclassifiable
Lander, WY: Fremont County (part) ..... The portion within the City of Lander	Attainment/Unclassifiable
Laramie, WY: Albany County (part)..... The portion within the City of Laramie	Attainment/Unclassifiable
Riverton, WY: Fremont County (part) ..... The portion within the City of Riverton	Attainment/Unclassifiable
Rock Springs, WY Sweetwater County (part)..... The portion within the City of Rock Springs	Attainment/Unclassifiable
Sheridan, WY Sheridan County (part) ..... The portion within the City of Sheridan	Attainment/Unclassifiable
Albany County (remainder)	Attainment/Unclassifiable
Big Horn County	Attainment/Unclassifiable
Campbell County (remainder)	Attainment/Unclassifiable
Carbon County	Attainment/Unclassifiable
Converse County	Attainment/Unclassifiable
Crook County	Attainment/Unclassifiable
Fremont County (remainder)	Attainment/Unclassifiable
Goshen County	Attainment/Unclassifiable
Hot Springs County	Attainment/Unclassifiable
Johnson County	Attainment/Unclassifiable
Laramie County (remainder)	Attainment/Unclassifiable
Lincoln County (remainder)	Attainment/Unclassifiable
Natrona County (remainder)	Attainment/Unclassifiable
Niobrara County	Attainment/Unclassifiable
Park County	Attainment/Unclassifiable
Platte County	Attainment/Unclassifiable
Sheridan County (remainder)	Attainment/Unclassifiable
Sweetwater County (remainder)	Attainment/Unclassifiable
Teton County (remainder)	Attainment/Unclassifiable
Uinta County (remainder)	Attainment/Unclassifiable

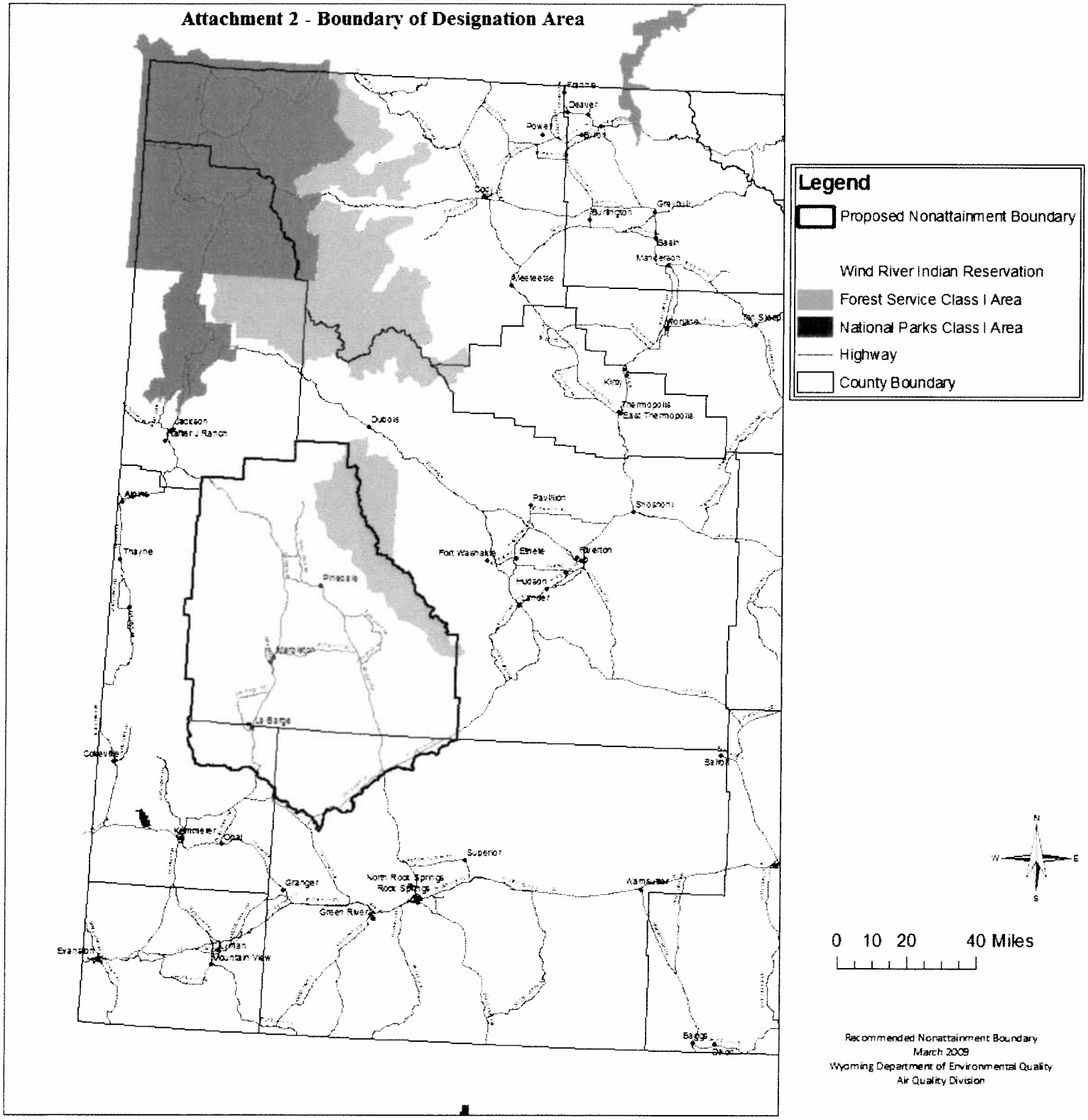
Attachment 1

2008 Primary and Secondary NAAQS 8-hour Primary and Secondary Ozone Standard
Wyoming Recommendations for Ozone Designations
For areas not under the jurisdiction of Tribal Authority

Region	8-hour Ozone Designation
Washakie County	Attainment/Unclassifiable
Weston County	Attainment/Unclassifiable
Upper Green River Basin Area: Sublette County: (all) Lincoln County: (part) The area of the county north and east of the boundary defined by a line starting at the point defined by the intersection of the southwest corner Section 30 Range (R) 115 West Township (T) 27N and the northwest corner of Section 31 R 115 West T 27N of Sublette County at Sublette County's border with Lincoln County. From this point the boundary moves to the west 500 feet to the Aspen Creek. The boundary follows the centerline of Aspen Creek downstream to the confluence of Aspen Creek and Fontenelle Creek (in R 116 W T26N, Section 1). From this point the boundary moves generally to the south along the centerline of Fontenelle Creek to the confluence of Fontenelle Creek and Roney Creek (in R115W T24N Section 6). From the confluence, the boundary moves generally to the east along the centerline of Fontenelle Creek and into the Fontenelle Reservoir (in R112W T24N Section 6). The boundary moves east southeast along the centerline of the Fontenelle Reservoir and then toward the south along the centerline of the Green River to where the Green River in R111W T24 N Section 31 crosses into Sweetwater County. Sweetwater County: (part) The area of the county west and north of the boundary which begins at the midpoint of the Green River, where the Green River enters Sweetwater County from Lincoln County in R111W T24N Section 31. From this point, the boundary follows the center of the channel of the Green River generally to the south and east to the confluence of the Green River and the Big Sandy River (in R109W R22 N Section 28). From this point, the boundary moves generally north and east along the centerline of the Big Sandy River to the confluence of the Big Sandy River with Little Sandy Creek (in R106W T25N Section 33). The boundary continues generally toward the northeast long the centerline of Little Sandy Creek to the confluence of Little Sandy Creek and Pacific Creek (in R106W T25N Section 24). From this point, the boundary moves generally to the east and north along the centerline of Pacific Creek to the confluence of Pacific Creek and Whitehorse Creek (in R103W T26N Section 10). From this point the boundary follows the centerline of Whitehorse Creek generally to the northeast until it reaches the eastern boundary of Section 1 R103W T 26North. From the point where Whitehorse Creek crosses the eastern section line of Section 1 R103W T 26North, the boundary moves straight north along the section line to the southeast corner of Section 36 R103W T27N in Sublette County where the boundary ends.	Non-attainment

R Range, T - Township, N - North, W - West

Attachment 2 - Boundary of Designation Area



Recommended Nonattainment Boundary
March 2009
Wyoming Department of Environmental Quality
Air Quality Division

Attachment 3

Design Values for Wyoming Ambient Ozone Monitors

Site Name	AQS ID	Year				3-Year Average 2005-2007 (ppm)	3-Year Average 2006-2008[1] (ppm)
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1-Q3[1] (ppm)		
Daniel South	56-035-0100	0.067[2]	0.075	0.067	0.074	N/A	0.072[1]
Boulder	56-035-0099	0.080[3]	0.073	0.067	0.101	0.073[3]	0.080[1]
Jonah	56-035-0098	0.076	0.070	0.069	0.082	0.072	0.074[1]
Yellowstone (NPS)	56-039-1011	0.060	0.069	0.064	0.065	0.064	0.066[1]
Thunder Basin	56-005-0123	0.063	0.072	0.072	0.074	0.069	0.073[1]
Campbell County	56-005-0456	0.063[4]	0.065	0.072	0.060	0.067[4]	0.066[1]

[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in July 2005
[3] Incomplete year; began operation in February 2005
[4] One quarter with less than 75% data completeness

4th Maximum 8-Hour Ozone Values for Ambient Monitors without 3 years of data

Site Name	AQS ID	Year			
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1-Q3[1] (ppm)
Murphy Ridge	56-041-0101	---	---	0.070	0.061
South Pass	56-013-0099	---	---	0.071[2]	0.065
OCI[3]	56-037-0898	---	0.071[3]	0.066	0.072
Wamsutter	56-005-0123	---	0.067[4]	0.064	0.064
Atlantic Rim	56-007-0099	---	---	0.047[5]	0.064

[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in March 2007
[3] Site operated by industry. Incomplete year; began operation in May 2006
[4] Incomplete year; began operation in March 2006
[5] Incomplete year; began operation in October 2007

Department of Environmental Quality

To protect, conserve and enhance the quality of Wyoming's environment for the benefit of current and future generations.

Dave Freudenthal, Governor

John Corra, Director

March 26, 2009

Ms. Carol Rushin
Acting Regional Administrator
USEPA Region 8
Mail Code: 8RA
1595 Wynkoop Street
Denver, CO 80202-1129

RE: Wyoming Technical Support Documents for Recommended 8-Hour Ozone Designations

Dear Ms. Rushin:

On March 12, 2009, Governor Freudenthal signed an 8-hour ozone area designation recommendation for all areas of Wyoming. The recommendation noted that a technical support document, which includes a 9-Factor Analysis, would be provided to you under separate cover. The enclosed Technical Support Document is a Wyoming Department of Environmental Quality (WDEQ) staff analysis which follows EPA's guidance on area designations dated December 4, 2008.

I encourage you to involve the State of Wyoming as you evaluate the Governor's recommendation. You are probably aware that we have devoted significant financial and human resources to the study and analysis of this unique winter time ozone challenge. The AQD staff have accumulated a tremendous amount of skill and knowledge about winter time ozone formation. They also have spent a great deal of time in understanding the unique meteorological conditions that act as important drivers to confining the ozone problems to the UGRB. This body of work was used to develop the boundary of the non-attainment area. As you and your staff review this boundary determination please do not hesitate to consult with our staff if there are any questions. Also, given the substantial work already invested by the AQD, we are looking forward to working with you on other aspects of your review, especially when you establish a classification for any nonattainment designation you ultimately make, and when you establish a baseline year for purposes of measuring reasonable progress for emission reduction goals.

I look forward to working with you to finalize the designations by March 12, 2010. If you have any questions, please call me at 307-777-7192 or David A. Finley, Administrator of the Air Quality Division, at 307-777-3746.

Sincerely

John V. Corra
Director
Wyoming Department of Environmental Quality

Enclosures: Ozone Monitoring Data
State of Wyoming Technical Support Documents for Recommended 8-Hour Ozone Designations, March 26, 2009

cc: David Finley, AQD Administrator
Lori Bocchino, AQD
Christine Anderson, AQD
Callie Videtich, Director, Air and Radiation Program, EPA Region 8 w/ Enclosures
Monica Morales, EPA Region 8 w/ Enclosures
Kerri Fiedler, EPA Region 8 w/ Enclosures

STATE OF WYOMING

Technical Support Document I
For Recommended 8-Hour Ozone Designation
For the Upper Green River Basin, WY

March 26, 2009

The Wyoming Department of Environmental Quality
Air Quality Division
Herschler Building, 122 West 25th Street
Cheyenne, Wyoming 82002

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EXECUTIVE SUMMARY

In March 2008 the US EPA promulgated a new National Ambient Air Quality Standard (NAAQS) for ozone. The new standard was lowered from 0.08 ppm to 0.075 ppm based on the fourth highest 8-hour average value per year at a site, averaged over three years. Based on monitoring results from 2006 through 2008, the entire state of Wyoming is in compliance with this standard except for at a single monitor, the Boulder monitor, in Sublette County.

The Wyoming Department of Environmental Quality, Air Quality Division (AQD) evaluated whether a nonattainment area should be designated due to the monitored results at the Boulder monitor. Using EPA's guidance in the Robert J. Meyers December 4, 2008 memo, the AQD performed a nine-factor analysis, which is the basis of this document. This analysis supports AQD's recommendation that the Upper Green River Basin (UGRB), as defined in the introduction to this document, be designated as nonattainment for the 2008 ozone NAAQS.

The AQD bases this recommendation on a careful review of the circumstances surrounding the incidence of elevated ozone events. Elevated ozone in the UGRB is associated with distinct meteorological conditions. These conditions have occurred in February and March in some (but not all) of the years since monitoring stations began operation in the UGRB in 2005. Our determination of an appropriate nonattainment area boundary is focused on an evaluation of EPA's nine factors, applied to the first quarter of the year. It is important to evaluate conditions during the first quarter of the year in order to focus on the very specific set of circumstances that lead to high ozone.

The most compelling reasons for the boundary recommendation are based on the meteorological conditions in place during and just prior to elevated ozone events. Elevated ozone episodes occurred in 2005, 2006 and 2008; they were associated with very light low-level winds, sunshine, and snow cover, in conjunction with a strong low-level surface-based temperature or "capping" inversion. The longest such event (February 19-23, 2008), which also resulted in the highest measured ozone of 122 ppb as an 8-hour average at the Boulder station, has been reviewed in detail and summarized in Section 7 of this document. Section 7 demonstrates that sources outside the recommended nonattainment area would not have a significant impact on the Boulder monitor due to the presence of an inversion and very low wind speeds, which significantly limit precursor and ozone transport from sources located outside of the UGRB.

The AQD carefully examined sources of ozone and ozone precursors within Sublette and surrounding counties. When evaluating sources, AQD considered these five of EPA's factors: population density, traffic and commuting patterns, growth rates and patterns, emission data, and level of control of air emissions. Sublette County is a rural county with a population density of two people per square mile; the most densely populated nearby county (Uinta) is also largely rural with a population density of ten people per square mile. As would be expected, the number of commuters into or out of the UGRB is small and does not represent a significant source of precursor emissions. While there is an interstate highway 80 miles south of the Boulder monitor, the attached analysis demonstrates that I-80 traffic is not considered to be a significant contributor of emissions that impact the Boulder monitor during ozone events.

Although population and population growth was not a significant factor, growth in the oil and gas (O&G) industry in Sublette County was considered pertinent. The volume of natural gas produced doubled between 2000 and 2008 in the county; the number of wells completed doubled between 2004 and 2008. Approximately 1,500 well completions were recorded in Sublette County in the last four years. Growth in the oil and gas industry in nearby areas is much slower.

AQD prepared an estimated inventory of emissions for the recommended nonattainment area and the surrounding counties. The inventory showed that approximately 94% of VOC emissions in the UGRB and 60% of NOx emissions are attributable to oil and gas production and development. Of the eleven major sources in the UGRB, all are O&G related. To the north, east and west there are few major sources in counties adjacent to the UGRB. In addition to the major sources, there are numerous minor sources in the UGRB including several concentrated areas of O&G development. Just to the south of the UGRB, there are a few major sources, several minor sources and again, a concentrated area of O&G wells. AQD then used other factors, meteorology, topography, and level of control of emissions, to determine which of the sources to the south of Sublette County should be included in the proposed nonattainment boundary.

The level of control of emissions in the Jonah and Pinedale Anticline Development is very stringent and new oil and gas production units in Sublette County and surrounding counties require permits including Best Available Control Technology (BACT). An interim policy for Sublette County which took effect in 2008 results in a net decrease in emissions of ozone precursors with every permit that is issued. Since stricter controls for O&G are already in place in Sublette County, if O&G sources outside of Sublette County might contribute ozone or ozone precursors to the Boulder monitor, including these O&G sources in the proposed nonattainment area would provide motivation to control these sources.

In evaluating topography, the east, north and west county boundaries are natural boundaries of high mountains. These geographical and jurisdictional boundaries also coincide with population boundaries and emission source boundaries. To the south, the topographical boundaries are less dramatic, but there are rivers, valleys, and buttes that form geographic boundaries near the southern border of Sublette County. Therefore, the AQD considered the county boundary to the north, east and west to be a reasonable boundary based on geography, jurisdictions, emission sources, population and growth.

However, meteorology provided the strongest basis for setting the southern boundary of the proposed nonattainment area. Elevated ozone in the UGRB is associated with distinct meteorological conditions. These conditions have occurred in February and March in some (but not all) of the years since monitoring stations began operation in the UGRB in 2005.

Meteorological conditions in place during and just prior to elevated ozone events provide the most specific data for setting the south boundary. Elevated ozone episodes are associated with very light low-level winds, cold temperatures, sunshine, and snow cover, in conjunction with strong low-level surface-based temperature inversions. Sources outside the recommended nonattainment area would not have a significant impact on the Boulder monitor due to the presence of an inversion and the very low wind speeds, which influence the transport of

emissions. Detailed meteorological data collected during intensive field studies shows that emissions from sources south of the recommended nonattainment area are generally carried toward the east and not into the UGRB during or just prior to an ozone episode. Speciated VOC data collected in the UGRB during elevated ozone episodes also has a dominant oil and gas signature, indicating the VOC concentrations are largely due to O&G development activities.

Meteorology and topography indicate that sources outside a southern boundary defined by the Little Sand Creek and Pacific Creek to the east and the Green River and Fontenelle Creek to the west do not contribute to ozone and ozone precursors which could affect the Boulder monitor.

The analysis conclusively shows that elevated ozone at the Boulder monitor is primarily due to local emissions from oil and gas (O&G) development activities: drilling, production, storage, transport, and treating. The ozone exceedances only occur when winds are low indicating that there is no transport of ozone or precursors from distances outside the proposed nonattainment area. The ozone exceedances only occur in the winter when the following conditions are present: strong temperature inversions, low winds, cold temperatures, clear skies and snow cover. If transport from outside the proposed nonattainment area was contributing to the exceedances, then elevated ozone would be expected at other times of the year. Mountain ranges with peaks over 10,000 feet border the area to the west, north and east influence the local wind patterns. Emission sources in nearby counties are not upwind of the Boulder monitor during episodes which exceed the 8-hour ozone standard in Sublette County.

The proposed nonattainment area boundary includes the violating monitor and the sources which are most likely to contribute ozone and ozone precursors to the monitored area. Using this as a boundary will allow the State to focus its resources on the emission sources that contribute to the ozone issue and will allow the State to control the ozone problem in a timely manner.

INTRODUCTION

BACKGROUND AND REGULATORY HISTORY

The U.S. Environmental Protection Agency (EPA) is charged with developing air quality standards for the protection of human health and welfare. EPA is also required to periodically evaluate those standards and revise them if scientific analyses indicate different standards would be more protective of public health and welfare. In March of 2008, EPA promulgated a new National Ambient Air Quality Standard (NAAQS) for ozone. This new standard lowered the 8-hour level of ozone from 0.08 parts per million (ppm) to 0.075 ppm, based on the fourth maximum 8-hour value at a site averaged over three years. Each state must recommend ozone designations no later than March 12, 2009 and final designations must be complete by March 12, 2010.

BASIS FOR TECHNICAL SUPPORT

This technical support document considers nine criteria, or "factors" to make a recommendation for the appropriate location and boundary of a nonattainment area. Those factors are derived from EPA's memorandum issued December 4, 2008, "Area Designations for the 2008 Revised Ozone National Ambient Air Quality Standards." States must submit an analysis of these nine factors, along with a proposed nonattainment boundary, for any areas that are not meeting the federal standard. The nine factors that must be addressed are:

Air quality data

Emissions data (location of sources and contribution to ozone concentrations)

Population density and degree of urbanization (including commercial development)

Traffic and commuting patterns

Growth rates and patterns

Meteorology (weather/transport patterns)

Geography/topography (mountain ranges or other air basin boundaries)

Jurisdictional boundaries (e.g., counties, air districts, existing nonattainment areas, Reservations, metropolitan planning organizations (MPOs))

Level of control of air emissions

RECOMMENDED NONATTAINMENT AREA BOUNDARY

The State of Wyoming recommends that the UGRB, with boundaries described as follows, be designated as a nonattainment area for the 2008 8-hour ozone standard:

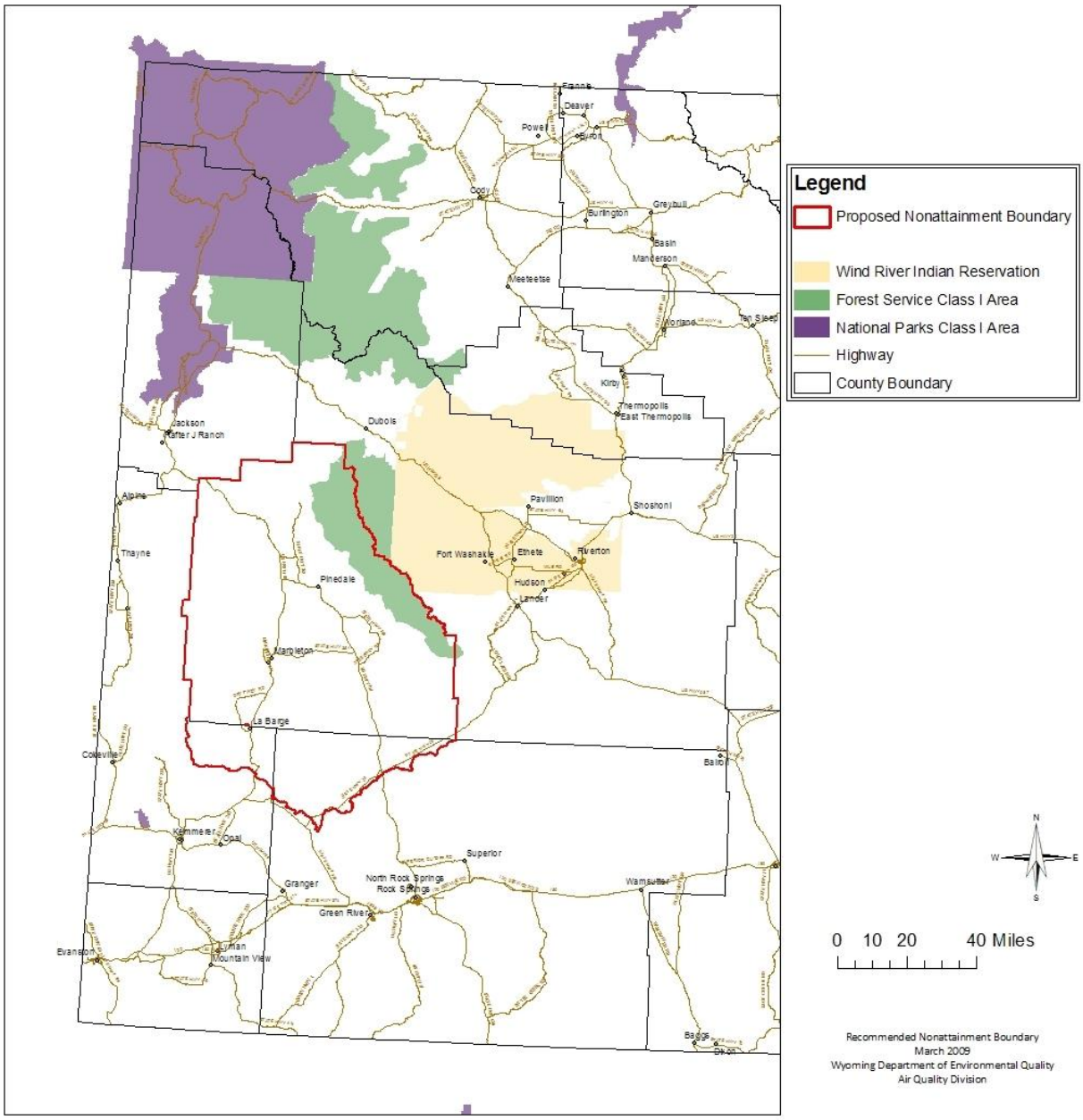
Sublette County: (all)

Lincoln County: (part) The area of the county north and east of the boundary defined by a line starting at the point defined by the intersection of the southwest corner Section 30 Range

(R) 115 West Township (T) 27N and the northwest corner of Section 31 R 115 West T 27N of Sublette County at Sublette County's border with Lincoln County. From this point the boundary moves to the west 500 feet to Aspen Creek. The boundary follows the centerline of Aspen Creek downstream to the confluence of Aspen Creek and Fontenelle Creek (in R 116 W T26N, Section 1). From this point the boundary moves generally to the south along the centerline of Fontenelle Creek to the confluence of Fontenelle Creek and Roney Creek (in R115W T24N Section 6). From the confluence, the boundary moves generally to the east along the centerline of Fontenelle Creek and into the Fontenelle Reservoir (in R112W T24N Section 6). The boundary moves east southeast along the centerline of the Fontenelle Reservoir and then toward the south along the centerline of the Green River to where the Green River in R111W T24 N Section 31 crosses into Sweetwater County.

Sweetwater County: (part) The area of the county west and north of the boundary which begins at the midpoint of the Green River, where the Green River enters Sweetwater County from Lincoln County in R111W T24N Section 31. From this point, the boundary follows the center of the channel of the Green River generally to the south and east to the confluence of the Green River and the Big Sandy River (in R109W R22 N Section 28). From this point, the boundary moves generally north and east along the centerline of the Big Sandy River to the confluence of the Big Sandy River with Little Sandy Creek (in R106W T25N Section 33). The boundary continues generally toward the northeast along the centerline of Little Sandy Creek to the confluence of Little Sandy Creek and Pacific Creek (in R106W T25N Section 24). From this point, the boundary moves generally to the east and north along the centerline of Pacific Creek to the confluence of Pacific Creek and Whitehorse Creek (in R103W T26N Section 10). From this point the boundary follows the centerline of Whitehorse Creek generally to the northeast until it reaches the eastern boundary of Section 1 R103W T 26North. From the point where Whitehorse Creek crosses the eastern section line of Section 1 R103W T 26North, the boundary moves straight north along the section line to the southeast corner of Section 36 R103W T27N in Sublette County where the boundary ends.

A picture of this area follows.



KEY ISSUES

Elevated ozone concentrations in most areas occur during the warm summer months, when there is abundant solar radiation and high temperatures. The elevated ozone concentrations at the Boulder monitor in Sublette County occur in late winter and early spring when sun angles are low so there is less solar radiation and temperatures are below freezing. Ozone formation at the Boulder monitor in Sublette County does not follow the pattern of ozone formation found in urban areas in the summer.

Moderately elevated ozone was first detected in Sublette County in February of 2005 and 2006. The Wyoming Air Quality Division (AQD) conducted intensive meteorological and ambient data collection and analyses in 2007 and 2008 in order to understand this phenomenon. AQD is continuing this effort in 2009. Although analysis of all the data is not complete, AQD has already determined that:

- Local meteorological conditions are the single most important factor contributing to the formation of ozone and the definition of the nonattainment boundary.
- Meteorological models that utilize only regional data will not correctly attribute ozone and ozone precursors to the sources which affect the UGRB.
- Trajectory analyses using detailed observation-based wind field data show that local scale transport of ozone and ozone precursors is dominant during periods of elevated ozone.
- Trajectory analyses using the wind field data show that regional transport of ozone and ozone precursors appears to be insignificant during periods of elevated ozone.

SECTION 1
AIR QUALITY DATA

SYNOPSIS

Ozone at levels exceeding the standard has been monitored at one of three stations in the UGRB – specifically, the Boulder monitor.

Measured ozone levels have not exceeded the standard in the counties adjacent to the UGRB.

Elevated ozone within the UGRB typically only occurs in January, February, or March.

VOCs detected in ambient air in the UGRB have a strong oil and gas signature.

ANALYSIS

The Wyoming Air Quality Division (AQD) operated three monitoring stations in the proposed nonattainment area in 2005-2008. Monitor locations are shown on the map in Figure S.1-1. This map also shows the location of monitors in adjacent counties.

FIGURE S.1-1: Map Showing Monitoring Stations In and Near the Upper Green River Basin

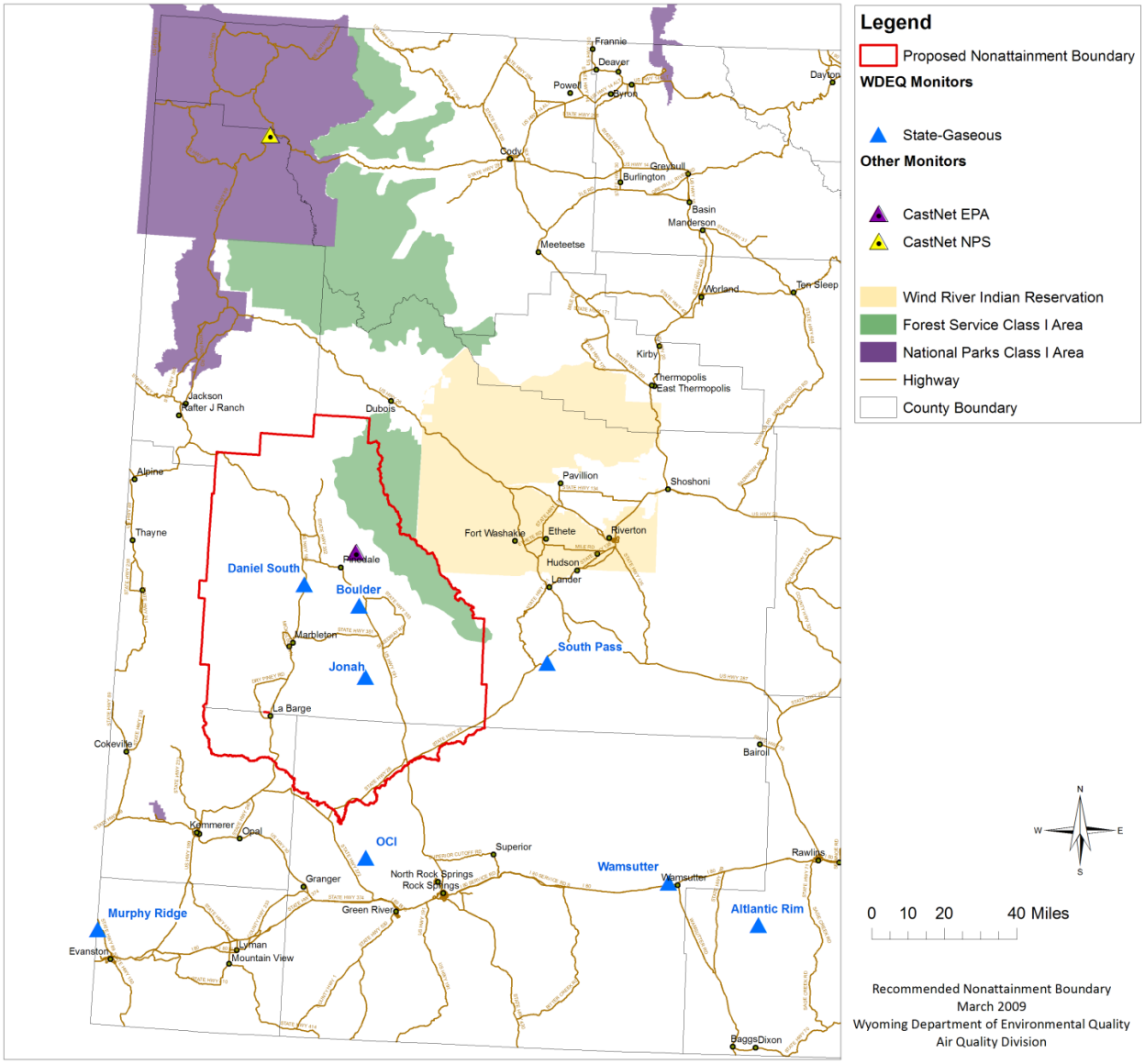


Table S.1-1 shows the ozone design values for the 8-hour standard for the Reference or Equivalent Method monitoring stations shown in Figure S.1-1. All data are collected by Reference or Equivalent Method monitors and meet EPA's criteria for quality and completeness unless otherwise noted. Please note, Pinedale CASTNet data are not included in the design values because this station was not operated in accordance with Part 58 QA requirements until 2007. The design value is the three-year average of the annual fourth highest daily maximum 8-hour ozone concentration (a calculated value less than or equal to 0.075 ppm indicates attainment of the standard; a calculated value of greater than 0.075 ppm is a violation of the standard). Table S.1-2 shows monitored data from other Federal Reference Method (FRM) or Federal Equivalent Method (FEM) ozone monitors in the counties surrounding the UGRB. These monitors have been running for less than 3 years and therefore do not have a design value calculated.

Table S.1-1: Design Values for Monitors In or Near the Upper Green River Basin

Site Name	AQS ID	Year				3-Year Average 2005-2007 (ppm)	3-Year Average 2006-2008[1] (ppm)
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1 – Q3 (ppm)		
Daniel South	56-035-0100	0.067[2]	0.075	0.067	0.074	N/A	0.072[1]
Boulder	56-035-0099	0.080[3]	0.073	0.067	0.101	0.073[3]	0.080[1]
Jonah	56-035-0098	0.076	0.070	0.069	0.082	0.072	0.074[1]
Yellowstone (NPS)	56-039-1011	0.060	0.069	0.064	0.065	0.064	0.066

[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in July 2005
[3] Incomplete year; began operation in February 2005

Table S.1-2: 4th Maximum 8-Hour Ozone Values for Monitoring in Surrounding Counties

Site Name	AQS ID	Year			
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1 – Q3 (ppm)
Murphy Ridge	56-041-0101	---	---	0.070	0.061[1]
South Pass	56-013-0099	---	---	0.071[2]	0.065[1]
OCI[3]	56-037-0898	---	0.071[3]	0.066	0.072[1]
Wamsutter	56-005-0123	---	0.067[4]	0.064	0.064[1]
Atlantic Rim	56-007-0099	---	---	0.047[5]	0.064[1]

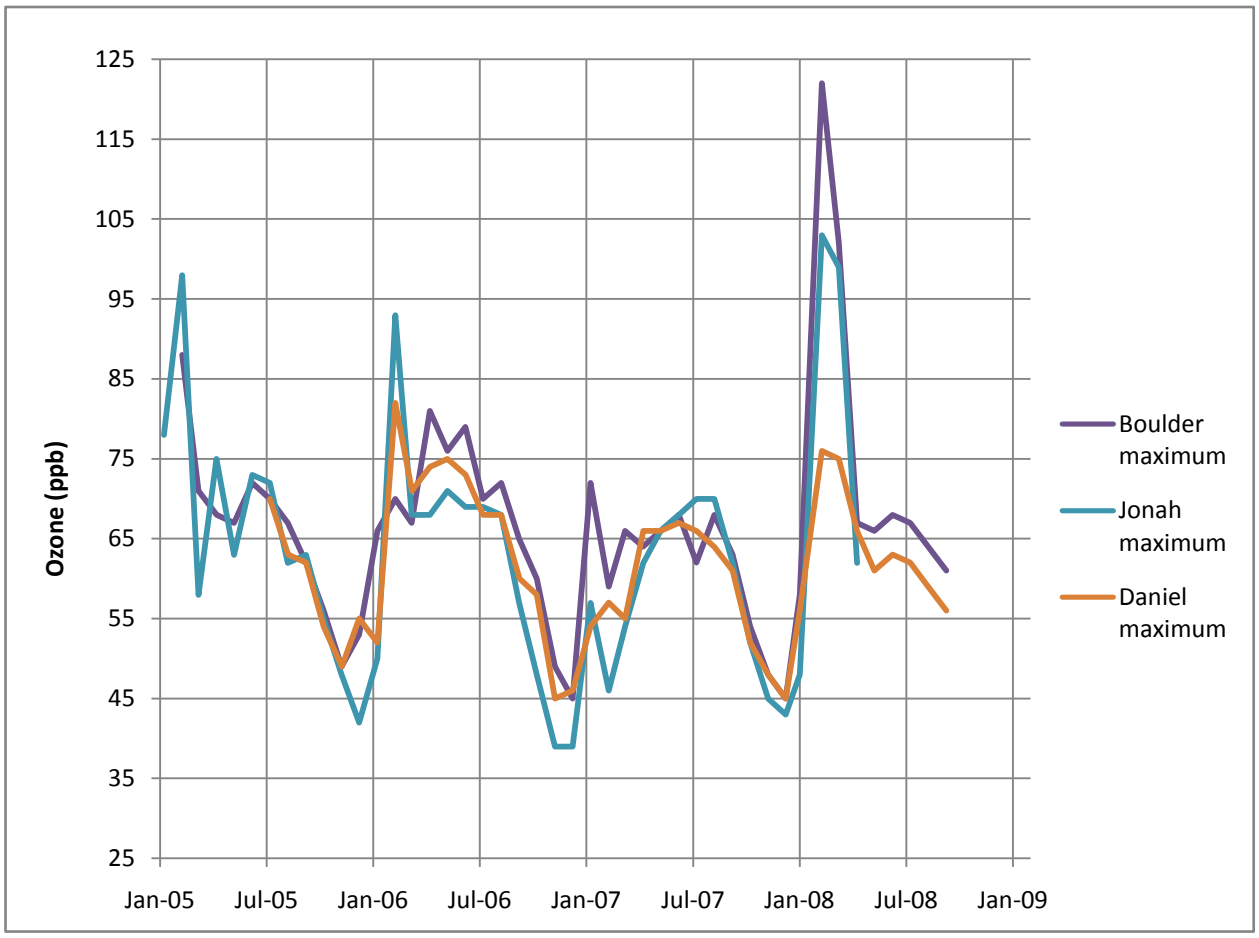
[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in March 2007
[3] Site operated by industry. Incomplete year; began operation in May 2006
[4] Incomplete year; began operation in March 2006
[5] Incomplete year; began operation in October 2007

Using only data from 2005 through 2007, the monitors for which a design value can be calculated indicate compliance with the ozone NAAQS. Year-to-date data from 2008, however, bring the 2006 - 2008 design value for the Boulder monitor to 0.080 ppm (compared to the standard of 0.075).

While monitors in counties adjacent to the UGRB have not been in operation for a full three-year period (with the exception of the Yellowstone NPS monitor), none of them have 4th-high maximum 8-hour ozone values above 0.075 ppm for any year. This would indicate that, based on ambient monitoring data, ozone levels have not been measured that exceed the standard outside of the UGRB (within Wyoming).

When the data from the Boulder monitoring station, the only monitor showing ozone levels in excess of the standard, is reviewed closely, it shows that elevated ozone typically occurs in the winter. This trend is also evident at the two stations nearby (South Daniel and Jonah). Figure S.1-2 shows the daily 8-hour maximum for these stations on a monthly basis over the last four years. This is an unprecedented phenomenon, as ozone was thought to be a summertime problem. The Wyoming DEQ, with the help of industry, has dedicated significant resources to better understand this situation. The studies indicate that elevated ozone occurs in the UGRB under very specific meteorological conditions, described in greater detail in Section 7 of this document. Briefly, these conditions are the presence of a strong temperature inversion in conjunction with low wind speeds, snow cover and clear skies. These conditions have occurred in January, February, and March.

Figure S.1-2: Monthly 8-Hour Maximum Ozone Within the UGRB



AQD performed Winter Ozone Studies in 2007, 2008 and 2009 in the UGRB. The purpose of these studies is to investigate and monitor the mechanisms of ozone formation during the winter months. These data will in turn be used to develop a conceptual model of ozone formation in the UGRB. As the study has progressed, the scope of the study has been refined as AQD has learned about the unique issue of winter ozone formation. In general terms, the scope of the winter ozone studies include:

1. Placing additional FEM and non-FEM (2B ozone analyzers) monitors throughout the UGRB to characterize spatial and temporal distribution of ground-level ozone.
2. Placing additional three-meter meteorological towers (mesonet) throughout the UGRB to characterize local micro-scale meteorology.
3. Placing additional precursor monitoring (e.g., VOC, NOx and CO) in a few sites around the UGRB to characterize precursor concentrations.
4. Flying a plane equipped with continuous ozone and $PM_{2.5}$ around the UGRB to characterize spatial distribution of ozone (above, in, and below the boundary layer).
5. Launching ozone and rawinsondes to characterize vertical meteorology and ozone distribution.

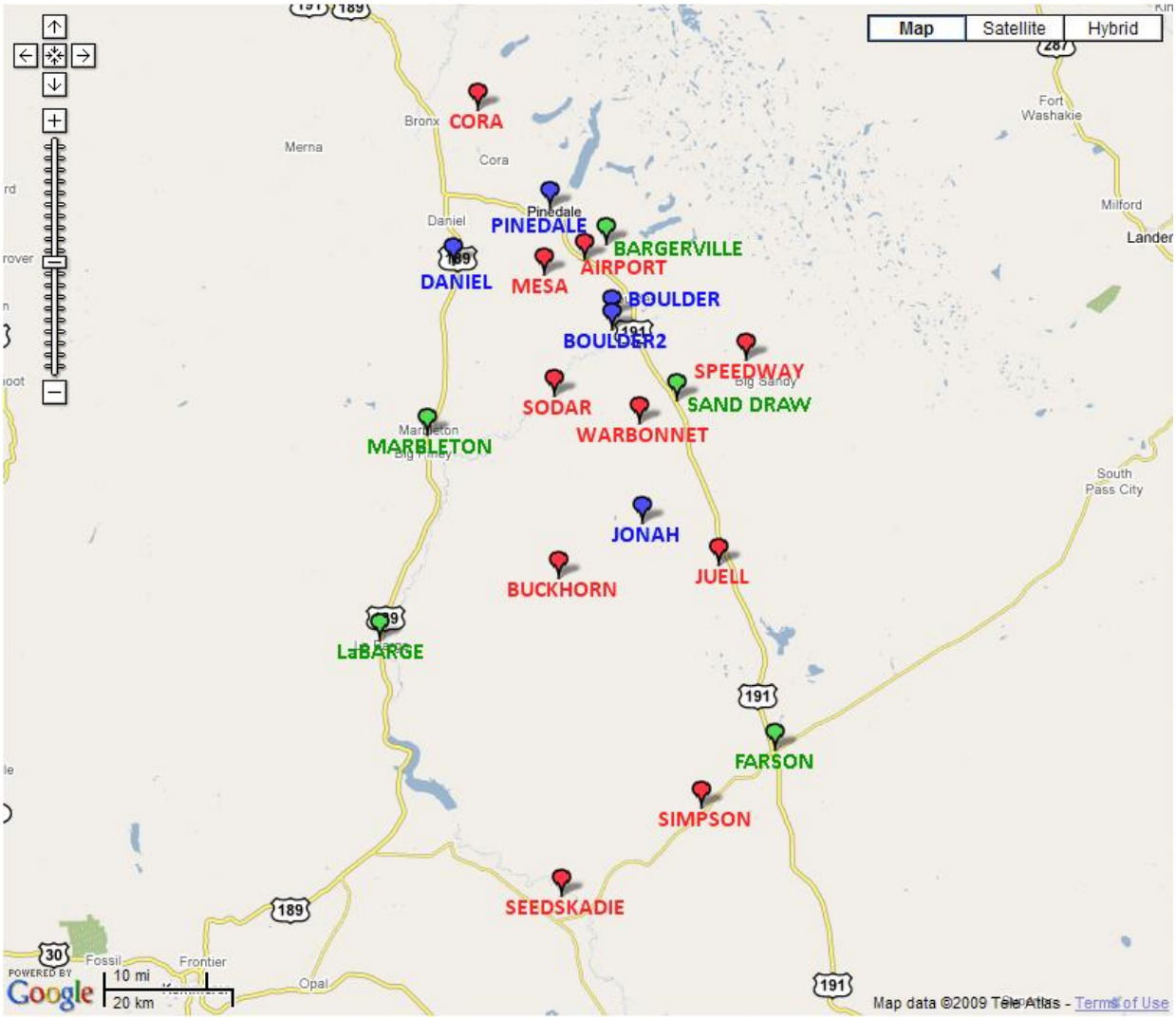
6. Operating ground based upper-air meteorological instruments (e.g., Mini-SODAR, RASS, Wind Profiler) to characterize mixing levels and inversion heights.

In 2007, meteorological conditions did not set up as they had in 2005 and 2006 and elevated ozone did not form in February and March. However, AQD collected data that helped to draw some conclusions about winter ozone formation. The speciated VOC samples collected had a strong oil and gas signature. AQD was able to investigate which detected VOC species were having a greater effect on ozone formation. UV radiation measurements showed that when fresh snow is available, greater than 80% of the ultra-violet light can be reflected.

During the 2008 winter study, several multi-day episodes of elevated ozone were studied. Six additional ozone monitoring locations were added and the plane was flown to provide more information on the spatial and temporal variability around the UGRB. AQD continued to collect speciated VOC samples which confirmed the strong oil and gas signature. These data also allowed us to identify species of interest with respect to elevated ozone formation. AQD also used a mini-SODAR and rawinsondes to characterize the mixing heights and inversion strength on elevated ozone days. It was found that on days with elevated ozone, mixing heights could be as shallow as 50-200 meters above ground level.

For the 2009 winter study, AQD has placed eleven FEM and non-FEM continuous ozone monitors around the UGRB. Additionally, AQD has placed five FEM ozone monitors in communities around the UGRB as part of an Air Toxics study. These monitors compliment the three long-term FEM ozone monitors currently operating. AQD has also added precursor monitoring at the Boulder, Jonah and SODAR stations. Figure S.1-3 shows the current configuration of ozone monitoring in the UGRB.

Figure S.1-3: Winter 2009 Ozone Monitoring in the Upper Green River Basin



While ozone data from these studies cannot be used directly for designation, AQD has used these data to support our recommendation on a nonattainment area boundary for the UGRB. Specifically, VOC data are referenced in Section 2 and mesonet data are used to develop a localized wind field referenced in Section 7. Final reports, quality assurance project plans, and databases from the 2007 and 2008 studies are available on the WDEQ/AQD website: (http://deq.state.wy.us/aqd/Monitoring%20Data.asp). Data from the 2009 study will be posted to the AQD Monitoring page after it has been fully quality assured.

SECTION 2
EMISSIONS DATA

SYNOPSIS

The primary sources of ozone-forming precursors in the recommended nonattainment area are associated with the oil and gas development and production industry in the UGRB.

ANALYSIS

Ground-level ozone is primarily formed from reactions of volatile organic compounds (VOCs) and oxides of nitrogen (NOx) in the presence of sunlight. VOCs and NOx are considered "ozone precursors." As part of the nine-factor analysis, the Air Quality Division compiled emission estimates for VOCs and NOx for ten source categories in the proposed nonattainment area as well as counties or portions of counties surrounding the area. This information is summarized in Table S.2-1 and represents preliminary estimated first quarter 2007 emission inventory data for all potential sources. Emissions information for 2007 is used because it is the most recently available data for all source sectors. Only the first quarter is shown because elevated ozone in the UGRB occurs during limited episodes in the first three months of the calendar year. In general, quarterly emissions for the second through fourth quarters of the year are the same as for the first quarter, with the exception that biogenic VOC emissions are expected to be greater in the spring and summer months.

When comparing the raw precursor emission totals in Table S.2-1, AQD is aware that the total for the area defined as "Sweetwater Outside of Upper Green River Basin" is the largest for both VOCs and NOx. However, after carefully reviewing the other eight factors to determine an appropriate boundary, AQD has concluded that there are no violations occurring in Sweetwater County, nor are the emissions sources in most of Sweetwater County contributing meaningfully to the observed violations in Sublette County. AQD will demonstrate in this document that the emissions identified in the UGRB, along with other key factors such as site-specific air quality data (Section 1), unique meteorological and geographical conditions (Sections 6 and 7), as well as extraordinary industrial growth rates (Section 5), will explain the exceedances of the ozone standard at the Boulder monitor in Sublette County.

AQD has taken the next step to focus in on the particular emission sources believed to be contributing to high ozone levels. Figure S.2-1 shows emission inventory data for the UGRB. These emission estimates indicate that the most significant sources of ozone precursors in the UGRB are biogenics and the oil and gas industry.

Biogenics

During the first quarter of the year, biogenic emissions are lower than emissions from the other months of the year. The 2007 and 2008 Upper Green Winter Ozone Study (described in Section 1) analyzed canister samples for four biogenic species: isoprene, a-pinene, b-pinene, and d-limonene. Of particular interest is that isoprene, which is a common and highly reactive species of overwhelmingly biogenic origin, was not detected in any of the samples collected at the Jonah

monitor and found only at levels just above the method detection limit in one sample at the Daniel monitor and two samples at the Boulder monitor. A-pinene, b-pinene and a-limonene were detected in 3% or less of the samples at each site. These results are consistent with the expected absence of biogenic VOCs in the study area during the winter months.

Biogenic emissions may be overestimated in the standard models used to prepare Table S.2-1, as typical biogenic species have not been detected in significant quantities in canister samples. Alternatively, they may be attributed to forested areas on the east and west flanks of the recommended nonattainment area, which may not influence air composition at Boulder, Daniel, and Jonah during the episodic ozone conditions when canister samples have been taken.

Oil and Gas Production and Development

Oil and gas production and development is the only significant industry emission source within the UGRB. We have divided the emissions from this industry further into those associated with construction, drilling, and completion of wells; well site production; and major sources. Oil and gas production is the largest source of VOCs, with the second largest being biogenic sources. The largest NOx emission sources are from rigs drilling the natural gas wells, natural gas compressor stations (O&G Major Sources) and gas-fired production equipment.

Figure S.2-2 shows the nonattainment boundary and the location of emission sources within and around the boundary. There are 11 major sources within the proposed boundary. Ten of these are compressor stations and one is a liquids gathering system. The figure also shows the distribution of oil and gas wells in the nonattainment and surrounding area.

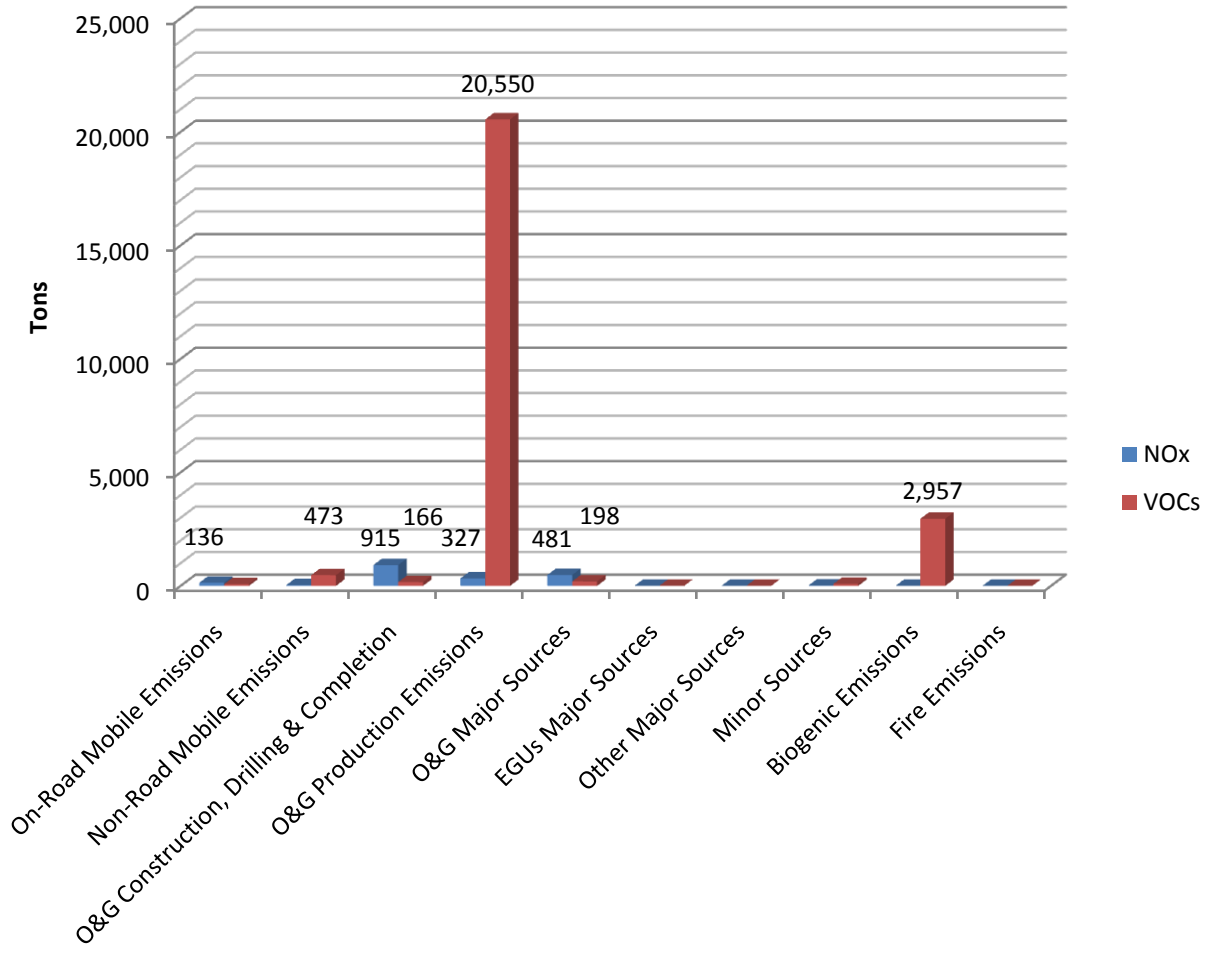
The boundary encompasses areas of oil and gas development and their respective emissions sources, defined by topography (Section 6) and meteorology (Section 7), which are the most likely sources of ozone-forming precursors influencing the Boulder monitor during elevated ozone episodes.

While the Air Quality Division has been studying the emissions from oil and gas production and development for a number of years, it is an extremely complex industry to understand from an air quality perspective. AQD has made a concerted effort to estimate the emissions impacting the monitors during very unusual circumstances. These efforts will continue and AQD has plans to refine these estimates over time.

Table S.2-1: 1st Quarter, 2007 Estimated Emissions Summary (tons)

	Upper Green River Basin		Lincoln Outside of Upper Green River Basin		Sweetwater Outside of Upper Green River Basin		Uinta		Fremont		Teton	
Emissions Sources	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs
On-Road Mobile Emissions	136	79	155	89	1,727	308	655	122	242	138	157	90
Non-Road Mobile Emissions	36	473	593	208	2,000	174	604	157	101	104	34	256
O&G Well Construction, Drilling & Completion	915	166	243	227	747	870	12	13	102	254	0	0
O&G Production Emissions	327	20,550	148	7,074	460	21,232	133	4,095	281	10,005	0	0
O&G Major Sources	481	198	488	63	9,631	2,200	174	196	111	20	0	0
EGUs Major Sources	0	0	3,151	24	6,335	75	0	0	0	0	0	0
Other Major Sources	0	0	0	0	2,445	1,929	0	0	0	0	0	0
Non-O&G Minor Sources	17	86	346	31	171	56	22	60	10	33	3	0
Biogenic Emissions	0	2,957	0	2,376	0	2,184	0	816	0	5,354	0	3,268
Fire Emissions	5	4	0	0	0	0	0	0	317	232	0	0
Total Emissions	**1,917**	**24,514**	**5,124**	**10,092**	**23,516**	**29,027**	**1,600**	**5,458**	**1,163**	**16,142**	**194**	**3,614**

Figure S.2-1: Estimated Upper Green River Basin Emissions
1st Quarter, 2007



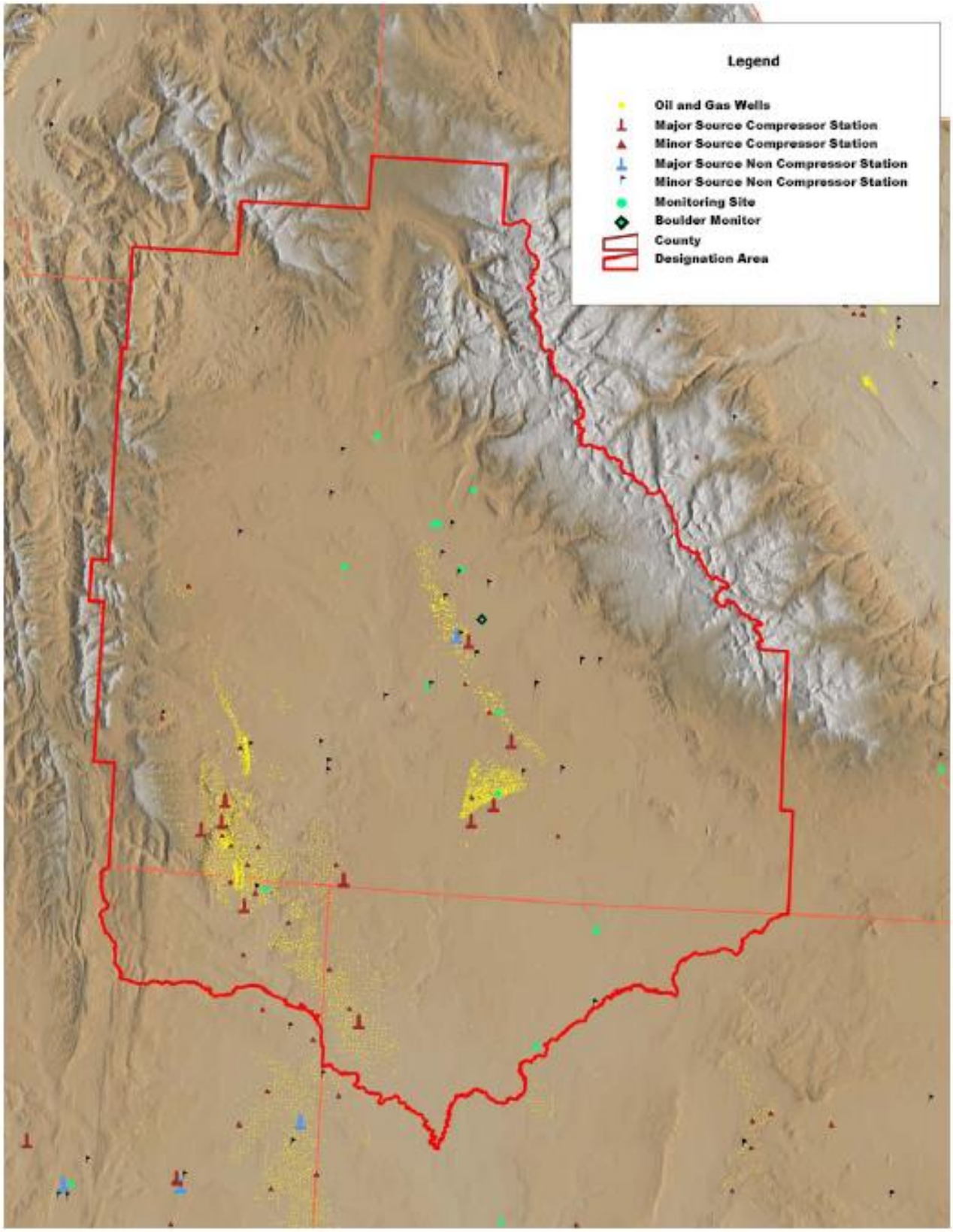


Figure 2.2-2: Designation Area Boundary

SECTION 3
POPULATION DENSITY AND DEGREE OF URBANIZATION

SYNOPSIS

Urbanized areas in surrounding counties do not affect ozone formation or precursors in the proposed nonattainment area just prior to and during elevated ozone episodes, because the urbanized areas are distant and in some cases separated by geographical features such as mountains.

The past and anticipated future rapid population growth is expected to be limited to the proposed nonattainment area, which would suggest that neighboring counties should not be included in the proposed nonattainment area.

Factors which are associated with ozone formation in urban areas have a lower significance for selecting the boundary for this nonattainment area since Southwest Wyoming is mostly rural with a low population density.

ANALYSIS

Sublette County and the surrounding counties (Table S.3-1) are rural with a low overall population density. There are no metropolitan areas with a population of 50,000 or more in this six-county area.

Table S.3-1: Population Density

	Sublette	Sweetwater	Lincoln	Uinta	Fremont	Teton
Estimated 2007 Population	7,925	39,305	16,171	20,195	37,479	20,002
Area (square mile)	4,882	10,426	4,069	2,082	9,183	4,008
Population/square mile	2	4	4	10	4	5
Percent in Urbanized Area*	0	89	20	59	48	56
Percent in Rural Area*	100	11	80	41	52	44

* Based on 2000 Census

The largest community in Sublette County is Pinedale. The estimated population in 2007 was 2,043. The largest communities in the counties surrounding Sublette are Rock Springs (population 19,659), Green River (population 12,072) and Evanston (population 11,483). Rock Springs, Evanston, Riverton and Jackson are classified by the U.S. Census Bureau as Micropolitan Statistical Areas. Table S.3-2 shows population estimates and projections from the Wyoming State Department of Administration and Information.

Table S.3-2: Population Estimates and Projections

County and Cities	2007 Estimate	2008 Forecast	2010 Forecast	2015 Forecast	2020 Forecast	2025 Forecast	2030 Forecast
Sublette	**7,925**	**8,340**	**9,170**	**11,200**	**13,370**	**15,010**	**16,930**
Big Piney	476	501	551	673	803	902	1,017
Marbleton	919	967	1,063	1,299	1,550	1,741	1,963
Pinedale	2,043	2,150	2,364	2,887	3,447	3,869	4,364
Fremont	**37,479**	**37,870**	**38,390**	**39,320**	**40,110**	**41,130**	**42,370**
Dubois	1,033	1,044	1,058	1,084	1,106	1,134	1,168
Lander	7,131	7,205	7,304	7,481	7,632	7,826	8,062
Riverton	9,833	9,936	10,072	10,316	10,523	10,791	11,116
Lincoln	**16,171**	**16,560**	**17,240**	**18,710**	**20,100**	**21,190**	**22,430**
Afton	1,782	1,825	1,900	2,062	2,215	2,335	2,472
Alpine	764	782	815	884	950	1,001	1,060
Kemmerer	2,427	2,485	2,587	2,808	3,017	3,180	3,366
Star Valley Ranch	1,567	1,605	1,671	1,813	1,948	2,053	2,174
Sweetwater	**39,305**	**40,180**	**41,700**	**44,430**	**46,530**	**47,220**	**48,130**
Green River	12,072	12,341	12,808	13,646	14,291	14,503	14,782
Rock Springs	19,659	20,097	20,857	22,222	23,273	23,618	24,073
Teton	**20,002**	**20,240**	**20,570**	**21,340**	**22,140**	**23,470**	**24,990**
Jackson	9,631	9,746	9,904	10,275	10,660	11,301	12,033
Uinta	**20,195**	**20,420**	**20,730**	**21,210**	**21,550**	**21,950**	**22,440**
Evanston	11,483	11,611	11,787	12,060	12,253	12,481	12,760
Lyman	1,990	2,012	2,043	2,090	2,124	2,163	2,211
Mountain View	1,176	1,189	1,207	1,235	1,255	1,278	1,307

Population in Sublette County and Sublette County communities is expected to increase at a rate of approximately 5% over the next 23 years. Population in surrounding counties is expected to increase more slowly at rates of 2% or less.

The population in Sublette County has increased at a greater pace than surrounding counties (Table S.3-3). In the period 2006 to 2007, Sublette County continued to see faster growth than surrounding counties.

Table S.3-3: Population Growth

Population	Sublette	Sweetwater	Lincoln	Uinta	Fremont	Teton
Estimated 2007	7,925	39,305	16,171	20,195	37,479	20,002
Estimated 2006	7,359	38,763	16,383	20,213	37,163	19,288
Estimated 2004	6,879	38,380	15,780	20,056	36,710	18,942
2000	5,920	37,613	14,573	19,742	35,804	18,251
Percent Population Increase						
2000 to 2007	34%	4%	11%	2%	5%	10%
2004 to 2007	15%	2%	2%	1%	2%	6%
2006 to 2007	8%	1%	-1%	0%	1%	4%

Sublette County does not have any urbanized areas. Urbanized areas in surrounding counties are geographically distant from the monitor with the ozone exceedance in Sublette County (the Boulder monitor). As is described in Section 7 of this document, meteorological conditions associated with elevated ozone episodes greatly limit the possibility of emissions transport. Table S.3-4 shows the approximate distance to the Boulder monitor from communities with a population greater than 9,000 in 2007. Additionally, Riverton is separated from the UGRB by the Wind River Range. (Appendix S3 - **Figure -** Wyoming Population Density by Census Tract)

Table S.3-4: Distance to Boulder Monitor
(Miles, approximate)

Riverton	Green River	Rock Springs	Jackson	Evanston
73	82	80	75	118

The analysis in Section 7 of this document will demonstrate that emissions from sources outside of the UGRB do not significantly influence ozone levels at the Boulder monitor during elevated ozone episodes.

References:

1. http://www.census.gov/main/www/cen2000.html, U.S. Census Data.
2. http://eadiv.state.wy.us/pop/CO-07EST.htm, State of Wyoming populations statistics and projections by county and city.
3. Appendix S.3., Population Density by Census Tract

SECTION 4
TRAFFIC AND COMMUTING PATTERNS

SYNOPSIS

The number of commuters into or out of Sublette County (and the UGRB) is small and does not support adding other counties or parts of counties into the nonattainment area based on contribution of emissions from commuters from other counties.

The percent of emissions from on-road mobile sources is small within the proposed nonattainment area: 7% of NOx and 0.3% of VOCs. Even if this source increases, it will remain a small percentage of total emissions.

Interstate 80, the interstate highway that is nearest to the Boulder monitor, is approximately 80 miles south of the Boulder monitor. Ozone monitors in closer vicinity to the interstate have not shown ozone exceedances. I-80 traffic is not considered to be a significant contributor of emissions that impact the Boulder monitor during ozone events.

ANALYSIS

Consistent with the rural character of the counties in southwest Wyoming including Sublette County, traffic volumes are low. The Wyoming Department of Transportation's (WYDOT)[1] inventory shows traffic volume at 447,953 daily vehicle miles traveled (DVMT) for Sublette County in 2007. WYDOT inventories are based on travel on paved roads. Table S.4-1 shows traffic volumes for Sublette County and surrounding counties for 1994, 2004 and 2007.

Emissions from mobile sources within the UGRB are very low, as would be expected from such low DVMTs. As shown in Table S.2-1, NOx emissions for the first quarter of 2007 are approximately 136 tons (7% of total NOx) and VOC emissions are 79 tons (0.3%). This makes emissions from this sector of much lower significance than is typically seen in urban nonattainment areas.

Approximately 90% of the traffic volume in Sweetwater and Uinta Counties is interstate traffic. Interstate 80 is located approximately 80 miles south of the Boulder monitor, the ozone monitor that showed the exceedance. There are five ozone monitors located closer to the Interstate: Wamsutter (~1 mile), OCI (~12 miles), South Pass (~45 miles), Murphy Ridge (~5 miles), and Jonah (~60 miles) (See Figure S.1-1). None of the monitors located closer to the Interstate have shown an ozone exceedance.

Table S.4-1: WYDOT - 2007 Traffic Surveys

	Sublette	Sweetwater	Lincoln	Uinta	Fremont	Teton
DVMT-2007	447,953	2,667,117	615,113	1,013,595	979,546	622,356
DVMT - interstate-2007		2,421,684		911,916		
DVMT-2004	342,034	2,473,882	564,771	944,416	892,814	600,836
DVMT-1994	229,553	1,917,738	466,753	761,626	737,863	504,904
Increase 1994 to 2007	95%	39%	32%	33%	33%	23%
Miles of roads	229.2	568.7	337.2	218.4	507.2	144.2
DVMT/mile of road	1954	4689	1824	4641	1931	4315

The Wyoming Department of Employment (DOE)[2] surveys commuting trends between counties. Table S.4-2 summarizes the average number of commuters for the years 2000 through 2005 that commute between Sublette County (the county with the Boulder monitor) and surrounding counties. Although commuting has increased for some neighboring counties, such as Sweetwater County, the volume of commuters is low.

Table S.4-2: Wyoming DOE Commuter Surveys 2000 Through 2005

Commuters driving to Sublette from:	2000	2001	2002	2003	2004	2005
Fremont	20	29	17	26	41	47
Lincoln	112	117	106	84	100	128
Sweetwater	62	86	79	77	111	185
Teton	49	52	45	35	38	49
Uinta	14	12	22	31	38	53
Total						462
Commuters driving from Sublette to:						
Fremont	81	67	70	37	48	44
Lincoln	77	59	76	114	97	93
Sweetwater	126	129	109	121	152	209
Teton	171	148	150	135	142	130
Uinta	33	66	55	31	20	26
Total						502

North Carolina's Economic Development Intelligence System (EDIS)[3] compiled 2000 Census data to determine the number of commuters in Wyoming counties. Extrapolating this data to 2008, to account for only population growth, the estimated number of commuters in Sublette County and surrounding counties is shown in Table S.4-3. Since rapid population growth in Sublette County is biased toward the working age population, the straight extrapolation from 2000 data is likely to underestimate the number of commuters. The EDIS data indicate the majority of commuters commute within their county of residence. The number of commuters leaving Sublette County calculated by the Wyoming DOE correlates well with the EDIS generated estimates of commuters leaving Sublette County.

Table S.4-3: Number of Commuters in Sublette and Surrounding Counties

	Sublette	Sweetwater	Lincoln	Uinta	Fremont	Teton
Estimated number of commuters in 2000*	2767	18,012	6069	8921	15,074	10,527
Estimated number of commuters in 2008	3357	18,726	7084	9114	15,761	11,811
Estimated number of 2008 commuters that stay in their county	2921	17,977	5596	7565	14,973	11,338

* 2000 Census data

Commuting patterns in Sublette County and in surrounding counties show that commuting to or from the adjacent counties is not a major source of VMT in Sublette County. Therefore, commuters from adjacent counties are not a significant factor in ozone generation in the proposed nonattainment area.

Reference:

1. Appendix S.4.A, 2007 Vehicle Miles on State Highways By County
2. Appendix S.4.B, Commuting Patterns in Sublette County
3. North Carolina Department of Commerce web site. https://edis.commerce.state.nc.us/docs/countyProfile/WY/

SECTION 5
GROWTH RATES AND PATTERNS

SYNOPSIS

The pace of growth in the oil and gas industry in Sublette County is significantly greater than in surrounding counties. While population is growing in Sublette County, the county and surrounding area is rural with a low population density. Population growth does not influence determination of a designation area boundary in this case.

ANALYSIS

Statistical data available is broken down on a county basis. The following analysis compares Sublette County to surrounding counties. While the recommended nonattainment area includes a portion of Sweetwater and Lincoln counties in addition to Sublette, the trends described for Sublette County also hold true, in general, to the recommended nonattainment area.

Population growth is described in Section 3. Sublette County population has grown at an annual rate of approximately five percent over the last seven to ten years. Sublette County is forecast to continue to grow at this rate for the foreseeable future. Counties surrounding Sublette have grown at rates of less than two percent during this time period and are forecast to continue to grow at this slower pace.

Industrial growth in Sublette County is driven by the oil and gas (O&G) industry. Table S.5-1 shows the increase in O&G production for Sublette County as shown by the number of well completions for years 2000 through 2008. Table S.5-2 shows total well completions for 2005 through 2008 for Sublette, Sweetwater, Uinta and Lincoln counties. Sweetwater and Lincoln counties also show an increasing trend in well completions, though to a lesser extent than in Sublette. Teton County is not listed because it has no oil and gas production. Fremont County is not shown because O&G production areas in Fremont County are separated from the other counties by the Wind River Mountain Range.

Table S.5-1: Completion Report Sublette County*

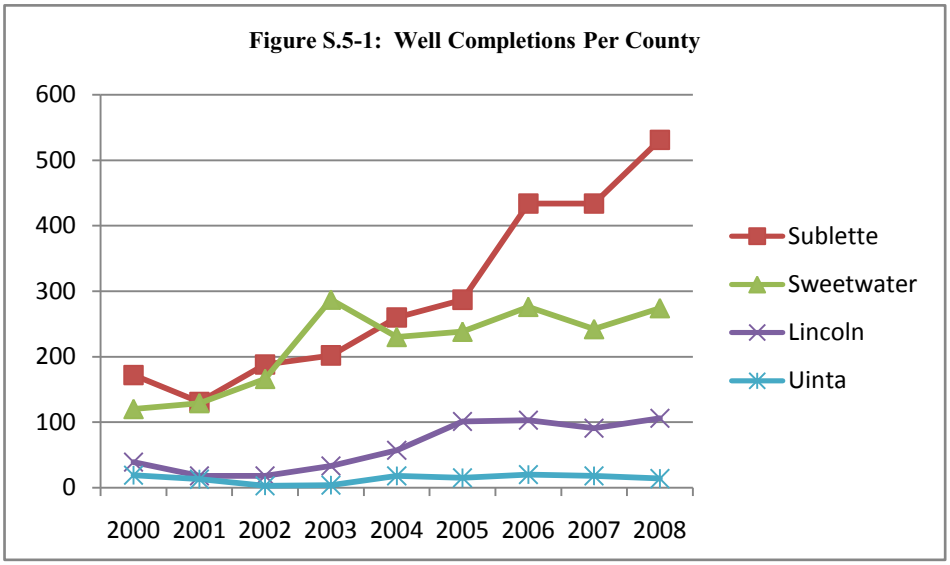
(Confidential Records Are Not Listed)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Distinct Gas Well Completion Count	126	110	150	185	252	281	428	420	517
Distinct Oil Well Completion Count	45	20	32	15	5	0	3	5	4
Total Distinct Well Completion Count	172	131	188	202	260	287	434	434	531

*Wyoming Oil and Gas Conservation Commission (WOGCC)

Table S.5-2: Total Well Completions/Oil, Gas, and CBM* (Confidential Records Are Not Listed)									
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sublette	172	131	188	202	260	287	434	434	531
Sweetwater	120	129	166	287	230	238	276	242	274
Lincoln	39	18	18	33	57	101	103	91	106
Uinta	19	13	3	4	18	15	20	18	14

*Wyoming Oil and Gas Conservation Commission (WOGCC)



As Figure S.5-1 shows, there have been more O&G well completions in Sublette than for the surrounding counties. Table S.5-3 and Figure S.5-2 show the steady growth in Sublette County O&G production since 2000.

Table: S.5-3 Sublette County Production Levels			
	Oil Bbls	**Gas Mcf**	**Water Bbls**
2008	7,666,396	1,143,614,170	22,921,983
2007	7,096,499	1,008,001,400	18,251,807
2006	5,769,581	880,855,575	13,203,000
2005	5,102,164	814,748,425	11,641,926
2004	4,705,836	731,276,509	11,812,077
2003	4,539,385	655,573,062	10,526,328
2002	4,380,011	571,000,866	13,950,895
2001	3,840,436	493,577,283	7,785,291
2000	3,345,063	448,281,668	7,364,792

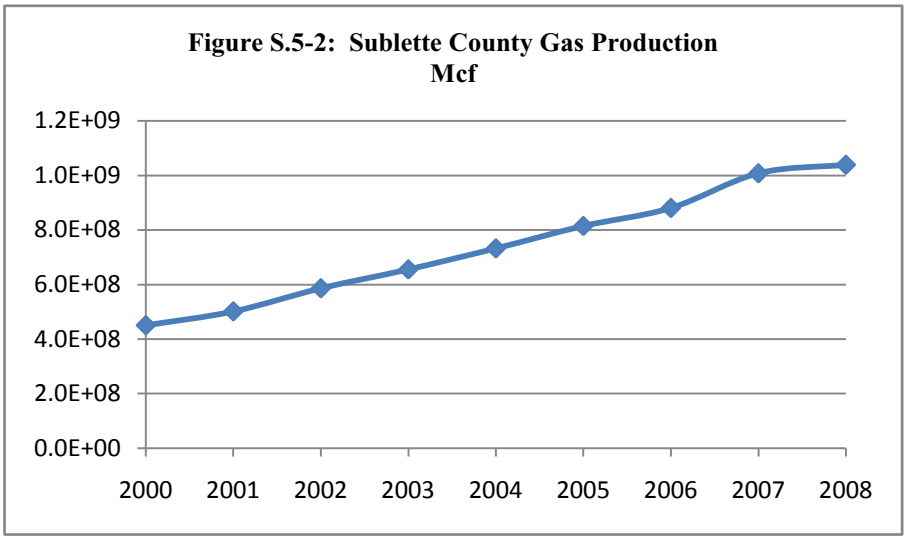


Table S.5-4 shows growth in the oil and gas industry by county through the following three measures: oil production (in barrels), gas production (in thousand cubic feet), and produced water generation (in barrels). Growth in production of gas and water is increasing in Sublette County and is either static or decreasing in the surrounding counties.

Table S.5-4: Four County Production				
	Oil Bbls			
	Sublette	Lincoln	Sweetwater	Uinta
2008	7,666,396	819,751	5,392,316	1,341,993
2007	7,096,499	801,807	5,738,262	1,506,562
2006	5,769,581	782,165	5,295,610	1,914,262
2005	5,102,164	762,801	4,872,531	2,246,896
	Gas Mcf			
2008	1,143,614,170	89,516,900	240,214,449	130,282,928
2007	1,008,001,400	89,189,164	235,687,851	128,068,870
2006	880,855,575	85,753,007	238,339,251	139,700,716
2005	814,748,425	83,579,467	222,772,057	141,490,407
	Water Bbls			
2008	22,921,983	1,228,058	42,026,953	3,011,981
2007	18,251,807	1,300,854	47,522,714	2,843,082
2006	13,203,000	1,375,969	49,928,115	2,641,554
2005	11,641,926	1,065,943	45,110,120	2,950,473

References:

Wyoming Oil and Gas Conservation Commission (http://wogccms.state.wy.us/)

SECTION 6
GEOGRAPHY/TOPOGRAPHY

SYNOPSIS

The Wind River Range, with peaks up to 13,800 feet, bounds the UGRB to the east and north; the Wyoming Range, with peaks up to 11,300 feet, bounds the UGRB to the west.

Significant terrain influences the weather patterns throughout Southwest Wyoming. Other terrain features such as river and stream valleys also influence local wind patterns.

Mountain-valley weather patterns in the UGRB tend to produce limited atmospheric mixing during periods when a high pressure system is in place, setting up conditions for temperature inversions, which are enhanced by the effect of snow cover.

ANALYSIS

Southwest Wyoming and the UGRB are within the Wyoming Basin Physiographic Province. Topography in the UGRB is characterized by low, gently rolling hills interspersed with buttes. Elevations range from approximately 7,000 to 7,400 feet above mean sea level (AMSL) in the lowest portions of the UGRB. The Wind River Range, with peaks up to 13,800 feet, bounds the UGRB to the east and north and the Wyoming Range, with peaks up to 11,300 feet, bounds the UGRB to the west. There are also important low terrain features such as the Green River Basin and the Great Divide Basin.

Mountain elevations decrease moving south along both the Wyoming and Wind River ranges. Along the western boundary of the Green River Basin, in the southern part of the Wyoming Range, the elevation decreases to about 6,900 feet above mean sea level (AMSL) with some peaks in the 7,500 to 8,000-foot range. Moving south along the Wind River Range, the elevation decreases to 7,800 feet at South Pass.

Figure S.6-1: Nonattainment area shown (blue outline) against an aerial view of the topography in the Upper Green River Basin and adjacent areas.

The surrounding significant terrain features effectively create a bowl-like basin in the northern portion of the Green River Basin, which greatly influences localized meteorological and climatological patterns relative to geographical areas located outside of the UGRB. Although difficult to quantify over the entire UGRB valley, the UGRB is roughly 900 to 1,300 meters (3,000 to 4,300 feet) lower than the terrain features bounding the UGRB to the east and west. Typical elevation profiles within the UGRB are illustrated in two different cut-planes (transects) across the UGRB, as shown in Figure S.6-2.

The southern boundary of the area is defined by river and stream channels. To the east the Big Sandy, Little Sandy and Pacific Creek drainages define the boundary and to the west the Green River and Fontenelle Creek drainages define the boundary.

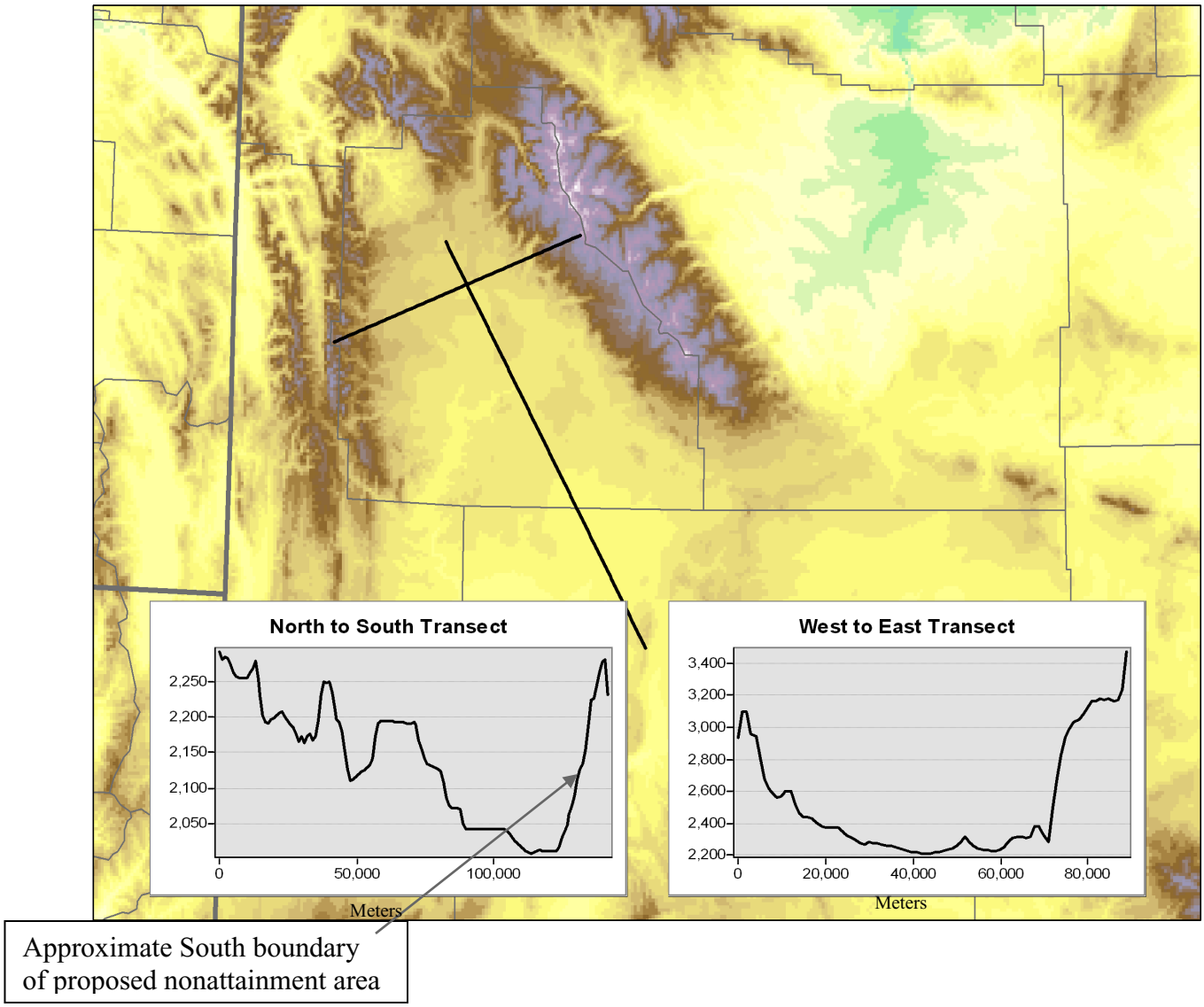


Figure S.6-2: Transects across the Upper Green River Basin (running north-south and west-east) showing cross sections of the terrain; terrain elevations and distance units shown in the transects are in meters.

Significant terrain in the UGRB has an impact on the local meteorology (wind speed, wind direction, and atmospheric stability). In mountain-valley areas – such as the UGRB – during the night cold air will accelerate down the valley sides (downslope winds), while during the day warmer air will flow up the valley sides (upslope winds). At night, this can create a cold pool of air within the UGRB that stratifies the atmosphere (inhibits mixing) since colder, denser air exists at the surface with warmer air above. Further, at the valley floor, the wind speed is likely to be lower than in an open plain as the roughness of the surrounding terrain tends to decrease wind speeds at the surface. The terrain obstacles surrounding the UGRB also tend to cut-off, block, or redirect air that might normally flow through the valley. This effect is exacerbated

during times of calm weather, such as the passage of a high pressure system that tends to set up conditions for strong surface-based temperature inversions.

The Wind River Range on the east and the Wyoming Range on the west provide significant barriers to movement of ozone and ozone precursors into the area proposed for a nonattainment area designation. Although the recommended southern boundary is not bordered by a mountain range, the southern boundary lies along two significant drainage divides: the Fontenelle/Green River and the Pacific/Big Sandy River. These geographic features influence air flow, although they do not provide an absolute barrier to migration. The influence of these geographic features on wind flows, especially during periods of low winds which are needed for ozone formation is illustrated in Figure S.7-17. This figure shows winds generally conforming to the drainages which establish the southern boundary of the proposed nonattainment area. The conclusions about the southern boundary are further supported by the meteorological analyses presented in Section 7.

SECTION 7
METEOROLOGY

SYNOPSIS

The unique meteorology in the UGRB of Wyoming creates conditions favorable to wintertime ozone formation.

The meteorology within the UGRB during winter ozone episodes is much different than on non-high ozone days in the winter, and is also much different than the regional meteorology that exists outside of the UGRB during these wintertime high ozone episodes.

The 2008 field study data reveal that, for the days leading up to the February 19-23, 2008 ozone episode, sustained low wind speeds measured throughout the monitoring network were dominated by local terrain and strong surface-based inversions, which significantly limited the opportunity for long-range transport of precursor emissions and ozone to reach the Boulder monitor.

Minimal emissions transport and dispersion, due to the influence of localized winds (light winds) in the UGRB characterize the February 19-23, 2008 ozone episode.

An ozone-event specific wind field was developed to more accurately simulate meteorological conditions in the UGRB and surrounding areas, and was used to drive a trajectory model for air parcel movement into and out of the UGRB.

Trajectory analyses were used to develop a reasonable southern boundary for the nonattainment area.

The unique meteorological conditions in the UGRB are one of the most significant factors for assigning this nonattainment boundary.

ANALYSIS

General

There is significant topographic relief in Wyoming which affects climate and daily temperature variations. This is a semiarid, dry, cold, mid-continental climate regime. The area is typified by dry windy conditions, with limited rainfall and long, cold winters. July and August are generally the hottest months of the year, while December and January are the coldest. Pinedale's mean temperature in January is 12.5°F with a mean of 60°F in July (Western Regional Climate Center, 2009). The high elevation and dry air contribute to a wide variation between daily minimum and maximum temperatures. At Pinedale, the total annual average precipitation is about 10.9 inches, and an average of 61 inches of snow falls during the year.

Strong winds are common in Wyoming, especially in the south. Wind velocity can be attributable, in part, to the prevailing westerly winds being funneled through the Rock Mountains at a low point in the Continental Divide.

The meteorological conditions conducive to the formation of high ozone levels in the UGRB during the winter and early spring are characterized by:

- A stable atmosphere, characterized by light low-level winds

- Clear or mostly sunny skies
- Low mixing heights or capping inversions
- Extensive snow cover
- Low temperatures

The above conditions take some time to develop (at least 48 hours after a storm frontal passage), and occur during periods when the synoptic weather is dominated by high pressure over the western Rockies.

Looking at the meteorological conditions in the UGRB, elevated ozone episodes in 2005, 2006 and 2008 were associated with strong temperature inversions and light low-level winds. This was the case during the February 19-23, 2008 ozone episode, in which the highest ozone concentrations monitored to date in the UGRB were recorded at the Boulder monitor. Because these meteorological conditions are common to all of the high ozone episodes in the UGRB observed to date, the ozone episode of February 19-23, 2008, a 5-day period marking the longest consecutive ozone episode observed, is considered to be representative of other ozone episodes. This particular 5-day ozone episode is the primary focus of this section on meteorological influences and wintertime high ozone.

Winter Ozone Field Studies

After elevated ozone levels were monitored in the winter of 2005 and 2006; the AQD initiated intensive field studies to collect meteorological and ambient data in the first quarter of 2007, 2008, and 2009 throughout the Green River Basin to better understand the relationships between winter meteorological conditions and high ozone levels versus low ozone levels. In spite of careful planning to record data, the winter of 2007 did not produce conditions conducive to the formation of ozone. In contrast, the winter of 2008 provided a significant amount of data on ozone formation since there were several high ozone episodes. A map showing the monitoring sites employed in the 2008 field study and regional terrain features in the 2008 study area is shown in Figure S.7-1. The entire data set and reports on the winter studies completed to date are available on the WDEQ/AQD website (http://deq.state.wy.us/aqd/Monitoring%20Data.asp). AQD has continued field studies into 2009, but those results will not be available until later in 2009.

During January and the beginning of February 2008, the study area was under the influence of a series of weak to moderately strong synoptic disturbances that migrated from the Gulf of Alaska, across the Pacific Northwest and southern British Columbia and the northern Great Basin and into the Northern Rockies. These weather features generally moved rapidly through southwest Wyoming as they migrated along a belt of strong westerly to northwesterly winds aloft that were associated with a persistent high pressure ridge located over the eastern Pacific, off California. In addition, a number of deep Pacific troughs moved across the area earlier in the winter and into the first half of January. The end result of all this activity was the deposit of substantial snow cover in southwestern Wyoming, including the UGRB, which was to remain in place through the rest of the winter. After mid-February, the eastern Pacific ridge exhibited a tendency to extend or migrate into the interior west until it finally moved directly over southwest Wyoming by February 20, 2008.

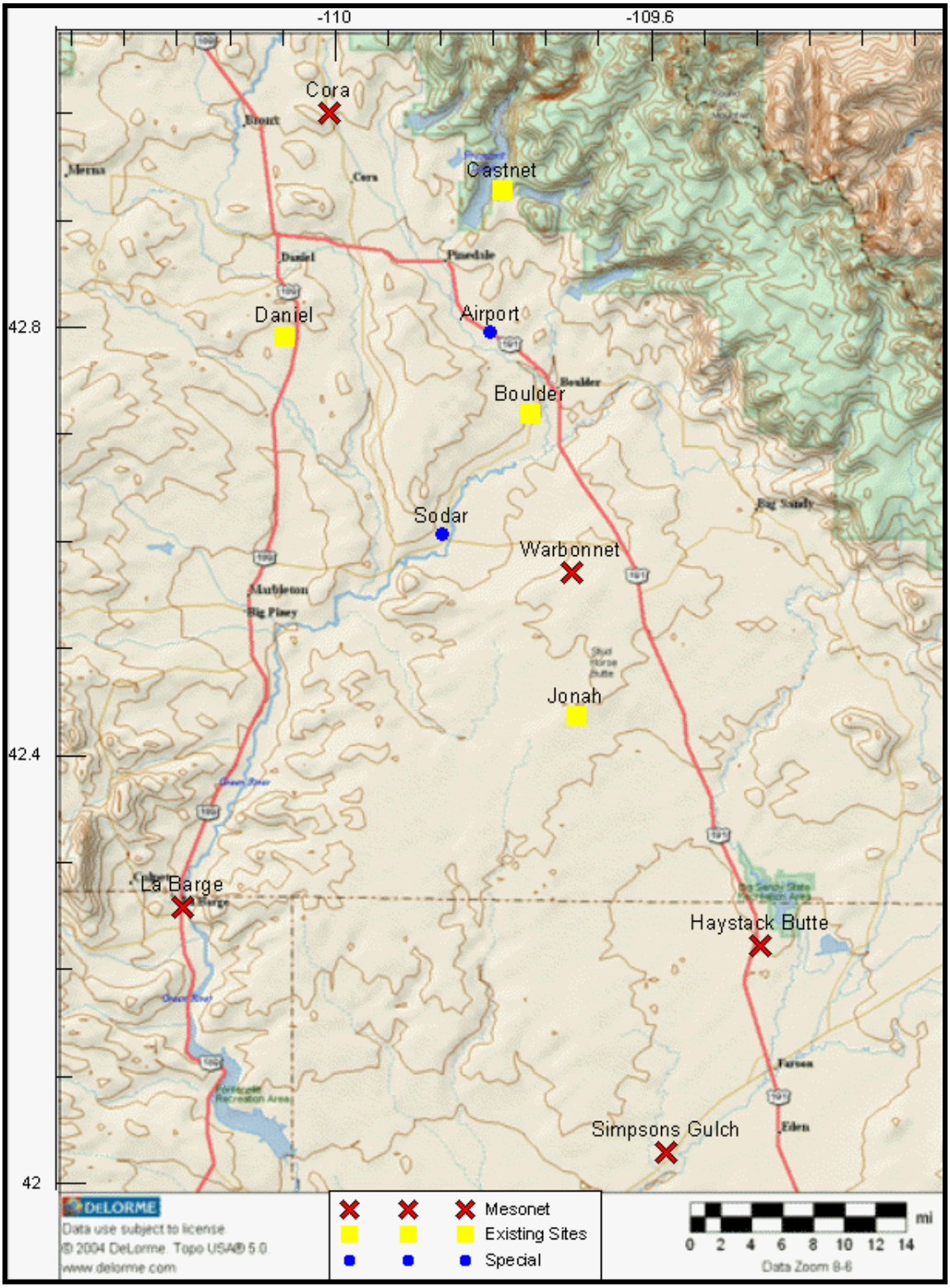


Figure S.7-1. Surface and upper air monitoring sites employed in the 2008 field study.

Comparison of 2007 and 2008 Field Study Observations

Snow Cover and Sunlight

Comparison of meteorological conditions in 2008 with those prevailing during the 2007 field study revealed that one of the key differences was the extensive snow cover in 2008 which was not present during 2007. Snow cover appears to be a key ingredient in winter ozone development, specifically, fresh snow, which results in higher surface albedo, perhaps as great as 0.9. The increased surface albedo results in greater actinic flux and therefore elevated NO_2 photolysis rates. The elevated photolysis rate due to the high (snow cover driven) albedo is likely greater than the photolysis rate in the UGRB in the summer months.

During the 2007 field study, although there were extended periods when synoptic-scale meteorological conditions were conducive to poor horizontal dispersion, the lack of snow cover and subsequent lower UV albedo reduced the amount of UV radiation available for photolysis and associated ozone production. In addition, the 2007 and 2008 field studies suggest that the sensible and radiative heat flux impacts of the snow cover enhance low-level atmospheric stability, substantially reducing vertical mixing during most or all of the daylight hours.

Low Wind Speeds

Stable, stagnant weather conditions occurred in southwest Wyoming during the period from February 18 through 22, 2008. The main synoptic feature responsible for this was a strong Pacific high pressure ridge that slowly migrated across the western United States. This period was dominated by low wind speeds in the boundary layer, which reduced pollutant transport and dispersion. This effect is shown in Figure S.7-2 where ozone concentrations and wind speeds are plotted for the Boulder monitor for February and March of 2008.

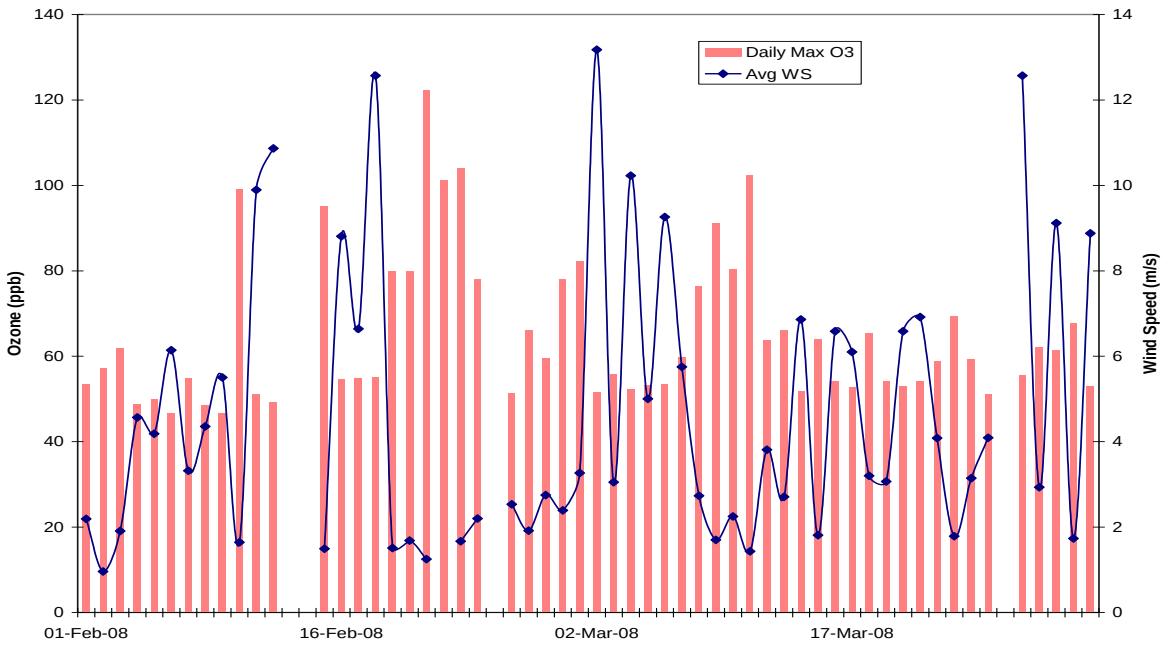


Figure S.7-2. Wind speed and ozone concentrations plotted for the Boulder monitor in February and March 2008.

The 2008 field study data reveal that the sustained low wind speeds measured throughout the monitoring network were dominated by local terrain and strong surface-based inversions, which significantly limited the opportunity for long-range transport of precursor emissions and ozone on the days leading up to the February 19-23, 2008 ozone episode.

Ozone Carryover

When the favorable synoptic conditions described above develop late in the day or during the night hours, the first high ozone concentrations typically develop the following day between approximately 11:00 and 13:00 so long as favorable conditions for high ozone formation persist. During a day of elevated ozone, such as February 20, 2008, the high readings at the monitors in the UGRB peak in the afternoon. As the day progresses, lower but still elevated concentrations continue, in some cases lasting well into the evening hours and, in a few cases, past midnight before lowering. When the following day continues to have these favorable weather conditions, the ozone levels begin to rise earlier than the previous day and frequently to much higher levels, indicative of some carryover of ozone and precursors from one day to the next. Once high ozone concentrations have formed, ozone levels were observed to remain elevated even with increasing cloud cover ahead of an approaching storm system. Additionally, wind reversals, which were most apparent at the Jonah and Boulder monitors, were observed at many of the monitoring sites during the field study; which further assisted in the carryover and build-up of ozone and ozone precursors from emission sources in close proximity to the monitors. Ozone concentrations do not return to near background conditions until brisk (usually west or northwesterly) winds have arrived and scoured out the surface inversion.

Atmospheric Mixing

The observed weather patterns in the 2007 field study showed that the winter storm systems generally did not provide a strong push of cold air and did not produce much precipitation in the project area, but did allow strong wind speeds aloft with considerable mixing of the atmosphere. Specifically, the weather conditions over the study area during February and March of 2007 were characterized by less precipitation (including less snow depth), stronger winds aloft and much warmer surface temperatures compared to the previous two winters. High pressure systems in 2007 tended to keep the air mass over the study area relatively well mixed and mild, which in turn did not allow for snow accumulation and strong inversion development.

Feb. 19 – 23, 2008 Case Study Illustrating the Specific Weather Conditions Which Produce Elevated Ozone in the Upper Green River Basin

This ozone episode is of particular interest for study, as it: 1) occurred over five days, marking the highest 1-hour and 8-hour ozone concentrations recorded at the Boulder monitor to date, 2) occurred during a field study Intensive Operating Period (IOP) that was in place to measure detailed actual ambient and meteorological conditions leading up to and during this multi-day winter ozone episode, 3) provides a high quality database of observations for several meteorological parameters, both during IOPs and regular hourly observations during this ozone episode, and 4) provides information which clearly shows how the topography in the Upper Green River Basin creates different meteorological conditions within the UGRB. A summary of the daily maximum 8-hour averaged ozone concentrations monitored at the Jonah, Boulder, and Daniel FRM monitors during this ozone episode, as well as the day immediately preceding it, are provided in Table S.7-1.

Date	Jonah (ppb)	Boulder (ppb)	Daniel (ppb)
2/18/09	45	55	54
2/19/08	80	79	74
2/20/08	75	79	76
2/21/08	84	122	62
2/22/08	102	101	76
2/23/08	76	104	74

Table S.7-1. Summary of daily maximum 8-hour averaged ozone concentrations monitored at the Jonah, Boulder, and Daniel monitors during February 18-23.

A synopsis of the particular meteorological conditions associated with the February 19-23, 2008 winter high ozone episode is provided below, describing the evolution of the meteorological conditions that were in place during the February 19-23, 2008 ozone episode.

Synopsis of 19 – 23 February 2008 Ozone Episode

Figure S.7-3 shows the 700 millibar (mb) chart for the morning of February 19, 2008, which shows the axis of the Pacific ridge extending north and south from the Four Corners area, through northwestern Idaho and up into eastern British Columbia. At that time, the ridge axis was still west of Wyoming, resulting in fairly strong northwesterly gradient flow (winds blowing from the northwest along the isobars) just above ground level in southwest Wyoming. With clear skies accompanying the approaching ridge, and a good snow cover at the surface, a capping inversion formed overnight and persisted throughout the next day in the UGRB. However, the strong winds above the stable layer, along with mixing heights on the order of several hundred meters, transferred sufficient momentum downward, allowing these northwest winds to mix down to the surface during the day resulting in predominant northwesterly wind patterns within the UGRB.

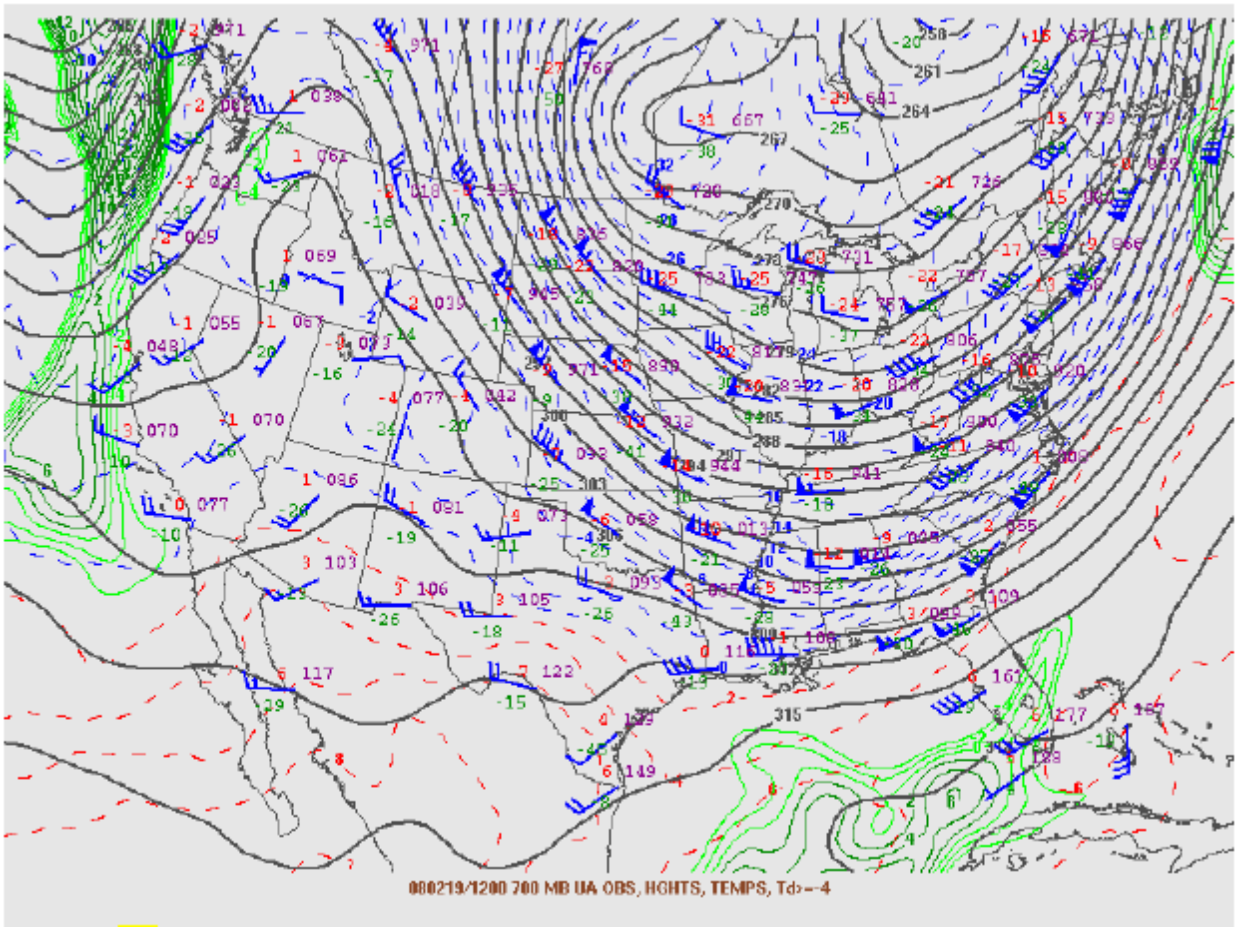


Figure S.7-3. Constant pressure map for 700 mb, 02/19/08 (1200 UTC) [(5 am LST)].

The high pressure ridge continued to progress slowly eastward during February 20th resulting in the central axis pushing into southwestern Wyoming by the middle of the day. As a result, a capping low-level inversion was observed throughout the day, and a weakened northwest gradient wind flow allowed the establishment of local valley flow patterns in the area. Local valley flow patterns are characterized by light variable winds with pronounced down slope winds at night. A weak storm system that moved out of California and across the southern Great Basin during February 20th forced some broken high cloudiness over southwestern Wyoming during the afternoon, but the clouds failed to curtail ozone production in the area, based on monitored data.

Figure S.7-4 shows the 700 mb chart for the evening of February 21, 2008. Although the high pressure ridge had weakened by the afternoon of February 21st, it had also flattened and the central ridge axis was over southwestern Wyoming through the entire day. The resulting light wind situation, characterized by low wind speeds and significantly reduced air flow movement within the UGRB, enabled the strongest ozone production seen to date in Sublette County.

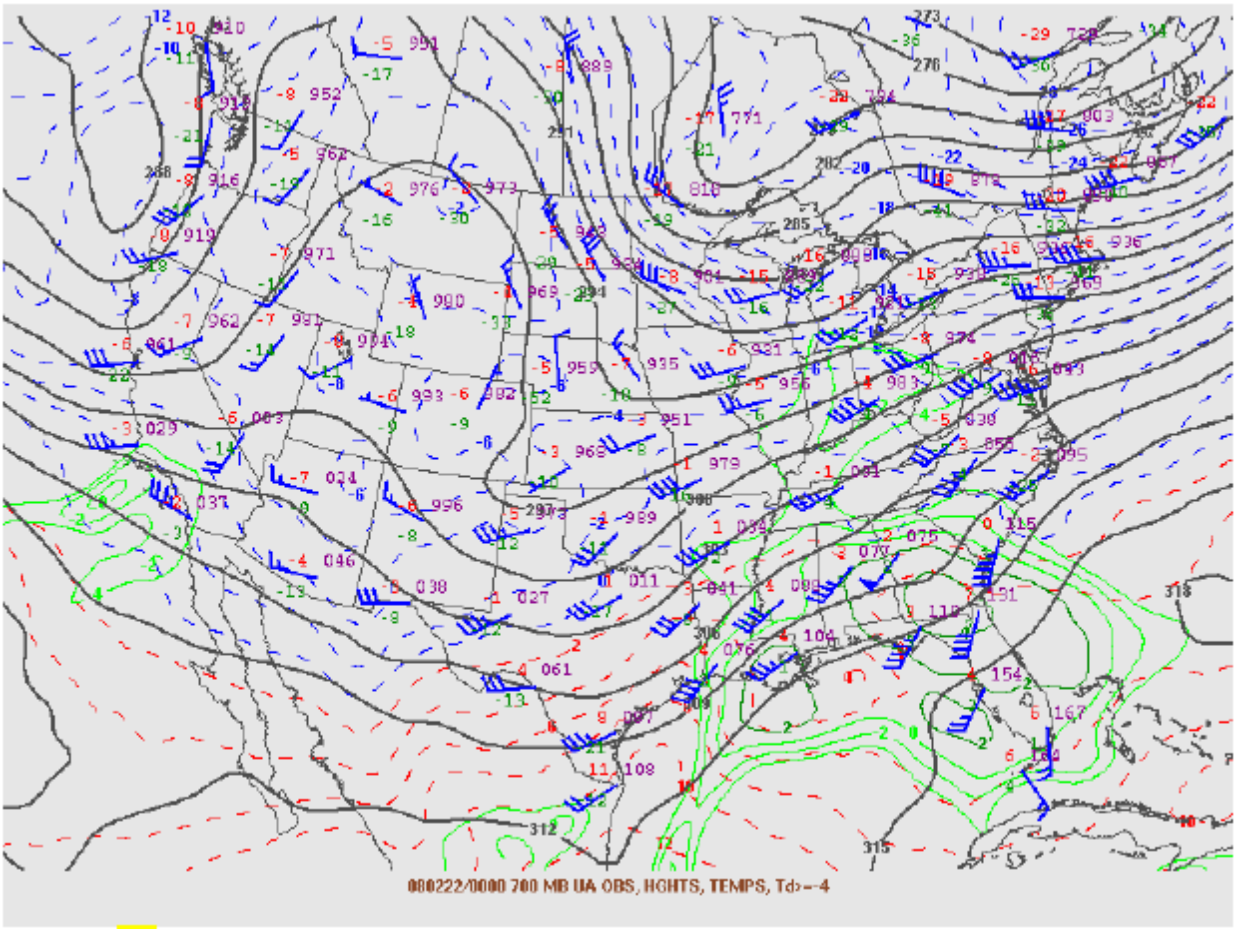


Figure S.7-4. Constant pressure map - 700 mb, 02/22/08 (0000 UTC) [02/21/08 (5 pmLST)].

On February 21, 2008, the low level inversion stayed intact through the entire daylight period, keeping ground level emissions trapped near the surface. With the very light and variable winds above the inversion (see Figure S.7-10) localized wind flow patterns near the ground level developed during the day allowing emissions to transport along those pathways (see Figure S.7-6 and Figure S.7-7). The height of the 700 mb pressure surface during the day was around 3,020 meters (MSL), the temperature averaged about -6° C, and the wind speeds were less than 5 knots. The height of the 500 mb pressure surface averaged around 5,550 meters (MSL) and the wind speeds at that height were around 15 knots.

The high pressure ridge continued to weaken during February 22, 2008, while a shortwave low pressure trough approached southwestern Wyoming from the northwest. Skies became mostly cloudy during the morning hours and light precipitation spread over the area later in the afternoon; the low level inversion stayed intact well into the afternoon, and ozone concentrations remained high during most of the day. It was anticipated that the stable layer would be mixed-out by the trough by early morning the next day and trapped emissions would be dispersed. Instead, the late arrival of the trough allowed one more day of high ozone concentrations.

Description of Surface Wind Data

With the addition of the temporary mesonet monitoring sites to the existing permanent meteorological monitoring stations in the 2007 and 2008 field studies, a fairly detailed picture of wind flow patterns within the UGRB was obtained, revealing that the wind flow patterns were distinctly different throughout the northern and southern portions of southwest Wyoming. A composite map of wind rose plots generated from meteorological data collected throughout southwest Wyoming during the time period 18 – 22, February 2008 is provided in Figure S.7-5.

As can be seen in Figure S.7-5, the wind patterns in the northern portion of Sublette County reflect the prevailing northwest winds typical of this area during most of the year. However, this moderately strong, organized northwest flow does not extend to the southern monitoring sites (Haystack Butte and Simpsons Gulch). Monitoring sites located in Sweetwater, Lincoln and Uinta Counties experienced a generally westerly wind flow, which was also a characteristic of the prevailing flows noted during the 2007 field study at those monitoring sites. Additionally, during the afternoon, winds reversed at some monitoring sites in the UGRB, shifting from the northwest to the southeast; this mid-day flow reversal is typical of high ozone days in the UGRB, and is thought to be causing recirculation of pollutants within the UGRB.

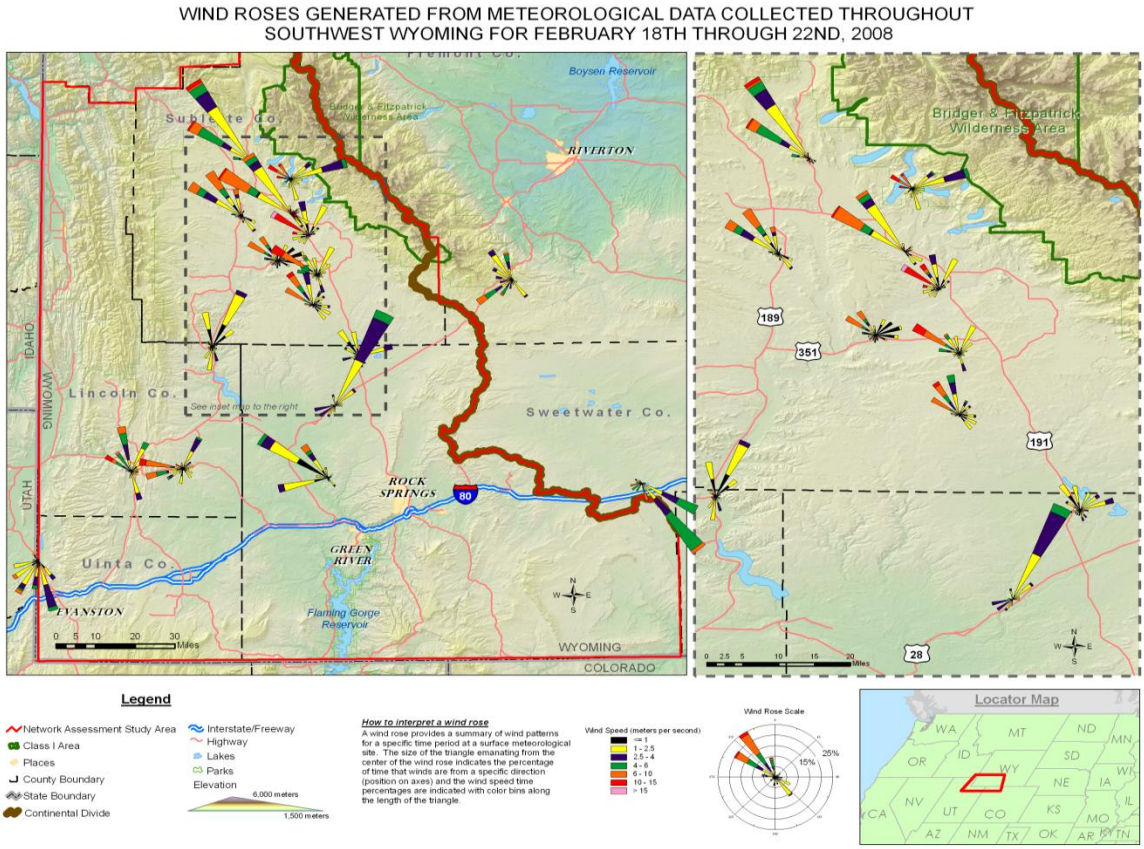


Figure S.7-5. Composite wind rose map for February 18 – 22, 2008 at monitoring sites located throughout Southwest Wyoming.

Wind vector fields were also examined spatially to gain an understanding of flow patterns in the field study area. Winds on a typical ozone episode day (February 20th), and on the day with the highest 8-hour ozone concentration recorded at the Boulder monitoring site (February 21st) are shown in Figure S.7-6 and Figure S.7-7.

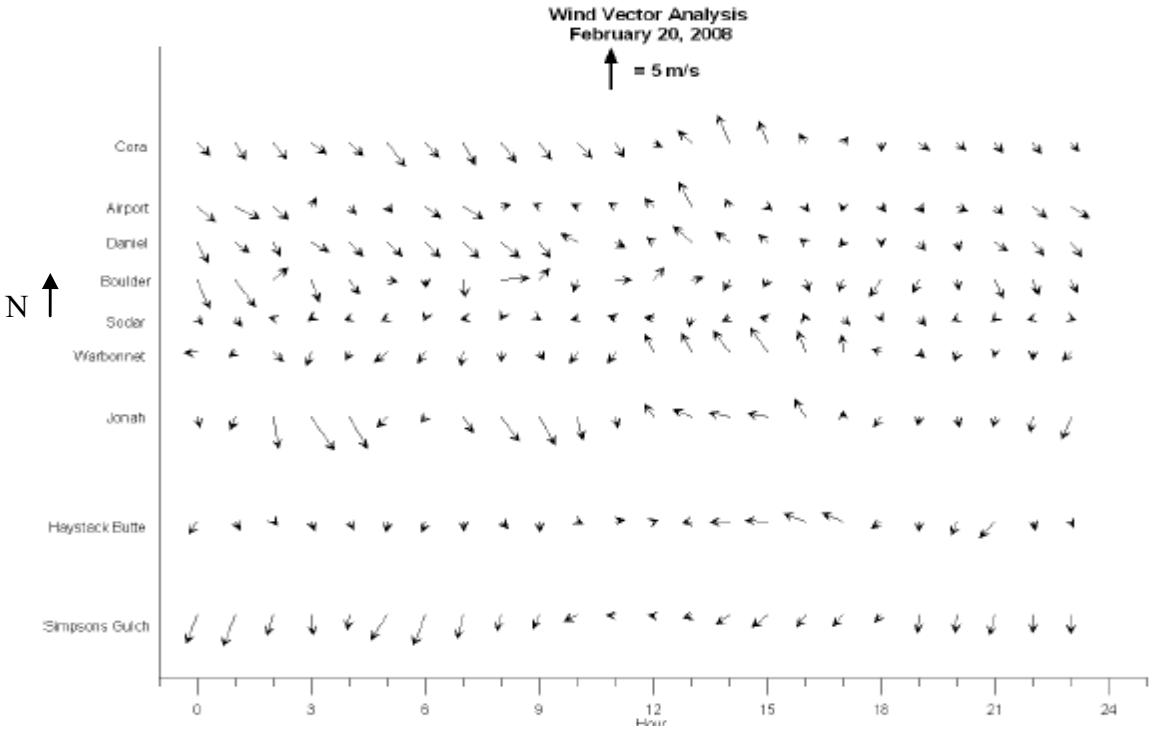


Figure S.7-6. Time-series showing February 20, 2008 hourly wind vectors for monitors used in 2008 field study monitoring network.

As shown in Figure S.7-6, winds in the UGRB are generally out of the northwest in the morning until about mid-day, at which point the flow has reversed with southeasterly winds, or at least southerly component winds are observed at most sites. This continues through the afternoon until 18:00 MST at which time the flow begins to switch back to the northwest, and by 6:00 MST the following morning, winds are northwest or northeast at nearly all of the monitoring sites. The switch from an overnight flow consisting of generally northwesterly or down slope winds, which last until approximately mid-day before reversing to a generally southeasterly wind flow pattern during the afternoon, was repeated on many of the 2008 ozone episode days.

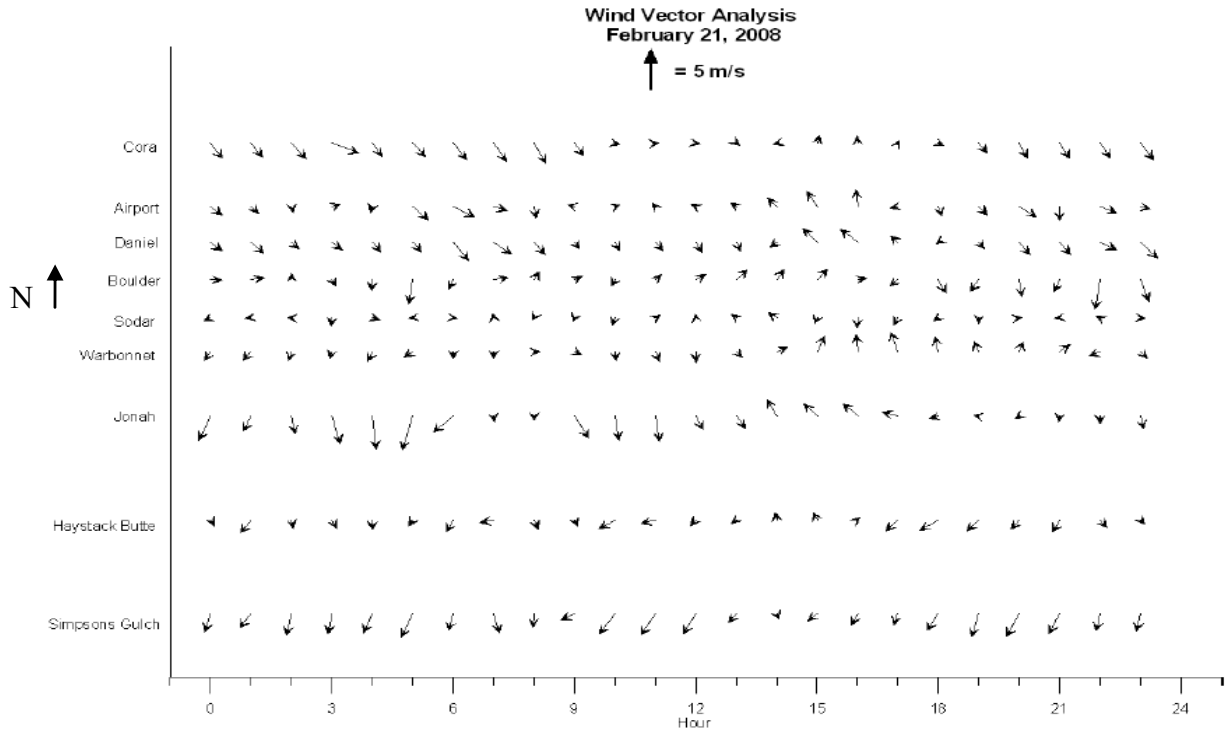


Figure S.7-7. Time-series showing February 21, 2008 hourly wind vectors for monitors used in 2008 field study monitoring network.

As shown in Figure S.7-7, winds on February 20th and 21st were generally light with variable directions throughout the monitoring network. There were two notable exceptions. After midnight, there was a general light northwest flow suggestive of a regional drainage pattern as colder, heavier air from the higher elevations flows downhill.

Generally stronger winds were measured at Jonah in the forenoon hours relative to the other sites in the network; this effect is also sometimes seen at Daniel and is likely due at least in part to the fact that winds at these two sites are measured on a standard 10 meter tower whereas the other sites made use of 3 meter high tripod mounted anemometers. During the afternoon, winds reversed at some sites, shifting to the southeast. This mid-day flow reversal is typical of high ozone days in the UGRB. On February 20, 2008, peak 8-hr ozone concentrations in the 70-85 ppb range were measured at sites throughout the study area; on February 21, 2008, the Boulder monitor recorded a 122 ppb 8-hr average ozone concentration. High ozone continued on February 22, 2008 with the Jonah monitor recording a daily maximum 8-hour average ozone concentration of 102 ppb. Minimal emissions transport and dispersion, due to the light winds in the UGRB, were characteristic throughout the February 19-23, 2008 ozone episode.

The South Daniel FRM monitor which is in the northwest portion of the recommended nonattainment area is typically upwind of local precursor sources and the Boulder monitor. On February 20 ambient nitrogen dioxide (NO_2) concentrations at the Daniel monitor were essentially equal to zero (0) ppb for all 24 hours; very low concentrations of VOCs were also measured in the VOC canister samples collected at Daniel on this day. Nearly identical values

were observed at the Daniel monitor and in the Daniel VOC canister samples obtained throughout the ozone episode (February 19-23, 2008); this was also the case during all three IOPs. The canister samples collected at the Daniel monitor in the 2007 field study also showed consistently low VOC concentrations. Additionally, monitored NOx concentrations recorded at Daniel have been very low since this site began operation nearly four years ago; the VOC canister data and the NOx monitoring conducted at Daniel clearly indicate the air coming into this area has low ozone precursor concentrations. Additionally, based on the 2008 field study data at the Daniel monitor, background ozone concentrations during the winter are typically in the 50 - 60 ppb range. Daily maximum 8-hour ozone concentrations at the Daniel monitoring site during the February 19-23, 2008 ozone episode ranged between 62-76 ppb.

One view of the surface wind direction-ozone relationship is shown on Figure S.7-8, which presents a wind rose using measurements from the Boulder monitoring site. This diagram is constructed using the daily peak 8-hr ozone level and 15:00 MST hourly averaged winds. These results show that high ozone levels were associated with afternoon winds from a variety of directions, reflecting the "light and variable" nature of the surface layer winds when the monitored 8-hour ozone levels were above 75 ppb, as opposed to 8-hour ozone concentrations that were less than 75 ppb, which tend to be associated with persistent higher wind speeds and the predominant northwest flow direction along the valley axis.

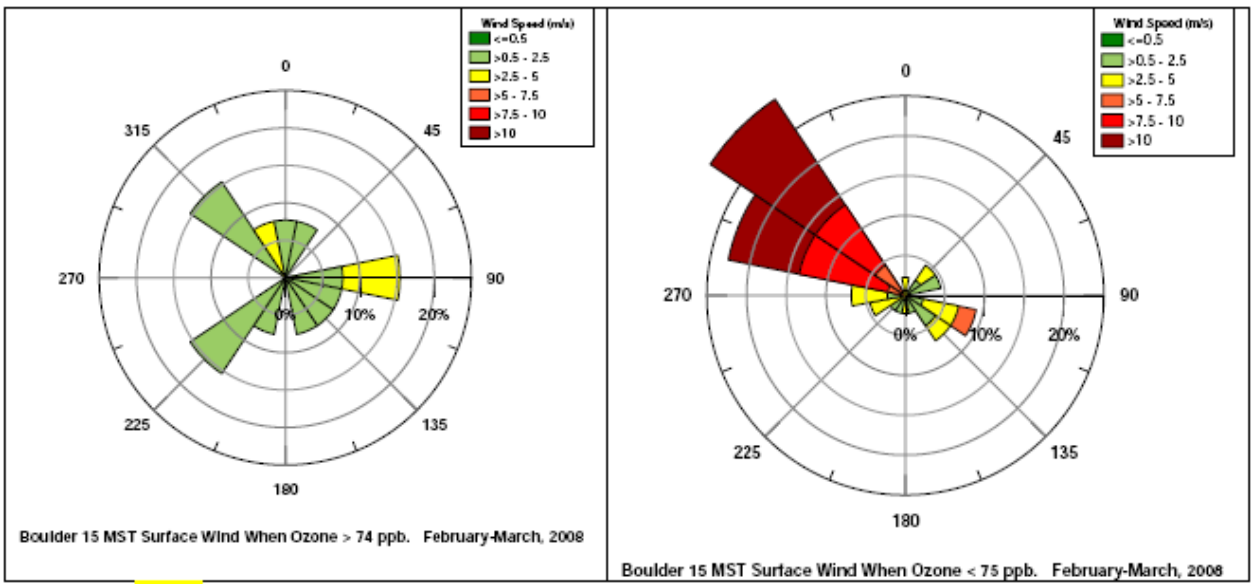


Figure S.7-8. Wind roses based on 15:00 (MST) data from the Boulder site for days with maximum 8-hour average ozone a) greater than 74 ppb (left) and b) less than 75 ppb (right).

Description of Conditions Aloft

A multi-level SODAR was operated continuously at a location approximately 3 miles southwest of the Boulder monitoring site during the 2008 field study. The SODAR provided two types of data: 1) vertical profiles of wind speed and wind direction at 10-meter increments up to 250 meters above ground level, and 2) information which allows an estimation of mixing height (mixed layer depth). The regular hourly observations during the 2008 field study were supplemented with high resolution measurements of vertical wind speed, wind direction, and temperatures during the IOPs. The hourly meteorological data capture rate was excellent. Comparing the measured wind data with peak 8-hour ozone concentrations at Boulder, a strong correlation between ozone concentrations and low mixed layer average wind speeds is evident. Looking at SODAR data on the afternoon of February 21, 2008, a day when 8-hour ozone concentrations above 75 ppb were noted throughout the field study area, reveals a top to the mixing layer at about 100 meters above ground level (AGL) representing a very shallow layer trapping ozone precursors and other pollutants in high concentrations near the surface.

Similar vertical profiles (soundings) and boundary layer development were measured by balloon-borne observations (ozone measurements, temperature, relative humidity and winds) on each of the high ozone days. Stable atmospheric conditions prevailed, and were characterized by strong low-level temperature inversions with very shallow mixing heights and light boundary-layer winds**.** Peak ozone concentrations were often observed somewhat above the surface but still within the stable inversion layer. As shown in Figure S.7-9, at low mixing heights (below 100 meters), the highest values of ozone were observed. Table S.7-2 provides a summary of the days with low-level capping inversions, and the measurements obtained, including the date and time of each balloon launch, the ground temperature and maximum inversion temperature (temperature at top of inversion layer), the difference between the maximum inversion temperature and the ground temperature (inversion layer Delta T), which reflects the strength of the temperature inversion. Note the highest inversion layer temperature measured is 14.5 (^{o}C) and occurs on February 19th.

Launch Date	Launch Time (MST)	Ground Temp (^oC)	Max Inversion Temp (^oC)	Inversion Layer ΔT (^oC)	Inversion Height (meters AGL)
2/18/08	11:00	-3.8	-3.2	0.6	150
2/18/08	16:00	-1.8	-1.7	0.1	47
2/19/08	7:00	-14.8	-0.3	14.5	489
2/19/08	1100	-8.1	1.3	9.4	442
2/19/08	13:00	-5.3	2.2	7.5	403
2/19/08	16:00	-4.5	1.8	6.3	445
2/20/08	7:00	-13.6	-2.4	11.2	398
2/20/08	1100	-13.9	-2.0	11.9	342
2/20/08	13:00	-7.7	-3.2	4.5	449
2/20/08	16:00	-5.4	-2.3	3.1	543
2/21/08	7:00	-17.4	-4.0	13.4	500
2/21/08	1100	-7.9	-3.0	4.9	405
2/21/08	13:00	-3.4	-2.6	0.8	373
2/21/08	16:00	-5.7	-2.9	2.8	494
2/27/08	8:00	-9.7	-1.4	8.3	670
2/27/08	1100	-5.4	0.1	5.5	711
2/27/08	13:00	-2.3	1.0	3.3	608
2/27/08	16:00	-1.2	0.7	1.9	527
2/28/08	8:00	-8.6	-2.3	6.3	149
2/28/08	1100	-1.4	-2.4	-1.0	265
2/28/08	13:00	1.8	0.0	-1.8	91
2/28/08	17:00	0.5	1.0	0.5	190
2/29/08	8:47	-6.2	-2.5	3.7	460
2/29/08	1100	-8.9	-0.3	8.6	396
2/29/08	13:00	-1.4	0.3	1.7	314
2/29/08	16:00	-0.3	1.5	1.8	470
3/10/08	8:00	-12.2	-5.8	6.4	470
3/10/08	1100	-7.6	-5.0	2.6	480
3/10/08	14:00	-1.6	-2.1	-0.5	312
3/10/08	17:00	-1.3	-2.0	-0.7	705
3/11/08	8:00	-13.1	1.3	14.4	373
3/11/08	1100	-2.4	1.5	3.9	312
3/11/08	13:00	2.1	2.0	-0.1	252
3/11/08	17:00	0.5	1.2	0.7	236
3/12/08	8:00	-9.3	-2.1	7.2	142
3/12/08	1100	2.3	2.5	0.2	90
3/12/08	15:00	3.5	-0.3	-3.8	261

Table S.7-2. Summary of low-level temperature measurements, and related data on inversion strength.

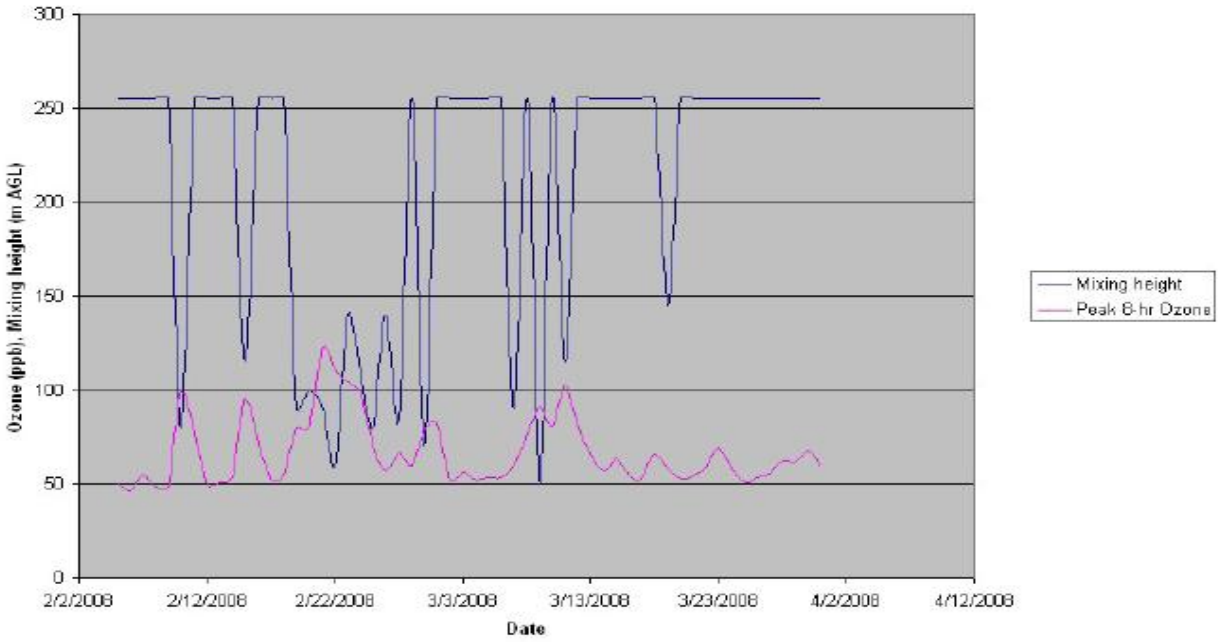


Figure S.7-9. SODAR-reported mixing height versus peak daily 8-hour ozone concentrations at Boulder. Measurements limited to below approximately 250 meters above ground level (AGL).

Soundings taken in the forenoon and afternoon of February 21, 2008 are shown in Figure S.7-10. Profiles for ozone (black line), temperature (red line), dew point temperature (dashed blue line) and winds (vectors) are plotted as functions of height above the ground elevation of the balloon launch site. A strong low-level inversion was present up to 2,500 meters-msl (~ 400 meters-agl) with a maximum temperature at the top of the inversion of -2.9 ^{o}C, several degrees warmer than the temperature at the surface. Boundary-layer winds in the forenoon were light from the west when ozone levels were ~50 ppb, before becoming southeast in the afternoon.

Figure S.7-10 shows the inversion is setting up in the morning of February 21, 2008, and that the inversion persisted through daylight hours, resulting in high ozone concentrations beneath the inversion. Figure S.7-10 also shows that at 11:00 (MST) ozone concentrations were ~ 50 ppb below the inversion height of 2,500 meters (MSL) which is shown by the green circle (left pane) towards the bottom of Figure S.7-10; measured ozone levels above the inversion layer were also generally ~ 50 ppb.

Normally, some vertical mixing of the air would exist, as the temperature aloft begins to fall off with increasing height above ground; however, the strong surface-based inversion persists to 4:00 pm, effectively inhibiting vertical mixing. A shallow layer of high ozone (> 110 ppb) was present in the afternoon (16:00 MST) sounding, which is shown by the green oval (right pane) towards the bottom of Figure S.7-10. Ozone concentrations decrease rapidly with height below the inversion; ozone levels above the inversion are about 50 ppb. Note that the vertical wind shear measured at the top of the inversion layer height above ground (wind arrows on the right side of graphs) attest to the complete decoupling of the boundary layer air from layers aloft.

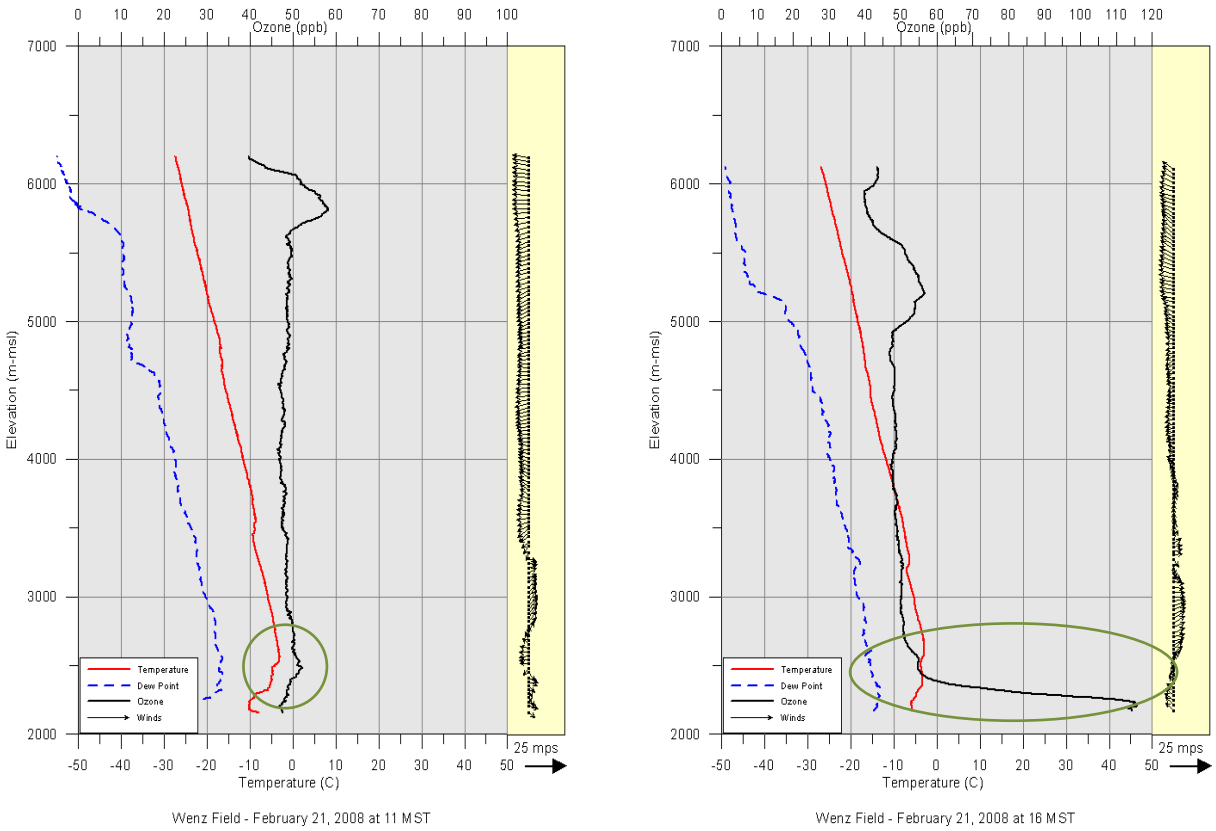


Figure S.7-10. February 21, 2008 balloon-borne soundings; Sounding at 11:00 (MST) (left); Sounding at 16:00 (MST) (right).

Tools to Evaluate Air Parcel Transport: HYSPLIT vs. AQplot Back Trajectory Analyses

Trajectory analyses were used to determine possible air parcel transport into the UGRB during February 20, 2008, as a means of evaluating possible precursor emissions and ozone transport in the UGRB and at the Boulder and Jonah monitors.

The HYSPLIT (HYbrid Single-Particle LaGrangian Integrated Trajectory) model is a trajectory model that is used for computing simple air parcel trajectories. HYSPLIT can use meteorological data from several archived meteorological modeling databases, including the NCEP Eta Data Assimilation System (EDAS), which is based on a 40 kilometer resolution data (2004-present). However, 40 kilometer (km) data may not provide sufficient resolution to resolve the significant terrain features that influence the wind flow patterns in the UGRB. The result of using such low resolution data to represent the terrain features in and surrounding the UGRB will be that the modeled terrain will be much smoother, and will not match the actual terrain (see Figure S.7-11). This will affect the wind trajectory analysis because the roughness of the terrain as well as terrain blocking and channeling effects may not be well represented, which would otherwise influence the wind speeds and the trajectory path lengths. In very complex terrain, such as in the UGRB, the HYSPLIT model trajectories may not be very accurate unless the local wind flow patterns are being driven by the large-scale synoptic conditions (e.g., strong winds).

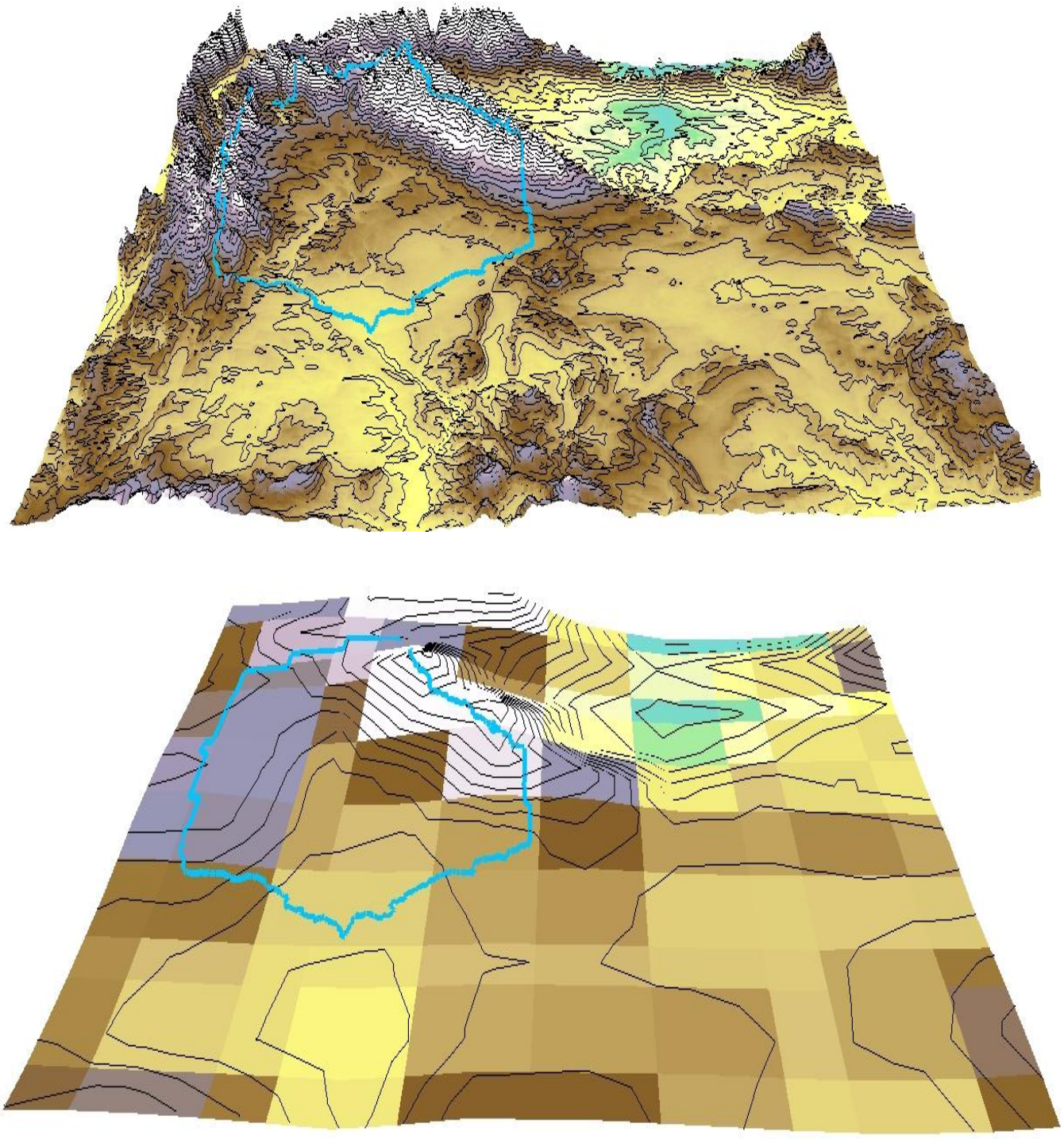


Figure S.7-11. A comparison of the local terrain features at 1 km and 40 km resolution, respectively, and the resulting "smoothed" terrain as shown in the 40 km 3-D topographic plot.

Figure S.7-12 shows a similar comparison of the local terrain features at 1 km and 40 km resolution as depicted in the 2-dimensional contour plots. Note the terrain features in the bottom pane are much less resolved (less terrain detail and decreased roughness) than those terrain features as shown in the top pane.

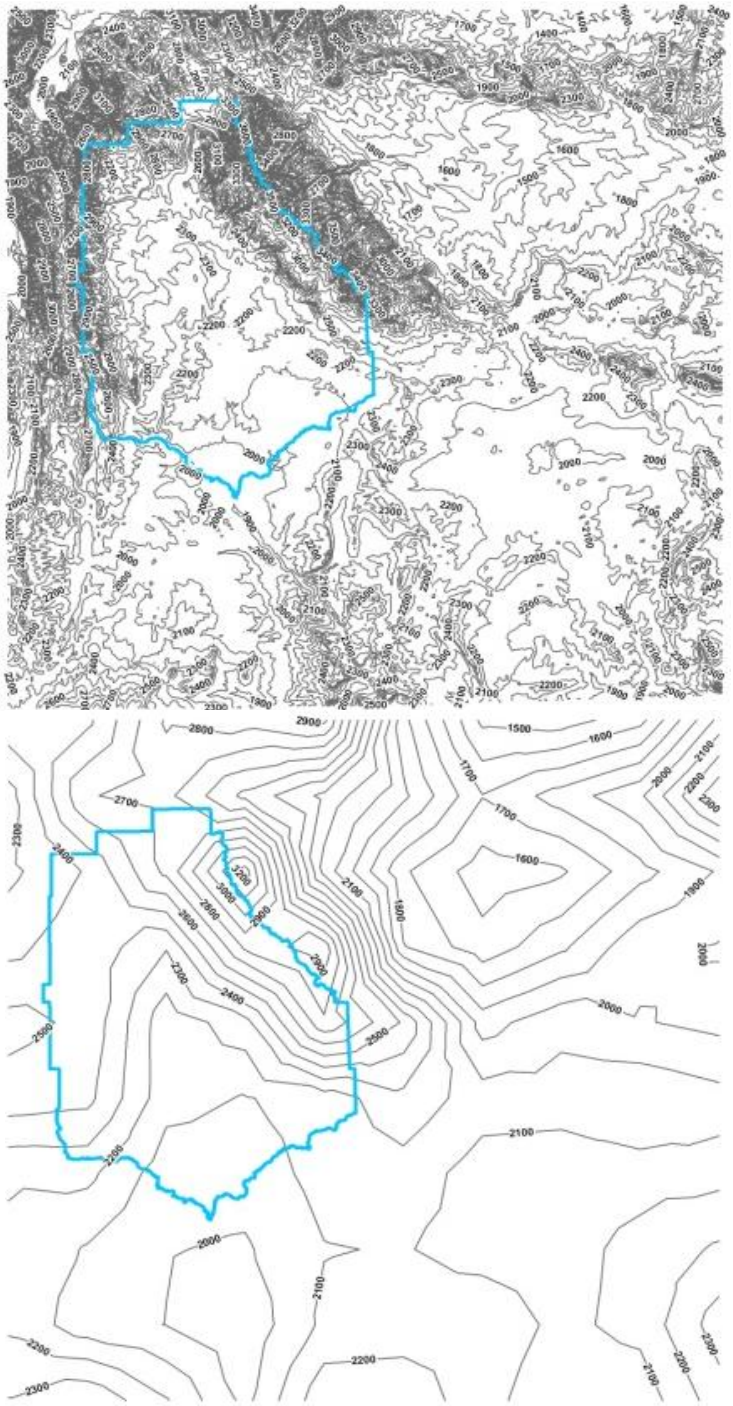


Figure S.7-12. A comparison of the local terrain features at 1 km and 40 km resolution, respectively, as depicted in the 2-D contour plots.

While the trajectory model is a useful tool in assessing approximate air parcel movement, and can be used to better understand potential pathways for pollutants moving within and into and out of the UGRB, trajectories are a highly simplified representation of the complex, two- and three-dimensional transport and turbulent diffusion processes that move pollutants from place to place. Thus, a particular trajectory path is subject to uncertainty and should not be interpreted as an exact representation of actual pollutant transport. Generally, the longer an air mass is tracked forward or backward in time, the more uncertain is its position (Kuo et al., 1985; Rolph and Draxler, 1990; Kahl and Samson, 1986).

Additionally, the trajectory model error is a function of the complexity of the meteorological scenario under study. In this analysis, the strong surface-based inversion layer in place on February 19-22, 2008 results in a decoupling of the upper air layers (above the inversion layer) and the lower air layers (below the inversion) and winds in the upper and lower layers will at times blow in different directions at different speeds. Winds are light and variable in the lower layer, adding to the complexity of the situation. This very complex meteorological scenario is difficult to represent accurately in a trajectory model.

AQD ran a comparison of 12-hour back trajectories from the Jonah and Boulder monitoring sites, using the HYSPLIT model with the EDAS 40 kilometer meteorological data, and AQplot, (a 2-dimensional trajectory model) using actual meteorological data from the Jonah and Boulder monitoring sites, respectively. This comparison shows that much different back trajectories are produced by these two models, as shown in Figures S.7-13 and S.7-14. The 2-dimensional trajectory model (AQplot), used in these analyses, was developed by the Texas Commission on Environmental Quality.

Additional trajectory analyses using a 3-D trajectory model are discussed in the next section. However, for this particular comparison, a 2-D trajectory model is an acceptable model to assess trajectories near the monitoring sites because the surface winds in the UGRB under these episodic winter conditions have been effectively decoupled from the upper air layers. The amount of vertical air movement is limited due to the capping inversion in place – in other words, the movement of air parcels below the inversion is not influenced by winds above the inversion, and there is little vertical mixing of air near the ground. Monitoring data of the localized meteorological patterns in the proposed nonattainment area boundary show that under these episodic conditions, the wind patterns are 2-dimensional, and the use of the 2-D AQplot trajectory model for this particular application is reasonable under these winter meteorological conditions (inversion, low mixing height, and stable atmosphere) as the air parcel trajectories start off and tend to stay close to the ground.

As shown in Figures S.7-13 and S.7-14, the resulting short trajectories never get very far away from the monitor site; considering the short duration of the trajectory analysis, less interpolation error would be expected. The HYSPLIT model does not consider the wind influences as measured in the 2008 field study surface monitoring network; the AQplot local-scale back trajectories are a more accurate depiction of what is going on because of the input of local data.

- **Trajectories ending 14:00 MST at Boulder on 20 February 2008**
- **Markers at 1-hour intervals; 12 hours total**
- **Very light, meandering surface winds at Boulder not reproduced by EDAS 40 km data set**

Figure S.7-13. Comparison of HYSPLIT (red) and AQplot (pink) 12-hour back trajectories from the Boulder monitoring site on February 20, 2008.

- **Regional-scale model: HY-SPLIT back trajectories using 40 km resolution EDAS**
- **Local scale: UGWOS '08 surface wind data (markers at 1-hour intervals)**

- **20 February 2008: 14:00 MST surface back trajectory from Jonah**
- **Markers at 1-hour intervals; 12 hours total**

Figure S.7-14. Comparison of HYSPLIT (red) and AQplot (green) 12-hour back trajectories from the Jonah monitoring site on February 20, 2008.

This comparison demonstrates that the HYSPLIT model overestimates the back trajectory path length because the localized low wind speed conditions and the wind flow reversal are not reproduced in 40 kilometer EDAS meteorological analysis fields. Additionally, the HYSPLIT model trajectory shows a less dramatic shift in wind direction and much higher wind speeds leading to a completely different result. A trajectory model that accurately reflects the terrain influence, sustained low wind speeds, and local-scale observed wind flow patterns was needed to effectively evaluate air parcel transport throughout the UGRB under these episodic conditions.

AQplot Back Trajectory Analysis

Back trajectories using the AQplot model and the meteorological data collected during the field study on February 20, 2008 are shown in Figure S.7-15; the trajectories were used to evaluate air parcel movement near the monitors during the 12 hours leading up to the February 20, 2008 monitored high ozone concentrations. These back trajectories start at 2:00 pm (MST), and show that the wind patterns leading up to the afternoon high monitored ozone concentrations at the Boulder monitoring site (and other monitors in close proximity to the Boulder monitor) produce short trajectories, with the air parcels remaining in close proximity to these monitors during this 12-hour period, due to the observed low wind speeds and recirculation patterns (wind reversals).

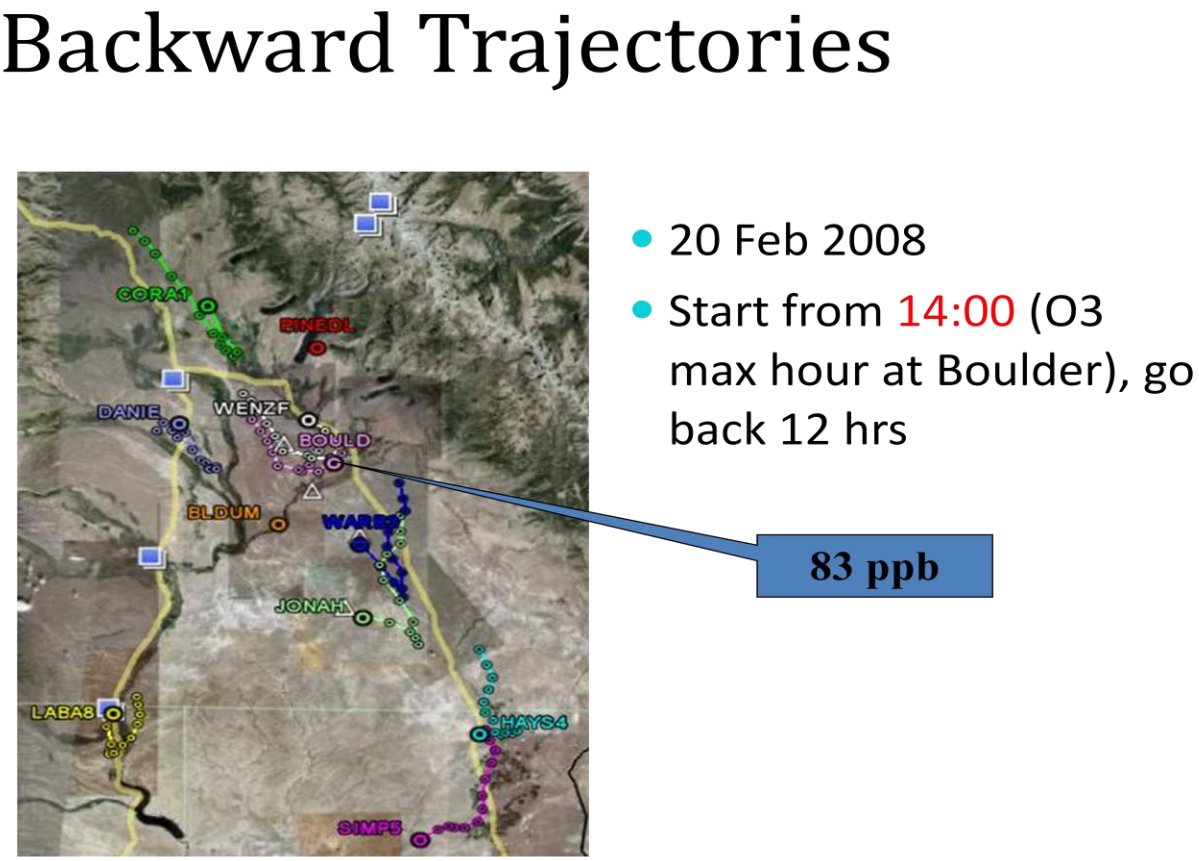


Figure S.7-15. 12-hour back trajectories near field study monitors on February 20, 2008.

Due to the complexity of the winds in the UGRB during February 19-23, 2008, including the significant terrain-dominated effects on localized winds, stable conditions, and wind flow reversals, as discussed, and the terrain-dominated regional meteorology outside of the UGRB, a high resolution 3-dimensional (3-D) wind field was needed that could correctly reproduce:

1) Shallow inversions and near-field wind flow patterns as measured at the SODAR, which is near the Boulder monitor; and
2) Regional-scale wind flow patterns.

This particular wind field would be utilized in conjunction with a full 3-D trajectory model to evaluate:

1) Air parcel movement in the study area;
2) Influences from the surrounding regional terrain on air parcel movement;
3) Air parcel inflow (ozone or precursor emissions transport) into Sublette County on the days leading up to and during the February 19-23, 2008 ozone episode.

AQD contracted out the development of a 3-D CALMET wind field to evaluate the above, which is discussed in the following section.

CalDESK Trajectory Analysis

AQD developed a high resolution (spatial and temporal) 3-dimensional wind field that uses the National Center for Environmental Prediction (NCEP) Rapid Update Cycle (RUC) model at 20 kilometer resolution, coupled with the high resolution observational database of surface and upper air meteorological data measurements obtained during the 2008 field study. It should be noted that the terrain elevation data used in this wind field is based on much higher terrain resolution than is currently used in the HYSPLIT model. The RUC and field meteorological data were processed through the CALMET diagnostic wind model to generate a 1 kilometer gridded wind field, using high resolution terrain and land use/land cover data, and actual observations of daily snow cover to account for actual snow cover (and albedo effects) within the CALMET domain. The complexity of the terrain, as represented in this 3-dimensional (3-D) CALMET wind field in shown in Figure S.7-16.

This CALMET wind field was developed to evaluate the ozone episode-specific meteorology associated with the February 18-23, 2008 ozone episode. The CALMET domain was set up using the same meteorological modeling domain (464 km x 400 km) developed for the Southwest Wyoming Technical Air Forum (SWWYTAF) modeling analyses (1999), with increased vertical resolution to total 14 vertical layers; the lower layers having small vertical depths in order to better resolve complex flow patterns and temperature inversions near the surface.

Figure S.7-17 provides a snapshot of the wind field based on the winds at 4:00 am (MST) on February 20, 2008, and shows the complexity of the terrain surrounding the UGRB is very well represented in the CALMET wind field. The wind field captures the strong terrain-dominated down slope winds during the early morning hours, and the strong channeling and drainage effects which are exhibited throughout the UGRB – CALMET “sees” the influence of the terrain.

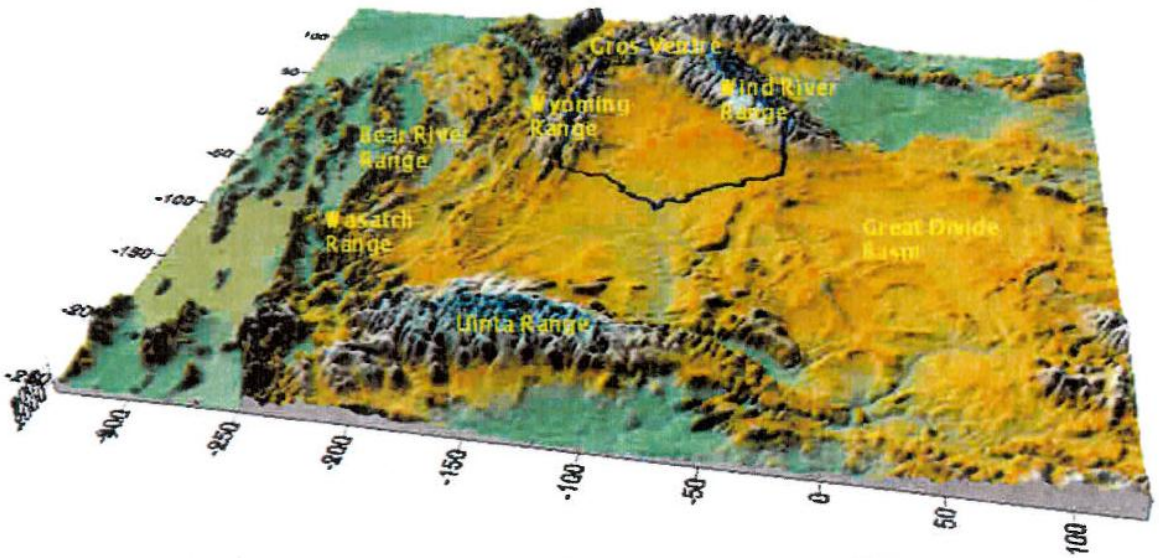


Figure S.7-16. Terrain features in CALMET modeling domain (464 km x 400 km).

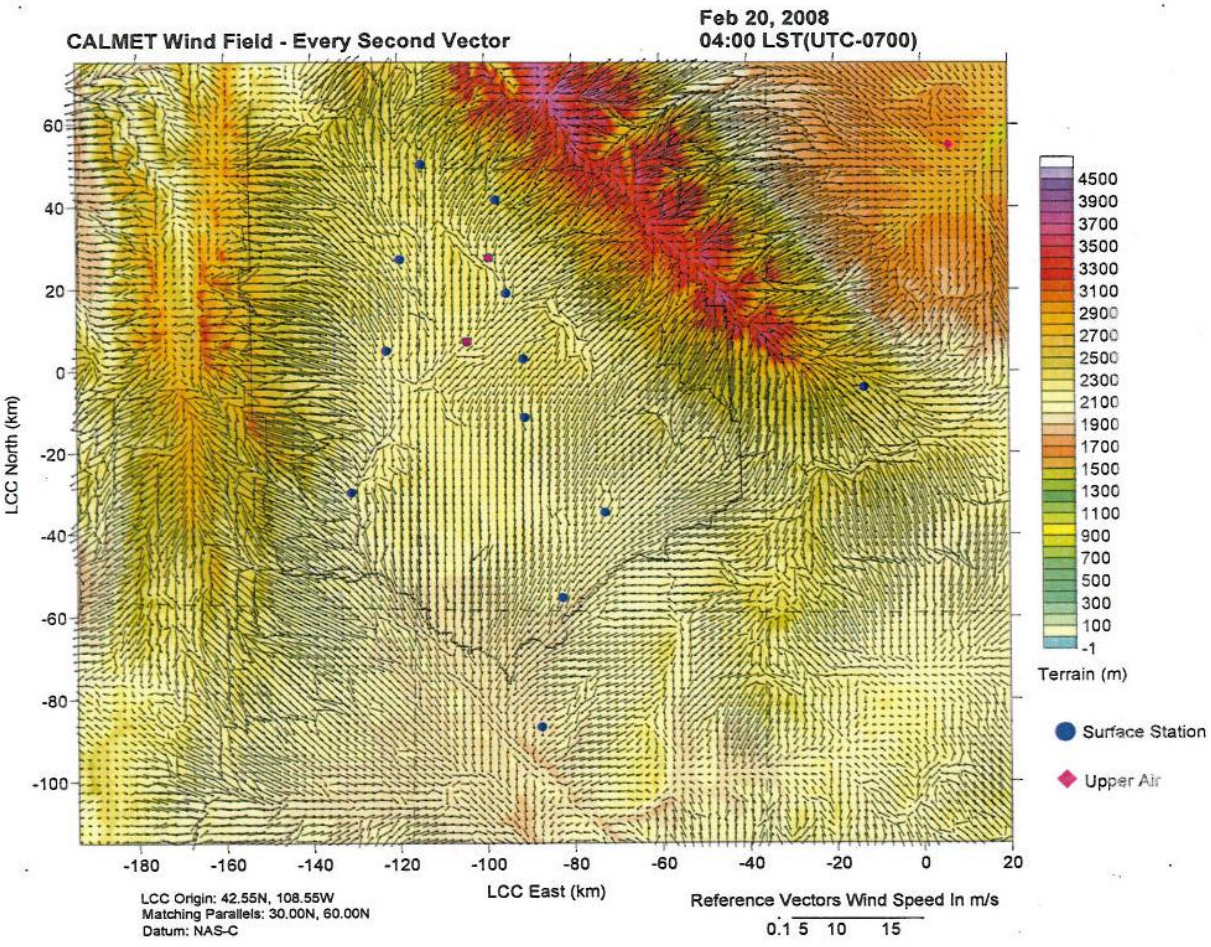


Figure S.7-17. CALMET wind field at 4:00 am (MST) on February 20, 2008. The 2008 field study meteorological monitoring sites are shown for reference.

The 3-D CALMET wind field accurately depicts meteorological conditions in the UGRB and surrounding area. A detailed report discussing the development of the CALMET wind field and the validation of the wind field compared to observations, entitled, "Upper Green River Winter Ozone Study: CALMET Database Development Phase I" will be posted on the DEQ web site and will be sent under separate cover to EPA shortly. Validation of this wind field has shown that the local-scale observed meteorological conditions are being reproduced:

- Temperature lapse rates associated with inversion conditions and low mixing heights
- Wind speeds and wind reversals
- Duration of down slope winds, which last until approximately mid-day before reversing to a generally southeasterly wind flow pattern

The trajectory analyses using this wind field lead to the conclusion that regional transport is insignificant, and local-scale precursor emissions transport is the dominant means of precursor transport during the high ozone periods. The trajectory analyses that follow were a key factor in selection of an appropriate southern boundary of the nonattainment area. The trajectory analyses demonstrate that the proposed southern boundary of the nonattainment area is reasonable, and that there is no significant contribution of ozone or ozone precursors from areas or sources outside the proposed nonattainment area during elevated ozone events.

Specific Examples of Trajectory Analyses Using CalDESK

Based on this wind field, AQD used the CalDESK visualization software to run forward trajectory analyses to evaluate air parcel transport into and out of the UGRB, specifically with respect to air parcels from large stationary sources (power plants and Trona plants) located to the south of the UGRB, and to evaluate the southern extent of air parcel inflow into the UGRB. A series of CalDESK forward trajectory analyses follow, along with a brief discussion of the resulting trajectories generated by CalDESK during February 18-23, 2008. CalDESK Forward Trajectory Analyses (FTA) for February 18, 2008 are shown in Figures S.7-18 through S.7-22.

NOTE: Trajectory figures (Figures S.7-18 through S.7- 49) are being updated to show the proposed nonattainment area boundary. Those figures will be available shortly. AQD will send those figure to EPA as replacement pages.

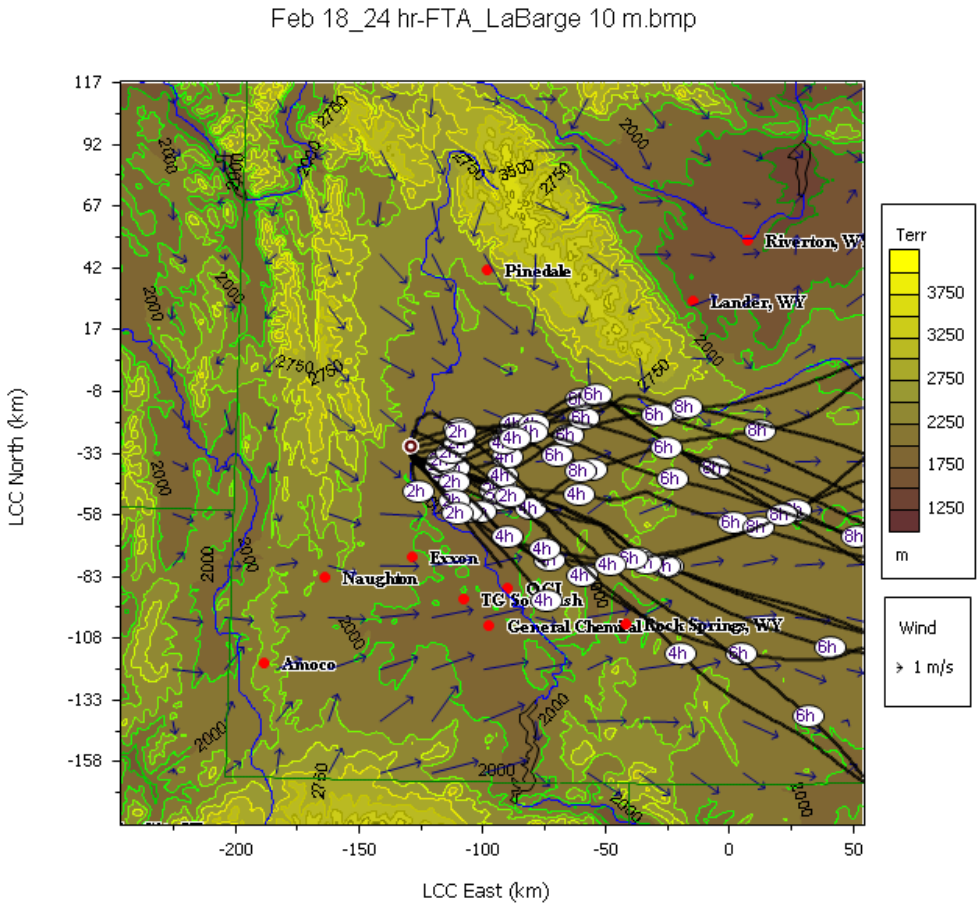


Figure S.7-18. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 18, 2008.

As shown in Figures S.7-18 through S.7-22, the prevailing northwest winds within the UGRB on this day limit air parcel transport into the UGRB from sources located south of Sublette County, which is reflected in the trajectory analysis for the LaBarge and Moxa Arch areas, the Naughton power plant, the OCI Trona processing facility, and the Bridger power plant. Additionally, the wind speeds at the monitoring sites on the Pinedale Anticline were also generally high and reflect the prevailing northwest winds typical of the study area during most of the year. This moderately strong, organized northwest flow does not extend to the field study southern monitoring sites (Haystack Butte and Simpsons Gulch); these southern monitoring sites experienced a generally westerly wind. The 2008 field study monitoring sites are shown in Figure S.7-1.

Wind speeds were generally high throughout the monitoring network on February 18th. These conditions continued throughout the night until the early morning of February 19th. Winds decreased significantly thereafter becoming light and variable for the remainder of the day, setting the stage for the next several days. Ozone levels were relatively low, in the 50 ppb range on February 18th; increasing on February 19th, with both the Boulder and Jonah monitoring sites experiencing 8-hr peaks of 80 ppb.

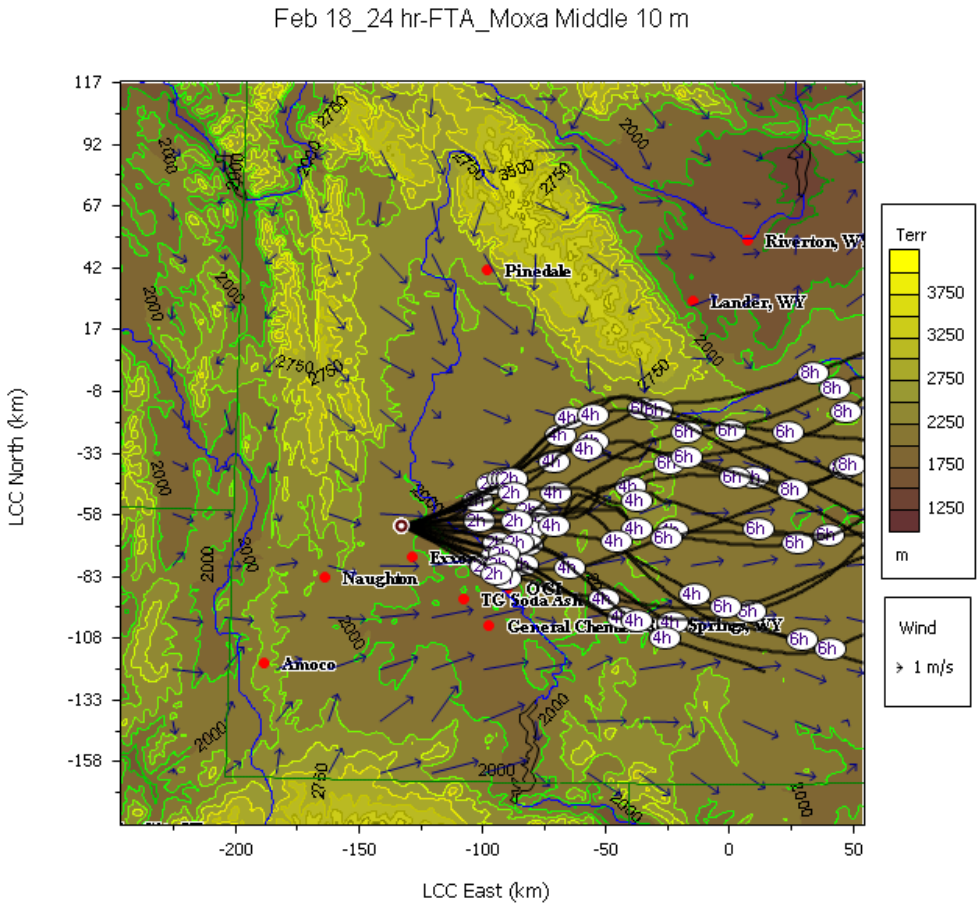


Figure S.7-19. 24-hour forward trajectory analysis in the Moxa Arch area on February 18, 2008.

The trajectory analysis shown in Figure S.7-19 places the initial air parcel release point in the northern part of the Moxa Arch field. The predominant paths shown trend to the east, and there is a slight northerly component to several of the modeled trajectories. These trajectories generally parallel the southern boundary of the proposed nonattainment area along Pacific Creek. While some of the trajectory paths lie within the proposed nonattainment area, none of the paths indicate that sources within the Moxa Arch cause or contribute to elevated ozone levels within the proposed nonattainment area.

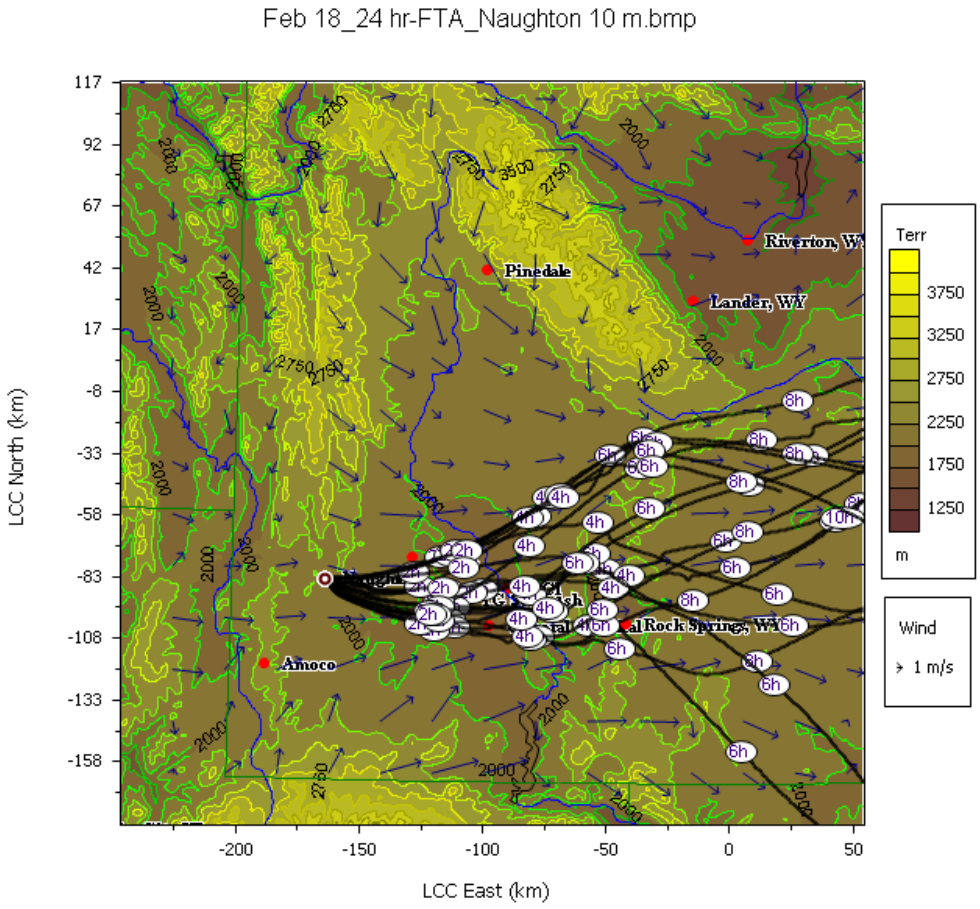


Figure S.7-20. 24-hour forward trajectory analysis at Naughton power plant on February 18, 2008.

The trajectory analysis in Figure S.7-20 shows all modeled trajectories from Naughton not entering the proposed nonattainment area.

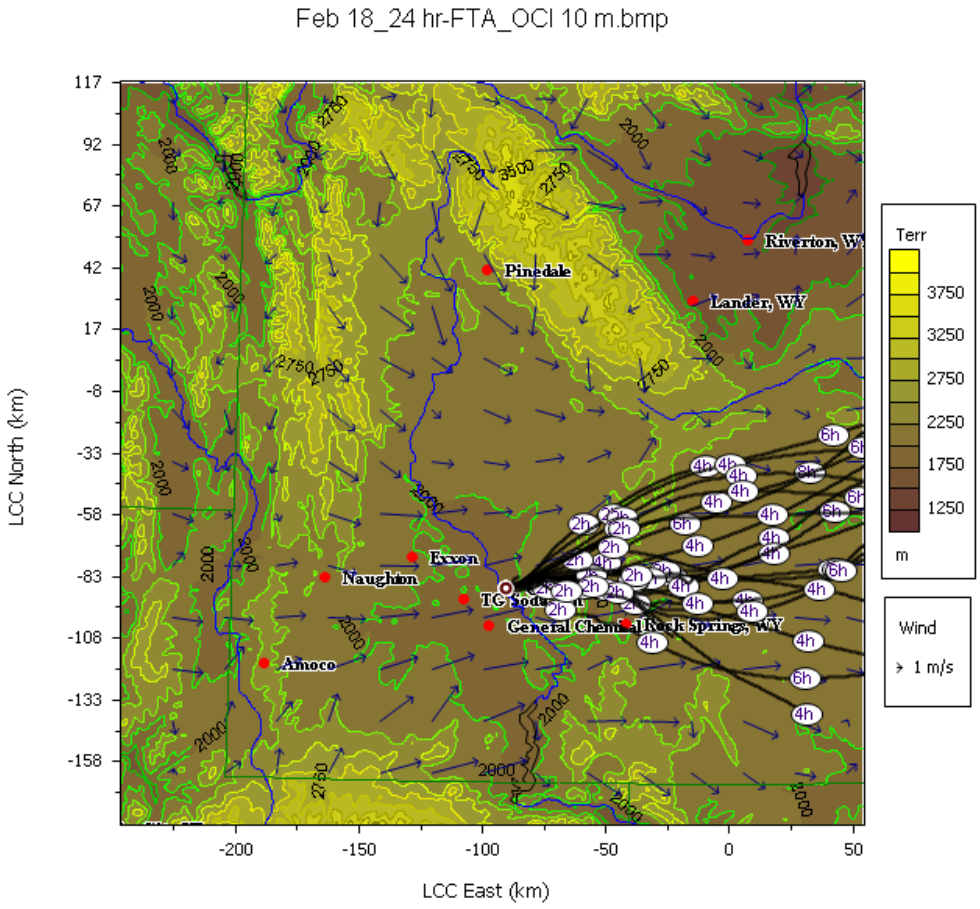


Figure S.7-21. 24-hour forward trajectory analysis at OCI Trona plant on February 18, 2008.

The trajectory analysis in Figure S.7-21 shows all modeled trajectories from OCI not entering the proposed nonattainment area.

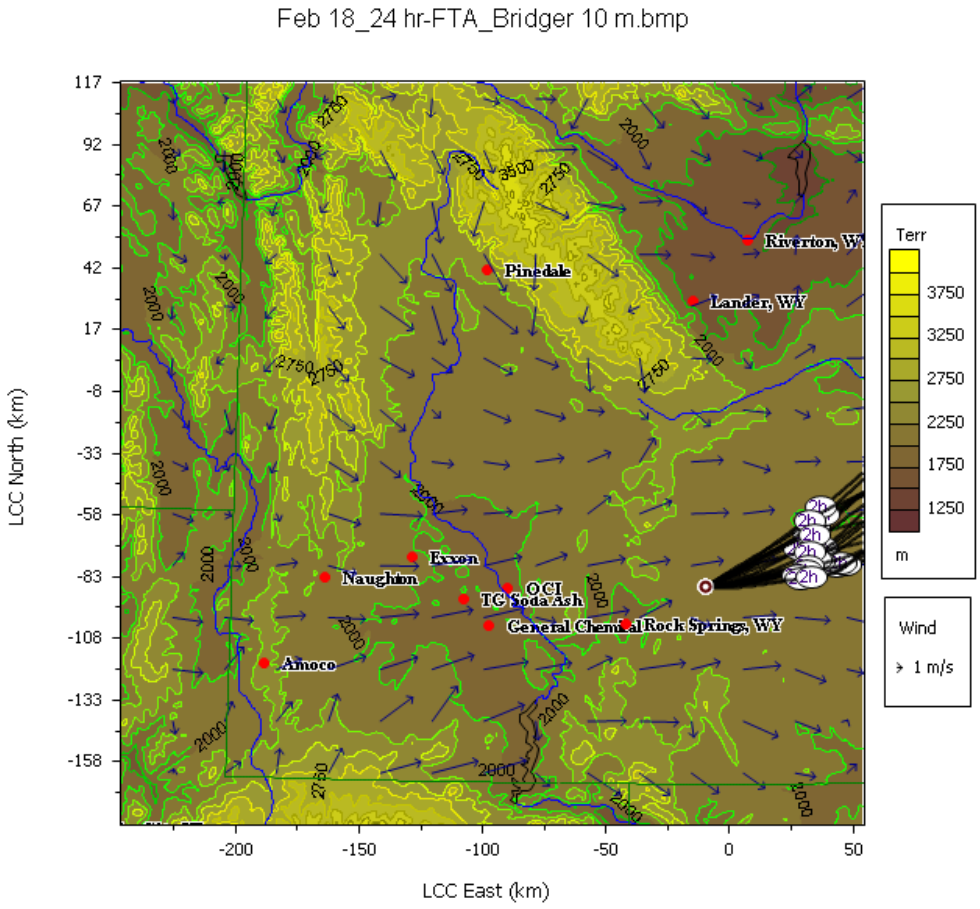


Figure S.7-22. 24-hour forward trajectory analysis at Bridger power plant on February 18, 2008.

The trajectory analysis in Figure S.7-22 shows all modeled trajectories from Bridger not entering the proposed nonattainment area.

CalDESK Forward Trajectory Analyses for February 19, 2008 are shown in Figures S.7-23 through S.7-29.

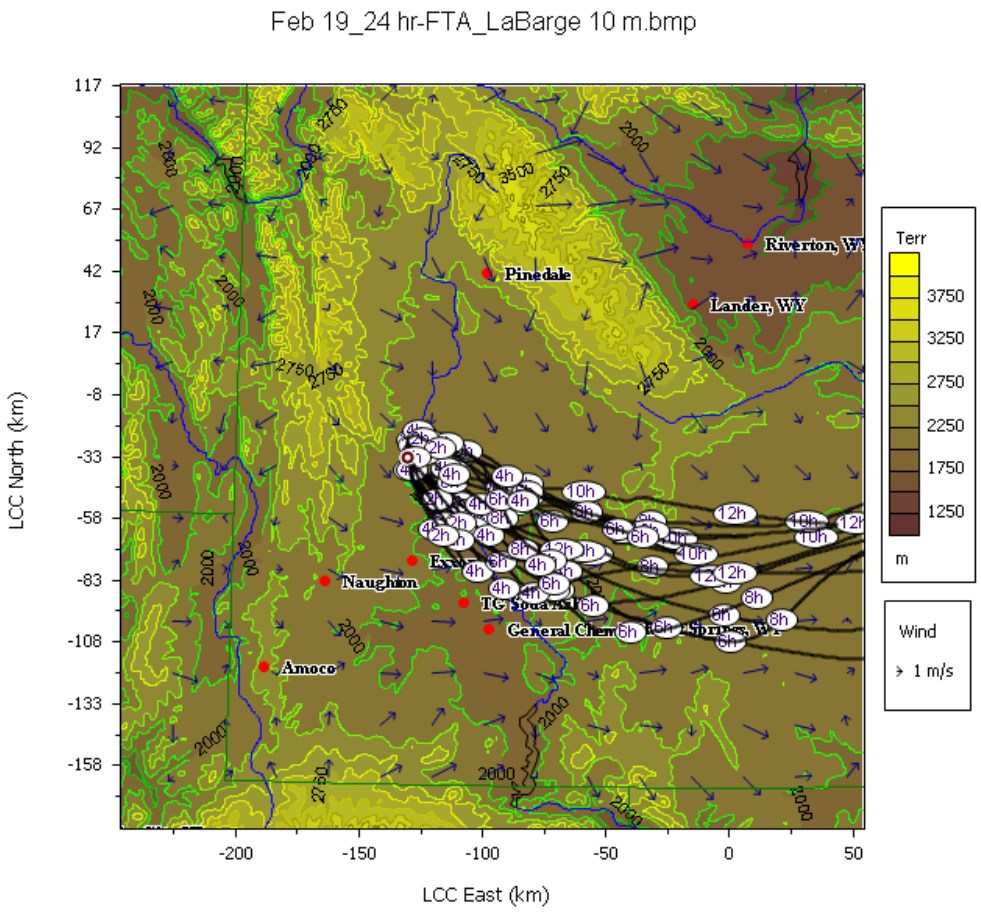


Figure S.7-23. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 19, 2008.

As shown in Figures S.7-23 through S.7-27, the prevailing northwest winds on February 19th continue to limit air parcel transport into the UGRB from the south, which is reflected in the trajectory analysis for the LaBarge and Moxa Arch areas, the Naughton power plant, the OCI Trona processing facility, and the Bridger power plant.

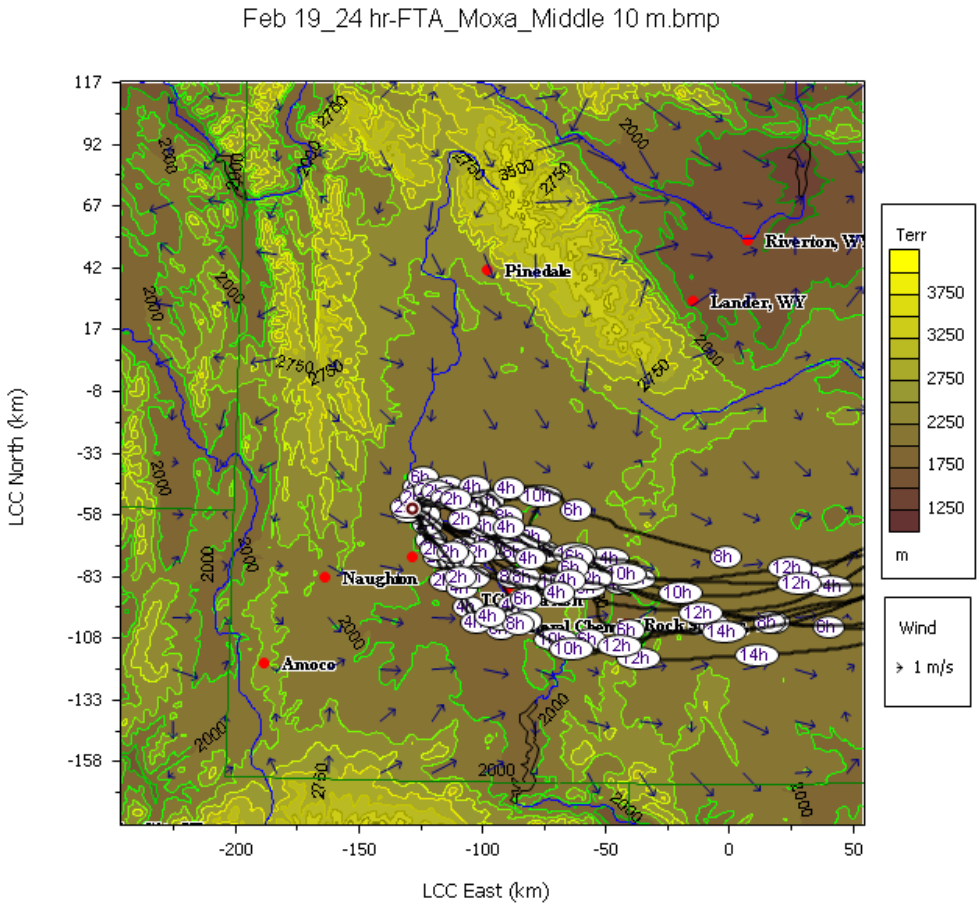


Figure S.7-24. 24-hour forward trajectory analysis in the Moxa Arch area on February 19, 2008.

The trajectory analysis in Figure S.7-24 shows all modeled trajectories from Moxa Arch not entering the proposed nonattainment area.

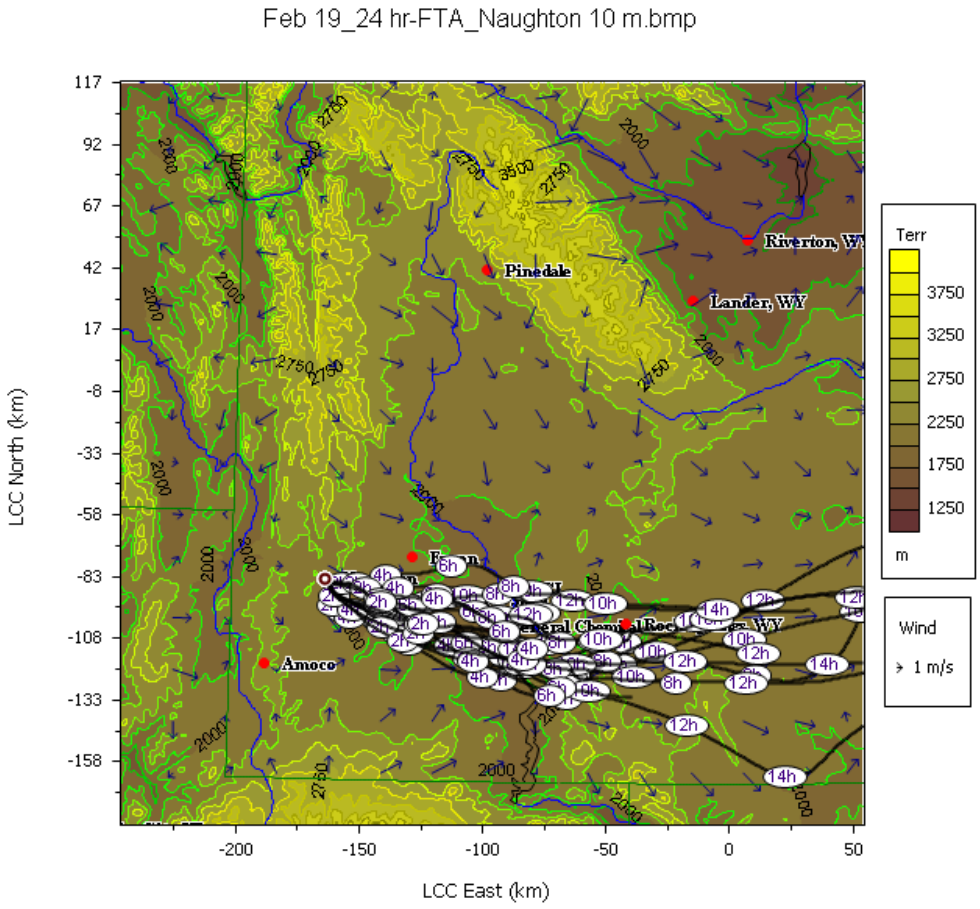


Figure S.7-25. 24-hour forward trajectory analysis at Naughton power plant on February 19, 2008.

The trajectory analysis in Figure S.7-25 shows all modeled trajectories from Naughton not entering the proposed nonattainment area.

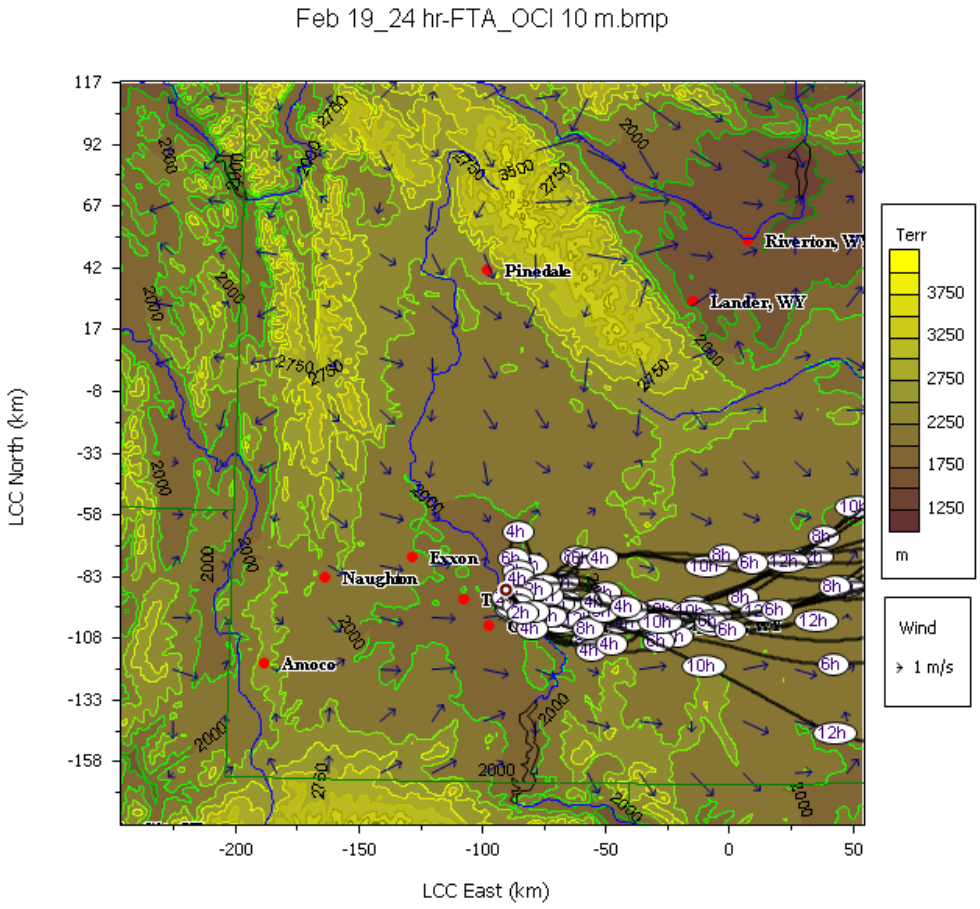


Figure S.7-26. 24-hour forward trajectory analysis at OCI Trona plant on February 19, 2008.

The trajectory analysis in Figure S.7-26 shows all modeled trajectories from OCI not entering the proposed nonattainment area.

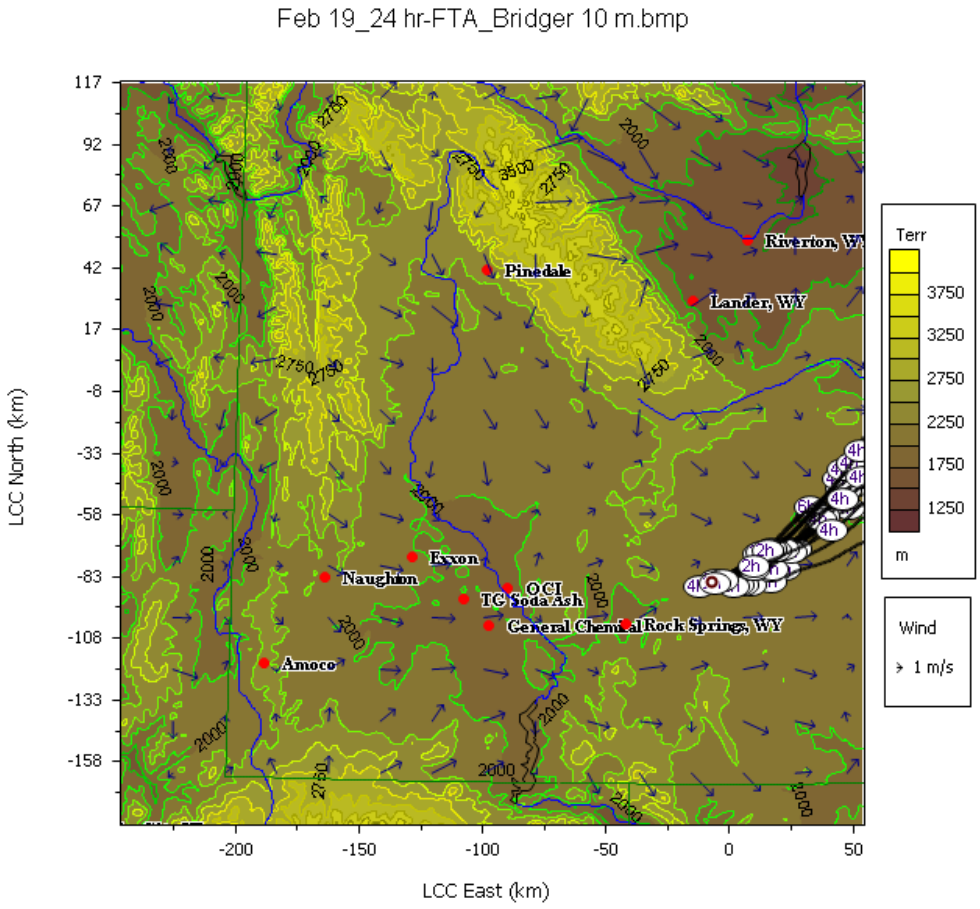


Figure S.7-27. 24-hour forward trajectory analysis at Bridger power plant on February 19, 2008.

The trajectory analysis in Figure S.7-27 shows all modeled trajectories from Bridger not entering the proposed nonattainment area.

CalDESK Forward Trajectory Analyses for February 20, 2008 are shown in Figures S.7-28 through S.7-32.

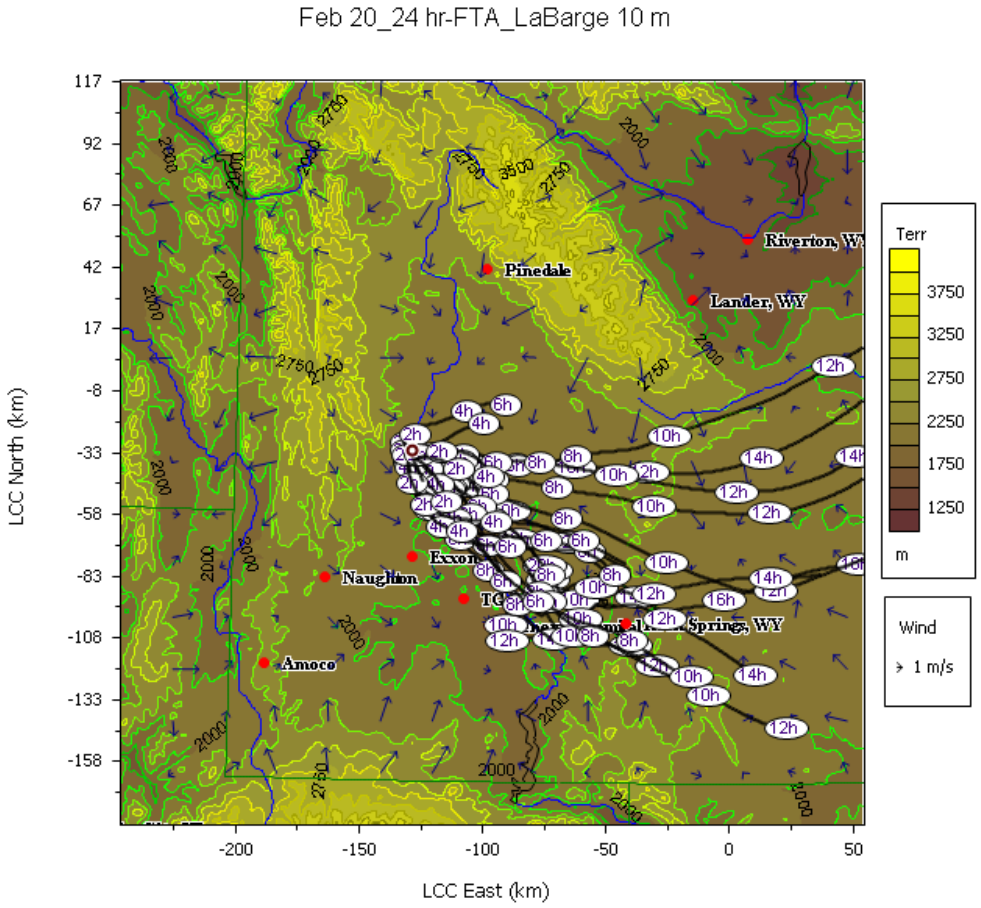


Figure S.7-28. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 20, 2008.

As shown in Figure S.7-28, on February 20, 2008, the trajectory analysis for the LaBarge area begins to exhibit a few possible trajectory paths into the area west of the Jonah oil and gas field, indicating some potential for upwind emissions transport at the Jonah monitor. Figures S.7-29 through S.7-32 show the prevailing northwest winds continue to limit southerly transport of emissions into the UGRB, along with the prevailing southwesterly winds along the Interstate-80 corridor, which are reflected in the trajectory analysis for the Moxa Arch area, the Naughton power plant, the OCI Trona processing facility, and the Bridger power plant.

It is important to note that as the trajectory start point is located further south, and out of the UGRB, the dominant northwest winds taper off, and the airflow at the south end of the UGRB mixes with the prevailing winds along the Interstate-80 corridor, which tend to dominate air parcel transport once the air parcel is out of the UGRB, south of the Wyoming Range terrain influence.

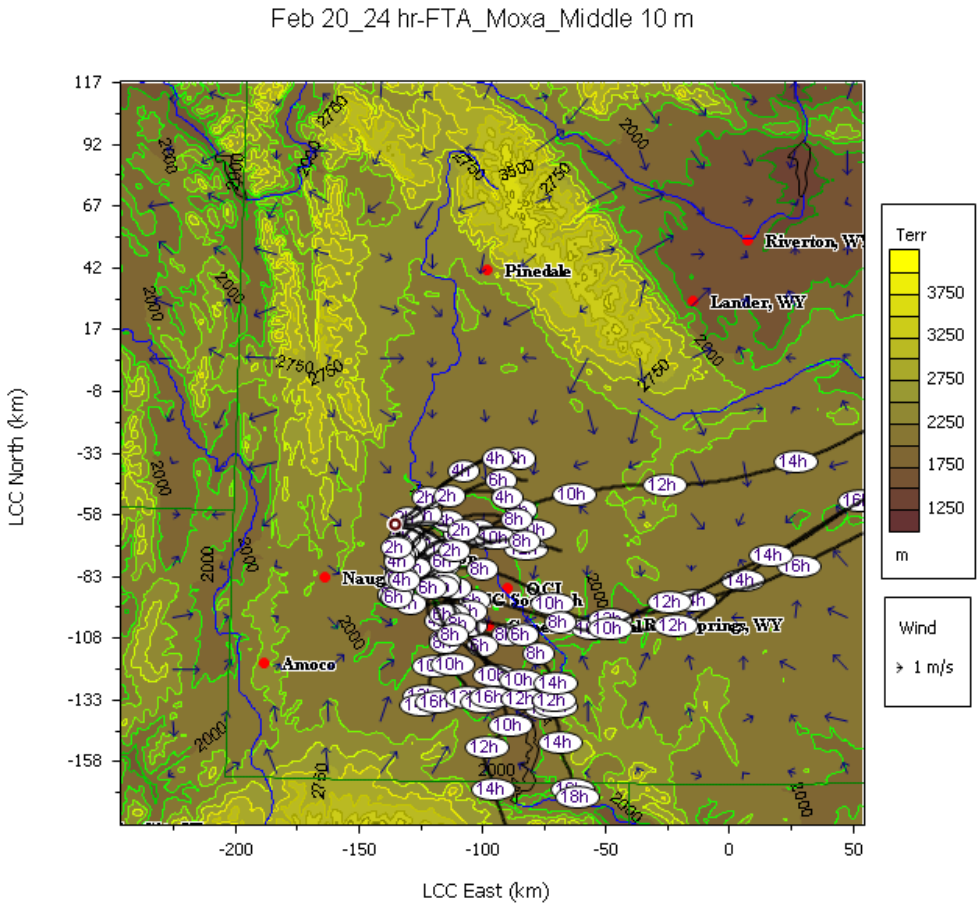


Figure S.7-29. 24-hour forward trajectory analysis in the Moxa Arch area on February 20, 2008.

The trajectory analysis in Figure S.7-29 shows all modeled trajectories from Moxa Arch not entering the proposed nonattainment area.

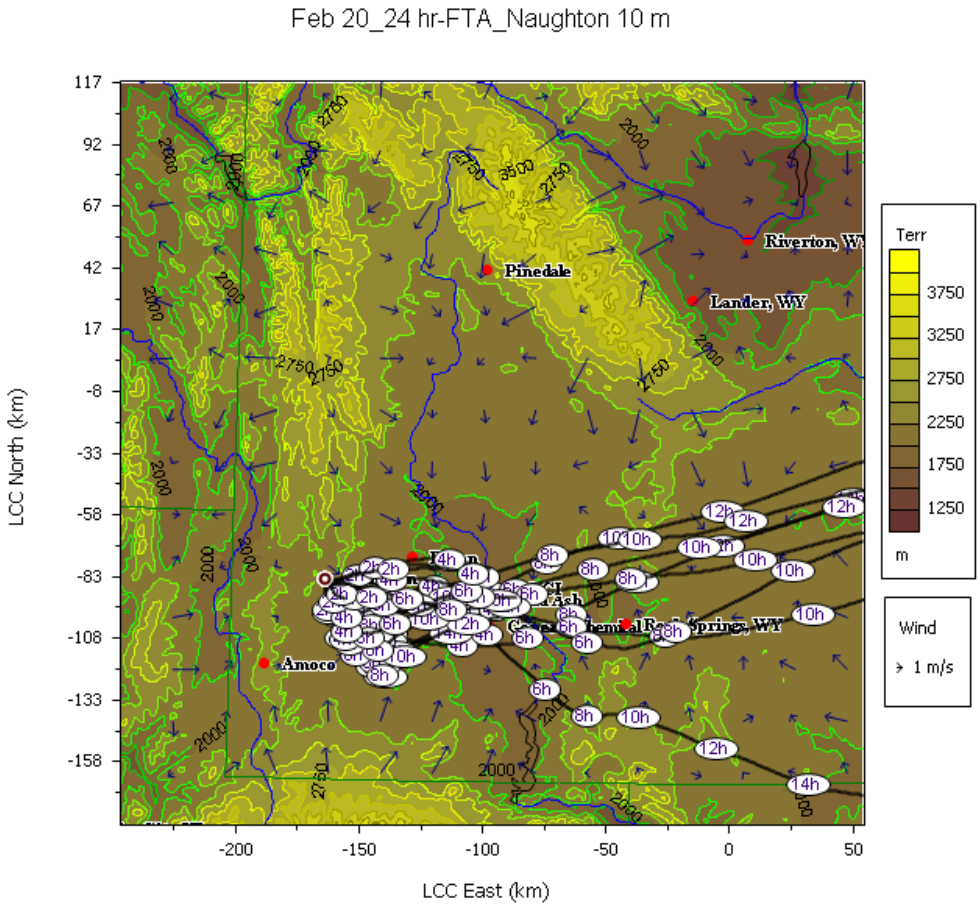


Figure S.7-30. 24-hour forward trajectory analysis at Naughton power plant on February 20, 2008.

The trajectory analysis in Figure S.7-30 shows all modeled trajectories from Naughton not entering the proposed nonattainment area.

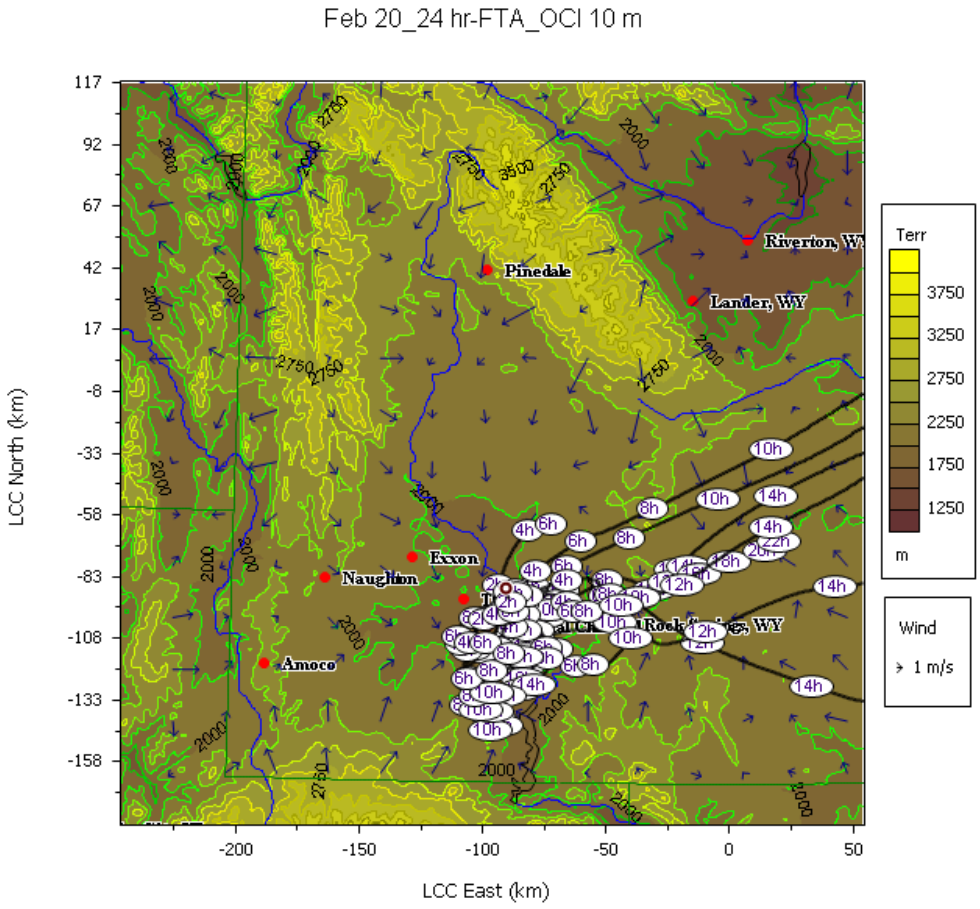


Figure S.7-31. 24-hour forward trajectory analysis at OCI Trona plant on February 20, 2008.

The trajectory analysis in Figure S.7-31 shows all modeled trajectories from OCI not entering the proposed nonattainment area.

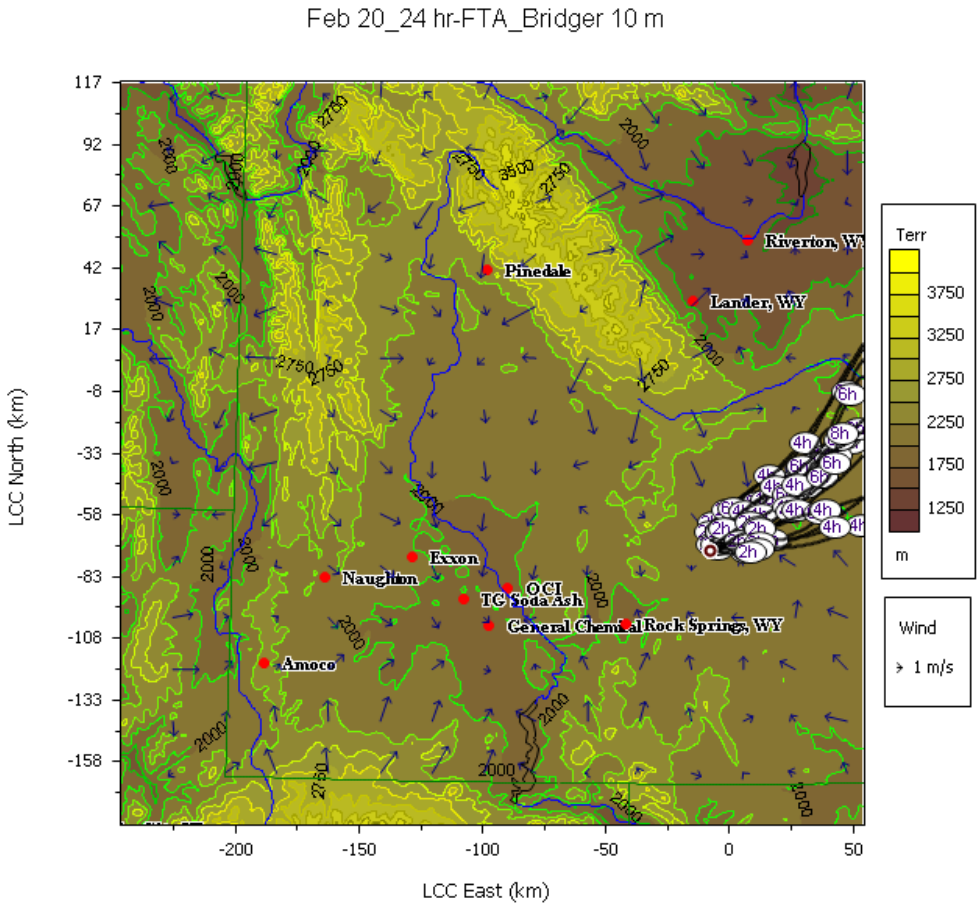


Figure S.7-32. 24-hour forward trajectory analysis at Bridger power plant on February 20, 2008.

The trajectory analysis in Figure S.7-32 shows all modeled trajectories from Bridger not entering the proposed nonattainment area.

CalDESK Forward Trajectory Analyses for February 21, 2008 are shown in Figures S.7-33 through S.7-37.

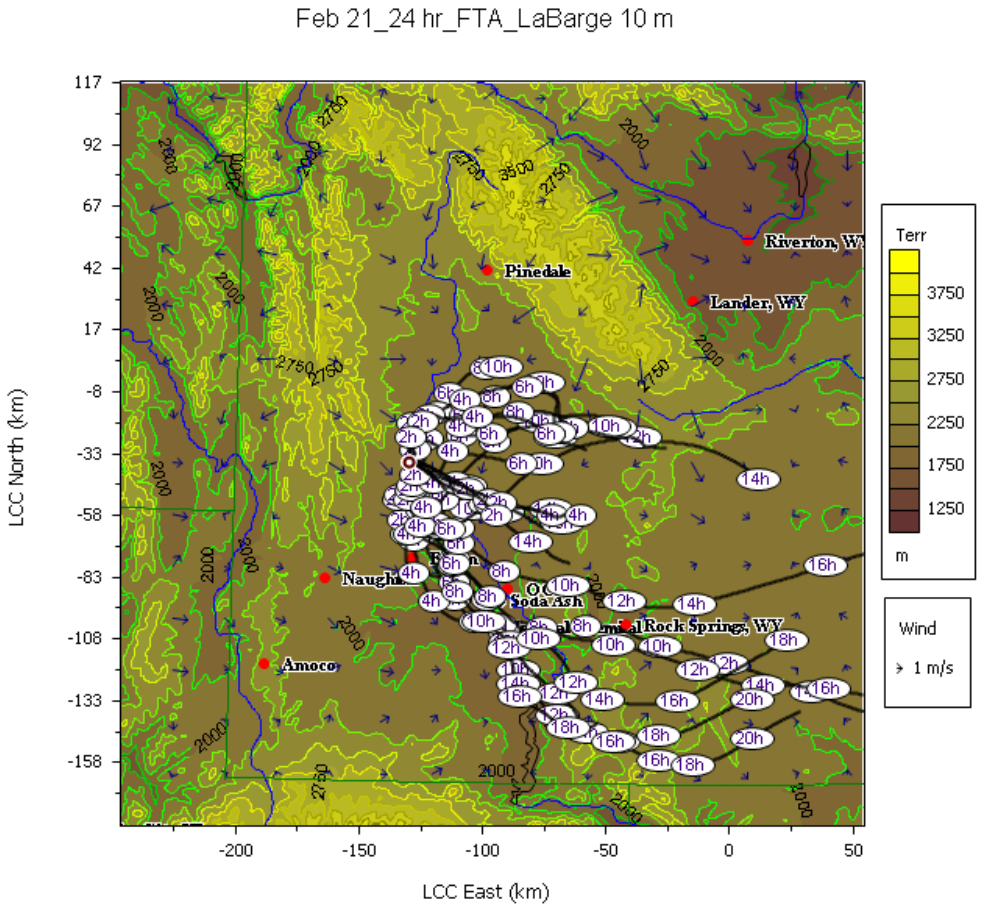


Figure S.7-33. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 21, 2008.

By the afternoon of February 21, 2008, the high pressure ridge had weakened, and had also flattened, and the central ridge axis was over or just east of southwestern Wyoming through the entire day; the resulting light wind stagnant situation also enabled the highest ozone production recorded at the Boulder monitoring site to date. These conditions were monitored during the first IOP, conducted February 18-21, 2008, in which a set of intensive meteorological and ambient measurements were collected when meteorological conditions similar to those associated with high ozone episodes during 2005 – 2006 had been forecast to occur during the 2008 field study.

The low level inversion was not quite as strong as on February 19, 2008, but it did stay intact through the entire daylight period, keeping ground level emissions trapped near the surface. With the very light and variable winds above the inversion, localized flow patterns near the ground level developed during the day allowing emissions to transport along those pathways.

As shown in Figure S.7-33, the trajectory analyses for the LaBarge area exhibit several possible air parcel paths to the northwest on February 21, 2008. Figure S.7-34 shows the trajectory analysis for the Moxa Arch area, which exhibits a few trajectories initially moving into the southernmost portion of the UGRB, but the strong northerly winds in the UGRB dominate the flow. This limits northward air parcel transport into the UGRB, and the vast majority of the trajectories continue to travel south out of the UGRB. The trajectory start point at Moxa Arch is approximately fourteen (14) miles south of the LaBarge trajectory start point, where the dominant northwest wind influence in the UGRB valley is tapering off, and mixes with prevailing westerly winds.

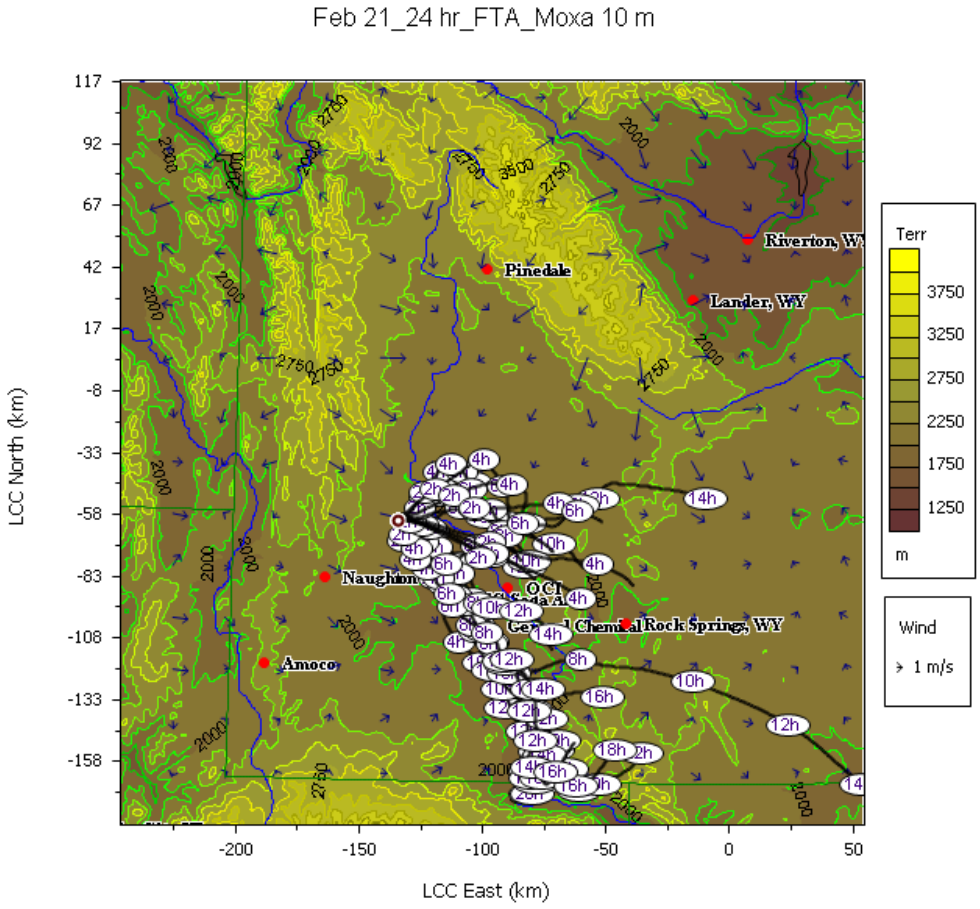


Figure S.7-34. 24-hour forward trajectory analysis in the Moxa Arch area on February 21, 2008.

Figure S.7-35 shows prevailing westerly winds at Naughton with air parcels moving eastward. The strong northwest winds in the UGRB and the terrain blocking effects of the Uinta Range to the south, collectively, influence the trajectory paths as they move from the Naughton power plant trajectory start point. The trajectory analysis in Figure S.7-35 shows all modeled trajectories from Naughton not entering the proposed nonattainment area

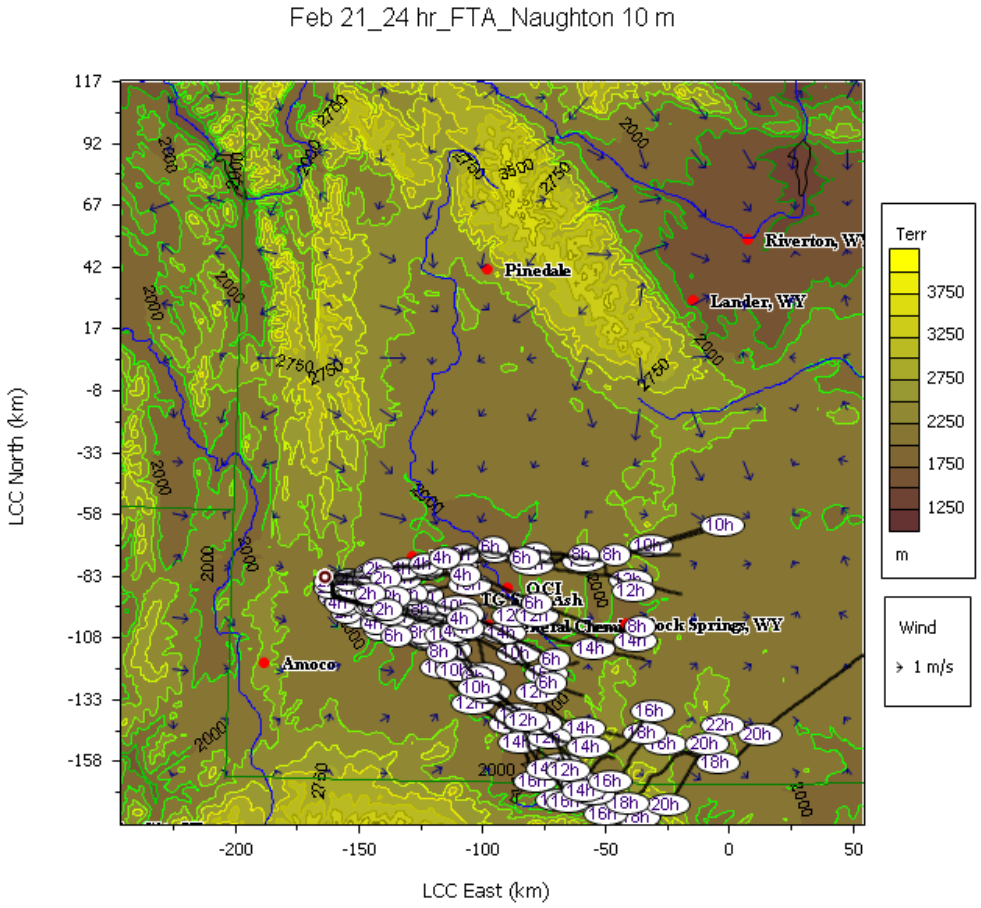


Figure S.7-35. 24-hour forward trajectory analysis at Naughton power plant on February 21, 2008.

Figures S.7-36 and S.7-37 show the prevailing westerly winds at the OCI Trona plant and the Bridger power plant, with the air parcels moving eastward and then northward. As noted with the forward trajectory paths from Naughton power plant, the strong northwest winds in the UGRB and the terrain blocking effects of the Uinta Range to the south continue to influence the trajectory paths as they move from the OCI and Bridger trajectory start points. The trajectory analysis in Figures S.7-36 and S.7-37 shows all modeled trajectories from OCI and Bridger not entering the proposed nonattainment area.

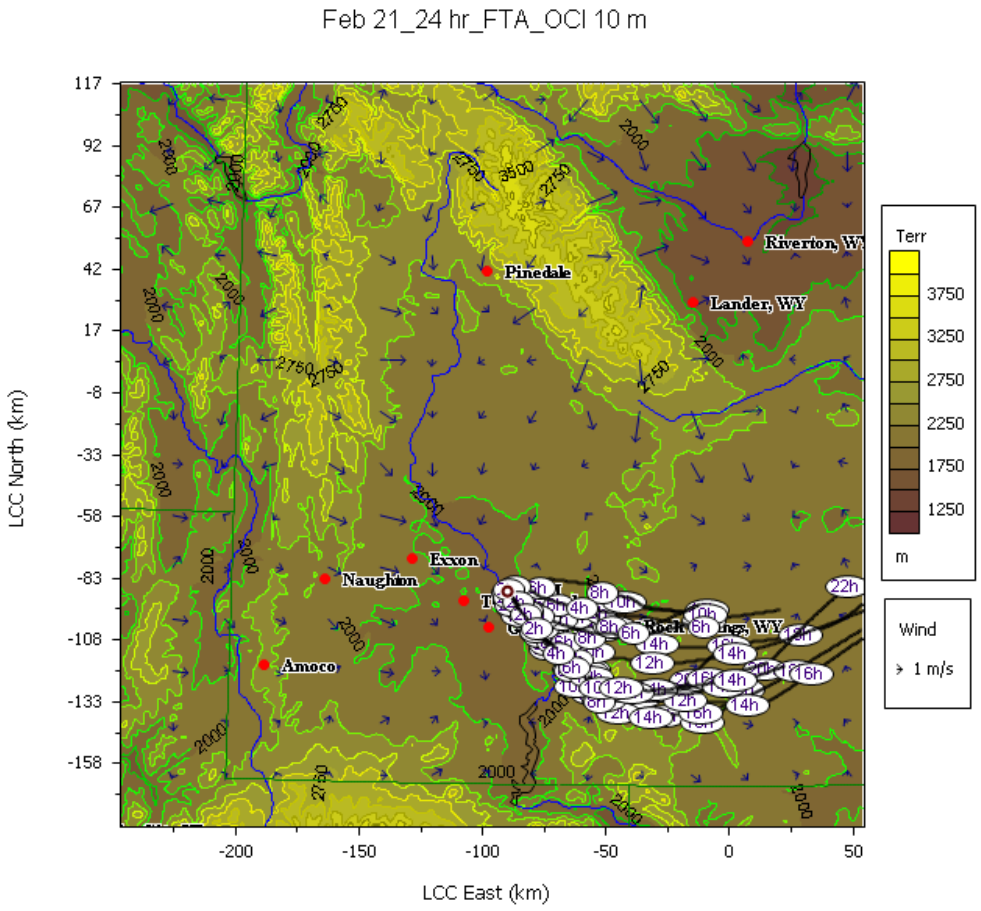


Figure S.7-36. 24-hour forward trajectory analysis at OCI Trona plant on February 21, 2008.

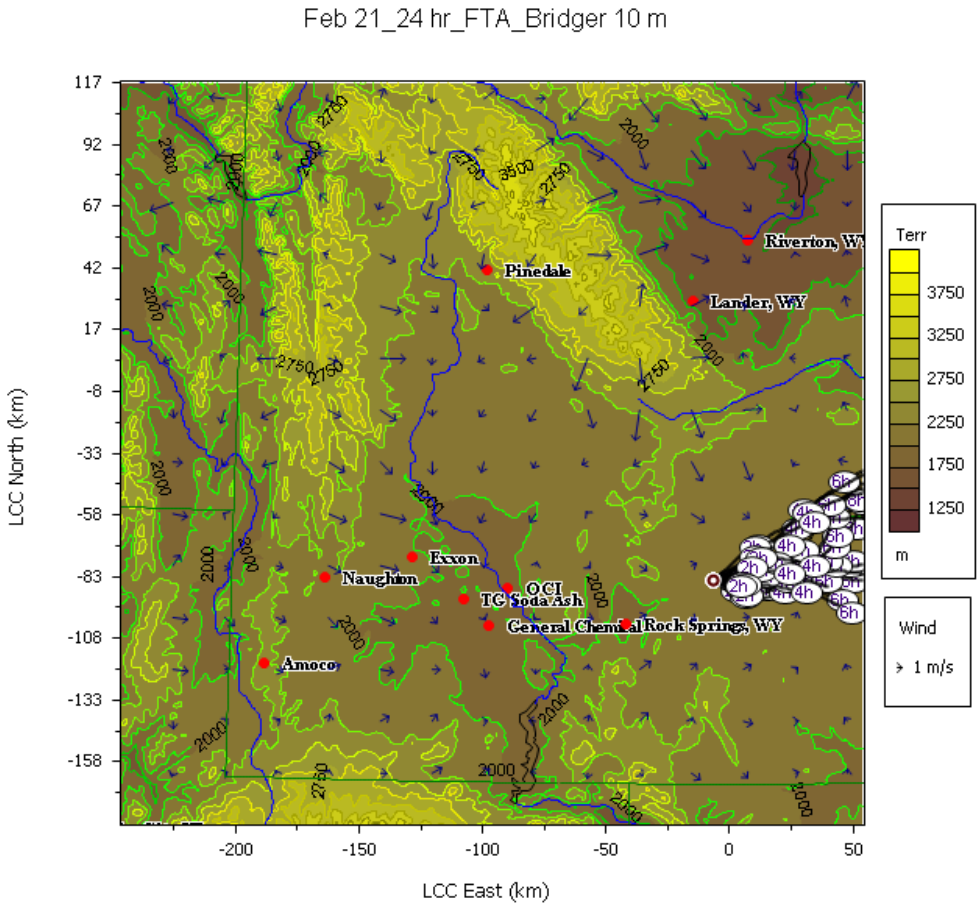


Figure S.7-37. 24-hour forward trajectory analysis at Bridger power plant on February 21, 2008.

As discussed previously, the localized meteorology within the UGRB during the ozone episodes influences air parcel movement within the UGRB, typically leading to shorter trajectory paths than if the trajectories were based on a start point located outside of the UGRB. CalDESK trajectory analyses that are initiated within the UGRB reflect the wind flow reversals and sustained low wind speeds; hence, shorter trajectory paths (and flow recirculation) are produced, which is consistent with the observed wind patterns.

During these wind reversals, the air flow changes direction. The winds are initially out of the northwest in the early morning, then out of the northeast, and then turn such that the winds flow out of the southeast later in the morning; the NW to SE wind flow reversal occurs approximately at 11:00 at the Boulder monitor on February 21, 2008.

CalDESK Forward Trajectory Analyses for February 22, 2008 are shown in Figures S.7-38 through S.7-42.

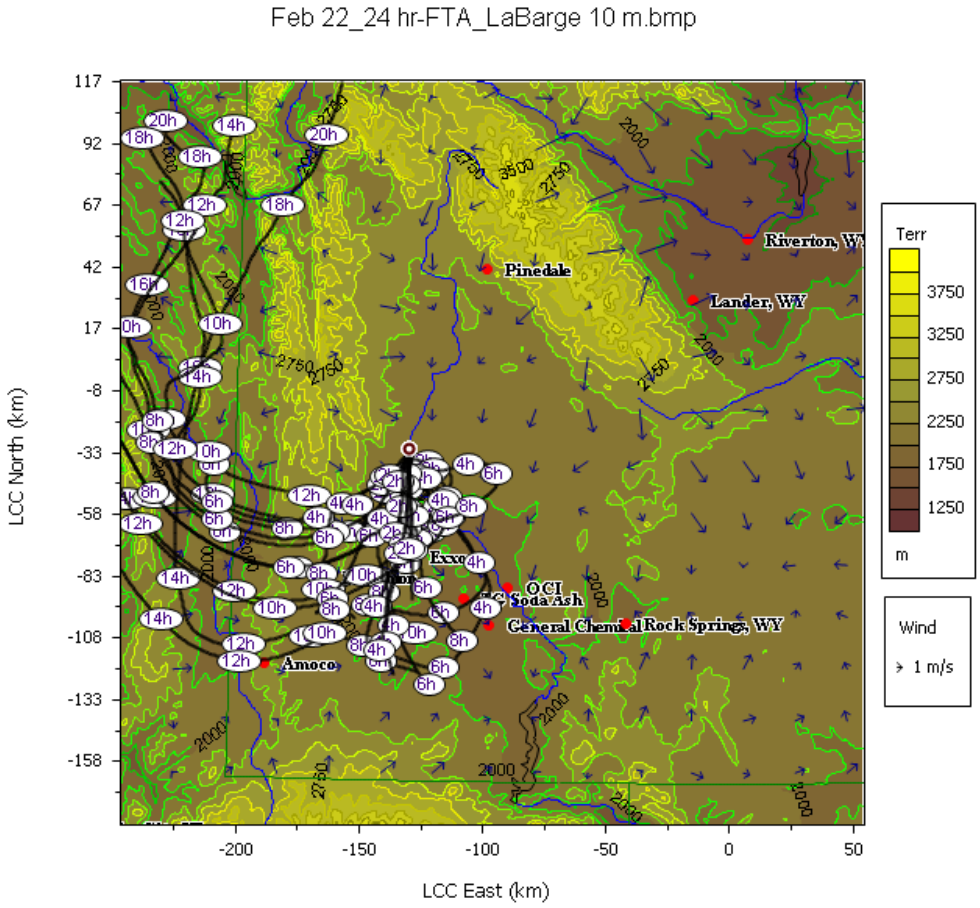


Figure S.7-38. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 22, 2008

The high pressure ridge continued to weaken during February 22, 2008, while a shortwave low pressure trough approached southwestern Wyoming from the northwest. Skies became mostly cloudy during the morning hours and light precipitation spread over the area later in the afternoon. However, the low level inversion stayed intact well into the afternoon, and ozone concentrations remained high during most of the day. No IOP operations were conducted this day because it was anticipated that the stable layer would be mixed-out by the trough by early morning and, therefore, trapped emission would be dispersed. Instead, the late arrival of the trough allowed one more day of high ozone concentrations.

As shown in Figure S.7-38, the trajectory analysis for the LaBarge area shows that most of the possible forward trajectory paths are now moving away from the UGRB during February 22nd. Figures S.7-38 through S.7-40 show air parcels tend to be blocked and channeled westward and then northward around the Wyoming Range, with limited air parcel movement into the UGRB. There are 1-2 trajectory paths showing air parcel movement from the Moxa Arch and Naughton areas into the UGRB, however, the vast majority of the air parcel trajectories do not enter the UGRB, due to the significant terrain blocking and channeling effects of the terrain that make up the Wyoming Range and the Wasatch Range. Terrain blocking and channeling effects can also be seen in Figure S.7-42 in the forward trajectories originating from the OCI Trona plant.

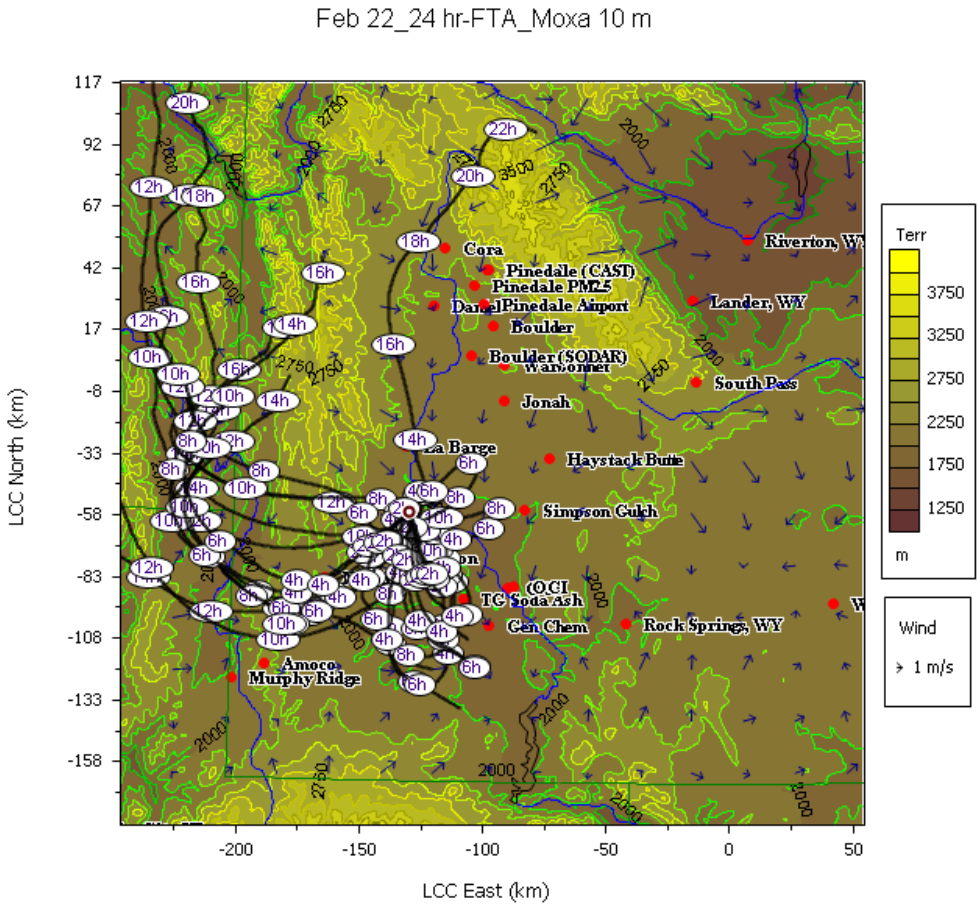


Figure S.7-39. 24-hour forward trajectory analysis in the Moxa Arch area on February 22, 2008.

Figure S.7-39 shows air parcels tend to be blocked and channeled westward and then northward around the Wyoming Range, with limited air parcel movement into the UGRB. There are 1-2 trajectory paths showing air parcel movement from the Moxa Arch into the UGRB, however, the vast majority of the air parcel trajectories do not enter the UGRB, due to the significant terrain blocking and channeling effects of the terrain that make up the Wyoming Range and the Wasatch Range.

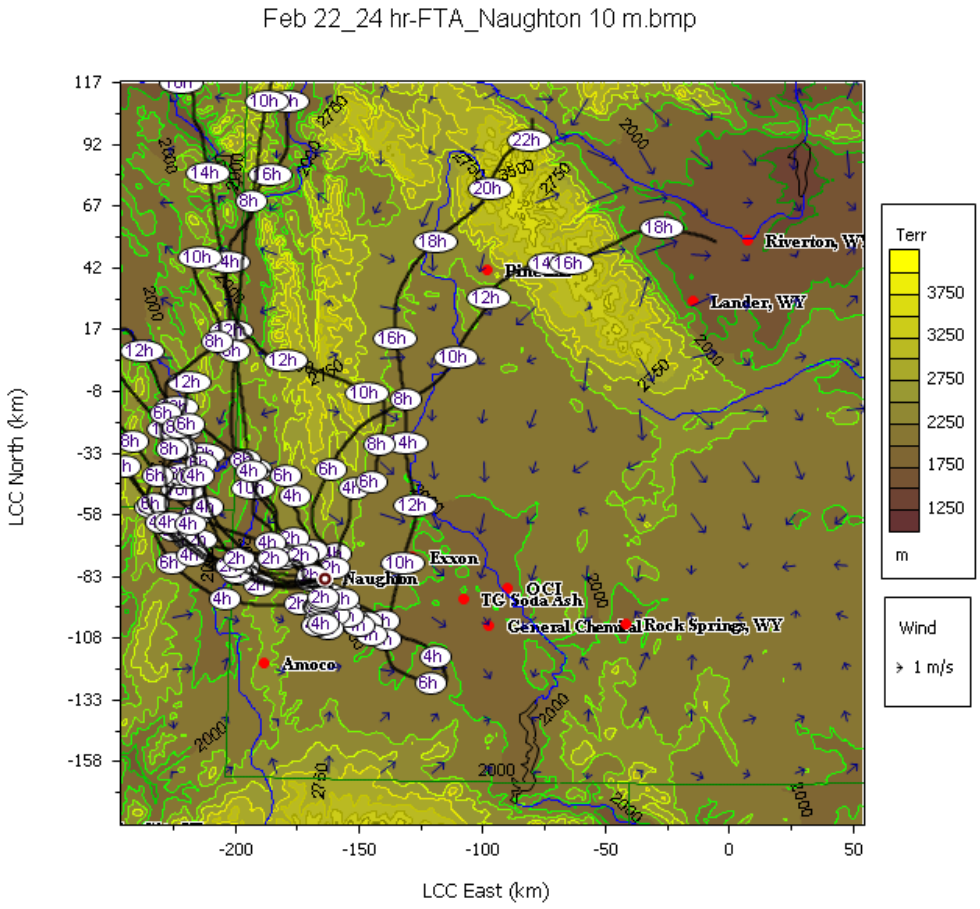


Figure S.7-40. 24-hour forward trajectory analysis at Naughton power plant on February 22, 2008.

There are two forward trajectory paths (2 am and 6 am) which show possible air parcel transport from the Naughton power plant into the UGRB. A 12-hour back trajectory analysis was performed at the Boulder monitor location (2 am – 2 pm) for February 22, 2008 to evaluate potential air parcel trajectories that could reach the Boulder monitor during this same time period (2 am and 6 am). The results of this back trajectory analysis are shown in Figure S.7-41.

Figure S.7-41 shows the calculated back trajectories of air parcels at the Boulder monitor tend to originate from within the UGRB, with very little air parcel movement occurring outside of the UGRB; the air parcels tend to stay within the UGRB during this 12 hour period (2 am – 2 pm) largely due to localized meteorological conditions in the UGRB. The back trajectory analysis in Figure S.7-41 shows a limited potential for sources outside the recommended nonattainment area to affect ozone measured at the Boulder monitor.

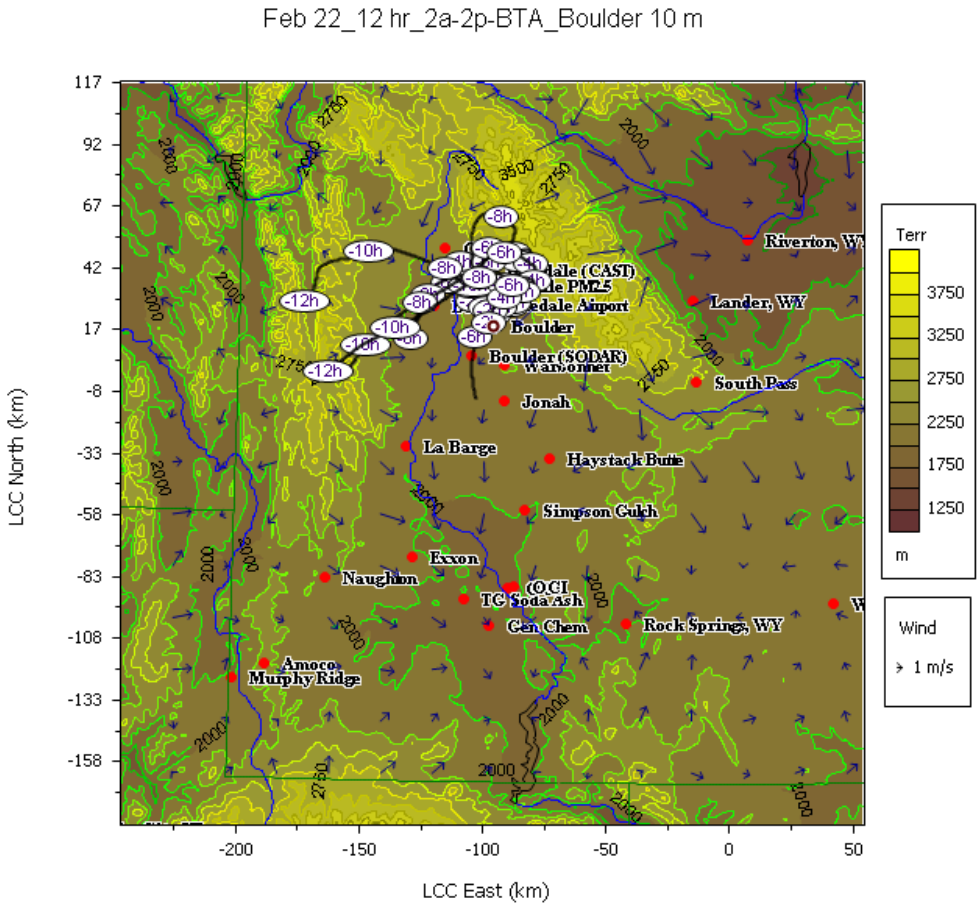


Figure S.7-41. 12-hour back trajectory analysis at Boulder monitor on February 22, 2008.

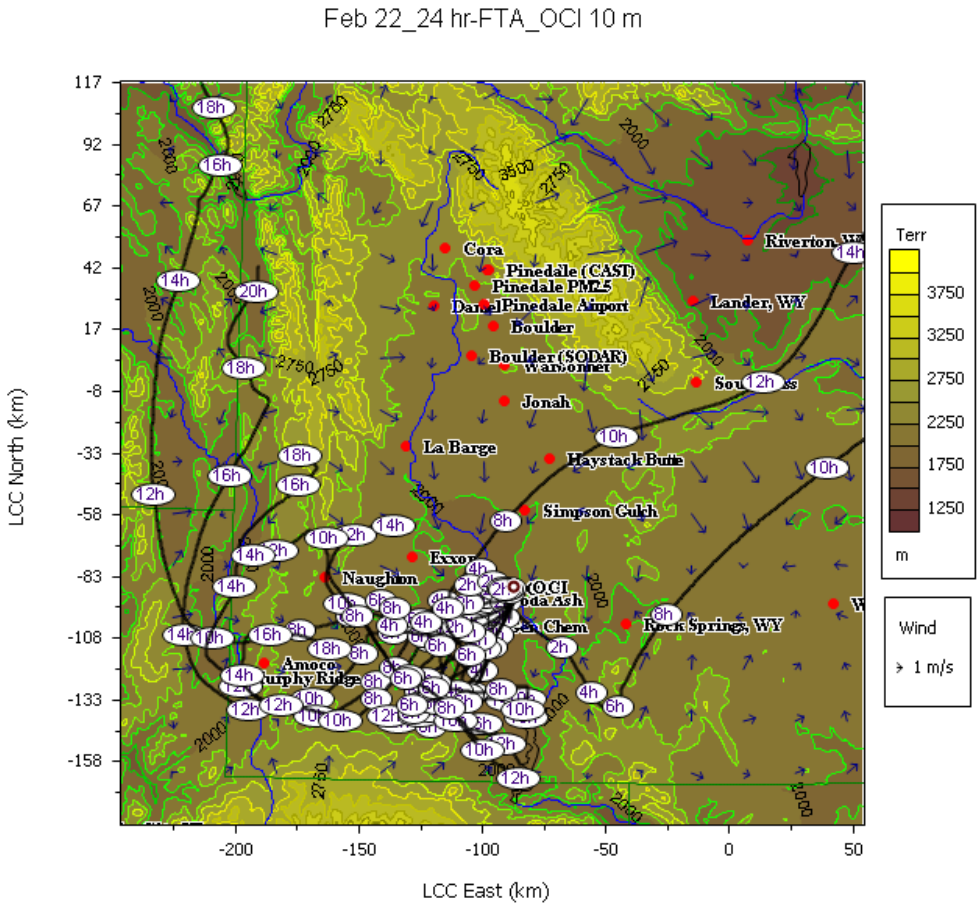


Figure S.7-42. 24-hour forward trajectory analysis at OCI Trona plant on February 22, 2008.

The predominant paths shown in the trajectory analysis shown in Figure S.7-42 trend to the south with northerly component to several of the modeled trajectories. Most of the possible forward trajectory paths are now moving away from the UGRB. Air parcels tend to be blocked and channeled westward and then northward around the Wyoming Range, with limited air parcel movement into the UGRB. There is one trajectory path showing air parcel movement from the OCI toward the UGRB. This trajectory generally parallels the southern boundary of the proposed nonattainment area along Pacific Creek. While some of the trajectory path may lie within the proposed nonattainment area, the path does not indicate that sources at OCI cause or contribute to elevated ozone levels within the proposed nonattainment area.

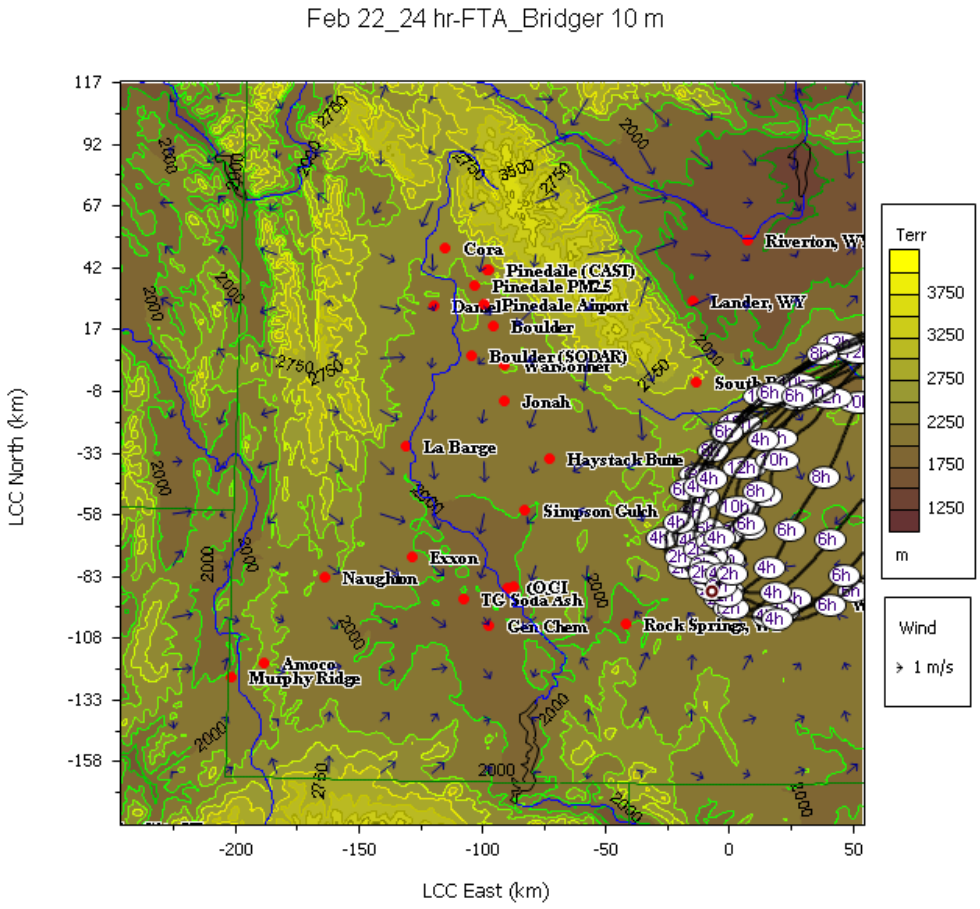


Figure S.7-43. 24-hour forward trajectory analysis at Bridger power plant on February 22, 2008.

The trajectory analysis in Figure S.7-43 shows all modeled trajectories from Bridger not entering the proposed nonattainment area.

CalDESK Forward Trajectory Analyses for February 23, 2008 are shown in Figures S.7-44 through S.7-48.

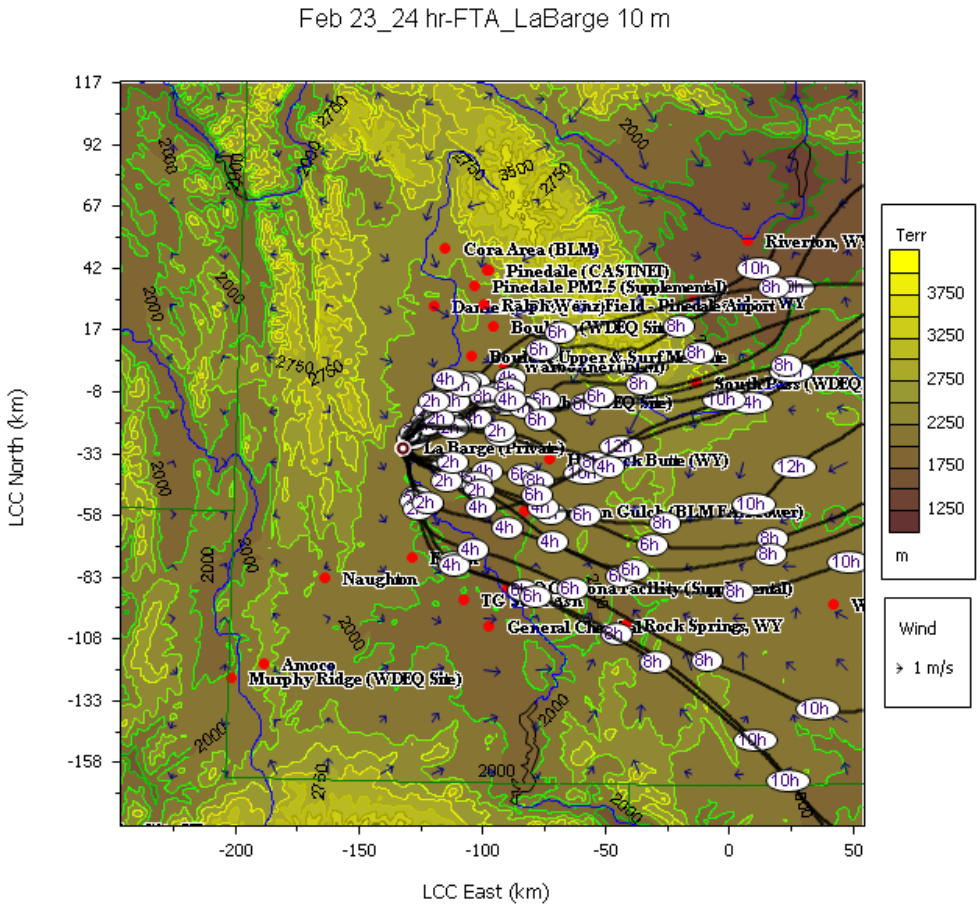


Figure S.7-44. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 23, 2008.

Figure S.7-44 shows the trajectory analysis for the LaBarge area; there are a few forward trajectory paths going northeast during Feb 23, 2008, but most are channeled around the rising terrain at the south end of the UGRB and the Wind River Range. As shown in Figures S.7-45 through S.7-48, the prevailing west and southwest winds generally move air parcels eastward and then northward, as reflected in the trajectory analysis for the Moxa Arch area, the Naughton power plant, the OCI Trona processing facility, and the Bridger power plant.

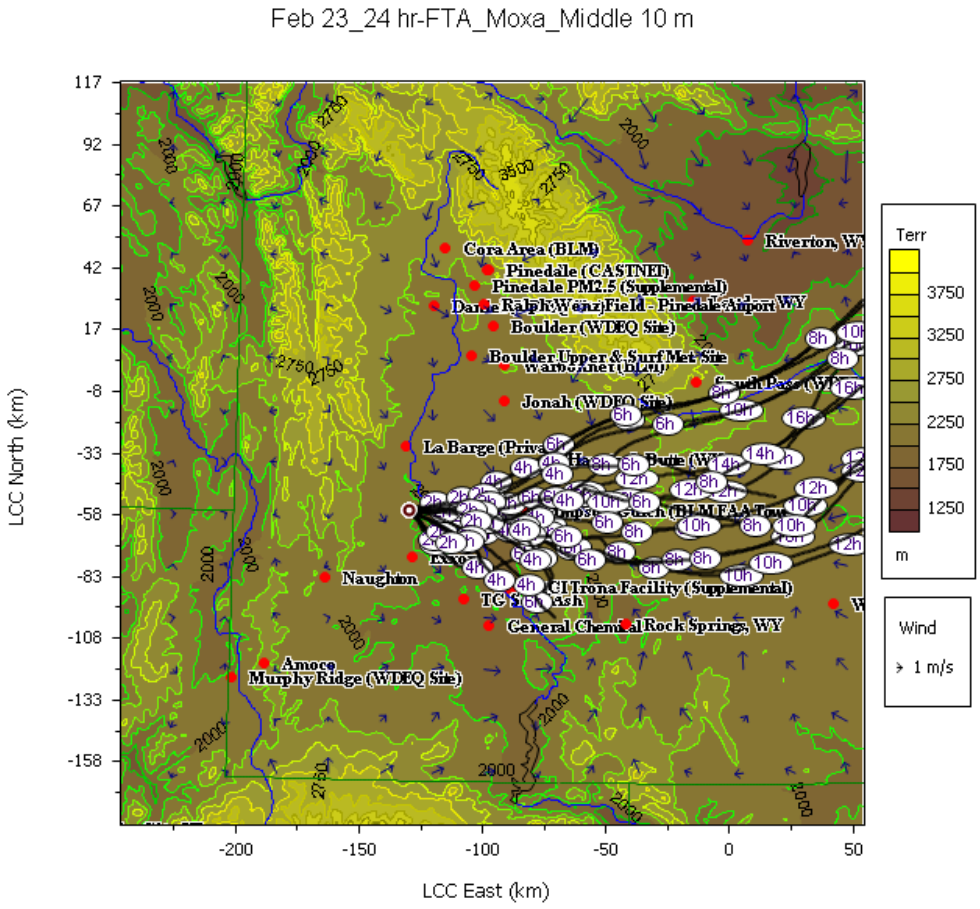


Figure S.7-45. 24-hour forward trajectory analysis in the Moxa Arch area on February 23, 2008.

The trajectory analysis shown in Figure S.7-45 places the initial air parcel release point in the northern part of the Moxa Arch field. The predominant paths shown trend to the east, and there is a slight northerly component to several of the modeled trajectories. These trajectories generally parallel the southern boundary of the proposed nonattainment area along Pacific Creek. While some of the trajectory paths lie within the proposed nonattainment area, none of the paths indicate that sources within the Moxa Arch cause or contribute to elevated ozone levels within the proposed nonattainment area.

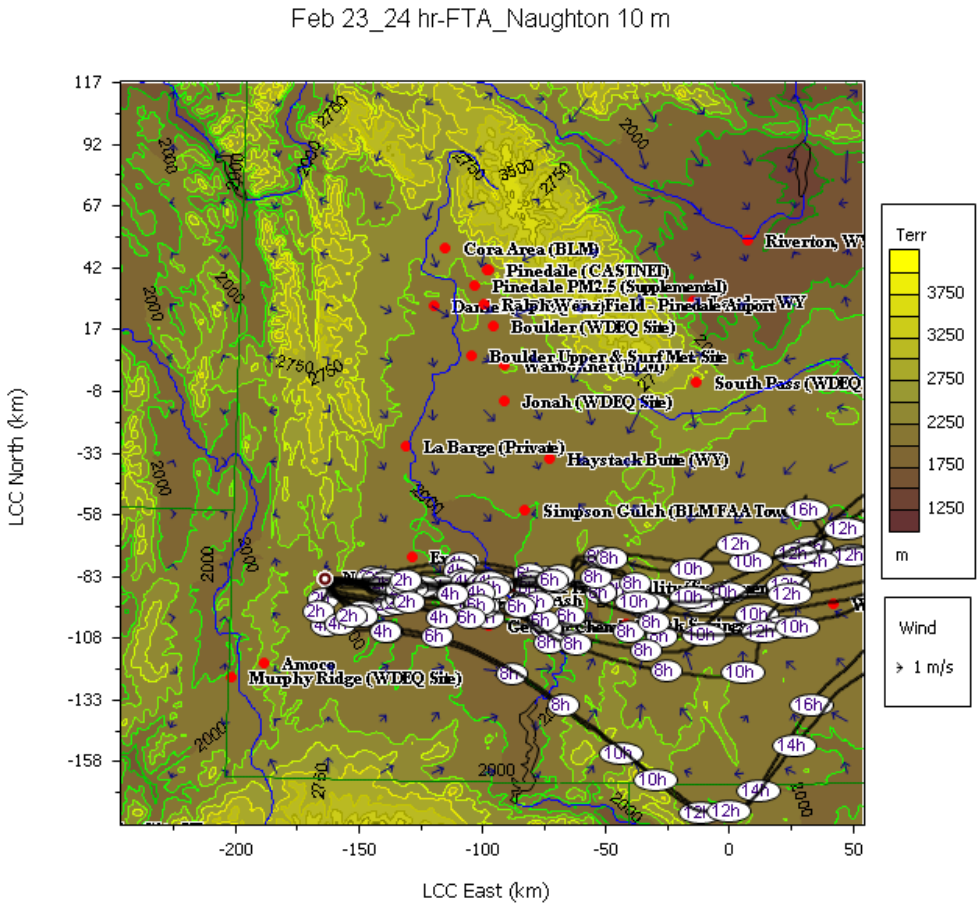


Figure S.7-46. 24-hour forward trajectory analysis at Naughton power plant on February 23, 2008.

The trajectory analysis in Figure S.7-46 shows all modeled trajectories from Naughton not entering the proposed nonattainment area.

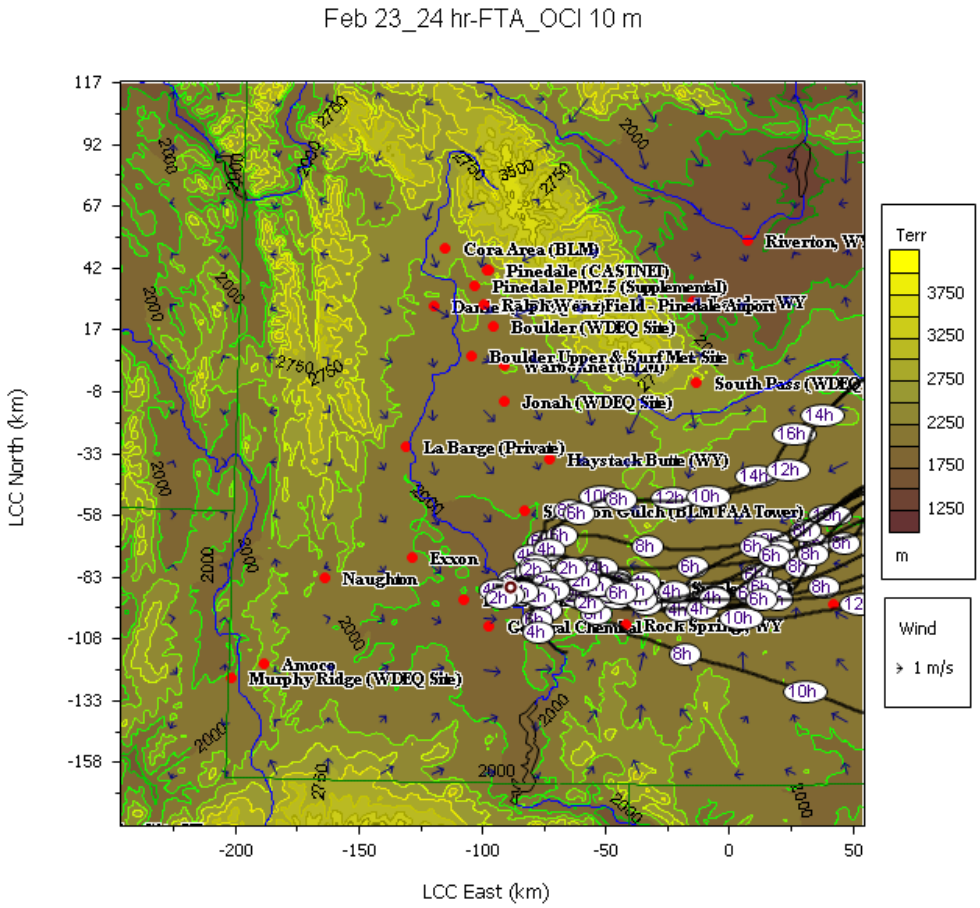


Figure S.7-47. 24-hour forward trajectory analysis at OCI Trona plant on February 23, 2008.

The trajectory analysis in Figure S.7-47 shows all modeled trajectories from OCI not entering the proposed nonattainment area.

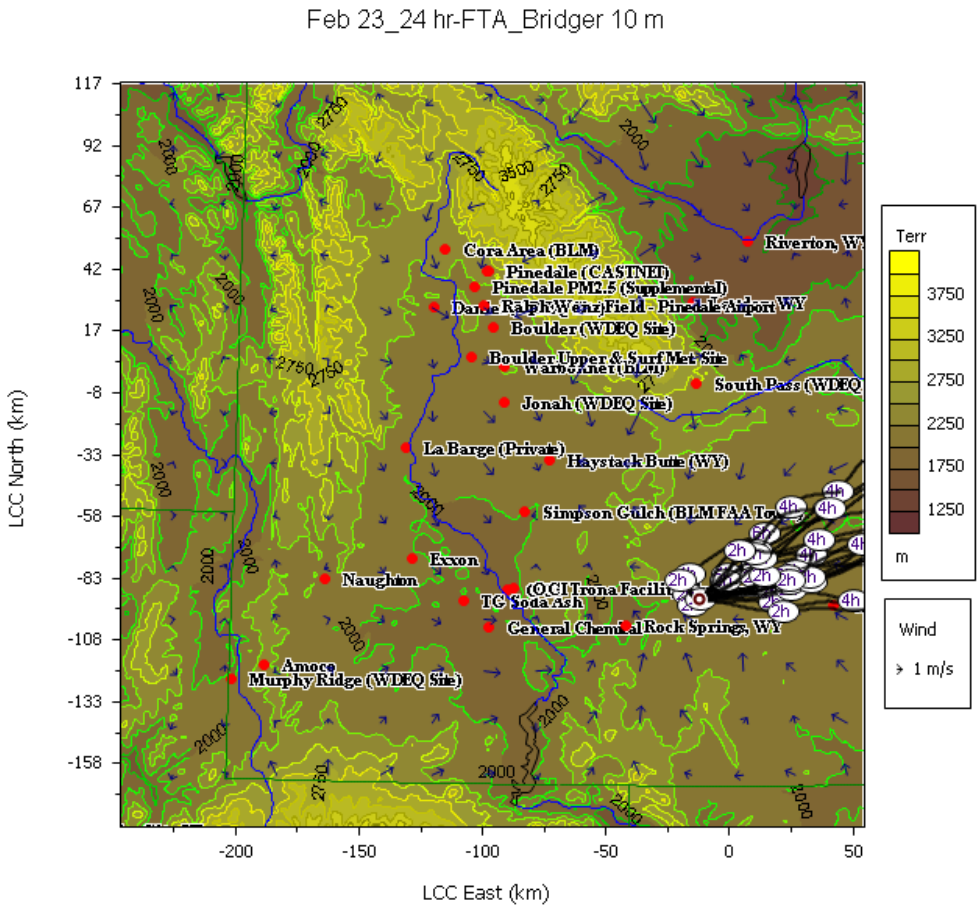


Figure S.7-48. 24-hour forward trajectory analysis at Bridger power plant on February 23, 2008.

The trajectory analysis in Figure S.7-48 shows all modeled trajectories from Bridger not entering the proposed nonattainment area.

Summary of Trajectory Analyses

The CalDESK trajectory analyses, based on a three dimensional wind field which incorporates the localized meteorological data collected during the 2008 field study have allowed AQD to evaluate air parcel movement as a means of evaluating precursor emissions and ozone transport into and out of the UGRB. These trajectories indicate that the southern boundary of the recommended nonattainment area defines an appropriate demarcation where emission sources within the nonattainment area may contribute ozone or ozone precursors to the Boulder monitor. Although the Fontenelle Creek, Little Sandy and Pacific drainages are not major topographic features, these drainage areas influence air movement into the UGRB from locations south of the recommended nonattainment area during the February 19-23, 2008 ozone episode and define a reasonable southern boundary for the nonattainment area. AQD has concluded that most, if not all, of the impact on the Boulder monitor just prior to and during these elevated ozone episodes is from emission sources located in the nonattainment area as described in this recommendation.

SECTION 8
JURISDICTIONAL BOUNDARIES

SYNOPSIS

The Sublette County jurisdictional boundary forms the northern and most of the western and eastern boundaries of the recommended nonattainment area. The remainder of the boundary is not jurisdictional but is based on topographical and meteorological considerations.

There is no existing local authority that transcends county boundaries, so the recommended nonattainment area has no single local administrative authority.

ANALYSIS

The Boulder monitor is located in Sublette County. Sublette County is governed by a three-person Commission. There are three incorporated towns in Sublette County: Pinedale, Big Piney and Marbleton. Approximately 80% of the land in Sublette County is owned by the government: BLM-40%; USFS-36%; State of Wyoming-4%. Federal and state land ownership in the surrounding counties follows a similar pattern.

The evaluation of the nonattainment area began with the Sublette County jurisdictional area as the presumptive boundary. This is consistent with EPA guidance in the December 4, 2008 memorandum which states: "Where a violating monitor is not located in a CBSA" (Core Based Statistical Area) "or CSA," (Combined Statistical Area) "we recommend that the boundary of the county containing the monitor serve as the presumptive boundary for the nonattainment area." The Boulder monitor is not in a CBSA or CSA.

The recommended nonattainment area includes all of Sublette County; the portion of Lincoln County northeast of the waterways of Aspen, Fontenelle, and Roney Creeks and northeast of Fontenelle Reservior and the Green River; and the portion of Sweetwater County northwest of the waterways of the Green River, the Big Sandy River, Little Sandy Creek, Pacific Creek, and Whitehorse Creek (see the detailed description in the introduction). This area includes the town of LaBarge in Lincoln County. The southern boundary of the recommended nonattainment area is defined based on topographical and meteorological considerations rather than jurisdictional boundaries. The Sublette County borders to the north, east, and west follow topographic features (mountain ranges) and are appropriate boundaries for the nonattainment area.

The six counties in Southwest Wyoming which were also included in the analysis are: Teton, Lincoln, Uinta, Sweetwater, and Fremont. Two Indian Tribal Nations are also located in the area, the Northern Arapahoe and Eastern Shoshone, at the Wind River Reservation in Fremont County. The reservation and the counties are shown in Figure S.1-1.

The recommended nonattainment area boundary does not fall under single authority, other than the State of Wyoming.

SECTION 9
LEVEL OF CONTROL OF EMISSION SOURCES

SYNOPSIS

Wyoming's NSR Program ensures that Best Available Control Technology (BACT) is utilized to reduce and eliminate air pollution emissions. Wyoming is fairly unique in that BACT is applied statewide to all new sources, both major sources and minor sources. Since 1995 all oil and gas production units that were constructed on or after May of 1974 require permits and BACT is utilized. In two of the gas fields in the proposed nonattainment area, more restrictive emission control requirements are already in effect. Wyoming has been focused on controlling emissions from oil and gas sources and has one of the most innovative and effective control programs in the nation.

While offset programs are traditionally limited to major source applications, the AQD issued an interim policy in August 2008 requiring offsets of ozone precursor emissions whenever a permit is issued for a new or modified source in Sublette County, regardless of major source applicability. This policy results in a net decrease in emissions of ozone precursors with every permit that is issued. This policy took effect after the ozone exceedances were recorded in the winter of 2008.

Data is not available for 2009, so it is too early to say with certainty whether this policy has contributed to reduced ozone concentrations at the Boulder monitor.

ANALYSIS

New Source Review Program

Wyoming's New Source Review (NSR) Program is a statewide permit program for the construction of new sources and modification of existing sources as established by Wyoming Air Quality Standards and Regulations (WAQSR) Chapter 6, Section 2, Permit requirements for construction, modification and operation and Chapter 6, Section 4, Prevention of significant deterioration. The primary purpose of the NSR Program is to assure compliance with ambient standards set to protect public health, assure that Best Available Control Technology is utilized to reduce and eliminate air pollution emissions, and to prevent deterioration of clean air areas. Any amount of air contaminant emissions from a facility subjects it to Wyoming's NSR Program.

Best Available Control Technology

Due to a desire to maintain and improve Wyoming's air quality, the Best Available Control Technology process is applied statewide to new sources, both major sources and minor sources, under the Wyoming NSR Program's permitting process. The BACT process is most appropriately defined as the elimination of pollutants from being emitted into the air whenever technically and economically feasible to do so. While the Air Quality Division takes the State

and federally-required BACT review in the Prevention of Significant Deterioration (PSD) permitting actions seriously, AQD takes the State-required BACT review in minor source permitting actions equally as seriously, as the bulk of AQD's permit applications are for minor sources.

Control of Oil and Gas Production Sources

Within the recommended nonattainment area, the bulk of the NSR Program activity is due to oil and gas production and is permitted per the *Oil and Gas Production Facilities Chapter 6, Section 2, Permitting Guidance* discussed below. The remainder of the activity is attributed to facility types such as the compressor stations, asphalt plants and crushing and screening operations, which are permitted per Chapter 6, Section 2 and Chapter 6, Section 4 as described above.

In October 1995, AQD initiated a program to ensure that all oil and gas production units in southwest Wyoming, as well as the entire state, that were constructed since May of 1974 (the effective date of Wyoming's NSR Permit Program) were permitted and that BACT is utilized to control or eliminate emissions from both major and minor sources. To guide oil and gas producers through the NSR permitting process, AQD developed an oil and gas industry guidance document (Guidance) that was released in June of 1997. The Guidance has been revised several times since it was originally released in June of 1997. The most recent revision took effect in August of 2007 and includes requirements that apply statewide as well as specifically to the Jonah and Pinedale Anticline Development (JPAD) Area. The emphasis of the Guidance relies on a "Presumptive BACT" process, which results in more emissions being controlled earlier in the life of the production site. This is accomplished by allowing start up or modification of the production site to occur prior to obtaining a construction permit, provided the operators of such facilities meet certain emission control requirements, including timely installation of controls, which have been established through the Presumptive BACT process. Within the JPAD Area, emission control requirements are more restrictive and become effective upon start up or modification of the production site.

Under the WAQSR, applicants for permits are required to demonstrate to the Administrator of the Air Quality Division, that "[t]he proposed facility will not prevent the attainment or maintenance of any ambient air quality standard." [WAQSR Chapter 6, Section 2(c)(ii)] To allow applications for new or modified emission sources of VOC and/or NOx to be processed while the Division and industry initiatives are taken to reduce the overall emission levels for VOC and/or NOx in Sublette County, AQD adopted the *Interim Policy on Demonstration of Compliance with WAQSR Chapter 6, Section 2(c)(ii) for Sources in Sublette County* on July 21, 2008. The Interim Policy describes options that AQD will consider as an adequate WAQSR Chapter 6, Section 2(c)(ii) demonstration for permit applications (i.e., new as well as applications currently under AQD analysis) for new or modified emission sources in Sublette County.

Options for the Chapter 6, Section 2(c)(ii) demonstration include:

a. Ambient ozone modeling for any application requesting increases in VOCs and/or NOx emissions.

b. Emission reductions for VOCs and/or NOx emissions.

c. Applicants may propose alternate innovative demonstrations to the AQD.

To date, most applicants have chosen to offset VOC and/or NOx emissions and permit conditions have been established to make the commitments to control emissions federally enforceable.

During the implementation of the Interim Policy, other long-term approaches (e.g., development of a regional ozone model and implementation of additional control strategies) to deal with unacceptable ozone levels in the recommended nonattainment area, will continue to be pursued by AQD.

Statewide and Industry-wide Control of Volatile Organic Compounds (VOC)

WAQSR Chapter 13 establishes minimum requirements for motor vehicle emission control.

The following federal rules which are incorporated by reference in WAQSR Chapter 5 by reference contain performance or emission standards for VOCs that may apply to sources within the recommended nonattainment area and in adjacent areas:

40 CFR Part 60, Subpart D - Standards of Performance for Fossil-Fuel-Fired Steam Generators for Which Construction is Commenced After August 17, 1971

40 CFR Part 60, Subpart Da - Standards of Performance for Electric Utility Steam Generating Units for Which Construction is Commenced After September 18, 1978

40 CFR Part 60, Subpart Db - Standards of Performance for Industrial- Commercial-Institutional Steam Generating Units

40 CFR Part 60, Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units

40 CFR Part 60, Subpart I - Standards of Performance for Hot Mix Asphalt Facilities

40 CFR Part 60, Subpart K - Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After June 11, 1973, and Prior to May 19, 1978

40 CFR Part 60, Subpart Ka - Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984

40 CFR Part 60, Subpart Kb - Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced After July 23, 1984

40 CFR Part 60, Subpart GG - Standards of Performance for Stationary Gas Turbines

40 CFR Part 60, Subpart WWW - Standards of Performance for Municipal Solid Waste Landfills

40 CFR Part 63, Subpart F - National Emission Standards for Organic Hazardous Air Pollutants From the Synthetic Organic Chemical Manufacturing Industry

40 CFR Part 63, Subpart H - National Emission Standards for Organic Hazardous Air Pollutants for Equipment Leaks

40 CFR Part 63, Subpart M - National Perchloroethylene Air Emission Standards for Dry Cleaning Facilities

40 CFR Part 63, Subpart R - National Emission Standards for Gasoline Distribution Facilities (Bulk Gasoline Terminals and Pipeline Breakout Stations)

40 CFR Part 63, Subpart T - National Emission Standards for Halogenated Solvent Cleaning

40 CFR Part 63, Subpart HH - National Emission Standards for Hazardous Air Pollutants From Oil and Natural Gas Production Facilities

40 CFR Part 63, Subpart OO - National Emission Standards for Tanks - Level 1

40 CFR Part 63, Subpart PP - National Emission Standards for Containers

40 CFR Part 63, Subpart QQ - National Emission Standards for Surface Impoundments

40 CFR Part 63, Subpart RR - National Emission Standards for Individual Drain Systems

40 CFR Part 63, Subpart SS - National Emission Standards for Closed Vent Systems, Control Devices, Recovery Devices and Routing to a Fuel Gas System or a Process

40 CFR Part 63, Subpart TT - National Emission Standards for Equipment Leaks - Control Level 1

40 CFR Part 63, Subpart UU - National Emission Standards for Equipment Leaks - Control Level 2 Standards

40 CFR Part 63, Subpart VV - National Emission Standards for Oil-Water Separators and Organic-Water Separators

40 CFR Part 63, Subpart WW - National Emission Standards for Storage Vessels (Tanks) - Control Level 2

40 CFR Part 63, Subpart HHH - National Emission Standards for Hazardous Air Pollutants From Natural Gas Transmission and Storage Facilities

40 CFR Part 63, Subpart UUU - National Emission Standards for Hazardous Air Pollutants for Petroleum Refineries: Catalytic Cracking Units, Catalytic Reforming Units, and Sulfur Recovery Units

40 CFR Part 63, Subpart VVV - National Emission Standards for Hazardous Air Pollutants: Publicly Owned Treatment Works

40 CFR Part 63, Subpart AAAA - National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills

40 CFR Part 63, Subpart EEEE - National Emission Standards for Hazardous Air Pollutants: Organic Liquids Distribution (Non-Gasoline)

40 CFR Part 63, Subpart YYYY - National Emission Standards for Hazardous Air Pollutants for Stationary Combustion Turbines

40 CFR Part 63, Subpart ZZZZ - National Emission Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines

40 CFR Part 63, Subpart CCCCC - National Emission Standards for Hazardous Air Pollutants for Coke Ovens: Pushing, Quenching, and Battery Stacks

40 CFR Part 63, Subpart GGGGG - National Emission Standards for Hazardous Air Pollutants: Site Remediation

40 CFR Part 63, Subpart HHHHH - National Emission Standards for Hazardous Air Pollutants: Miscellaneous Coating Manufacturing

40 CFR Part 63, Subpart LLLLL - National Emission Standards for Hazardous Air Pollutants: Asphalt Processing and Asphalt Roofing Manufacturing

Statewide and Industry-wide Nitrogen Oxides (NOx)

WAQSR Chapter 2 establishes ambient air quality standards for those areas under WDEQ's jurisdiction. The standard for nitrogen oxides (NOx) is 100 ug/m^3 as an annual arithmetic mean. All facilities that are required to obtain a New Source Review (NSR) permit or a Title V permit under WAQSR Chapter 6 must demonstrate compliance with the State's ambient air quality standard before a permit can be issued.

WAQSR Chapter 3, Section 3 specifies nitrogen dioxide emission standards. Permitting rules require sources to meet NOx emission standards.

The following federal rules, which are incorporated by reference into Chapter 5, Sections 2 and 3

contain performance or emission standards for NOx that may apply to sources in the proposed nonattainment area and in the surrounding counties:

40 CFR Part 60, Subpart D - Standards of Performance for Fossil-Fuel-Fired Steam Generators for Which Construction is Commenced After August 17, 1971

40 CFR Part 60, Subpart Da - Standards of Performance for Electric Utility Steam Generating Units for Which Construction is Commenced After September 18, 1978

40 CFR Part 60, Subpart Db - Standards of performance for Industrial- Commercial-Institutional Steam Generating Units

40 CFR Part 60, Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units

40 CFR Part 60, Subpart GG - Standards of Performance for Stationary Gas Turbines

The following federal New Source Performance Standards have not yet been adopted into State rules, but are scheduled for adoption. The federal standards will still apply.

NSPS Subpart IIII - Standards of Performance for Stationary Compression Ignition Internal Combustion Engines

NSPS Subpart JJJJ - Standards of Performance for Stationary Spark Ignition Internal Combustion Engines

NSPS Subpart KKKK - Standards of Performance for Stationary Combustion Turbines)

Contingency Plans

AQD requested that producers in parts of the proposed nonattainment area prepare emission reduction plans to be implemented when an ozone advisory is issued. The BLM adopted a contingency plan requirement in the Pinedale Anticline ROD. Producers, which cumulatively account for greater than 99% of production in the Pinedale Anticline, submitted contingency plans to the AQD. During the first quarter of 2009, the AQD issued ozone advisories on February 4th and 5th. The contingency plans were implemented and no 8-hour ozone values above 0.075 ppm were recorded at FRM monitors for those days.

CONCLUSIONS

The information presented in the preceding nine-factor analysis provides documentation and compelling evidence supporting a finding that the UGRB, as shown on the map in the Introduction, should be designated as nonattainment for the 2008 ozone NAAQS. It is important to note that only areas over which Wyoming has direct air quality jurisdiction are included in this nonattainment finding and recommendation. The Northern Arapahoe and Eastern Shoshone Indian Tribes are distinct nations or entities and consequently such Tribal lands (the Wind River Reservation) are specifically excluded from this designation recommendation.

The Wyoming AQD bases this recommendation on a careful review of the circumstances surrounding the incidence of elevated ozone events. Elevated ozone in the UGRB is associated with distinct meteorological conditions. These conditions have occurred in February and March in some (but not all) of the years since monitoring stations began operation in the UGRB in 2005. Our determination of an appropriate nonattainment area boundary is focused on an evaluation of EPA's recommended nine factors, applied to the first quarter of the year, during which winter ozone episodes occur. This timing does not change how the factors are reviewed, except for emissions inventory and meteorology. It is important to evaluate inventory and meteorology during the first quarter of the year in order to focus on the very specific conditions that lead to high ozone.

The most compelling reasons for the boundary recommendation are based on the meteorological conditions in place during and just prior to elevated ozone events. Elevated ozone episodes occurred in 2005, 2006 and 2008; they were associated with very light low-level winds, sunshine, and snow cover, in conjunction with a strong low-level surface-based temperature or "capping" inversion. The longest such event, which also resulted in the highest measured ozone of 122 ppb as an 8-hour average at the Boulder station, has been reviewed in detail and summarized in Section 7 of this document. Section 7 demonstrates that sources outside the recommended nonattainment area would not have a significant impact on the Boulder monitor due to the presence of the inversion and very low winds, which significantly limit emissions and ozone transport from sources located outside of the UGRB. Using detailed meteorological data collected during the February 19-23, 2008 ozone episode, a 1 kilometer high resolution (spatial and temporal) 3-dimensional gridded wind field was developed and used in trajectory analyses. The trajectory analyses show that air parcels originating at sources located south of the recommended nonattainment area – including power plants, Trona facilities, and the Moxa Arch gas field – are generally transported eastward and do not enter the UGRB just prior to and during the February 19-23, 2008 ozone episode. The meteorological conditions present during this multi-day ozone episode are representative of the meteorological conditions that were present during previous wintertime elevated ozone events that occurred in 2005 and 2006. From the trajectory analyses, it is concluded that emission sources located outside of the recommended nonattainment boundary could only have a very limited impact on the Boulder monitor, as the mountains to the west, north and east, along with the observed low wind speeds, would greatly limit the possibility of emissions transport.

The nine-factor analysis also concluded the following:

1. Ozone monitoring outside of the UGRB throughout Wyoming shows attainment of the 2008 NAAQS.
2. Emissions inventories of ozone precursors indicate that sources within the UGRB emit significant levels of precursors. Emissions from outside of the UGRB (while comparable to [for VOCs] or greater than [for NOx] emissions from within the UGRB) do not significantly influence the formation of ozone during and immediately preceding episodes of elevated ozone.
3. Population densities in Sublette and surrounding counties are very low and are not expected to be an important factor in ozone formation. This is also true of traffic and commuting patterns, which would be expected to be more important in urban areas rather than the rural communities and open spaces of southwest Wyoming.
4. The pace of growth in the oil and gas industry is significantly higher in the UGRB than in surrounding areas, which would correspond to a more rapid increase in emissions within the recommended nonattainment area in recent years.
5. Significant terrain features influence the meteorology throughout southwest Wyoming. Under a stagnating high pressure system, strong temperature inversions and low mixing heights tend to produce limited atmospheric mixing and precursor emissions can build up to high concentrations.

The elevated ozone episodes within the UGRB represent a unique situation which is quite different from other ozone nonattainment areas. The UGRB is rural with a very low population density; the only significant industry present is oil and gas. The significant terrain features surrounding the UGRB and the very low wind speeds associated with elevated ozone episodes may limit the ability of trajectory models, such as the HYSPLIT model, to accurately represent movement of air parcels within, into and out of the UGRB during these winter ozone events.

Due to the importance of meteorology to the formation of elevated ozone at the Boulder monitor – that is, ozone at levels that result in an exceedance of the NAAQS occurs during periods characterized by low mixing heights, temperature inversions and sustained low wind speeds – any emission reduction applied to sources outside of the UGRB will not result in any meaningful change in ozone levels at the Boulder monitor during these episodic conditions.

The information presented in this technical support document provides a strong weight-of-evidence basis for the recommended nonattainment boundary.

Appendix S.1.
Final Report 2008 Upper Green River Winter Ozone Study

Final Report
2008 UPPER GREEN RIVER WINTER OZONE STUDY

Prepared for

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October 2008

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Many individuals in addition to the staff of ENVIRON, T&B Systems and MSI contributed to the successful completion of the 2008 Upper Green Winter Ozone Study and the creation of 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 guidance and comments throughout the study. Jennifer Frazier of the WDEQ's Jonah Interagency Office once again provided invaluable and tireless field support without which many measurement opportunities would have been lost. Ms. Frazier also helped in coordinating with personnel at the Bureau of Land Management's Pinedale Field Office who provided the necessary land use permits in a timely fashion. As in the 2007 study, Jim McLellan again served as our able pilot for the instrumented aircraft sampling program. Air Resource Specialists and Inter-Mountain Laboratories provided meteorological and air quality monitoring data they collected at Boulder and Daniel along with use of their field facilities for VOC sampling.

EXECUTIVE SUMMARY

Background

Unusual high ozone concentrations occasionally exceeding 85 ppb (8-hour average) have been observed during three out of the past four winter seasons at monitoring sites in the oil and gas production regions of the upper Green River Basin of western Wyoming. These elevated ozone concentrations occurred exclusively during the late winter months (February – April) when temperatures were nearly always well below freezing. Such high concentrations of ozone are unusual in a rural environment, especially during the winter months when low temperatures and low sun angles normally act to limit ozone formation. The recent high ozone readings occur at a time when economic growth in the area is rapid, primarily driven by an increase in oil & gas production. Air quality impacts from this growth have been a key concern of local citizens, environmental groups, the State of Wyoming and the U.S. Environmental Protection Agency. Impacts of concern in the Upper Green River Basin have historically focused on visibility and acid deposition, particularly in the nearby protected Bridger and Fitzpatrick Wilderness Areas, but the recent monitoring data have resulted in a new interest in ozone impacts.

Given the unusual nature of these events and the potential regulatory implications of concentrations exceeding the ozone air quality standard (now set at 75 ppb) on future oil and gas development and associated economic growth in the region, the state of Wyoming embarked on a program to better understand the meteorology and chemistry involved in the elevated ozone episodes. As part of this program, the Wyoming Department of Environmental Quality sponsored an extensive field measurement program known as the Upper Green River Winter Ozone Study (UGWOS) which took place during February through mid-April 2007. Unfortunately, conditions during the 2007 study period were generally not conducive to formation of high ozone levels. As a result, field study operations were curtailed in 2007 and the remaining project resources, together with additional funding provided by the WDEQ, were used to conduct a similar field study carried out from mid-January to March, 2008. As was the case in the 2007 study, the UGWOS ’08 study was designed to meet the following objectives:

- Provide information needed to develop a conceptual understanding of processes leading to the occurrence of high ozone events in the Upper Green River Basin.
- Provide data needed to develop accurate meteorological and air quality numerical simulations of high ozone events in the region.

Summary of Field Operations

Planning for UGWOS ’08 began in November, 2007 and continued through early January, 2008. Routine field operations took place between mid-January and the end of March, 2008. The field study design included a set of routine measurements conducted throughout the six week study period and a set of intensive measurements conducted during selected Intensive Operating Periods (IOPs) when conditions similar to those associated with high ozone episodes during 2005 – 2006 were forecast to occur. Daily weather forecasts were issued by a team of meteorologists for purposes of identifying upcoming periods potentially suitable for conducting IOP operations.

A Monitoring and Quality Assurance Plan was prepared prior to commencement of operations which describes the sampling and analysis methodologies, sampling locations and schedules, and quality assurance / quality control procedures used in the study (see Appendix D). The UGWOS study plan called for enhancement of the existing monitoring network in the Jonah-Pinedale area during the mid-January – March study period (supplemental routine monitoring) along with intensive monitoring of local meteorology and ambient air quality parameters at the surface and aloft during periods when high ozone concentrations were forecast to occur. Daily weather forecasts were issued by a team of meteorologists assigned to the project for purposes of identifying upcoming periods potentially suitable for conducting IOP operations.

An enhanced network of temporary monitoring sites, known as "mesonet" sites was established using tripod mounted, battery powered anemometers with an instrument height of just under 3 m (see Figure 2-2). Wind measurements from these stations were found to be useful despite the low instrument height given the open terrain and lack of obstructions in the study area. Ozone analyzers (2B Technologies model 202 continuous UV photometric) were also deployed at these sites. While these low-cost battery operated analyzers do not meet EPA's Federal Equivalent Method requirements (and therefore data obtained from them cannot be used to officially determine if ozone concentrations are in exceedance of the National Ambient Air Quality Standard for ozone), results from UGWOS show that they provided high quality data which agreed well with FEM UV analyzers during test runs.

Intensive monitoring consisting of instrumented light-aircraft sampling, surface and aloft canister sampling of organic gasses, rawinsondes/ozonesondes, and wind profiler measurements was conducted during Intensive Operating Periods (IOPs) when high ozone was forecast to occur. A summary of the measurement methods used via the various instrument platforms is provided in Table ES-1. Figure ES-1 shows the study area and monitoring site locations. Weather conditions were considerably more favorable for ozone production during the 2008 study period than was the case in 2007 and three IOPs were conducted representing a total of 10 intensive sampling days.

Table ES-1. Summary of UGWOS measurements.

Platform	Location(s)	Mode	Measurements
Mesonet sites	Cora, Airport, Warbonnet, La Barge, Haystack, Simpson's Gulch	Continuous	Wind speed, direction, O_3
Sodar	Sodar site	Continuous	Upper level winds, mixing height (sfc winds from standard met station)
Aircraft	Project area	Morning and Afternoon flights during IOPs	Continuous Ozone (KI method), $PM_{2.5}$ (DustTrak), Temperature and VOC & carbonyl grab samples
Rawinsonde	Airport (Wenz Field)	Four per day during IOPs	Upper level winds, temperature, RH
Ozonesonde	Airport (Wenz Field)	Two each afternoon during IOPs	Upper level ozone (KI method)
Special purpose monitoring	Jonah, Boulder, Daniel	Three 3-hour integrated samples during each IOP day	VOCs (SUMMA canisters, TO-14); carbonyls (DNPH cartridges, TO-11)
UV radiation	Boulder	Continuous	Upward and downward facing twin Eppley total UV radiometers
Routine fixed sites	Jonah, Boulder, Daniel, Pinedale-CASTNET*	Continuous	Std. sfc meteorology package; O_3, $NO/NO_2/NOx$, PM_{10}(TEOM)

* Ozone and meterology only at Pinedale-CASTNET.

Results

Comparison of results from the 2007 and 2008 winter sampling studies suggests that the most significant factor contributing to the absence of high ozone during 2007 was the lack of consistent snow cover. UV radiation measurements from a brief period in early February 2007 during which snow cover was present showed that up to about 80% of the incoming UV was reflected back from the snow surface, thus significantly increasing the amount of UV radiation available for ozone chemistry compared to snow free ground cover. Snow is also highly reflective at longer solar wavelengths, thus limiting the degree of daily heating of the Earth's surface. This in turn enhances the strength and longevity of shallow, surface-based temperature inversions. In 2008, snow cover was more extensive and several high ozone events occurred which were well documented by the enhanced network measurements. Concentrations exceeded EPA's new 75 ppb ozone standard on 14 days between 15 January and 31 March. Boulder was a key site during these high ozone events. Not only did Boulder record the highest 8-hour average concentration (122 ppb) during the study, Boulder was the only site at which concentrations exceeded 75 ppb on all 14 high ozone days, Boulder recorded the highest 8-hour average reading out of all reporting sites in the Jonah – Pinedale area on 10 of these days, and Boulder was within 1 ppb of the maximum site value on three of the remaining four high ozone days.

High ozone events observed during the 2008 IOPs allowed for development of some initial understanding of the meteorological characteristics of such events, which were characterized by an area of high pressure building into southwestern Wyoming from the west. Low level winds were typically out of the southeast during the afternoon hours on episode days. These winds usually follow a light northwesterly (down valley) surface flow that develops during the previous night and continues well into the morning. Winds aloft under these events are westerly to northwesterly. The afternoon surface southeasterly winds occur only within the inversion layer. This flow pattern serves to re-circulate ozone and ozone precursors within the study area, thereby enhancing ozone production. Surface winds in the southern portion of the study area (i.e., south of Jonah) were often observed to be in a different direction from those at locations north of Jonah.

When the favorable synoptic conditions described above develop late in the day or during the night hours, the first high ozone concentrations usually develop the following day beginning between approximately 11:00 and 13:00 so long as the favorable conditions persist. During a day of elevated ozone, the high readings peak in the afternoon and can last well into the evening hours and in some cases past midnight before lowering, suggesting that ozone loss mechanisms such as dry deposition are minimal. If the following day continues to have favorable weather conditions, the ozone levels begin to rise earlier than the previous day and frequently to much higher levels, indicative of the carry over of ozone and precursors from one day to the next. Once high ozone concentrations have formed, the ozone levels were observed to remain elevated even under increasing cloud cover ahead of an approaching storm system. Elevated concentrations persisted until brisk (usually west or northwesterly) winds arrived and scoured out the surface inversion.

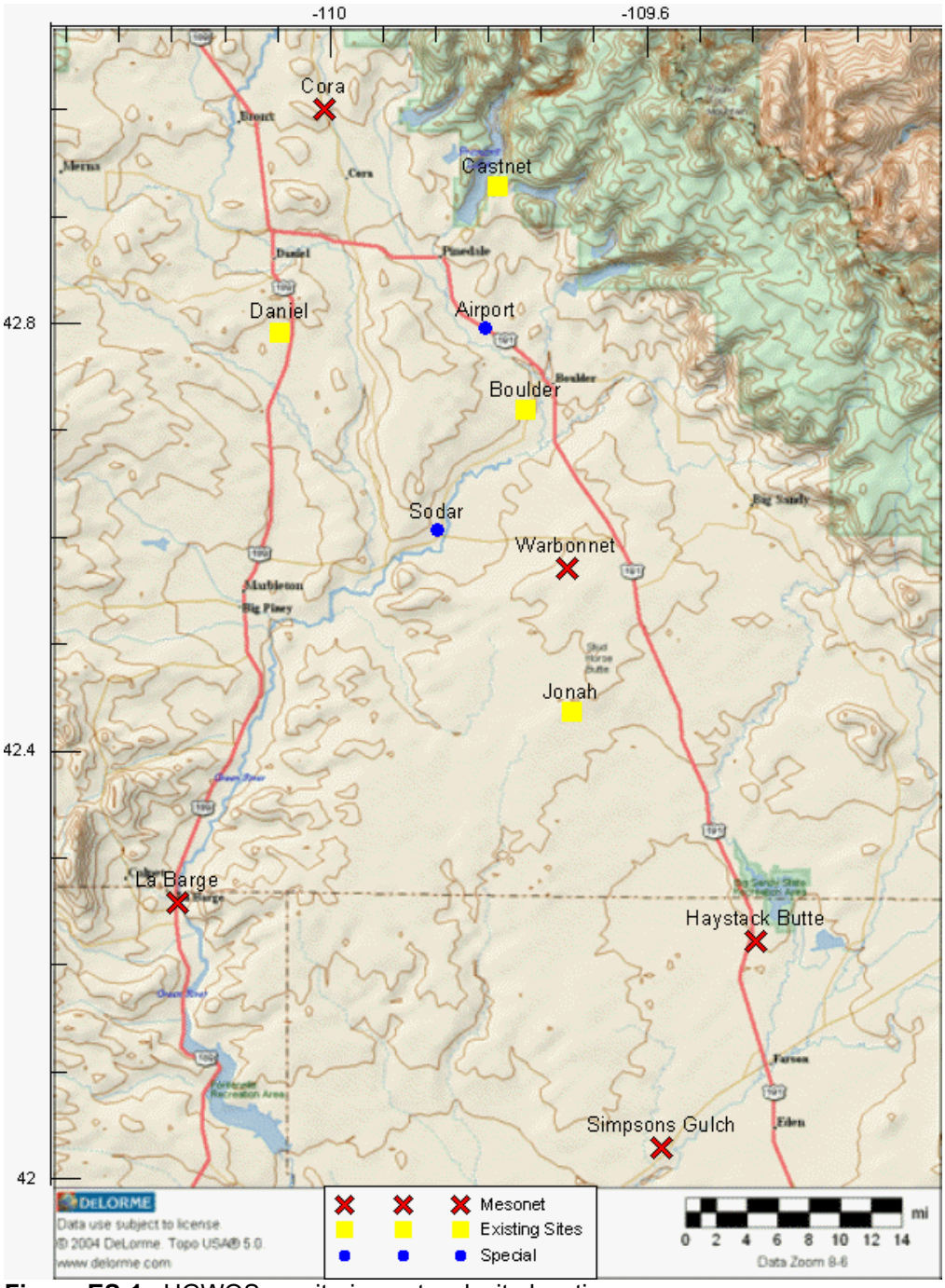

Figure ES-1. UGWOS monitoring network site locations.

Elevated ozone was observed within the mixed layer by aircraft as far north as Pinedale on some occasions but did not extend to the higher elevation Pinedale CASTNET monitoring site or as far west as Daniel. Ozone concentrations at Cora which is located at the northern end of the study area were also lower than at locations to the south, exceeding a 75 ppb 8-hour average on just one day (23 February). Aircraft observations showed that high ozone concentrations extended at least as far south as Simpson's Gulch on some days. Elevated ozone was confined to a relatively shallow mixed layer extending at most a few hundred meters above ground level on all IOP days. Ozone concentrations above the mixed layer were generally in the 50 – 60 ppb range, with higher concentrations observed at much higher altitudes on a few occasions. The 50-60 ppb ozone observed above the mixed layer is consistent with values observed at the Pinedale-CASTNET site and overnight values observed at Cora and Daniel during the IOPs. It is also consistent with values observed at South Pass and Murphy Ridge during these periods. These results demonstrate that "regional background" ozone during the IOP events was in the 50-60 ppb range. Both surface and aircraft observations showed that ozone and PM concentrations within the mixed layer were frequently positively correlated.

As was the case in 2007, periods of very high NOx and hydrocarbon concentrations were observed at Jonah on episode days, with maximum 3-hour average TNMHC concentrations exceeding 10,000 ppbC and maximum NOx concentrations exceeding 100 ppb. Concentrations at Boulder and Daniel were significantly lower.

Recommendations

Additional field measurements are needed to more fully characterize high ozone events in southwestern Wyoming. Results from the 2007 and 2008 field studies suggest that particular priority be placed on the following:

- Extend field operations further south into Sweetwater, Lincoln and Uinta counties to allow exploration of the full spatial extent of episode conditions and gain a better understanding of the influence of major sources, including other oil and gas fields, trona sources, and the Bridger and Naughton power plants on regional air quality.
- Expand the scope of ozone precursor monitoring to include key nitrogen species such as NOy and HONO. This would provide a better understanding of the role of NOx in ozone formation during the unusual winter conditions.
- Perform airborne UV photolysis rate measurements to provide more spatially representative measurements and better understand the influence of snow cover.
- Perform speciated PM sampling to better characterize aerosols found to be associated with elevated ozone in Sublette County.
- Perform trace SO_2 sampling to evaluate the potential influence of industrial sources south of Sublette County.

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GLOSSARY

2B Analyzer	Low-cost batter powered ozone analyzer manufactured by 2B Technologies
agl	Height above ground level
Albedo	Fraction of incoming radiation reflected from the Earth's surface
Anticline	Geological formation associated with oil and gas production
Boundary layer	Lowest layer of the atmosphere in which effects of the Earth's surface have a significant impact
Carbonyls	Organic compounds such as formaldehyde containing a carbonyl (carbon atom double bonded with an oxygen atom) group
CASTNET	Clean Air Status and Trends Network
Dew point temperature	Temperature at which air becomes saturated with respect to water vapor
FEM	Federal Equivalent Method
GC/FID	Gas chromatography with flame ionization detector: laboratory procedure used to measure concentrations of organic compounds
Insolation	Incoming solar radiation
IOPs	Intensive Operating Periods
JPA	Jonah-Pinedale area
JPDA	Jonah-Pinedale Development Area
KI method	A method for measuring ozone concentration in ambient air based on reaction of ozone with potassium iodide
Mesonet	Network of temporary, battery powered, tripod mounted measurement stations
miniSODAR	A low power SODAR
MQOs	Measurement Quality Objectives
msl	Height above mean sea level
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Oxides of Nitrogen ($NO + NO_2$)
Ozonesonde	Similar to rawinsonde but for measuring the ozone as a function of height
ppbC	For an organic compound, the mixing ratio of the compound in ppbV multiplied by the

	number of carbon atoms in the compound
ppbV	Parts per billion by volume
ppmV	Parts per million by volume
QA/QC	Quality assurance / quality control
Rawinsonde	Instrument system based on use of a helium balloon to measure winds, temperature, and dew point temperature as a function of height
SODAR	Sound Detection and Ranging: a technique for using sound waves as in a radar to remotely probe the vertical structure of the lower atmosphere
Tethersonde	Similar to rawindsonde but using a balloon that remains tethered to the surface rather than a free ascending balloon; can also be used to measure vertical profiles of ozone or other contaminants
UGWOS	Upper Green River Winter Ozone Study
Vertical wind sheer,	A (generally rapid) change of wind direction with height
VOCs	Volatile Organic Compounds
WDEQ	Wyoming Department of Environmental Quality
Wind Run	Linear distance traveled by a parcel of air over a given time period; equal to the length of the time interval times the average wind speed during the interval

1. INTRODUCTION

Several days with elevated ozone concentrations were observed in rural Sublette County, Wyoming during February of 2005 and 2006. An additional high ozone event occurred in April of 2006. Concentrations were generally lower in 2007, but one additional elevated ozone event occurred in late January. Such high concentrations of ozone are unusual in a rural environment, especially during the winter months when low temperatures and low sun angles normally act to limit ozone formation. The recent high ozone readings occur at a time when economic growth in the area is rapid, primarily driven by an increase in oil & gas production. Air quality impacts from this growth have been a key concern of local citizens, environmental groups, the State of Wyoming and the U.S. Environmental Protection Agency. Impacts of concern in the Upper Green River Basin have historically focused on visibility and acid deposition, particularly in the nearby protected Bridger and Fitzpatrick Wilderness Areas, but the recent monitoring data have resulted in a new interest in ozone impacts.

Ozone episodes observed in the Upper Green River Basin are unusual in that elevated concentrations have been recorded during the late winter and early spring (late January to April) when sun angles are relatively low and temperatures are generally below freezing. This is in marked contrast to ozone episodes in other areas, which occur during the warm summer months when abundant solar radiation and high temperatures act to increase precursor emissions and enhance many of the atmospheric reactions that result in ozone formation near the earth's surface (i.e., within the planetary boundary layer). In addition, the Upper Green River Basin is a rural area lacking the extensive conglomeration of ozone precursor sources found in urban areas, thus leading to questions about the availability of sufficient amounts of reactive volatile organic compounds and nitrogen oxides (NOx) needed for ozone production.

Due to the pressing need to manage air quality in the Upper Green River Basin and the limited amount of information currently available about the nature and causes of the unusual wintertime high ozone events observed during February and March of 2005 and 2006, the WDEQ funded the Upper Green Winter Ozone Study (UGWOS) field study during the 2007 late winter – early spring season. Results from the 2007 UGWOS study were summarized in a previous report (ENVIRON, 2008). Unfortunately, conditions during the February – March 2007 study period were generally not conducive to formation of high ozone levels. As a result, field study operations were curtailed in 2007 and the remaining project resources, together with additional funding provided by the WDEQ , were used to conduct a similar field study carried out from mid-January to March, 2008. As was the case in the 2007 study, the UGWOS '08 study was designed to meet the following objectives:

- Provide information needed to develop a conceptual understanding of processes leading to the occurrence of high ozone events in the Upper Green River Basin.
- Provide data needed to develop accurate meteorological and air quality numerical simulations of high ozone events in the region.

Planning for UGWOS '08 began in November, 2007 and continued through early January, 2008. Routine field operations took place between mid-January and the end of March, 2008. The field study design included a set of routine measurements conducted throughout the two month study period and a set of intensive measurements conducted during selected Intensive Operating Periods (IOPs) when conditions similar to those associated with high ozone episodes during

2005 – 2006 were forecast to occur. Daily weather forecasts were issued by a team of meteorologists assigned to the project for purposes of identifying upcoming periods potentially suitable for conducting IOP operations.

This report presents a summary of UGWOS '08 field operations and results of the measurement programs. An overview of the routine and supplemental measurements carried out as part of UGWOS '08 is presented in Section 2 together with a description of the forecast procedures and methodologies used to identify the IOPs. Data quality assurance, validation and archiving procedures are described in Section 3. Procedures and results of the January – March 2008 routine and intensive monitoring are presented in Section 4; procedures and results of the aircraft and organic compound sampling programs conducted during the IOPs are presented in Sections 5 and 6, respectively. A summary of results and our conclusions are presented in Section 7. A complete set of study data are available in an ACCESS database at http://deq.state.wy.us/AQD/Monitoring%20Data.asp.

2. SUMMARY OF FIELD OPERATIONS

Planning for the UGWOS 2008 field operations began in November, 2007 and continued through early January, 2008. The monitoring network components and forecast protocol were fully operational by January 15, 2008 and remained operational through March 31, 2007. The sole exception was the miniSodar, which became operational on February 10. A map showing the monitoring sites and regional terrain features is shown on Figure 2-1. A summary of the measurement methods used via the various instrument platforms is provided in Table 2 – 1.

Field operations consisted of two tiers of measurements: routine measurements conducted throughout the study period and intensive operating period (IOP) measurements conducted on selected days with high ozone formation potential as forecast by the study team. Routine and IOP measurements are discussed in more detail below.

2.1 Summary of Meteorological Conditions

Weather and operational forecasts were made daily as described in Section 2.3. During the first half of the 2008 field program, the study area was under the influence of a seemingly endless series of weak to moderately strong synoptic disturbances that migrated from the Gulf of Alaska, across the Pacific Northwest and southern British Columbia and the northern Great Basin and into the Northern Rockies. These weather features generally moved rapidly through the project area as they migrated along a belt of strong westerly to northwesterly winds aloft that were associated with a persistent high pressure ridge located over the eastern Pacific off California. In addition, a number of deep Pacific troughs moved across the area earlier in the winter and into the first half of January. The end result of all this activity was the deposit of a substantial snow cover in southwestern Wyoming, including the upper Green River Basin, that was to remain in place through the rest of the winter.

After mid-February, the eastern Pacific ridge exhibited a tendency to extend or migrate into the interior west until it finally moved directly over the project area by February 20, 2008, marking the beginning of the first multi-day high ozone event of the winter, and the first since 2006.[1] Project IOP operations took place during that event as well as another at the end of February, and third around March 10. A high ozone event occurred at the end of March, but measured ozone concentrations in the monitoring networks failed to reach exceedance levels at that time. A summary of the synoptic weather patterns associated with the high ozone events are presented in Section 2.5 of this report.

[1] A limited ozone exceedance event occurred in the Boulder area on 10 February and another event was recorded at Boulder and Jonah on 15 February.

Table 2-1. Summary of measurement methods used for 2008 field study.

Platform	Mode	Measurement	Instrumentation	
			Method	**Model**
Mesonet sites	Continuous	Wind speed	Propeller anemometer	RM Young 05305
		Wind direction	Vane	RM Young 05305
		Ozone	UV photometric	2B Technologies 202
Sodar	Continuous	Upper level winds	Doppler sodar	ASC 4000 miniSodar
		Mixing height	Doppler sodar	ASC 4000 miniSodar
		Surface wind speed	Propeller anemometer	RM Young 05305
		Surface wind direction	Vane	RM Young 05305
Aircraft	Intensive (IOPs)	Ozone	KI method	T&B Systems
		PM2.5	Light scattering	TSI DustTrak
		Temperature	Thermister	T&B Systems
		VOCs	SUMMA canisters; TO-14	Canisters provided by EAS, Inc.
		Carbonyls	Pump, flowmeter, and DNPH-coated cartridges; TO-11	T&B Systems
		3-D position	GPS	Garmin Vista
Pinedale Airport	Continuous	Surface wind speed	Propeller anemometer	RM Young 05305
		Surface wind direction	Vane	RM Young 05305
		Ozone	UV Photometric	Dasibi 1003 AH
Rawinsonde	Intensive (IOPs)	Upper level winds, temperature, RH	GPS-based balloon soundings	SIPPICAN Mark II Microsondes
Ozonesonde	Intensive (IOPs)	Upper level ozone	GPS-based balloon soundings, KI method	EN-SCI Corporation KZ-ECC Ozonesondes
WDEQ monitoring sites	Intensive (IOPs)	VOCs	SUMMA canisters; TO-14	
		Carbonyls	Pump, flowmeter, and DNPH-coated cartridges; TO-11	

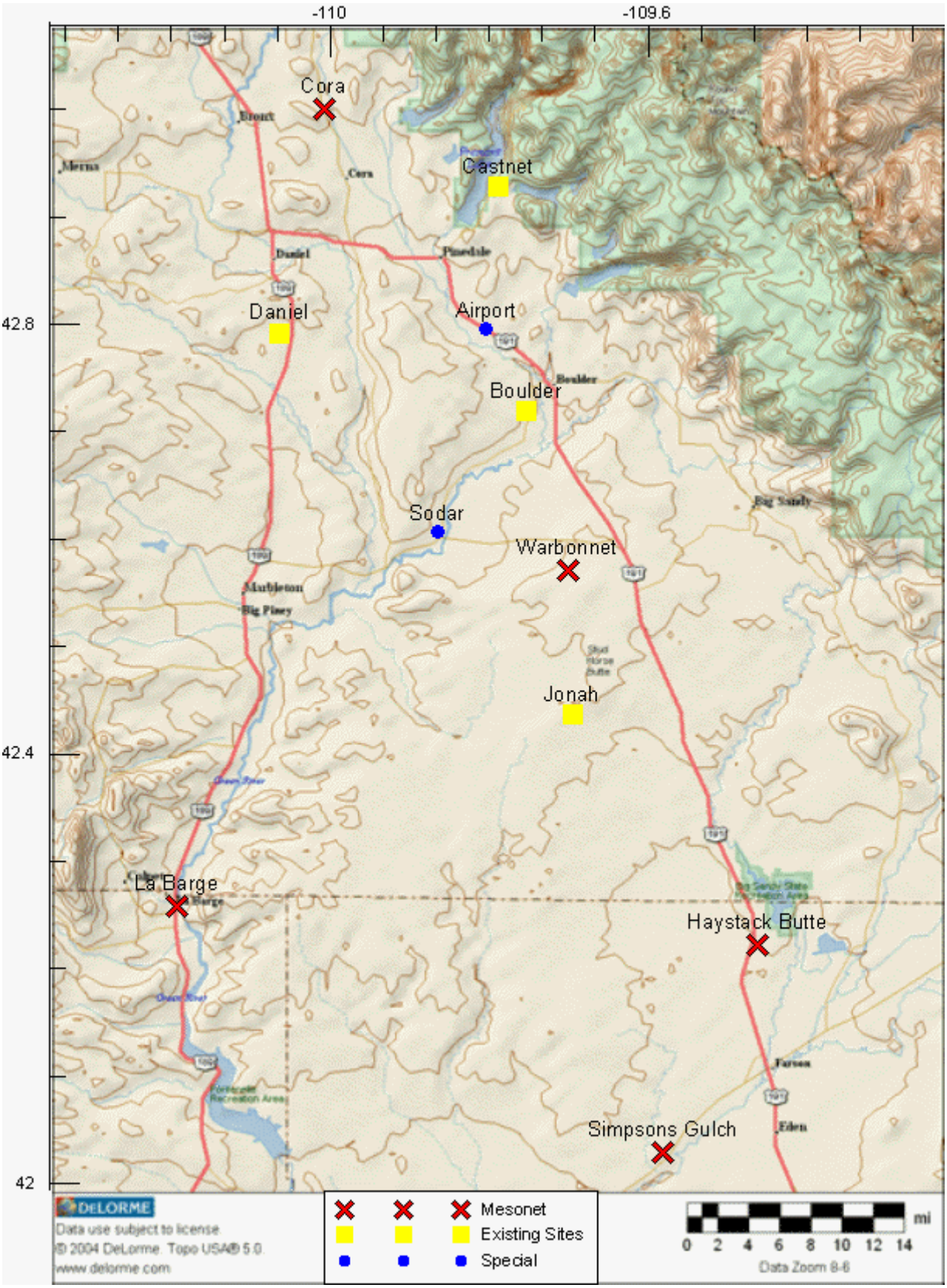

Figure 2-1. UGWOS 2008 monitoring network sites.

2.2 Continuous Measurements

Project-specific measurements from the continuous monitoring sites shown in Figure 2-1 were obtained for the 15 January – 31 March 2008 field study period. These measurements included surface and boundary layer meteorological data and surface air quality data.

Routine aerometric monitoring (O_3, NO, NO_2, PM_{10}) was conduced at the permanent Boulder, Daniel, and Jonah WY DEQ monitoring sites. Continuous surface ozone measurements using a designated EPA equivalent analyzer were conducted during the UGWOS '08 study period at the Pinedale airport (Wenz Field). In addition, continuous ozone measurements were made at a network of five mesonet sites using portable 2B ozone analyzers as described below.

Surface meteorological measurements were obtained at the three WY DEQ sites (Boulder, Daniel, Jonah) shown in Figure 2-1 and over a set of five temporary stations set out in the field as described below (denoted by red Xs in Figure 2-1) and at the miniSodar site and the Wenz Field (Pinedale airport) site (blue dots). Incoming and reflected UV radiation was measured at the Boulder site throughout the study period by Air Resource Specialists using the instrumentation package from the 2007 study as described by ENVIRON. (2008).

A network of six meteorological tripod stations (mesonet stations) were used in the ozone study during 2008. A typical station is shown in Figure 2-2. Data from the mesonet started at various periods in mid-January and are available through late March or early April. The sites and data availability are:

- Cora January 14 through April 1
- Airport January 16 through March 22
- Haystack January 14 through April 1
- La Barge January 13 through April 2
- Simpson January 14 through April 1
- Warbonnet January 13 through April 1

Figure 2-2. Solar powered tripod mesonet station used for wind and ozone measurements at Warbonnet (see map, Figure 2-1). Mast height is just under 3 m. Battery pack and 2B ozone analyzer are located in the cooler at base of tripod.

Each of the mesonet stations continuously recorded ozone concentration, wind direction, and wind speed. Only the meteorological data was collected by the mesonet tripod station at the airport, ozone was measured at this location by a Federal Equivalent Method UV analyzer.

2.3 Forecasts and Operational Readiness

Given the intermittent nature of elevated ozone episodes in the study area and the need for a 48 hour lead time to allow for deployment of the IOP supplemental measurement program described in the preceding section, an IOP forecasting protocol was developed and implemented as described in Appendix A. Methods used to guide forecasts for IOP events in 2008 were the same as those used in 2007, with the exception that snow cover was weighted more heavily in making the decision to deploy for an IOP.

2.4 Intensive Operating Periods

During periods when high ozone levels were forecast, a variety of supplemental measurements were initiated. The key components of these intensive operating periods (IOPs) were:

- VOC and carbonyl measurements at Boulder, Daniel and Jonah
- Ozone/rawinsonde operations
- Aircraft measurements

Field measurements made during UGWOS '08 are summarized in Table 2-1. The periods of operations varied by measurement. The 'existing' sites ran air quality and meteorological observations continuously with the exception of VOC sampling which was conducted during IOPs only. Ozone and meteorological measurements (winds only) at mesonet sites also ran continuously during the 11-week study as did the miniSodar upper-air measurements. The VOC sampling at the three existing sites occurred three-times daily during IOPs (see Section 6). Airplane sampling flights were conducted twice daily on each IOP day with one flight during the morning and one during the afternoon. All flights originated and ended at Wenz Field (Pinedale) and each sampling mission lasted approximately 3 to 4 hours. Rawinsondes occurred three-times daily, with ozone sondes used for two launches daily, and were timed to measure initial conditions when the atmosphere was most stable: early morning, late-morning (to document the daytime boundary layer growth), and in the afternoons (when mixing is typically the most vigorous).

Table 2-1. Summary of UGWOS measurements (R = routine measurement; I – intensive operating period measurement).

Site		Surface Data			Aloft Data	
Name	**Type**	**Ozone**	**Meteorology**	**VOC/Carb**	**Ozone**	**Meteorology**
Cora	Mesonet	R	R			
Warbonnet	Mesonet	R	R			
Haystack	Mesonet	R	R			
Simpsons	Mesonet	R	R			
La Barge	Mesonet	R	R			
Jonah	Existing	R	R	I		
Daniel	Existing	R	R	I		
Boulder	Existing	R	R	I		
miniSodar	Special		R			R[2]
Wenz Field	Special	R	R		I[3]	I[4]
Airplane	Special			I	I[5]	I[6]

2.5 Synoptic Weather Summaries of IOP Events

After the dozens of days of well-mixed dispersion conditions that persisted in the project area during the first six weeks of the UGWOS 2008 project, the synoptic weather pattern finally turned favorable for IOP field monitoring by February 18, 2008. Operational forecasting for the project was quite successful during the initial period of 2008 because the protocol that was developed in 2007 enabled the forecasters to make the correct decisions to not mobilize IOP field operations during poor to marginal situations. Furthermore, the three IOP exercises that were carried out in 2008 were initiated during periods when significant ozone formation actually occurred. The successful forecasting indicates that both the empirically based objective criteria, and the more subjective pattern recognition forecasting approaches used for the study are valid. Errors in timing, particularly in starting and ending operations too soon for the first IOP, and again ending too early during the second IOP, were due to the slowing down of the progression of the major synoptic weather features. This was a problem related to forecasting the evolution

[2] miniSODAR
[3] Ozonesonde
[4] Rawinsonde
[5] Ozone and PM measurements
[6] Temperature

and movement of the large-scale weather features based on the standard numerical models, not the specialized operational forecasting approach.

In the remainder of this section, the synoptic scale weather features affecting the project area during the three IOP's will be summarized using a few example weather charts for each IOP period and by presenting the measured values for some of the key objective meteorological parameters.

Feb 18 – 22

Stable stagnant weather conditions first arrived in the project area during the period from February 18 through February 22, 2008. The main synoptic feature responsible for this was a strong Pacific high pressure ridge that slowly migrated across the interior west. The forecasts that initially triggered the IOP mobilization called for the ridge to start affecting the project area by February 18th. Slower than anticipated eastward migration of the ridge resulted in its arrival in the area about 36 hours late. The configuration and progression of the ridge is illustrated by a series of 700 mb constant pressure maps as described below.

Figure 2-3 presents the 700 mb chart for the morning of February 19, 2008. The map clearly shows the axis of the Pacific ridge extending north and south from the Four Corners area, through northwestern Idaho and on up into eastern British Columbia. At that time, the ridge axis was still west of Wyoming, resulting in fairly strong northwesterly gradient flow just above ground level in the project area. With the clear skies accompanying the approaching ridge, and a good snow cover at the surface, a capping inversion did form overnight in the valley, but the strong winds above the stable layer transferred momentum to the surface enough during the day to inhibit northward transport of emissions from the southern most portions of the project area.

The high pressure ridge continued to progress slowly eastward during February 20th resulting in the central axis pushing into southwestern Wyoming by the middle of the day. As a result, a capping low-level inversion kept local emissions trapped in the project area throughout the day, and light gradient wind flow allowed the establishment of local valley flow patterns in the area. A weak storm system that moved out of California and across the southern Great Basin during the 20th forced some broken high cloudiness over southwestern Wyoming during the afternoon, but the clouds failed to curtail ozone production in the area. The height of the 700 mb pressure surface during the day averaged 3020 m msl, the temperature at that level was about -4° C, and the wind speeds were less than 5 knots. The height of the 500 mb pressure surface averaged about 5580 m msl and the wind speeds at that level were around 10 knots.

Figure 2-4 shows the 700 mb chart for the afternoon of Feb 21, 2008. Although the high pressure ridge had weakened by this time, it had also flattened and the central ridge axis was over or just east of southwestern Wyoming through the entire day. The resulting light wind stagnant situation enabled the strongest ozone production seen to date in the project area. The low level inversion was not quite as strong as the one on the 19th, but it did stay intact through the entire daylight period, keeping ground level emissions trapped near the surface. With the very light and variable winds above the inversion, localized flow patterns near the ground level developed during the day allowing emissions to transport along those pathways in the project sampling grid. The height of the 700 mb pressure surface during the day was around 3020 m msl, the temperature averaged about -6° C, and the wind speeds were less than 5 knots. The height of the 500 mb pressure surface averaged around 5550 m msl and the wind speeds at that height were around 15 knots

The high pressure ridge continued to weaken during February 22nd, while a shortwave low pressure trough approached southwestern Wyoming from the northwest. Skies became mostly cloudy during the morning hours and light precipitation spread over the area later in the afternoon. Nevertheless, the low level inversion stayed intact well into the afternoon, and ozone concentrations remained high during most of the day. No IOP operations were conducted day because it was anticipated that the stable layer would be mixed-out by the trough by early morning and, therefore, trapped emission would be dispersed. Instead, the late arrival of the trough allowed one more day of high ozone concentrations.

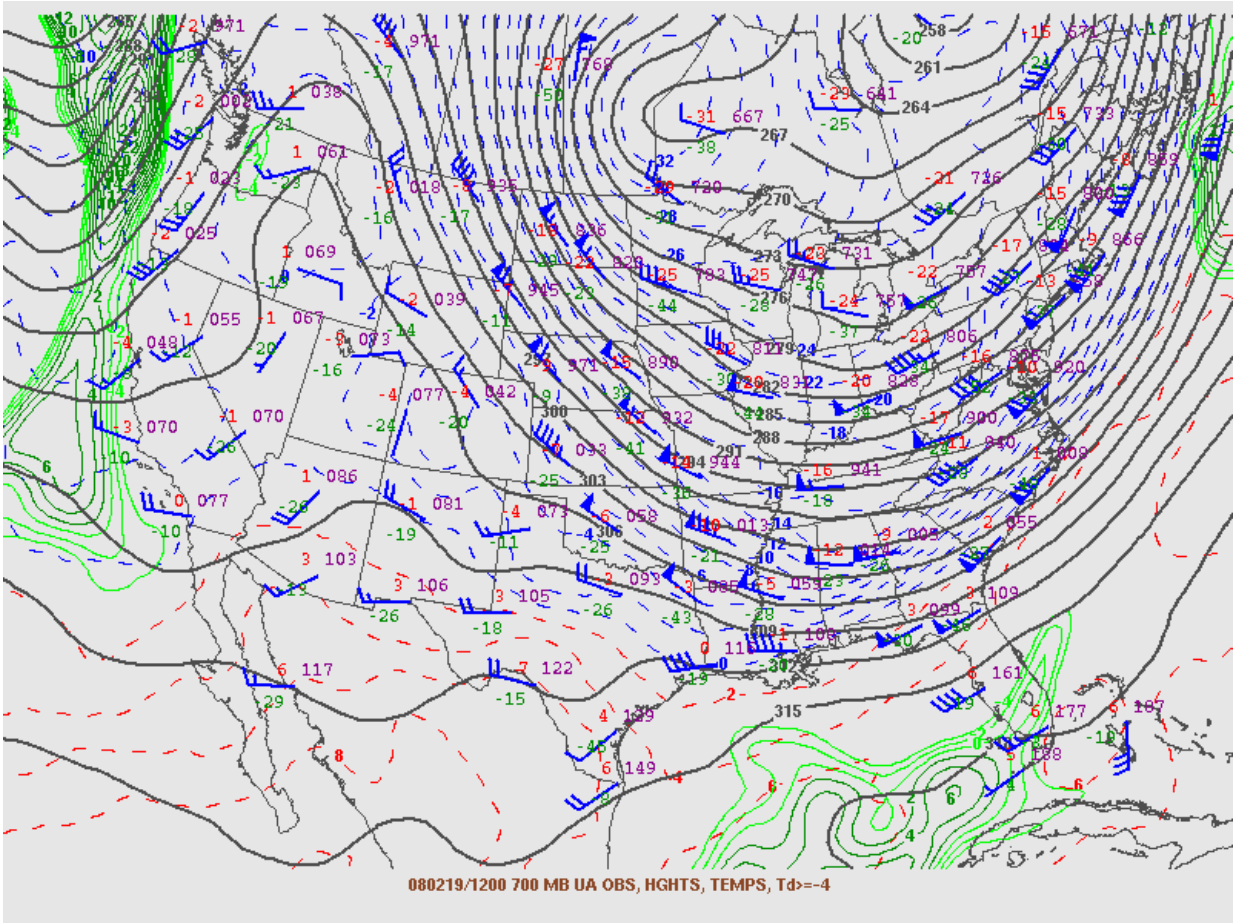

Figure 2-3. Constant pressure map for 700 mb, morning (1200 UTC) of 02/19/08 (Source: http://www.spc.noaa.gov).

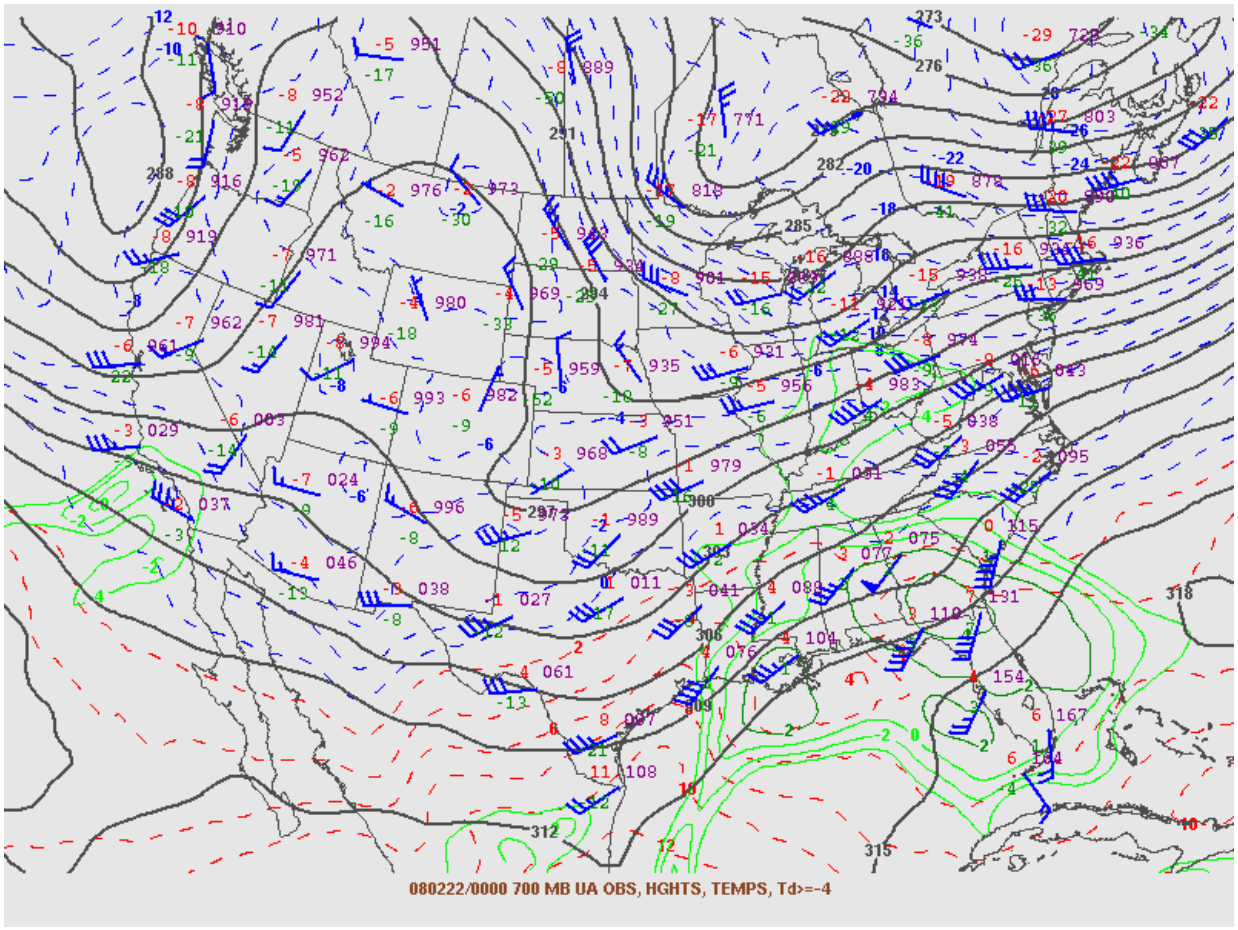

Figure 2-4. Constant pressure map for 700 mb, afternoon (2400 UTC) of 02/21/08 (Source: http://www.spc.noaa.gov).

Feb 27 – 29

The synoptic weather during the three-day period of the second UGWOS 2008 IOP was characterized by the slow passage of a flattening ridge of higher pressure through the project area on Feb 29th.

Figure 2-5 presents the 700 mb constant pressure chart for the morning of Feb 27, 2008. The map shows an eastern Pacific high pressure ridge drifting into the western Great Basin. The decision to attempt the three-day IOP operation was based on the forecast of the migration of the ridge into southwestern Wyoming during the day on the 28th. The position and configuration of the ridge on the 27th indicated that the forecast was accurate at that time. Because of the location of the ridge to the west of the project area on the 27th, southwestern Wyoming remained under strong northwesterly gradient flow that day and therefore, the light winds and strong capping inversion conditions needed for high ozone production had not yet developed. On Feb 28th, a weak disturbance aloft that was embed in the strong northwesterly flow stream, unexpectedly slid through northern Wyoming, contrary to the forecasted pattern. The result was the weakening and flattening of the high pressure ridge, and the slowing down of its timing of movement toward the east. Although the disturbance did not bring any weather other than some broken high clouds to the project area, the stagnant dispersion conditions needed for increased ozone production did not materialize because of the relative instability of the air mass and the continued strong northwesterly winds just above the surface.

Figure 2-6 shows the 700 mb constant pressure map for the afternoon of Feb 29, 2008. After the upper air disturbance of the 28th had cleared the region, the flattened high pressure ridge continued its migration to the east that evening. By the afternoon of the 29th, the ridge had flattened to such an extent that its axis was barely discernable. Nevertheless, conditions in southwestern Wyoming during the day were sufficient to produce elevated ozone in the project area. The weak ridging pattern brought in a more stable air mass and lighter winds to the area. This, coupled with the substantial snow cover, enabled the low level inversion to be sustained under mostly sunny skies throughout the daylight hours. The height of the 700 mb pressure surface during the 29th averaged 3010 m msl, the temperature at that level was about -2° C, and the wind speeds were around 15 knots. The height of the 500 mb pressure surface averaged about 5730 m msl and the wind speeds at that level were around 35 knots.

During March 1, 2008, another short wave disturbance approached southwestern Wyoming from the northwest. That feature brought broken to overcast skies, increasing surface wind speeds and decreasing stability to the project area. The affects of the trough were forecast to arrive in the area by the midday on the 1st, but instead they arrived about six hours later. As a result, ozone levels remained elevated in the project area through most of the afternoon, despite an increasing cloud cover. The arrival of light precipitation, stronger winds and decreased stability that evening finally scoured out the residual ozone in the study area.

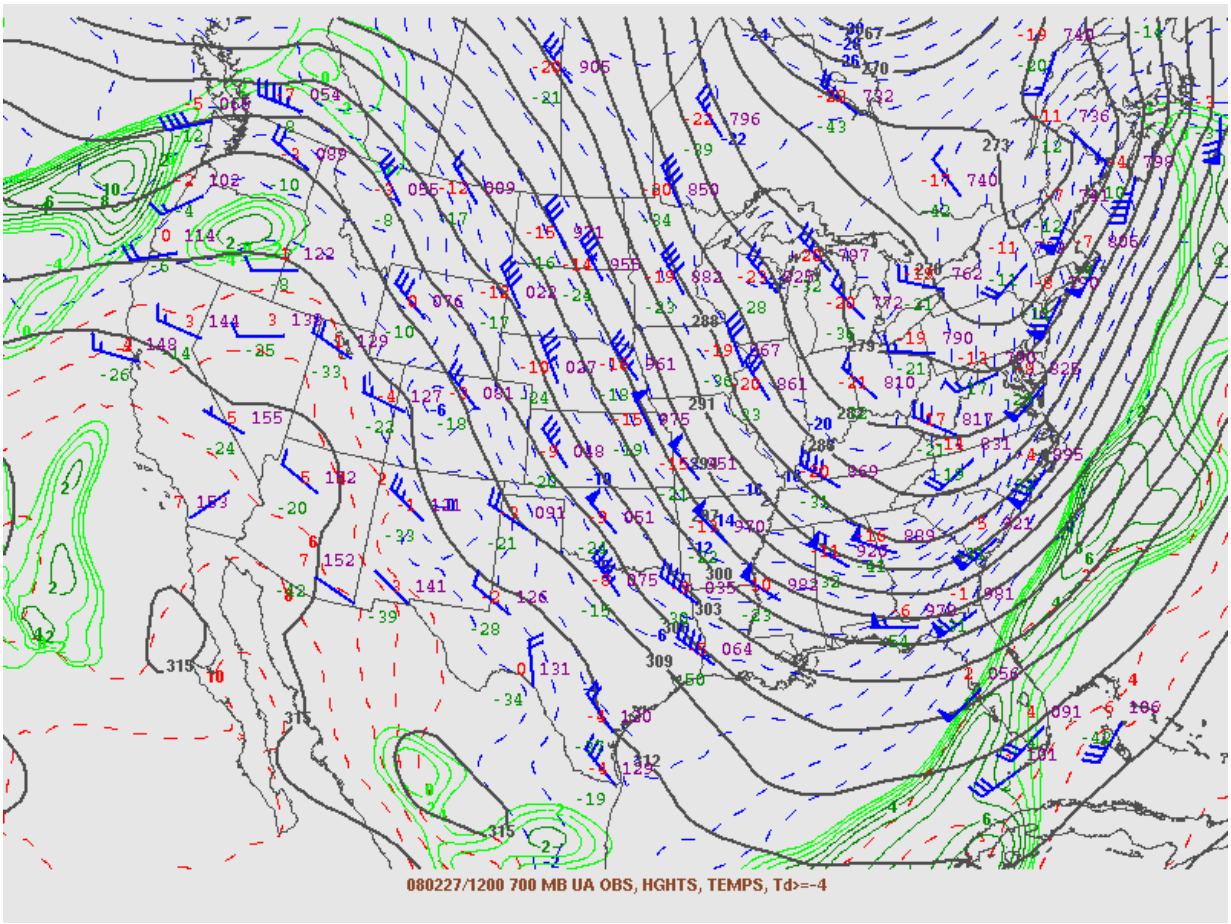

Figure 2-5. Constant pressure map for 700 mb, morning (1200 UTC) of 02/27/08 (Source: http://www.spc.noaa.gov).

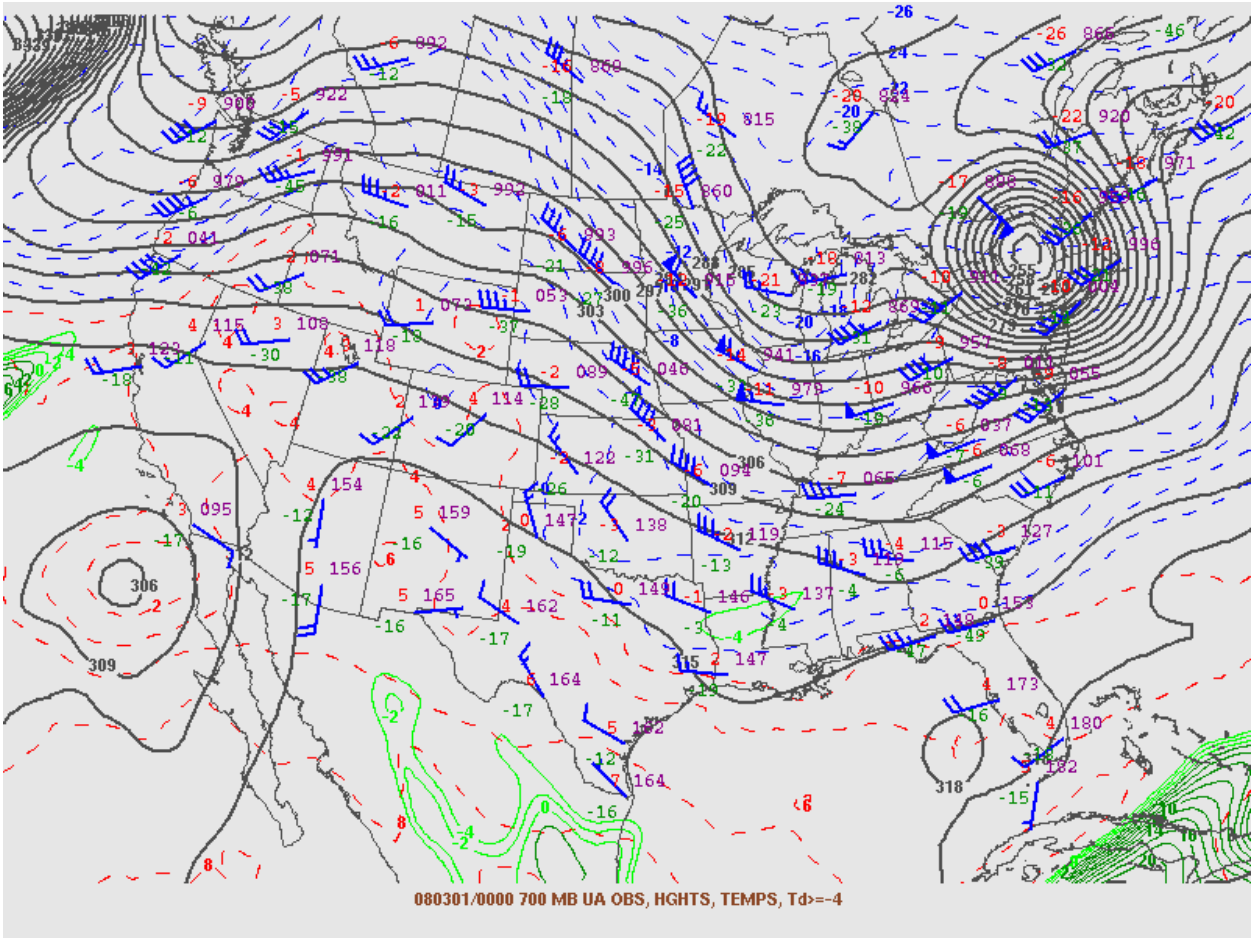

Figure 2-6. Constant pressure map for 700 mb, afternoon (2400 UTC) of 02/29/08 (Source: http://www.spc.noaa.gov).

March 10 – 12

A fast moving short ridge of high pressure migrated from the Pacific Northwest coast, across the northern Great Basin and into southwestern Wyoming during a 48 hour span on March 10 and 11, 2008. The ridge provided a short-lived window for elevated ozone in the project area during the afternoons of the 10th and 11th before disappearing by early on March 12th.

Figure 2-7 shows the 700 mb constant pressure chart for the morning of March 10th. The axis of the approaching high pressure ridge was located over the western Great Basin at that time, running from southwestern Nevada, through western Idaho and up into eastern British Columbia. Gradient flow out ahead of the ridge over southwestern Wyoming was generally northwesterly through the day, but wind speeds were not generally strong, reflecting the relatively flat gradient in the interior west at that time. With the relatively low gradient winds speeds and mostly clear skies, a low level stable layer formed over night, but its relative weakness and height above the ground resulted in a deeper and less stable mixing layer as compared to previous high ozone events. The light gradient winds did allow, local surface flow patterns to develop during the day, but the relative weakness of the stable layer did allow some coupling of the winds aloft with the surface, resulting in a general drift toward the southeast.

Figure 2-8 presents the 700 mb constant pressure map from the morning of March 11, 2008. The short high pressure ridge that had entered the Great Basin the previous day had continued to progress eastward but the flow pattern associated with the ridge had become much more zonal making it much less discernable in the large scale pattern. The air mass associated with the ridge still maintained its overall subsidence stability, but a Pacific trough that was pushing the ridge from the west was beginning to erode the stability of the boundary layer by later that day. Nevertheless, a strong nocturnal inversion did develop overnight capping the lowest layer of the atmosphere in a manner similar to that seen in previous high ozone events. The shallow inversion persisted through the entire day maintaining its cap on the lower mixing layer even though there was increasing high and middle level cloudiness over the area. The height of the 700 mb pressure surface during the 11th averaged 3020 m msl, the temperature at that level was about -3° C, and the wind speeds were around 18 knots. The height of the 500 mb pressure surface averaged about 5720 m msl and the wind speeds at that level were around 40 knots. As the ridge flattened into a more zonal pattern during the day, regional gradient wind flow increased and became more westerly. Although the lower level stable layer kept the stronger westerly winds decoupled from the surface during the day, the winds eventually penetratde to ground level and the air mass destabilized that evening as the trough approached from the west. By March 12th, the stronger gradient westerly winds and well-mixed baroclinic zone associated with the approaching trough had scoured out the project area.

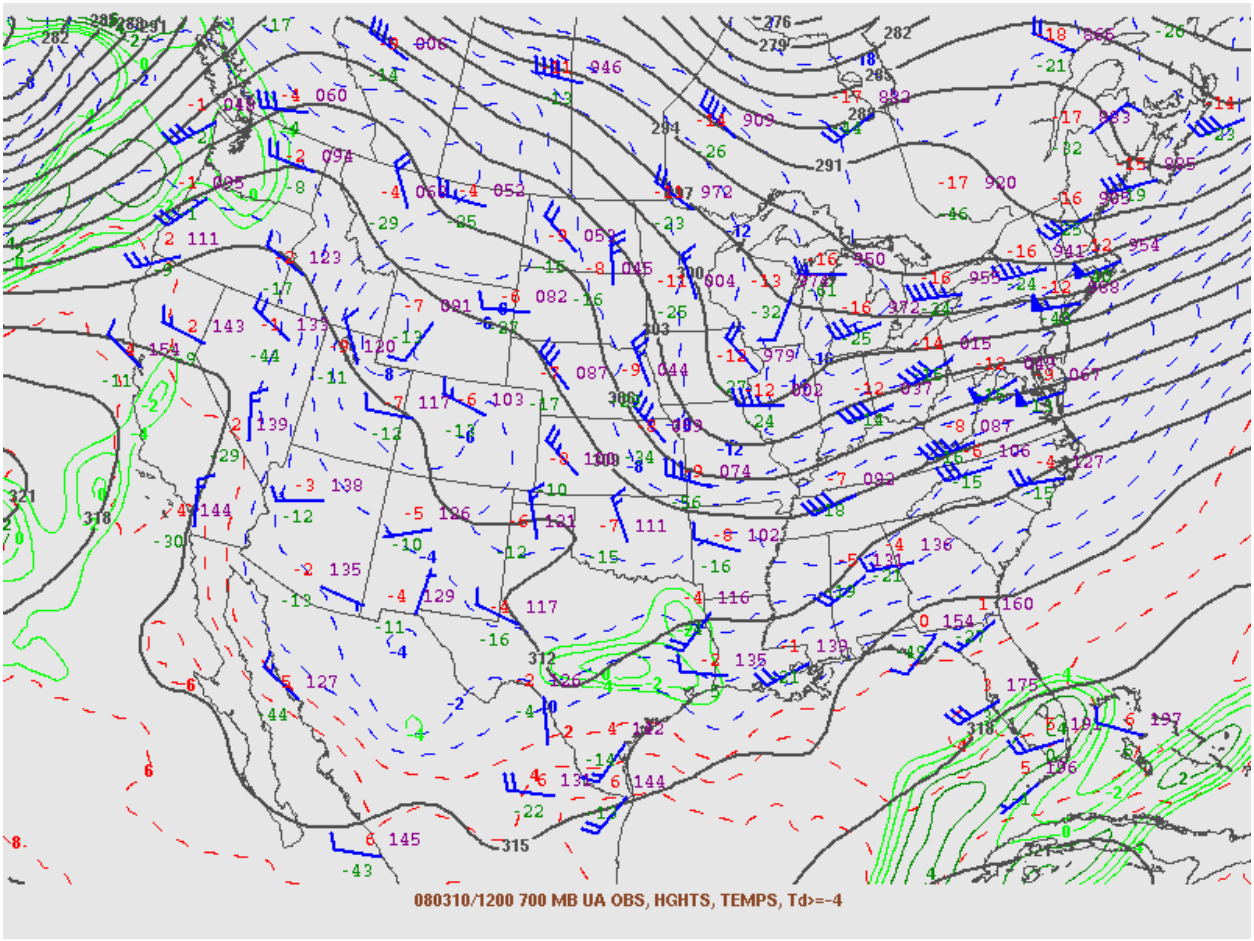

Figure 2-7. Constant pressure map for 700 mb, morning (1200 UTC) of 03/10/08 (Source: http://www.spc.noaa.gov).

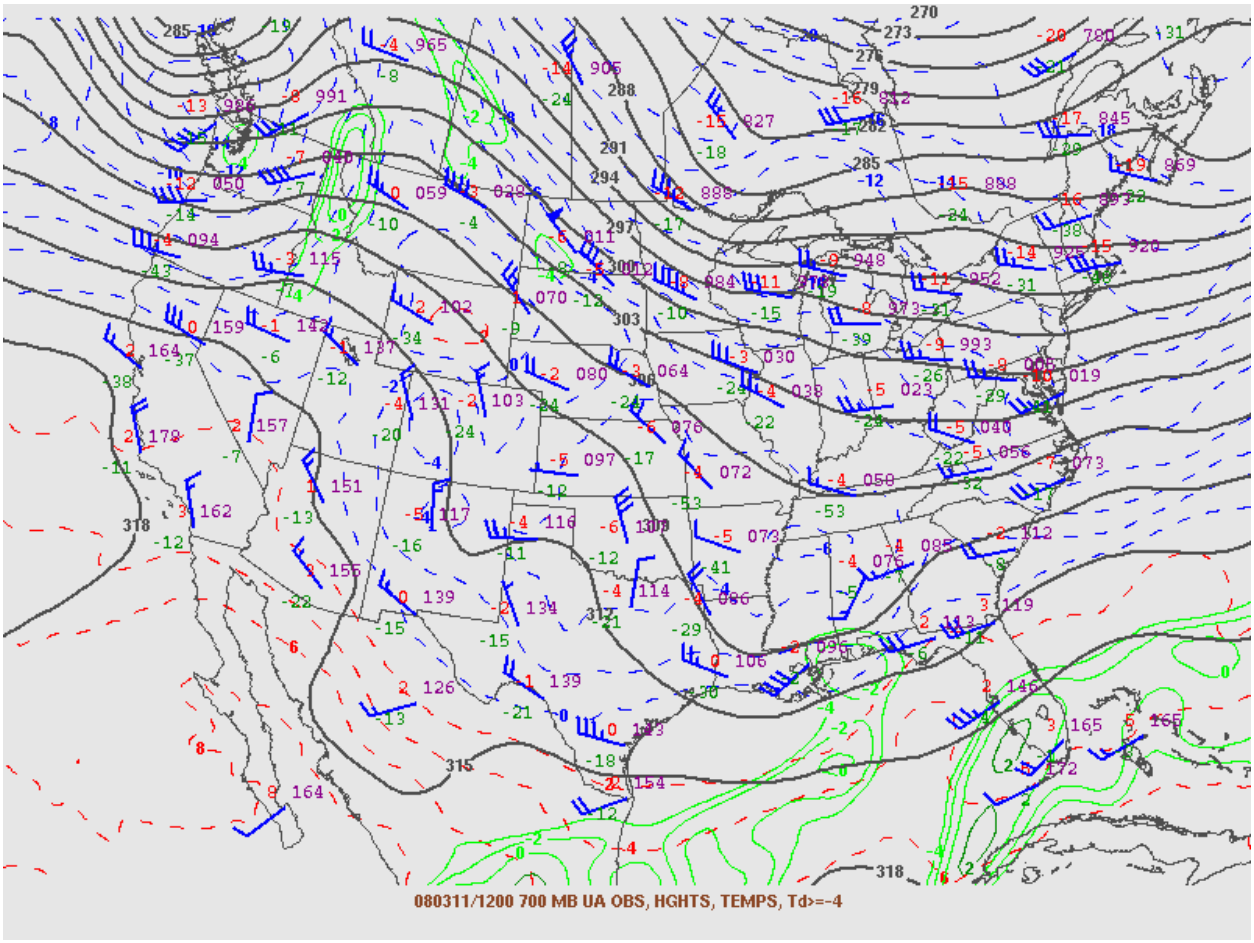

Figure 2-8. Constant pressure map for 700 mb, morning (1200 UTC) of 03/11/08 (Source: http://www.spc.noaa.gov).

3. DATA QUALITY ASSURANCE, VALIDATION AND ARCHIVING

A primary study objective was to produce an adequately validated data set from the field measurements that is well defined and documented. The data management system utilized was designed to be straightforward and easy to maintain. Each study participant was responsible for reviewing and validating their collected data, and submitting the data to the Data Manager in a prescribed format. A brief summary of procedures used is provided in this section. A complete description of data collection, quality assurance, validation, and data reporting procedures is available in Appendix D.

3.1 Data Management and Reporting

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. A Monitoring and Quality Assurance document was prepared and approved by all the project participants (see Appendix D). Each of the participants that provided data was responsible for reviewing and validating their respective data. This included flagging values for instrument downtime and performance tests, applying any adjustments for calibration deviation, investigating extreme values and applying appropriate flags.

Flags used for the UGWOS data set are presented in Table 3-1. Each data provider was also responsible for documenting their validation process so that it could be provided to the Data Manager and other analysts if needed.

Table 3-1. Data flags used in the UGWOS database.

Flag	Description
V	Valid. Data meets primary MQOs.
S	Valid, but does not meet primary MQOs. Secondary MQOs in effect.
I	Data invalid.
M	Missing. Measurement not taken.

In addition, each data provider was responsible for furnishing information regarding the monitoring equipment used in the field study and any additional information to the Data Manager requested to enhance the overall documentation of the study. In particular, participants provided the Monitoring Quality Objectives (MQOs) defining the quality of all data submitted as "valid." These MQOs contained the accuracy, precision, lower quantifiable limit, resolution and completeness of each measurable. This information is available in metafiles that accompany the data base.

Standards for time reference, averaging period, parameter names and units were all defined beforehand and 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 given a value of -9999. Suspect data were flagged as such but the data was included.

3.2 Quality Assurance

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 Monitoring and Quality Assurance Plan was submitted to the WDEQ and approved prior to the start of monitoring (See Appendix D). This document provides a detailed discussion of the quality assurance program implemented in this study. 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. This included a dry run of all measurement methods, during which operating procedures were refined and fully documented. Standard operating procedures (SOPs) for measurements were completed prior to the start of monitoring.

All ozone analyzers and samplers were routinely checked using a certified transfer standard following operating procedures consistent with EPA guidelines. Calibrations were conducted on the mesonet ozone analyzers before and after each IOP. Linear regressions were calculated for each calibration. The averages of the linear regression slopes and intercepts over all of the calibrations performed on each analyzer during the course of the study was used to 'correct' the raw data. A zero check and ground truth comparison was performed on the aircraft ozone sampler which was operated in a similar manner to the other ozone analyzers and samplers. Other QC steps taken included comparisons of aircraft data with ground-based instruments as described in Section 3.3.2.

The status of the miniSodar was checked daily via remote access of the data. When problems were noted, WDEQ field staff were 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 are provided in Appendix D.

VOC canister samplers were checked for contamination prior to the IOP by filling a clean canister using each individual sampler and submitting it for analysis. VOC and carbonyl sampling field blanks totaling approximately 5 percent of the collected field samples were collected and analyzed. In addition, during sampling periods immediately following IOP#2 and IOP#3, two VOC and carbonyl samplers were collocated to collect duplicate samples as a precision check. On-going laboratory QA was performed on each batch of samples as they were received and analyzed including method blanks, QC duplicates, laboratory control spikes and laboratory control duplicates.

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 (Appendix D).

Calibrations of the ozone instruments were performed upon initial installation and at the end of the study period. Additional calibrations were performed on an as-needed basis in the event of equipment repair or replacement. All calibrations were performed in accordance with the

manufacturer's recommendations and were consistent with USEPA guidelines. Calibrations and zero/span checks of all ozone monitoring equipment were conducted using a transfer standard certified against a local ozone standard maintained at the Pinedale airport. This local standard in turn had been certified against T&B System's primary standard maintained following EPA's guidelines at their office in Valencia, CA. This standard has also been certified in January, 2007 against the US EPA Region 8 primary standard maintained at Boulder, CO. The two certifications showed very good agreement.

All meteorological sensors were calibrated at the beginning and ending of the study. Wind speed sensors were calibrated using an RM Young constant rpm motor simulating wind speeds at several points across the sensor's operating range. Wind direction sensors were calibrated by checking responses at standard increments.

3.3 Data Validation

3.3.1 Procedures

Each study participant was responsible for reviewing and validating their collected data. The data were validated to *Level 1* as described by Watson, et al. (2001) before being submitted 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.

Mesonet data from all sites (including the data from the Pinedale Airport) were plotted together and reviewed for inconsistencies. In addition, the 5-minute average data for each site were reviewed for any unusual spikes that may have affected the 1-hour averages. Data from each mesonet ozone analyzer were adjusted for calibration results as described in Section 3.2.

VOC canisters each were accompanied by a field data sheet which included the following information: Sample date and start and stop time, canister number, sample number, canister pressure at the start and canister pressure at the end of the sampling period. Sample date and start time were checked against the date and start time embedded in the sample number. All canister documentation was checked to confirm that samples were taken during the 3-hour period specified for the IOP measurement. All canisters were checked to confirm that they had reasonable positive pressure at the end of sampling. Analytical results were checked to confirm the proper canister number and sample number.

Carbonyl DNPH cartridges were accompanied by a field data sheet which included the following information: Sample date, start and stop times, sample number and sample flow rate. Sample date and start time were checked against the date and start time embedded in the sample number. All carbonyl documentation was checked to assure that samples were taken during the 3-hour period specified for the IOP measurement. After sampling, DNPH cartridges were inserted into the aluminized envelopes provided and sealed with stickers containing the sample number. Sample flow rates were verified periodically during the IOP and if the rates changed an average flow rate was assigned to the appropriate period.

Analytical results for both VOC and Carbonyl samples contain fields for data qualifiers assigned by the laboratory (LAB QUALS) and by the field sampling technicians (SAM QUALS).

Laboratory and field sampling data qualifiers are presented in Table 3-2 and Table 3-3 respectively.

Table 3-2. Laboratory data qualifiers for VOC and carbonyl data.

LAB QUALS Data Qualifiers	Description
B	This compound was detected in the blank above the Reporting Limit (RL)
D	This report was calculated from a secondary dilution factor
E	Compound exceeds the calibration range and is an estimated value
J	The amount reported is an estimated value because it is between the Reporting Limit (RL) and the Method Detection Limit (MDL)
F	Higher detection limit due to sample matrix
G	Higher detection limit due to limited sample size
Q	Compound secondary ion ratio qualifiers are outside the standard acceptance criteria
R	Compound secondary retention time (RT) is outside the acceptance criteria for the method
U	Compound is less than the Method Detection Limit (MDL)

Table 3-3. Field sampling data qualifiers for VOC and carbonyl data.

SAM QUALS Data Qualifiers	Description
Z	Zero air sample to check for sampler contamination
FB	Field Blank
L	Normally pumped 3-hour canister leaked back to ambient pressure due to solenoid valve malfunction
5	6-liter canister filled at 1.2 lpm and theoretically was full in 5 minutes due to flow controller malfunction
X	Invalid sample: Tubing disconnected – Sampled shelter air

The UGWOS database for both VOC and Carbonyl data was spot checked against the original analytical results to confirm content.

Daily reviews of the SODAR data included a general scan of the data to identify any potential instrument problems but did not include data editing.

Rawinsonde and ozonesondes quality checking began with ground truth readings prior to instrument releases. Temperature, relative humidity, and ozone readings from independent sensors were recorded and compared with the sonde readings. If any sensor seemed in error, the sonde was rejected. Post processing procedures included reviews of the data by an experienced meteorologist. Successive soundings were compared for reasonableness.

All aircraft data were plotted as time series charts on a per flight basis. That data reviewed for consistency amongst parameters, such as decreasing temperature with increasing height. Position data were plotted on a map overlay to verify that all heading and position data were valid. Ozone concentrations while on the surface at Pinedale Airport were compared against the continuous sampler being operated at that site and with data from other surface sites during near passes as described in the following section.

3.3.2 Comparisons of Ozone Monitoring Methods

Prior to comparing ozone data from the study, it is important to discuss the different equipment used to measure ozone during the study. The WDEQ sites (Boulder, Jonah, Daniel) and the Pinedale CASNET site all employ EPA "equivalent" designated (i.e., Federal Equivalent Method or FEM) analyzers approved for regulator air quality monitoring. These analyzers operate using a UV photometric method for analyzing ozone, based on the known degree of absorption of UV light by ozone. Similarly, an FEM designated analyzer was also installed for the study at the Airport site, where power was readily available.

The mesonet sites (Cora, Warbonnet, Haystack Butte, Simpson's Gulch, and La Barge) monitored ozone using a 2B Technologies Model 202 ozone analyzer. The 2B also operates using the UV photometric method, but is designed to be compact and to operate using a 12 V DC power source. Due to its simplified construction, the sampler does not have an EPA FEM designation. However, the analyzer was subjected to the same calibrations as those used for the conventional EPA FEM analyzers, using ozone concentrations traceable to a certified ozone standard. (see the QA plan in Appendix D). The mesonet 2B analyzers were checked at the beginning and end of each IOP period. Results of the check showed that all analyzers met the data quality objectives for accuracy of ±10%.

In contrast to the surface ozone measurements, upper air ozone measurements, including the aircraft measurements, were conducted using a method based on the chemical reaction of ozone with potassium iodide (KI). As part of the routine quality control checks, aircraft data obtained during the takeoff and landing ground rolls were compared against 5-minute averages recorded by the EPA "equivalent" analyzer sited at the airport. The results of these comparisons are plotted in Figure 3-1. The plot and resulting regression statistics show very good agreement between the aircraft KI method and the surface UV method, with a regression slope within 5% of 1.00 and an intercept of only 2 ppb. When reviewing Figure 3-1, it is important to remember that this agreement was obtained using two entirely different methods. Both of these methods have known but entirely different possible interferences, and the agreement effectively demonstrates that neither method was significantly affected by any interferences.

Further comparisons of the study ozone data were performed by comparing data from the aircraft with data reported by the mesonet sites as the aircraft flew over the site. The Haystack Butte and Simpson's Gulch sites were chosen for these comparisons, as they were frequent waypoints for the aircraft flight pattern and were relatively far away from local sources of NOx emissions that may have titrated the near-ground ozone concentrations. Figures 3-2 and 3-3 present the results of these comparisons, once again showing good agreement. In evaluating the comparisons, it should be noted that the measurements are inherently different in both time and location: the surface measurements are hourly averages whereas the aircraft measurement is essentially an instantaneous measurement as the aircraft flew over the site. Furthermore, the aircraft was nominally about 50 to 75 meters above the surface.

These comparisons thus address two key issues important in understanding the study measurements. First, they provide another demonstration of agreement between the KI method used in the aircraft and the UV method, in this case confirming measurements made by the mesonet 2B UV ozone measurement systems. Second, they address the representativeness of the aircraft data in describing conditions at the surface. Looking at the Haystack Butte comparison (Figure 3-2), the regression statistics show an apparent over-reporting of ozone concentrations by the aircraft relative to the surface site. However, two separate groups of measurements are noted

– higher concentrations associated with the afternoon flight and lower concentrations associated with the morning flights. The high concentrations are closely clustered, and show very close to 1-to-1 agreement. The lower concentrations show notably more scatter and surface concentrations that are on average lower than the aircraft concentrations, producing the bias in the regression statistics. This is consistent with a more well-mixed surface layer during the afternoon relative to morning conditions (an observation supported by the sodar data) minimizing possible differences between surface and aircraft concentrations. Figure 3-3 presents a similar comparison using the Simpson's Butte mesonet site, demonstrating essentially the same conclusions. Once again, close to 1-to-1 agreement is noted at higher, afternoon concentrations and higher aircraft readings relative to surface readings during lower, morning concentrations. Thus, the good agreement between the surface and aircraft readings during the afternoon confirm not only comparability between ozone measurement methods and platforms, but also the overall representativeness of aircraft data collected just below the top of the mixed layer in describing surface conditions during the critical afternoon period.

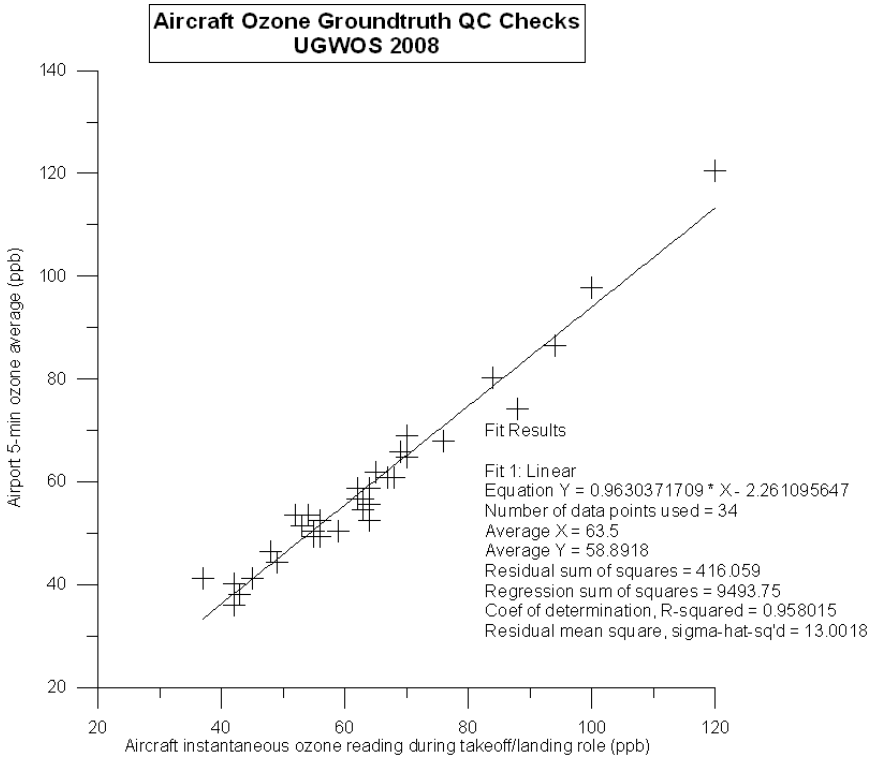

Figure 3-1. Comparison of aircraft ground roll ozone readings (2B ozone analyzer) at Wenz Field with ozone readings from Federal equivalent method UV analyzer located at the airport.

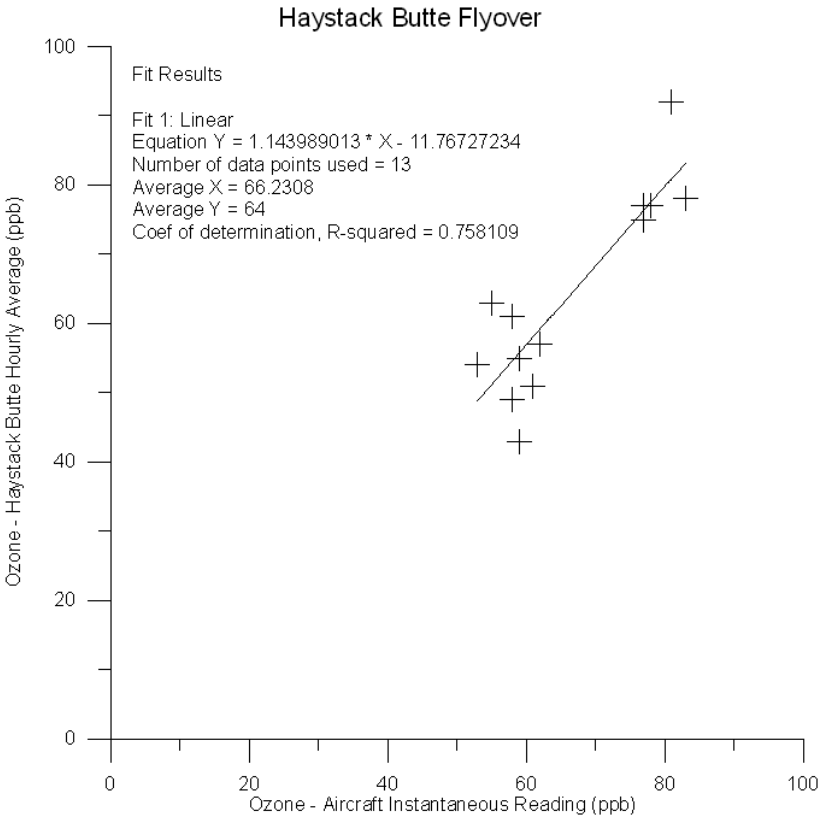

Figure 3-2. Comparison of aircraft (KI method) ozone readings with surface (UV method) readings during flyovers at the Haystack Butte mesonet site.

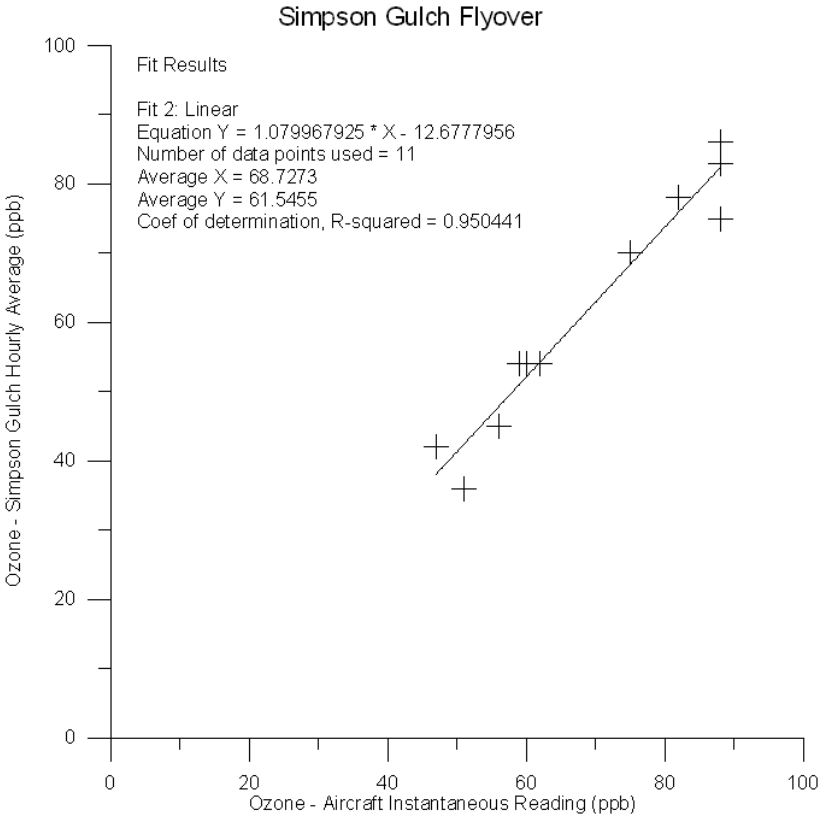

Figure 3-3. Comparison of aircraft (KI method) ozone readings with surface (UV method) readings during flyovers at the Simpson's Gulch mesonet site.

3.4 Data Archiving

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

- Parts per million for O_3, NO, NO_2, NOx
- Micrograms per cubic meter for PM_{10}
- Meters per second for wind speed (as a general rule, metric units will be used)
- Degrees Celsius for ambient temperature
- Percent for relative humidity
- Parts per Billion Carbon for non-methanated hydrocarbon species
- Watts/m^2 for radiation
- 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 are available for download from the Wyoming Department of Environmental Quality website (http://deq.state.wy.us/AQD/Monitoring%20Data.asp).

4. METEOROLOGICAL AND ROUTINE AEROMETRIC MEASUREMENT PROGRAM RESULTS

In this section we present a descriptive summary of conditions observed during the mid-January thru March 2008 field study based on the routine meteorological and air quality measurement program laid out in Section 2. Descriptive summaries of the supplemental upper-air balloon sounding observations made during the Intensive Operating Periods (IOPs) are also presented here. Results of the aircraft sampling performed during the IOP are presented in Section 5 and results of the VOC and carbonyl sampling conducted during the IOPs are presented in Section 6.

4.1 Conditions during the 2008 UGWOS Study Period

4.1.1 Overview of Air Quality Conditions

In sharp contrast to the relatively low ozone concentrations that prevailed during the 2007 study period, conditions in 2008 resulted in several high ozone events in the Jonah-Pinedale area. February and March monthly average and maximum 8-hour average ozone concentrations at the three permanent monitoring sites in the Jonah-Pinedale area for 2005 – 2008 are listed in Table 4-1. During this four year period, 2007 stands out as having the lowest average and maximum concentrations in both months. As described by Stoeckenius et al. (2007), meteorological conditions during 2007 were not favorable for ozone formation. February exceedances of the United State Environmental Protection Agency's new, more stringent, 75 ppb 8-hour ozone air quality standard (which became effective in May, 2008) occurred at one or more sites on three out of four years while March exceedances occurred on two out of four years.

Table 4-1. Monthly average and maximum 8-hour average ozone concentrations for February – March 2005 – 2008 at permanent monitoring sites.

	Average			Maximum		
February	**8-Hour Ozone (ppb)**			**8-Hour Ozone (ppb)**		
Year	**Jonah**	**Boulder**	**Daniel**	**Jonah**	**Boulder**	**Daniel**
2005	42.9	51.1	NA	98.4	89.3	NA
2006	39.5	48.1	49.5	93.0	71.1	82.6
2007	29.3	42.7	40.7	46.8	59.2	57.0
2008	40.6	54.1	50.7	102.4	122.4	76.2
	Average			**Maximum**		
March	**8-Hour Ozone (ppb)**			**8-Hour Ozone (ppb)**		
Year	**Jonah**	**Boulder**	**Daniel**	**Jonah**	**Boulder**	**Daniel**
2005	40.0	48.3	[1]	58.4	71.9	NA
2006	44.9	48.9	50.8	68.1	67.4	71.1
2007	32.7	44.3	40.7	44.9	65.9	55.5
2008	39.0	53.0	50.1	98.2	102.5	75.0

Several high ozone periods occurred during the 2008 study period as illustrated by the time series of daily maximum 8-hour average values in Figure 4-1. Concentrations exceeded 75 ppb on 14 days between 15 January and 31 March (see Table 4-2)*. Boulder was a key site during these high ozone events. Not only was Boulder the only site at which concentrations exceeded 75 ppb on all 14 days, Boulder also recorded the highest reading out of all reporting sites in the Jonah – Pinedale area on 10 of these days and was within 1 ppb of the maximum site on three of the remaining four days.

Table 4-2. Daily maximum 8-hour average ozone concentrations on days in 2008 with concentrations exceeding the 75 ppb standard at one or more locations* (shaded cell indicates location of maximum on each day).[a,b]

Date	Cora	Warbonnet	Haystack	Simpson	Airport	LaBarge	Jonah	Daniel	Boulder
2/10	58	**79**	48	44	61	49	56	71	**99**
2/15	NA[c]	71	49	44	**80**	53	**82**	60	**95**
2/19	68	68	55	51	55	63	**80**	74	**79**
2/20	75	**80**	74	**85**	67	74	75	**76**	**79**
2/21	64	**88**	**78**	**76**	**87**	**79**	**84**	62	**122**
2/22	68	**99**	**83**	**83**	**82**	**76**	**102**	**76**	**101**
2/23	**90**	**80**	**93**	68	**82**	61	**76**	74	**104**
2/24	68	**79**	63	57	63	67	65	70	**78**
2/29	53	62	70	64	67	55	**77**	53	**78**
3/1	NA[c]	70	75	70	70	63	68	72	**82**
3/8	64	59	62	56	70	48	37	57	**76**
3/9	70	**79**	69	65	**78**	60	NA[c]	58	**91**
3/10	63	73	**76**	**77**	69	61	**76**	74	**80**
3/11	61	68	**87**	74	**89**	56	**98**	57	**102**

[a] Boulder data missing 8-hour averages on 2/22 with start hours 0900 through 1400.
[b] Jonah data missing 8-hour averages from 3/8 start hour 2200 through 3/10 start hour 0900.
[c] Missing data due to pump failure

* Caution is required in comparing results from different monitoring sites shown in Table 4-2 and Figure 4-1: Only data from the Jonah, Boulder and Daniel site were collected using Federal Equivalent Method (FEM) monitoring instruments; data from the other monitoring sites are from non-FEM instruments. Only FEM data can be compared directly with EPA's ambient air quality standard to determine if an exceedance has occurred. Non-FEM instrumentation provides approximate ozone concentrations that do not meet EPA's legal requirements for quantifying ozone in ambient air.

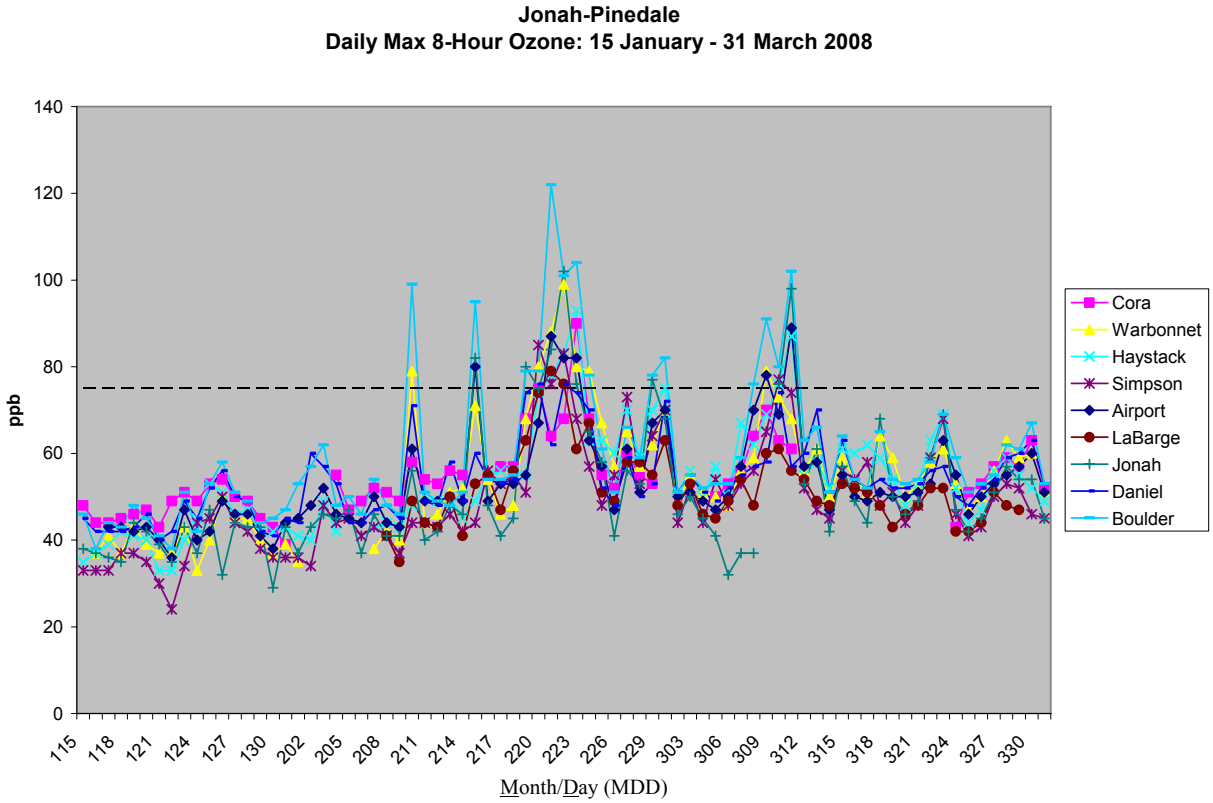

Figure 4-1. Daily maximum 8-hour average ozone concentrations for all monitoring sites in the Jonah-Pinedale area operating between 15 January and 31 March 2008.

Comparisons of Jonah-Pinedale area ozone data with data from other southwestern Wyoming sites and other sites in other parts of the state are shown in Figures 4-2 and 4-3, respectively. Data from the EPA CASTNET Pinedale monitor, which is located 220 m above the town of Pinedale, are included in Figure 4-2. Also included in this figure for reference purposes are the daily maxima over all Jonah-Pinedale area (JPA) sites that were included in Figure 4-1. The JPA maximum concentration is typically higher than concentrations recorded at any of the other southwestern Wyoming monitors, consistent with the formation of significant amounts of ozone from precursor sources local to the JPA. In fact, ozone concentrations at sites outside of the JPA did not exceed 75 ppb throughout this period with the exception of a single day (21 February) on which both the OCI and Wamsutter monitors recorded exceedances (OCI also recorded an exceedance on 22 February but Wamsutter did not. As noted above, 21 February was also the day on which the highest 8-hour average ozone concentration was recorded within the JPA and every monitor in the JPA except for Cora and Daniel recorded an exceedance of 75 ppb on this day. As was the case during the 2005 and 2006 winter JPA exceedance episodes, ozone levels at the Pinedale CASTNET site were much lower and did not exceed 75 ppb. Overall, the high JPA ozone events did not extend to other sites in southwestern Wyoming. Similarly, Figure 4-3 shows that the high JPA events were not replicated elsewhere in Wyoming although the late February and early March JPA exceedance events did coincide with elevated values at Thunder Basin and to a lesser extent at Centennial. In fact, three days of exceedances of 75 ppb were recorded at the Thunder Basin monitor in northeastern Wyoming during this period. Further analysis of the Thunder Basin data is suggested but is beyond the scope of this study. There is

no reason, however, to expect any causal relationship between the JPA events and the Thunder Basin exceedances given the large distance between these sites.

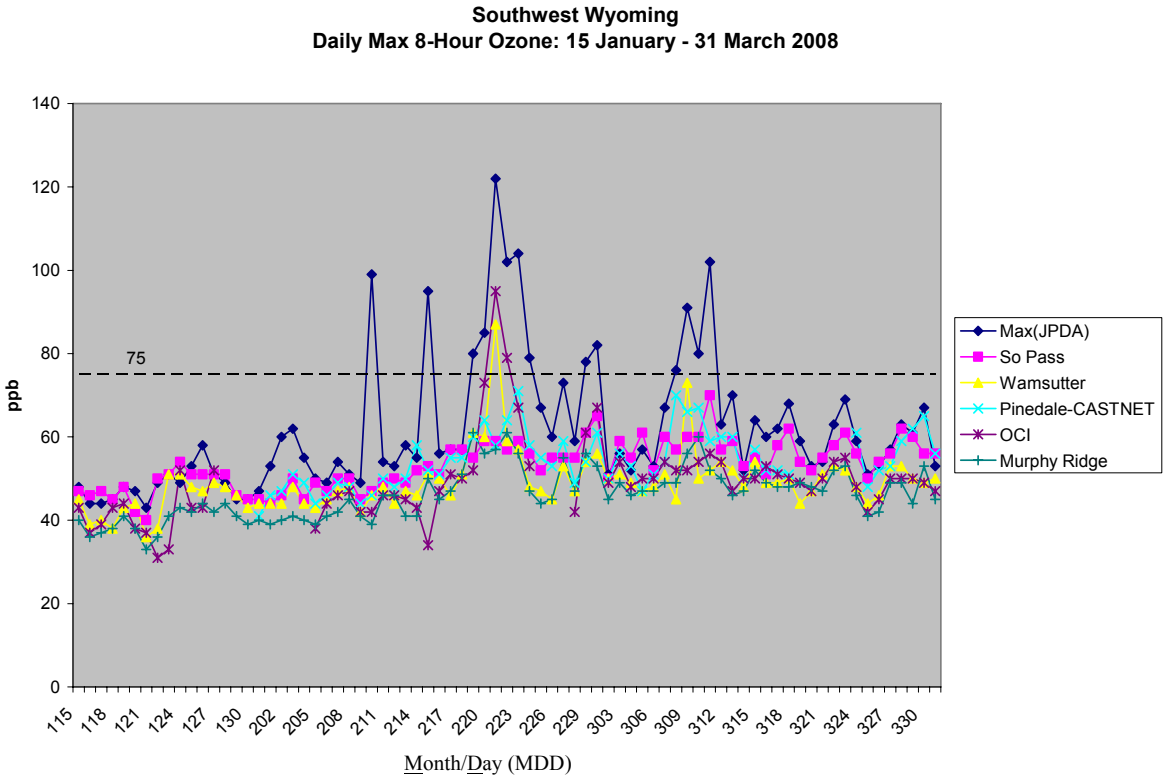

Figure 4-2. Daily maximum 8-hour average ozone concentrations at monitoring sites in southwestern Wyoming (only maximum daily value shown for the group of Jonah-Pinedale area sites for which data were presented in Figure 4-1).

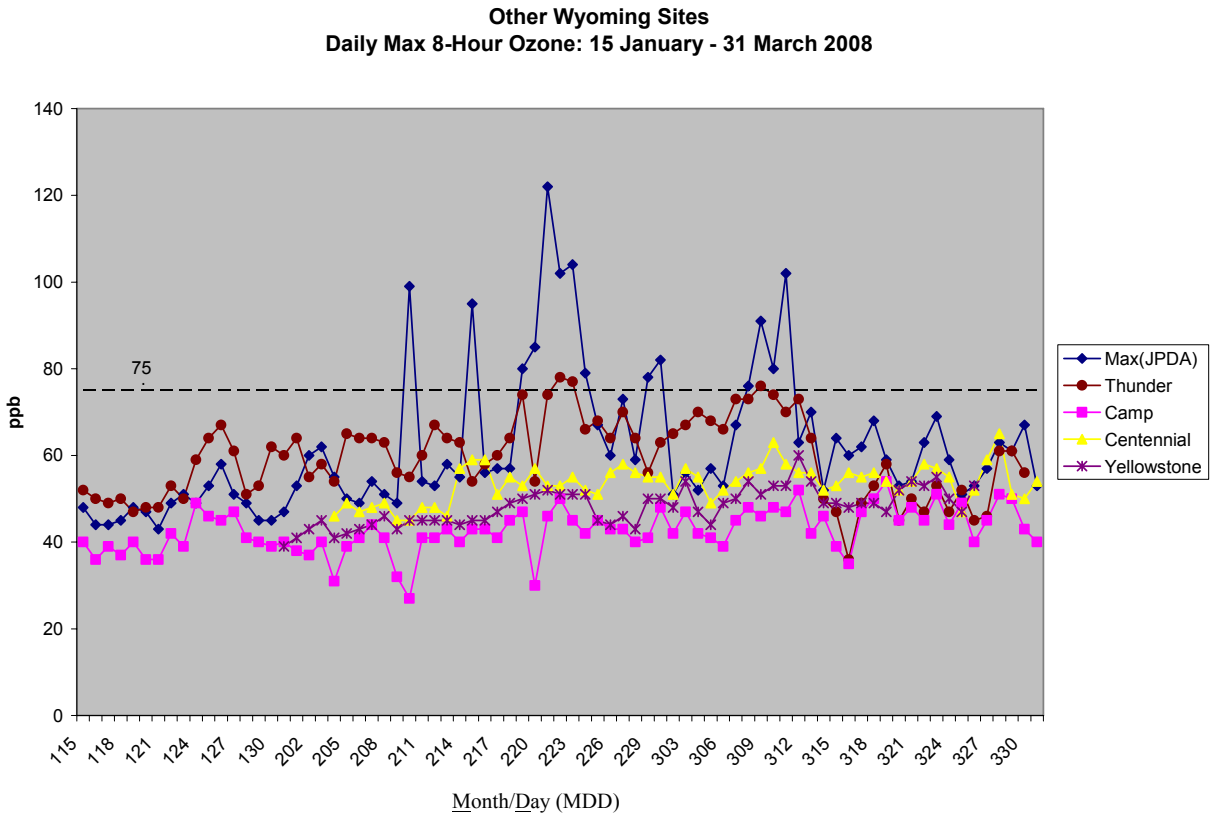

Figure 4-3. Daily maximum 8-hour average ozone concentrations in the Jonah – Pinedale area compared to other monitoring sites outside of southwestern Wyoming (only maximum daily value shown for the group of Jonah-Pinedale area sites for which data were presented in Figure 4-1).

4.1.2 Overview Of Meteorological Conditions

A description of average meteorological conditions at the surface and aloft during the 2008 study period with a comparison to conditions during prior winters (2005 – 2007) is provided in Appendix C. Overall, *average* conditions during 2008 were similar to those in the three previous years, with the notable exception of a much more extensive snow cover during 2008.

4.2 Description of Surface Air Quality Data

As noted above, the three permanent monitoring sites (Jonah, Boulder and Daniel) were supplemented during the study period with a network of five mesonet sites that recorded ozone conditions during UGWOS using portable 2B analyzers as described in Section 2. As noted in Section 3, calibration checks of the mesonet as well as the fixed site ozone analyzers were accomplished prior to the beginning of the study. These calibrations assured that all instruments were operating normally prior to the beginning of the study on 15 January. Exceptions to this were the instrument at Cora which came online on February 4 and the instrument at LaBarge which came online on February 8, 2008 due to pump problems with these two units. Calibrations on the mesonet ozone analyzers were again completed after the first and second IOPs and before and after the third IOP.

Mesonet site locations (Figure 4-4) were chosen to provide a representative sampling of conditions across the upper Green River study area. The straight line distance between Cora in the north and Simpsons' Gulch in the south is approximately 111 km (69 miles) and the distance between La Barge is the west and Haystack Butte is the east is approximately 60 km (37 miles).

Maximum, minimum, and average hourly ozone values observed during 15 January – 31 March 2008 along with data recovery rates are shown in Table 4-3. Identical statistics are shown for the 8-hour averaged ozone in Table 4-4. Note data recovery rates at Cora and La Barge were relatively low due to pump failures. Maximum hourly values reached as high as 136 ppb which was recorded at Warbonnet on 22 February. Maximum 8-hour average concentrations exceeded 75 ppb at all of the mesonet sites. Very low hourly minimum values at all sites except Cora indicate a significant ozone depletion mechanism which is likely the result of NO titration due to input of fresh emissions from combustion sources.

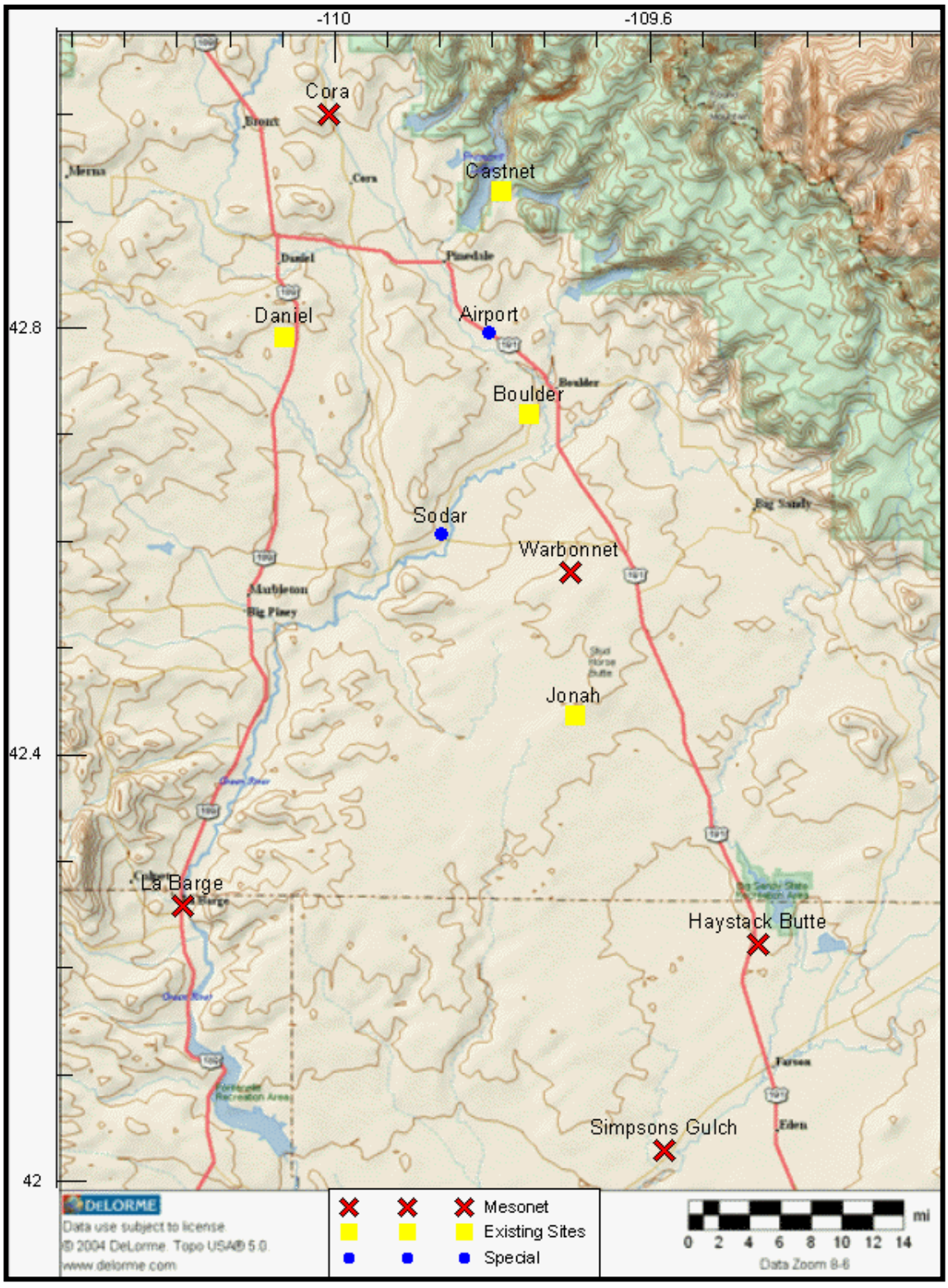

Figure 4-4. Location of monitoring sites.

Table 4-3. Mesonet statistics of hourly ozone readings (ppb) – January 15th - March 2008.

	Cora	Warbonnet	Haystack Butte	Simpson's Gulch	Airport	LaBarge
Maximum	92	136	99	108	130	88
Minimum	32	1	7	7	10	7
Average	47.6	41.6	44.0	45.7	45.9	42.0
Percent Data	68%	89%	95%	99%	96%	64%

Table 4-4. Mesonet statistics of 8- hour ozone readings (ppb) – January 15th - March 2008.

	Cora	Warbonnet	Haystack Butte	Simpson's Gulch	Airport	LaBarge
Maximum	87	94	91	87	89	79
Minimum	34	14	11	14	19	19
Average	47.1	41.2	43.5	45.2	45.3	41.6
Percent Data	67%	90%	95%	99%	96%	64%

1-hour and 8-Hour ozone data plotted for the two month period shows that the six sites recorded ozone concentration patterns that were in general agreement with each other throughout the study period. February and March 1-hour ozone data is presented in Figure 4-5 and 8-hour data are shown in Figure 4-6.

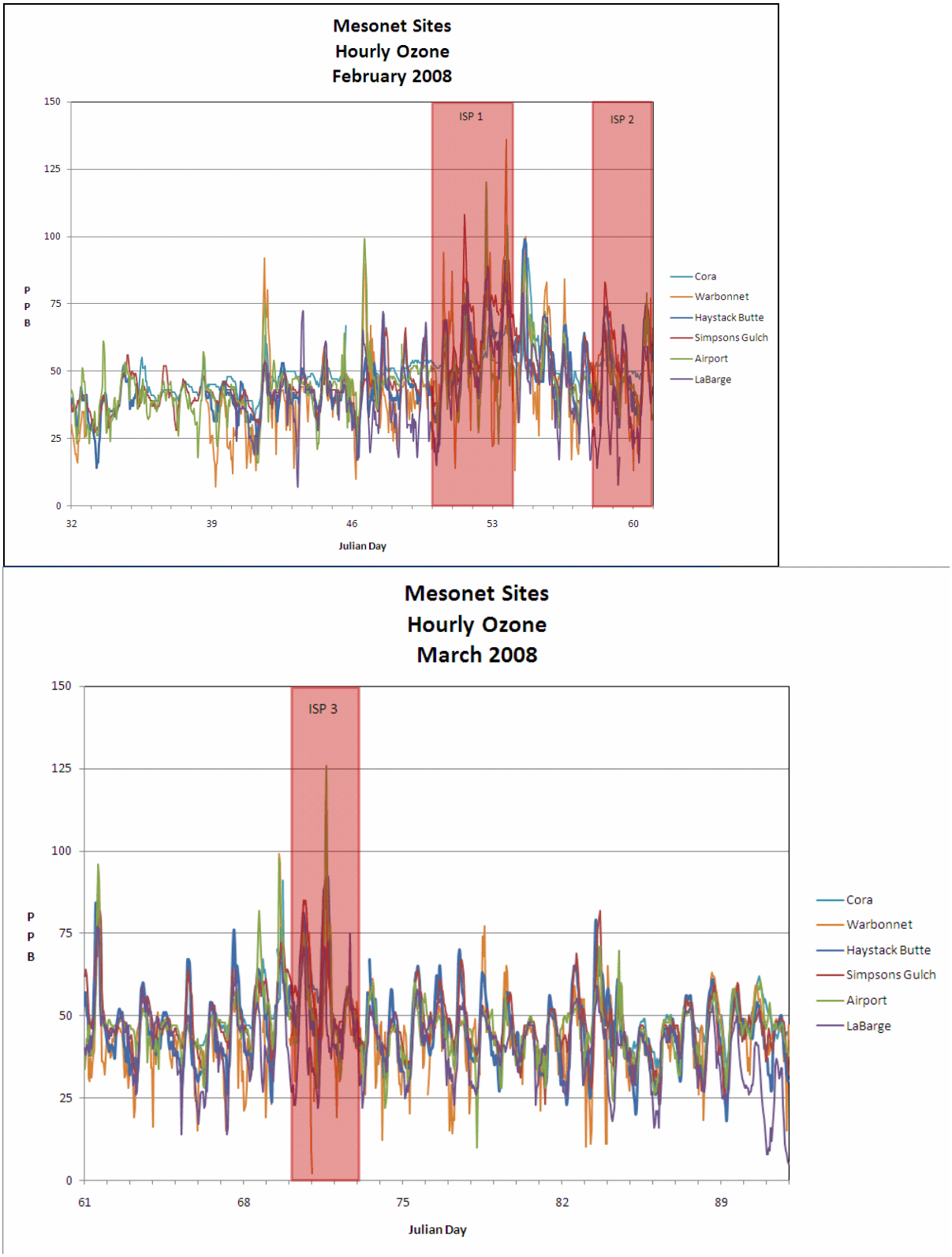

Figure 4-5. Hourly ozone concentrations at mesonet monitoring sites: February 2008 (top) and March 2008 (bottom).

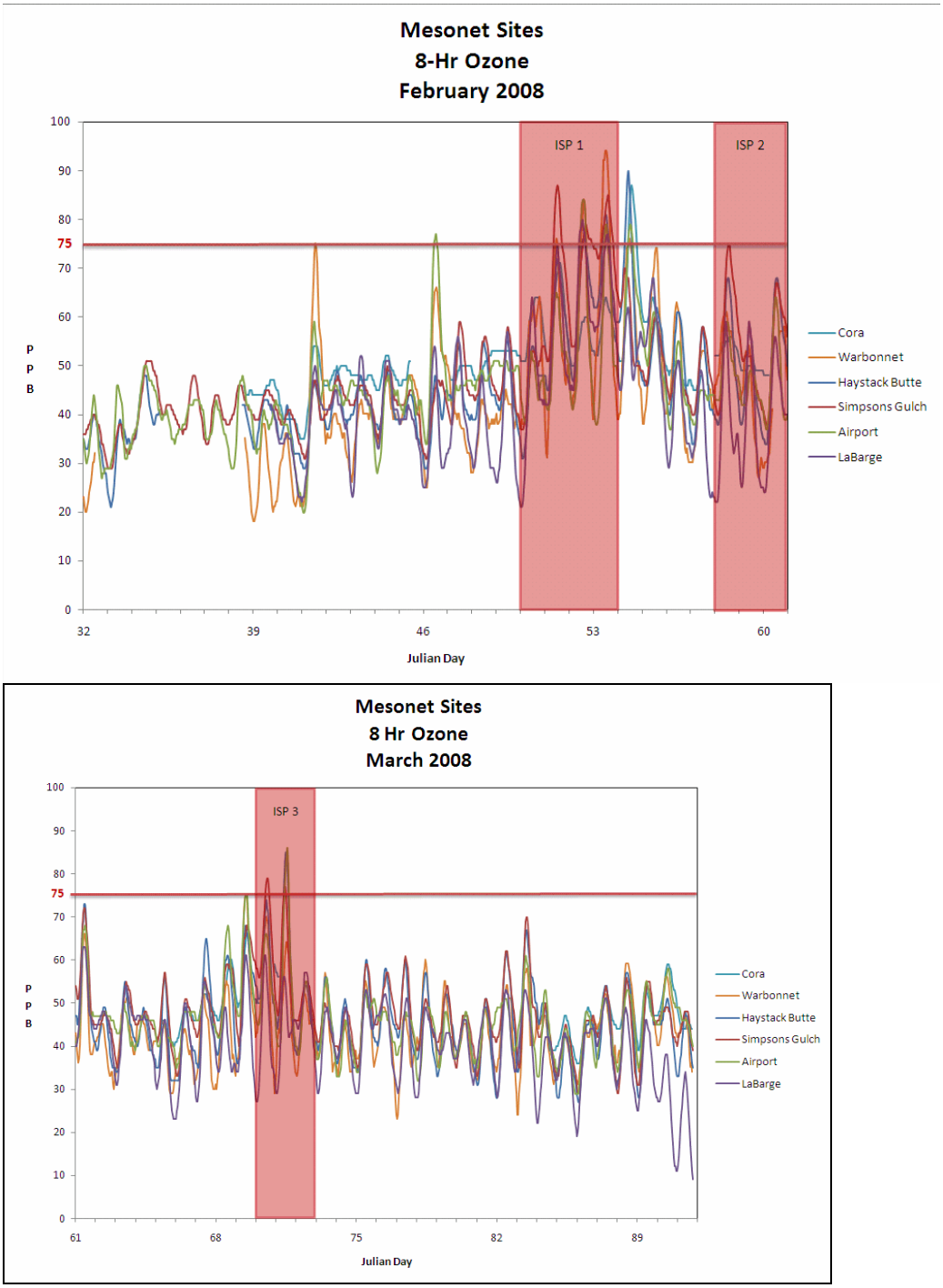

Figure 4-6. Eight-hour average ozone concentrations at mesonet monitoring sites: February 2008 (top) and March 2008 (bottom).

Spatial correlations of daily maximum 8-hour average ozone data were computed for all available monitoring sites in the study area to evaluate spatial relationships and identify potentially redundant sites. Inter-site Pearson product-moment correlation coefficients were computed between time series of daily maximum 8-hour average ozone concentrations at each monitoring site. Results (Table 4-5) show particularly strong relationships between the Simpson's Gulch and Haystack sites in the southern part of the study region and between Boulder and the Pinedale Airport sites. Other correlations are generally consistent with inter-site distances, the main exception being a moderately strong correlation between the Airport and Haystack.

Table 4-5. Spatial correlations of daily maximum 8-hour average ozone concentrations at monitoring sites in the study area (yellow highlight indicates correlations > 0.8, orange highlight indicates correlations > 0.9).

Table of Correlation Coefficents Between the Network Sites for Daily 8-Hour Maximum

	Cora	Warbonnet	Haystack	Simpson	La Barge	Airport	Jonah	Daniel	Boulder	Castnet
Cora		0.787	0.709	0.649	0.696	0.735	0.619	0.823	0.718	0.748
Warbonnet			0.780	0.763	0.734	0.820	0.811	0.694	0.866	0.672
Haystack				0.914	0.747	0.818	0.727	0.593	0.715	0.685
Simpson					0.821	0.759	0.716	0.616	0.667	0.657
La Barge						0.693	0.723	0.728	0.734	0.536
Airport							0.839	0.626	0.939	0.713
Jonah								0.693	0.838	0.519
Daniel									0.714	0.676
Boulder										0.578
Castnet										

0.90
0.80

Average diurnal variations in ozone recorded at all of the monitoring sites in the study region are shown in Figures 4-7 and 4-8. Results for the Warbonnet site, which is located approximately in the middle of the study region, are shown on both graphs. One noteworthy feature of these results is that, based on early morning minimums, LaBarge appears to have been impacted by fresh emissions on most days as was the case for Jonah and Warbonnet in the south half whereas Haystack and Simpsons were not. Note that in the northern tier of sites (Cora, Pinedale-CASTNET, Daniel), ozone remained at 50 ppb or greater on average except at Warbonnet. Also, morning ozone production at La Barge is comparable to that seen at the other southern sites but ozone formation ends two hours earlier, suggesting that the something is interrupting the photochemical process. This could be related to a lack of sufficient amounts of precursors at the start of the day or a shift in prevailing winds after 13:00 MST. In the north, Cora, Daniel and the Pinedale-CASTNET sites exhibit a late peak, consistent either a lack of fresh NO emissions or transport of polluted air from the southeast. Both the Warbonnet and Airport sites exhibit very similar average ozone levels from 07:00 – 22:00 MST but ozone at Warbonnet drops below the background 50 ppb average after midnight (most likely due to fresh NO emissions from continuously operating oil & gas sources) whereas the airport does not. The relatively rapid ozone reduction between 04:00 and 07:00 MST at the airport is suggestive of possible morning mobile source activity.

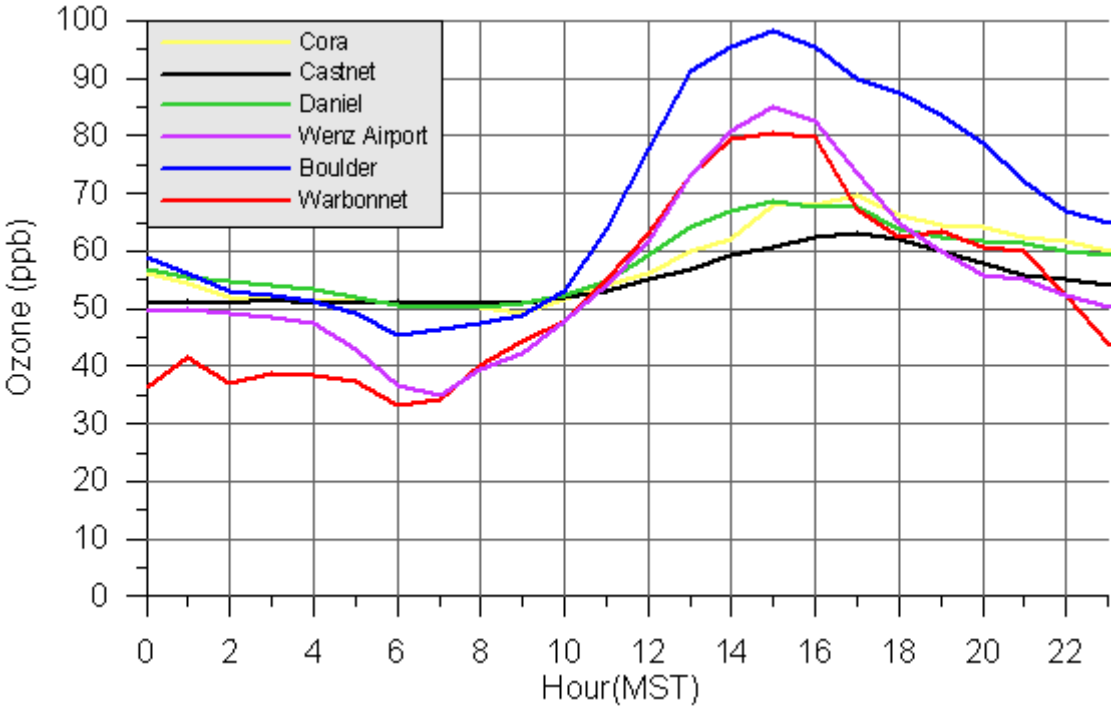

Figure 4-7. Average diurnal ozone concentrations on high ozone days (8 hr >75 ppb) for northern mesonet sites.

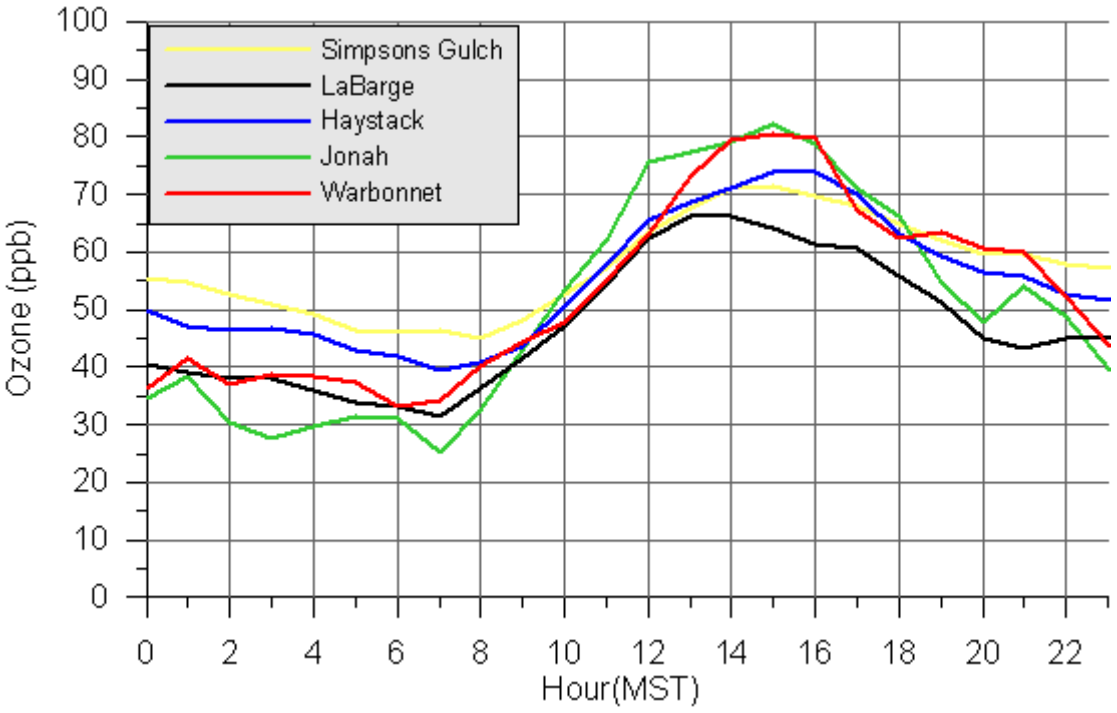

Figure 4-8. Average diurnal ozone concentrations on high ozone days (8 hr >75 ppb) for mesonet sites in the southern portion of the study area.

4.3 Description of Surface Wind Data

With the addition of the temporary mesonet monitoring sites to the existing permanent meteorological monitoring stations, a fairly detailed picture of wind flow patterns within the JPA was obtained. An overview of the wind data collected during the study period is provided by a set of daily plots showing the progression of hourly wind vectors at each site. An examples of these plots for the February 18 to 21 IOP are provided in **Figures 4-13 through 4-16.** The complete set of wind vector time series plots for each IOP day is provided in Appendix B. In these plots, the north-to-south orientation of the monitoring sites (see Figure 4-4) is roughly depicted by top-to-bottom graphs with Cora being the northernmost site and Simpsons Gulch the southernmost site.

February 18th was forecast to be a lead-in to the ozone episode. As can be seen on Figure 4-13, wind speeds at the sites on the Pinedale anticline were generally high and reflect the prevailing northwest winds typical of the study area during most of the year. Interestingly, this moderately strong, organized northwest flow does not extend to the southern sites (Haystack Butte and Simpsons Gulch). These sites experienced a generally westerly wind, which was also a characteristic of the prevailing flows noted during the 2007 field study. Wind speeds were generally high throughout the network on this day. These conditions continued throughout the night until the early morning of the 19th (Figure 4-14). Winds decreased significantly thereafter becoming light and variable for the remainder of the day--setting the stage for the next several days. Ozone levels were relative low in the 50 ppb range on the 18th, increasing substantially on the 19th with both Boulder and Jonah experienced 8-hr peaks of 80 ppb.

Winds on the 20th and 21st were generally light with variable directions throughout the network. There were two notable exceptions. After midnight, there was a general light northwest flow suggestive of a regional drainage patterns as colder, heavier air from the higher elevations flows downhill. Generally stronger winds were measured at Jonah in the forenoon hours relative to the other sites in the network; this effect is also sometimes seen at Daniel and is likely due at least in part to the fact that winds at these two sites are measured on a standard 10 m tower whereas the other sites made use of 3 m high tripod mounted anemometers. During the afternoon, winds reversed at some sites, shifting to the southeast. A review of the plots in Appendix B shows that this mid-day flow reversal is typical of high ozone days in the JPA. On the 20th, Simpsons Gulch experienced the highest ozone (85 ppb). Peak 8-hr ozone in the 70-80 ppb range was measured at the other network sites. Boulder experienced a 122 ppb 8-hr averaged peak ozone on the 21st. High ozone continued on the 22nd with Jonah recording an 8-hour average of 102 ppb. Minimal transport and dispersion characterized this period.

Experience with conditions in the Jonah – Pinedale area has clearly shown that elevated ozone episodes are associated with unusually light winds, as was the case during the 19 – 22 February 2008. Low wind speeds in the boundary layer reduce dispersion, providing the potential for poor air quality due to local sources. This is clearly shown on Figures 4-9 and 4-10 in which we have plotted time-series of wind run (equal to the integration of instantaneous wind speed over the 12 hour period from 7:00 to 18:00 MST each day) at Boulder and Jonah, respectively. The wind run is thus directly proportional to the average wind speed during this period. A long wind run indicates good ventilation whereas a short wind run indicates stagnation and poor ventilation. Days with 8-hour ozone were greater than 75 ppb are noted on both charts. As can be seen, transport (and by implication dispersion) was notably low on the high ozone days. It is equally important to note that, although high ozone levels were always associated with weak boundary layer winds, not all sites where stagnation occurred experienced high ozone. The areas of

impacts from the meandering polluted plumes are critical as well as other factors (insolation and mixing height). This is illustrated by the similar plot of wind run and ozone for the Daniel site on the northwest side of the Pinedale anticline (Figure 4-11). As can be seen, high ozone (>75ppb) was only experienced on two days although wind speeds were comparable to Boulder and Jonah. By comparison, the site at Wenz Field which is located approximately due east of Daniel on the east side of the anticline experienced 6 high ozone days, also during stagnation events.

Diurnal variations of winds was also examined by a variety of means. Earlier investigations reported that high ozone levels at Jonah were generally associated with a shift in wind direction from morning northwest winds to afternoon southeast winds.[2] Results from the 2008 study presented below confirm that this midday wind shift was often measured at one or more sites in the expanded mesonet network on high ozone days, with the most consistent wind shifts noted at Jonah. More generally, it can be said that ozone and precursors embedded in plumes were meandering and potentially recirculating within the anticline.

One view of the wind direction-ozone relationship is shown on Figure 4-12. This figure presents a pollution (ozone) rose using Boulder measurements. This diagram is constructed using the daily peak 8-hr ozone level and 15 MST hourly averaged wind. These results show that high ozone levels were associated with afternoon winds from a variety of directions, reflecting the "light and variable" nature of the boundary layer winds when ozone levels are high.

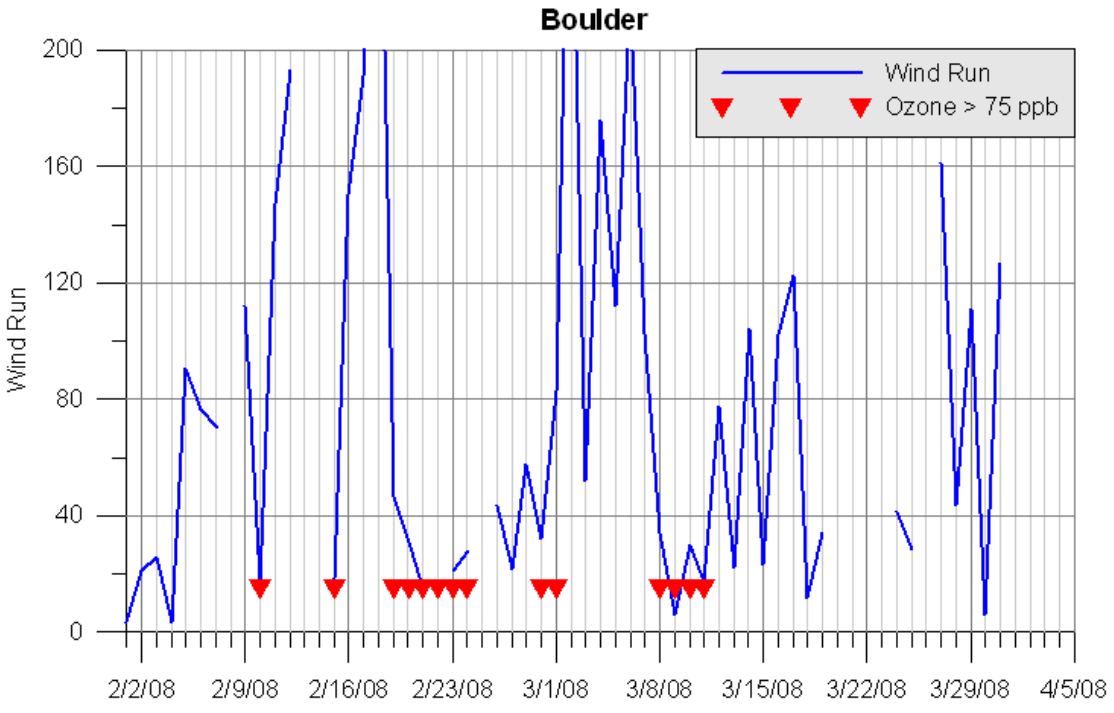

Figure 4-9. Horizontal dispersion (as indicated by 12hr daytime wind run in km) at Boulder. Red triangles denote peak daily 8-hr ozone levels in excess of 75 ppb.

[2] Bill Hauze, Meteorological Solutions Inc., personal communication, September 2006.

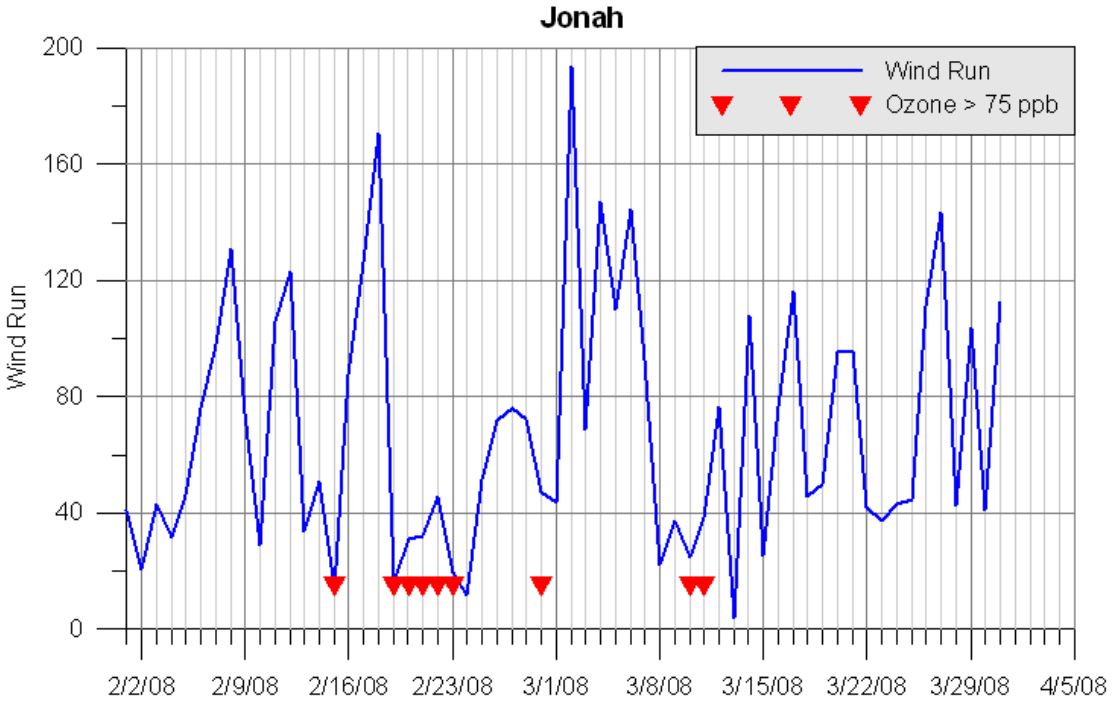

Figure 4-10. Horizontal dispersion (as indicated by 12hr daytime wind run in km) at Jonah. Red triangles denote peak daily 8-hr ozone levels in excess of 75 ppb.

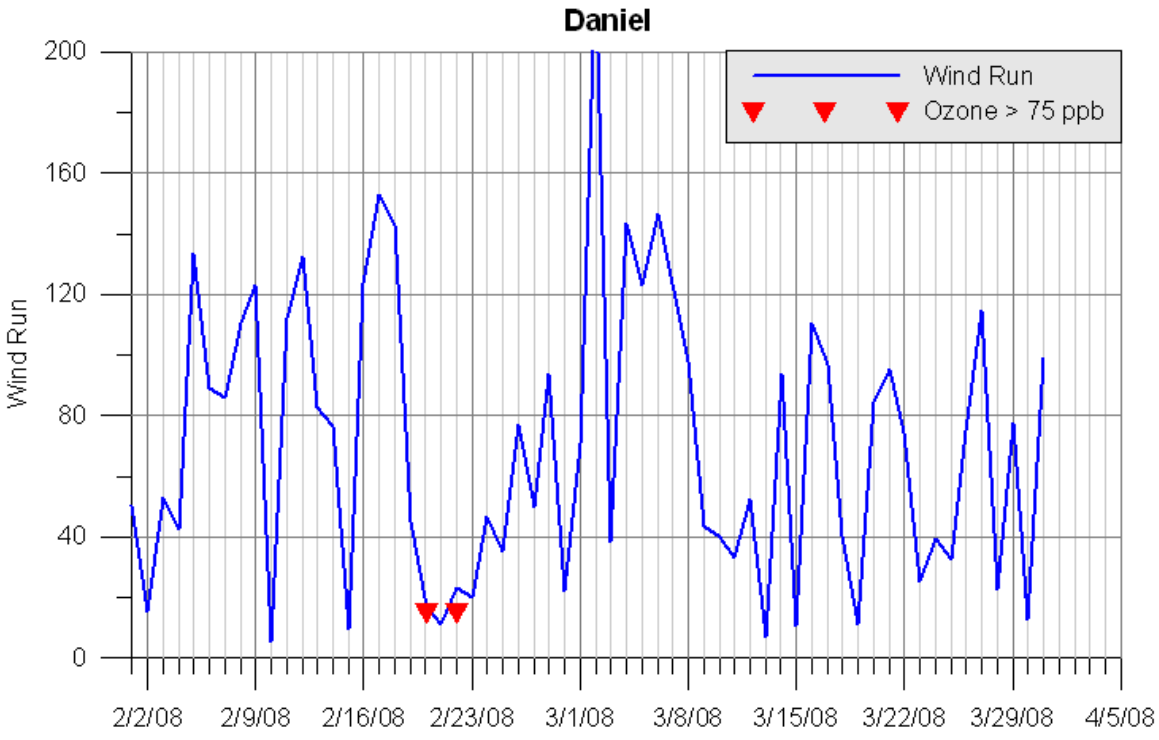

Figure 4-11. Horizontal dispersion (as indicated by 12hr daytime wind run in km) at Daniel. Red triangles denote peak daily 8-hr ozone levels in excess of 75 ppb.

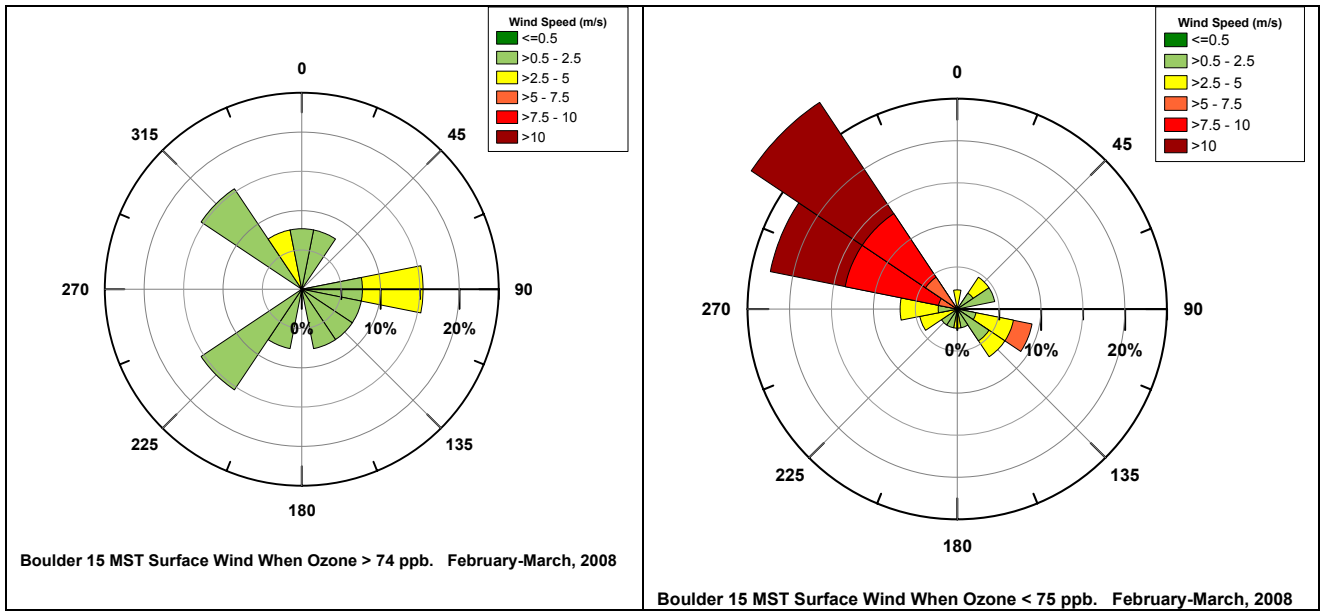

Figure 4-12. Wind roses based on 15:00 MST data from Boulder monitoring site for days with maximum 8-hour average ozone greater than 74 ppb (left) and less than 75 ppb (right).

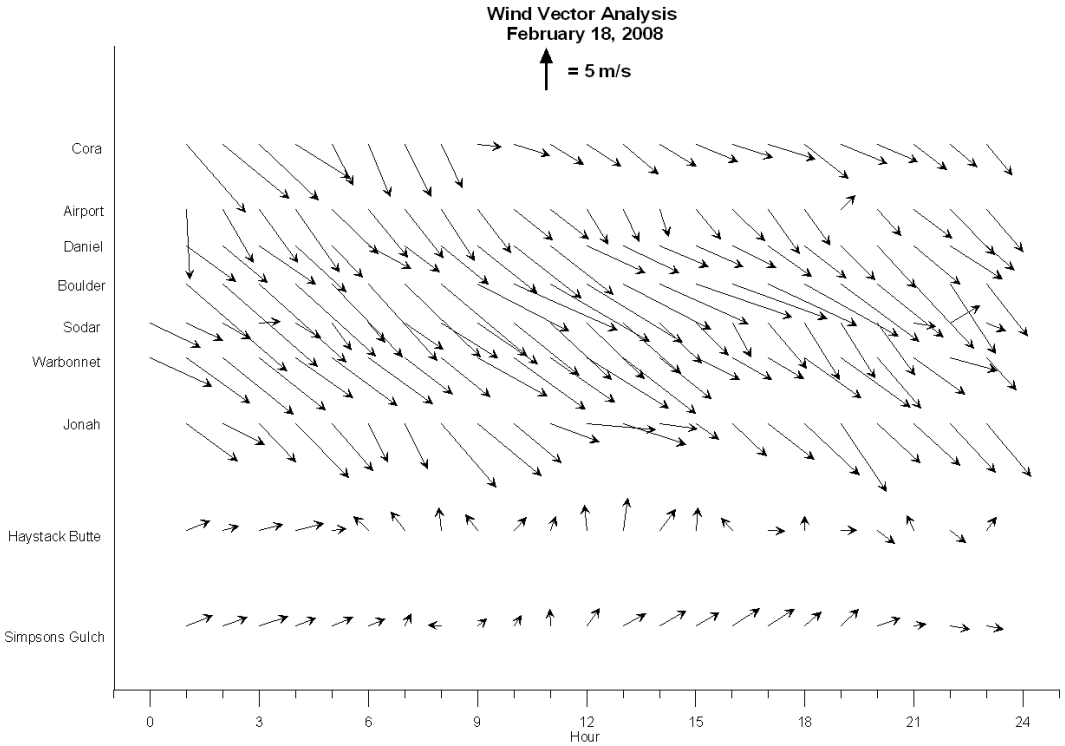

Figure 4-13. Time-series showing February 18 hourly wind vectors for UGWOS surface network.

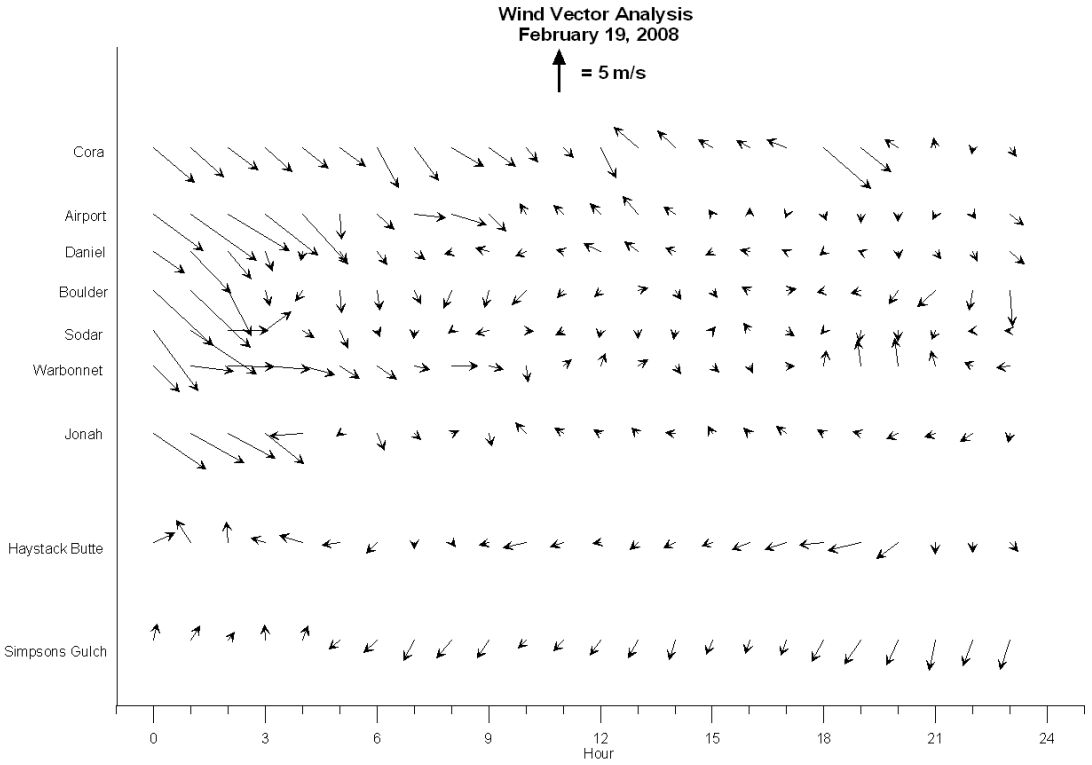

Figure 4-14. Time-series showing February 19 hourly wind vectors for UGWOS surface network.

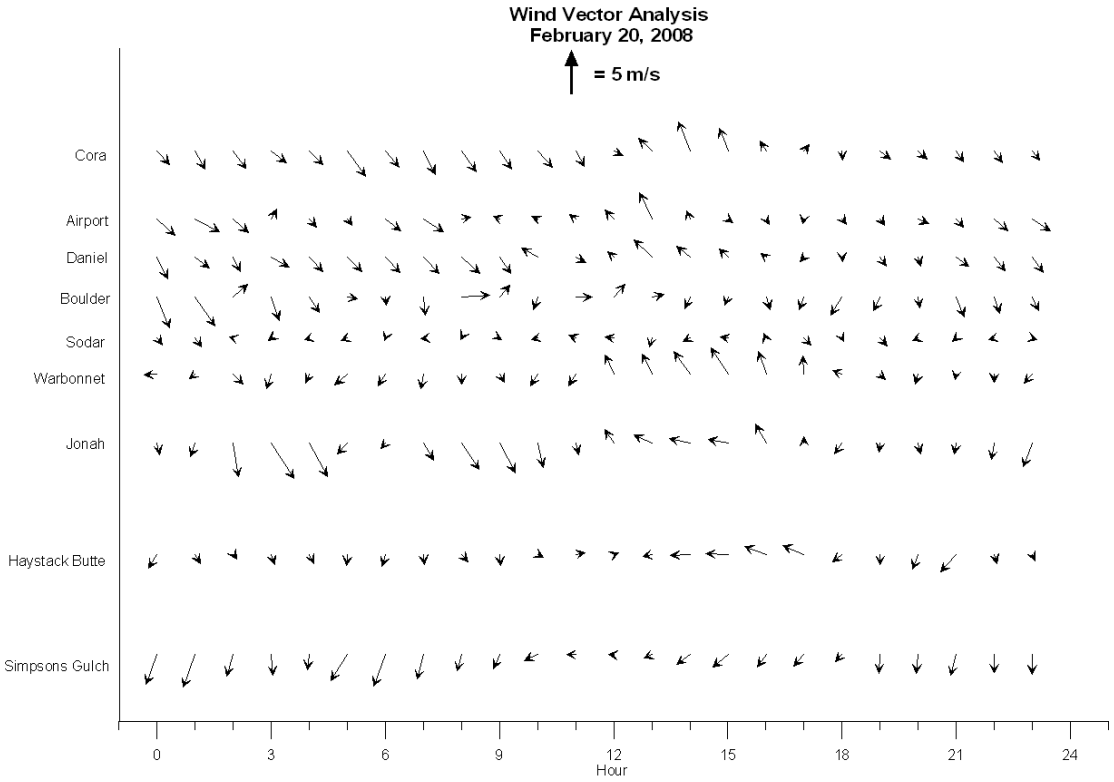

Figure 4-15. Time-series showing February 20 hourly wind vectors for UGWOS surface network.

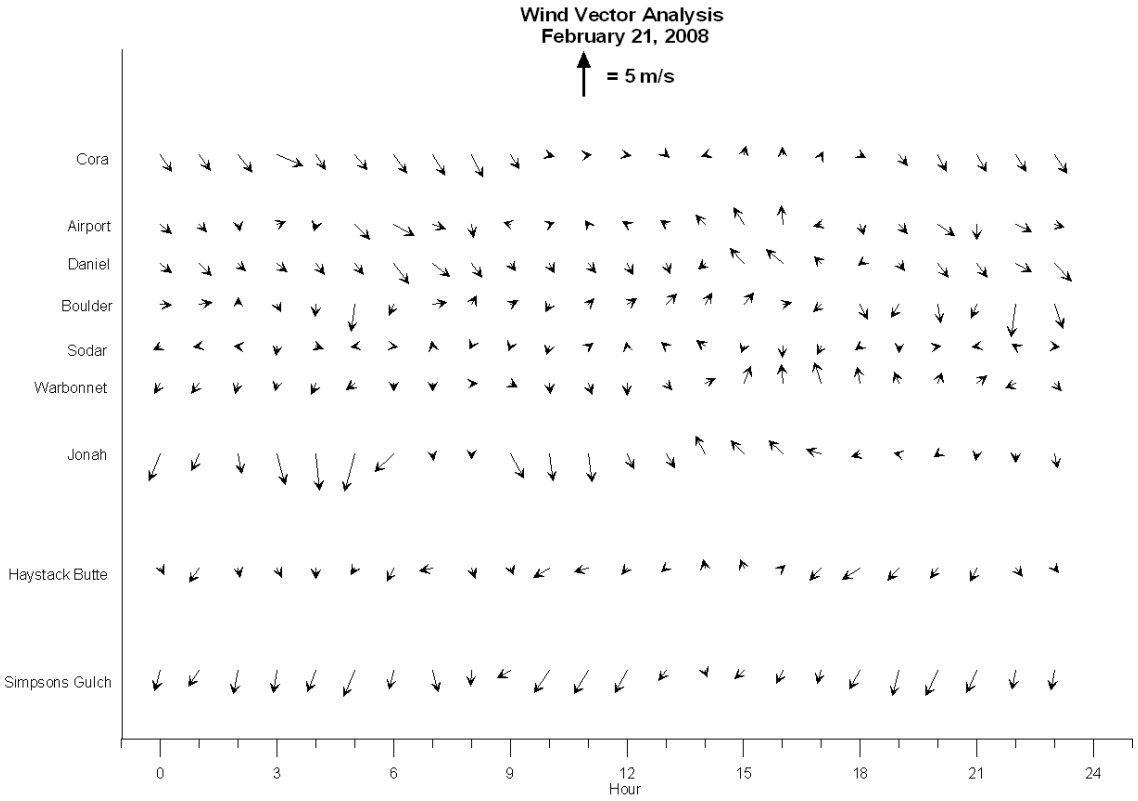

Figure 4-16. Time-series showing February 21 hourly wind vectors for UGWOS Surface Network.

Wind vector fields were also examined spatially to gain an understanding of flow patterns in the study region. Winds on a typical ozone episode day (20 February) are shown in Figure 17. Winds are generally out of the northwest in the morning until about mid-day, at which point the flow has reversed with southeasterly winds or at least southerly component winds are observed at most sites. This continues through the afternoon until 18:00 MST at which time the flow begins to switch back to the northwest and by 6:00 MST the following morning (bottom right panel), winds are northwest or northeast at nearly all of the monitoring sites. The switch from a overnight flow consisting of generally northwesterly or down slope winds which last until approximately mid-day before reversing to a generally southeasterly winds during the afternoon was repeated on many of the 2008 ozone episode days.

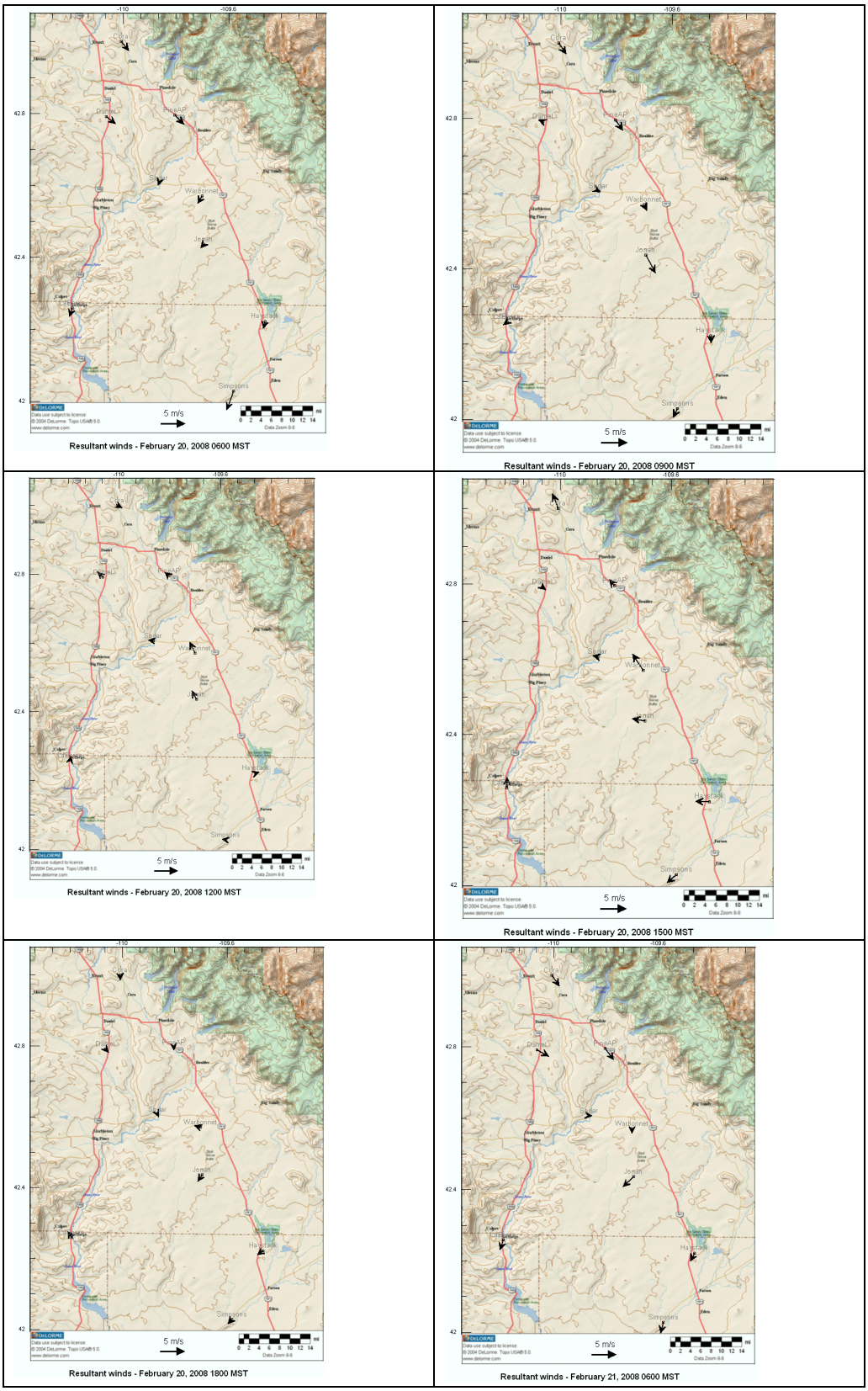

Figure 4-17. Hourly resultant wind vectors on 20 February 2008 for hours 6:00, 9:00, 12:00, 15:00 and 18:00 MST and 6:00 MST on 21 February.

4.4 Description of Conditions Aloft

As described in Section 2, measurements of meteorological and air quality parameters above the surface layer were made using free-ascending balloons released at regular intervals from the airport near Pinedale (Wenz Field) and via an acoustic sounding instrument (mini SODAR) located near Boulder. These data were used to probe vertical ozone, temperature and wind profiles.

In this report, the vertical temperature structure of the atmosphere is defined in terms of mixing height or depth, and inversion base and top. These features are depicted on Figure 18 which shows two examples of temperature variation as functions of height. Typically in the free troposphere away from the influence of the Earth's surface, temperature decreases with increasing altitude. In a well mixed (dry) atmosphere, the temperature *lapse* rate is approximately a 1 ^{o}C drop in temperature per 100 m gain in altitude. However, due to a variety of processes the lower atmosphere is layered and the temperature structure complex. Often the temperature increases with height forming a temperature inversion. Temperature inversions create so-called stable layers in which pollutants can be trapped and unable to disperse vertically. The blue temperature trace on Figure 18 depicts a surface-based inversion which frequently develops at night due to the earth's surface losing heat more rapidly than the air just above it. The top of the inversion is where the lapse rate reverses and temperature begins to decrease with height. Low level inversions may disappear or "break" during the day as the sun's rays warm the earth's surface and in turn the layer of air just above the surface. This is less common when the ground is covered by snow which reflects most of the sun's energy rather than absorbing it. In addition, much of the energy that is not reflected goes into melting and evaporating (sublimating) the snow. These processes combine to keep the air temperature near the surface nearly constant throughout the day, with only limited weakening of the inversion and vertical mixing of surface-based emissions. In the intermediate case, there is some limited surface heating resulting in a complex temperature structure as shown by the solid red line in Figure 18. In this example, the inversion base is elevated to about 100 meters above the ground. Mixing of pollutants can readily occur within this 100 m deep mixing layer but deep mixing is limited by the stable layer above the inversion base.

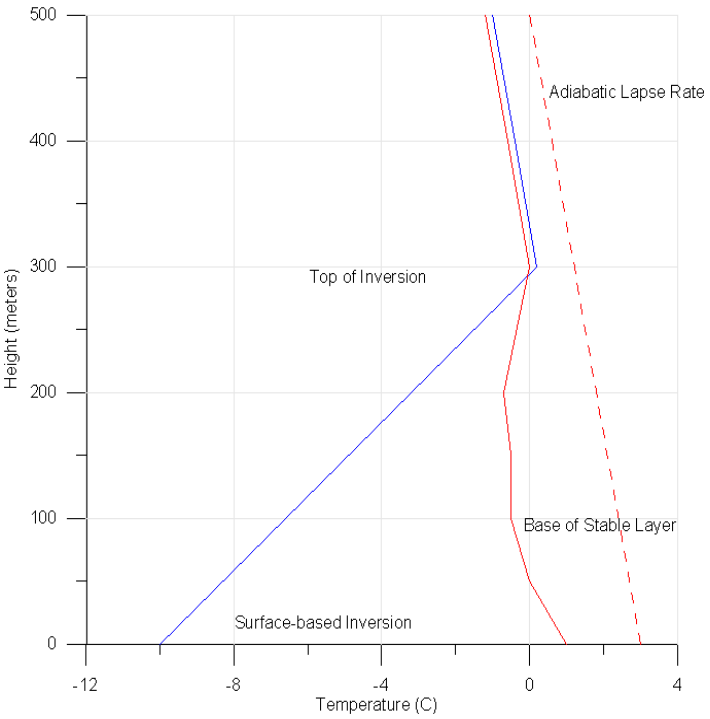

Figure 4-18. Schematic illustration of atmospheric vertical temperature structure.

4.4.1 SODAR Data

As described in Section 2, a miniSODAR was operated continuously at a location southwest of Boulder during the study period. The sodar provided two types of data: 1) vertical wind profiles at 10-meter increments up to 250 meters above ground level and 2) information on inversion heights and mixed layer depths.

The sodar provides information about inversion heights and mixed layer depth in the form of "fax" charts. Figure 4-19 shows a fax chart for February 18, 2008, a day when the boundary layer was deep and well mixed. The chart is characterized by regular transition from strong to weak signal strength with increasing altitude, with a spiky appearance to the display. In contrast, Figure 4-20 shows the same afternoon period on February 21, a day when high ozone concentrations were noted throughout the study area. The fax trace shows sudden changes in signal strength, including some areas where the signal strength actually increases with altitude. These traces reveal a top to the mixing layer at about 100 meters-agl representing a very shallow layer trapping ozone precursors and other pollutants in high concentrations near the surface.

In a traditional sense, mixing height can be defined as height above the surface through which relatively vigorous vertical mixing occurs (Holzworth 1972). The ability of the atmosphere to mix, or allow vertical motion, is related to thermally induced turbulence (resulting from an unstable vertical temperature structure) and, mechanically induced turbulence (resulting from the wind drag at the surface). Unstable conditions readily mix the atmosphere; during neutral conditions, moderate mixing occurs; stable conditions result in little vertical mixing (Baxter 1990). During the stable conditions, while the short term mixing that occurs in less than one hour will be greatly reduced, over time the pollutants may accumulate through the stable layer. It is during this accumulation that a surface stable layer may represent a longer term mixed layer

depth, or pollutant accumulation layer. From basic acoustic theory, the monostatic sodar (a sodar that uses the same transmit and receive antenna) will detect returns from a non-neutral atmosphere that is marked with turbulent eddies. It is within these eddies that density differences occur that will effectively reflect the acoustic pulse back to the transmit antenna at a 180° angle. Thus, even though the atmosphere is stable, if reflections are observed then there is turbulence present. The turbulence, while limited in vertical motion, will still aid in the migration of pollutants to the top of the surface layer. The sodar will show this surface mixed layer with a relatively sharp cut-off in intensity at the top. It is the top of this turbulence marked surface layer that we define here as the mixed layer depth observed from the sodar during stable conditions. The structure of the layer will be predominantly horizontal, with changes in the layer height caused by various atmospheric phenomena such as gravity waves, wind sheer, or thermal plumes. During periods when there is significant snow cover, absorption of incoming radiation and resulting thermal convection will be minimal. Thus, with adequate snow cover very shallow stable layers can remain throughout the daytime period even under a cloud-free sky, as evidenced by the sodar reflectivity (facsimile) records showing stable layers as shallow as a few tens of meters.

For the sodar derived mixed layer depths, the height is defined as the height from the surface to the top of the first turbulenced marked stable layer. During periods when the surface layer is not present, and thermal plumes or a neutral region is evidenced at the surface, the mixed layer depth is defined as the distance from the surface to the base of the first stable layer. In the event that there are no surface stable layers present or the structure reflects an unstable regime at the surface with no capping stable layers aloft, the mixed layer depth is reported as greater than the top of the facsimile chart record (>255 m).

Table 4-6 summarizes the average winds for all measured levels (typically limited to those levels below an inversion) for a typical afternoon hour (the hour beginning at 1600 MST) for the period 5 February – 31 March 2008. Comparing the wind data with peak 8-hour ozone concentrations at Boulder, a strong correlation between ozone concentrations and low mixed layer average wind speeds is evident. In addition, days of higher concentrations are typically associated with afternoon winds with a southerly component.

We have included in Table 4-6 afternoon mixing height values estimated from the sodar fax charts. Mixing heights show a strong inverse relationship with ozone concentrations, as shown by the plot presented in Figure 4-21.

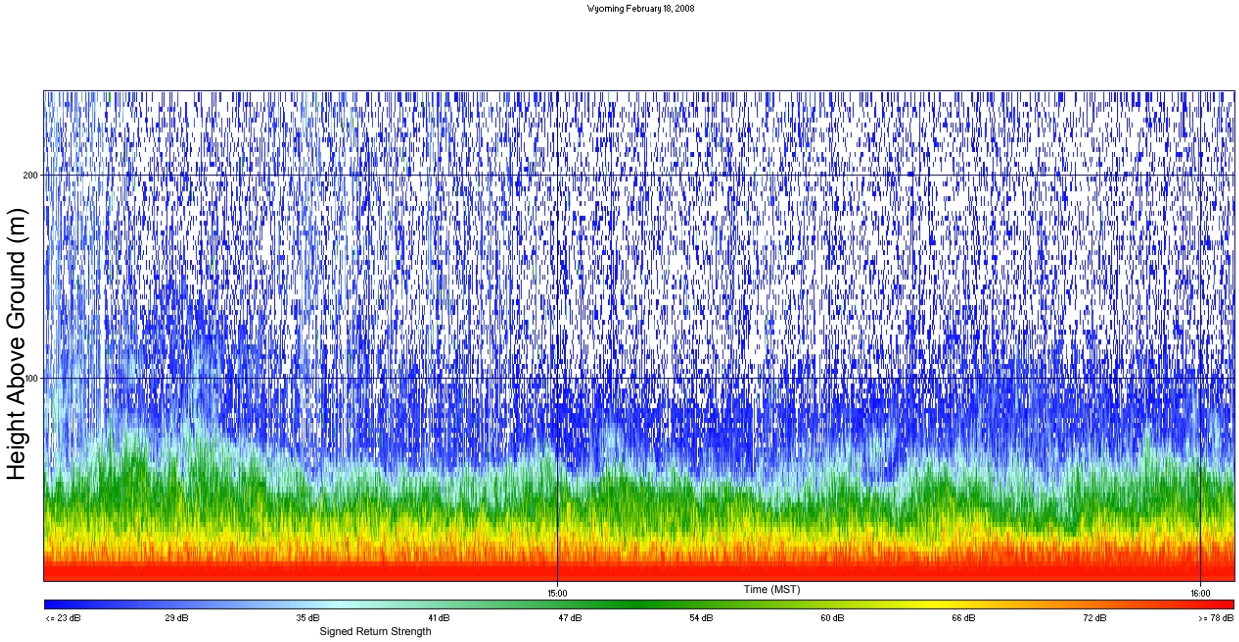

Figure 4-19. Sodar fax display for 18 February showing well-mixed boundary layer.

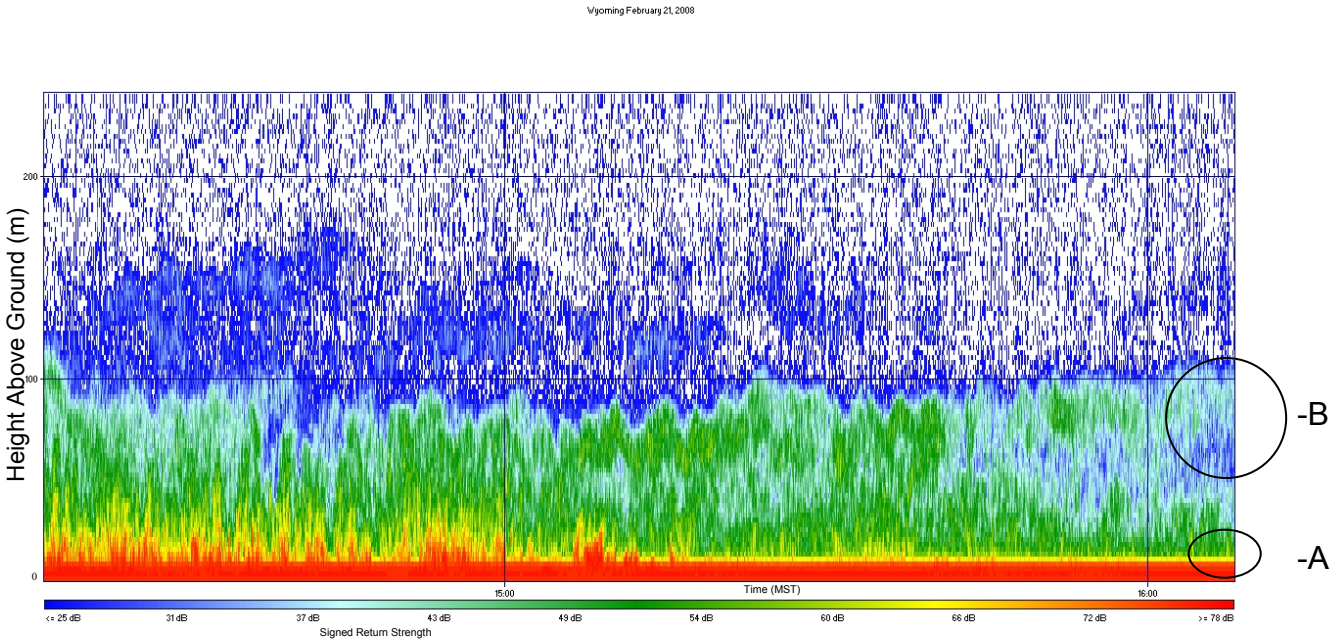

Figure 4-20. Sodar fax display for 18 February showing stable layers and lowered mixing height within the boundary layer (A: sharp, signal strength boundary; B: return signal strength increases with height).

Table 4-6. Summary of sodar afternoon (16:00 MST) mixed layer depth and wind data for hour beginning 1600 MST and same-day peak 8-hour ozone concentration at Boulder. Wind speed and wind direction are averages of values for all reported heights.

Date	Mixing height (m AGL)	Peak 8-hr Ozone (ppb)	Sodar WS (m/s)	Sodar WD	Comments
2/5/2008	>255	50	12.9	307	
2/6/2008	>255	47	13.3	299	
2/7/2008	>255	55	12.4	270	
2/8/2008	>255	49	8	320	
2/9/2008	>255	49	6.8	309	
2/10/2008	80	99	0.7	98	
2/11/2008	>255	76	7.4	317	
2/12/2008	>255	49	10.7	288	
2/13/2008	>255	51	3.7	331	
2/14/2008	>255	54	3	250	
2/15/2008	115	95	1.5	58	
2/16/2008	>255	71	7.2	313	
2/17/2008	>255	52	6	304	
2/18/2008	>255	55	8.7	333	
2/19/2008	90	80	1.7	131	
2/20/2008	100	80	1.1	48	
2/21/2008	90	122	1.6	60	
2/22/2008	60	111	0.8	219	
2/23/2008	140	104	2.9	116	
2/24/2008	110	99	4.8	326	Lower wind speeds through morning and early afternoon.
2/25/2008	80	71	1.7	101	
2/26/2008	140	58	9.1	284	
2/27/2008	85	66	1.6	118	Morning winds were significantly higher
2/28/2008	>255	60	3.5	264	
2/29/2008	70	78	1.6	237	
3/1/2008	>255	82	11.3	322	Transition period. Winds and mixing ht immediately prior to this hour were much lower with a SW component.
3/2/2008	>255	52	11.9	315	
3/3/2008	>255	56	4.6	128	
3/4/2008	>255	52	10.4	300	
3/5/2008	>255	53	8.9	302	
3/6/2008	>255	53	9.4	321	
3/7/2008	90	60	2.1	241	Predominantly high winds during the rest of the day
3/8/2008	>255	76	3.4	254	
3/9/2008	50	91	2.4	203	
3/10/2008	>255	81	4.3	116	
3/11/2008	115	103	1.7	103	
3/12/2008	>255	82	8.9	307	Early morning (nighttime) peak - carryover from previous day
3/13/2008	>255	66	2.7	86	Compare with 3/11. Slightly higher, predominantly E winds may have steared away from Boulder
3/14/2008	>255	57	11.2	301	
3/15/2008	>255	64	3.6	127	
3/16/2008	>255	55	6.7	327	
3/17/2008	>255	53	10.7	297	
3/18/2008	>255	65	5.7	320	
3/19/2008	145	58	2.4	337	
3/20/2008	>255	53	7.5	321	
3/21/2008	>255	54	7.6	299	
3/22/2008	>255	59	3.3	120	
3/23/2008	>255	70	3.9	109	
3/24/2008	>255	59	9.7	258	
3/25/2008	>255	51	Missing	Missing	
3/26/2008	>255	53	12.1	317	
3/27/2008	>255	56	9.9	297	
3/28/2008	>255	62	6.2	87	
3/29/2008	>255	62	9	322	
3/30/2008	>255	68	1.3	335	
3/31/2008	>255	59	11.5	312	

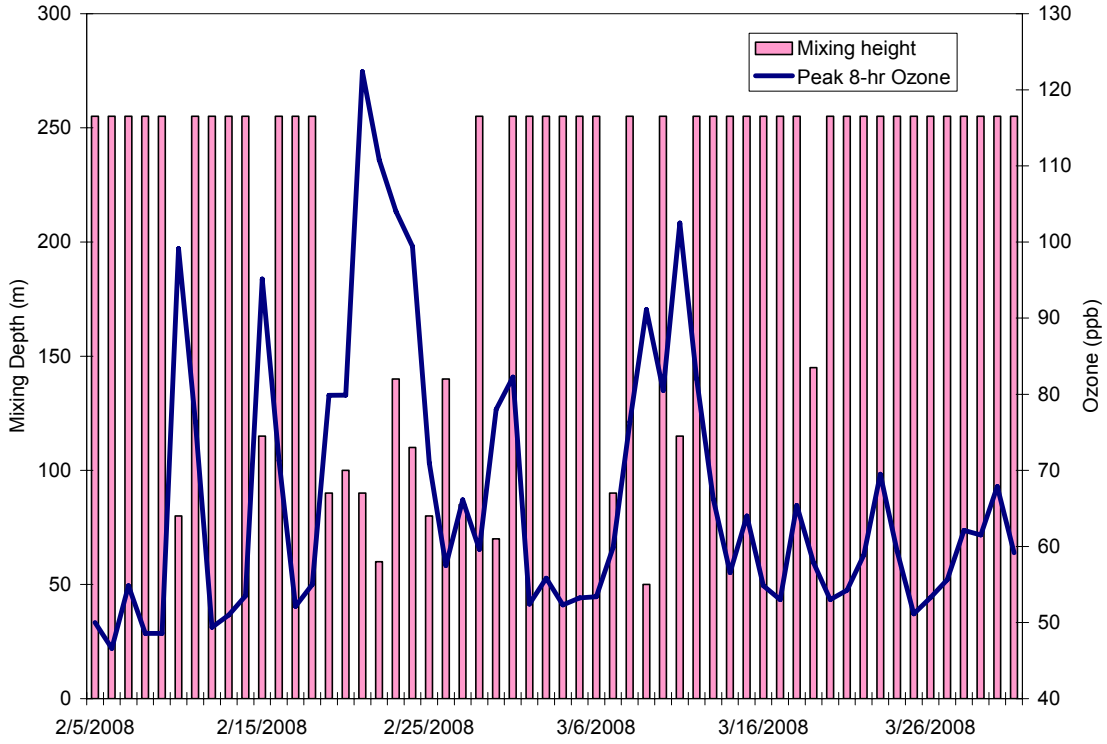

Figure 4-21. Sodar-reported afternoon (16:00 MST) mixed layer depth versus peak daily 8-hour average ozone concentrations at Boulder. Mixing depth measurements are limited to a maximum of approximately 250 m agl due to limitations on sodar signal strength.

4.4.2 Rawinsonde/Ozonesonde Measurements

During the IOPs, free-ascending balloons were released from the airport near Pinedale (Wenz Field). Measurables were height, temperature, humidity, winds and, optionally, ozone. Data were obtained at 1 second intervals which corresponds to a height interval of approximately 4 m. The flight package consisted of a standard-type rawinsonde similar to those routinely used by NOAA in their routine rawinsonde observation network. The instruments used in this project were modified to interface with an ozone analyzer based on the same technology used for the tethersondes during the 2007 study and for the airplane sampling (see Appendix D). The schedule of soundings is given in Table 4-7. Four soundings were taken on most days: two in the morning and two in the afternoon. Project resources did not permit the deployment of an ozonesonde on each sounding, thus the ozone measurements were limited to one or two of the afternoon ascents on most days.

Table 4-7. Rawinsonde/Ozonesonde schedule of observations – UGWOS 2008

Date	Release Time (MST)	Comments
February 18	1100	T, RH, Winds
February 18	1600	T, RH, Winds
February 19	0700	T, RH, Winds
February 19	1100	T, RH, Winds
February 19	1300	T, RH, Winds and Ozone
February 19	1600	T, RH, Winds and Ozone
February 20	0700	T, RH, Winds
February 20	1100	T, RH, Winds
February 20	1300	T, RH, Winds and Ozone
February 20	1600	T, RH, Winds and Ozone
February 21	0700	T, RH, Winds
February 21	1100	T, RH, Winds and Ozone
February 21	1300	T, RH, Winds
February 21	1600	T, RH, Winds and Ozone
February 27	0800	T, RH, Winds
February 27	1100	T, RH, Winds
February 27	1300	T, RH, Winds
February 27	1600	T, RH, Winds and Ozone
February 27	0800	T, RH, Winds
February 28	1100	T, RH, Winds
February 28	1300	T, RH, Winds
February 28	1700	T, RH, Winds and Ozone
February 29	0847	T, RH, Winds
February 29	1100	T, RH, Winds
February 29	1300	T, RH, Winds and Ozone
February 29	1600	T, RH, Winds and Ozone
March 10	0800	T, RH, Winds
March 10	1100	T, RH, Winds
March 10	1400	T, RH, Winds and Ozone
March 10	1700	T, RH, Winds and Ozone
March 11	0800	T, RH, Winds
March 11	1100	T, RH, Winds and Ozone
March 11	1300	T, RH, Winds and Ozone
March 11	1700	T, RH, Winds and Ozone
March 12	0800	T, RH, Winds
March 12	1100	T, RH, Winds
March 12	1500	T, RH, Winds and Ozone

In many respects, similar vertical profiles and boundary layer development was measured by the balloon-borne observations on each of the high ozone days. Stable atmospheric conditions prevailed characterized by strong low-level temperature inversions with very shallow mixing heights and light boundary-layer winds**.** Ozonesonde and aircraft flights launched at the Wenz Field monitoring site during the 2008 IOP field operations indicated that the highest measured concentrations of ozone at that location were associated with the low level stable layer at the bottom of the vertical boundary layer. Table 4-8 presents a summary of the stable layer observations from all of the ozonesonde and rawinsonde flights launched at Wenz Field during the 2008 Project. In the table, the "Sonde Temp (C°) at Launch" refers to the initial temperature measured by each sonde immediately after release, and is a good representation of the ambient air temperature near the surface. The "MAX Stable Layer Temp (C°)" is the highest temperature recorded aloft during the respective soundings and represents a good indicator of the top of the stable layer. The "Stable Layer Δ Temp (C°)" is the difference between the initial temperature

near the surface and the maximum temperature measured aloft. Negative Δ Temps are indicative of relatively strong boundary layer mixing whereas positive numbers indicate greater stability and poor mixing. The "Height of Max Temp (mAGL)" refers to the altitude above ground level where the maximum temperature aloft was measured. Since this height indicates the top of the stable layer, it also defines the thickness of the layer assuming the bottom of the layer is located at ground level. The "WD/WS (mps)" column in the table presents the wind direction (degrees clockwise from true north), and the windspeed (meters per second) measured by the respective sondes within the stable layer at the beginning of each sounding. These parameters are strong indicators of the transport trajectory of effluents trapped in the stable layer. The "Peak Sonde O3 (ppb)" values presented in the table are the highest concentrations (parts per billion) detected by the ozonesonde during each respective flight. Naturally, ozone aloft data is not available (NA) for rawinsonde flights. However, ozone data aloft at Wenz Field was measured during takeoffs and landings of the project aircraft when many of the rawindsonde balloon soundings were taking place. Plots of all of the project rawinsonde and ozonesonde flights are available in Appendix F of this report.

Peak ozone concentrations were often observed somewhat above the surface but still within the stable inversion layer. This phenomenon could arise via a variety of mechanisms, including loss of ozone at the surface due to deposition or NO titration from local combustion sources or vertical wind shears resulting in transport of air parcels from different directions at the surface and aloft. High ozone plumes which appear elevated at Wenz Field where the ozonesondes were taken may have impacted the surface at other locations either due to impaction on elevated terrain or before experiencing near surface losses from NO titration. Winds within the boundary are generally light, and significant vertical shear is present at the top of the boundary layer.

Table 4-8. Inversion observations from rawinsonde/ozonesonde.

Launch Date	Launch Time (mst)	Sonde Temp (C°) at Launch	Max Stable Layer Temp (C°)	Stable Layer Δ Temp (C°)	Height of Max Temp (mAGL)	WD/WS (mps)	Peak Sonde O 3 (ppb)	Comments
2/18/08	1100	-3.8	-3.2	0.6	150	308/10	NA	
2/18/08	1600	-1.8	-1.7	0.1	47	292/06	NA	
2/19/08	700	-14.8	-0.3	14.5	489	277/02	NA	
2/19/08	1100	-8.1	1.3	9.4	442	043/01	NA	
2/19/08	1300	-5.3	2.2	7.5	403	127/02	65	O3 peak elevated
2/19/08	1600	-4.5	1.8	6.3	445	123/01	61	O3 peak elevated
2/20/08	700	-13.6	-2.4	11.2	398	319/02	NA	
2/20/08	1100	-13.9	-2.0	11.9	342	098/02	NA	
2/20/08	1300	-7.7	-3.2	4.5	449	129/03	94	O3 peak at ground level
2/20/08	1600	-5.4	-2.3	3.1	543	106/01	96	O3 peak elevated
2/21/08	700	-17.4	-4.0	13.4	500	302/02	NA	
2/21/08	1100	-7.9	-3.0	4.9	405	315/01	54	O3 peak at ground level
2/21/08	1300	-3.4	-2.6	0.8	373	340/02	NA	
2/21/08	1600	-5.7	-2.9	2.8	494	127/03	122	O3 peak at ground level
2/27/08	800	-9.7	-1.4	8.3	670	338/02	NA	
2/27/08	1100	-5.4	0.1	5.5	711	085/02	NA	
2/27/08	1300	-2.3	1.0	3.3	608	142/02	NA	
2/27/08	1600	-1.2	0.7	1.9	527	134/01	61	O3 peak elevated
2/28/08	800	-8.6	-2.3	6.3	149	102/01	NA	
2/28/08	1100	-1.4	-2.4	-1.0	265	325/03	NA	
2/28/08	1300	1.8	0.0	-1.8	91	136/02	NA	
2/28/08	1700	0.5	1.0	0.5	190	127/02	66	O3 peak elevated
2/29/08	847	-6.2	-2.5	3.7	460	274/02	NA	
2/29/08	1100	-8.9	-0.3	8.6	396	175/02	NA	
2/29/08	1300	-1.4	0.3	1.7	314	302/01	64	O3 peak at ground level
2/29/08	1600	-0.3	1.5	1.8	470	114/01	84	O3 peak at ground level
3/10/08	800	-12.2	-5.8	6.4	470	318/01	NA	
3/10/08	1100	-7.6	-5.0	2.6	480	125/04	NA	
3/10/08	1400	-1.6	-2.1	-0.5	312	132/03	74	O3 peak elevated
3/10/08	1700	-1.3	-2.0	-0.7	705	050/01	82	O3 peak elevated
3/11/08	800	-13.1	1.3	14.4	373	317/02	NA	
3/11/08	1100	-2.4	1.5	3.9	312	280/02	61	O3 peak elevated
3/11/08	1300	2.1	2.0	-0.1	252	151/01	69	O3 peak at ground level
3/11/08	1700	0.5	1.2	0.7	236	116/02	90	O3 peak at ground level
3/12/08	800	-9.3	-2.1	7.2	142	327/02	NA	
3/12/08	1100	-2.3	-2.5	-0.2	80	144/01	NA	
3/12/08	1500	3.5	-0.3	-3.8	261	312/04	58	O3 peak at ground level

Examples of the vertical structure of the atmosphere and ozone are provided below for each of the three IOP's, and noteworthy features are discussed. A complete set of sounding results is provided in Appendix F.

Soundings taken in the forenoon and afternoon of 21 February are shown on Figure 4-22. Profiles for ozone (black line), temperature (red line), dew point temperature (dashed blue line) and winds (vectors) are plotted as functions of height. A strong low-level inversion was present up to 2,500 meters-msl (~400 meters-agl) with a maximum temperature at the top of the inversion of -2.9 ^{o}C, several degrees warmer than the temperature at the surface. Boundary-layer winds in the forenoon were light from the west when ozone levels were ~50 ppb, before becoming southeast in the afternoon. A shallow layer of high ozone (~115 ppb) impacting the surface was present on the afternoon sounding. The vertical wind shears at the top of the inversion attest to the complete decoupling of the boundary layer air from layers aloft. Ozone levels above the boundary layer were generally ~ 50 ppb. Of secondary interest but noteworthy was the elevated 55-60 ppb ozone layer at 6,000 meters lowering to near 5,000 meters on the afternoon sounding. Dew point temperature decreases in the same layer suggest a different source of the airmass associated with this slightly elevated ozone.

On February 29th, a somewhat different ozone vertical profile was observed (Figure 4-23). Similar to February 21, a temperature inversion top at ~ 2,500 m-msl (~400 meters-agl) was maintained throughout the day and high ozone concentrations were measured in the boundary layer. However, in this instance peak ozone was elevated above the ground at the balloon release

time—increasing from 65 to 85 ppb. Surface levels at the airport did reach 79 ppb (1-hr average) on the afternoon of the 29th suggesting that more complete mixing occurred during the afternoon. The low-level temperature profile suggests the surface mixed layer extended to ~2,400 meters-msl (300 meters-agl). A significant wind shear was measured at the top of the inversion. Similar to the situation on 21 February, a layer of elevated ozone is present at about 5,300 meters-msl on the 13 MST sounding with readings reaching 65 ppb.

On March 11, mixing was similarly as shallow as on the 21st and boundary layer ozone increased correspondingly as can be seen on Figure 4-24. The inversion top was ~2,400 meters-msl (300 meters agl) and was maintained throughout the day. Again, the low-level wind shear indicates the decoupling of the air masses. An ozone layer aloft reaching 75 ppb was measured on the 13 MST sounding again near 5,000 meters-msl. This layer of elevated ozone was associated with a dry, stable layer aloft. These elevated upper-level ozone maxima were not observed to descend below about 4000 meters-msl.

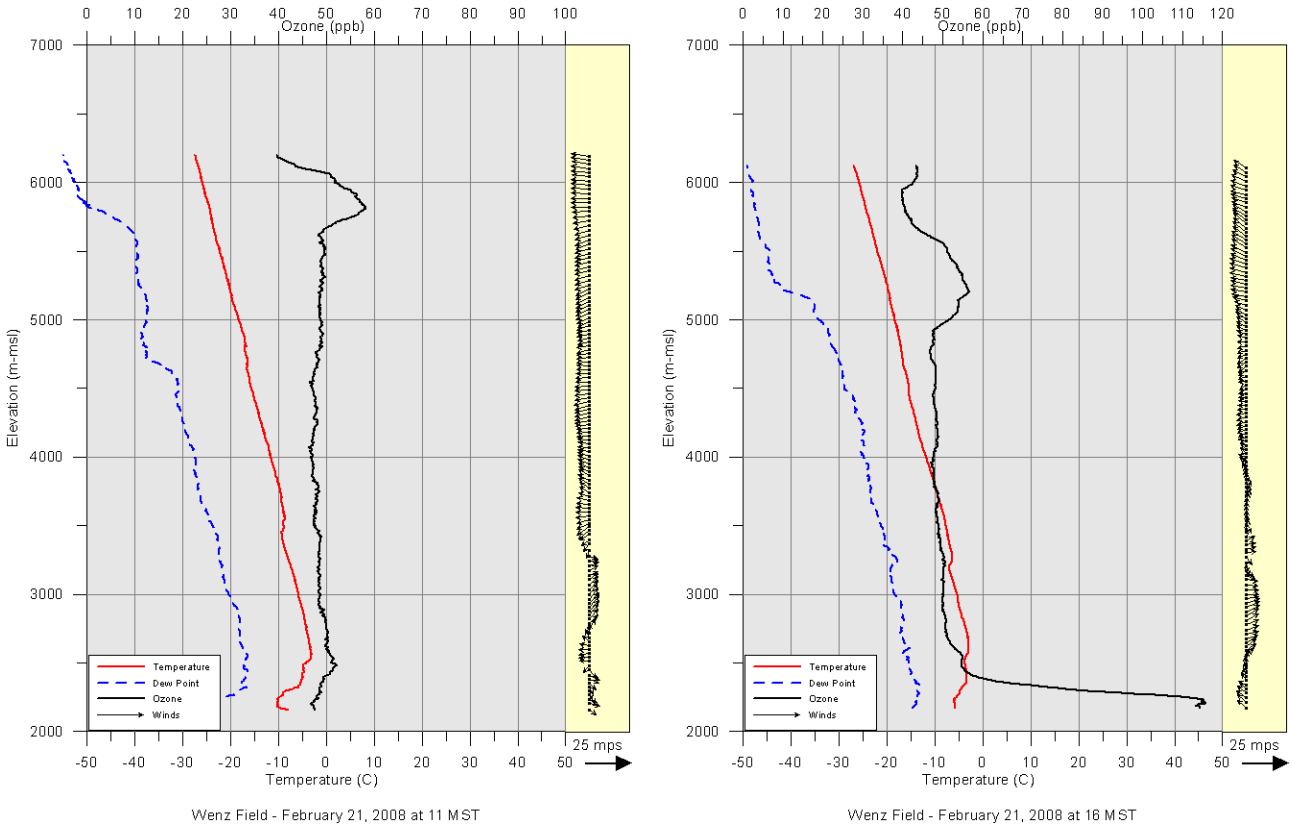

Figure 4-22. February 21, 2008 balloon-borne soundings. At 11 MST on left panel. At 16 MST on right panel.

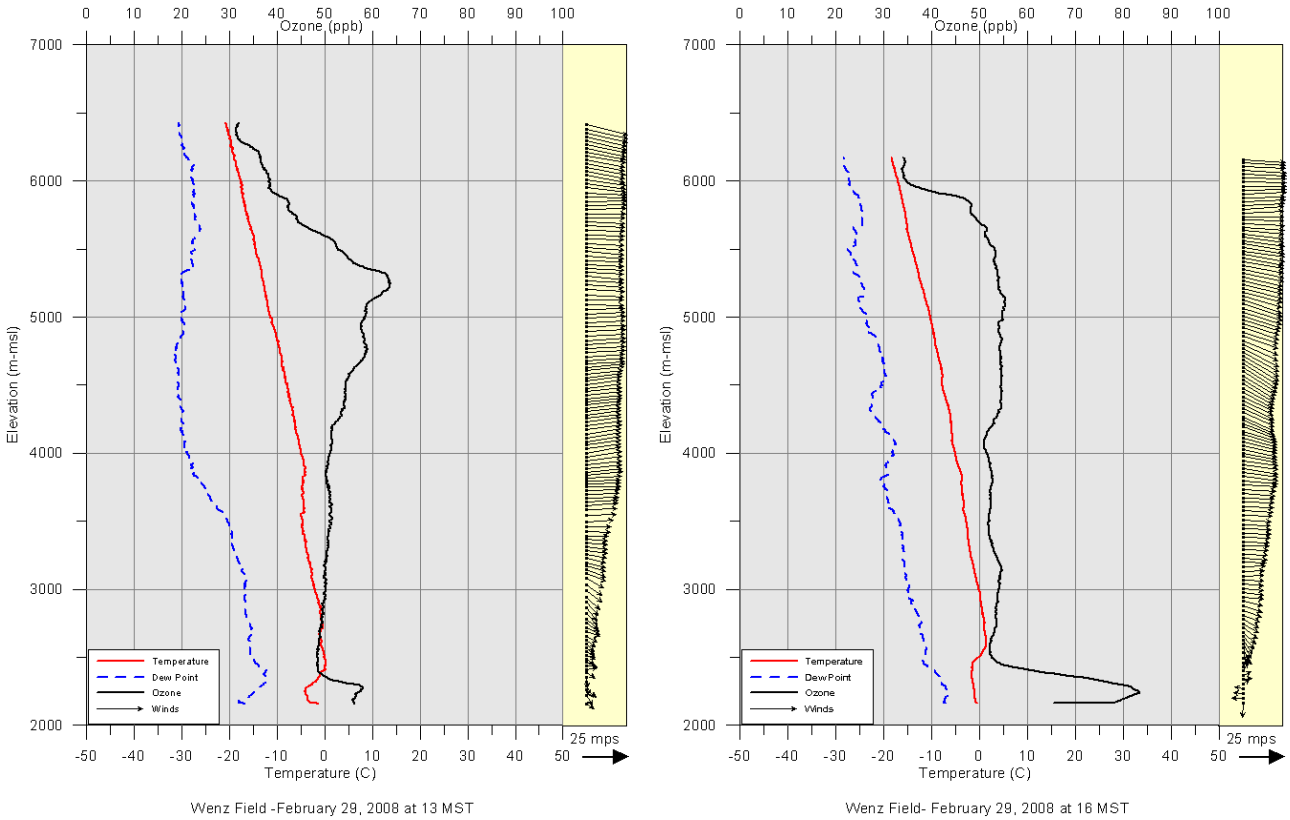

Figure 4-23. February 29, 2008 balloon-borne soundings. At 13 MST on left panel. At 16 MST on right panel.

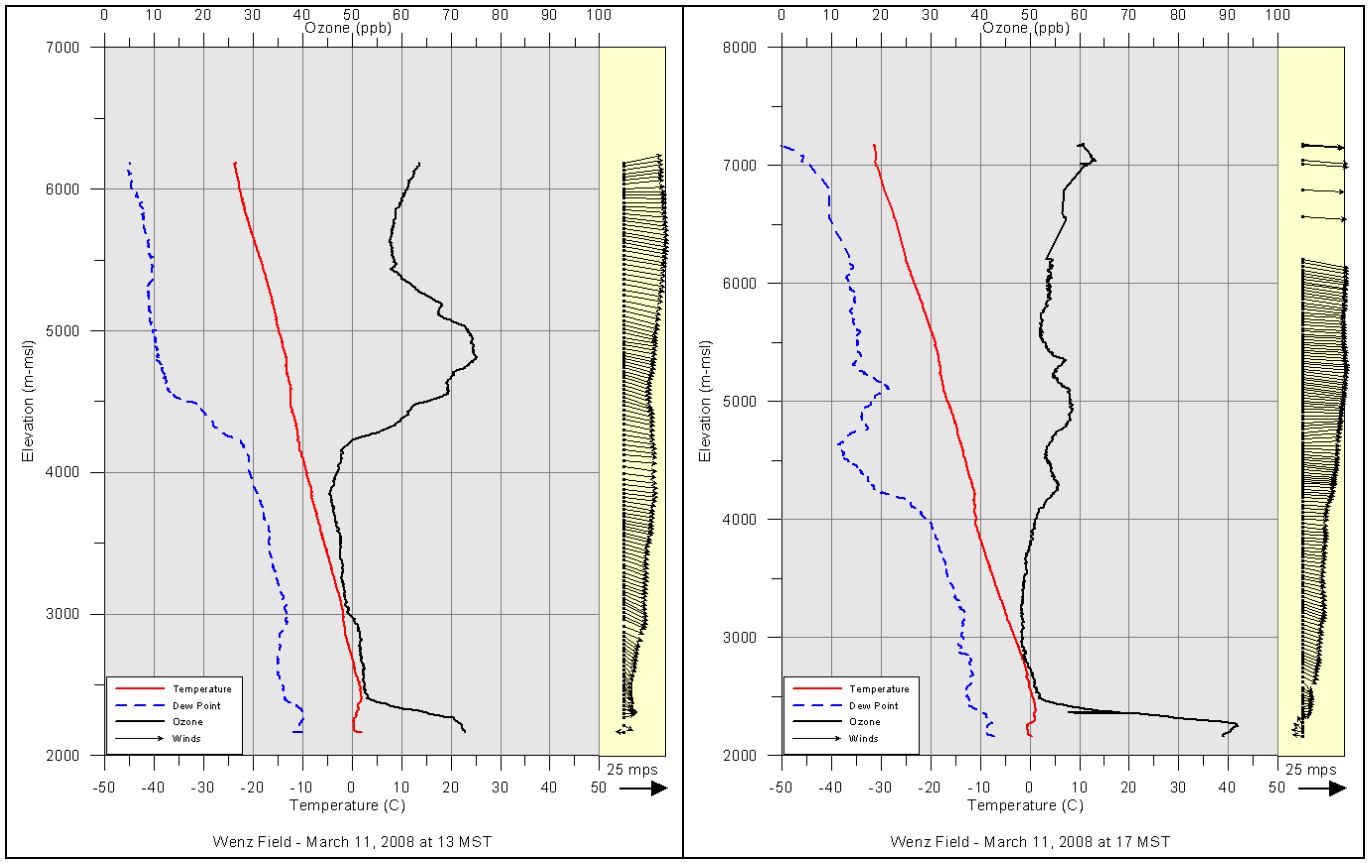

Figure 4-24. March 11, 2008 balloon-borne soundings. At 13 MST on left panel. At 17 MST on right panel.

4.5 UV Radiation Measurements

Incoming and reflected UV radiation in addition to total solar radiation were part of the routine long-term measurements at the Boulder site. These measurements were begun during the 2007 field study, after which operation of the instruments was taken over by Air Resource Specialists, Inc. Unfortunately, a review of the UV data for the 2008 study period raised serious concerns about their validity. As a result, the data set was flagged as suspect in the UGWOS 2008 database although it does provide important qualitative information.

Two UV radiometers were mounted on either side of a flat aluminum plate and suspended about one-meter above ground level, one facing downward and one upward. As reported by Stoeckenius et al. (2008), measurements made during the 2007 field study indicated a maximum albedo of approximately 80 percent when the ground was covered with snow, with values falling to less than 10% after the snow cover melted. In contrast, measurements during the January-March 2008 study (Figure 4-25) showed generally higher ratios of outgoing to incoming radiation along with periods during which the reported outgoing *exceeded* the incoming amount, thus indicating a significant problem with the 2008 data. From January until mid-March, there are noteworthy periods when the incoming UV radiation (insolation) falls well below the reflected component. In some cases this occurs during periods when it was likely that snowfall accumulated on the upward-facing sensor. However, it is not clear that this accounts for all of the periods during which the measured outgoing exceeded the incoming. The snow cover began

receding on the ground surface in the last week of March, corresponding to the reduction in reflected UV as shown in the figure.

UV data for 2008 are compared with the 2007 data for the month of March in Figure 4-26. Snow cover was present during only the first portion of the 2007 period as verified by photographic evidence (see Stoeckenius et al., 2008). During the time that snow cover was present, the outgoing UV energy was at most 80% of the incoming.

We can only speculate on the cause of the anomalous behavior in the 2008 data. One possible explanation is that dust deposited on the upward facing radiometer during 2008. It should be noted that to our knowledge the sensors were not cleaned nor visually checked on a regular basis during the 2008 study period. The sensors were removed after the end of the 2008 field study and taken to the site operator's facilities and checked by orientating both sensors the same and comparing readings. The two radiometers were found to agree within approximately 5 percent, which is considered an acceptable tolerance. Both units have since been sent back to the manufacturers for recertification. Until this matter is resolved, the reader is cautioned against using the 2008 data quantitatively.

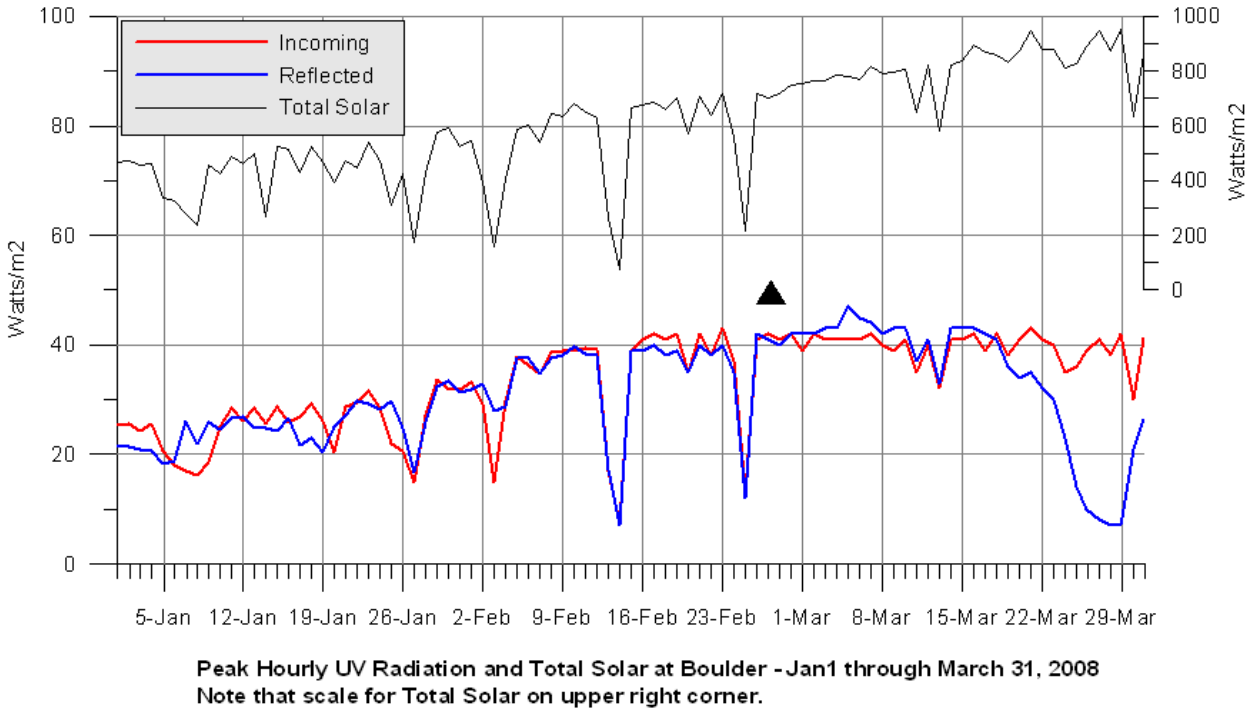

Figure 4-25. Peak hourly incoming and reflected UV radiation measured by upward and downward facing Epply total UV radiometers and total solar radiation at the Boulder monitoring site for 1 January – 31 March 2008.

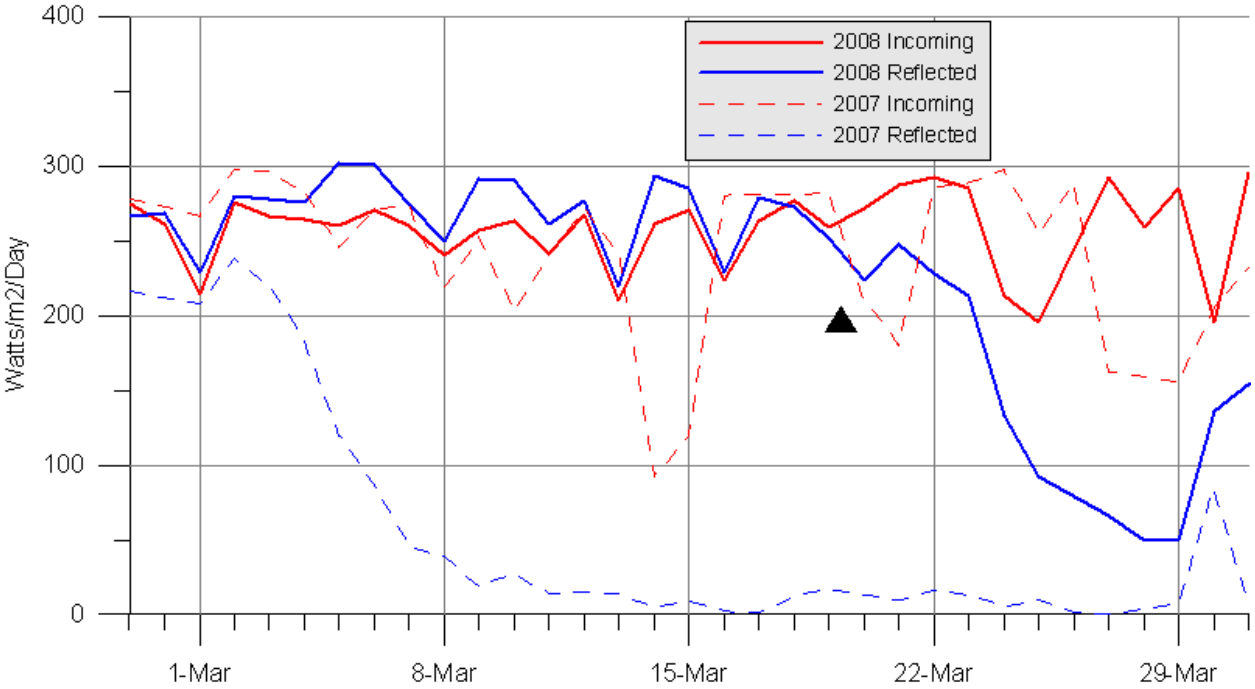

Figure 4-26. Daily total incoming and reflected UV radiation at Boulder for March 2008 (solid lines) and March 2007 (dashed lines).

5. AIRCRAFT

As described in Section 2 and Appendix D, measurements of temperature, ozone, and particulate matter (PM) were made during each intensive operating period (IOP) using a Cessna 172 aircraft instrumented with a portable sampling package (Figure 5-1). Air samples were also collected at points of interest along the flight path for analysis of organic compounds (VOCs and carbonyls). Two flights were made on most of the IOP days: one in the morning and one in the afternoon.

In this section we present a brief summary of results from each flight, including a map of the ozone concentrations along the flight path, a time series plot showing the airplane's altitude along with the temperature, ozone, and $PM_{2.5}$ concentrations and one or more vertical profile plots of data (temperature, ozone, and $PM_{2.5}$) collected from spiral flight patterns executed at key locations. Key features of each day's results are described below.

5.1 IOP #1: 18 – 21 February 2008

18 February 2008 Afternoon Flight

This sampling occurred on the day prior to the onset of the high ozone episode. Results (Figures 5-2 through 5-4) show that the boundary layer was deep and well-mixed, resulting in relatively uniform ozone concentrations averaging approximately 55 ppb throughout the study area. There is no indication of contamination of the instrument readings by the airplane exhaust as evidenced by the near zero PM 2.5 concentrations, lack of any O_3 titrations due to exhaust NO below values observed at surface monitoring sites and lack of elevated hydrocarbons in the aircraft canister sample collected at 15:00 MST. The vertical sounding obtained from the spiral flown over Boulder (Figure 5-4) shows a steady decrease in temperature with height, indicating a neutral or unstable atmosphere, resulting in significant vertical mixing throughout the measured layer. A uniform ozone concentration of 55 ppb prevails throughout the study area, and $PM_{2.5}$ concentrations are near-zero. A plume of slightly elevated O_3 and PM was observed in the vicinity of Haystack. This flight provides a good representation of baseline conditions in the study region prior to the onset of a high ozone episode.

19 February 2008 Morning Flight

This flight occurred during the morning of the first day of a multi-day ozone event. Ozone concentrations were initially found to be similar to the "baseline" concentrations observed the previous afternoon, though there is a gradual trend upward as the morning progresses (Figures 5-5 and 5-6). In contrast to the previous afternoon, a temperature inversion layer has formed over the surface. Figure 5-7 details a sounding over Boulder, showing the top of the inversion at approximately 500 meters AGL. However, as can be seen from Figure 5-6, $PM_{2.5}$ concentrations within the boundary layer remain near zero. The exception is over the Farson area, between Haystack and Simpsons Gulch. The elevated light scattering measured by the DustTrak 8520 instrument used to make the $PM_{2.5}$ measurements may have been associated with a ground-based fog that settled in this low-lying area.

19 February 2008 Afternoon Flight

Sampling on the afternoon of 19 February was characterized by widespread development of high ozone concentrations, particularly in the Jonah area, as demonstrated by Figures 5-8 and 5-9. High near-surface concentrations are noted well east of Hwy 191, in the foothills of the Wind River Range. Ozone levels in the 135-150 ppb range were not uncommon. High concentrations are capped by the inversion first noted during the morning flight that persists throughout the study area. Based on $PM_{2.5}$ concentrations, which are measured by the fastest responding instrument on the airplane, the effective mixing height is approximately 300 meters-agl (Figure 5-10). $PM_{2.5}$ concentrations are notably higher than during the morning and highly correlated with ozone, characterizing the polluted air mass. Again, the Farson area is a notable exception, showing a negative correlation between ozone and $PM_{2.5}$, suggesting the presence of a different $PM_{2.5}$ source.

20 February 2008 Morning Flight

On average, ozone concentrations in the boundary layer were generally about 10 ppb higher this morning than during the previous morning, and $PM_{2.5}$ concentrations are also notably higher (Figure 5-12), suggesting overnight accumulation under more stable conditions than during the previous night and the possibility of carryover of pollutants from the previous day. Soundings continue to show a mixed layer of about 300 meters AGL (Figure 5-13). Ozone and $PM_{2.5}$ concentrations above the inversion remain similar to the "baseline" concentrations noted on 18 February, consistent with the hypothesis that ozone production is occurring locally and only near the surface. The highest ozone readings occurred over the New Fork River basin southwest of Boulder towards the end of the flight. It is not clear if these elevated readings are the result of photochemical production that took place since sunrise or if they are at least partially an indication of an area of higher carryover of pollutants from the previous day.

20 February 2008 Afternoon Flight

This was another afternoon characterized by high ozone concentrations throughout the study area. Soundings (Figure 5-16) continued to show a surface inversion with vertical mixing limited to a shallow layer. Based on the particulate measurements, effective mixing was only to approximately 150 meters AGL (the slower fall off in ozone concentrations due to slower instrument response with height may be at least partially of the ozone analyzer). In contrast to 19 February, the highest concentrations are not over the Jonah area, but are in areas southwest and northwest of Jonah (Figure 5-14). The region near the confluence of the New Fork and Green Rivers had particularly high ozone concentrations, in excess of 150 ppb, consistent with higher readings in that area during the morning flight. Again, ozone and $PM_{2.5}$ concentrations are highly correlated (r^2=0.79 for the entire data set), as apparent in Figure 5-15.

21 February 2008 Morning Flight

Similar to the previous morning, the study area is characterized by a surface inversion limiting mixing to about 400 meters AGL (Figure 5-19), with ozone concentrations fairly uniformly in the 60 to 70 ppb range throughout (Figures 5-17 and 5-18). Some slightly higher ozone concentrations were noted in the southern part of the study area. Spikes in $PM_{2.5}$ that are inversely correlated with ozone towards the end of the flight in the general vicinity of Jonah are consistent with input of fresh NOx and PM emissions.

21 February 2008 Afternoon Flight

As with the previous 2 days, in the afternoon high ozone concentrations were experienced in many areas during the afternoon of the 21st, with the area along the New Fork River near Boulder showing the highest concentrations (Figure 5-20). The effective mixing height as indicated by the vertical distribution of $PM_{2.5}$ is only a little over 200 meters AGL (Figure 5-22), similar to the previous afternoon. Unlike on prior days, some layering is apparent in the spiral sounding taken over boulder. Ozone concentrations above the inversion are around 60 ppb, whereas below the inversion, concentrations are as high as 160 ppb. Ozone readings in Figures 5-20 and 5-21 appear to show a number of distinct plumes with concentrations dipping to as low as 60 - 70 ppb in between the high readings. As on previous flights, ozone concentrations are highly correlated with $PM_{2.5}$ concentrations.

5.2 IOP #2: 27 – 29 February 2008

27 February 2008 Morning Flight

This is the first sampling flight of the second IOP and shows initial conditions similar to those at the start of the first IOP. A surface inversion up to about 600 meters AGL characterizes a stable layer that limited mixing throughout the period. Ozone concentrations average approximately 50 ppb throughout the flight, though "baseline" concentrations above the inversion are closer to 40 ppb (Figure 5-25), lower than those noted during the first IOP. Once again, higher $PM_{2.5}$ concentrations are noted in the low-lying areas near Farson in contrast to near zero concentrations elsewhere. The higher readings were associated with reduced visibility and are likely attributable to fog in the area.

27 February 2008 Afternoon Flight

As was the case in IOP #1, increasing ozone concentrations were noted during this afternoon flight. However, the vertical profile is notably different from those during the first IOP, showing an elevated stable layer, beginning with an isothermal layer at about 300 meters AGL and an inversion top near 600 or 700 meters AGL (Figure 5-28). This produces a more layered structure, with ozone concentrations higher near the surface, at 60 ppb within the elevated inversion, and dropping to 40 ppb (the "baseline" values noted during the morning sounding) above the inversion. The greater depth of the surface mixed layer on this afternoon as compared to IOP #1 is likely the main reason for the lower boundary layer ozone concentrations on this afternoon although the lower ozone levels aloft may also have contributed.

28 February 2008 Afternoon Flight

The surface inversion that occurred on the previous day did not occur on February 28 (Figure 5-31). Thus, the boundary layer was relatively deep and well mixed, resulting in conditions not conducive for formation of high ozone concentrations. Afternoon ozone concentrations remained around 60 ppb throughout the study area. These concentrations are nevertheless significantly higher than the "baseline" value of 40 ppb noted the previous day. Despite the unfavorable meteorology for a repeat of the high ozone observed on earlier sampling flights, an increase in ozone was observed as the afternoon progressed (Figure 5-30).

29 February 2008 Morning Flight

With the onset once again of a strong, surface-based inversion on this morning (Figure 5-34), the stage was set for conditions leading to higher ozone concentrations later in the day. $PM_{2.5}$ concentrations during this sampling flight are already higher than those during the previous afternoon suggesting increased ozone precursor concentrations. Some ozone generation is apparent during the final portion of the flight, again correlated with an area of higher $PM_{2.5}$ southeast of Boulder (Figure 5-33).

29 February 2008 Afternoon Flight

The morning surface inversion noted above remained intact during the afternoon as can be seen from Figure 5-37 with mixing limited to approximately 200-300 meters AGL. A widespread area of high ozone concentrations was measured south and east of Jonah with maximum concentrations in the 120-130 ppb range. An additional area of higher ozone concentrations was noted between Boulder and Wenz Field near the end of the flight. The aircraft altitude appears to have alternated between just above and just below the sharp inversion layer while traveling between Jonah and Boulder, resulting in a pattern of alternating low and high ozone and PM readings. "Baseline" ozone concentrations above the inversion are around 60 ppb, consistent with the previous afternoon, but notably different from the 40 ppb values seen on 27 February.

5.3 IOP #3: 10 – 12 March 2008

10 March 2008 Morning Flight

As was the case during the previous two IOPs, a surface inversion was present during this morning flight, with stable conditions limiting vertical mixing. However, the inversion during this IOP was considerably deeper than during the first two IOPs. The initial sounding over Boulder (Figure 5-40) shows stable conditions to at least 1,200 meters AGL in contrast to 500-600 meters generally present in earlier IOPs. $PM_{2.5}$ measurements indicate some mixing occurred up to about 200 meters-AGL. Initial "baseline" ozone concentrations within this layer are around 60 ppb throughout the region, similar to those found during the other IOPs.

10 March 2008 Afternoon Flight

Results from this flight show moderately high ozone concentrations occurring throughout the region during the afternoon, with the highest concentrations (~110 ppb) found around and over the Mesa area. An elevated inversion base is evident at about 500 meters AGL and some limited mixing to about 400 – 450 meters is evident from the $PM_{2.5}$ levels (Figure 5-43). This relatively deep mixing is the most likely explanation for the lower boundary layer ozone concentrations observed during this afternoon. Figure 5-42 again shows a high correlation between ozone and $PM_{2.5}$ readings, though the $PM_{2.5}$ readings are proportionately high relative to the ozone concentrations. For the flight as a whole, the correlation between ozone and $PM_{2.5}$ is only moderate ($r^2 = 0.52$). However, when the data collected in the vicinity of Farson is removed, the correlation becomes significantly stronger $r^2 = 0.81$). The strong correlation between ozone and PM outside of Farson was noted on other afternoon flights and suggests that sources of PM or chemical conditions around the Farson area are somewhat different from those found over rest of the study area.

11 March 2008 Morning Flight

Conditions during this flight were similar to those found during other IOP mornings, with a surface-based inversion extending to 300 to 400 meters AGL and "baseline" ozone concentrations in the 55 to 60 ppb range (Figure 5-46). Results in Figures 5-44 and 5-45 show that higher ozone concentrations were measured at the southern portion of the flight. Since these ozone concentrations are accompanied by well-correlated increases in $PM_{2.5}$, similar to those noted during many of the afternoon flights, it seems likely that these higher ozone readings represent carryover of pollutants from the previous day.

11 March 2008 Afternoon Flight

Conditions during this sampling flight were characterized by particularly shallow mixing limited by a persisting and widespread surface-based inversion with a depth extending only to about 200 meters AGL (Figure 5-49), and high ozone concentrations (Figures 5-47 and 5-48). Of particular note is that the highest concentrations measured during the 2008 study (~175 ppb) occurred on this flight. The highest concentrations were observed along the western foothills of the Wind River Range, where increasing terrain heights may have constricted the boundary layer further and allowed precursors to accumulate. "Baseline" ozone concentrations above the inversion remained at about 60 ppb. Again, ozone and $PM_{2.5}$ concentrations were highly correlated, with r^2=0.92, the highest of the study (Figure 5-50).

12 March 2008 Morning Flight

Meteorological and air quality conditions during this morning were similar to those observed on other IOP days. A surface inversion is present restricting mixing to less than 150 meters AGL (Figure 5-53). Ozone concentrations were relatively uniform at ~ 60 ppb, both vertically and horizontally—increasing to ~ 70 ppb during the latter half of the flight (Figures 5-51 and 5-52) as ozone production starts to increase during the late morning.

12 March 2008 Afternoon Flight

The inversion noted during the morning had disappeared by the time of the afternoon flight (Figure 5-53), allowing deeper mixing within the boundary layer and resulting in relatively low ozone levels. Afternoon ozone concentrations returned to the "baseline" values of 60 ppb throughout the area. This feature is clearly illustrated in Figures 5-54 and 5-55. Peak ozone concentrations measured by the aircraft is ~ 70 ppb which occurred at low (near surface) altitude.

23 March 2008 Afternoon Flight

After the end of the last IOP on 12 March, the aircraft was left configured for an additional flight in the event conditions of interest to the study team arose prior to the end of field operations on 31 March. On the afternoon of 23 March, an elevated stable layer produced enough of a cap on the boundary layer to cause some high surface ozone concentrations to form (Figures 5-56 and 5-57). This stable layer can be seen as a weakening of the lapse rate at about 700 to 800 meters AGL (Figure 5-58). Higher concentrations were noted in the southeast portion of the study area during this afternoon flight. Of interest during this flight is a visual notation by the pilot that the higher ozone readings appeared to have been related to the presence of snow cover beneath the flight path. We were able to confirm this observation by superimposing the flight data over the MODIS satellite photo for 23 March (Figure 5-59). As can be seen from the figure, uniform

snow cover is present in the southeast quadrant while only scattered snow cover generally prevails elsewhere. Although the reported coincidence between elevated ozone and snow cover in this case may be spurious, this observation is nevertheless consistent with the hypothesis that ozone formation in these winter episodes is critically dependent on the presence of snow cover.

(a). UGWOS aircraft – Cessna 172.

(b). Ozone sampler/data logger package.

(c). Sample tubing.

(d). Leading edge sample inlet.

Figure 5-1. Cessna 172 used for airborne sampling during IOP events.

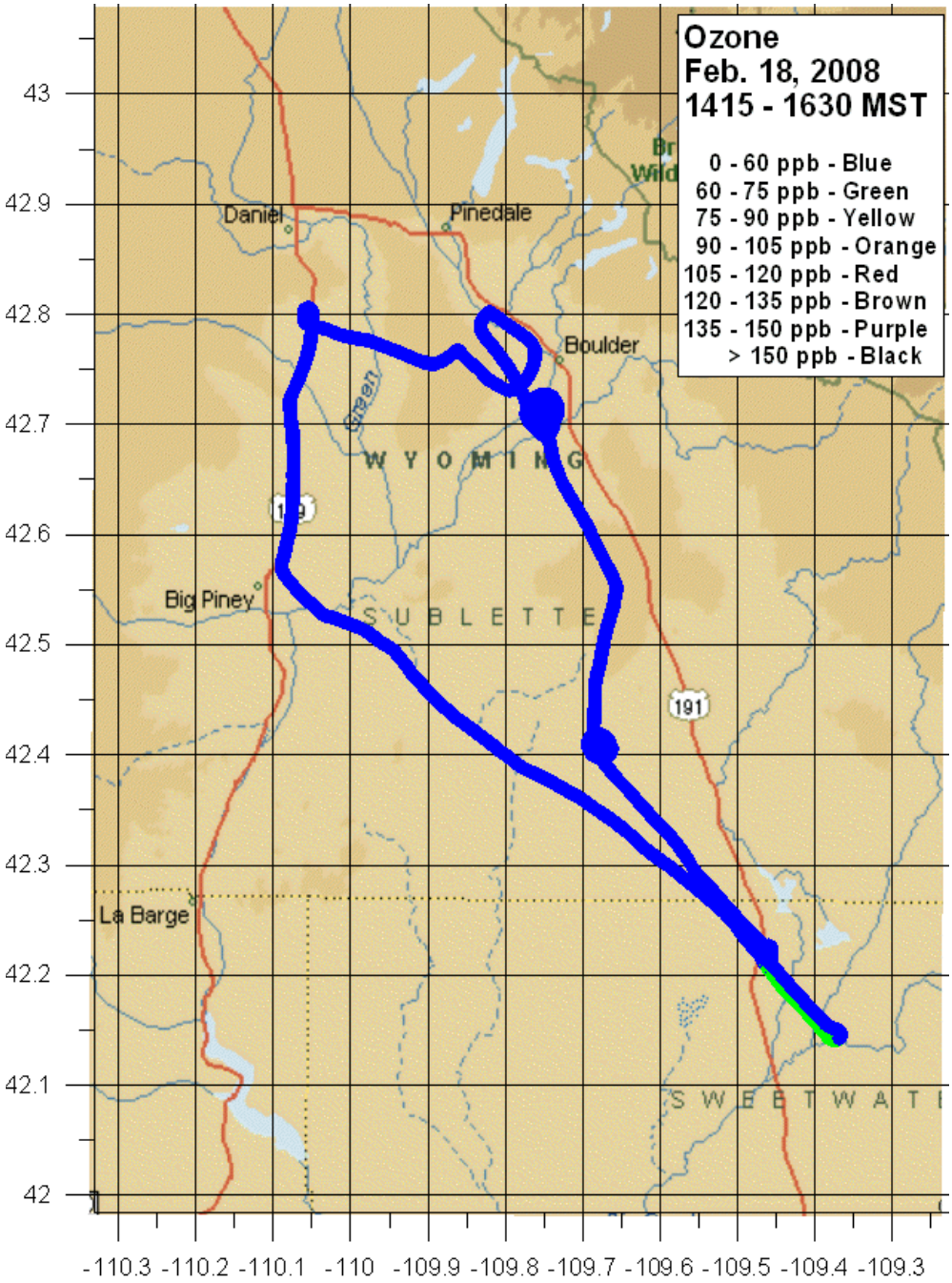

Figure 5-2. Ozone concentrations along aircraft flight path on afternoon of 18 February 2008.

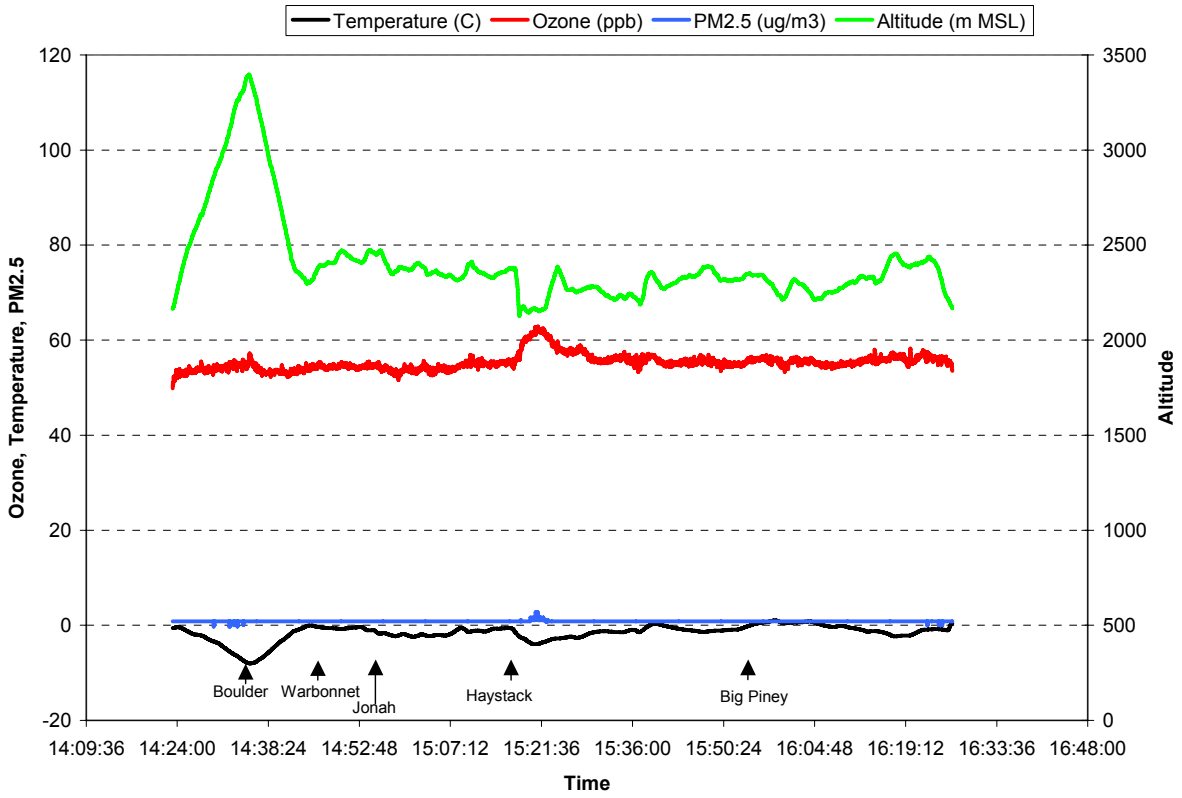

Figure 5-3. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 18 February.

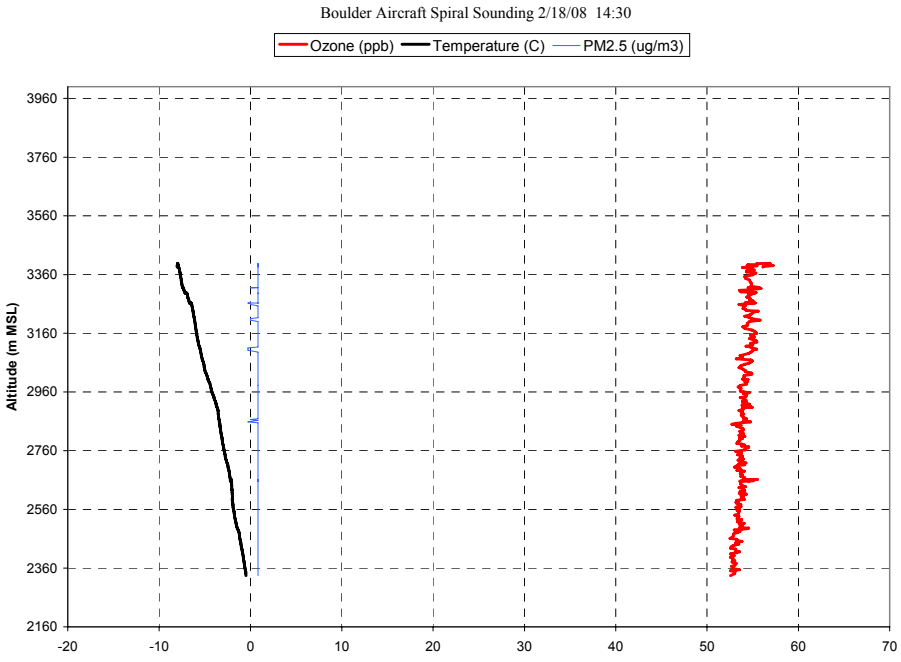

Figure 5-4. Vertical profiles of ozone temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 18 February, 14:30 MST (base of plot is at ground level).

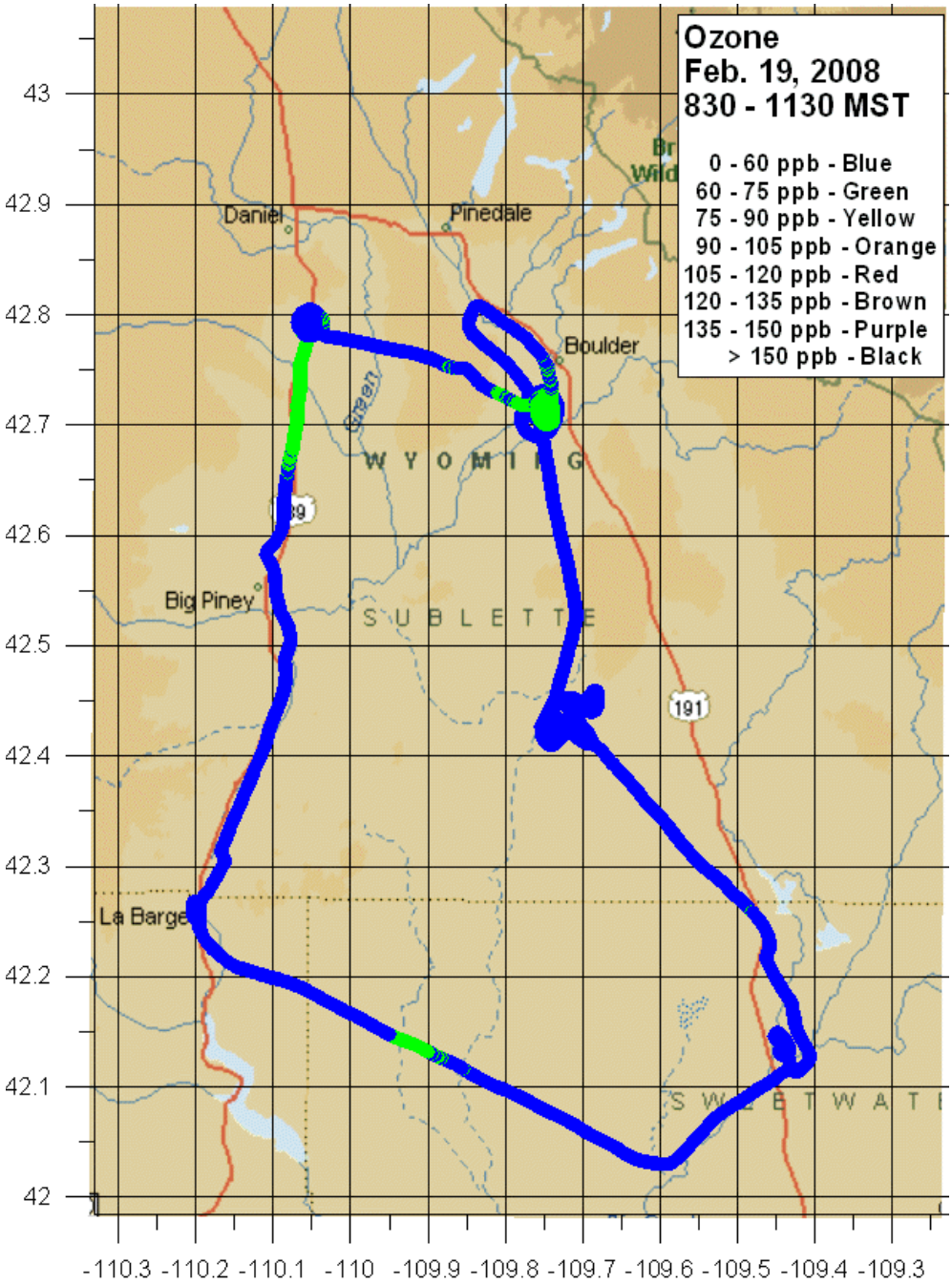

Figure 5-5. Ozone concentrations along aircraft flight path on morning of 19 February.

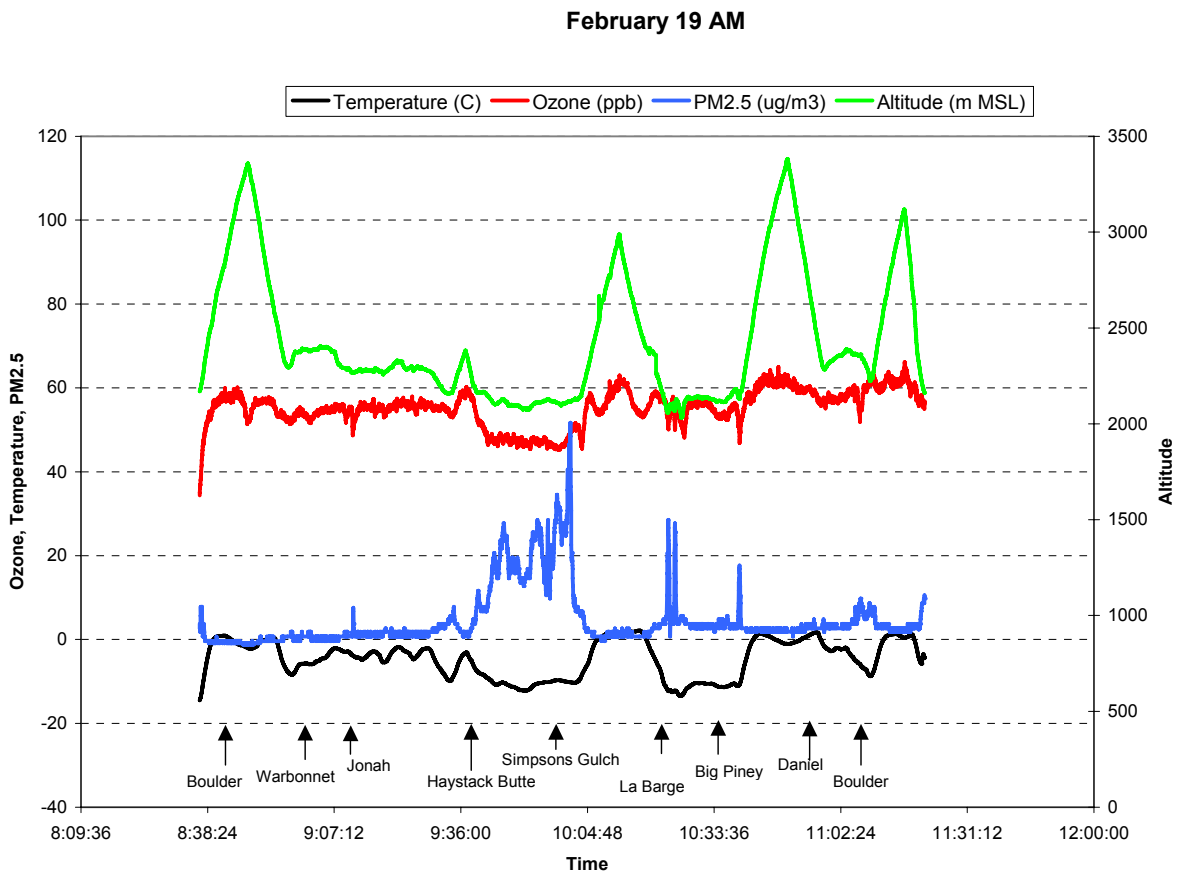

Figure 5-6. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 19 February.

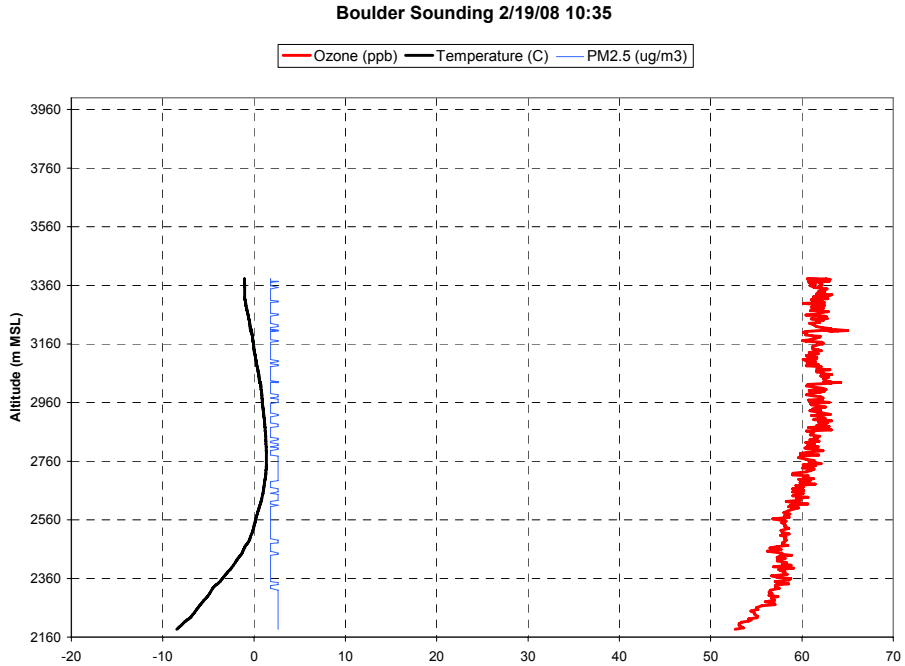

Figure 5-7. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 19 February, 10:30 MST (base of plot is at ground level).

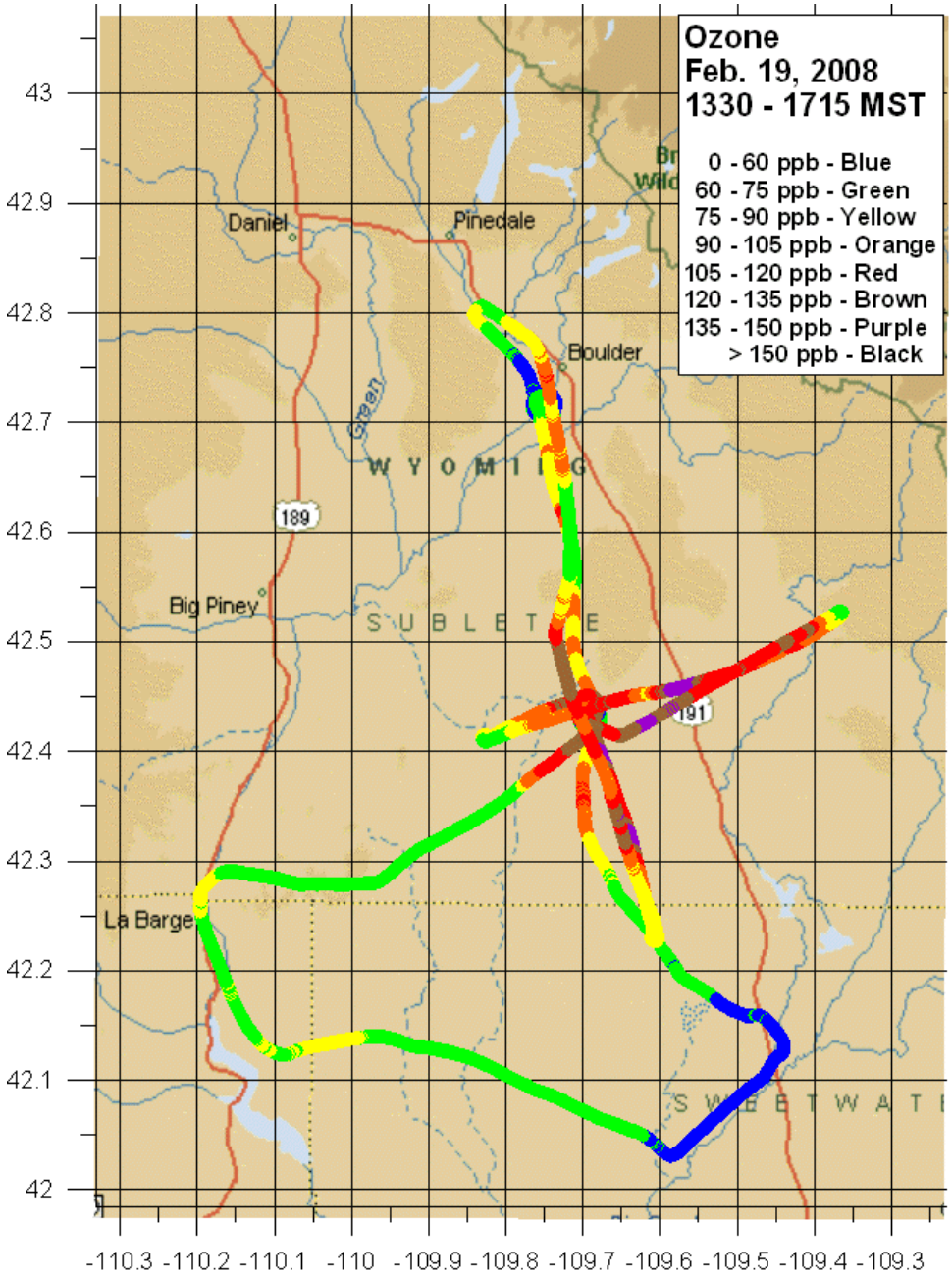

Figure 5-8. Ozone concentrations along aircraft flight path on afternoon of 19 February.

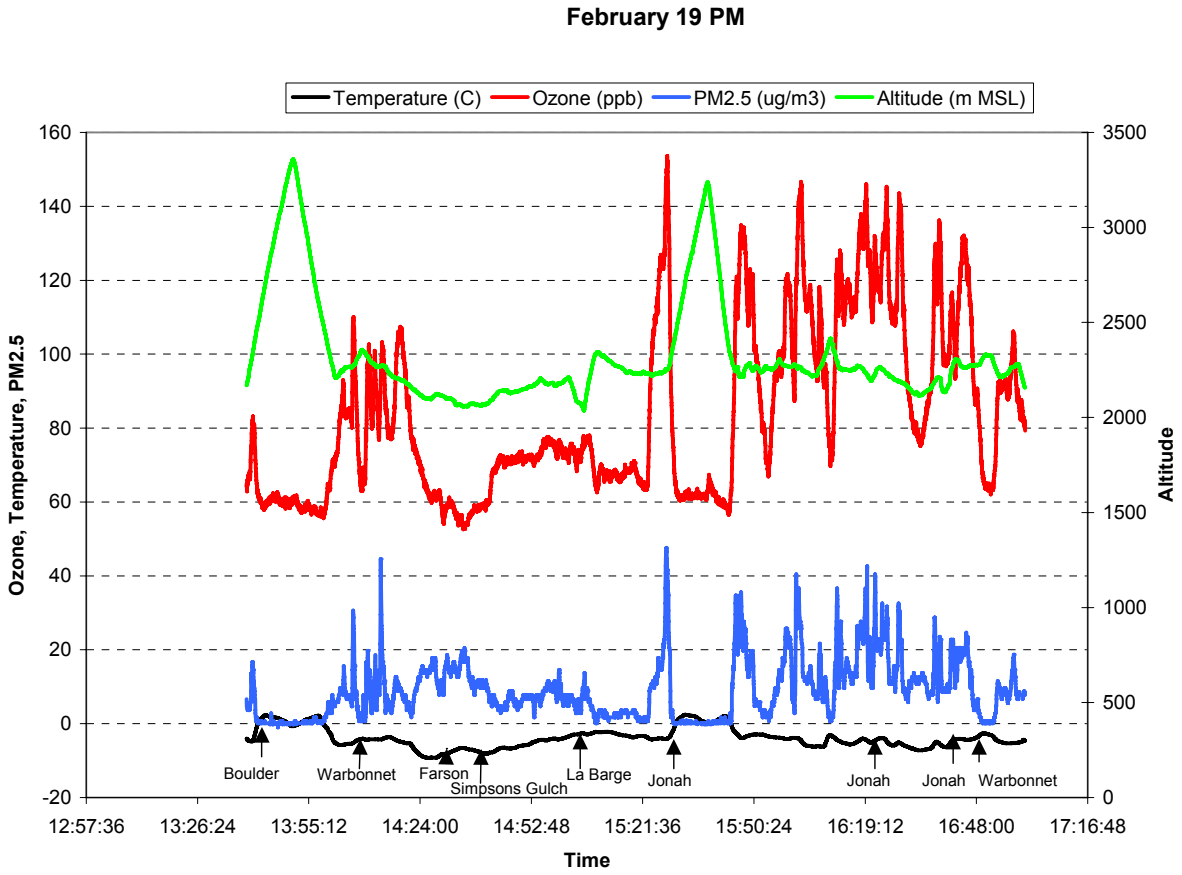

Figure 5-9. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 19 February.

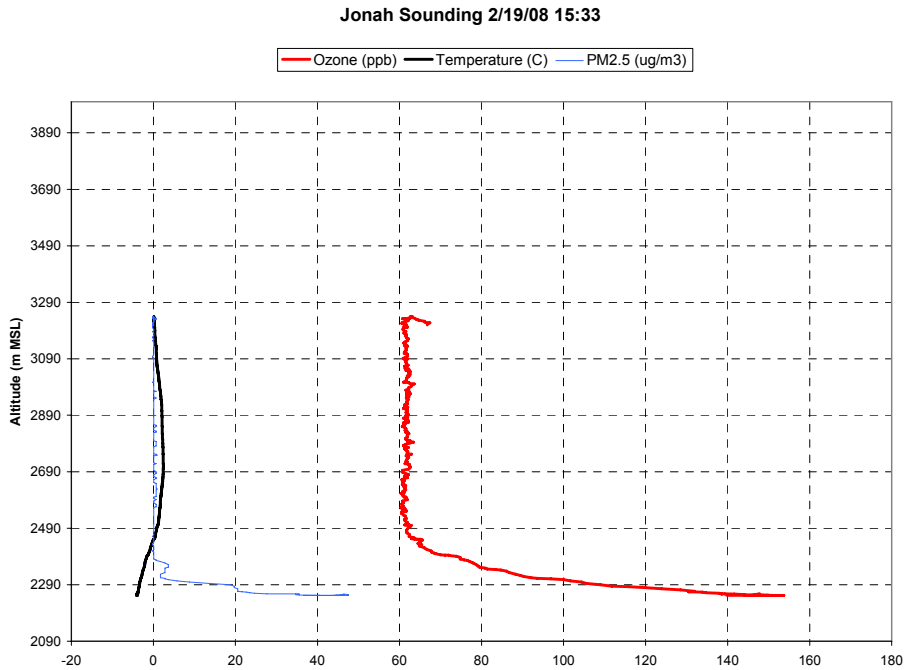

Figure 5-10. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Jonah on 19 February, 15:33 MST (base of plot is at ground level).

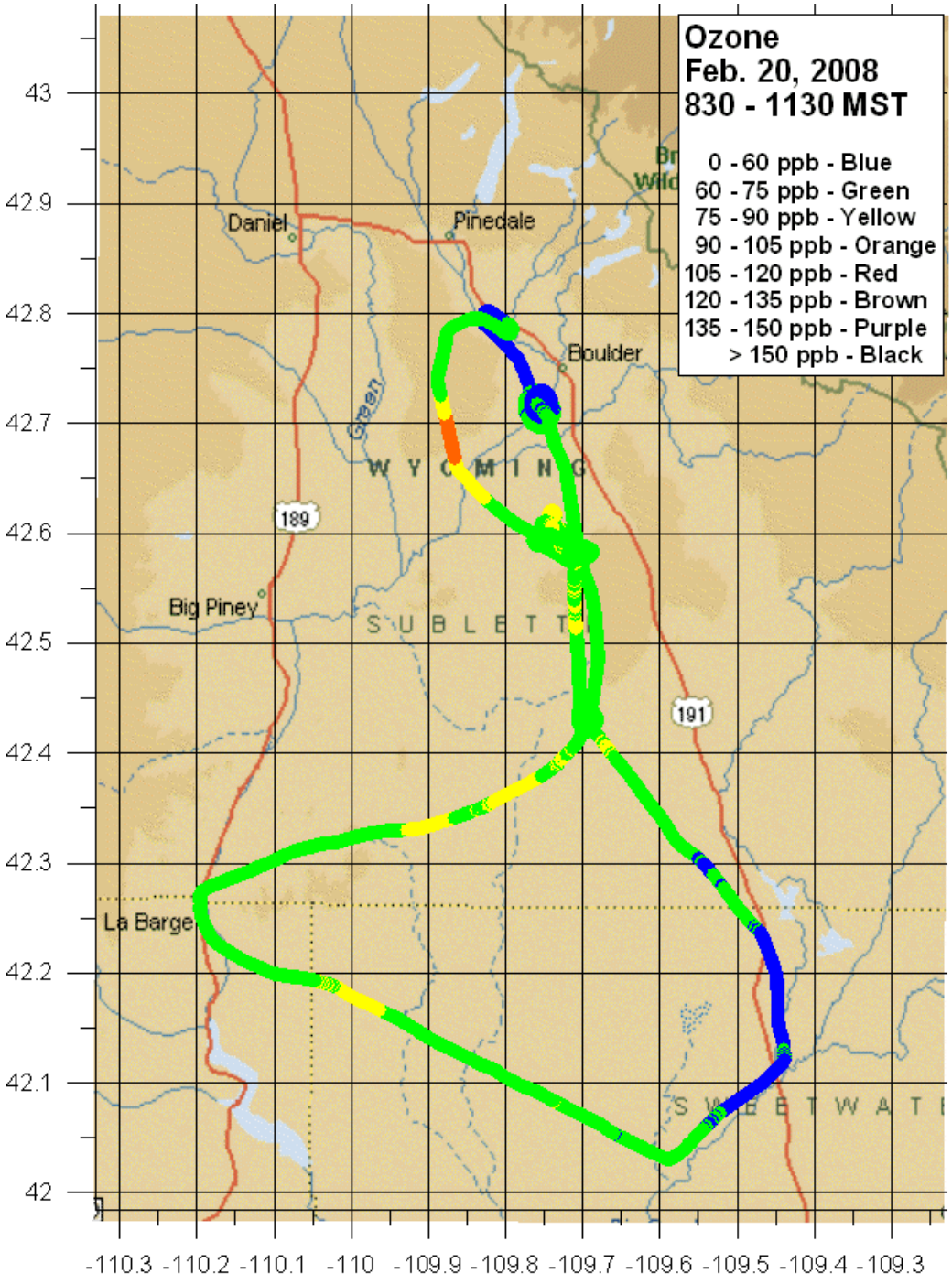

Figure 5-11. Ozone concentrations along aircraft flight path on morning of 20 February.

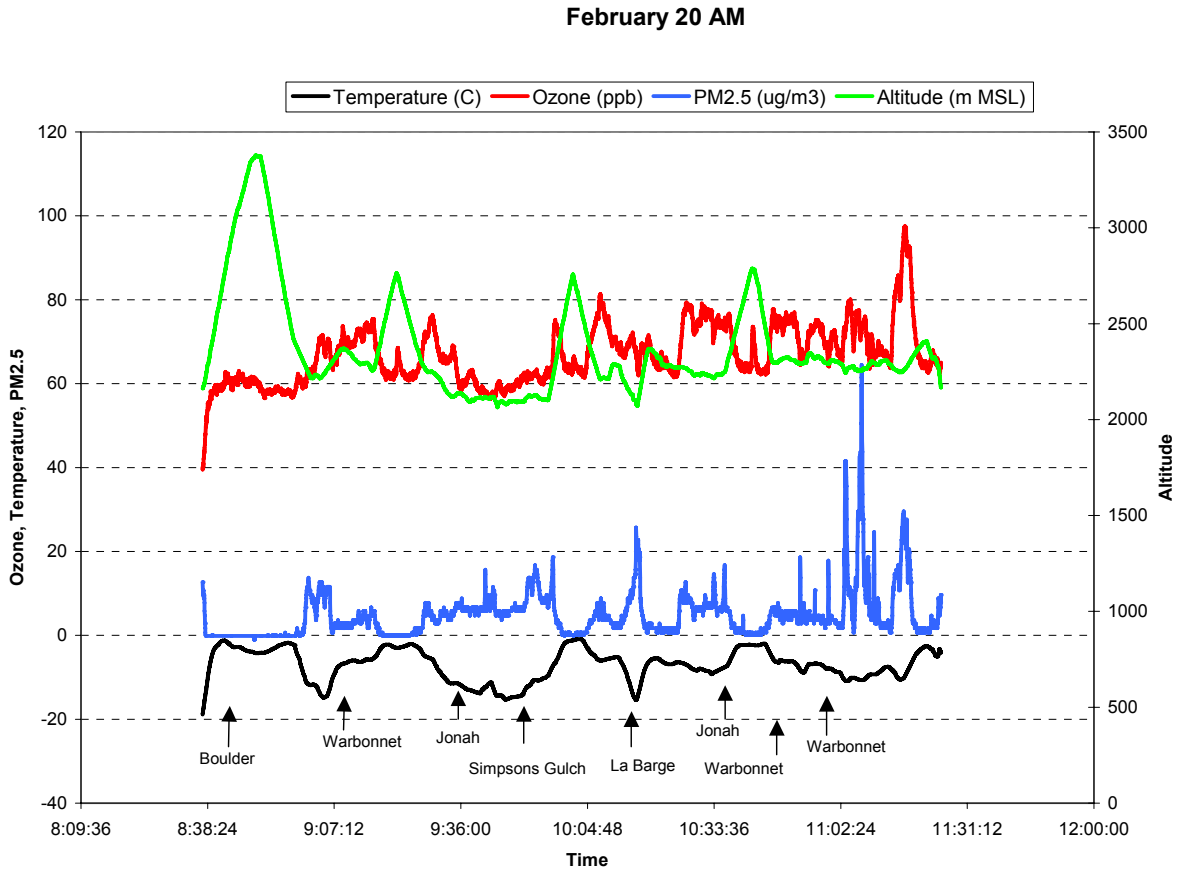

Figure 5-12. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 20 February.

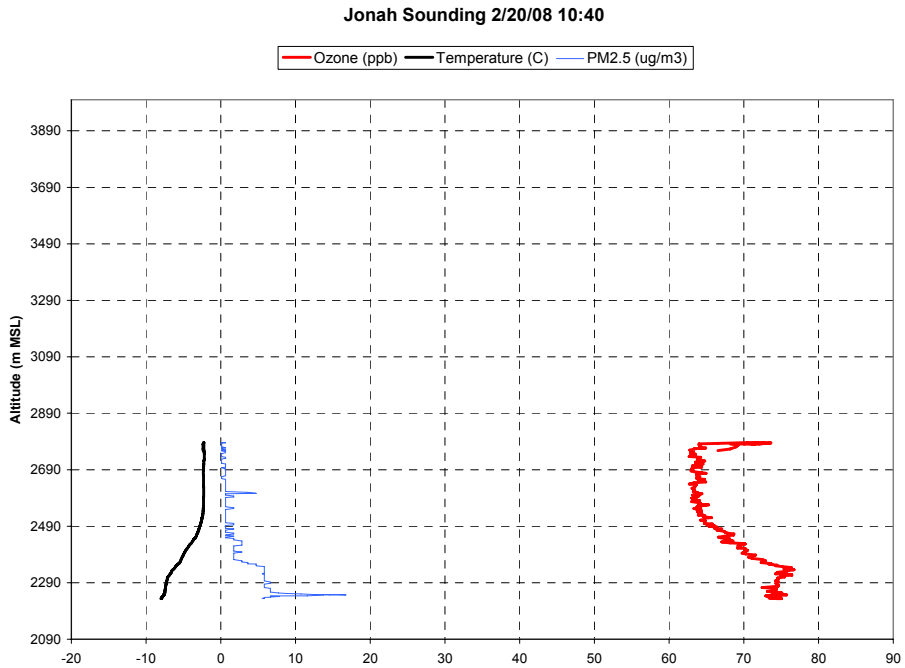

Figure 5-13. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Jonah on 20 February, 10:40 MST (base of plot is at ground level).

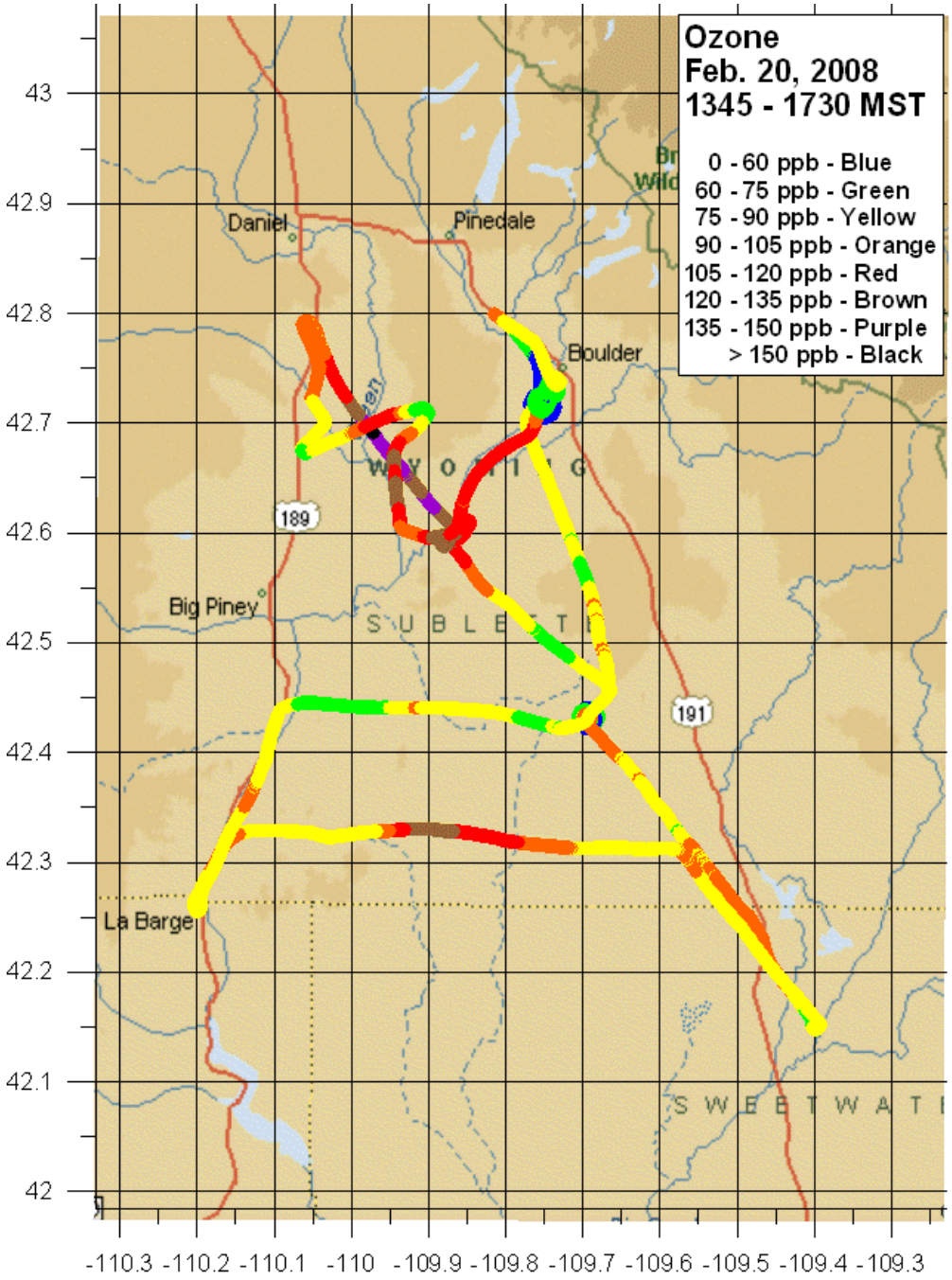

Figure 5-14. Ozone concentrations along aircraft flight path on afternoon of 20 February.

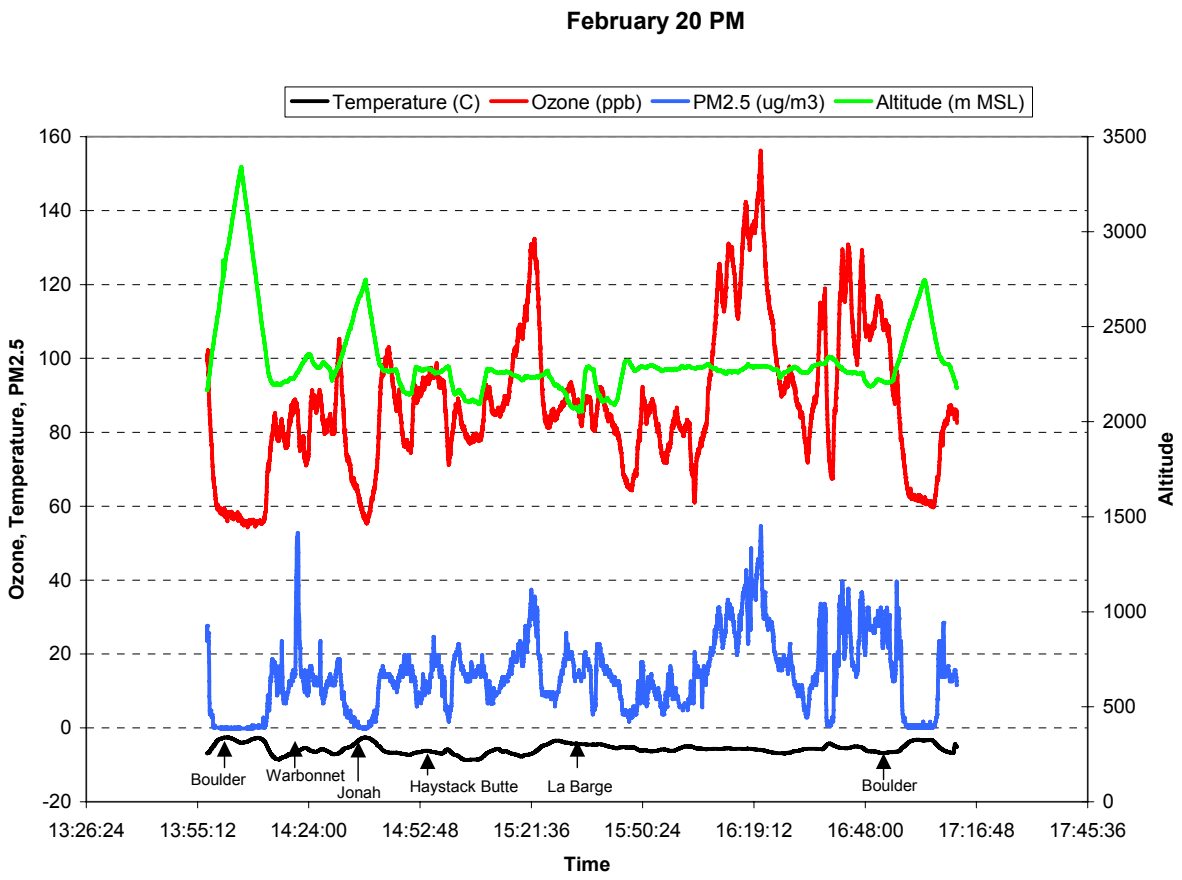

Figure 5-15. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude afternoon flight on 20 February.

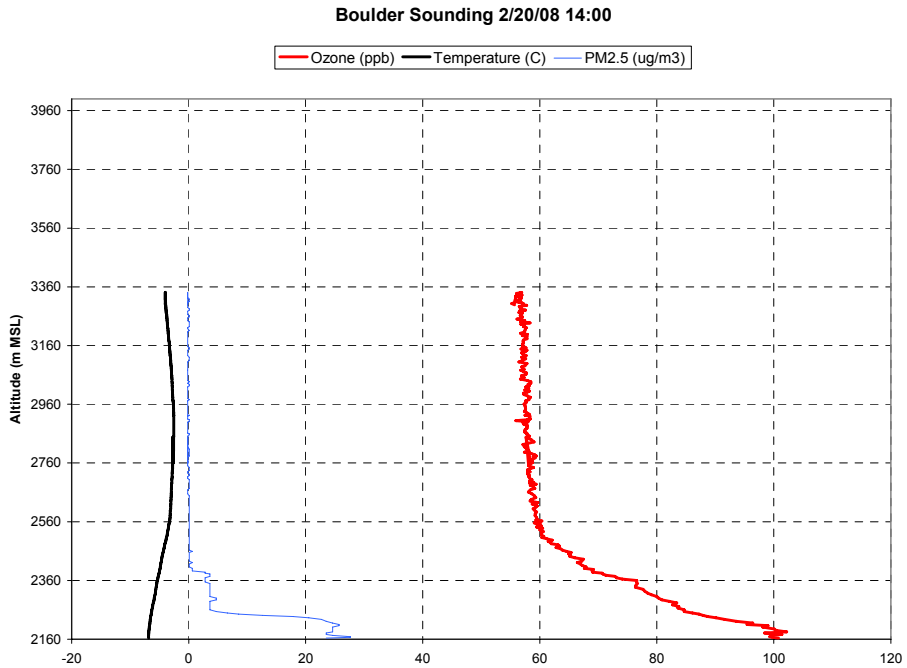

Figure 5-16. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder Sounding on 20 February, 14:00 MST (Base of plot is at ground level).

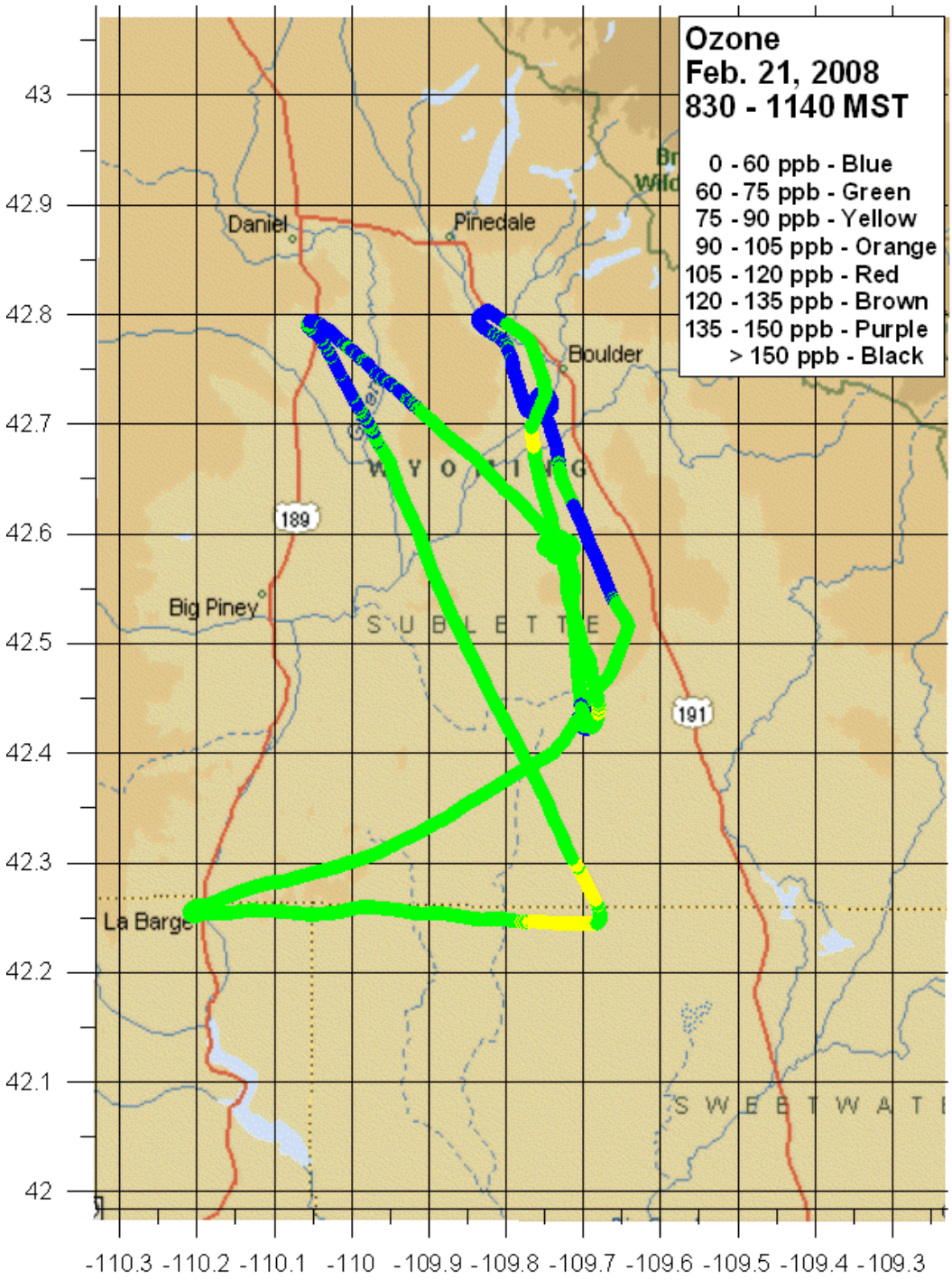

Figure 5-17. Ozone concentrations along aircraft flight path on morning of 21 February.

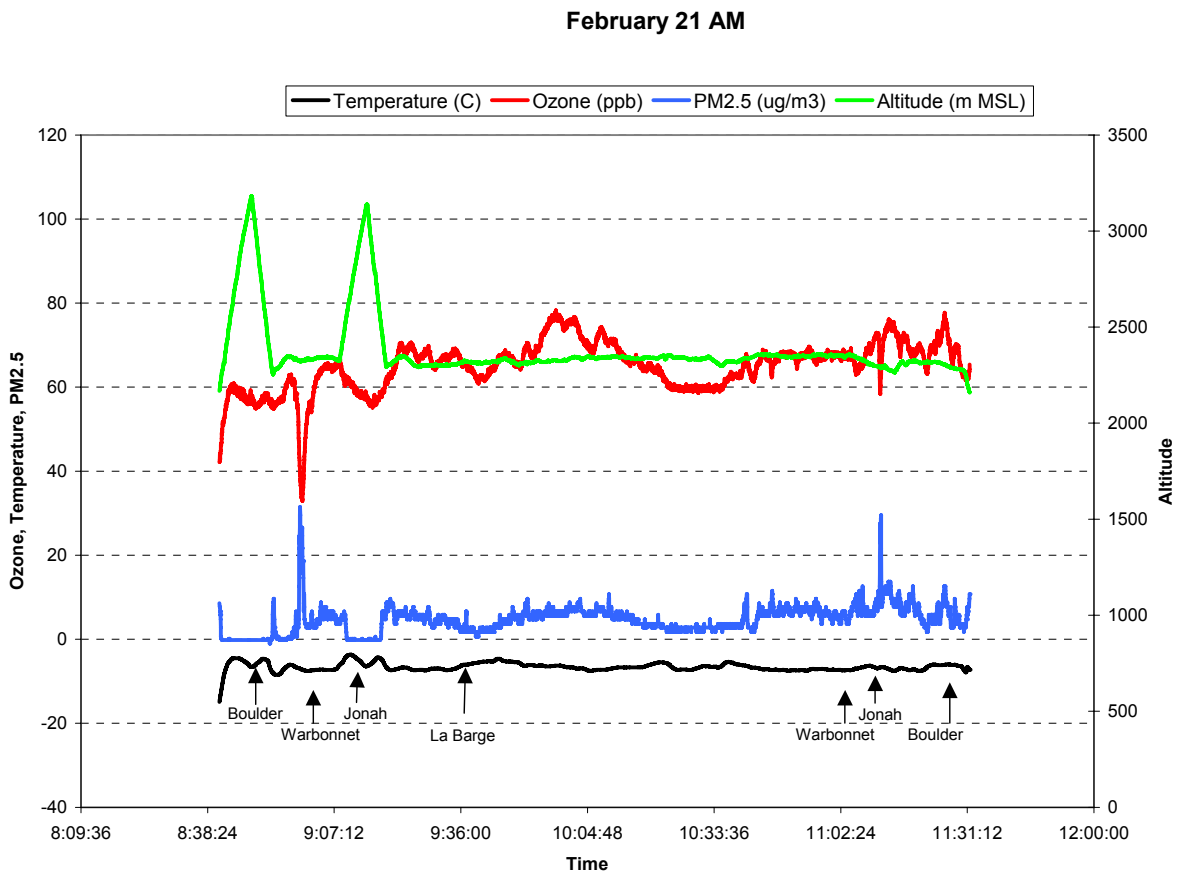

Figure 5-18. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 21 February.

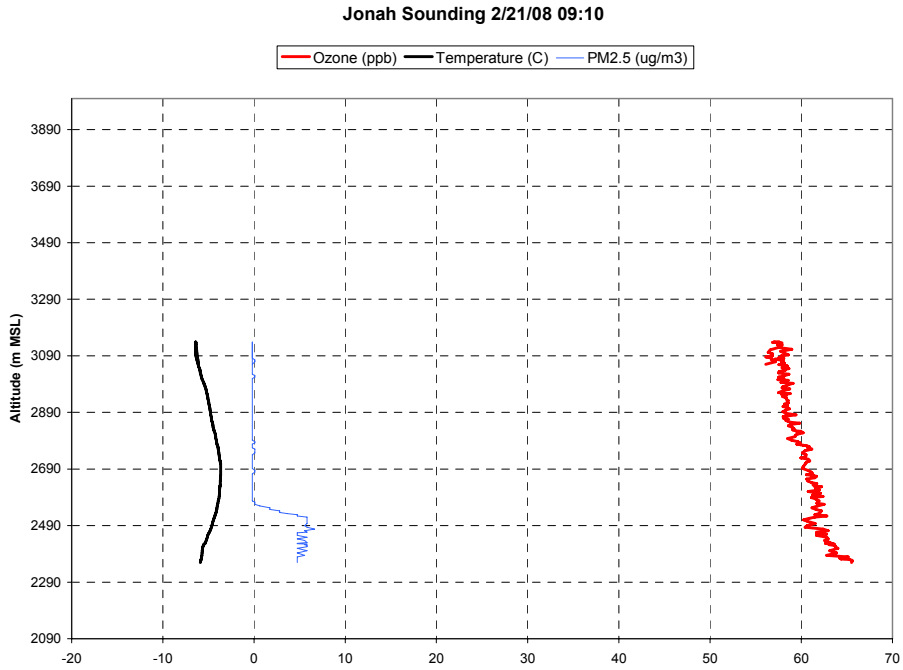

Figure 5-19. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Jonah on 21 February, 9:10 MST (base of plot is at ground level).

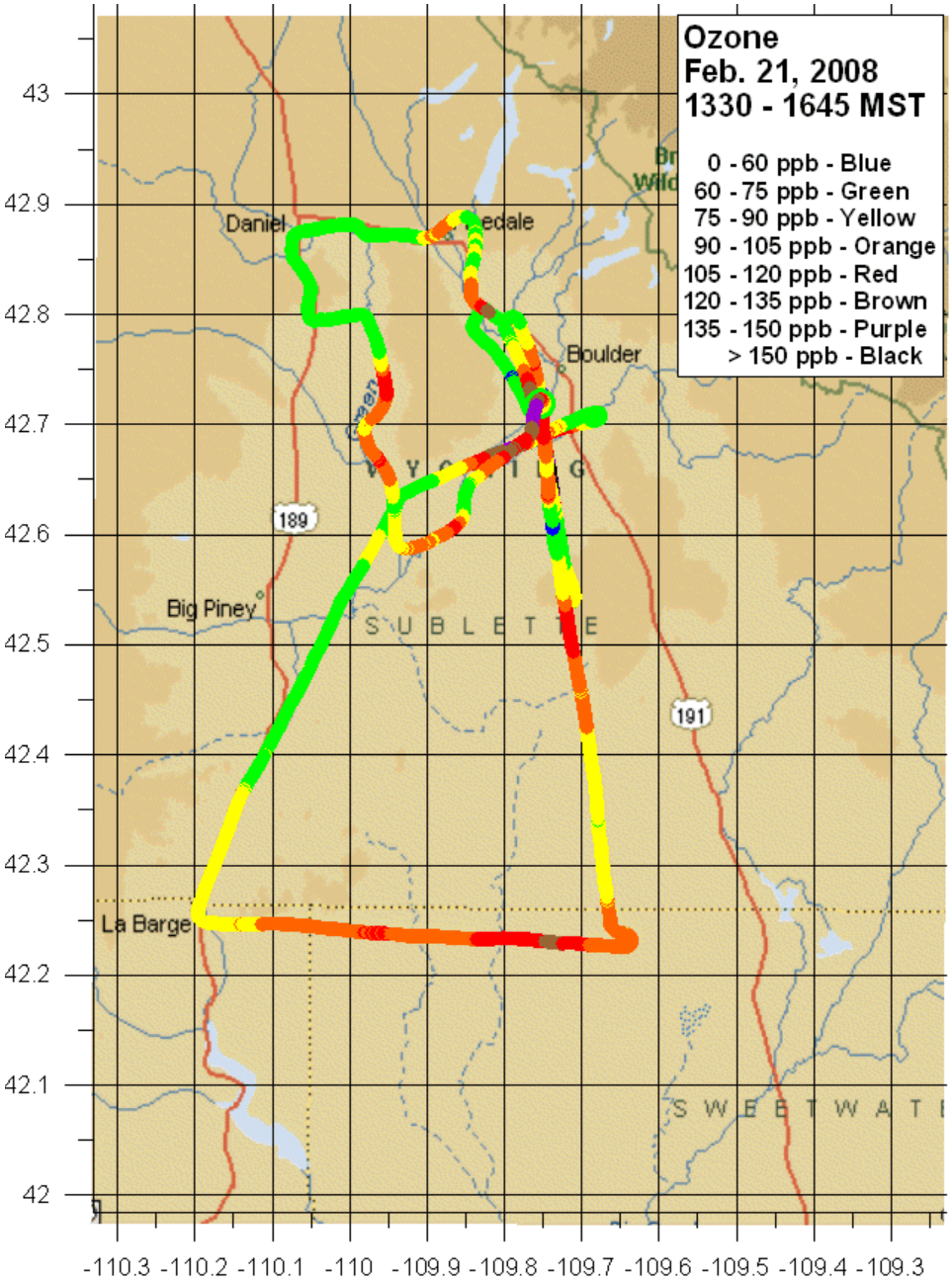

Figure 5-20. Ozone concentrations along aircraft flight path on afternoon of 21 February.

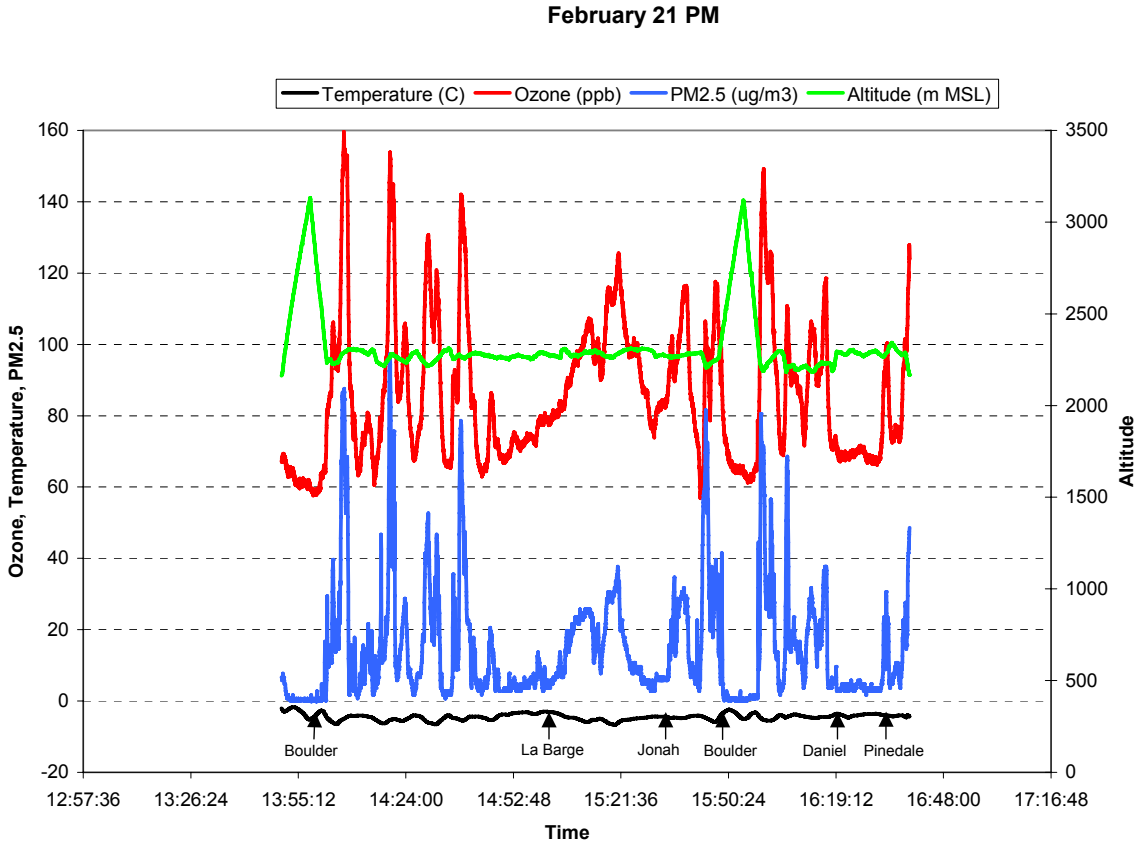

Figure 5-21. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 21 February.

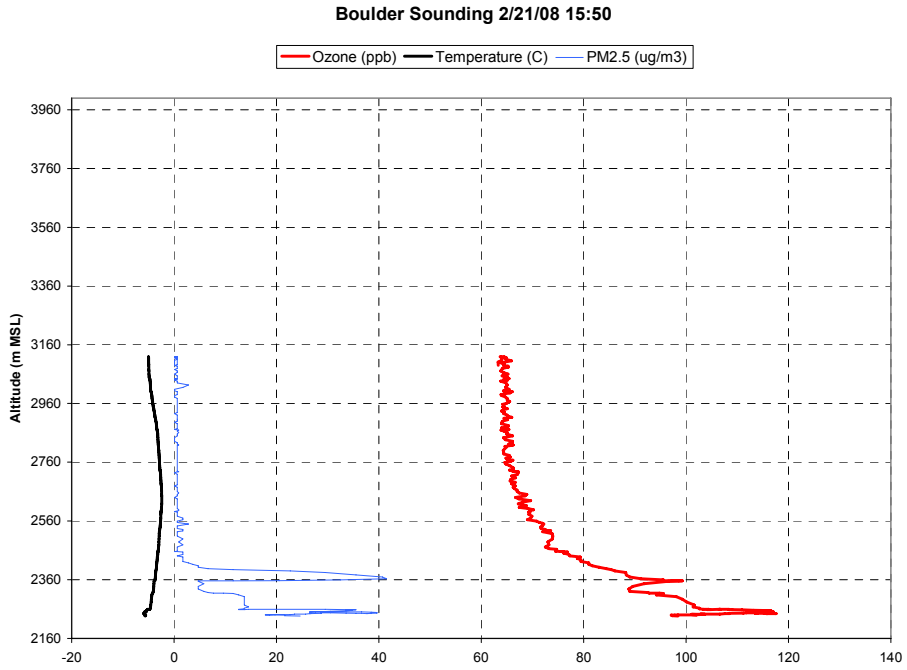

Figure 5-22. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 21 February, 15:50 MST (base of plot is at ground level).

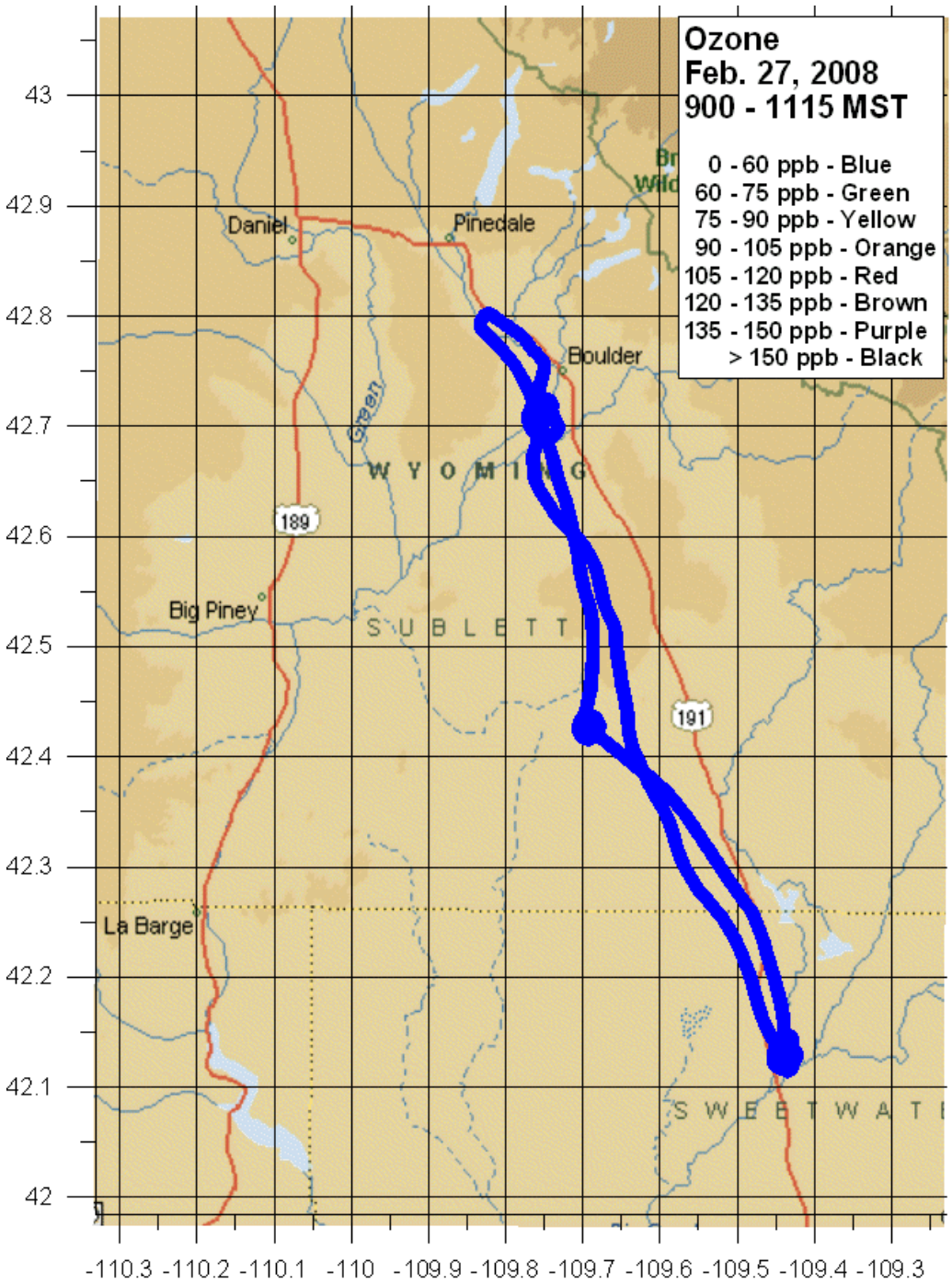

Figure 5-23. Ozone concentrations along aircraft flight path on morning of 27 February.

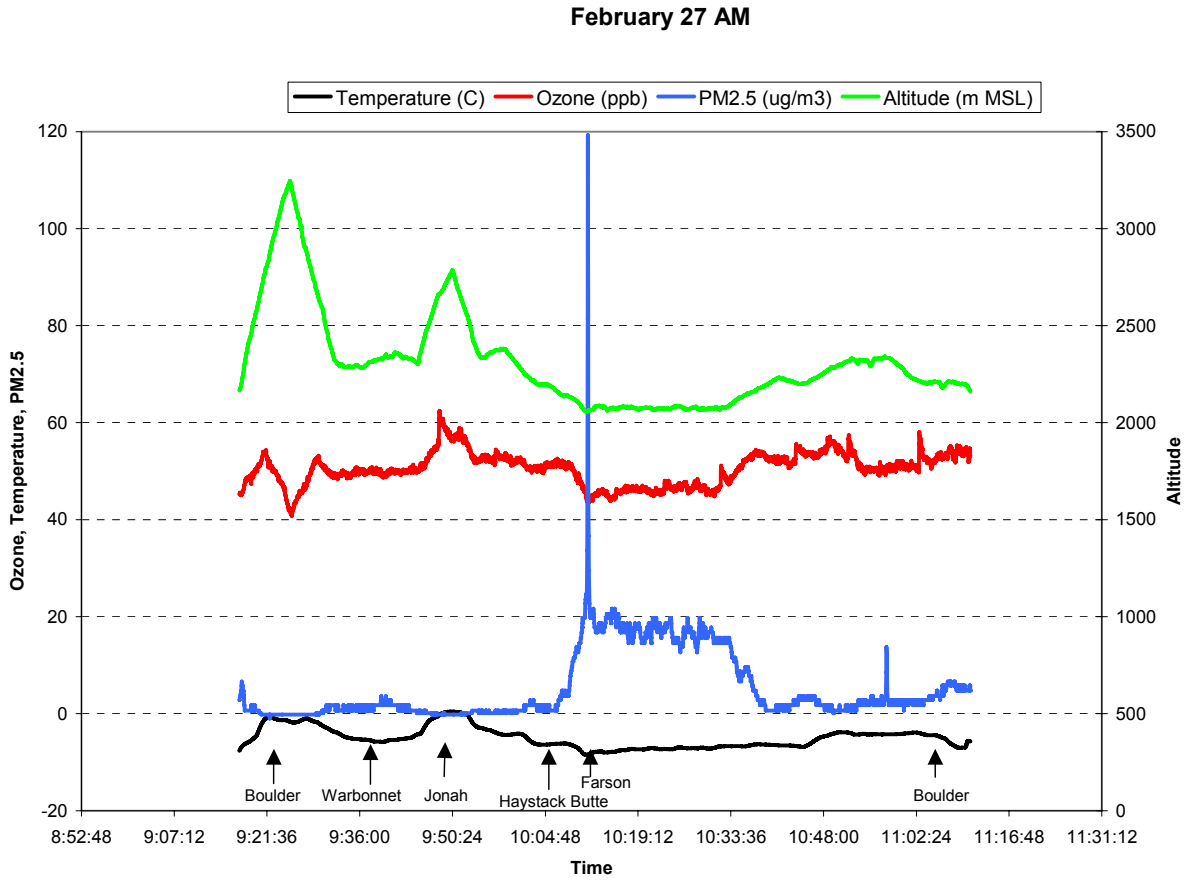

Figure 5-24. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 27 February.

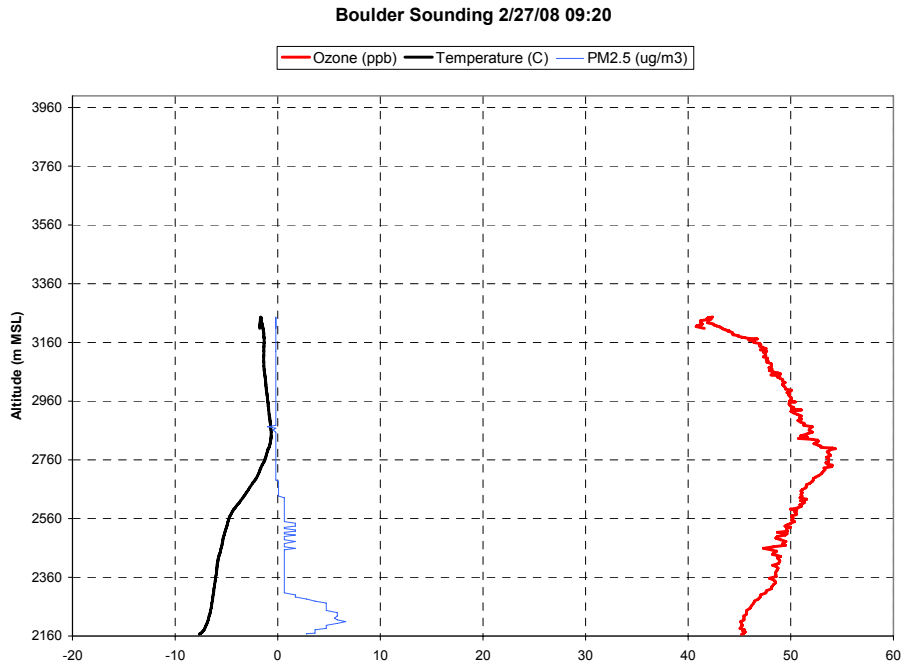

Figure 5-25. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 27 February, 9:20 MST (base of plot is at ground level).

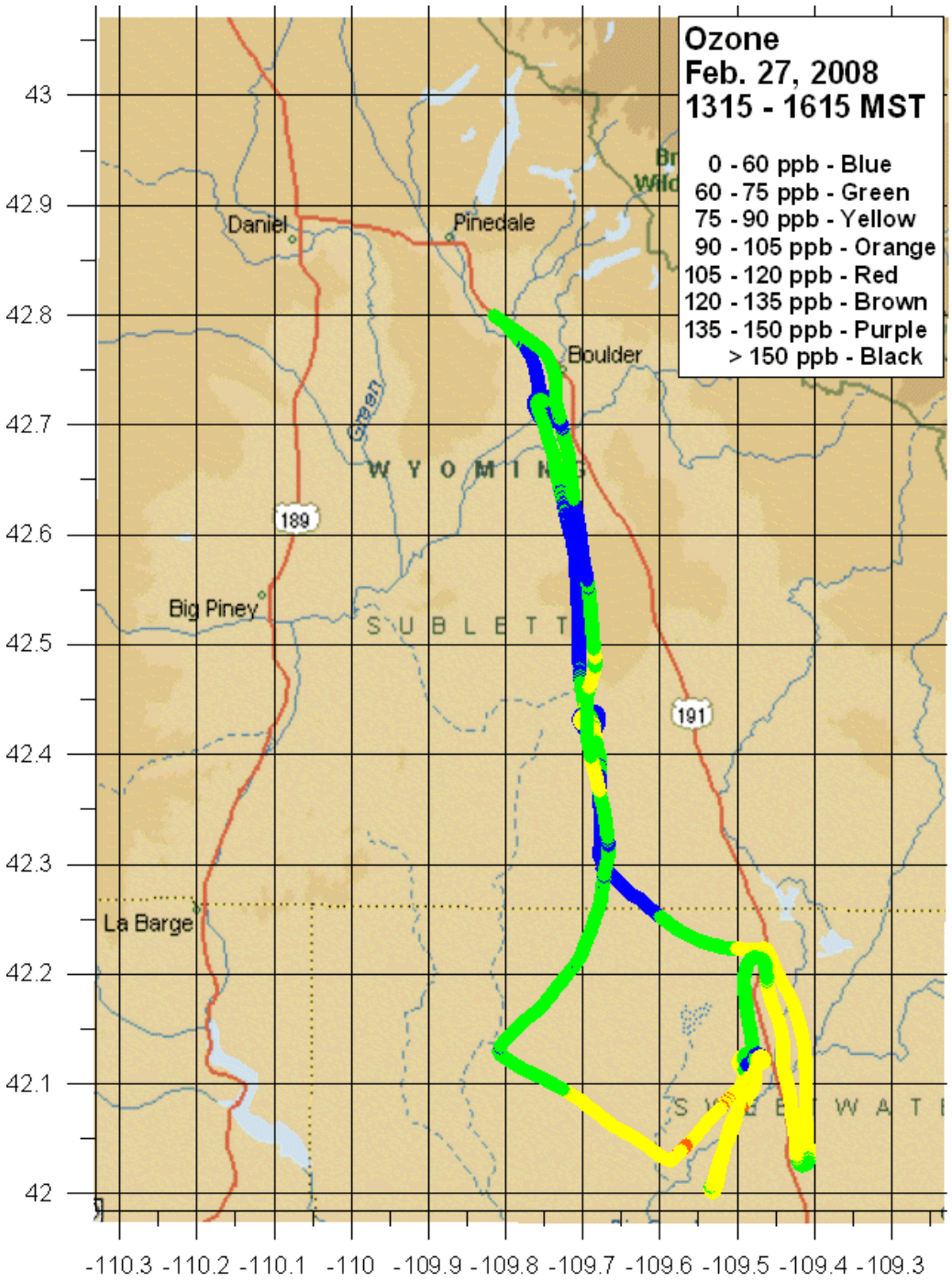

Figure 5-26. Ozone concentrations along aircraft flight path on afternoon of 27 February.

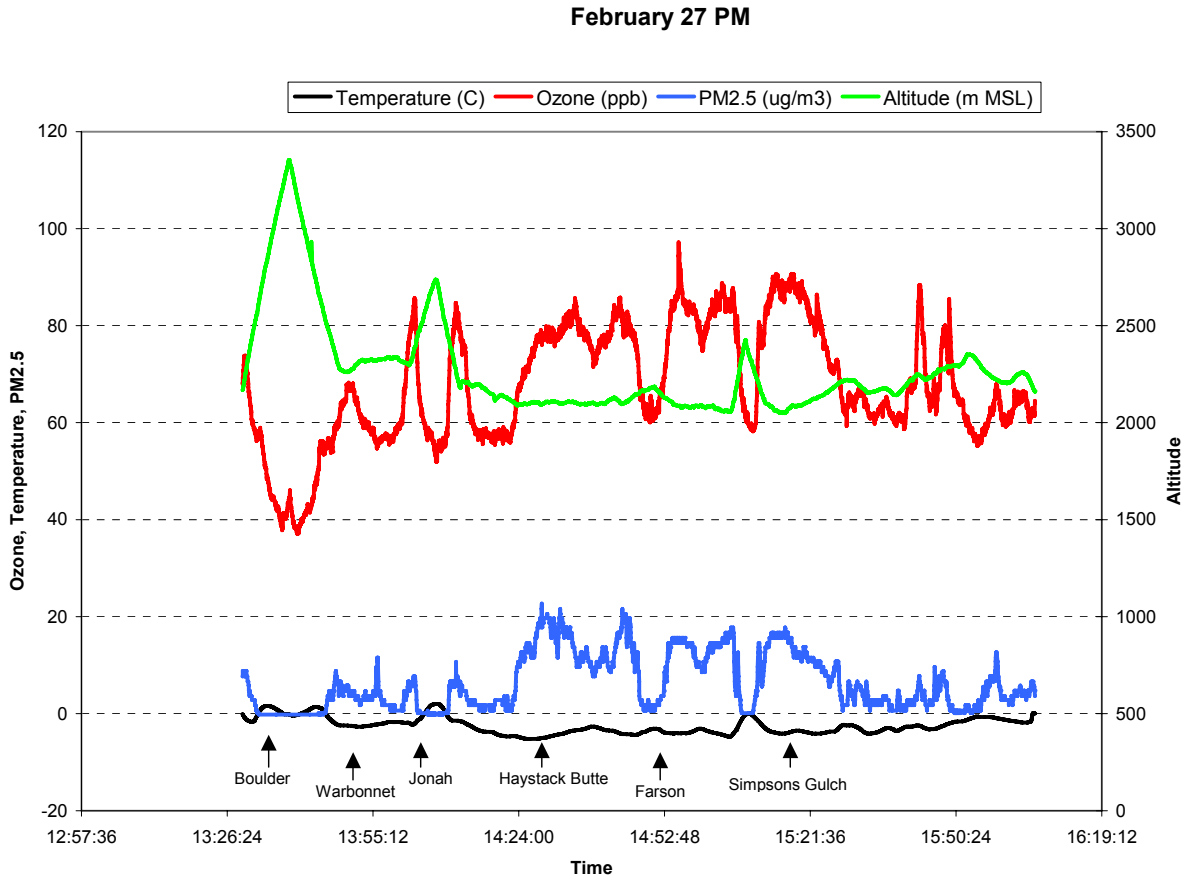

Figure 5-27. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 27 February.

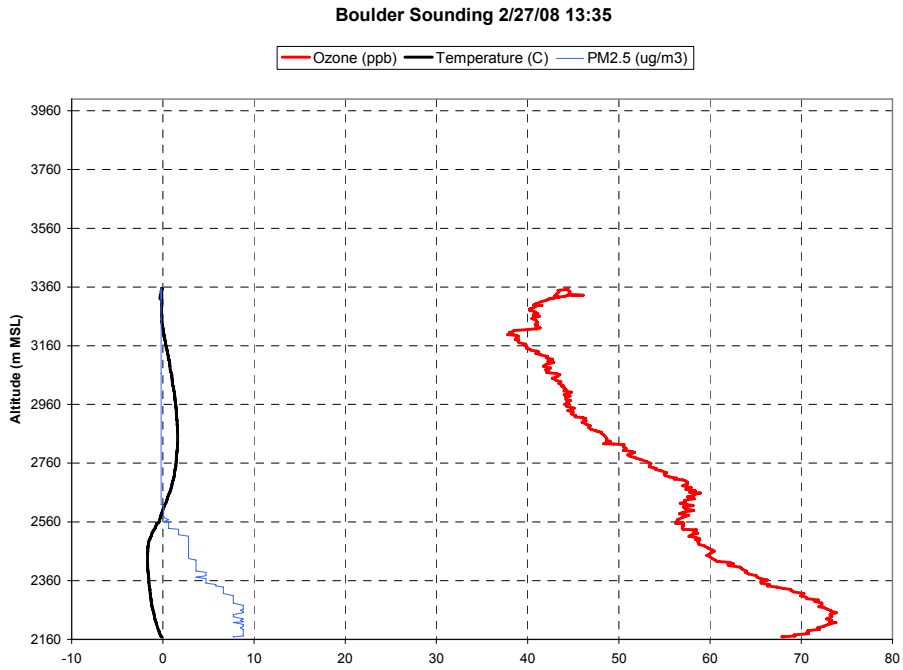

Figure 5-28. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 27 February, 13:35 MST (base of plot is at ground level).

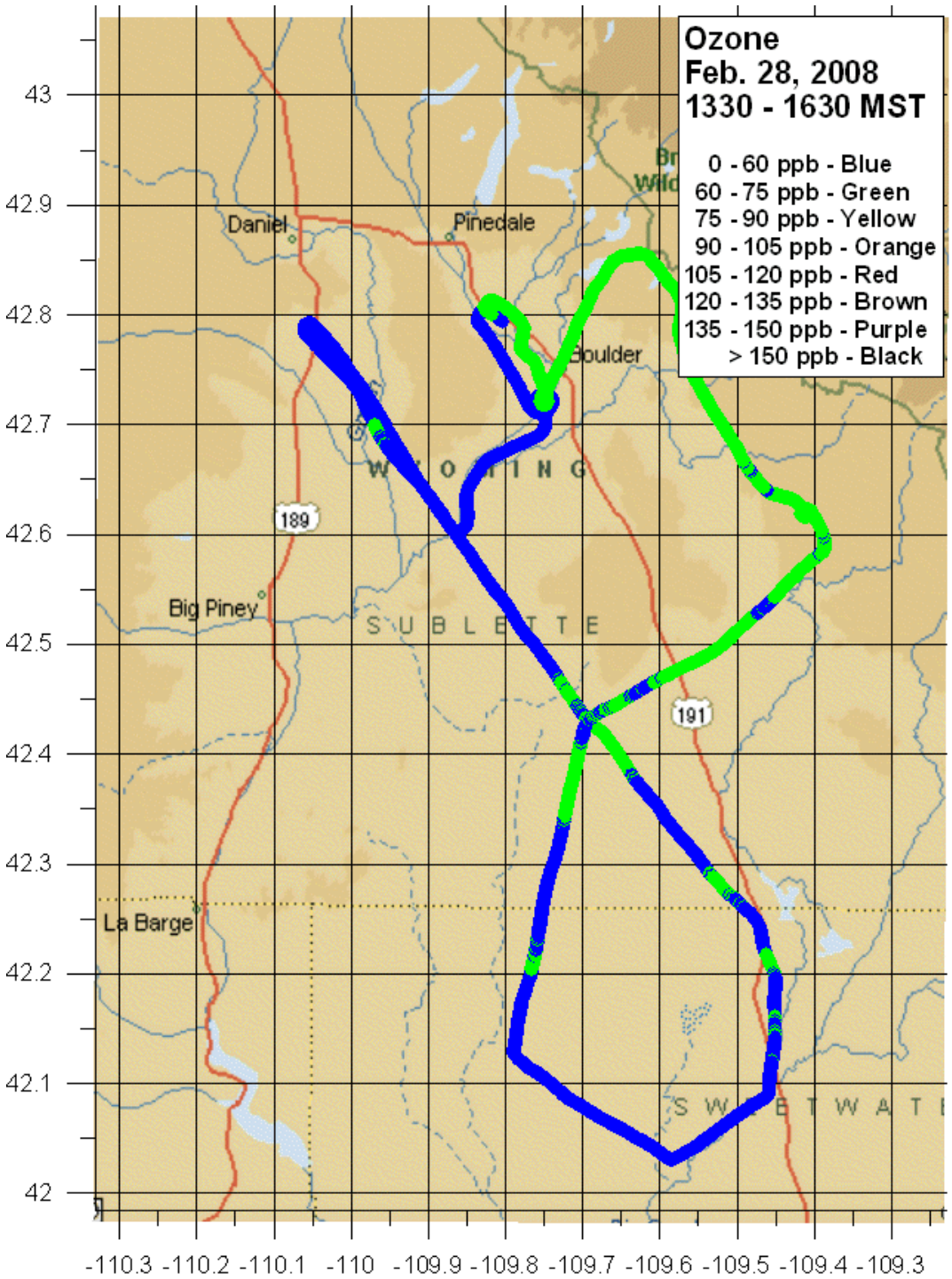

Figure 5-29. Ozone concentrations along aircraft flight path on afternoon of 28 February.

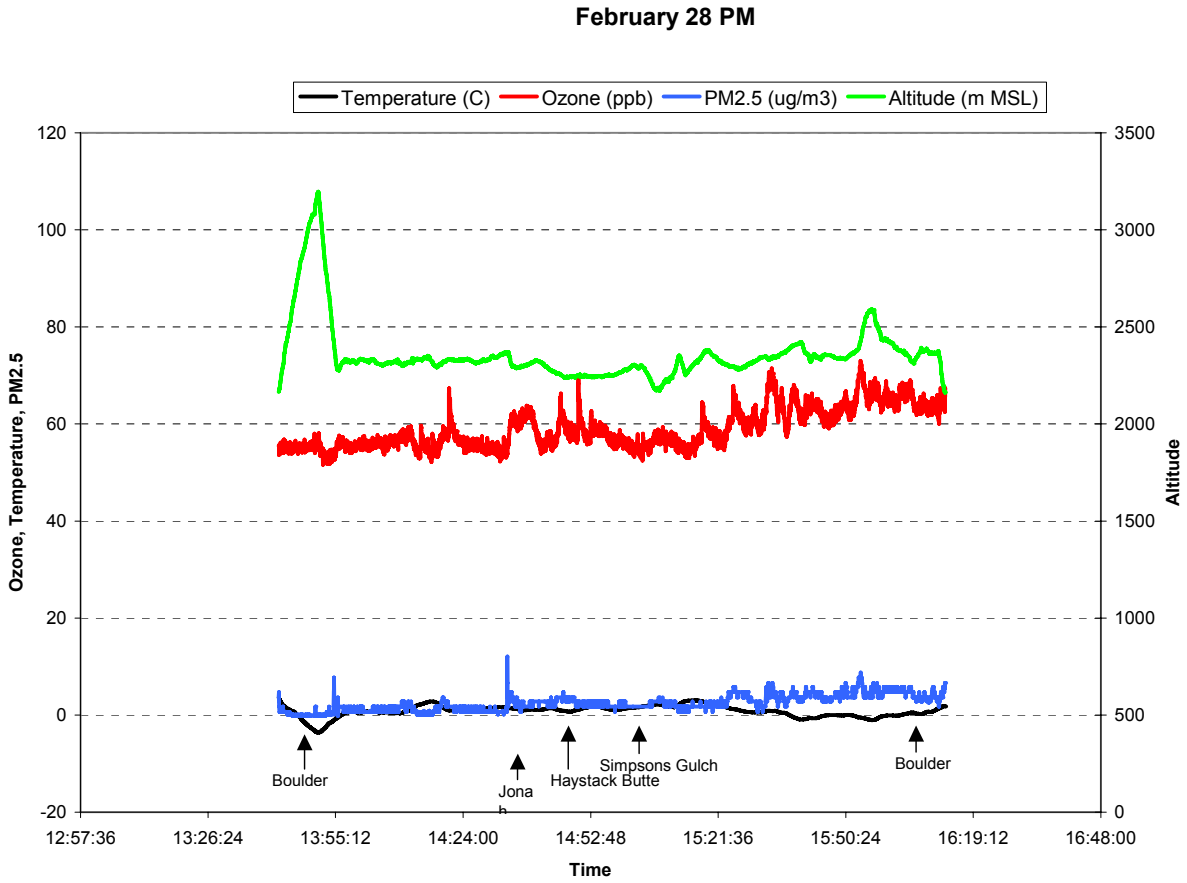

Figure 5-30. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 28 February.

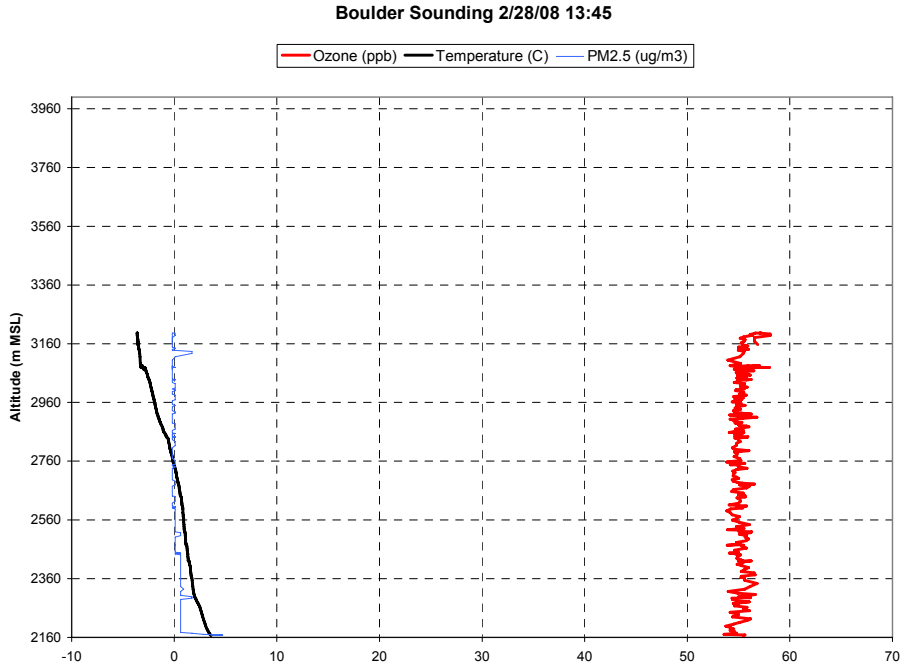

Figure 5-31. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 28 February, 13:45 MST (base of plot is at ground level).

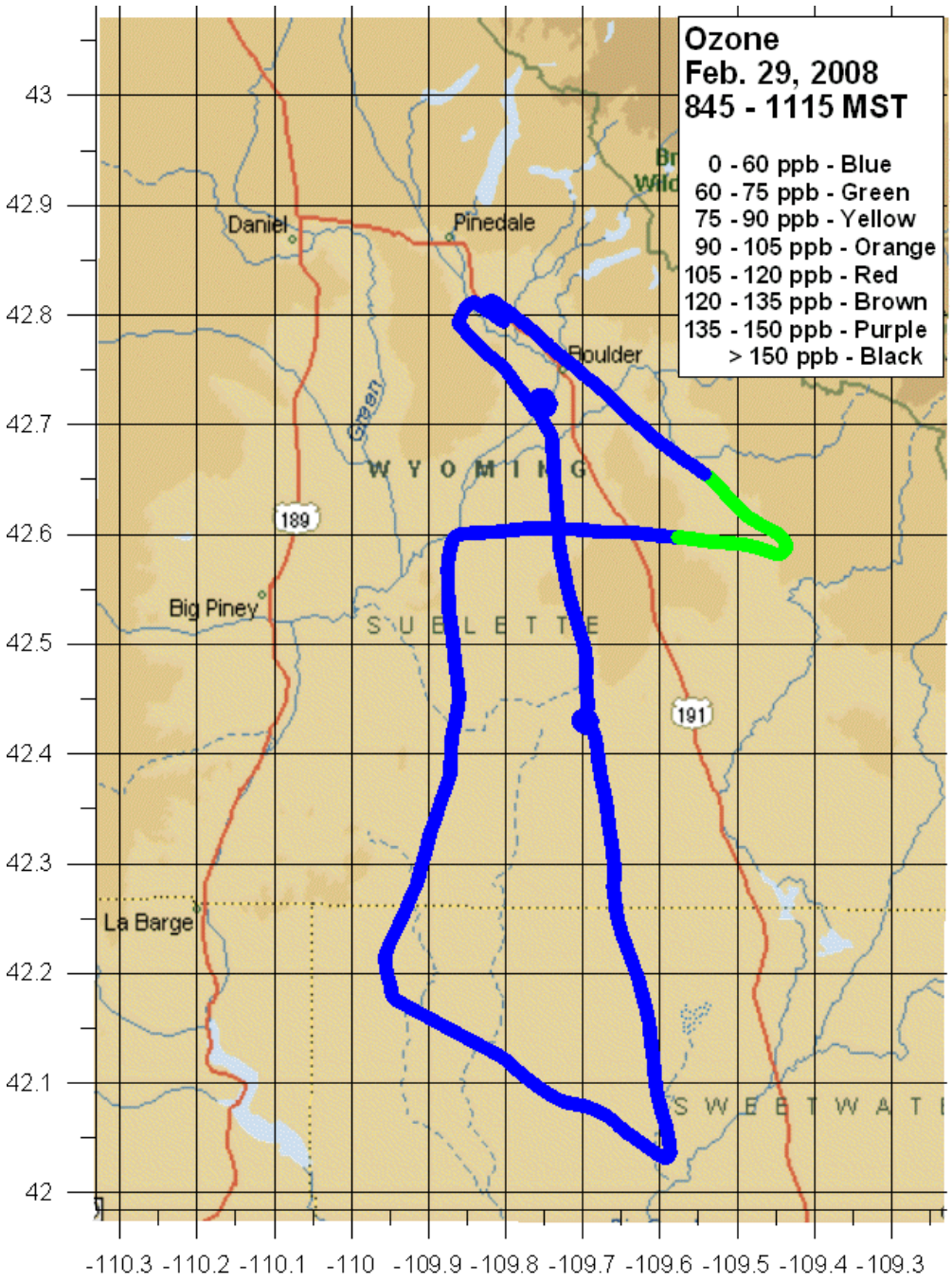

Figure 5-32. Ozone concentrations along aircraft flight path on morning of 29 February.

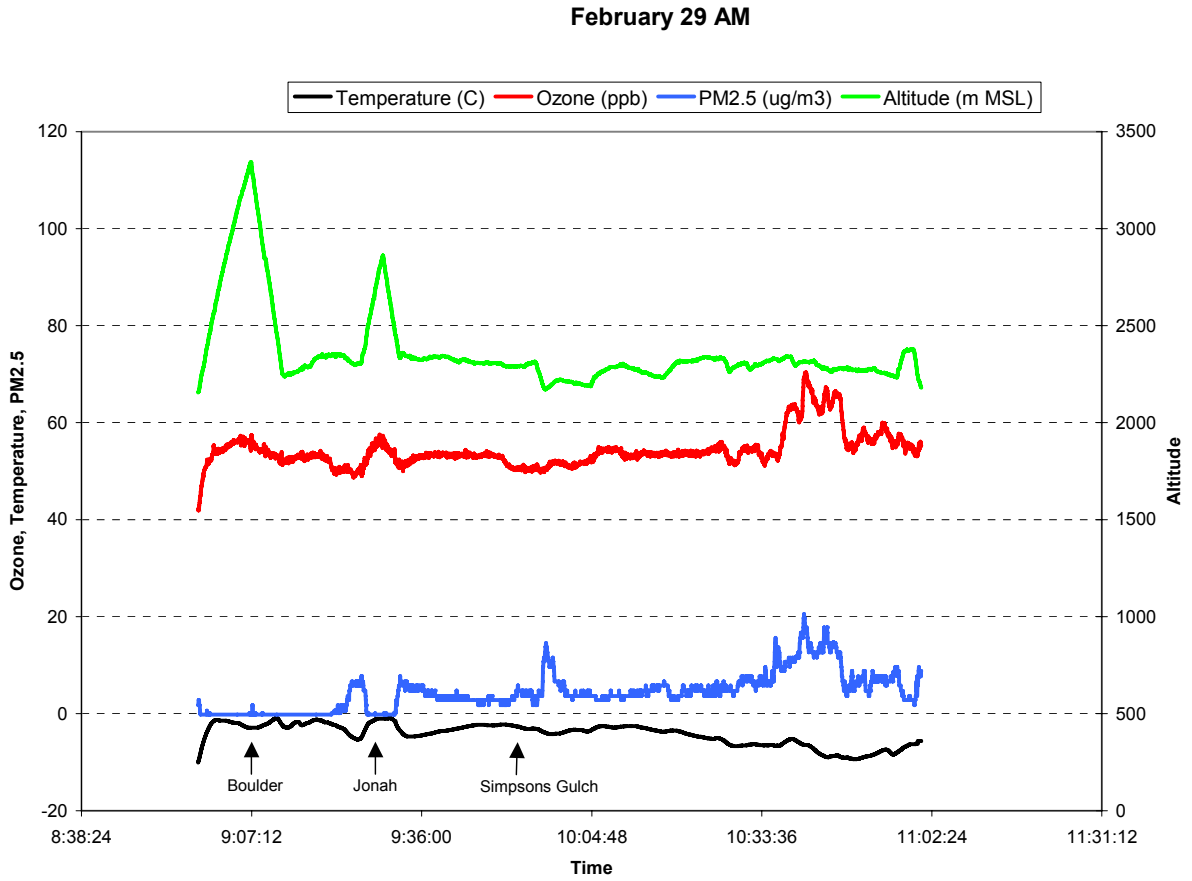

Figure 5-33. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 29 February.

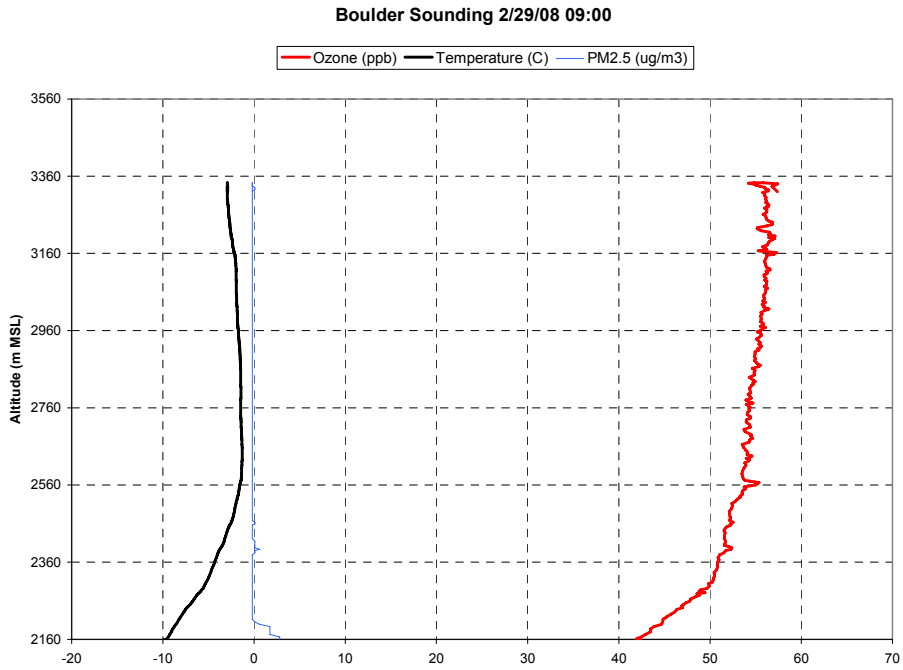

Figure 5-34. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 29 February, 9:00 MST (base of plot is at ground level)..

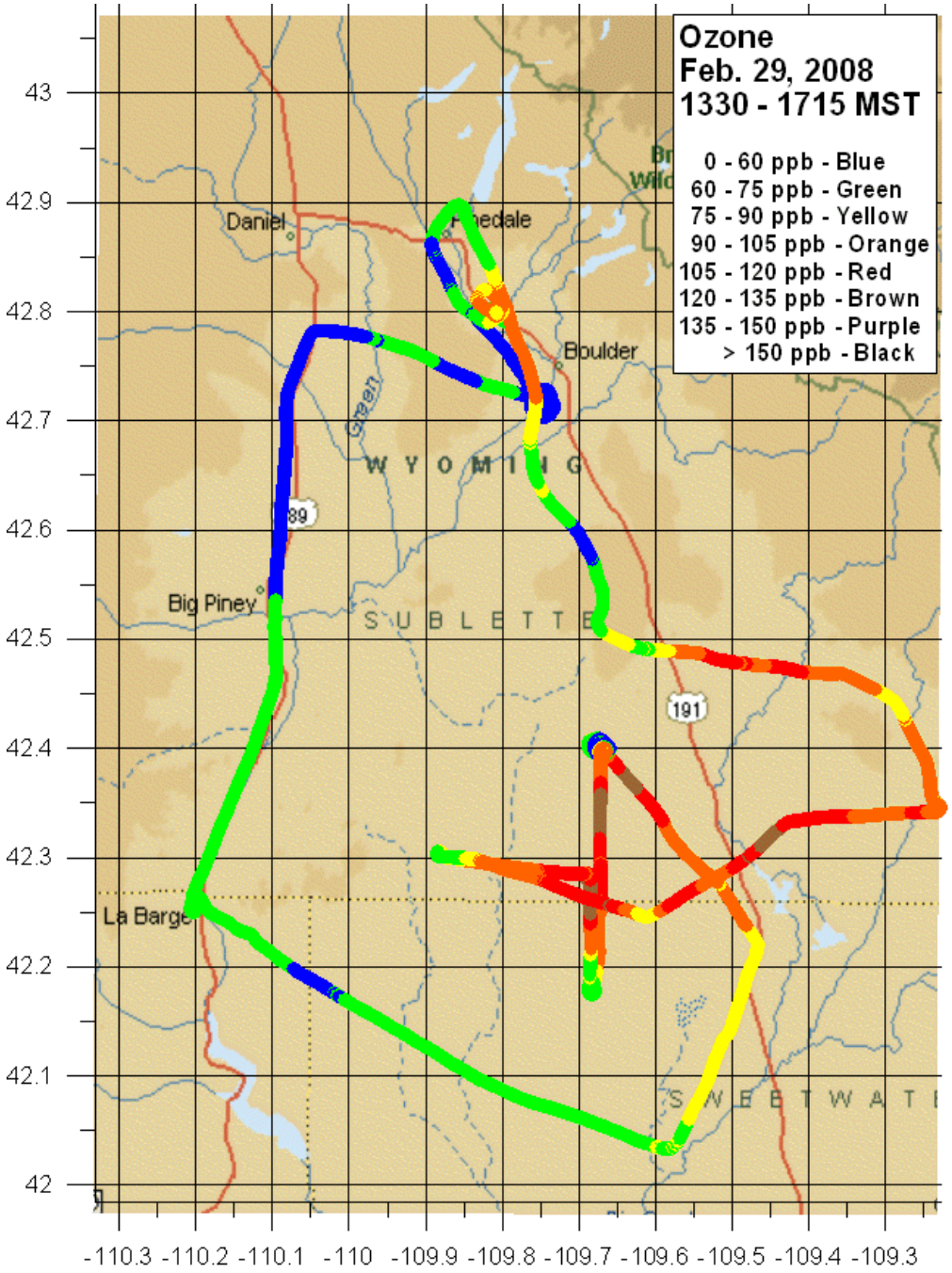

Figure 5-35. Ozone concentrations along aircraft flight path on afternoon of 29 February.

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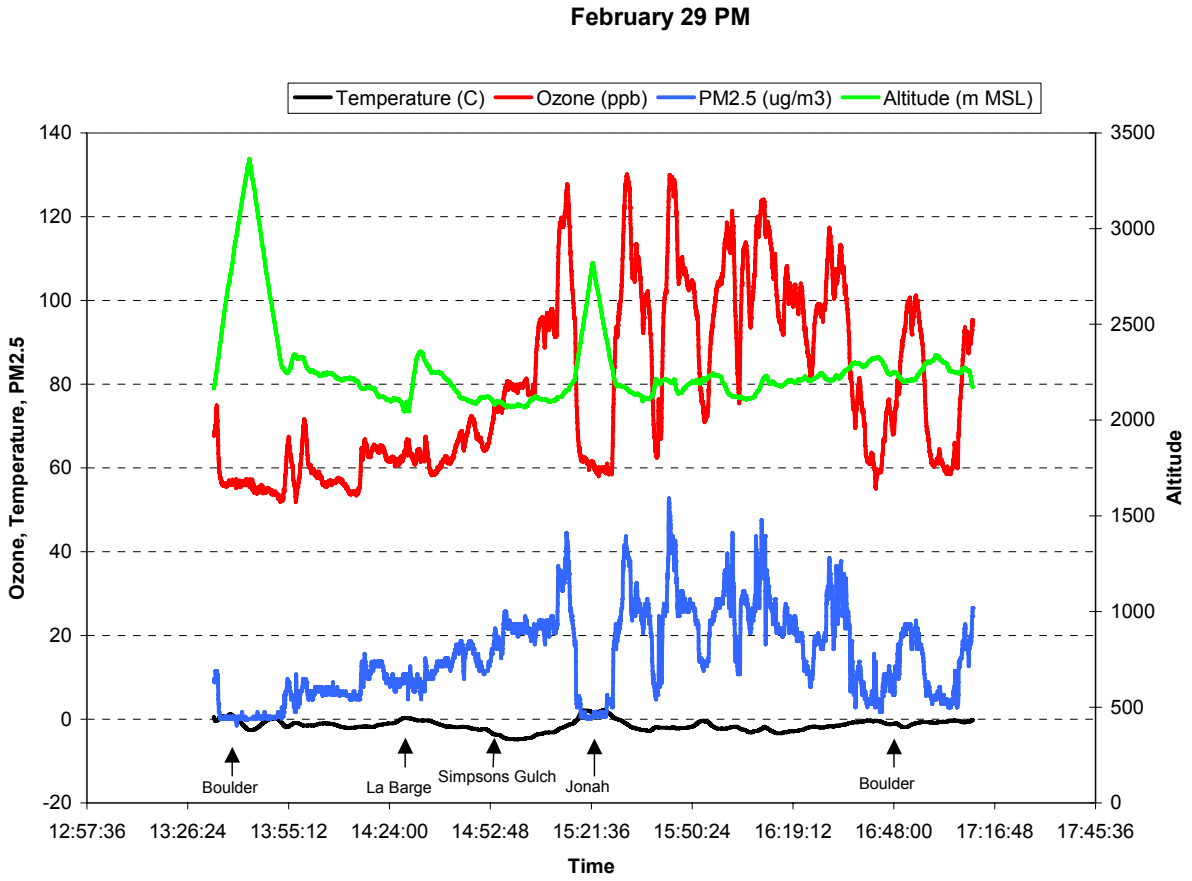

Figure 5-36. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 29 February.

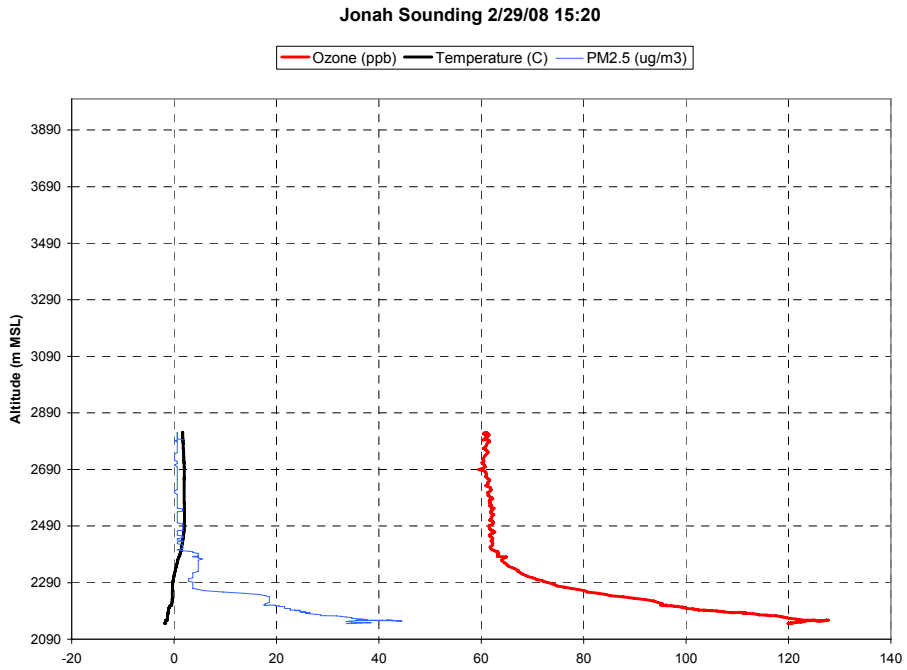

Figure 5-37. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Jonah on 29 February, 15:20 MST (base of plot is at ground level).

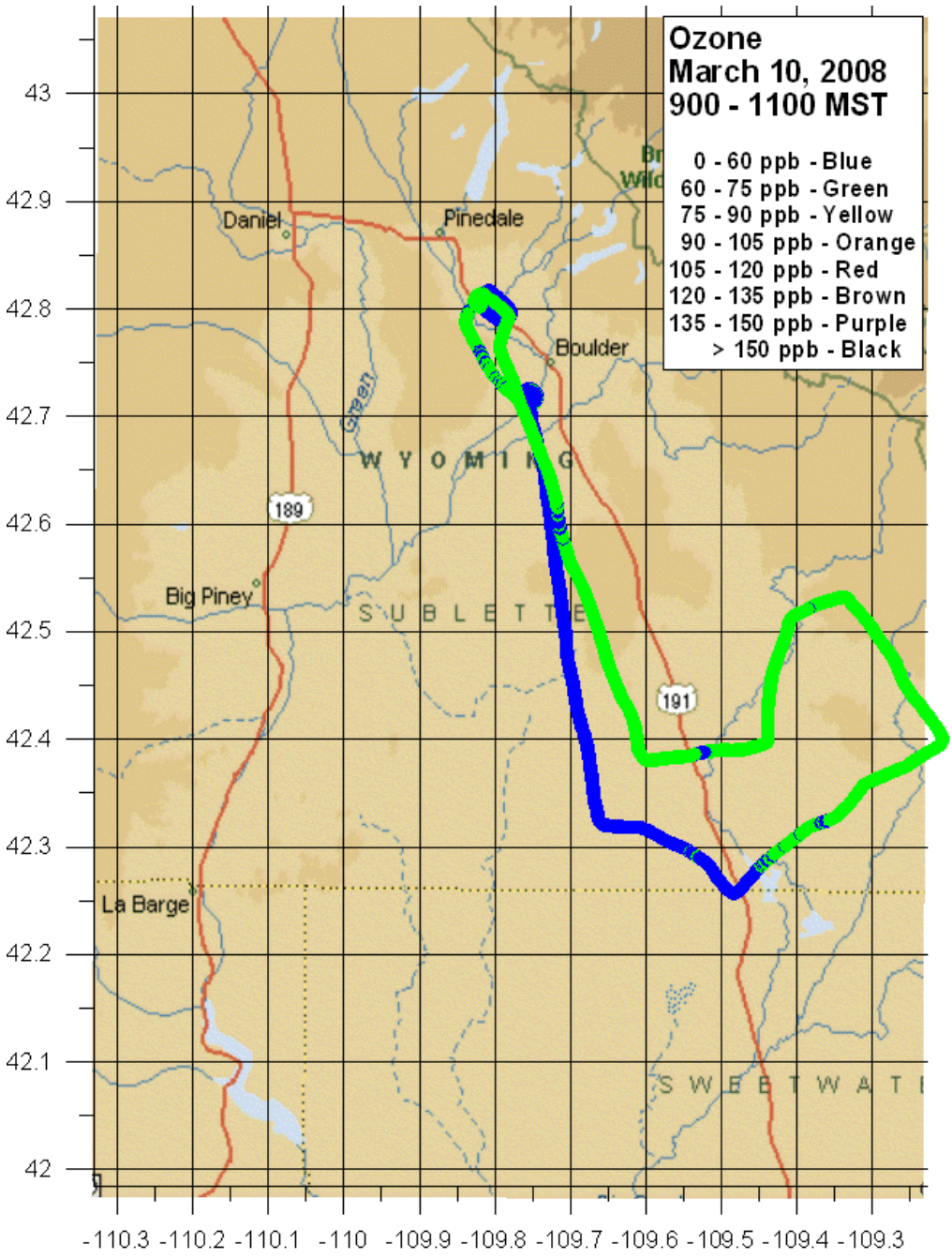

Figure 5-38. Ozone concentrations along aircraft flight path on morning of 10 March.

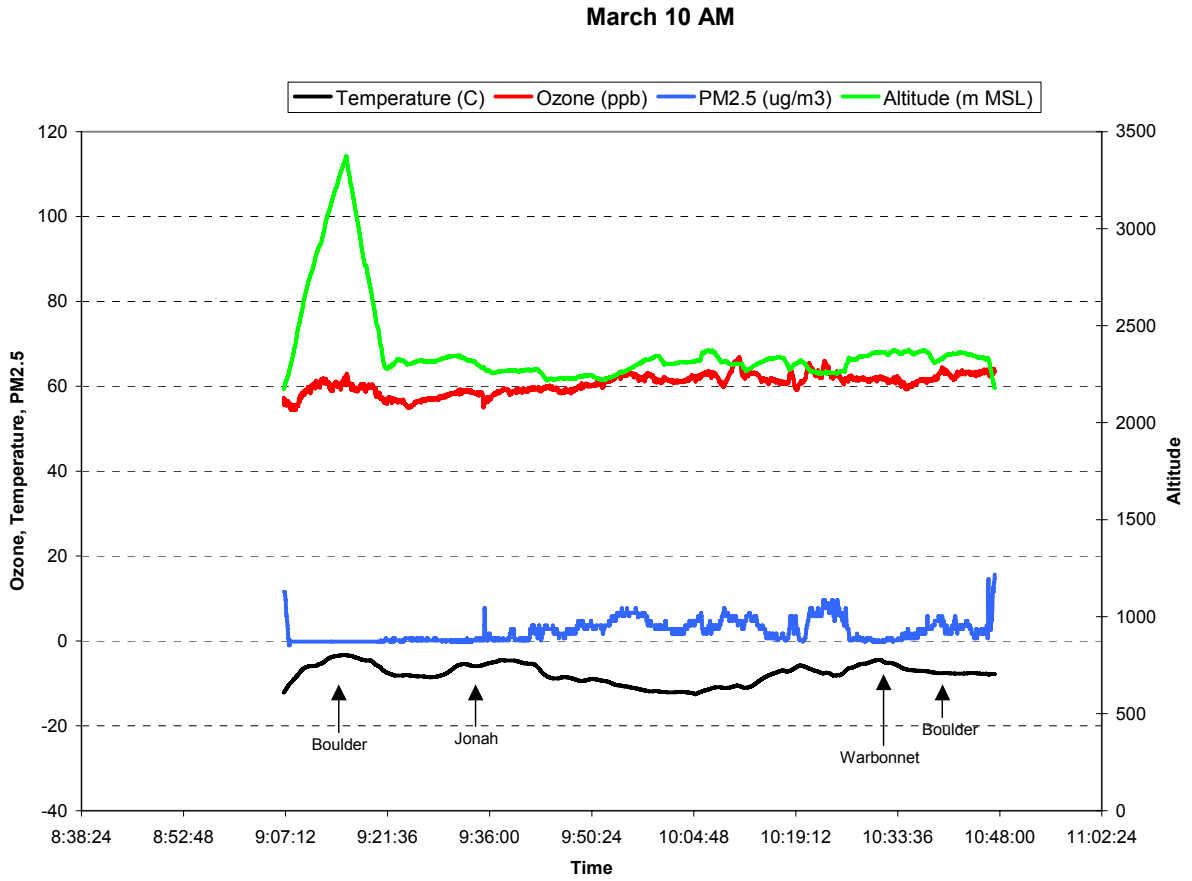

Figure 5-39. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 10 March.

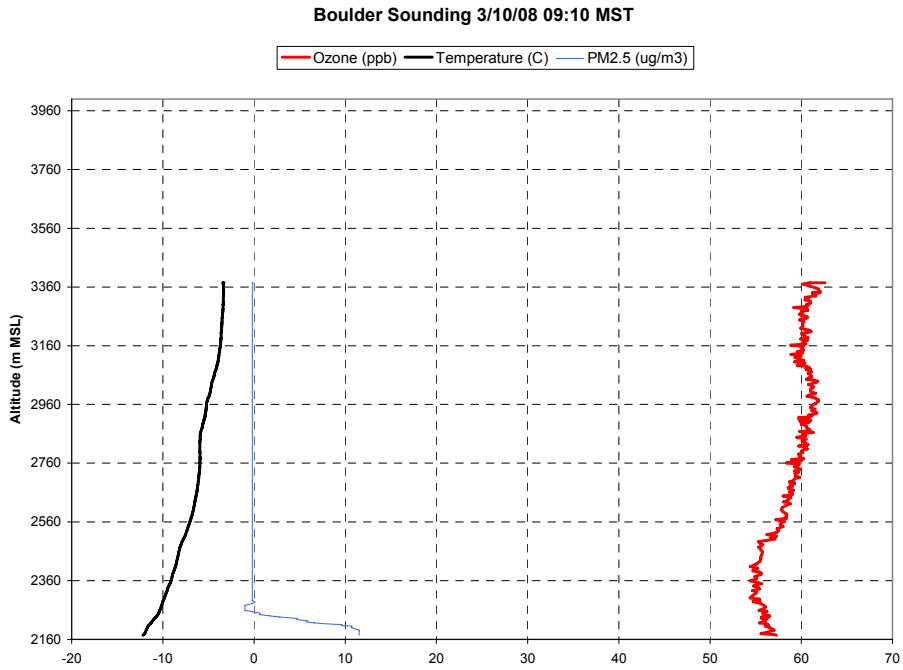

Figure 5-40. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 10 March, 9:10 MST (base of plot is at ground level).

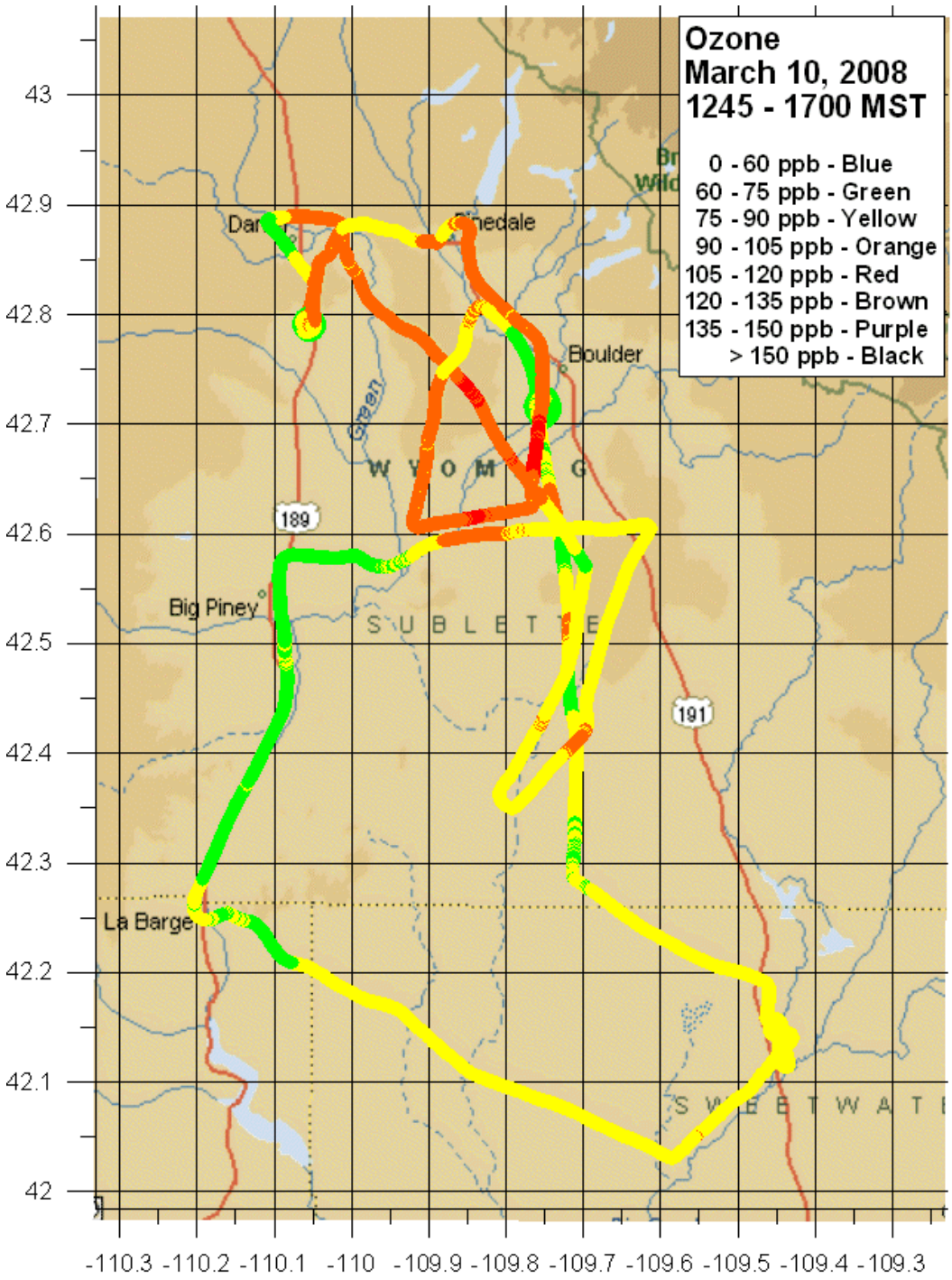

Figure 5-41. Ozone concentrations along aircraft flight path on afternoon of 10 March.

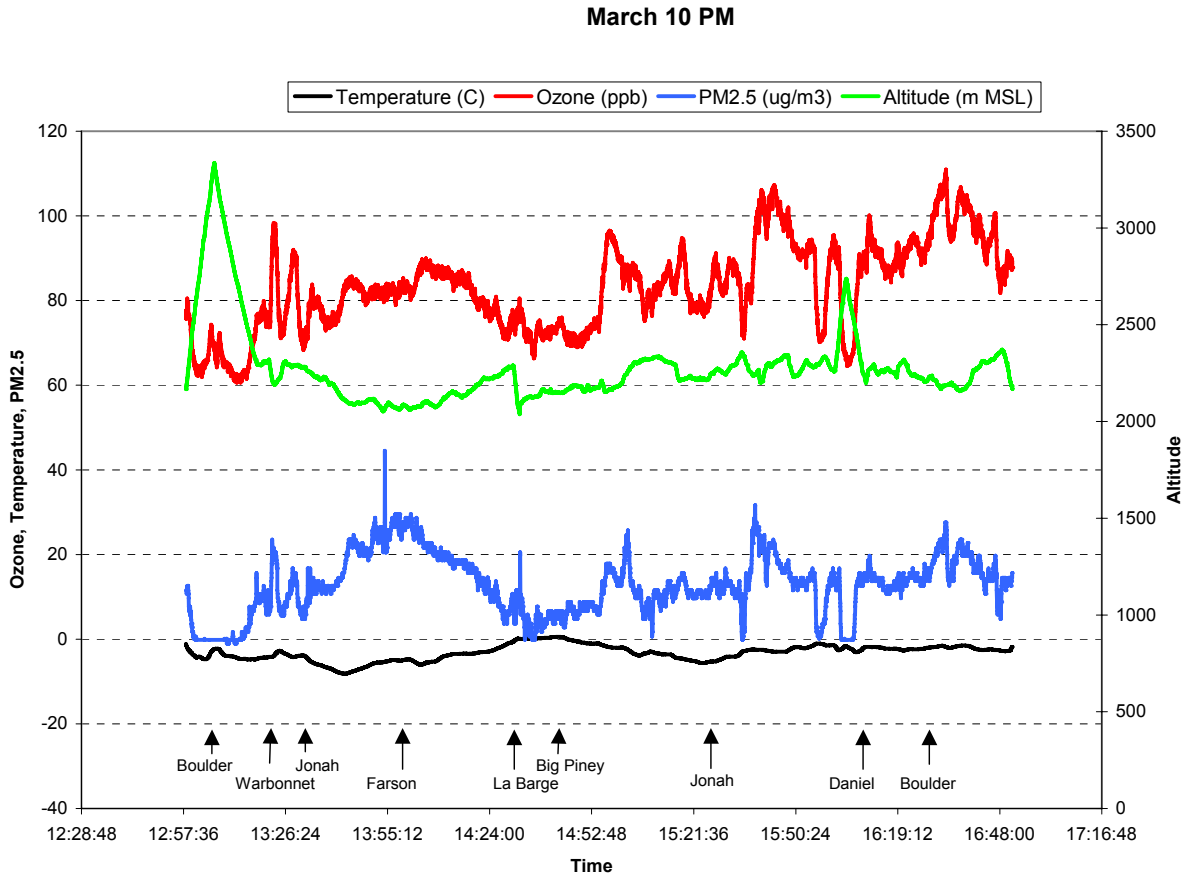

Figure 5-42. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 10 March.

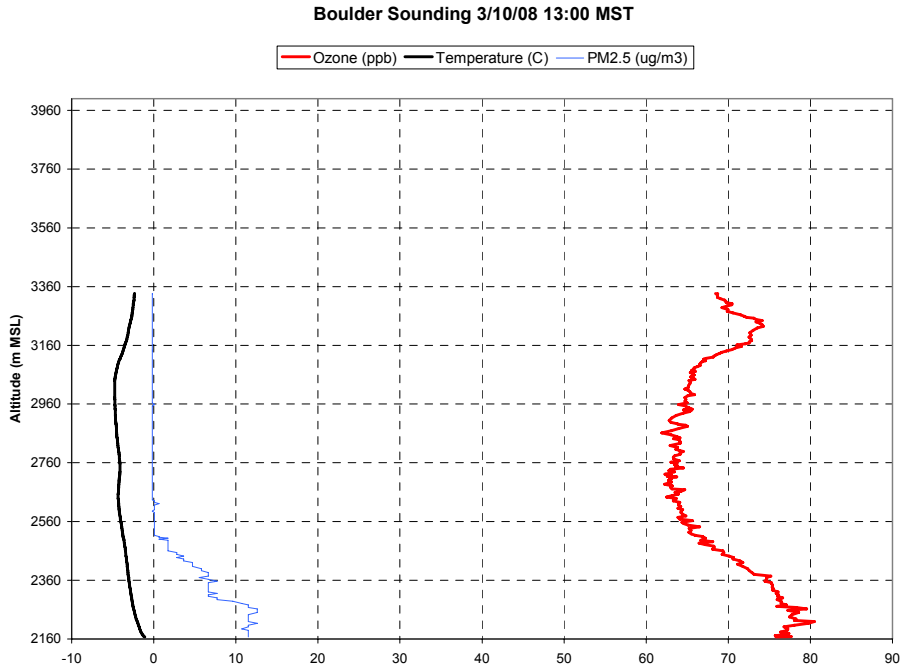

Figure 5-43. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 10 March, 13:00 MST (base of plot is at ground level).

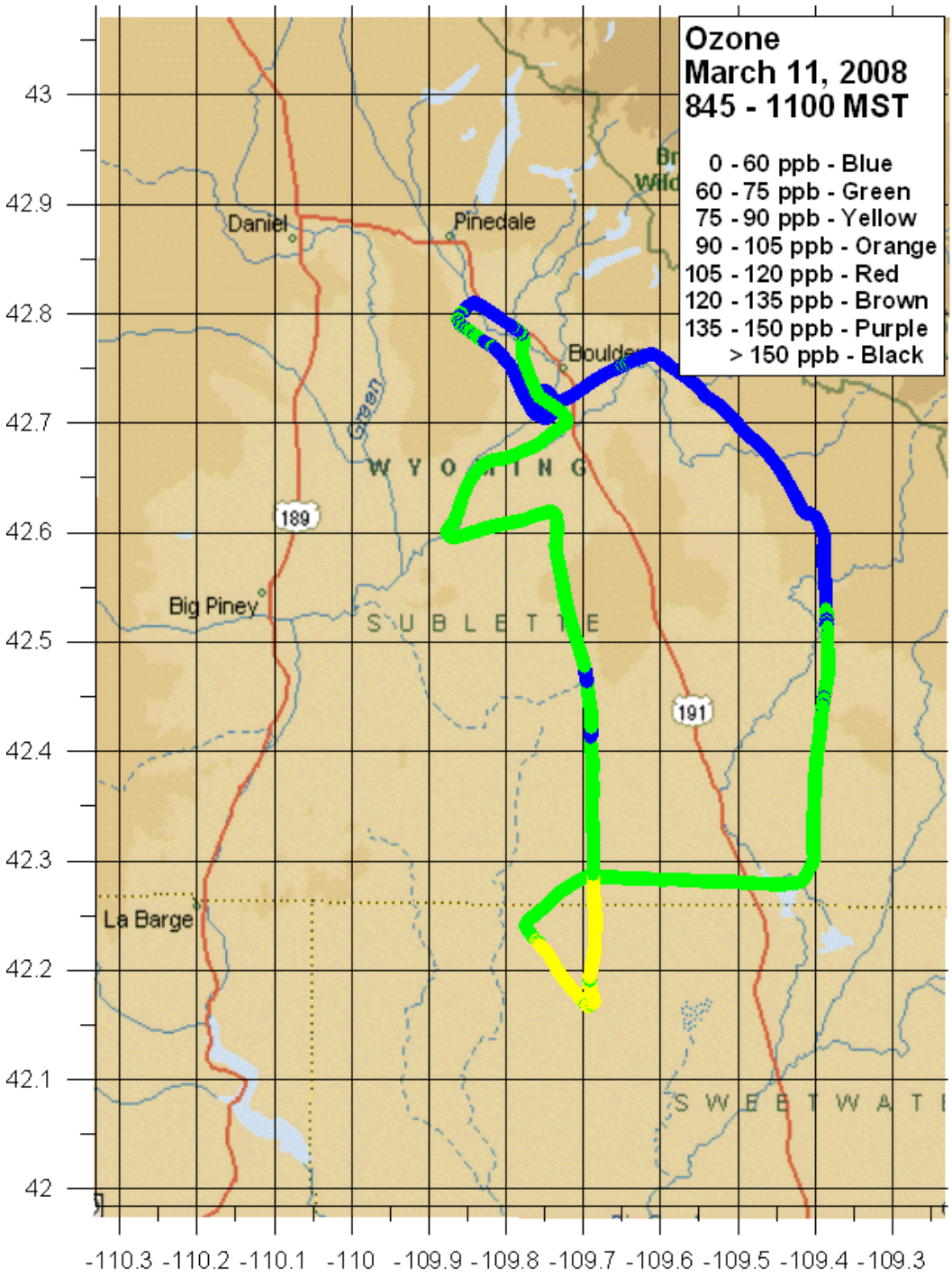

Figure 5-44. Ozone concentrations along aircraft flight path on morning of 11 March.

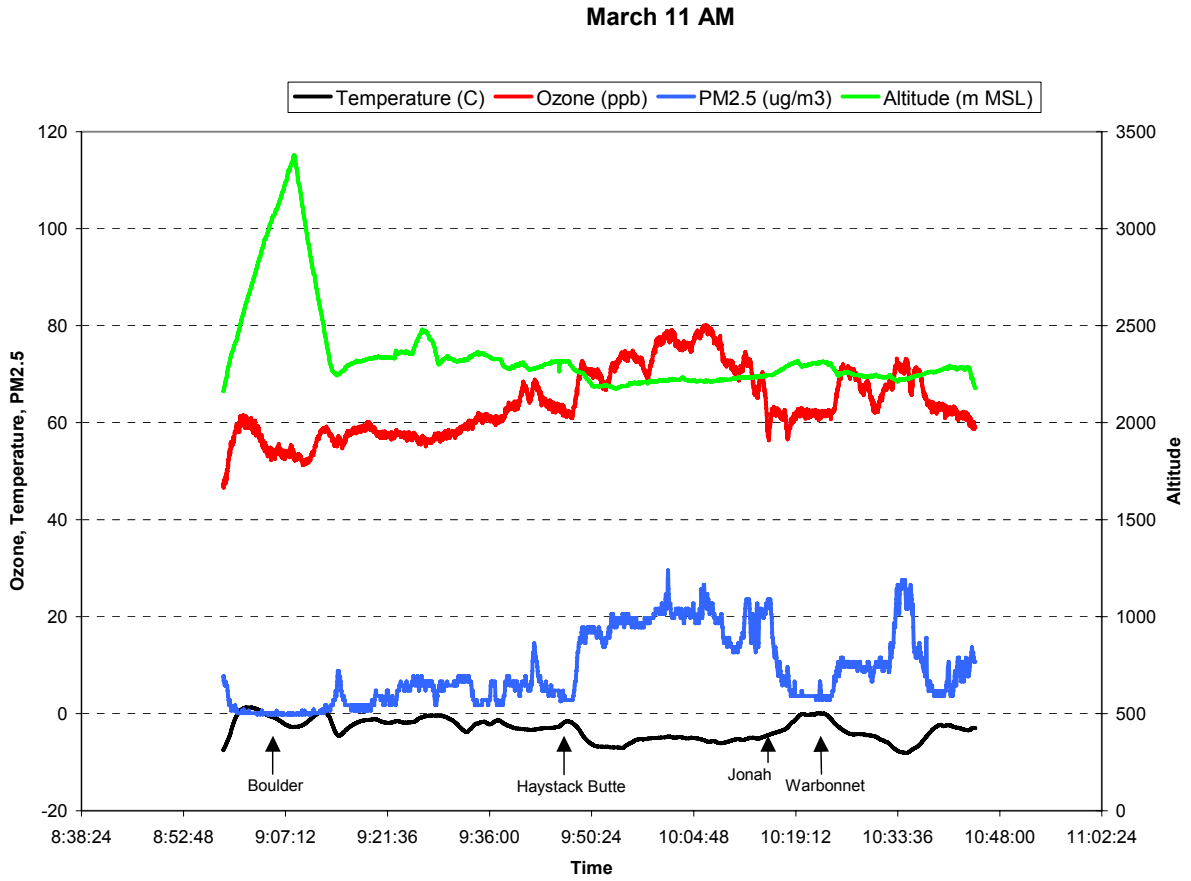

Figure 5-45. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 11 March.

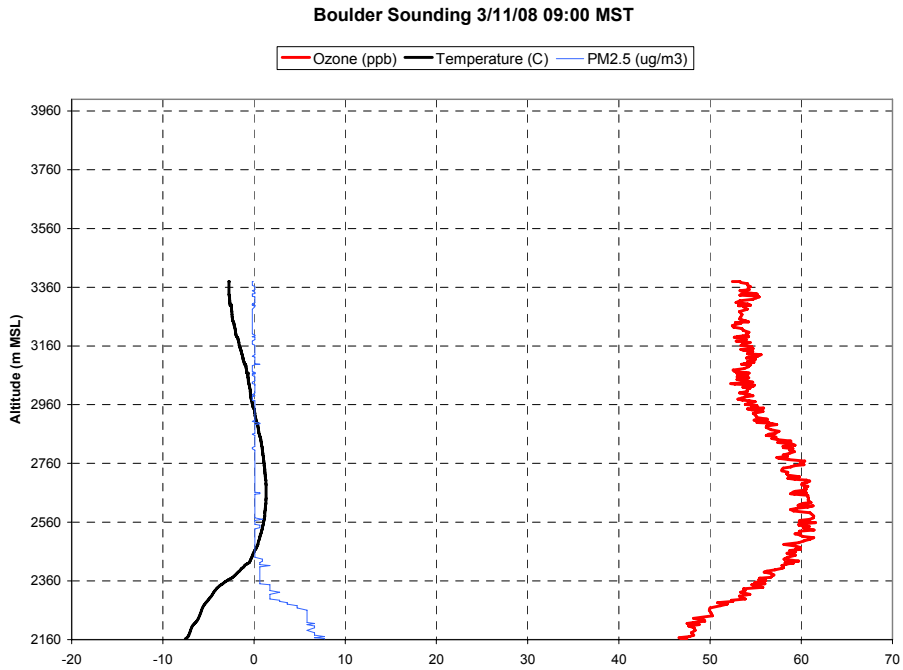

Figure 5-46. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 11 March, 9:00 MST (base of plot is at ground level).

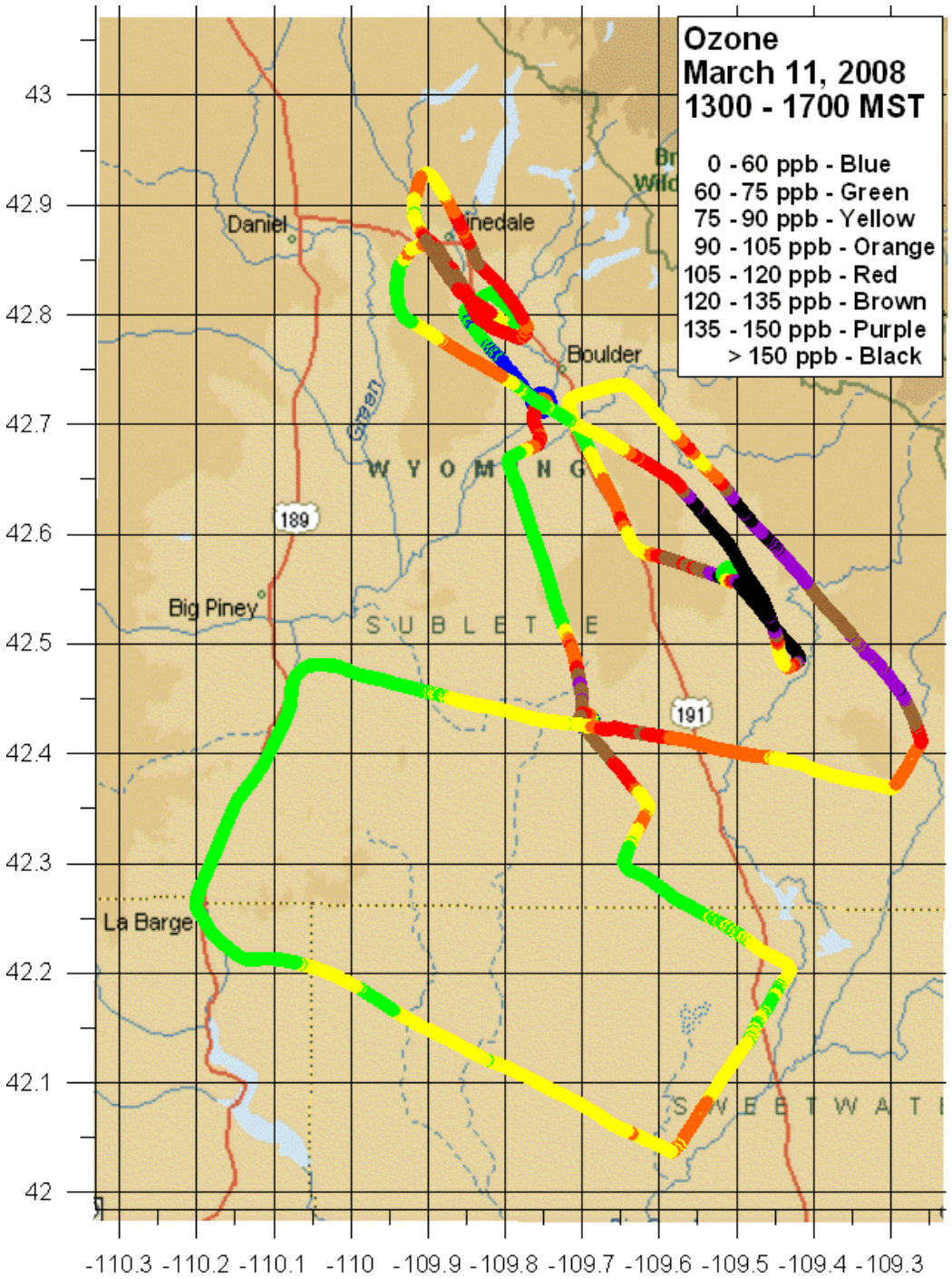

Figure 5-47. Ozone concentrations along aircraft flight path on afternoon of 11 March.

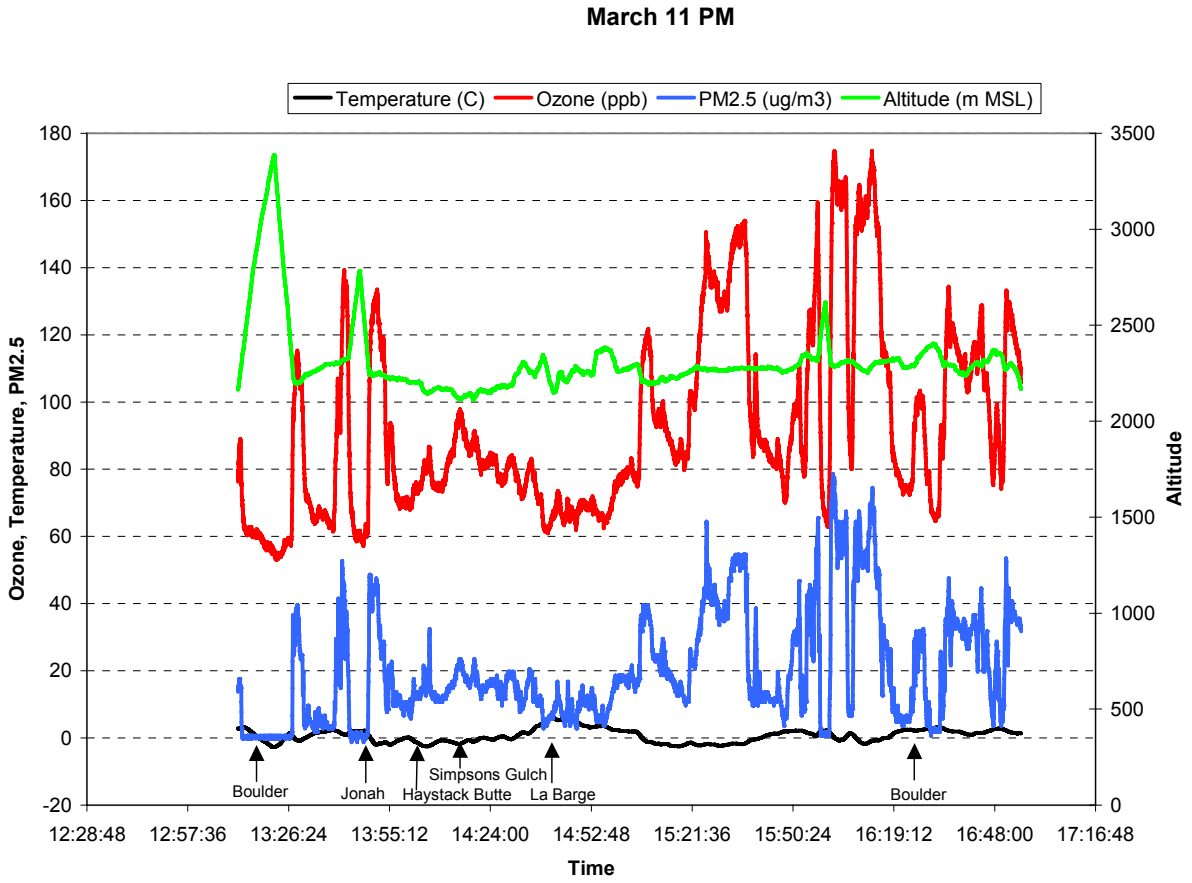

Figure 5-48. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 11 March.

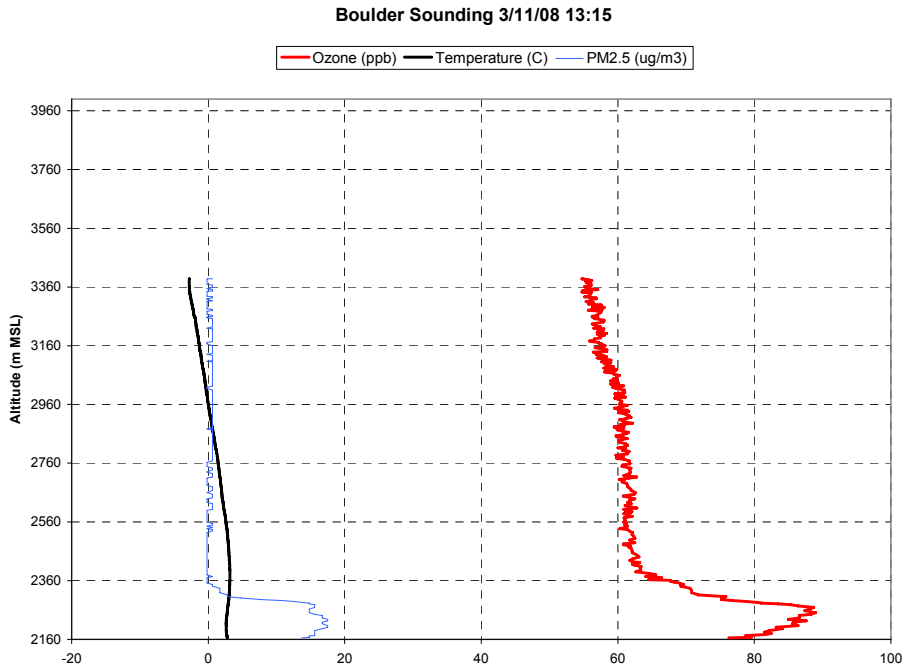

Figure 5-49. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 11 March, 13:15 MST (base of plot is at ground level).

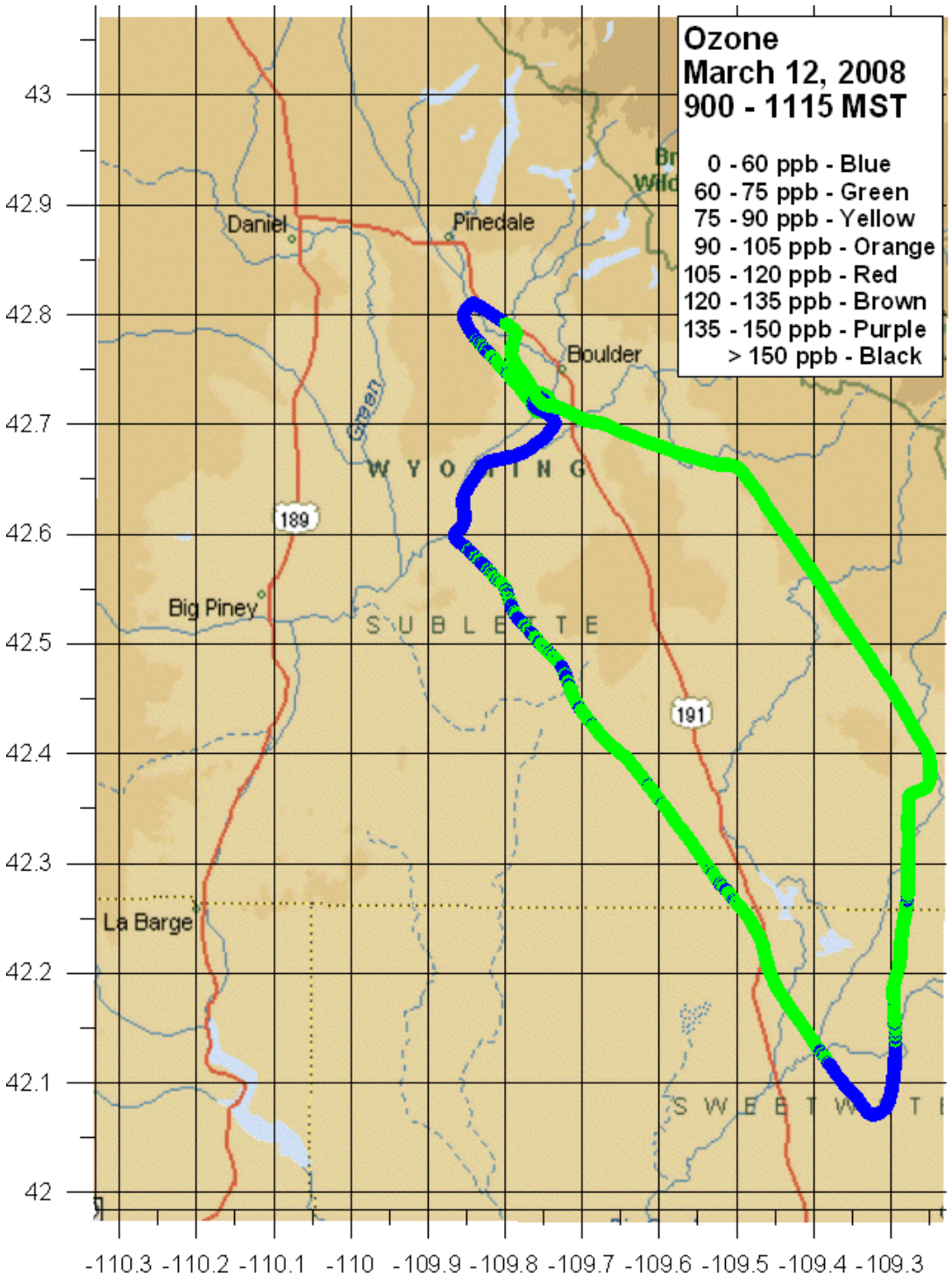

Figure 5-50. Ozone concentrations along aircraft flight path on morning of 12 March.

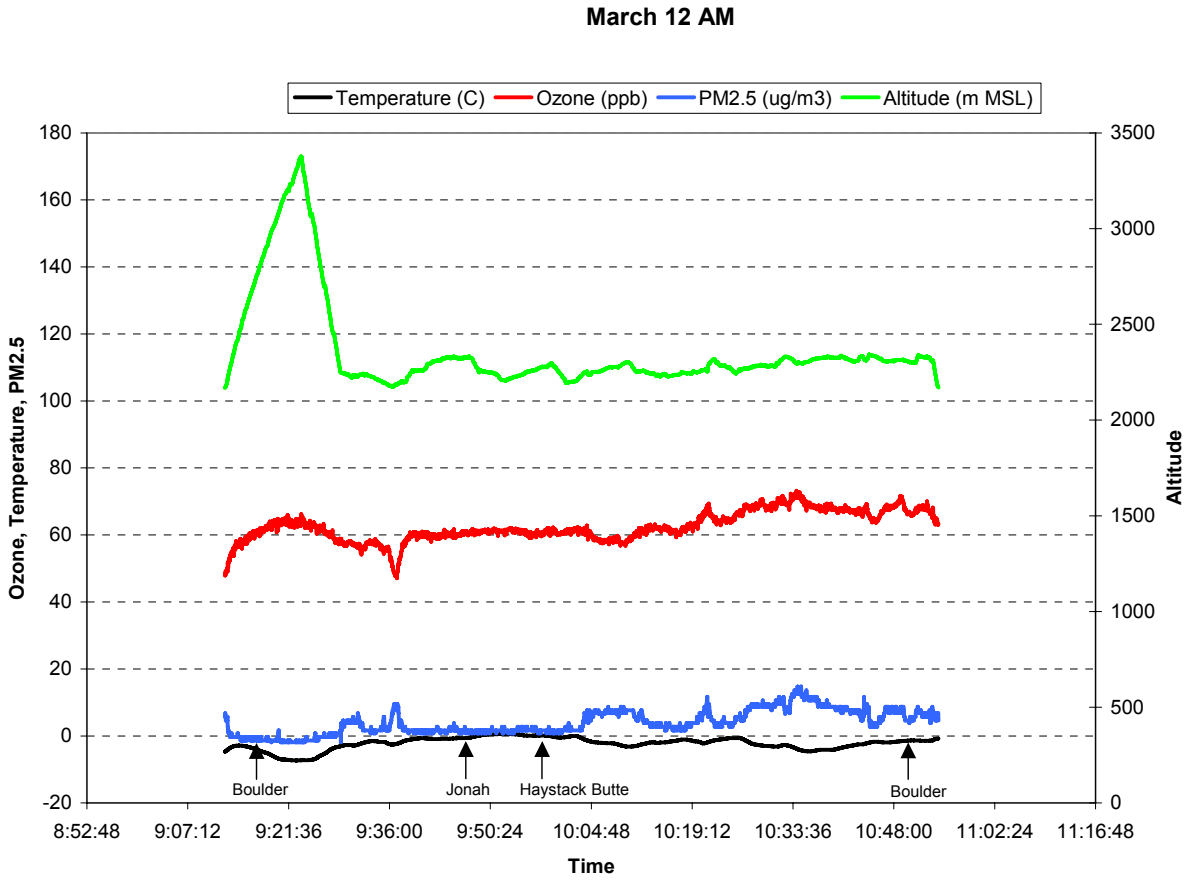

Figure 5-51. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, morning flight on 12 March.

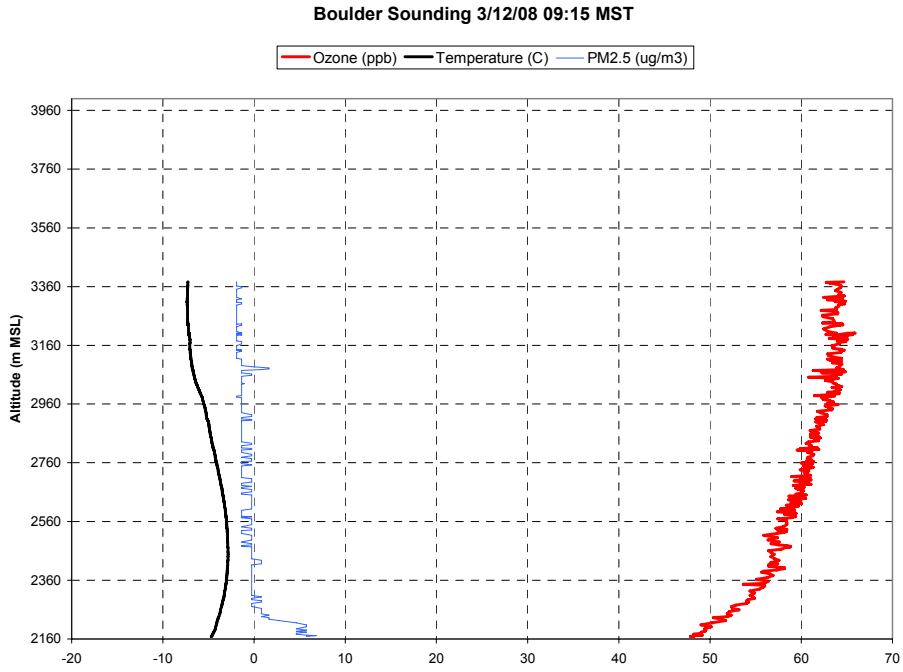

Figure 5-52. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 12 March, 9:15 MST (base of plot is at ground level).

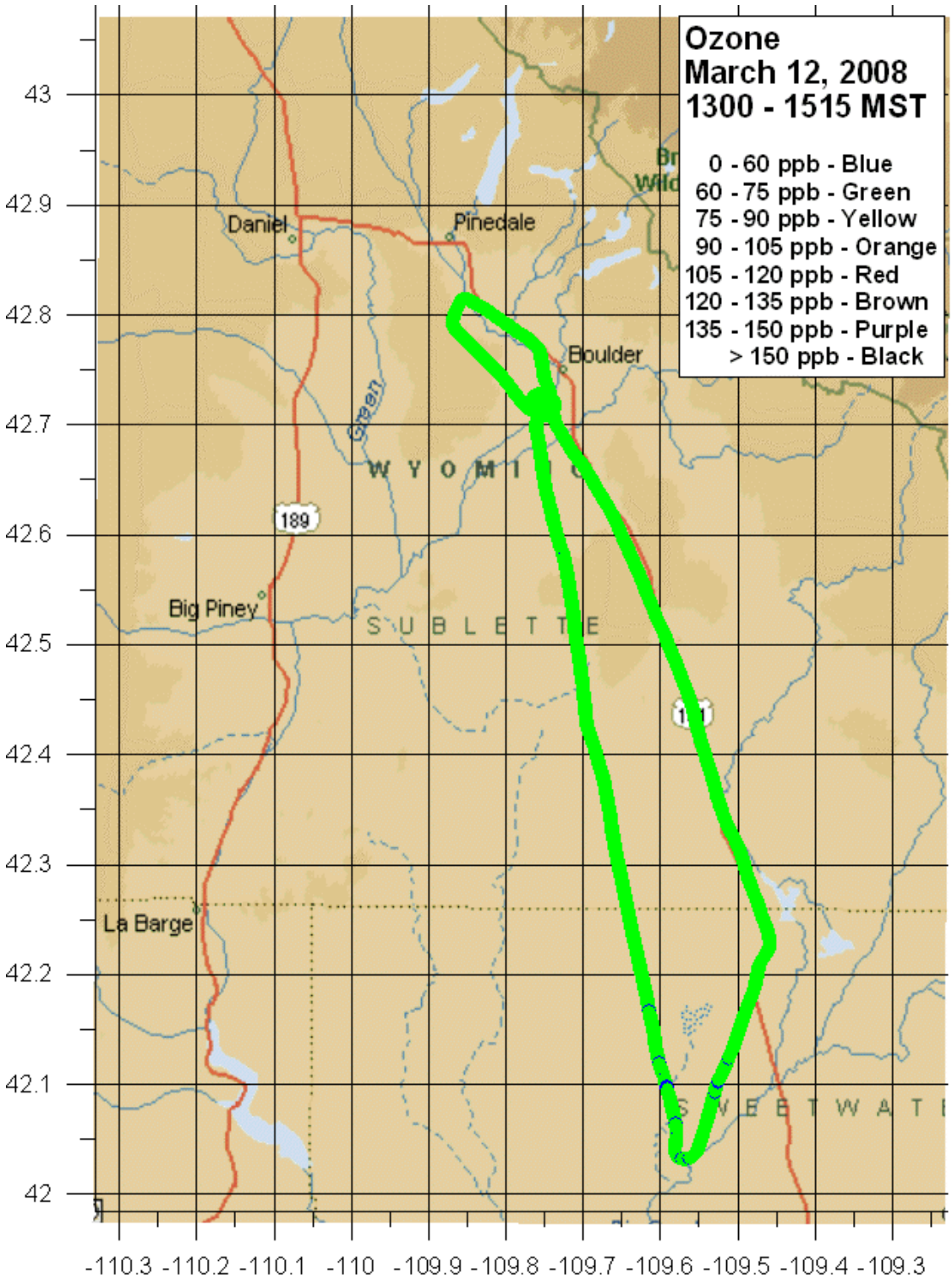

Figure 5-53. Ozone concentrations along aircraft flight path on afternoon of 12 March.

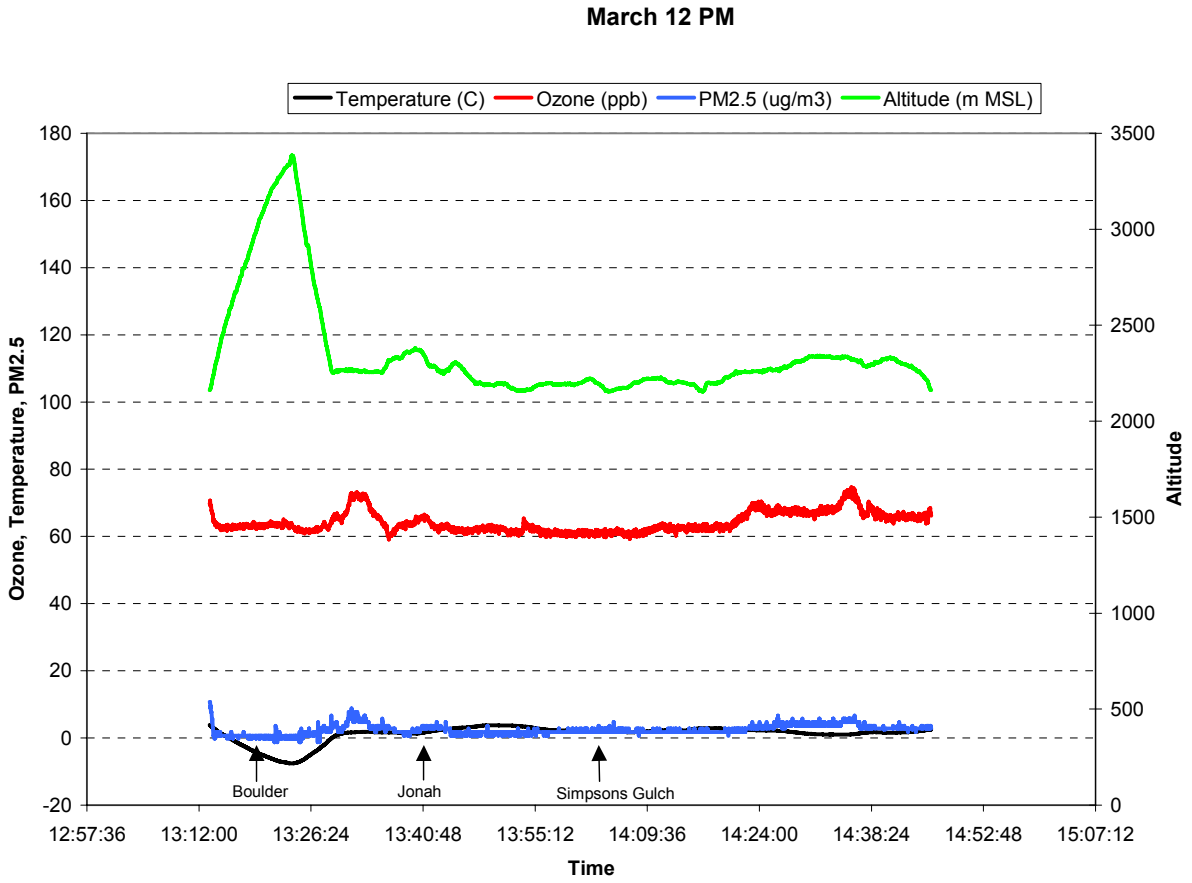

Figure 5-54. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 12 March.

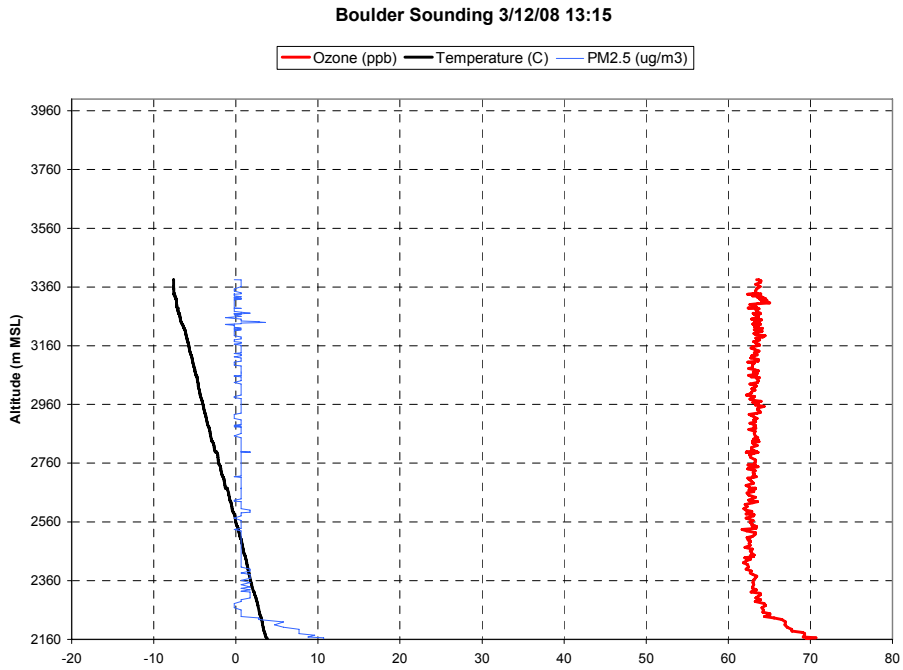

Figure 5-55. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 12 March, 13:15 MST (base of plot is at ground level).

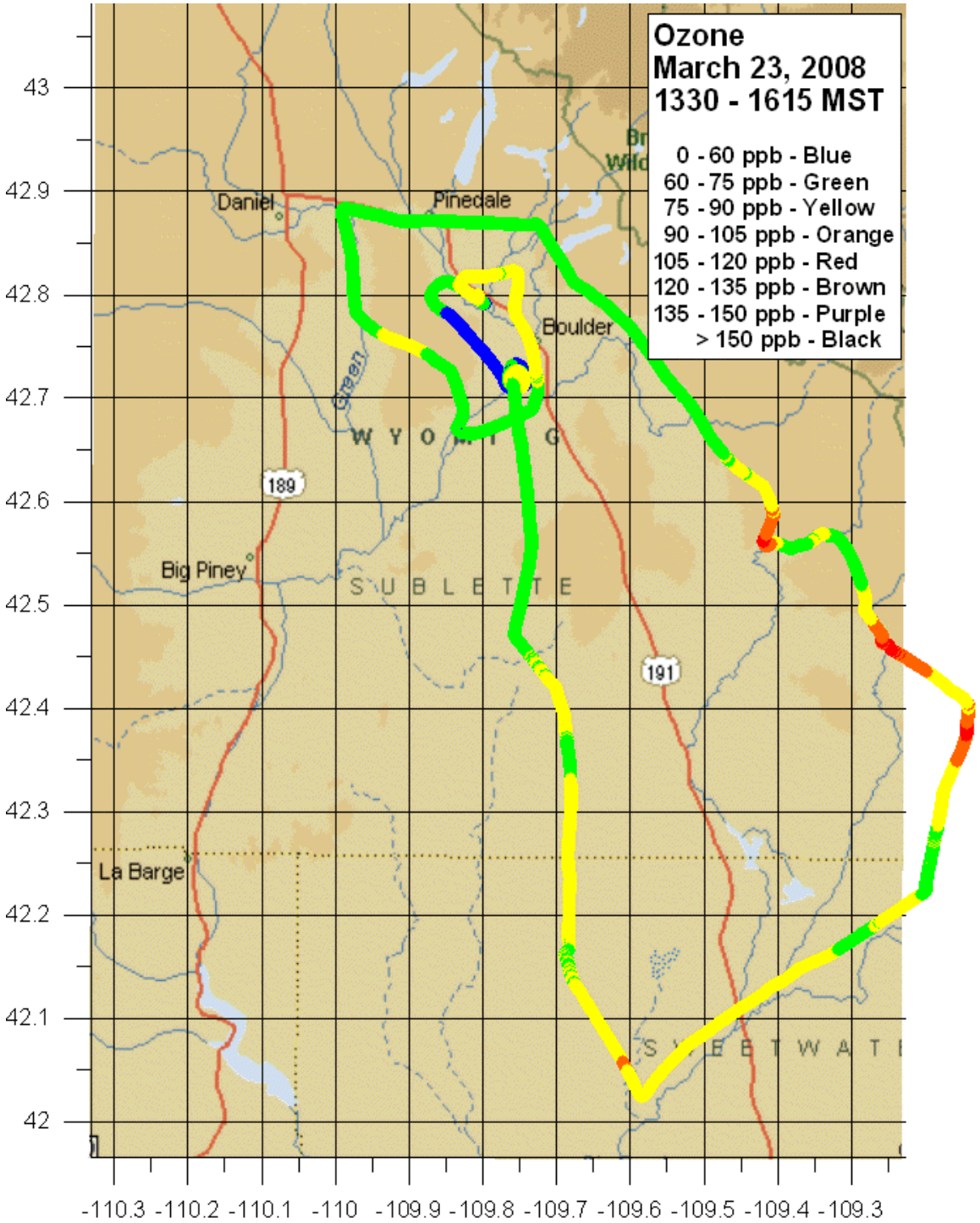

Figure 5-56. Ozone concentrations along aircraft flight path on afternoon of 23 March.

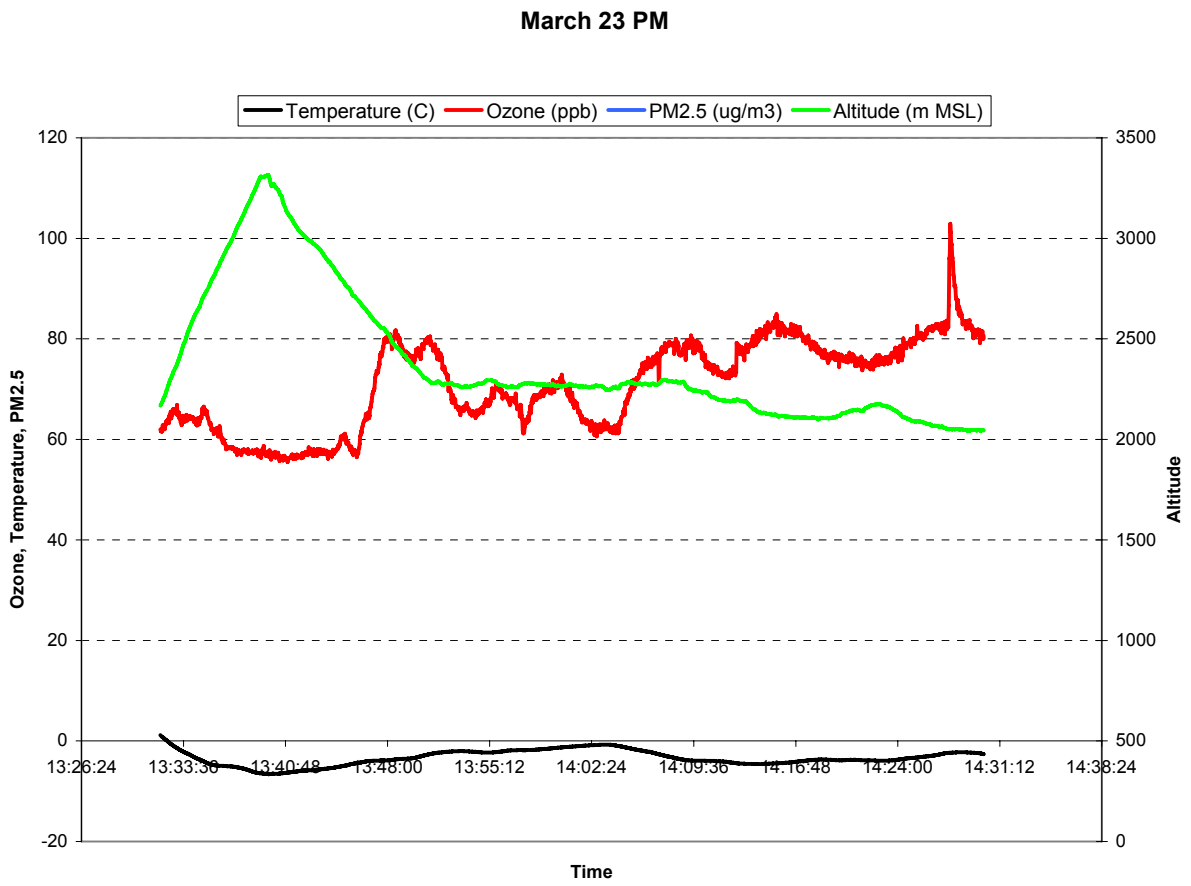

Figure 5-57. Time series of temperature, ozone, $PM_{2.5}$ and aircraft altitude, afternoon flight on 23 March.

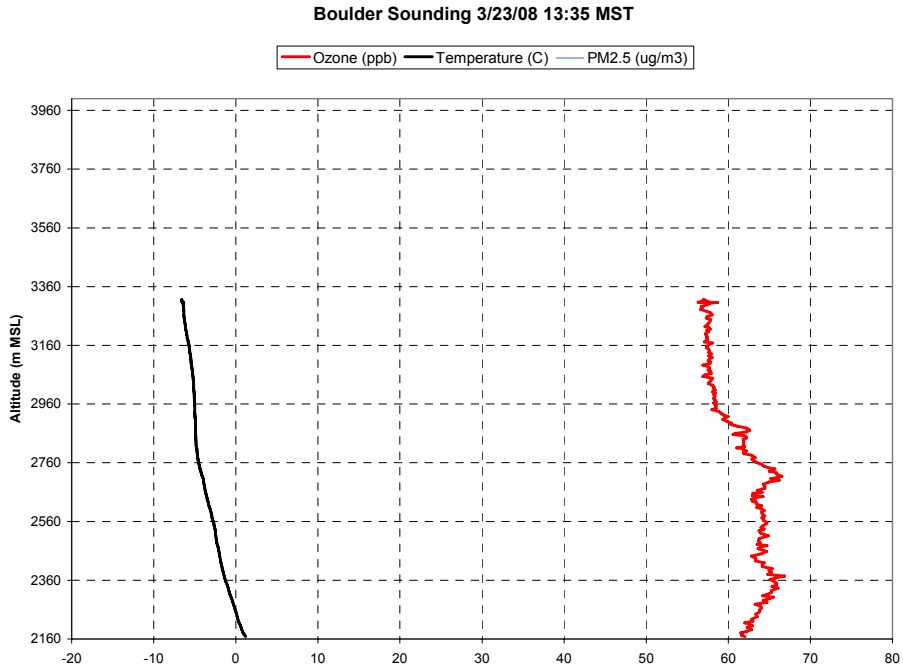

Figure 5-58. Vertical profiles of ozone, temperature and $PM_{2.5}$ measured via aircraft spiral sounding at Boulder on 23 March, 13:35 MST (base of plot is at ground level).

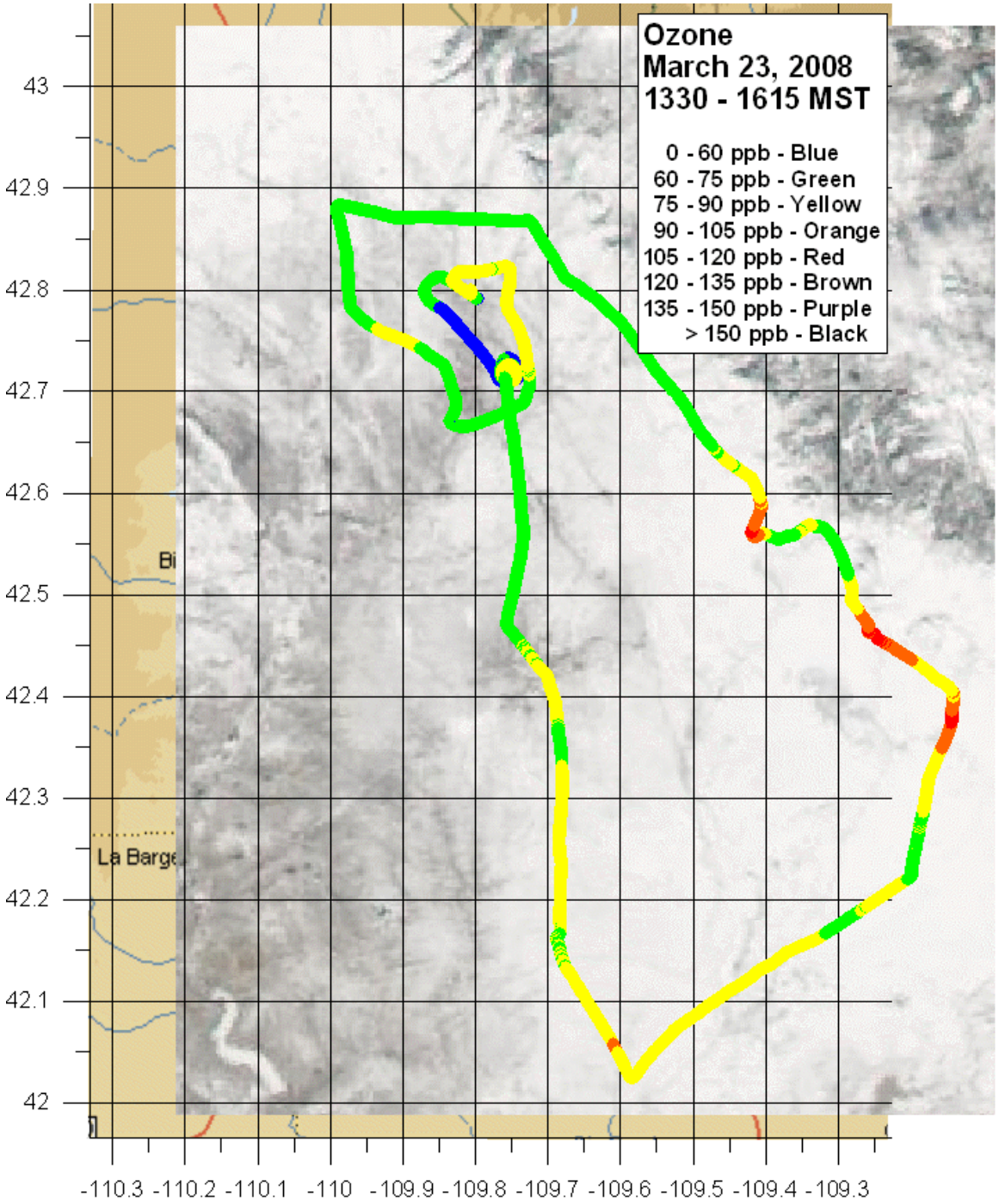

Figure 5-59. As in Figure 5-56 but flight path superimposed on MODIS satellite photograph showing extent of snow cover.

6. VOC AND CARBONYL MEASUREMENTS

Systematic measurements of organic gasses were conducted during each of the three Intensive Operating Periods (IOPs) during February and March, 2008. Sampling of organics was conducted in pairs:

- *VOC sampling*: Whole air samples were collected in specially prepared stainless steel canisters and shipped to the laboratory (Environmental Analytical Service, Inc.) for analysis of volatile organic compounds (VOCs) and other non-polar C2 – C12 hydrocarbons via gas chromatography with a flame ionization detector (GC/FID).
- *Carbonyl sampling*: Sample air was pumped through 2,4-dinitrophenylhydrazine (DNPH) coated adsorbent cartridges which were then analyzed in the laboratory for formaldehyde and other carbonyl compounds via high performance liquid chromatography (HPLC).

A total of 130 VOC canister and 120 carbonyl cartridge samples were collected and analyzed during the UGWOS 2008 field measurement program. VOC canister/Carbonyl cartridge pairs were collected simultaneously at the existing WDEQ monitoring stations at Jonah, Boulder and Daniel and from the project aircraft during intensive operational periods (IOP's). Sequential samplers were used initially at each site to automate the filling of canisters, thus allowing samples to be collected with only one site service visit per day. This was intended to free up project personnel for other critical duties. Because of occasional problems with sample sequence initiation and solenoid valve leaks in the sequential units, however, manually operated samplers were utilized after IOP#1.

Prior to the first IOP, 3-hour integrated VOC canister/carbonyl cartridge samples were collected according to the standard collection schedule shown below at Daniel and Boulder on a non-IOP day (7 February). The sequential sampler at Jonah failed to start during this test and no samples were collected.

Date	Jonah Site	Boulder Site	Daniel Site
2-07-08	-	0400 MST	0400 MST
	-	0900 MST	0900 MST
	-	1400 MST	1400 MST

During each IOP, VOC canister/ Carbonyl cartridge sample pairs were taken simultaneously at Daniel, Boulder and Jonah. Sampling was set to start at 0400, 0900, and 1400 MST during each IOP day. Sample duration was three (3) hours. In addition, VOC/carbonyl grab samples were taken from the aircraft. Sample pairs were collected at the start times shown in Table 6-1. Sample numbers listed in the UGWOS database contain sampling site, date and start time embedded in the sample number identifier (e.g. JON0218081400 is the sample collected at Jonah between 14:00 – 17:00 MST on 18 February 2008).

Table 6-1. VOC/carbonyl sample pairs (times in MST) collected during each IOP.

IOP #1

Date	Jonah Site	Boulder Site	Daniel Site	Acft VOC	Acft Carbonyl
2-18-08	0400	0400	0400	1500	1500
	0900	0900	0900		
	1400	1400	1400		
2-19-08	0400	0400	0400	0818	0808
	0900	0900	0900	0845	0840
	1400	1400	1400	1618	1620
2-20-08	0400	-	0400	1100	1050
	0900	-	0900	1620	1613
	1400	1400	1400		
2-21-08	0400	0400	0400	1047	1043
	0900	0900	0900	1419	1417
	1400	1400	1400	1616	

IOP#2

Date	Jonah Site	Boulder Site	Daniel Site	Acft VOC	Acft Carbonyl
2-27-08	0400	0400	0400	1011	1013
	0900	0900	0900	1429	1433
	1400	1400	1400		
2-28-08	0400	0400	0400		
	0900	0900	0900		
	1400	1400	1400		
2-29-08	0400	0400	0400	1041	1528
	0900	0900	0900	1512	
	1400	1400	1400		

IOP#3

Date	Jonah Site	Boulder Site	Daniel Site	Acft VOC	Acft Carbonyl
3-10-08	0400	0400	0400	1345	1346
	0900	0900	0900	1555	
	1400	1400	1400		
3-11-08	0400	0400	0400	0954	1352
	0900	0900	0900	1329	1554
	1400	1400	1400	1524	
3-12-08	0400	0400	0400		
	0900	0900	0900		
	1400	1400	1400		

For quality assurance purposes, duplicate VOC/carbonyl sample pairs were taken following IOP#2 and IOP#3 at Jonah at the following start times:

Date	Jonah Site
3-01-08	0400 MST
3-13-08	0400 MST
	0900 MST (VOC only)

VOC canister samplers were checked for contamination prior to IOP#1 by filling a clean canister with ultra-pure air using each individual sampler and submitting it for analysis. In addition, six field/trip blanks were collected for VOCs and 5 field/trip blanks were collected for carbonyls during the 2008 program.

On-going laboratory QA was performed on each batch of samples as they were received and analyzed by the lab, including method blanks, QC duplicates, laboratory control spikes and laboratory control duplicates. All of these QA results are included in the UGWOS database.

6.1 Summary of Carbon Monoxide Data

All canister samples were analyzed for CO using method ATSM D 3416. Results are summarized in Table 6-2. Minimum values at Daniel suggest a regional background level of approximately 220 – 260 ppb which is slightly greater than the global northern hemisphere background level of about 150 ppb (Warneck, 2000; Yurganov, 2000). Values at Jonah exhibit the influence of combustion sources, especially in the 4:00 – 7:00 MST samples. The average amount by which CO concentrations at Jonah exceed the 220-260 ppb regional background decreases by about a factor of 3 between the morning and afternoon samples. In contrast, CO levels at Boulder are roughly on par with those at Daniel.

Table 6-2. Summary of CO analysis results for three-hour integrated canister samples; quartiles are defined as follows: 25% of observations are less than Q1, 50% are less than Q2, and 75% are less than Q3 (all CO concentration values shown in ppb).

Location	Time	Max	Min	Mean	Q1	Q2	Q3	N
Boulder	4:00	460	260	330	280	320	370	9
	9:00	430	260	322	270	310	380	9
	14:00	660	270	363	293	320	395	10
Daniel	4:00	490	240	322	285	315	335	10
	9:00	350	220	288	263	295	310	10
	14:00	610	260	365	310	350	398	10
Jonah	4:00	1,370	420	707	575	710	745	11
	9:00	930	320	515	405	490	565	11
	14:00	550	280	382	320	340	430	10

6.2 Summary of VOC Data

Results of the laboratory analysis revealed that most samples only contained a limited range of fairly common hydrocarbon species. Table 6-3 shows which compounds on the target list of compounds detectable by the GC/FID were not detected in *any* of the samples collected at the indicated site. Table 6-4 provides the same information for the carbonyl samples. Note that throughout this report we refer to the list of target compounds informally as "volatile organic compounds" or "VOCs" although not all of these compounds (e.g. ethane) are included in EPA's definition of VOCs.

Table 6-3. Summary of VOC compound detections (ND indicates compound was not detected in *any* of the samples analyzed; percentage values indicate fraction of samples above the method detection limit; shaded rows indicate compounds detected in at least one sample at all sites).

Compound	Boulder	Daniel	Jonah	Aircraft
1,2,3,5-Tetramethylbenzene	ND	ND	ND	ND
1,2,3-Trimethylbenzene	39%	3%	12%	11%
1,2,4,5-Tetramethylbenzene	ND	ND	ND	ND
1,2,4-Trimethylbenzene	19%	12%	58%	32%
1,2-Dimethyl-4-ethylbenzene	3%	ND	ND	11%
1,3,5-Trimethylbenzene	3%	6%	27%	16%
1,3-Butadiene	ND	ND	ND	ND
1,3-Diethylbenzene	13%	ND	3%	5%
1,3-Dimethyl-4-ethylbenzene	6%	ND	ND	ND
1,4-Diethylbenzene	42%	ND	6%	5%
1,4-Dimethyl-2-ethylbenzene	ND	ND	ND	ND
1-Butene	45%	30%	36%	42%
1-Hexene	16%	ND	9%	11%
1-Nonene	ND	ND	3%	11%
1-Pentene	3%	ND	3%	ND
2,2,4-Trimethylpentane	13%	ND	67%	42%
2,2-Dimethylbutane	35%	3%	64%	21%
2,3,4-Trimethylpentane	3%	ND	9%	21%
2,3-Dimethylbutane	ND	ND	3%	5%
2,3-Dimethylhexane	ND	ND	12%	16%
2,3-Dimethylpentane	10%	ND	61%	58%
2,4-Dimethylhexane	ND	ND	15%	16%
2,4-Dimethylpentane	55%	6%	91%	58%
2,5-Dimethylhexane	ND	3%	33%	21%
2-Ethyltoluene	3%	6%	3%	ND
2-Methyl-1-butene	ND	ND	ND	16%
2-Methyl-1-heptene	ND	3%	3%	11%
2-Methyl-1hexene	10%	3%	33%	11%
2-Methyl-2-butene	3%	ND	3%	5%
2-Methylheptane	10%	3%	58%	11%
2-Methylhexane	32%	ND	88%	53%
2-Methylpentane	58%	12%	88%	63%
3-Ethyl-3-methylpentane	ND	ND	ND	ND
3-Ethyltoluene	3%	3%	18%	16%
3-Methyl-1-butene	6%	3%	ND	ND
3-Methylcyclopentene	6%	ND	ND	16%
3-Methylheptane	10%	ND	76%	16%
3-Methylhexane	32%	18%	85%	58%
3-Methylpentane	68%	6%	88%	53%
4-Ethyltoluene	ND	ND	12%	5%
4-Methylheptane	ND	ND	ND	5%
Acetone	23%	21%	12%	11%
Acetylene	65%	64%	73%	58%
a-Pinene	ND	ND	ND	ND
Benzene	90%	33%	97%	89%
b-Pinene	3%	3%	ND	5%
c-2-Butene	ND	ND	ND	5%

Table 6-3. (Continued.)

Compound	Boulder	Daniel	Jonah	Aircraft
c-2-Pentene	3%	ND	12%	5%
Cyclohexane	71%	15%	94%	74%
Cyclopentane	35%	3%	82%	53%
Cyclopentene	ND	12%	6%	16%
Diisopropyl ether	ND	ND	ND	ND
d-Limonene	ND	3%	3%	5%
Dodecane	ND	ND	ND	ND
Ethane	100%	100%	100%	100%
Ethanol	16%	67%	12%	21%
Ethene	71%	36%	79%	58%
Ethyl tert butyl ether	ND	ND	ND	ND
Ethylbenzene	35%	ND	76%	42%
i-Butane	97%	48%	100%	100%
Indan	ND	ND	ND	11%
i-Pentane	87%	82%	100%	100%
i-Propylbenzene	ND	ND	ND	11%
Isoprene	6%	3%	ND	ND
Isopropanol	ND	ND	6%	5%
m,p-xylene	90%	52%	97%	79%
Methanol	ND	ND	ND	ND
Methyl tert butyl ether	ND	ND	ND	ND
Methylcyclohexane	71%	15%	91%	58%
Methylcyclopentane	13%	12%	ND	ND
Naphthalene	ND	ND	ND	ND
n-Butane	97%	85%	94%	95%
n-Butylbenzene	32%	ND	3%	5%
n-Decane	16%	6%	45%	16%
n-Heptane	65%	15%	91%	68%
n-Hexane	74%	24%	94%	68%
n-Nonane	35%	ND	73%	32%
n-Octane	65%	15%	88%	53%
n-Pentane	87%	45%	100%	95%
n-Propanol	3%	9%	ND	5%
n-propylbenzene	ND	ND	3%	ND
o-xylene	55%	12%	79%	42%
Propane	100%	100%	100%	100%
Propene	52%	33%	79%	53%
Styrene	13%	15%	24%	21%
t-2-Butene	ND	ND	ND	ND
t-2-Pentene	ND	ND	3%	5%
Tert amyl methyl ether	ND	ND	ND	ND
Tert butyl alcohol	ND	ND	ND	ND
Toluene	94%	91%	97%	100%
Total Non-Methane Hydrocarbons	100%	100%	100%	100%
Undecane	ND	ND	3%	ND

Table 6-4. Summary of carbonyl compound detections (ND indicates compound was not detected in *any* of the samples analyzed; percentage values indicate fraction of samples above the method detection limit; shaded rows indicate compounds detected in at least one sample at all sites).

Compound	Boulder	Daniel	Jonah	Aircraft
2,5-Dimethylbenzaldehyde	ND	ND	ND	ND
Acetaldehyde	93%	91%	100%	36%
Acetone	100%	100%	100%	100%
Acrolein	ND	ND	ND	ND
Benzaldehyde	ND	ND	ND	ND
Butyraldehyde	4%	ND	ND	ND
Crotonaldehyde	21%	27%	28%	29%
Formaldehyde	93%	82%	100%	7%
Hexaldehyde	ND	ND	ND	ND
Isovaleraldehyde	ND	ND	ND	ND
m-Tolualdehyde	ND	ND	ND	ND
o-Tolualdehyde	ND	ND	ND	ND
Propionaldehyde	ND	ND	ND	ND
p-Tolualdehyde	ND	ND	ND	ND
Valeraldehyde	ND	ND	ND	ND

Of particular note is the fact that isoprene, which is a common and highly reactive species of overwhelmingly biogenic origin, was not detected in any of the samples collected at Jonah and found only at levels just above the MDL in one sample at Daniel and two samples at Boulder. These results are consistent with the expected absence of biogenic VOCs in the study area during the winter months.

Carbonyl species detected in at least some samples at each site included acetaldehyde, acetone, crotonaldehyde, and formaldehyde. Butyraldehyde was detected in just one sample which was collected at the Boulder site. No other carbonyl compounds were detected.

Method detection limits (MDLs) for VOCs were generally very good, with average MDLs for all target species falling between 0.26 and 0.52 ppbV (Table 6-5). Carbonyl MDLs at surface sites are also low ranging from 0.09 to 0.38 ppbV. However, due to the limited amount of air sample that we were able to run through the DNPH cartridge in the aircraft, the aircraft carbonyl sample MDLs are significantly higher (see Table 6-6).

Table 6-5. Average method detection limits (MDLs) for individual VOC species for samples collected at Jonah, Boulder and Daniel.

Compound	Average MDL (ppbV)		Compound	Average MDL (ppbV)
1,2,3,5-Tetramethylbenzene	0.52		Cyclohexane	0.26
1,2,3-Trimethylbenzene	0.52		Cyclopentane	0.26
1,2,4,5-Tetramethylbenzene	0.52		Cyclopentene	0.26
1,2,4-Trimethylbenzene	0.34		Diisopropyl ether	0.52
1,2-Dimethyl-4-ethylbenzene	0.52		d-Limonene	0.52
1,3,5-Trimethylbenzene	0.34		Dodecane	0.52
1,3-Butadiene	0.26		Ethane	0.26
1,3-Diethylbenzene	0.52		Ethanol	0.52
1,3-Dimethyl-4-ethylbenzene	0.52		Ethene	0.52
1,4-Diethylbenzene	0.52		Ethyl tert butyl ether	0.52
1,4-Dimethyl-2-ethylbenzene	0.52		Ethylbenzene	0.26
1-Butene	0.34		i-Butane	0.34
1-Hexene	0.34		Indan	0.52
1-Nonene	0.52		i-Pentane	0.26
1-Pentene	0.34		i-Propylbenzene	0.52
2,2,4-Trimethylpentane	0.34		Isoprene	0.34
2,2-Dimethylbutane	0.34		Isopropanol	0.52
2,3,4-Trimethylpentane	0.52		m,p-xylene	0.26
2,3-Dimethylbutane	0.34		Methanol	0.52
2,3-Dimethylhexane	0.52		Methyl tert butyl ether	0.52
2,3-Dimethylpentane	0.34		Methylcyclohexane	0.52
2,4-Dimethylhexane	0.52		Methylcyclopentane	0.34
2,4-Dimethylpentane	0.34		Naphthalene	0.52
2,5-Dimethylhexane	0.52		n-Butane	0.26
2-Ethyltoluene	0.52		n-Butylbenzene	0.34
2-Methyl-1-butene	0.34		n-Decane	0.34
2-Methyl-1-heptene	0.52		n-Heptane	0.26
2-Methyl-1hexene	0.34		n-Hexane	0.26
2-Methyl-2-butene	0.34		n-Nonane	0.34
2-Methylheptane	0.52		n-Octane	0.26
2-Methylhexane	0.34		n-Pentane	0.26
2-Methylpentane	0.34		n-Propanol	0.52
3-Ethyl-3-methylpentane	0.52		n-propylbenzene	0.52
3-Ethyltoluene	0.52		o-xylene	0.26
3-Methyl-1-butene	0.34		Propane	0.26
3-Methylcyclopentene	0.34		Propene	0.34
3-Methylheptane	0.52		Styrene	0.52
3-Methylhexane	0.34		t-2-Butene	0.34
3-Methylpentane	0.34		t-2-Pentene	0.34
4-Ethyltoluene	0.52		Tert amyl methyl ether	0.34
4-Methylheptane	0.52		Tert butyl alcohol	0.52
Acetone	0.52		Toluene	0.26
Acetylene	0.52		Undecane	0.52
a-Pinene	0.52		Total Non-Methane Hydrocarbons	13.94
Benzene	0.26			
b-Pinene	0.52			
c-2-Butene	0.34			
c-2-Pentene	0.34			

Table 6-6. Average method detection limits (MDLs) in ppbV for carbonyl species.

	Surface site average (Jonah, Boulder, Daniel)	Aircraft sample average
Formaldehyde	0.38	1.87
Acetaldehyde	0.26	1.27
Acrolein	0.21	1.00
Acetone	0.20	0.97
Propionaldehyde	0.20	0.97
Crotonaldehyde	0.16	0.80
Butyraldehyde	0.16	0.78
Benzaldehyde	0.11	0.53
Isovaleraldehyde	0.13	0.65
Valeraldehyde	0.13	0.65
o-Tolualdehyde	0.10	0.47
m-Tolualdehyde	0.10	0.47
p-Tolualdehyde	0.10	0.47
Hexaldehyde	0.12	0.56
2,5-Dimethylbenzaldehyde	0.09	0.42

Tables 6-7 thru 6-9 present VOC data summary statistics for Jonah, Boulder and Daniel, respectively, after removal of non-detected compounds. Note that ethane and acetone are included in the "VOC" list although these two compounds are not defined as a VOC under U.S. EPA regulations. Each table shows the number of samples (N) with a listed compound above the method detection limit (MDL) and the number of samples with non-detects (ND) for a listed compound. N plus ND equals the total number of samples taken. The tables also present the maximum, minimum, and mean concentrations for compounds detected in one or more samples. In addition, the sample concentrations were divided into quartiles (Q1, Q2, Q3) for species for which a sufficient number of observations above the MDL was available. Quartiles are defined as follows: 25% of observations are less than Q1, 50% are less than Q2, and 75% are less than Q3. Thus, Q2 corresponds to the sample median. Table 6-10 presents the same summary statistics for the carbonyl data. Overall, these data show results broadly similar to what was found in the 2007 data (ENVIRON, 2008). Graphical summaries of the data are presented below.

Table 6-7. VOC summary statistics based on values above MDL for samples collected at Jonah.

Jonah - VOC Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
1,2,3-Trimethylbenzene (ppbV)	1.38	0.71	1.05	0.71	0.75	1.35	29	4	88%	33
1,2,4-Trimethylbenzene (ppbV)	3.21	0.36	1.07	0.6	0.74	1.1	14	19	42%	33
1,3,5-Trimethylbenzene (ppbV)	1.73	0.38	0.88	0.47	0.73	1.46	24	9	73%	33
1,3-Diethylbenzene (ppbV)	0.87	0.87	0.87				32	1	97%	33
1,4-Diethylbenzene (ppbV)	0.89	0.63	0.76				31	2	94%	33
1-Butene (ppbV)	3.15	0.79	1.6	0.84	1.27	1.86	21	12	64%	33
1-Hexene (ppbV)	0.42	0.38	0.41				30	3	91%	33
1-Nonene (ppbV)	0.73	0.73	0.73				32	1	97%	33
1-Pentene (ppbV)	0.57	0.57	0.57				32	1	97%	33
2,2,4-Trimethylpentane (ppbV)	9.81	0.41	1.96	0.68	1.14	2.24	11	22	33%	33
2,2-Dimethylbutane (ppbV)	4.38	0.4	1.24	0.57	0.96	1.85	12	21	36%	33
2,3,4-Trimethylpentane (ppbV)	3.73	1.09	2.08				30	3	91%	33
2,3-Dimethylbutane (ppbV)	0.35	0.35	0.35				32	1	97%	33
2,3-Dimethylhexane (ppbV)	2.3	0.59	1.1	0.59	0.64	0.87	29	4	88%	33
2,3-Dimethylpentane (ppbV)	2.98	0.39	1.14	0.5	0.83	1.31	13	20	39%	33
2,4-Dimethylhexane (ppbV)	1.5	0.75	1.02	0.84	0.97	1.5	28	5	85%	33
2,4-Dimethylpentane (ppbV)	22.49	1.04	4.98	1.78	3.5	6.47	3	30	9%	33
2,5-Dimethylhexane (ppbV)	2.99	0.57	1.22	0.75	1.01	1.3	22	11	67%	33
2-Ethyltoluene (ppbV)	1.07	1.07	1.07				32	1	97%	33
2-Methyl-1-heptene (ppbV)	0.83	0.83	0.83				32	1	97%	33
2-Methyl-1hexene (ppbV)	3.7	0.41	1.2	0.43	0.74	1.44	22	11	67%	33
2-Methyl-2-butene (ppbV)	42.04	42.04	42.04				32	1	97%	33
2-Methylheptane (ppbV)	4.49	0.6	1.33	0.74	1.11	1.39	14	19	42%	33
2-Methylhexane (ppbV)	9.8	0.45	2.29	0.91	1.41	3.31	4	29	12%	33
2-Methylpentane (ppbV)	33.26	1.27	7.28	3.38	5.49	9.37	4	29	12%	33
3-Ethyltoluene (ppbV)	1.47	0.53	1.1	0.67	1.13	1.41	27	6	82%	33
3-Methylheptane (ppbV)	4.23	0.55	1.35	0.92	1.07	1.55	8	25	24%	33
3-Methylhexane (ppbV)	9.07	0.42	2.04	0.84	1.19	2.55	5	28	15%	33
3-Methylpentane (ppbV)	18.91	0.88	4.57	1.94	3.95	5.78	4	29	12%	33
4-Ethyltoluene (ppbV)	1.8	0.56	0.94	0.56	0.68	0.71	29	4	88%	33
Acetone (ppbV)	66.28	1.01	20.13	1.01	1.7	11.53	29	4	88%	33
Acetylene (ppbV)	90.2	0.59	20.29	1.47	1.98	39.65	9	24	27%	33
Benzene (ppbV)	41.07	0.38	8.69	3.37	5.16	11.37	1	32	3%	33
c-2-Pentene (ppbV)	0.97	0.4	0.62	0.4	0.51	0.58	29	4	88%	33
Cyclohexane (ppbV)	35.54	0.3	7.7	2.51	5.5	11.03	2	31	6%	33
Cyclopentane (ppbV)	9.38	0.35	2.14	0.8	1.62	2.61	6	27	18%	33
Cyclopentene (ppbV)	2.58	1.1	1.84				31	2	94%	33
d-Limonene (ppbV)	0.79	0.79	0.79				32	1	97%	33
Ethane (ppbV)	1268	24.73	232.1	72.2	172	282	0	33	0%	33
Ethanol (ppbV)	78.79	3.41	39.06	3.41	35.92	38.13	29	4	88%	33
Ethene (ppbV)	107.4	0.64	6.66	1.12	1.79	3.62	7	26	21%	33
Ethylbenzene (ppbV)	2.98	0.32	0.93	0.51	0.61	1.34	8	25	24%	33
i-Butane (ppbV)	195.3	1.55	39.91	13.98	25.23	56.29	0	33	0%	33
i-Pentane (ppbV)	104.6	0.59	23.89	7.98	17.16	31.22	0	33	0%	33
Isopropanol (ppbV)	51.31	7.14	29.22				31	2	94%	33
m,p-xylene (ppbV)	22.93	0.31	4.57	1.73	3.11	4.92	1	32	3%	33
Methylcyclohexane (ppbV)	61.04	1.77	13.16	4.78	7.71	16.64	3	30	9%	33
n-Butane (ppbV)	220.4	2.08	42.81	15.01	29.33	55.49	2	31	6%	33
n-Butylbenzene (ppbV)	1.75	1.75	1.75				32	1	97%	33
n-Decane (ppbV)	7.82	0.34	1.31	0.39	0.67	1.43	18	15	55%	33
n-Heptane (ppbV)	20.94	0.72	4.59	1.69	2.84	5.9	3	30	9%	33
n-Hexane (ppbV)	41.72	0.37	9.05	2.87	6.33	12.12	2	31	6%	33
n-Nonane (ppbV)	4.33	0.39	1.22	0.55	0.79	1.31	9	24	27%	33
n-Octane (ppbV)	12.21	0.52	2.76	1.12	2.37	3.38	4	29	12%	33
n-Pentane (ppbV)	83.84	0.54	17.66	5.84	10.9	24.09	0	33	0%	33
n-propylbenzene (ppbV)	0.62	0.62	0.62				32	1	97%	33
o-xylene (ppbV)	4.21	0.38	1.19	0.55	0.78	1.57	7	26	21%	33
Propane (ppbV)	631.2	8.65	128.2	44.03	84.47	173.3	0	33	0%	33
Propene (ppbV)	62.06	0.42	3.29	0.52	0.8	1.27	7	26	21%	33
Styrene (ppbV)	0.94	0.52	0.68	0.54	0.62	0.7	25	8	76%	33
t-2-Pentene (ppbV)	0.72	0.72	0.72				32	1	97%	33
Toluene (ppbV)	69.69	0.37	14.08	5.35	8.54	15.56	1	32	3%	33
Undecane (ppbV)	5.59	5.59	5.59				32	1	97%	33

Jonah - VOC Lumped Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Paraffins (ppbC)	6285	91.04	1215	407.3	853.1	1537	0	33	0%	33
Isoparaffins (ppbC)	2107	14.6	448.5	165.4	334.7	636.7	0	33	0%	33
Olefins (ppbC)	493	1.78	66.9	13.58	20.15	91.78	0	33	0%	33
Aromatics (ppbC)	1081	10.55	222	95.18	149.1	244.4	0	33	0%	33
Napthlenes (ppbC)	687.4	2.42	141	48.28	86.64	176.6	1	32	3%	33
Oxygenates (ppbC)	275.1	0.41	81.09	11.91	34.58	157.6	24	9	38%	33
Total Non-Methane Hydrocarbons (ppbC)	11112	286.4	2431	1298	1677	3281	0	33	0%	33

Table 6-8. VOC summary statistics based on values above MDL for samples collected at Boulder

Boulder - VOC Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
1,2,3-Trimethylbenzene (ppbV)	1.41	0.76	1.04	0.83	0.99	1.17	19	12	61%	31
1,2,4-Trimethylbenzene (ppbV)	3	0.37	1.3	0.39	1.1	1.5	25	6	81%	31
1,2-Dimethyl-4-ethylbenzene (ppbV)	0.58	0.58	0.58				30	1	97%	31
1,3,5-Trimethylbenzene (ppbV)	0.96	0.96	0.96				30	1	97%	31
1,3-Diethylbenzene (ppbV)	0.83	0.52	0.65	0.52	0.58	0.67	27	4	87%	31
1,3-Dimethyl-4-ethylbenzene (ppbV)	0.53	0.51	0.52				29	2	94%	31
1,4-Diethylbenzene (ppbV)	2.68	0.58	1.57	1.2	1.65	1.82	18	13	58%	31
1-Butene (ppbV)	2.16	0.39	1.04	0.58	0.91	1.4	17	14	55%	31
1-Hexene (ppbV)	1	0.38	0.5	0.38	0.38	1	26	5	84%	31
1-Pentene (ppbV)	1.2	1.2	1.2				30	1	97%	31
2,2,4-Trimethylpentane (ppbV)	0.96	0.39	0.61	0.39	0.44	0.65	27	4	87%	31
2,2-Dimethylbutane (ppbV)	1.84	0.34	0.64	0.46	0.47	0.68	20	11	65%	31
2,3,4-Trimethylpentane (ppbV)	0.33	0.33	0.33				30	1	97%	31
2,3-Dimethylpentane (ppbV)	0.43	0.29	0.37				28	3	90%	31
2,4-Dimethylpentane (ppbV)	2.97	0.36	1.12	0.49	0.97	1.8	14	17	45%	31
2-Ethyltoluene (ppbV)	5.5	5.5	5.5				30	1	97%	31
2-Methyl-1hexene (ppbV)	0.49	0.4	0.43				28	3	90%	31
2-Methyl-2-butene (ppbV)	1	1	1				30	1	97%	31
2-Methylheptane (ppbV)	1.42	0.62	1.01				28	3	90%	31
2-Methylhexane (ppbV)	1.39	0.34	0.76	0.51	0.67	0.76	21	10	68%	31
2-Methylpentane (ppbV)	4.63	0.46	1.65	0.74	1.2	2.33	13	18	42%	31
3-Ethyltoluene (ppbV)	0.84	0.84	0.84				30	1	97%	31
3-Methyl-1-butene (ppbV)	1.7	1	1.35				29	2	94%	31
3-Methylcyclopentene (ppbV)	2.57	0.55	1.56				29	2	94%	31
3-Methylheptane (ppbV)	0.79	0.54	0.64				28	3	90%	31
3-Methylhexane (ppbV)	1.34	0.39	0.78	0.5	0.67	1.13	21	10	68%	31
3-Methylpentane (ppbV)	2.82	0.29	1.08	0.51	0.89	1.66	10	21	32%	31
Acetone (ppbV)	9.8	0.64	2.92	0.86	1.4	3.79	24	7	77%	31
Acetylene (ppbV)	60.14	0.51	5.24	0.72	1.15	2.74	11	20	35%	31
Benzene (ppbV)	6.26	0.27	1.77	0.72	1.18	2.17	3	28	10%	31
b-Pinene (ppbV)	11.7	11.7	11.7				30	1	97%	31
c-2-Pentene (ppbV)	0.62	0.62	0.62				30	1	97%	31
Cyclohexane (ppbV)	4.6	0.33	1.48	0.75	0.9	1.96	9	22	29%	31
Cyclopentane (ppbV)	1.47	0.29	0.67	0.41	0.56	0.94	20	11	65%	31
Ethane (ppbV)	279.2	0.96	59.92	15.35	35.73	71.07	0	31	0%	31
Ethanol (ppbV)	58.4	3.86	17.66	4.13	10.82	58.4	26	5	84%	31
Ethene (ppbV)	4.4	0.47	1.44	0.64	0.93	1.31	9	22	29%	31
Ethylbenzene (ppbV)	0.98	0.16	0.51	0.33	0.39	0.65	20	11	65%	31
i-Butane (ppbV)	33.51	0.38	7.52	1.76	5.1	10.27	1	30	3%	31
i-Pentane (ppbV)	17.28	0.31	4.51	1.63	3.28	5.18	4	27	13%	31
Isoprene (ppbV)	0.52	0.34	0.43				29	2	94%	31
m,p-xylene (ppbV)	18.6	0.29	2.01	0.48	1.2	1.94	3	28	10%	31
Methylcyclohexane (ppbV)	8.39	0.75	2.81	1.52	1.85	3.88	9	22	29%	31
Methylcyclopentane (ppbV)	1.4	0.39	0.84	0.39	0.77	0.8	27	4	87%	31
n-Butane (ppbV)	34.4	0.38	7.67	1.63	4.8	10.05	1	30	3%	31
n-Butylbenzene (ppbV)	2.35	0.87	1.52	1.2	1.46	1.79	21	10	68%	31
n-Decane (ppbV)	11	0.34	2.72	0.46	0.46	11	26	5	84%	31
n-Heptane (ppbV)	3.04	0.32	1.05	0.53	0.75	1.42	11	20	35%	31
n-Hexane (ppbV)	5.21	0.12	1.64	0.63	1	2.27	8	23	26%	31
n-Nonane (ppbV)	1.82	0.36	0.65	0.38	0.48	0.65	20	11	65%	31
n-Octane (ppbV)	2.47	0.26	0.83	0.44	0.58	0.93	11	20	35%	31
n-Pentane (ppbV)	11.58	0.35	2.96	0.76	2	3.7	4	27	13%	31
n-Propanol (ppbV)	168.7	168.7	168.7				30	1	97%	31
o-xylene (ppbV)	1.9	0.26	0.61	0.31	0.41	0.82	14	17	45%	31
Propane (ppbV)	117	1.16	26.13	6.23	16.22	32.15	0	31	0%	31
Propene (ppbV)	12.6	0.27	1.71	0.37	0.42	1.17	15	16	48%	31
Styrene (ppbV)	1.1	0.57	0.78	0.57	0.58	0.86	27	4	87%	31
Toluene (ppbV)	10.37	0.33	3.16	1.7	2.3	4	2	29	6%	31

Boulder - Lumped VOC Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Paraffins (ppbC)	1173	13.35	266.1	68.72	186	368.3	0	31	0%	31
Isoparaffins (ppbC)	332.7	2.67	77.07	22.14	51.9	107.6	0	31	0%	31
Olefins (ppbC)	134.8	2.61	22.79	6.94	11.69	20.1	0	31	0%	31
Aromatics (ppbC)	213	3.73	81.26	43.94	73.94	117.2	0	31	0%	31
Napthlenes (ppbC)	90.12	0.31	23.79	7.28	17.49	33.45	0	31	0%	31
Oxygenates (ppbC)	634.3	1.05	74.62	2.65	7.73	29.4	21	10	68%	31
Total Non-Methane Hydrocarbons (ppbC)	2643	141.72	843.6	416.4	792	1131	1	30	3%	31

Table 6-9. VOC summary statistics based on values above MDL for samples collected at Daniel.

Daniel - VOC Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
1,2,3-Trimethylbenzene (ppbV)	1.3	1.3	1.3				32	1	97%	33
1,2,4-Trimethylbenzene (ppbV)	1	0.38	0.54	0.38	0.38	0.4	29	4	88%	33
1,3,5-Trimethylbenzene (ppbV)	1.46	0.78	1.12				31	2	94%	33
1-Butene (ppbV)	3	0.35	1.4	0.88	1.13	1.97	23	10	70%	33
2,2-Dimethylbutane (ppbV)	0.69	0.69	0.69				32	1	97%	33
2,4-Dimethylpentane (ppbV)	0.47	0.35	0.41				31	2	94%	33
2,5-Dimethylhexane (ppbV)	1.2	1.2	1.2				32	1	97%	33
2-Ethyltoluene (ppbV)	3	2.2	2.6				31	2	94%	33
2-Methyl-1-heptene (ppbV)	0.6	0.6	0.6				32	1	97%	33
2-Methyl-1hexene (ppbV)	6.3	6.3	6.3				32	1	97%	33
2-Methylheptane (ppbV)	0.6	0.6	0.6				32	1	97%	33
2-Methylpentane (ppbV)	1.3	0.38	0.74	0.38	0.62	0.67	29	4	88%	33
3-Ethyltoluene (ppbV)	3.07	3.07	3.07				32	1	97%	33
3-Methyl-1-butene (ppbV)	48.7	48.7	48.7				32	1	97%	33
3-Methylhexane (ppbV)	0.79	0.34	0.56	0.36	0.53	0.74	27	6	82%	33
3-Methylpentane (ppbV)	0.53	0.44	0.48				31	2	94%	33
Acetone (ppbV)	16.31	0.54	5.29	0.54	3	8.4	26	7	79%	33
Acetylene (ppbV)	39.31	0.58	5.11	1.3	2.24	4.2	12	21	36%	33
Benzene (ppbV)	0.86	0.3	0.57	0.34	0.63	0.76	22	11	67%	33
b-Pinene (ppbV)	0.6	0.6	0.6				32	1	97%	33
Cyclohexane (ppbV)	0.48	0.27	0.37	0.33	0.35	0.48	28	5	85%	33
Cyclopentane (ppbV)	1.2	1.2	1.2				32	1	97%	33
Cyclopentene (ppbV)	2.1	0.39	0.97	0.39	0.69	0.71	29	4	88%	33
d-Limonene (ppbV)	0.6	0.6	0.6				32	1	97%	33
Ethane (ppbV)	58.37	1.08	10.49	3.77	6.12	12.7	0	33	0%	33
Ethanol (ppbV)	94.48	11.51	36.11	23.54	31.71	41.95	11	22	33%	33
Ethene (ppbV)	5.73	0.52	1.73	0.65	0.98	1.88	21	12	64%	33
i-Butane (ppbV)	5.5	0.5	2.26	0.73	1.54	3.02	17	16	52%	33
i-Pentane (ppbV)	4.5	0.29	1.48	0.44	0.92	2.19	6	27	18%	33
Isoprene (ppbV)	0.47	0.47	0.47				32	1	97%	33
m,p-xylene (ppbV)	5.8	0.29	1.06	0.41	0.54	1.15	16	17	48%	33
Methylcyclohexane (ppbV)	1.17	0.51	0.82	0.54	0.78	1.17	28	5	85%	33
Methylcyclopentane (ppbV)	1.7	0.9	1.25	0.9	1.05	1.34	29	4	88%	33
n-Butane (ppbV)	6.24	0.26	1.39	0.39	0.79	1.65	5	28	15%	33
n-Decane (ppbV)	0.9	0.6	0.75				31	2	94%	33
n-Heptane (ppbV)	6.36	0.28	1.56	0.34	0.41	6.36	28	5	85%	33
n-Hexane (ppbV)	0.83	0.26	0.47	0.32	0.42	0.52	25	8	76%	33
n-Octane (ppbV)	0.7	0.3	0.52	0.4	0.57	0.7	28	5	85%	33
n-Pentane (ppbV)	2.5	0.27	0.86	0.38	0.65	1.14	18	15	55%	33
n-Propanol (ppbV)	26.63	5.92	14.02				30	3	91%	33
o-xylene (ppbV)	2.6	0.3	1.07	0.3	0.48	0.9	29	4	88%	33
Propane (ppbV)	15	0.64	3.72	0.93	1.75	5.07	0	33	0%	33
Propene (ppbV)	2.33	0.35	0.72	0.39	0.55	0.78	22	11	67%	33
Styrene (ppbV)	1.5	0.51	0.95	0.67	0.85	1.5	28	5	85%	33
Toluene (ppbV)	7	0.33	1.51	0.61	0.77	1.52	3	30	9%	33

Daniel - Lumped VOC Species										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Paraffins (ppbC)	127.6	6.85	46.38	19.17	26.7	72.47	0	33	0%	33
Isoparaffins (ppbC)	51.2	2.05	18.35	7.81	13.82	32.12	0	33	0%	33
Olefins (ppbC)	243.6	2.69	22.85	6.76	8.67	13.41	1	32	3%	33
Aromatics (ppbC)	114	5.25	29.1	13	21.11	33.87	0	33	0%	33
Napthlenes (ppbC)	26.6	0.62	5.59	1.37	3.78	7.37	9	24	27%	33
Oxygenates (ppbC)	268.9	1.62	67.74	36.84	56.06	94.82	6	27	18%	33
Total Non-Methane Hydrocarbons (ppbC)	876.1	92.34	337.6	193.3	277.2	395.2	1	32	3%	33

Table 6-10. Summary of carbonyl data.

Jonah - Carbonyls										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Acetaldehyde (ppbV)	2.41	0.29	0.91	0.53	0.65	1.18	0	32	0%	32
Acetone (ppbV)	6.76	1.2	2.69	1.77	2.38	3.47	0	32	0%	32
Crotonaldehyde (ppbV)	3.08	0.18	0.92	0.55	0.75	0.95	23	9	72%	32
Formaldehyde (ppbV)	4.71	0.62	1.95	1.22	1.52	2.08	0	32	0%	32
Boulder - Carbonyls										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Acetaldehyde (ppbV)	3.02	0.27	0.76	0.5	0.59	0.84	2	26	7%	28
Acetone (ppbV)	5.77	1.22	2.48	1.71	2.28	2.87	0	28	0%	28
Butyraldehyde (ppbV)	0.7	0.7	0.7				27	1	96%	28
Crotonaldehyde (ppbV)	3.04	0.18	1.19	0.6	0.63	1.5	22	6	79%	28
Formaldehyde (ppbV)	3.47	0.45	1.12	0.84	1	1.25	2	26	7%	28
Daniel - Carbonyls[a]										
Compound	Max	Min	Mean	Q1	Q2	Q3	ND	N	%ND	N+ND
Acetaldehyde (ppbV)	0.97	0.23	0.42	0.3	0.36	0.53	3	25	11%	28
Acetone (ppV)	3.65	1.03	1.82	1.32	1.61	1.99	0	28	0%	28
Crotonaldehyde (ppbV)	1.88	0.18	0.67	0.34	0.36	0.42	20	8	71%	28
Formaldehyde (ppbV)	1.25	0.33	0.65	0.45	0.48	0.97	6	22	21%	28

[a] Samples taken at 9:00am of Feb 7, 18, 19, 20, and 21 were flagged as “suspicious” and were removed before calculating the Daniel carbonyls statistics.

Average TNMHC concentrations and sample compositions are illustrated in Figure 6-1. VOC concentrations were highest by far at Jonah, followed by Boulder and then Daniel. This spatial distribution is consistent with the distance of each location from the major concentrations of gas wells. Average sample compositions are roughly similar at Jonah and Boulder with Jonah having a somewhat higher paraffin and isoparaffin fraction. Sample composition at Daniel is more variable due to the very low VOC levels found at this site. It is important to note that the percent compositions for paraffins & isoparaffins, olefins, aromatics & napthlenes and oxygenates shown in Figure 6-1 represent fractions of the total *identified* compounds (and thus add to 100%). The "unidentified %" values shown in this figure represent the fraction of TNMHC left over after accounting for all of the identified compounds. Thus, the similarities between Jonah and Boulder in percent composition refers to the distribution of identified compounds. In contrast, the fraction of TNMHC comprised of unidentified compounds is significantly higher on average at Boulder than at Jonah. Additional investigation is needed to determine the nature and likely sources of unidentified compounds at Boulder. The relatively high unidentified fraction at Daniel is not surprising given the very low average TNMHC levels at this site.

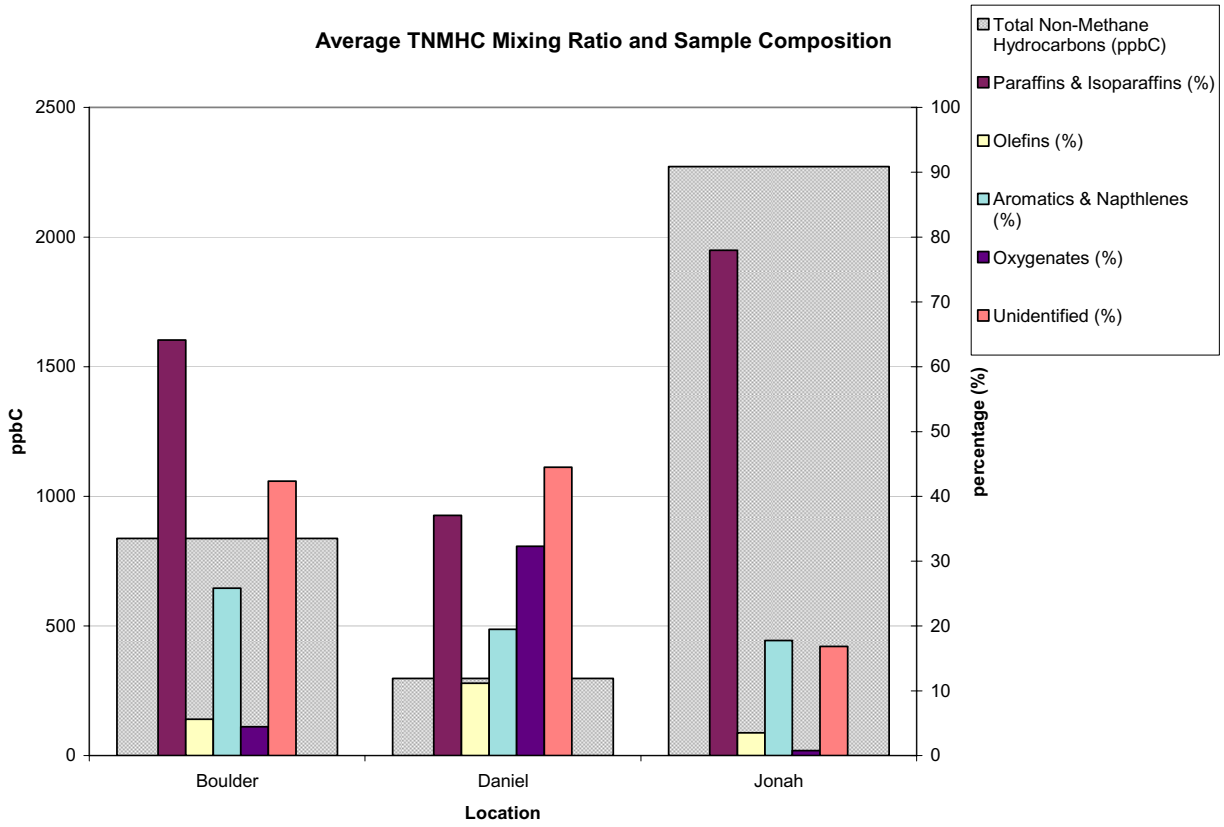

Figure 6-1. TNMHC concentrations (wide grey bars) and average VOC sample compositions by sampling location.

Average TNHMC concentrations and sample compositions by time of day are shown in Figure 6-2. Sample compositions shown in this figure were calculated in the same manner as these shown in Figure 6-1. TNMHC concentrations are lower in the afternoon due to enhanced mixing. Sample compositions do not change significantly during the course of the day, suggesting these

averages, which are dominated by the high concentrations sampled at Jonah, are generally representative of fresh emissions throughout the day.

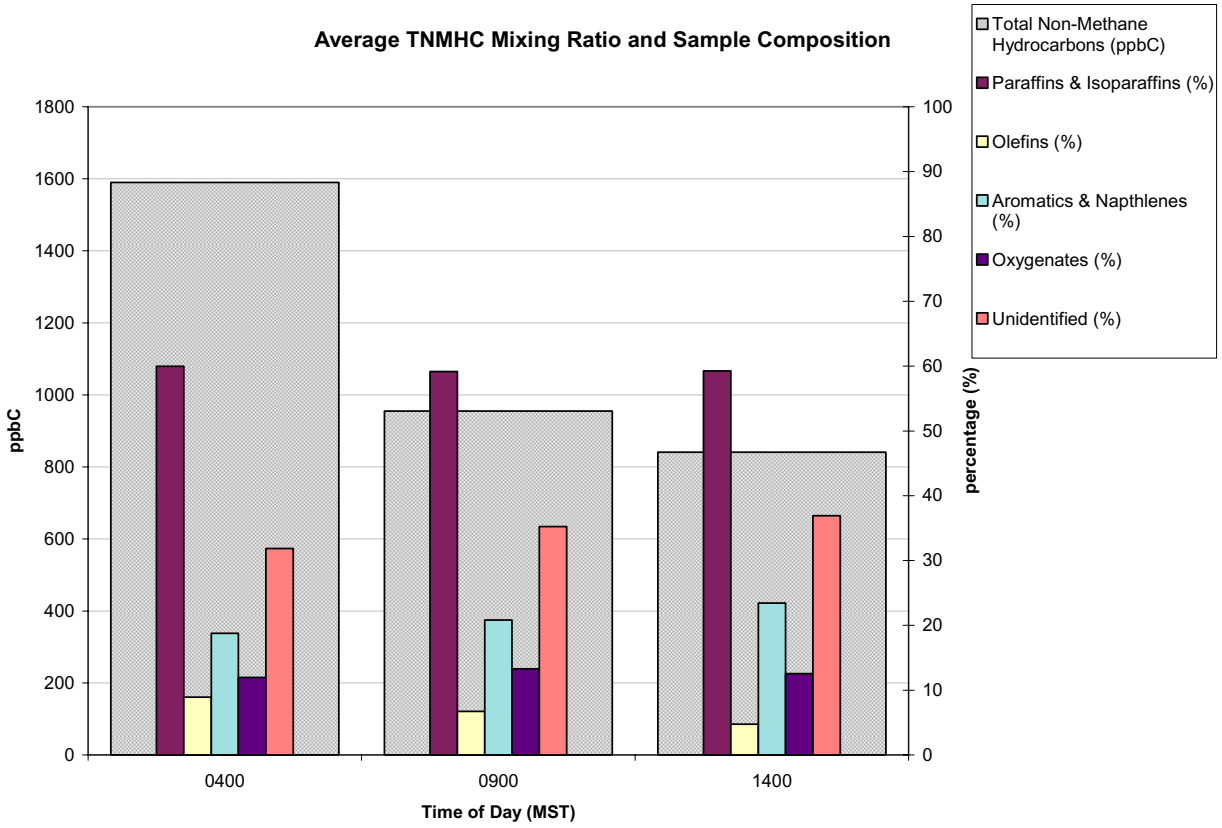

Figure 6-2. TNMHC concentrations (wide grey bars) and average VOC sample compositions by sampling time.

Average concentrations of abundant VOC species are shown for all sites in Figure 6-3. Note that concentrations are represented on a log scale on this plot. Species shown in this plot are those which were detected in at least 75% of all samples collected at Jonah. Light, paraffinic hydrocarbons found in natural gas dominate the composition at Jonah and Boulder, concentrations are much lower at Daniel. A similar summary for maximum incremental reactivity (MIR)weighted average VOC species concentrations (with carbonyl species included) is presented for data collected at Jonah (Figure 6-4) and Boulder (Figure 6-5) in which species are sorted left to right based on decreasing average (unweighted) concentrations. MIR weighted concentrations reflect the relative importance of each species in ozone formation (Carter, 1998). Note the first six species are paraffins which were shown above to be extremely abundant at all sites. However, due to their low reactivities, these species are not significantly more important on a MIR-weighted basis than toluene, and m,p-xylene. Overall, the total reactivity of VOCs found in the study region is relatively low compared to typical urban air samples.

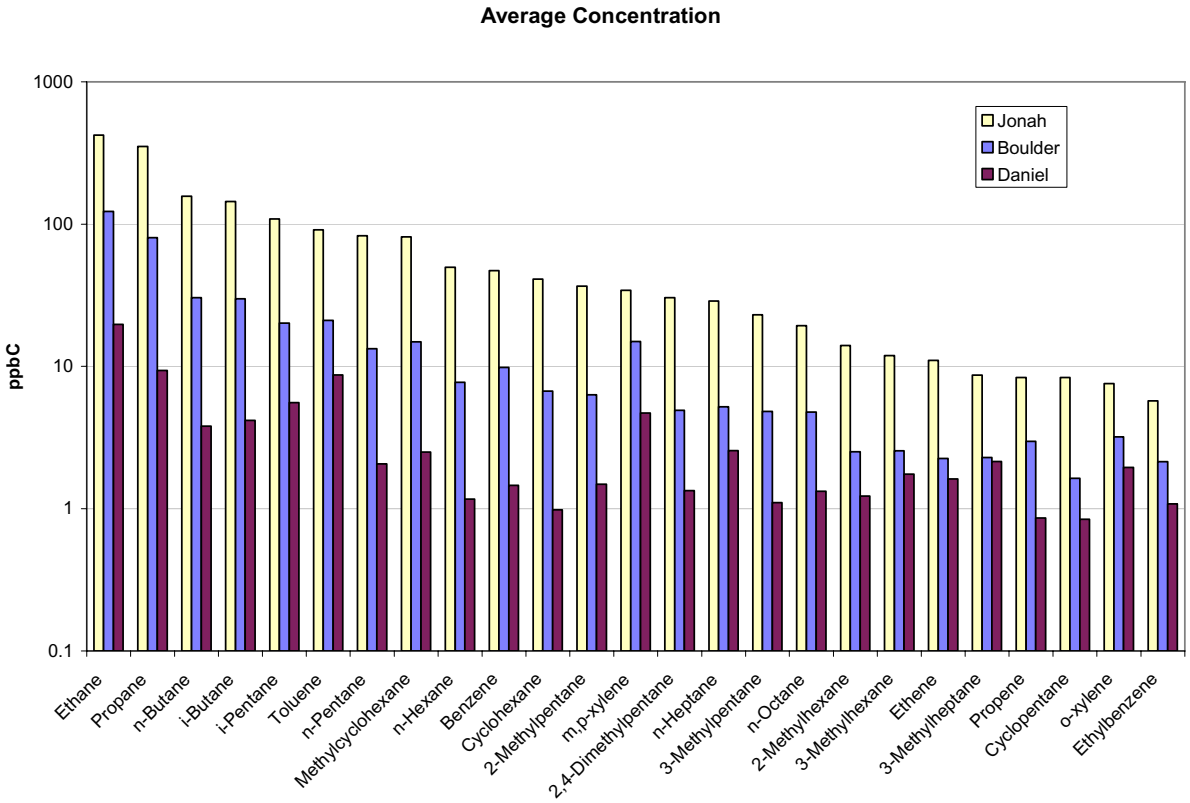

Figure 6-3. Average concentrations in ppbC of most abundant VOC species at each sampling site (includes species listed are those detected in at least 75% of samples collected at Jonah).

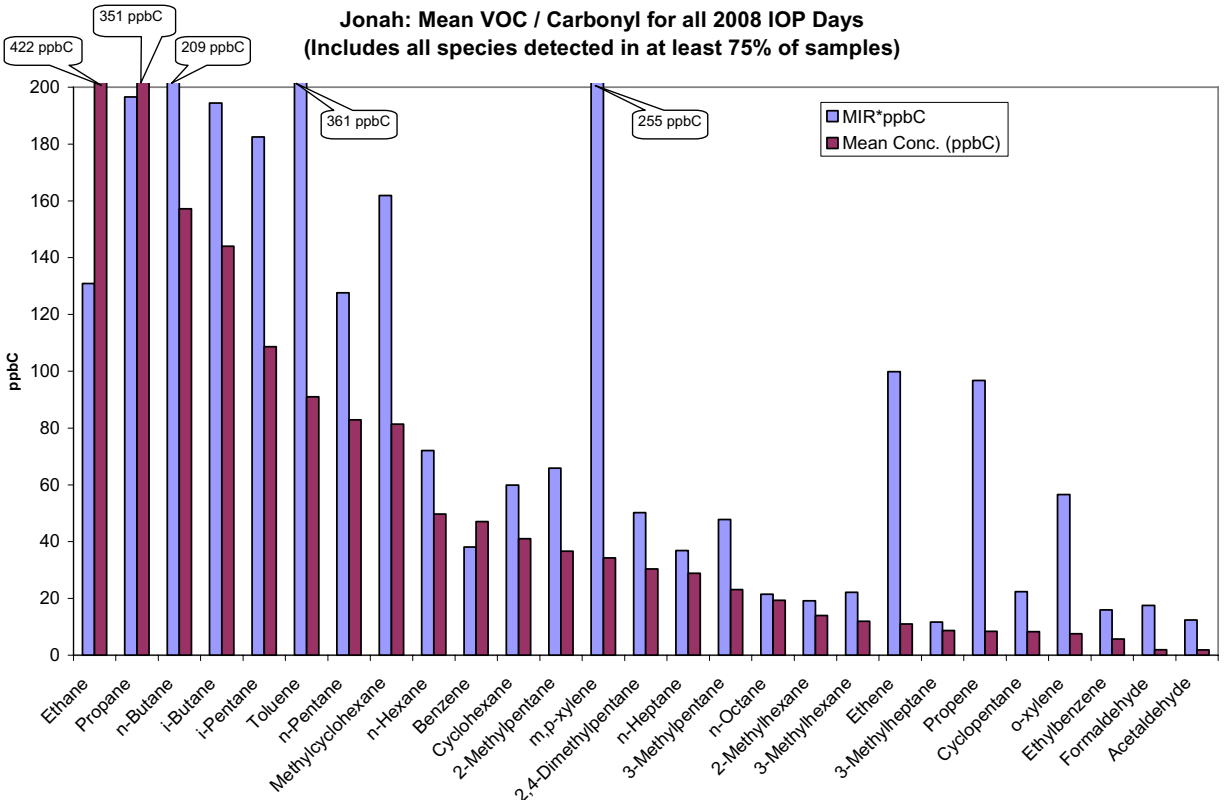

Figure 6-4. Average VOC species concentrations in ppbC and MIR weighted concentrations for most abundant VOC and carbonyl species at Jonah.

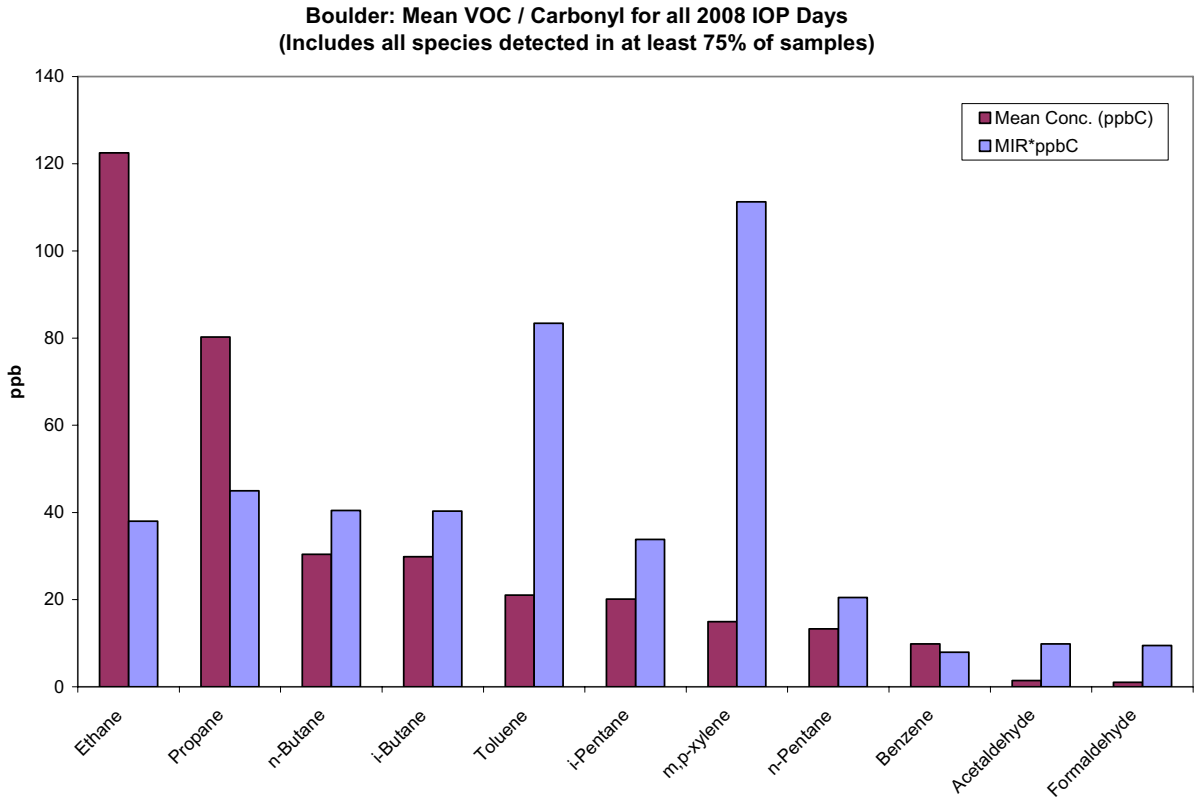

Figure 6-5. Average VOC species concentrations in ppbC and MIR weighted concentrations for most abundant VOC and carbonyl species at Boulder.

Variations in concentration by time of day for formaldehyde are displayed graphically in Figure 6-6. Concentrations are generally low at all sites with the highest concentration at Jonah in the early morning which decrease during the day. This suggests primary (i.e., directly emitted) formaldehyde is the dominant source of formaldehyde at Jonah with very limited photochemical production of formaldehyde during the day. In contrast, formaldehyde concentrations increase during the course of the day at Boulder. This may represent photochemically produced (secondary) formaldehyde production or transport of primary formaldehyde to Boulder during the day, or a combination of both.

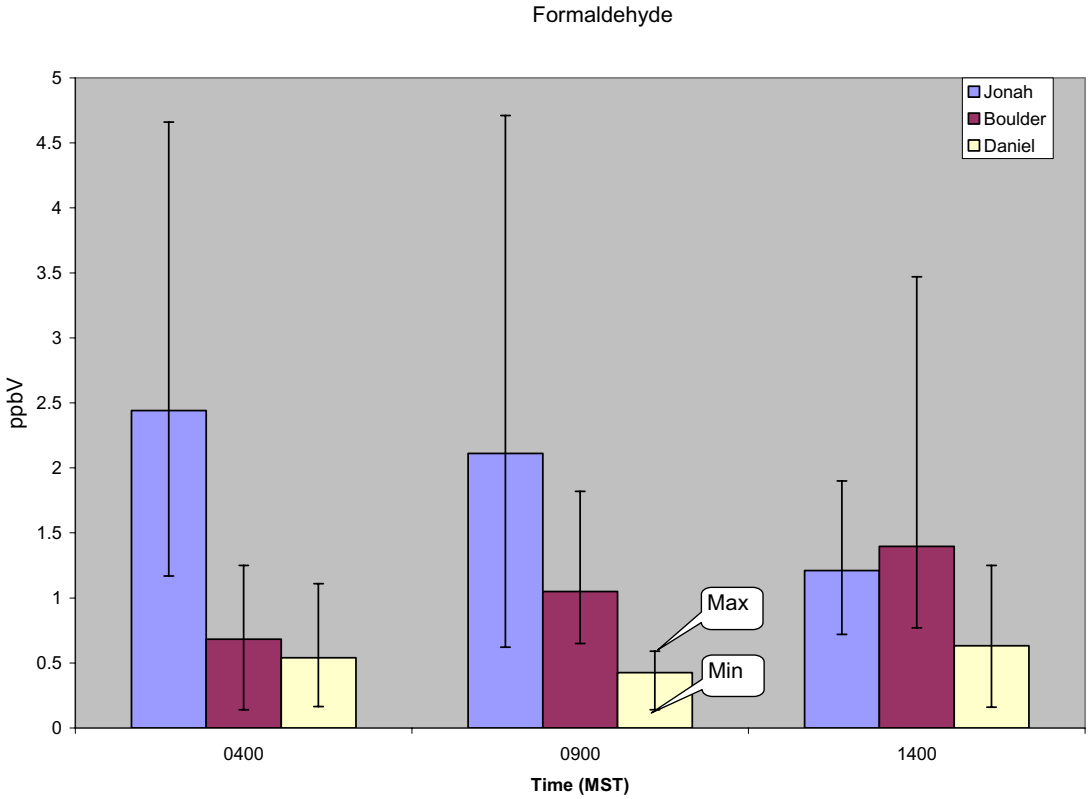

Figure 6-6. Average formaldehyde concentrations at each monitoring site by time of day.

A total of 18 VOC canister samples and 14 carbonyl cartridge samples were collected via the aircraft as described above. A few samples showed very low VOC levels associated with flight through clean background air. A summary of VOC samples collected during afternoon flights at locations where very high ozone levels were recorded is presented in Table 6-11. Average sample compositions at Jonah and Boulder are also shown in this table for comparison. Samples with moderately high TNMHC levels had compositions generally similar to those found in the Jonah and Boulder samples, with paraffins and isoparaffins dominating. Two notable exceptions are the 15:55 MST sample from the 10 March flight and the 15:24 MST sample from the 11 March flight which contained very high levels of iso-butane, iso-pentane and xylenes. Samples with significant quantities of TNMHC and such high aromatics content were not found at the surface sites. Further investigation will be needed to determine the potential origins of the VOCs in these samples.

Table 6-11. Summary of VOC sample compositions from aircraft samples associated with elevated ozone levels.

	02/19/08	02/20/08	02/21/08		02/29/08			03/10/08	03/11/08		Avg 14:00 - 17:00 samples at:	
Parameter	**16:18**	**16:20**	**14:19**	**16:16**	**14:29**	**14:57**	**15:12**	**15:55**	**13:29**	**15:24**	**Jonah**	**Boulder**
TNMHC (ppbC)	1833	1891	1374	846	540	431	874	5538	440	9821	1261	851
Total Identified (%)	84%	90%	77%	74%	67%	48%	85%	82%	57%	90%	79%	53%
Paraffins (%)	51%	42%	47%	41%	31%	30%	47%	8%	10%	7%	44%	26%
Isoparaffins (%)	21%	19%	13%	12%	21%	8%	21%	30%[b]	4%	43%[b]	17%	7%
Aromatics (%)	5%	9%	12%	8%	12%	7%	11%	42%[c]	2%	36%[c]	10%	13%
Napthlenes (%)	6%	6%	4%	3%	1%	2%	6%	1%	1%	1%	5%	3%
Olefins (%)	1%	13%[a]	2%	2%	2%	1%	1%	1%	1%	1%	3%	3%
Oxygenates (%)	0%	0%	0%	9%	0%	0%	0%	0%	39%	2%	2%	0%
Ozone (ppb)	133	147	130	111	64	79	114	92	108	130	--	--

[a] High acetylene
[b] High i-butane and i-pentane
[c] High xylenes

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

An extensive field study was undertaken between 15 January and 31 March 2008 to study ozone episode development in southwestern Wyoming, focusing on conditions in the Jonah – Pinedale area. Meteorological and aerometric measurement activities in 2008 were substantially similar to those conducted during the 2007 winter study with the exception that tethersonde operations were not conducted in 2008 due to resource limitations. These operations consisted of routine aerometric and meteorological monitoring at six supplemental sites in addition to the three permanent monitoring sites (Jonah, Boulder, Daniel) in the study area and a series of special monitoring activities carried out during three intensive operating periods (IOPs).

7.1 Meteorological Characteristics of High Ozone Events

In contrast to results of the 2007 measurement campaign which did not capture any high ozone events, conditions in 2008 produced several high ozone episodes which were well captured during the three IOPs. Comparisons of meteorological conditions in 2008 with those prevailing during the 2007 field study revealed that one of the key differences was the extensive snow cover in 2008 which was not present during 2007. Snow cover appears to be a key ingredient in winter ozone development. During the 2007 study, although there were extended periods when synoptic-scale meteorological conditions resulted in relatively light winds in the study area, the lack of snow cover and subsequent lower UV albedo reduced the amount of UV radiation available for photolysis and associated ozone production. In addition, our results show that snow cover allows the low level inversion to persist strongly during most or all of the daylight hours thus enhancing low-level atmospheric stability and substantially reducing vertical mixing.

High ozone events observed during the 2008 IOPs allowed for development of some initial understanding of the meteorological characteristics of such events, which were characterized by an area of high pressure building into southwestern Wyoming from the west. Low level winds were typically out of the southeast during the afternoon hours on episode days. These winds usually follow a light northwesterly (down valley) surface flow that develops during the previous night and continues well into the morning. Winds aloft under these events are westerly to northwesterly. The afternoon surface southeasterly winds occur only within the inversion layer. This flow pattern serves to recirculate ozone and ozone precursors within the study area, thereby enhancing ozone production. Surface winds in the southern portion of the study area (i.e., south of Jonah) were often observed to be in a different direction from those at locations north of Jonah.

When the favorable synoptic conditions described above develop late in the day or during the night hours, the first high ozone concentrations usually develop the following day beginning between approximately 11:00 and 13:00 MST if the favorable conditions persist. During a day of elevated ozone, the high readings peak in the afternoon and can last well into the evening hours and in some cases past midnight before lowering, suggesting that ozone loss mechanisms such as dry deposition are minimal. If the following day continues to have favorable weather conditions, the ozone levels begin to rise earlier than during the previous day and frequently to higher levels, suggestive of carry over of ozone and precursors from one day to the next. Once high ozone concentrations have formed, the ozone levels remained elevated even under

increasing cloud cover ahead of an approaching storm system. Elevated concentrations persisted until brisk (usually west or northwesterly) winds arrived and scoured out the surface inversion.

7.2 Air Quality Conditions during High Ozone Events

A total of 14 days with 8-hour average ozone greater than 75 ppb were observed during the 15 January – 31 March 2008 study period. On nearly all occasions, concentrations at the Boulder monitor were either the highest or nearly the highest out of all surface monitoring sites in Southwest Wyoming. Elevated ozone was observed within the mixed layer by aircraft as far north as Pinedale on some occasions but did not extend to the higher elevation Pinedale CASTNET monitoring site or as far west as Daniel. Ozone concentrations at Cora which is located at the northern end of the study area were also lower than at locations to the south, exceeding a 75 ppb 8-hour average on just one day (23 February). Aircraft observations showed that high ozone concentrations extended at least as far south as Simpson's Gulch on some days. Elevated ozone was confined to a relatively shallow mixed layer extending at most a few hundred meters above ground level on all IOP days. Ozone concentrations above the mixed layer were generally in the 50 – 60 ppb range, with higher concentrations observed at much higher altitudes on a few occasions. The 50-60 ppb ozone observed above the mixed layer is consistent with values observed at the Pinedale-CASTNET site and overnight values observed at Cora and Daniel during the IOPs (see Figure 4-7). It is also consistent with values observed at South Pass and Murphy Ridge during these periods. These results demonstrate that "regional background" ozone during the IOP events was in the 50-60 ppb range. Both surface and aircraft observations showed that ozone and PM concentrations within the mixed layer were frequently positively correlated.

As was the case in 2007, periods of very high NOx and hydrocarbon concentrations were observed at Jonah on episode days, with maximum 3-hour average TNMHC concentrations exceeding 10,000 ppbC and maximum NOx concentrations exceeding 100 ppb. Concentrations at Boulder and Daniel were significantly lower.

7.3 Recommendations

Additional field measurements are needed to more fully characterize high ozone events in southwestern Wyoming. Results from the 2007 and 2008 field studies suggest that particular priority be placed on the following:

- Extend field operations further south into Sweetwater, Lincoln and Uinta counties to allow exploration of the full spatial extent of episode conditions and gain a better understanding of the influence of major sources, including other oil and gas fields, trona sources, and the Bridger and Naughton power plants on regional air quality.
- Expand the scope of ozone precursor monitoring to include key nitrogen species such as NOy and HONO. This would provide a better understanding of the role of NOx in ozone formation during the unusual winter conditions.
- Perform airborne UV photolysis rate measurements to provide more spatially representative measurements and better understand the influence of snow cover.
- Perform speciated PM sampling to better characterize aerosols found to be associated with elevated ozone in Sublette County.

- Perform trace SO_2 sampling to evaluate the potential influence of industrial sources south of Sublette County.

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APPENDIX A

Ozone Forecasting Methodology Development

Based on an analysis of prior high ozone events in the study area, meteorological conditions conducive to the formation of high ozone levels during the winter and early spring were determined to be characterized by clear skies, light winds 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.

Statistical analyses were carried out on meteorological data measured during periods of elevated ozone concentrations in the Jonah – Pinedale monitoring network during 2005 and 2006. Because the three-dimensional meteorological dispersion conditions (dilution, mixing layer depth and transport) are critical factors in pollution formation, the focus of the conceptual model was on determining the probable atmospheric characteristics aloft during project area ozone events. There were no measurements of conditions aloft that are representative of the Upper Green River Basin. As a result, pressure/height, temperatures and winds aloft measured during the twice-daily National Weather Service (NWS) rawinsondes at Riverton Wyoming were used. In addition, composite synoptic-scale surface and upper air contour maps of various parameters generated from NWS-analyzed upper-air charts on days when ozone levels were high were examined. Figure A-1 shows the configuration of the heights of the 700 mb constant-pressure surface as an example. Similar contours were generated for the mean sea level pressure (mslp), 700 mb wind speeds and temperatures, 500 mb heights, and 500 mb wind speeds. From these statistical analyses, objective criteria for the values of a number of meteorological parameters were determined that were useful in providing guidance in forecasting the probability of ozone formation in the project area. The criteria for elevated ozone levels in the project area were determined to be:

- Mean Sea Level Pressure (MLSP) 1020 mb or higher
- Surface wind speeds less than 8 knts
- 700 mb pressure level higher than 3060 meters
- 700 mb pressure temperatures 0 to –8 C
- 700 mb pressure level wind speeds less than 20 knts
- 500 mb pressure level higher than 5700 meters
- 500 mb pressure level winds less than 30 knts
- Surface snow cover

Note that the last factor listed above is surface snow cover. It was postulated that snow cover in the project area is a very important factor for two reasons: 1) it helps minimize surface heating during the day, thus further stabilizing the lower boundary layer and 2) it restarts a large fraction of the incoming UV radiation, thus increasing the total UV flux and photolysis rates.

Our analyses also showed that the pressure/height pattern at the 700 mb level is probably a more useful indicator of the general synoptic-scale pattern most affecting ozone formation than the

500 mb constant pressure pattern. Note the ridging pattern over the interior west in Figure A-1, and also the close proximity of the ridge axis to the project area.

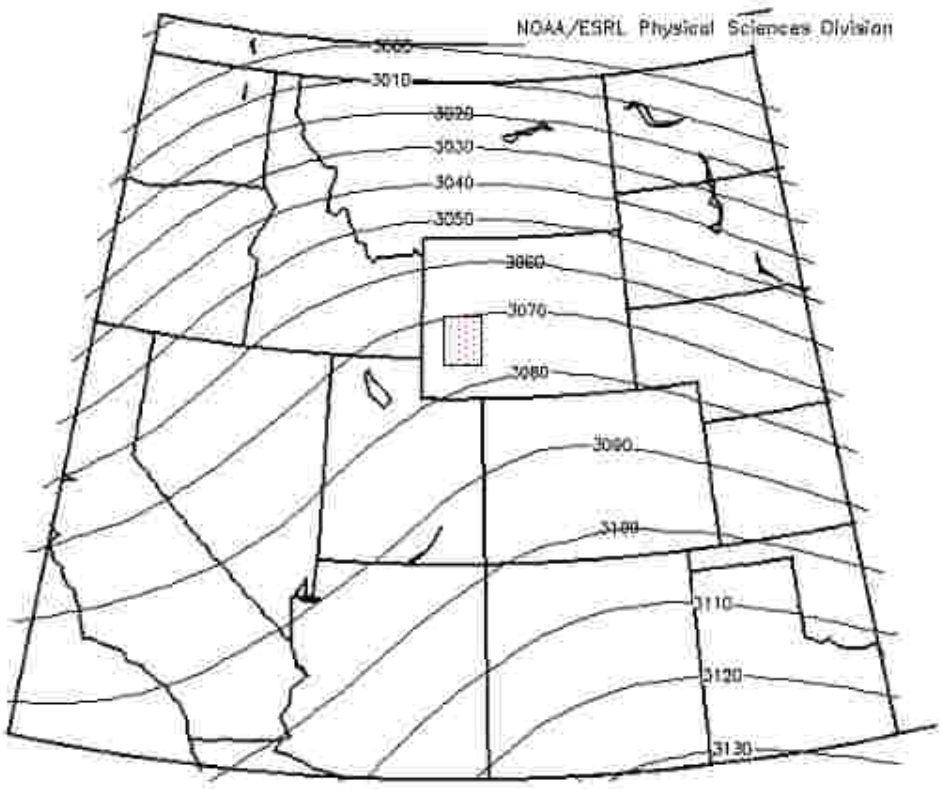

Figure A-1. Composite 700 mb heights during High Ozone Periods (Project area is indicated as shaded rectangle).

Figure A-2 presents an example of the 700 mb constant pressure-height contour pattern that was typical during high ozone events. Note the similarity of this pattern to the composite analysis result shown in Figure A-1. Of particular importance is the close proximity of the ridge axis to the project area, and the light wind speeds over the region. As a result of this information, the forecasting goal during the course of the UGWOS 2007 field study was to call for the commencement of IOP operations when the predicted synoptic pattern resembled the key conceptual characteristics as closely as possible.

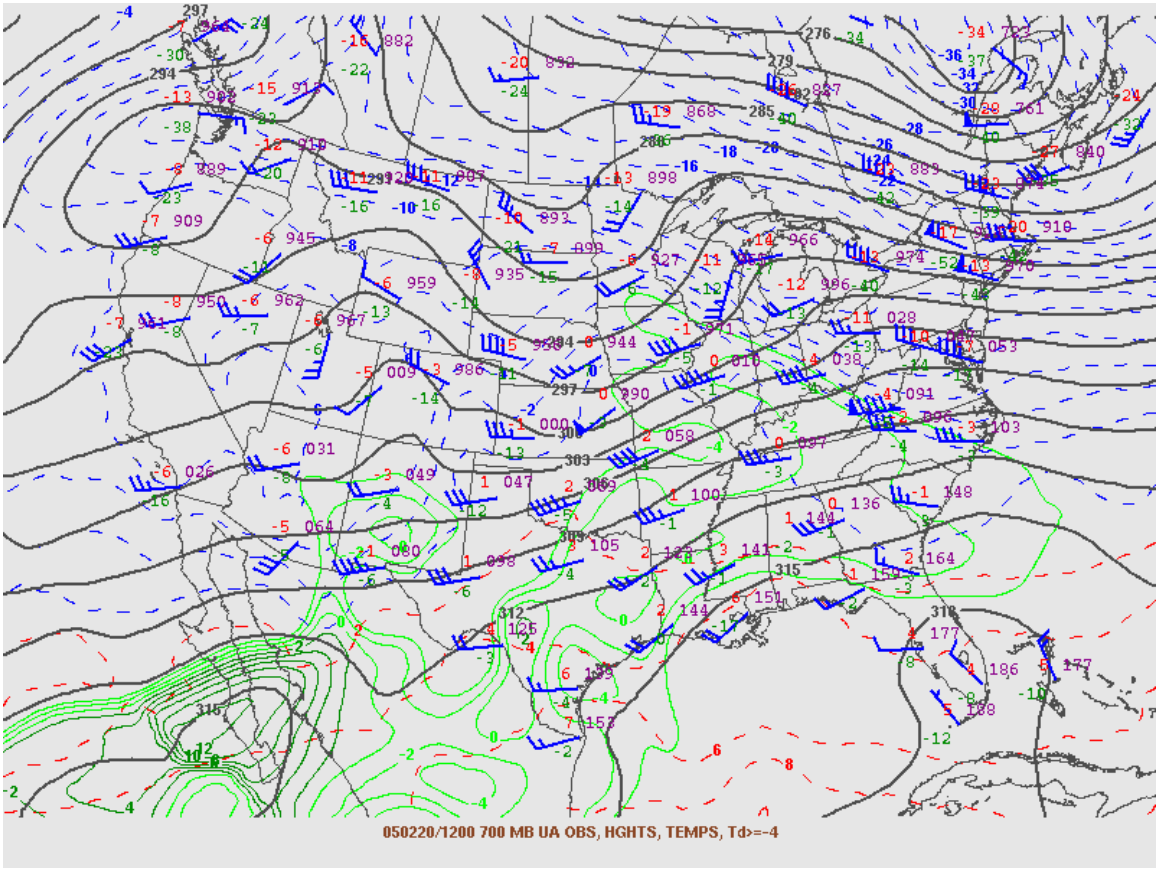

Figure A-2. Constant pressure map for 700 mb, AM (1200 UTC), 02/20/05 (Source: http://www.spc.noaa.gov)

Advanced recognition of the onset and establishment of the conceptual model characteristics was key to the operational forecasting solution for the UGWOS field measurements operations. 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, provided MSI and T&B Systems weather forecasters with the basis for daily long- and medium-range operation forecasts. As noted above, it was also recognized that the presence of sufficient snow cover to provide the radiation component needed for ozone chemistry was necessary. Local observations (i.e., real-time pictures) provided this information on a day-to-day basis.

An operational forecast, posted to the project web page, was issued by 10 MST each day that included both the short-term and long-term weather forecasts. Project participants were required to provide any changes in their operational readiness daily to the Field Project Manager and that information was incorporated into the operational forecast. When conditions were developing that were considered conducive to the development of high ozone, an alert was issued. Owing to the time required to shuttle people to the field, the uncertainties in forecasting, and budget realities, it was critical to not miss an operational opportunity while at the same time avoiding crew deployment when conditions were not conducive to operations. With this in mind, a "GO" alert was issued at the 10 MST forecast at least 48 hrs before an IOP was to begin.

Field crews began making preparations to debark to the field the following morning. A final GO or NO GO was issued by 17 MST that afternoon. If the forecast remained a GO, the crews deployed as scheduled.

The field crews met in Pinedale the following evening for a briefing and to coordinate setting up for the IOP. All equipment was deployed and checked for readiness the following day. In this manner, it was possible to begin an IOP within 48 hours of the initial GO forecast.
A major element of the monitoring was the mesonet ozone measurements. Due to the importance of having the complete suite of measurements correctly operating at the start of an IOP, procedures were established to have the ozone analyzers removed at the end of each IOP and brought back to field headquarters. This allowed us to check each samplers' operational condition and deploy units to the field quickly at the start of each IOP.

APPENDIX B

Time Series of Resultant hourly wind vectors for IOP days

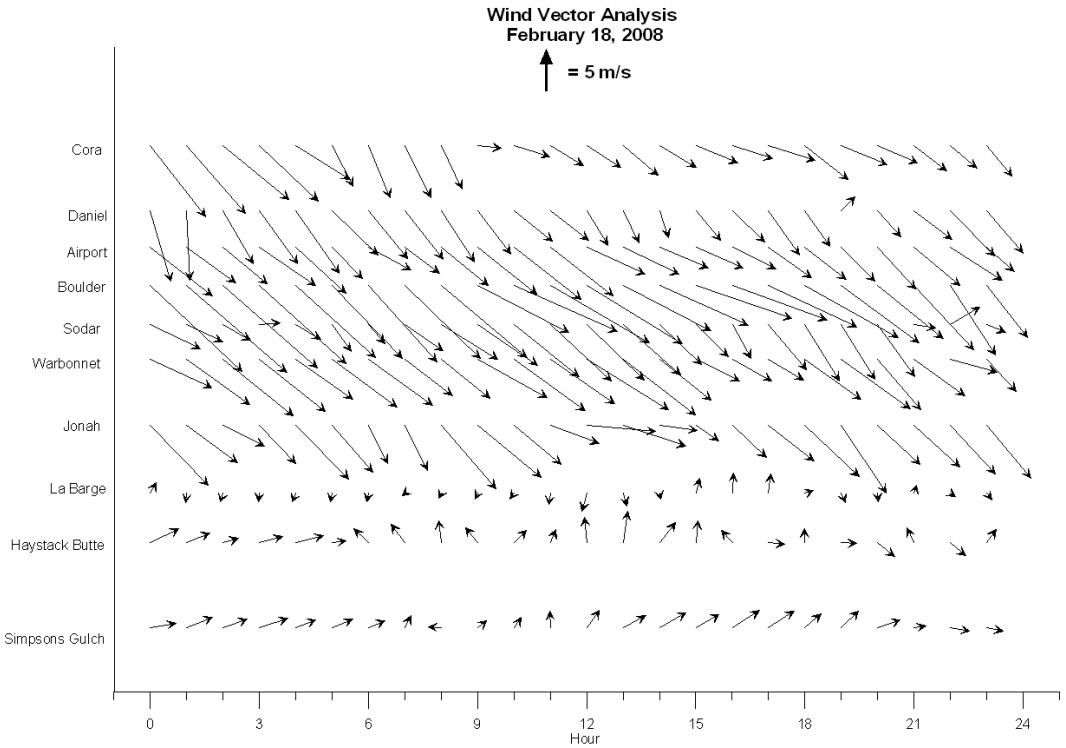

Figure 1. February 18 wind vector analysis.

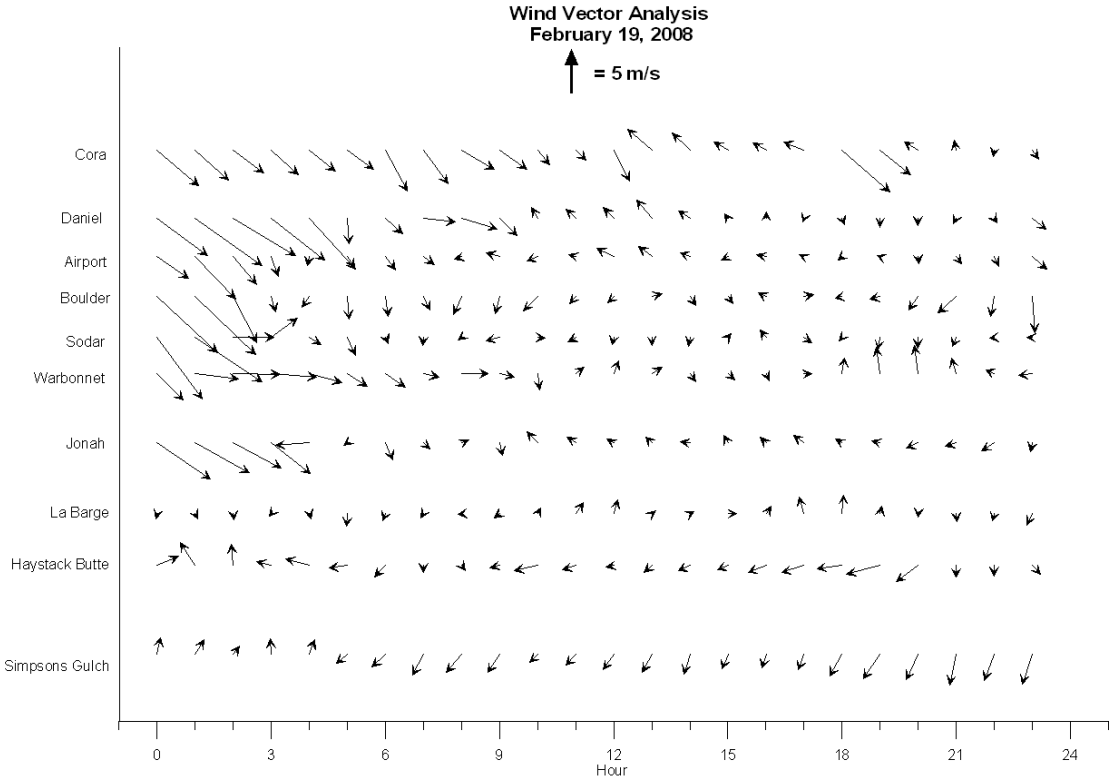

Figure 2. February 19 wind vector analysis.

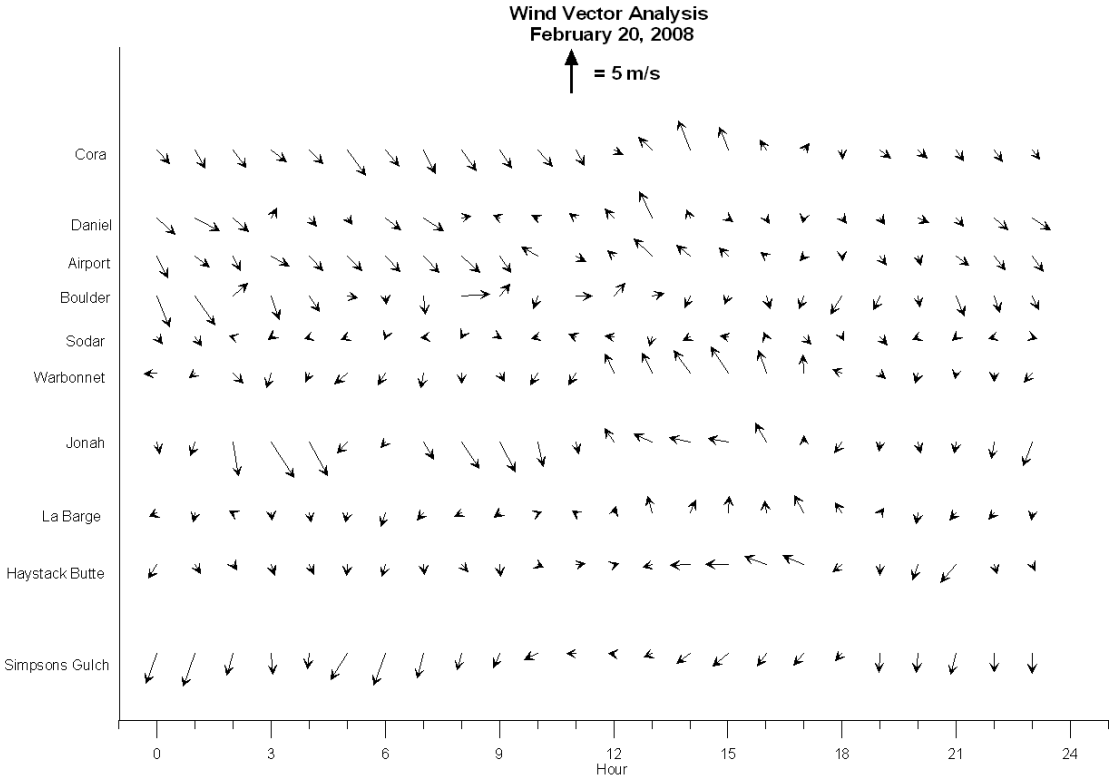

Figure 3. February 20 wind vector analysis.

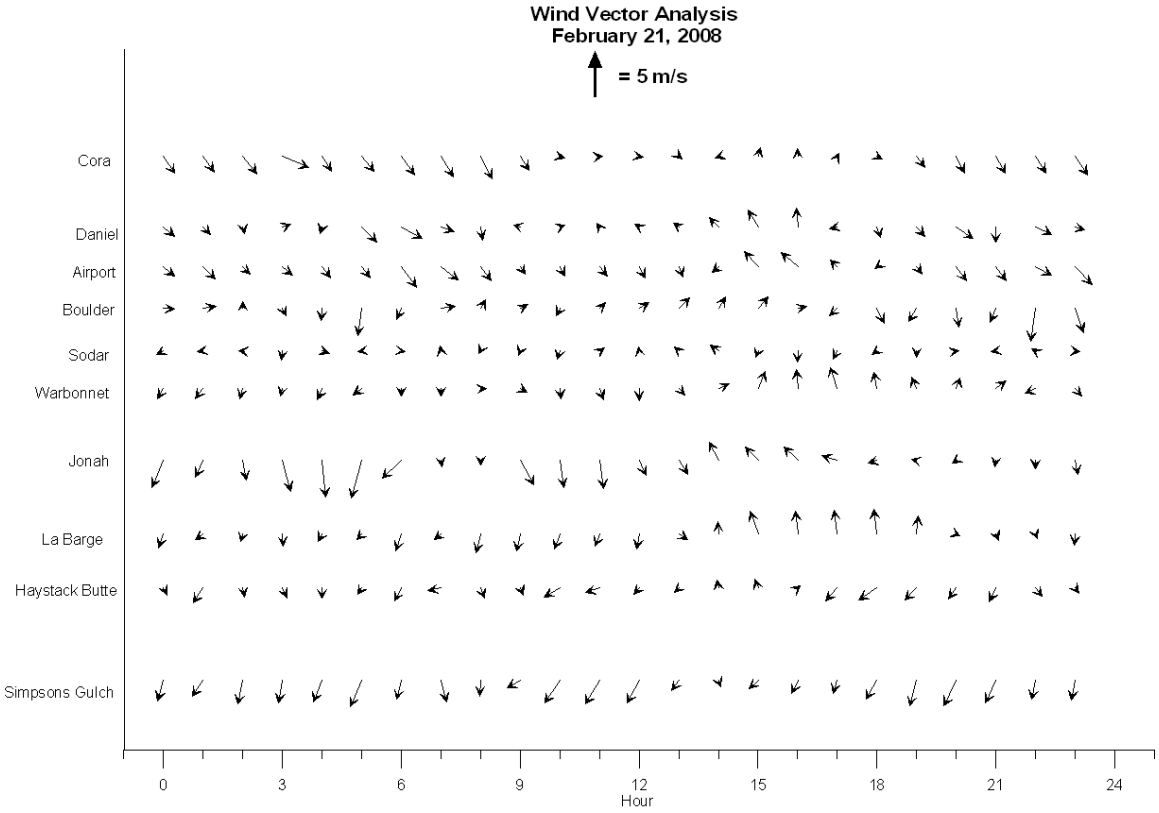

Figure 4. February 21 wind vector analysis.

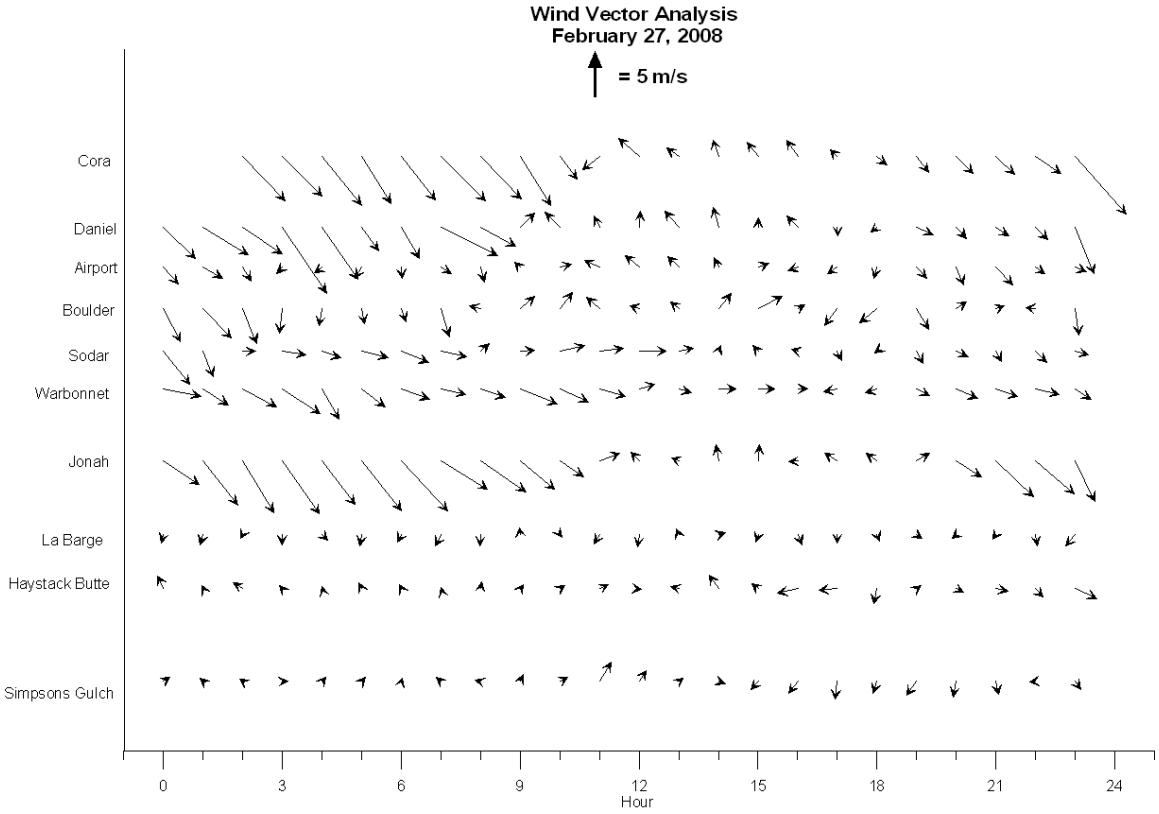

Figure 5. February 27 wind vector analysis.

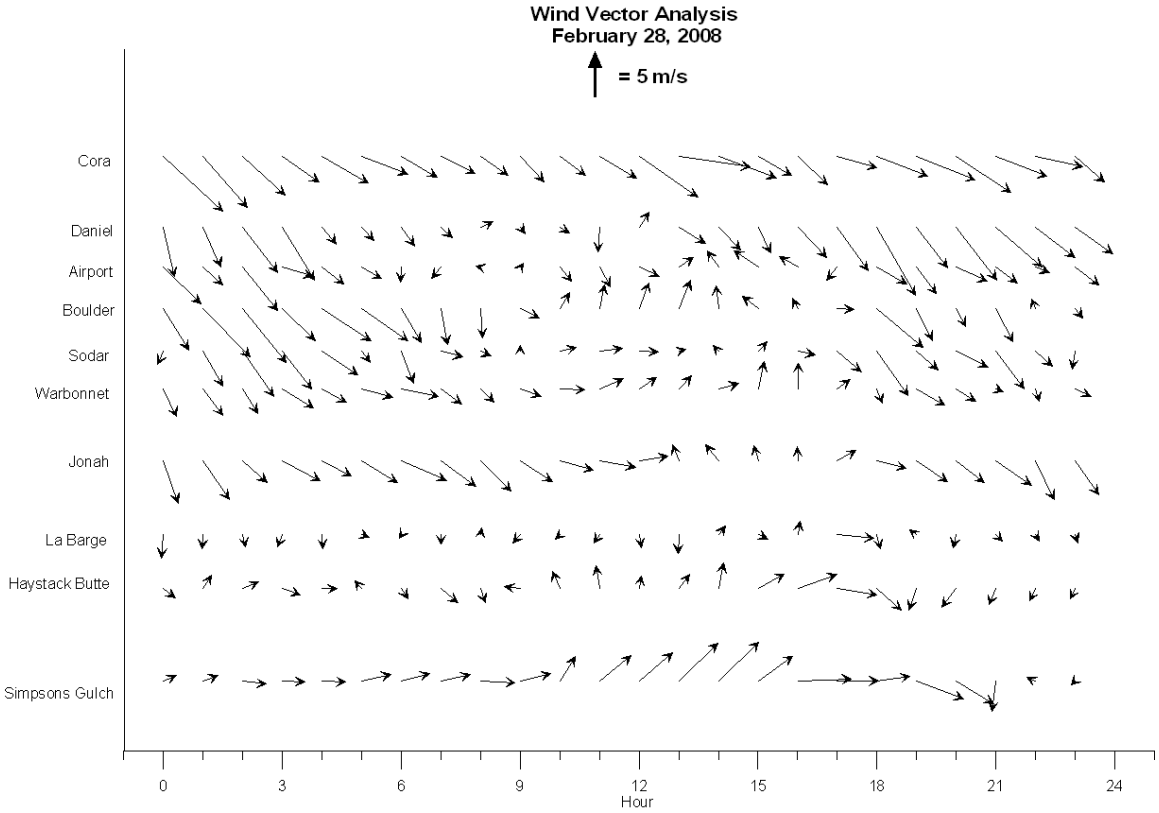

Figure 6. February 28 wind vector analysis.

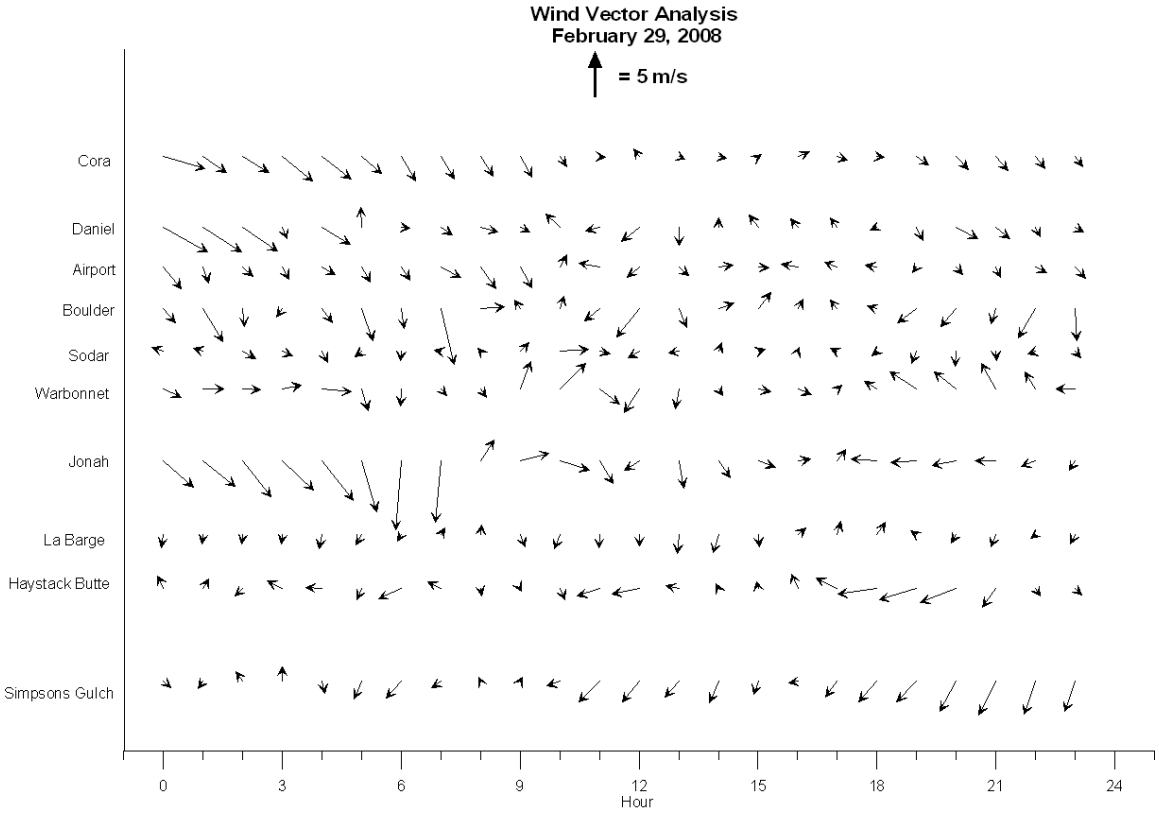

Figure 7. February 29 wind vector analysis.

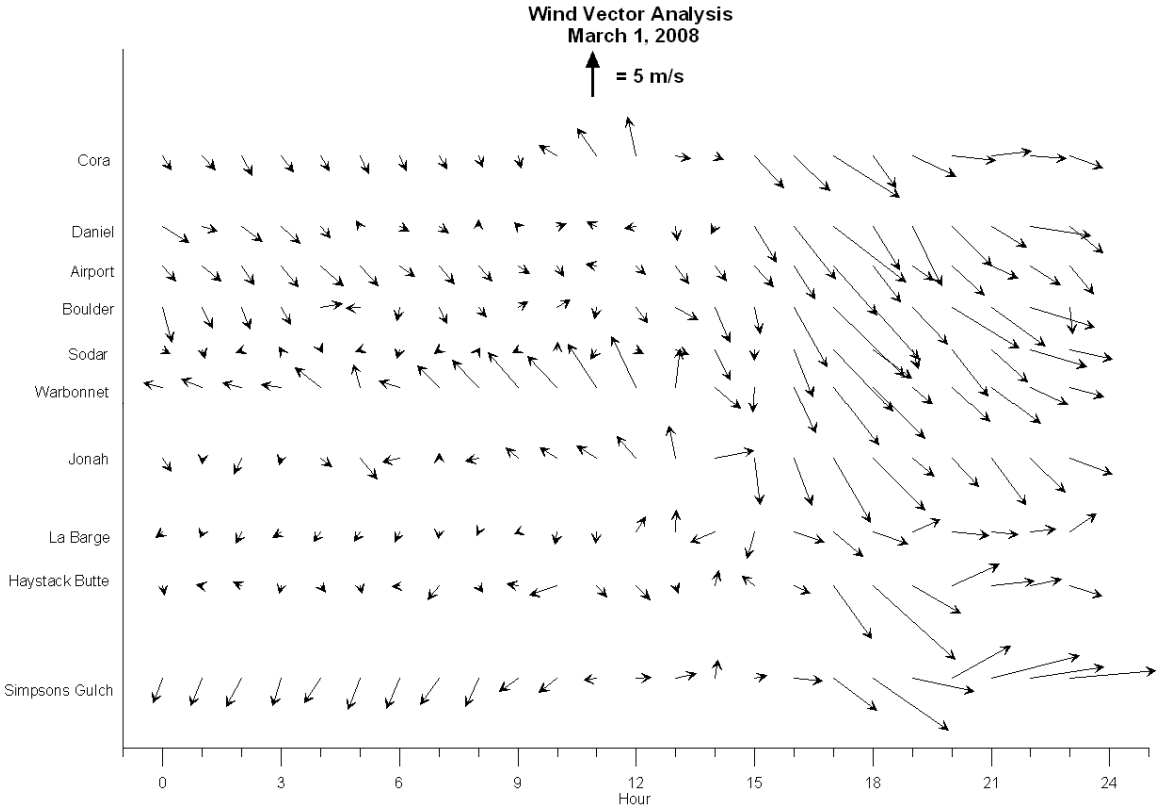

Figure 8. March 1 wind vector analysis.

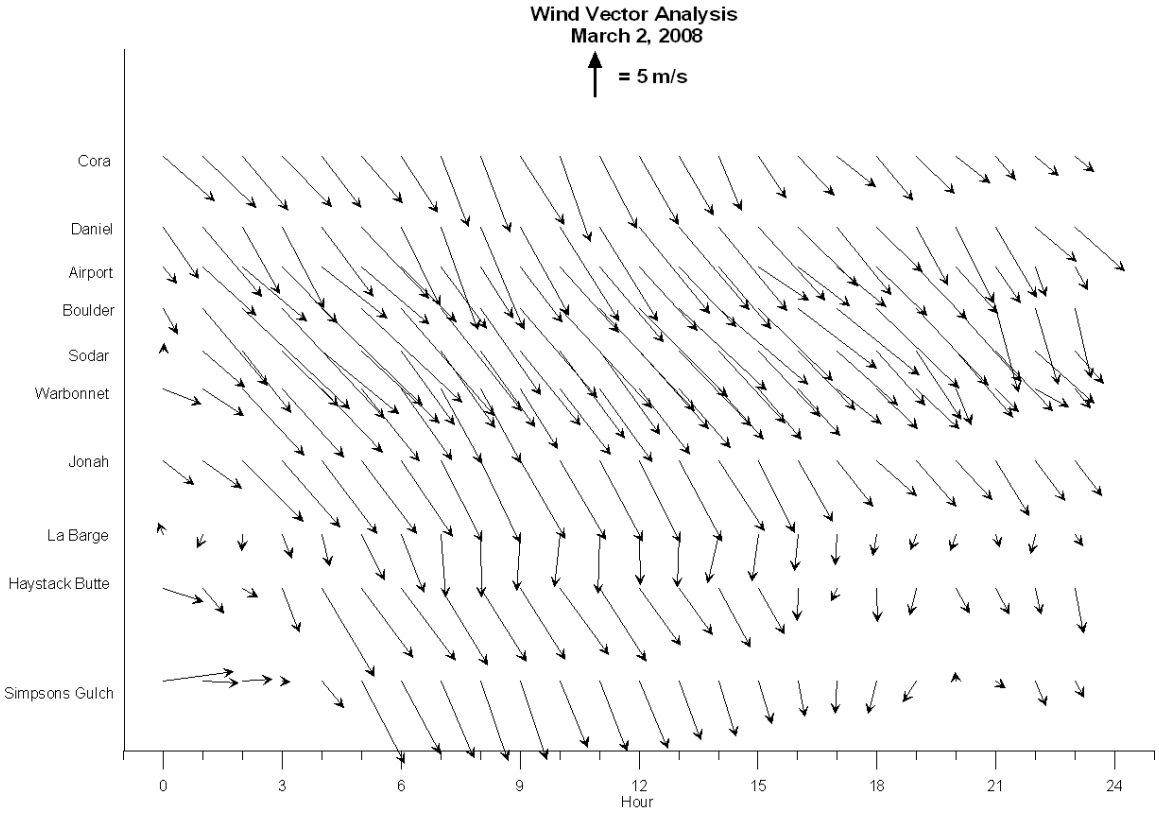

Figure 9. March 2 wind vector analysis.

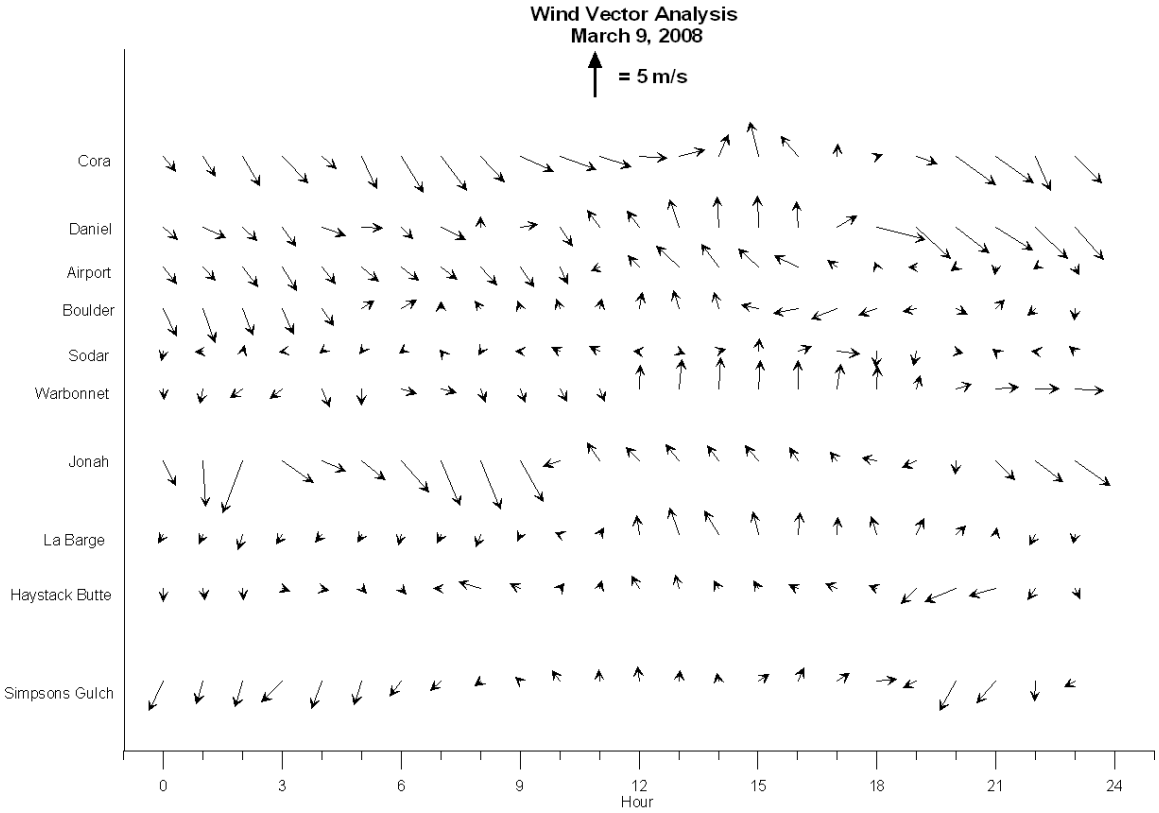

Figure 10. March 9 wind vector analysis.

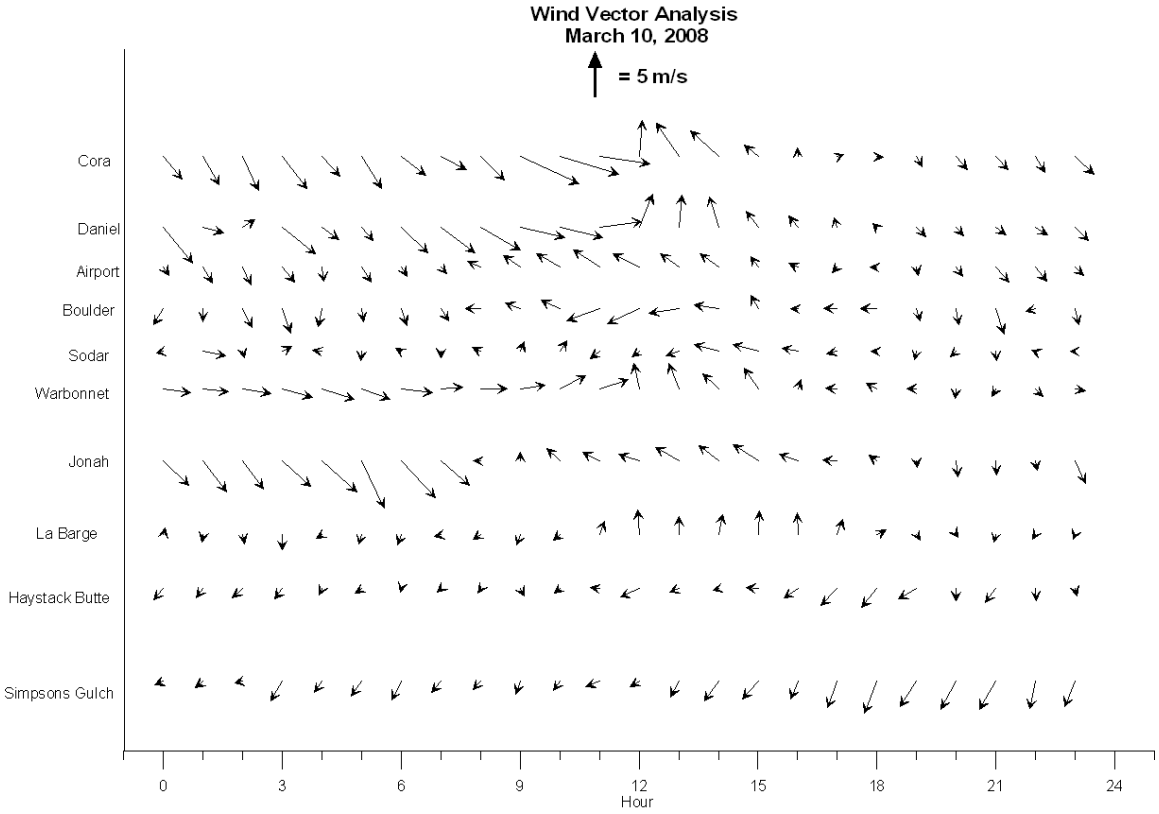

Figure 11. March 10 wind vector analysis.

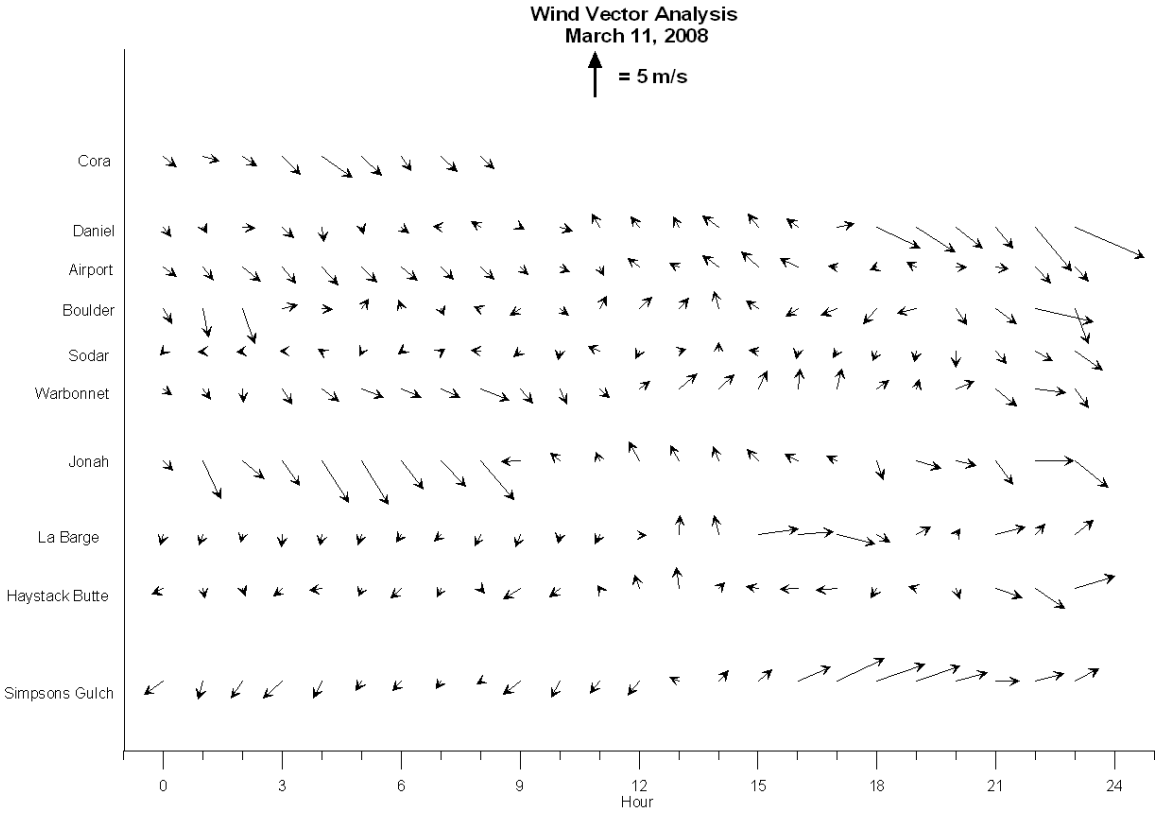

Figure 12. March 11 wind vector analysis.

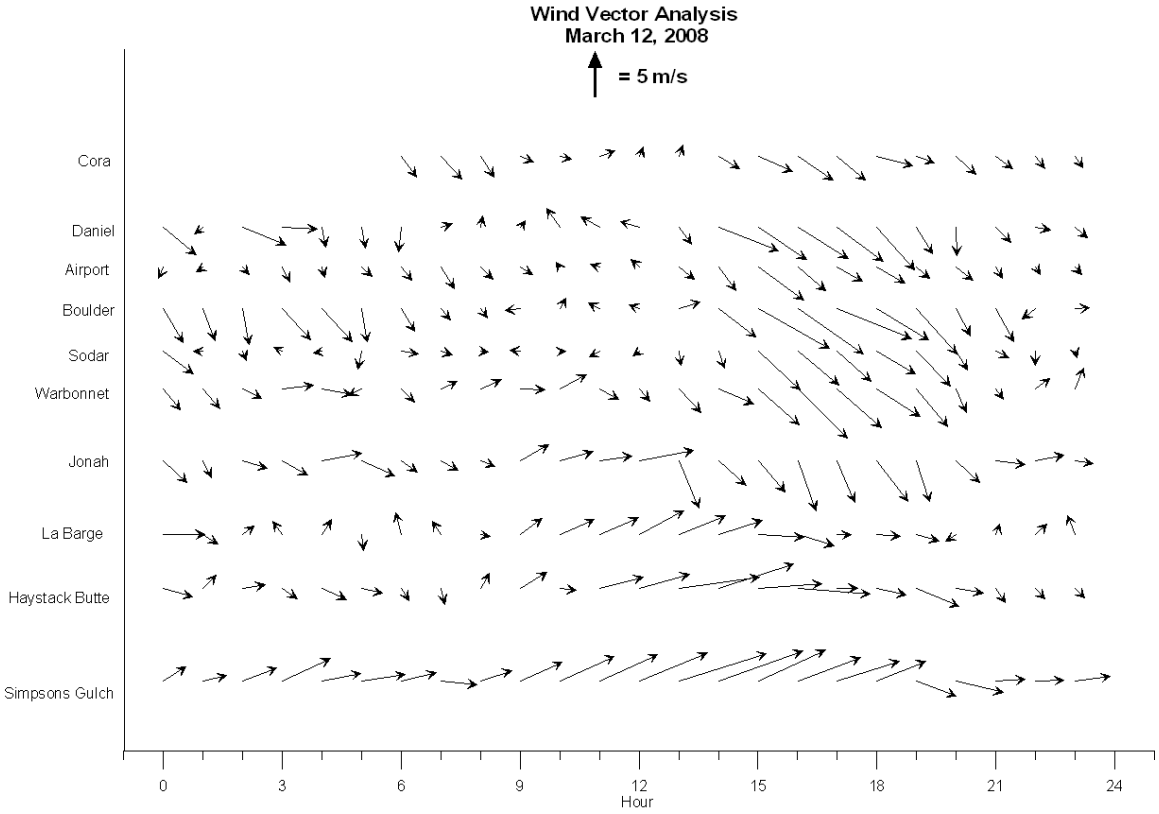

Figure 13. March 12 wind vector analysis.

APPENDIX C

Summary of Meteorological Conditions during UGWOS 2008

During the February through March period of 2008, the averaged [1] pressure pattern at the 700 and 500 millibar (mb) levels showed higher pressure southwest of the ozone study area and lower pressure to the northeast. The surface pressure indicated a high pressure center in the averaged data over the Oregon and northern California border, and that the averaged pressure was lower along the east slopes of the Rockies from Canada southward to New Mexico. These averaged pressure patterns were similar with those observed in the previous three years. There were variations in the averaged heights of the 700 and 500 mb levels directly over the ozone study area, and only slight variation in the averaged surface pressure over the study area. Table #.1 shows the averaged pressure height at 700 and 500 mb during the February/March period for the current year and the previous three years, as well as the averaged surface pressure for the same years. Averaged surface pressures during the four years were very similar.

Table #.1
Averaged Pressure Levels Over the Ozone Study Area for 2004 through 2008

February/March Period	Surface Pressure (mb)	700 mb Height (m)	500 mb Height (m)
2005	1020.0	3032	5588
2006	1020.6	3016	5550
2007	1019.7	3042	5604
2008	1020.8	3018	5552

Visually the averaged patterns at 700 and 500 mb look nearly identical over the two month period for all four years. Figures 1 through 8 show the 700 and 500 mb pressure height patterns for 2005 through 2008. The black dot in the southwestern corner of Wyoming in all figures indicates the study area location. The averaged surface pressure patterns also look nearly identical, at least for 2005 through 2007. In each of these years the surface pressure had a high center located in southwest Montana. However, the averaged surface pressure pattern in 2008 has a very different look, with the highest pressure centered well to the west along the Oregon and northern California border, and a secondary weaker center in eastern Idaho. Figures 9 through 12 show the averaged surface pressure patterns for 2005 through 2008.

[1] [1] Averaged data from ESRL web site using NCEP Reanalysis data, http://www.cdc.noaa.gov/cgi-bin/PublicData/getpage.pl

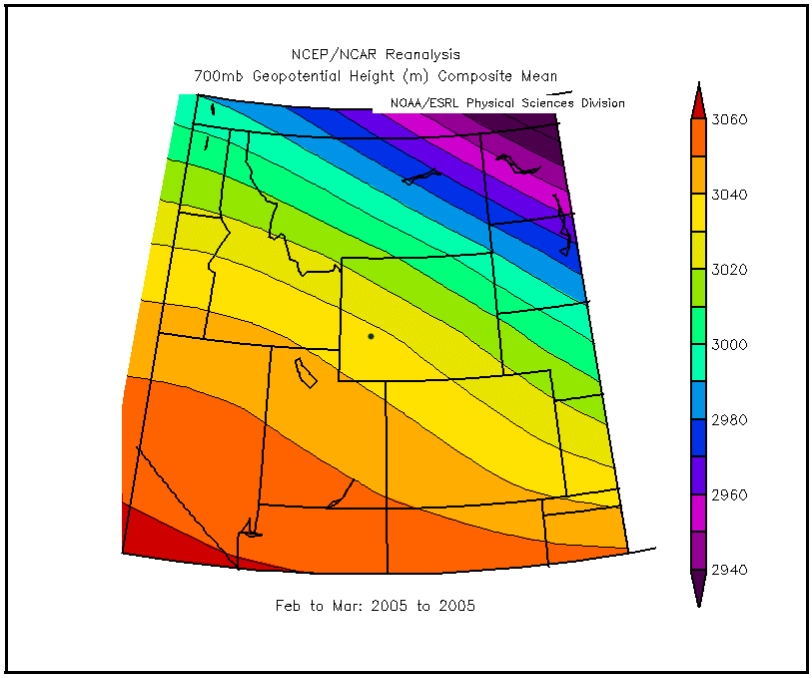

Figure 1
2005 Averaged 700 mb Height

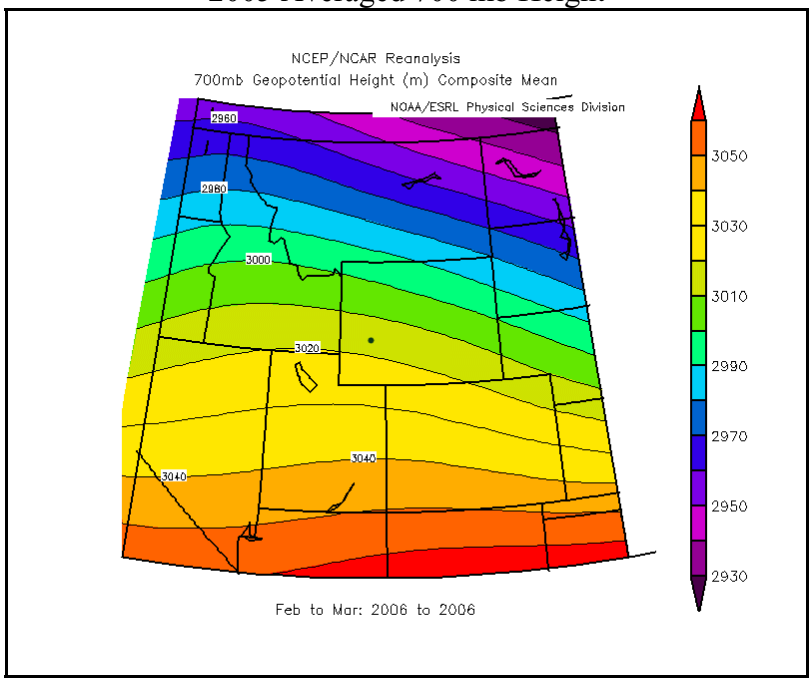

Figure 2
2006 Averaged 700 mb Height

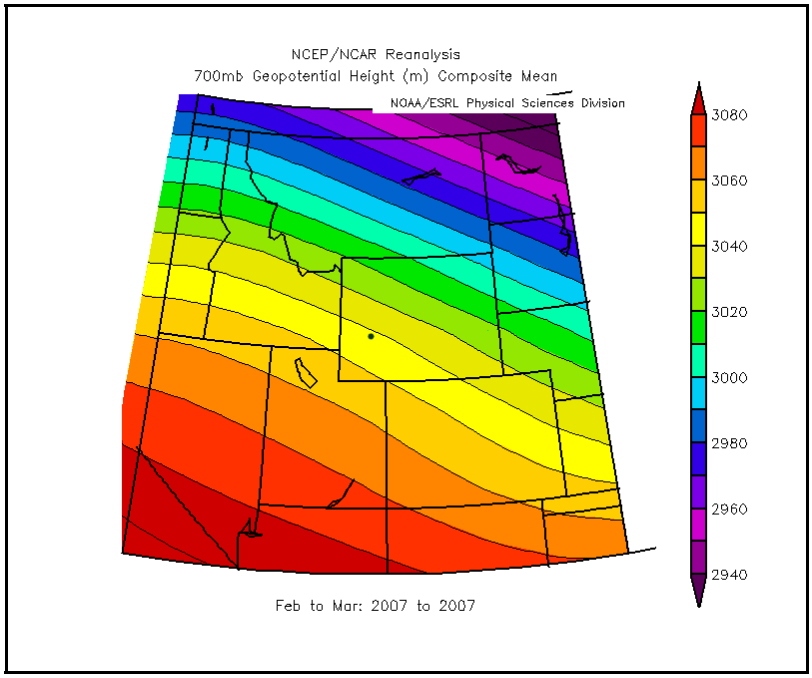

Figure 3
2007 Averaged 700 mb Height

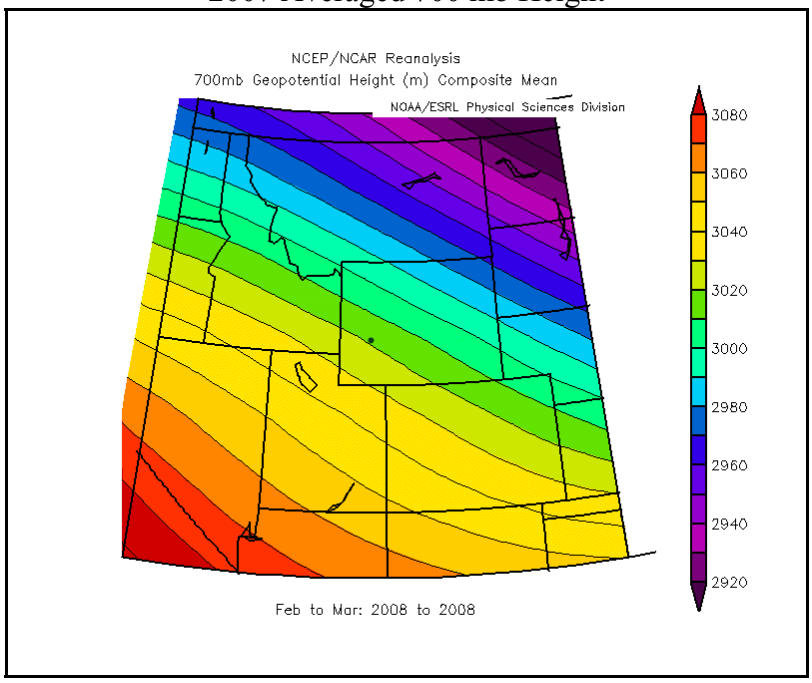

Figure 4
2008 Averaged 700 mb Height

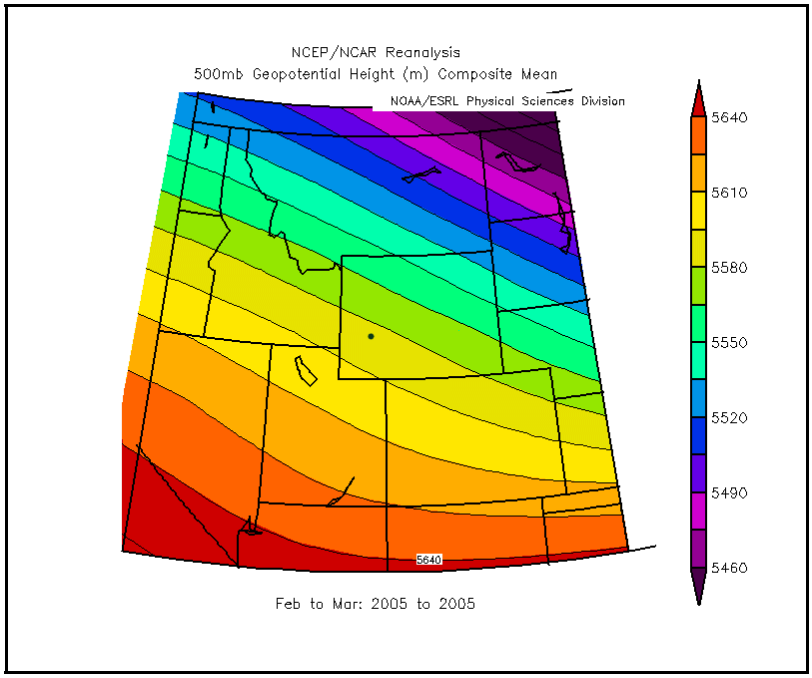

Figure 5
2005 Averaged 500 mb Height

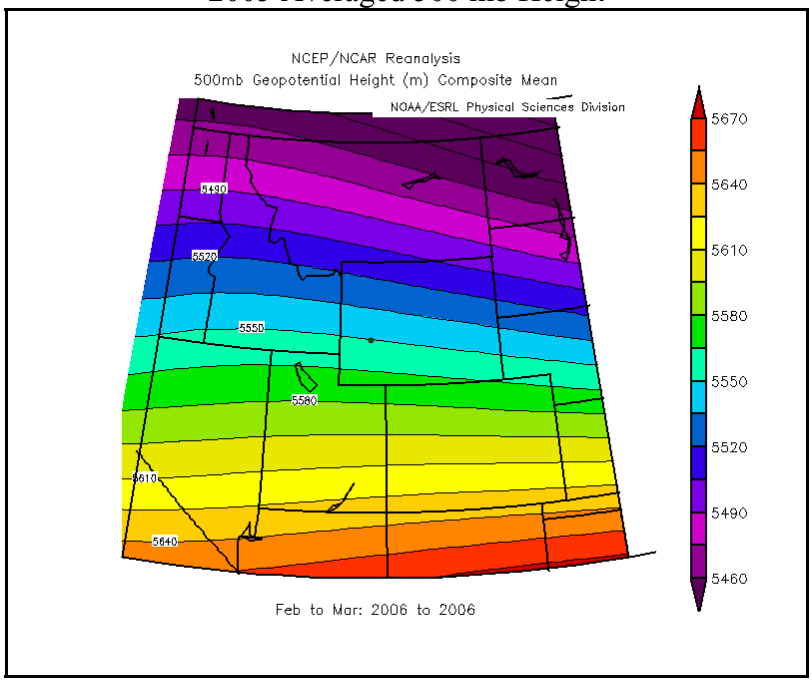

Figure 6
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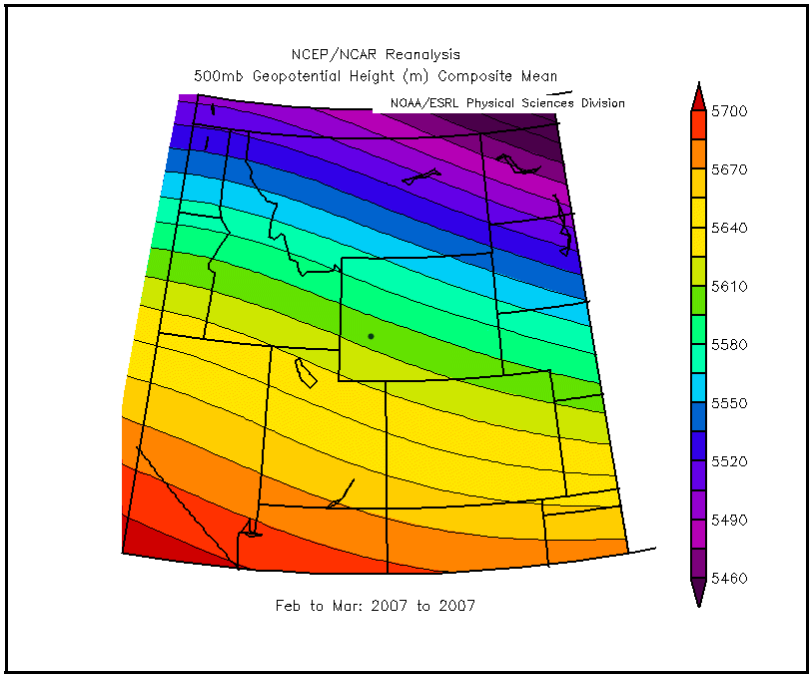

Figure 7
2007 Averaged 500 mb Height

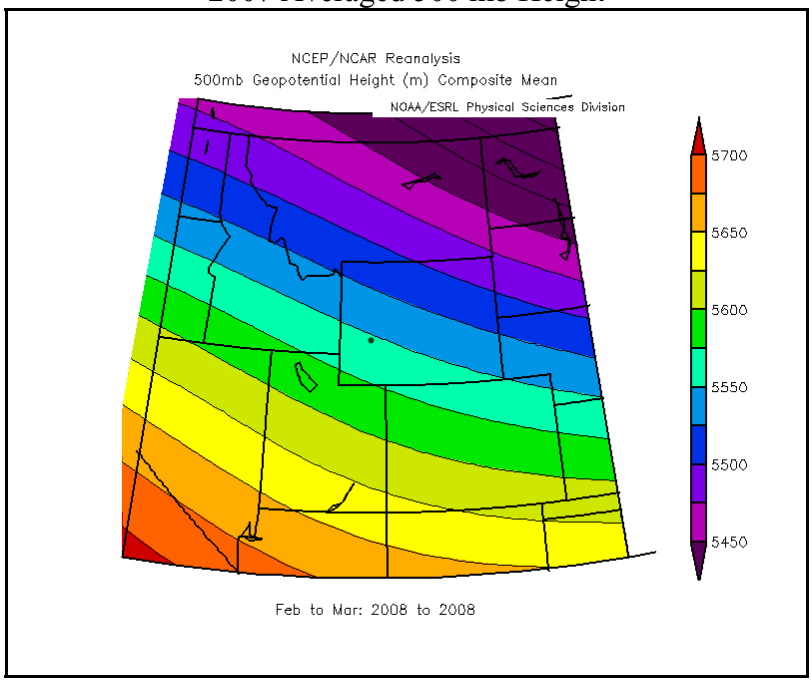

Figure 8
2008 Averaged 500 mb Height

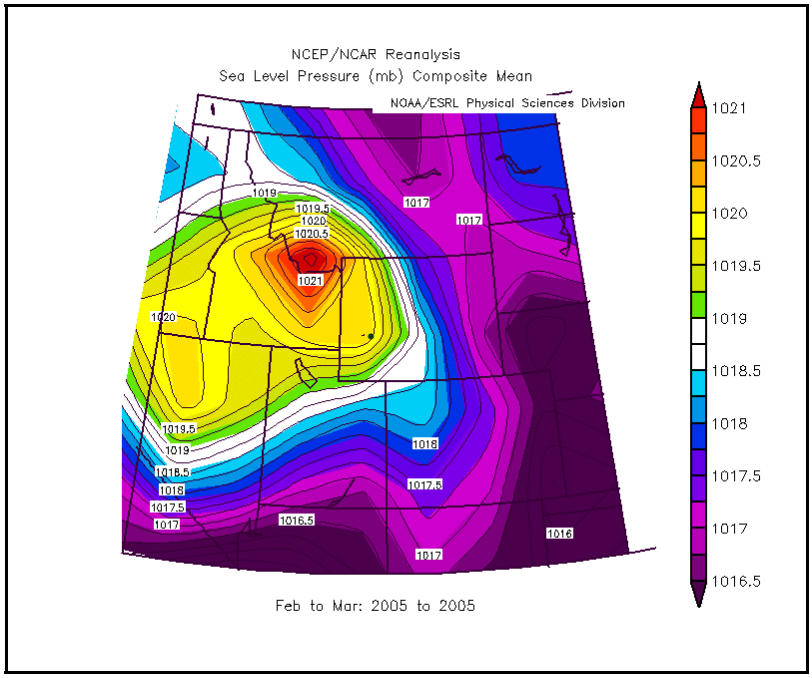

Figure 9
2005 Averaged Surface Pressure

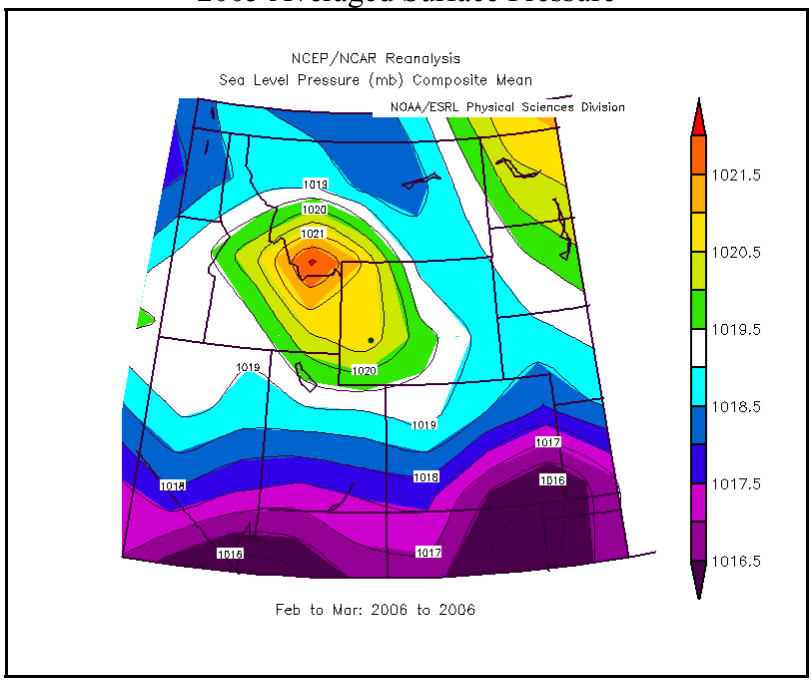

Figure 10
2006 Averaged Surface Pressure

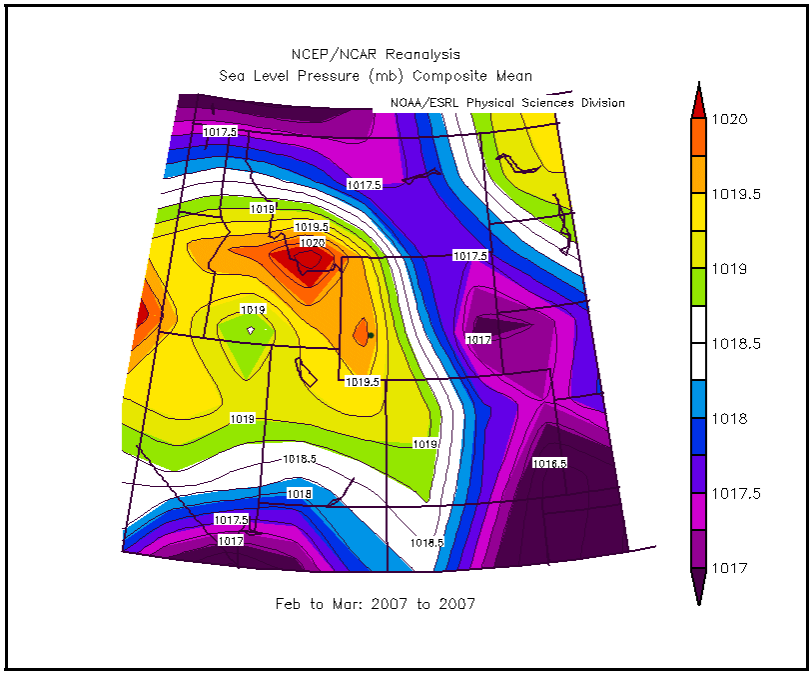

Figure 11
2007 Averaged Surface Pressure

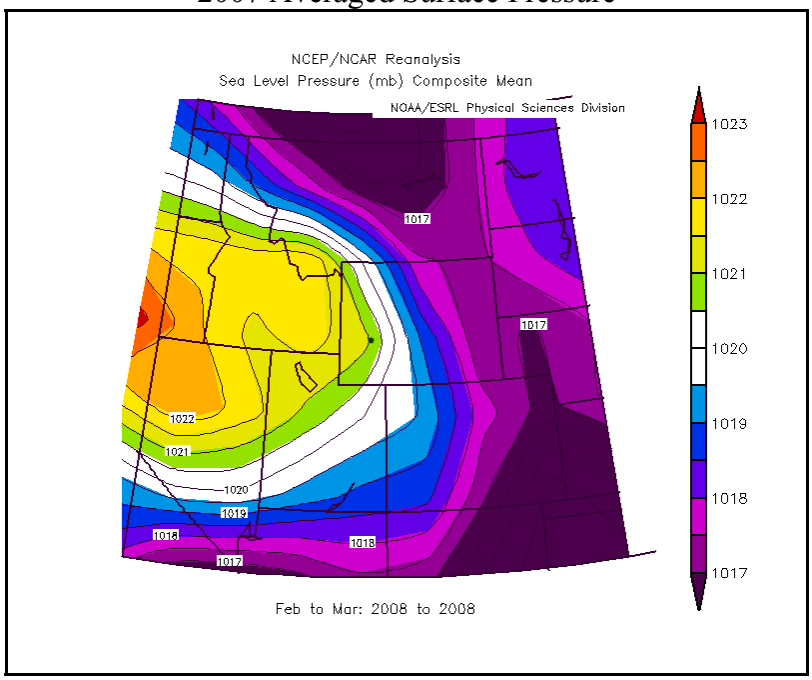

Figure 12
2008 Averaged Surface Pressure

Averaged temperatures at the surface and at the 700 mb height level show considerable differences from year to year in the 2005 through 2008 period. Table #.2 summarizes these temperatures. In 2007 when there were no significant ozone episodes detected the surface temperatures were considerably warmer on average than during other years. In 2008 when multiple strong ozone episodes were detected they were much cooler. Conditions were similar at

700 mb where 2007 had the warmest temperatures of the four year period while 2008 had the coldest.

Table #2 Averaged Temperatures Over the Ozone Study Area for 2004 Through 2008

February/March Period	Surface Temperature (°C)	700 mb Temperature (°C)
2005	-4.0	-5.9
2006	-6.0	-8.0
2007	-2.6	-5.1
2008	-5.2	-8.2

Figures 13 through 16 show the averaged surface temperature patterns for 2005 through 2008 and Figures 17 through 20 present the 700 mb averaged temperature pattern during each of the same four years. At both the surface and 700 mb the pattern is similar with colder temperatures to the north and warmer to the south. The main difference from year to year is the temperature itself. The differences from year to year vary considerably as is indicated in Table #.2.

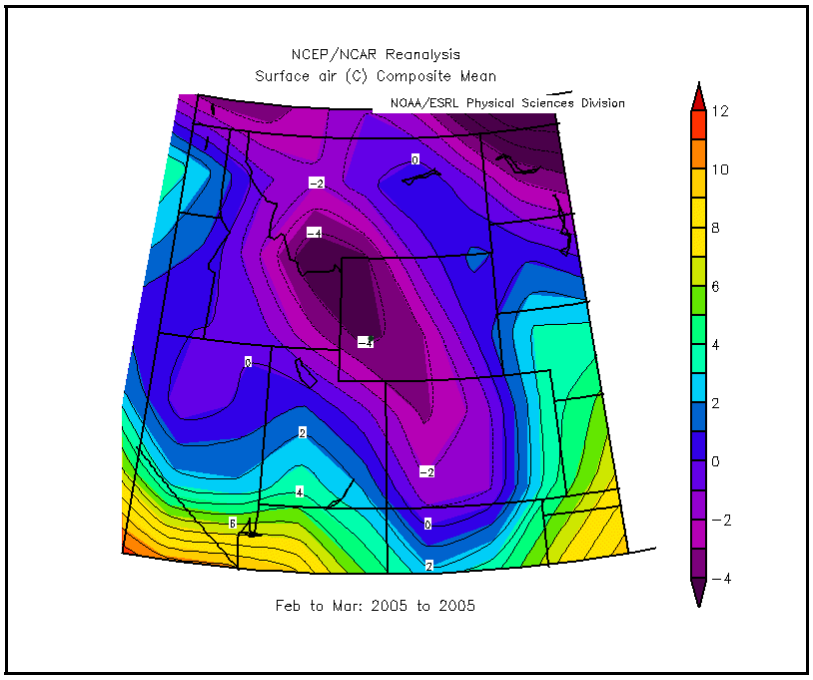

Figure 13
2005 Averaged Surface Temperature (°C)

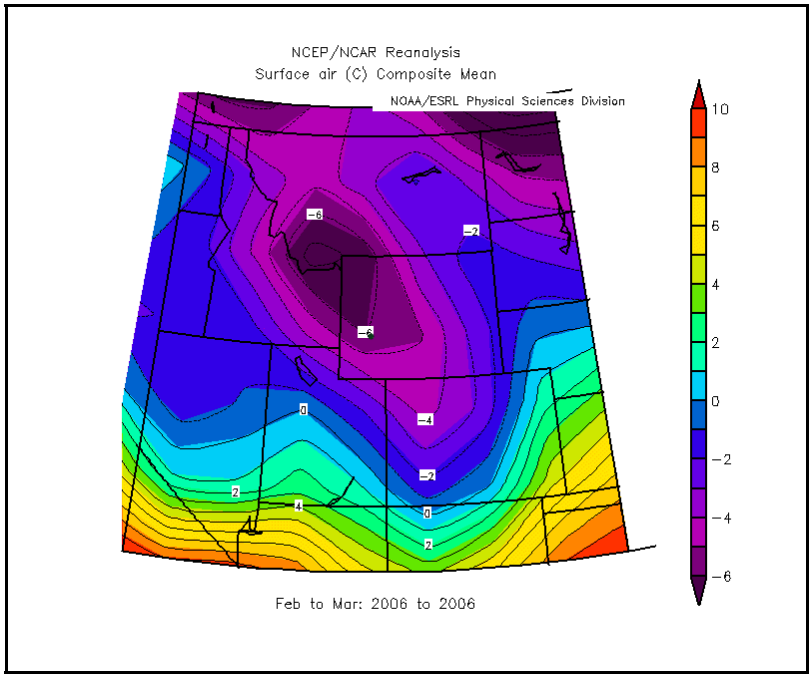

Figure 14
2006 Averaged Surface Temperature (°C)

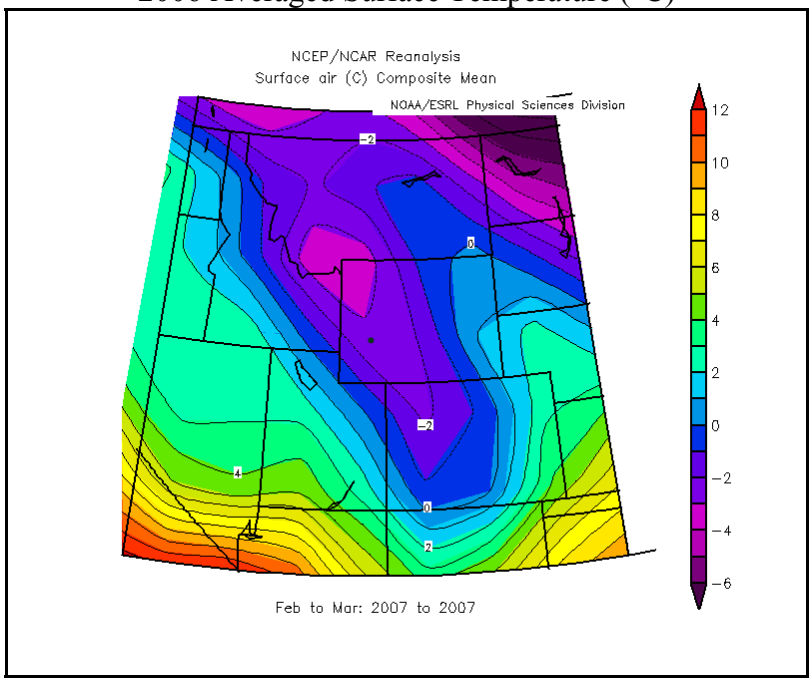

Figure 15
2007 Averaged Surface Temperature (°C)

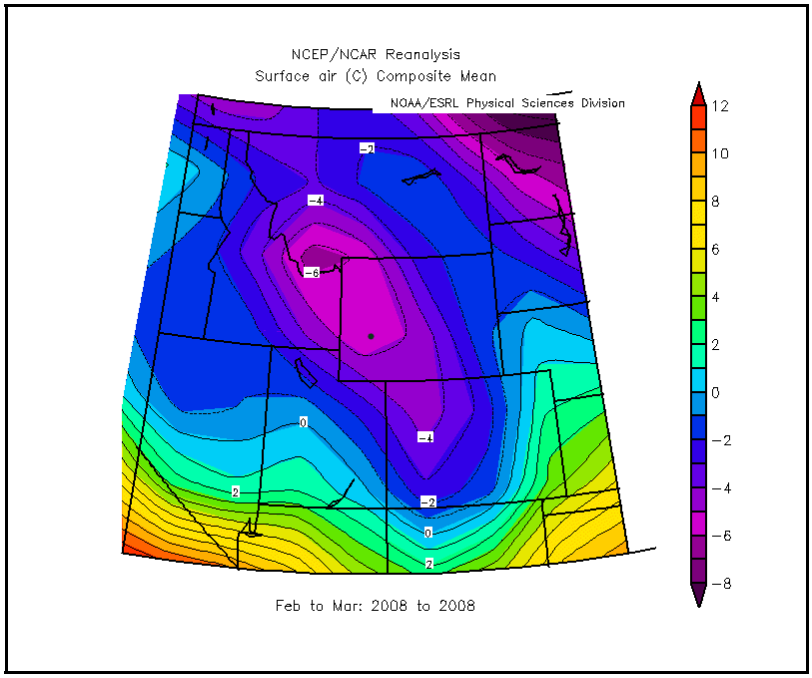

Figure 16
2008 Averaged Surface Temperature (°C)

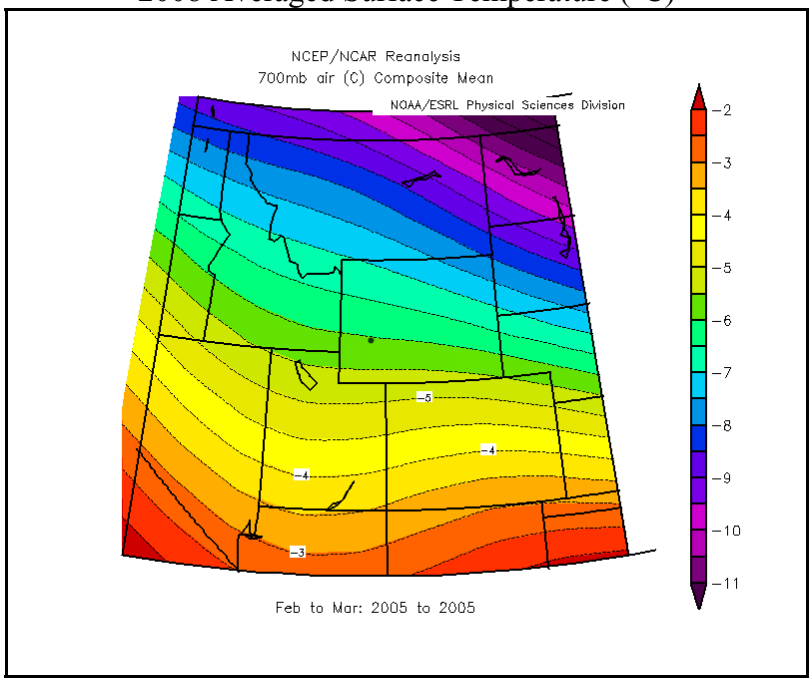

Figure 17
2005 Averaged 700 mb Temperature (°C)

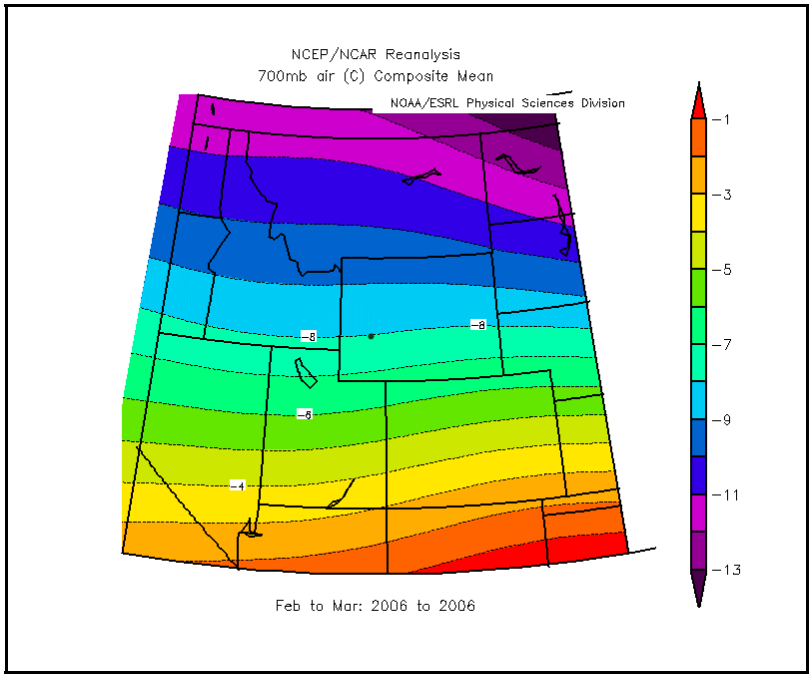

Figure 18
2006 Averaged 700 mb Temperature (°C)

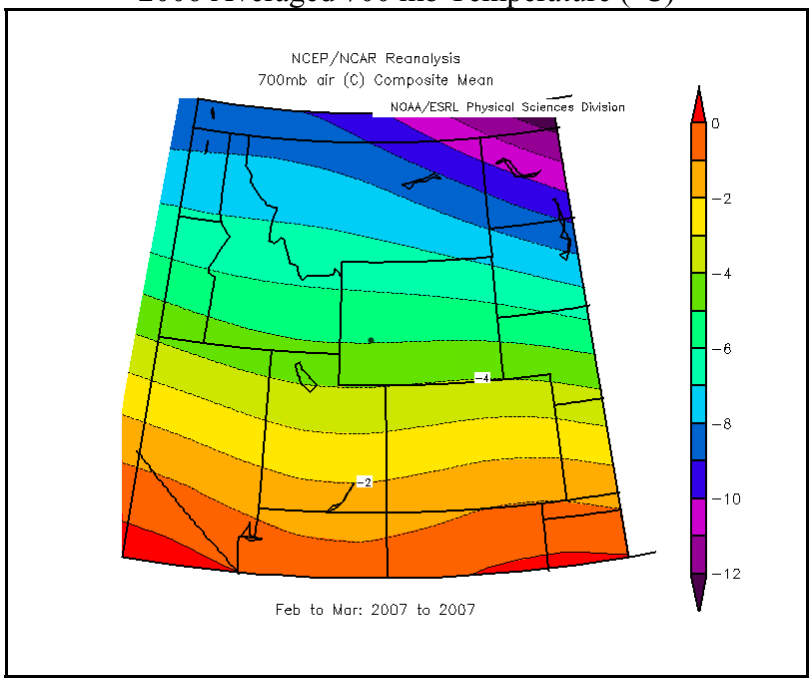

Figure 19
2007 Averaged 700 mb Temperature (°C)

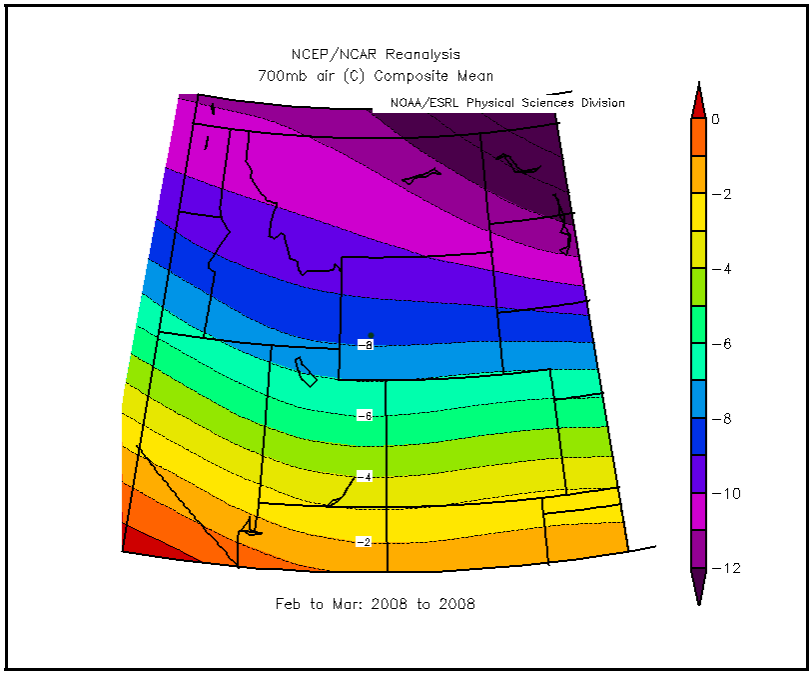

Figure 20
2008 Averaged 700 mb Temperature (°C)

Averaged winds at the surface during the 2008 study were near 3.8 mps. This speed was similar to other years during the two month study period. At 700 mb wind speeds were considerably higher during 2007 and 2008 when compared to the previous two year of 2005 and 2006. Table #.3 shows the results of the summary of winds at the surface and 700 mb level over the ozone study area.

Table #.3
Averaged Wind Speeds Over the Ozone Study Area for 2004 Through 2008

February/March Period	Surface Wind Speed (mps)	700 mb Wind Speed (mps)
2005	3.2	7.5
2006	4.1	9.2
2007	4.2	10.4
2008	3.8	10.1

Figures 21 through 24 show the averaged surface wind speeds over the central Rockies for each year 2005 through 2008. The pattern presented in each of the four years figures for the surface feature a very similar look. Highest wind speeds are found north of Wyoming in central Montana or southern Canada, while a strong gradient is positioned across central Wyoming from north to southeast, with lighter winds over southwest Wyoming.

Figures 25 through 28 show the same information as the surface wind speed figures for the 700 mb level. The pattern that develops is similar to the surface features although the stronger winds are more to the northeast and east, with the lightest winds centered over Utah. As does the surface patterns, a strong gradient between the highest and lowest speeds lies across Wyoming from northeast to southwest during each year.

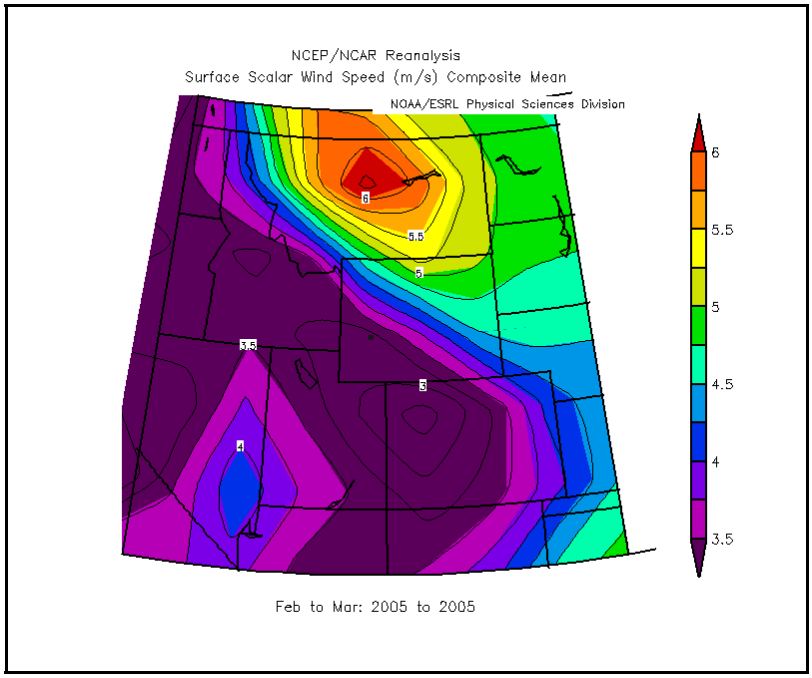

Figure 13
2005 Averaged Surface Wind Speed (m/s)

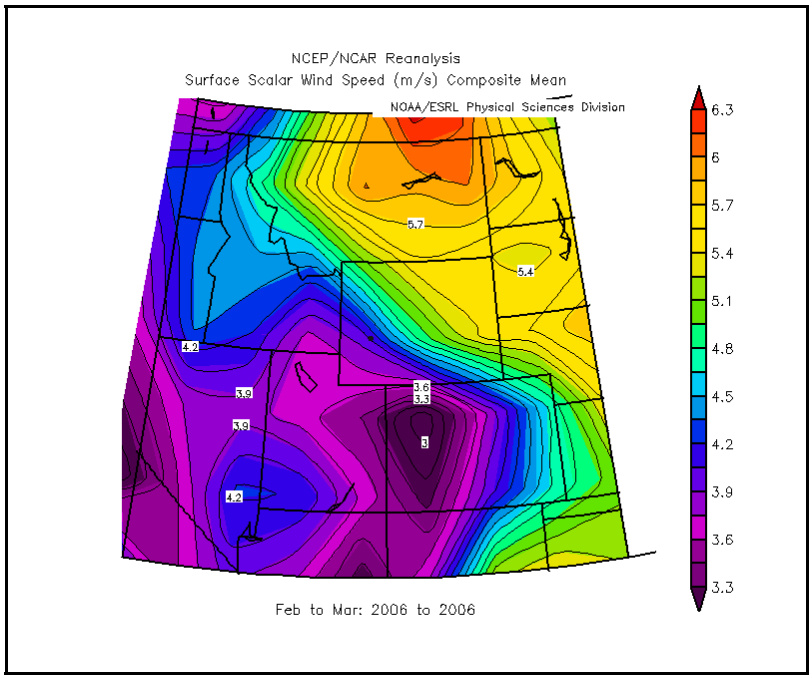

Figure 14
2006 Averaged Surface Wind Speed (m/s)

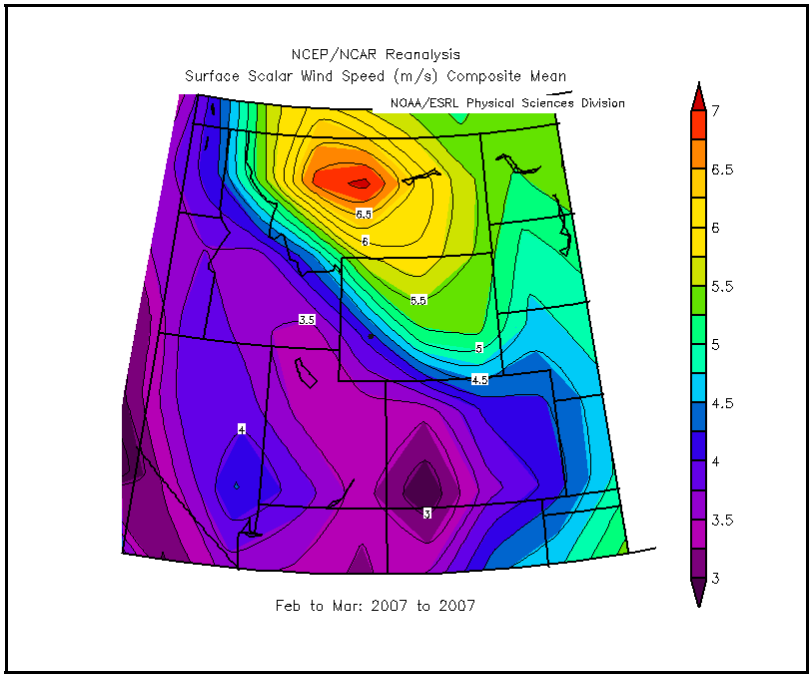

Figure 15
2007 Averaged Surface Wind Speed (m/s)

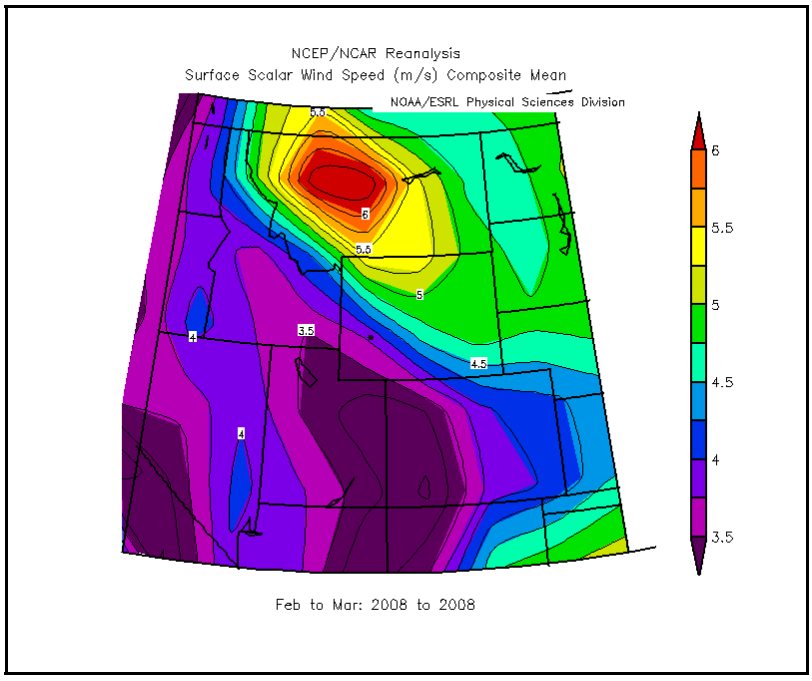

Figure 16
2008 Averaged Surface Wind Speed (m/s)

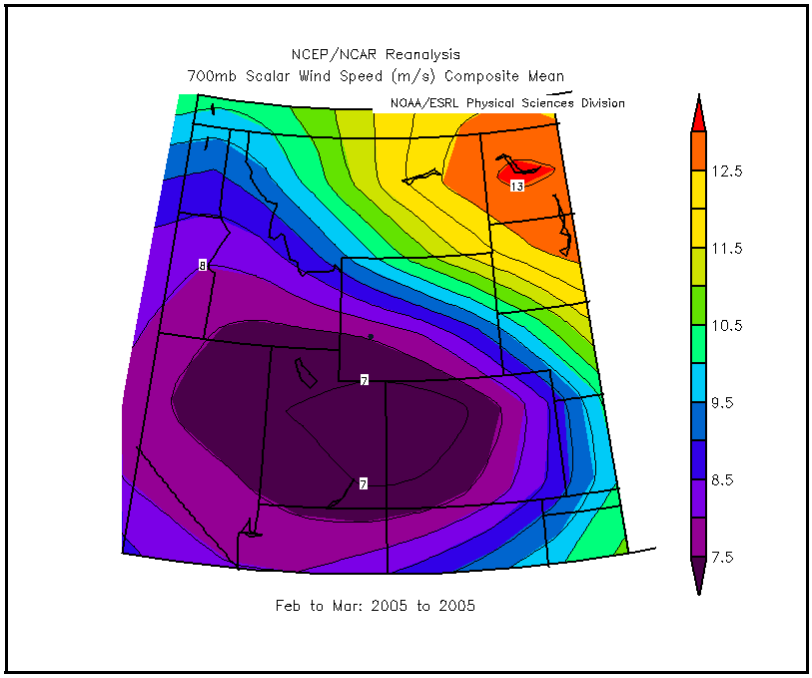

Figure 17
2005 Averaged 700 mb Wind Speed (m/s)

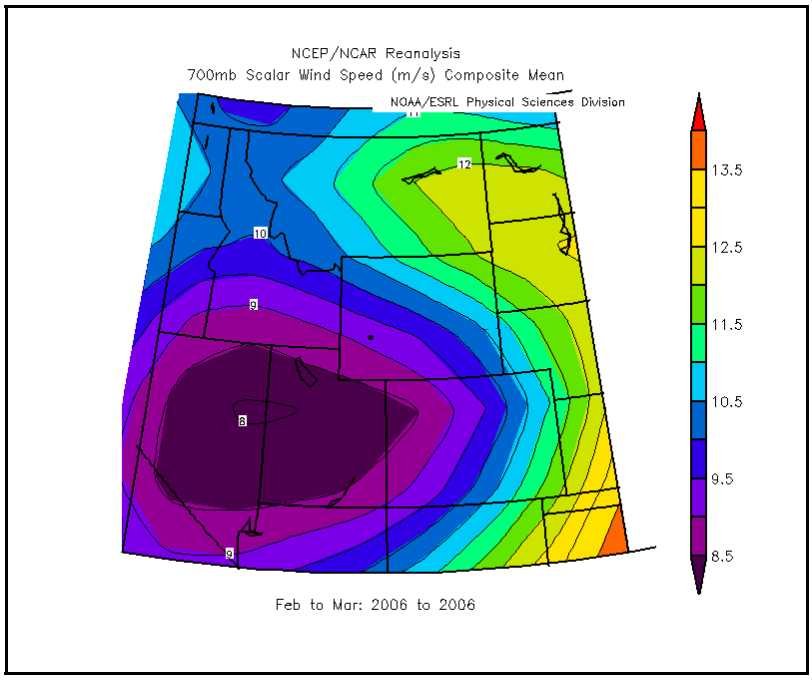

Figure 18
2006 Averaged 700 mb Wind Speed (m/s)

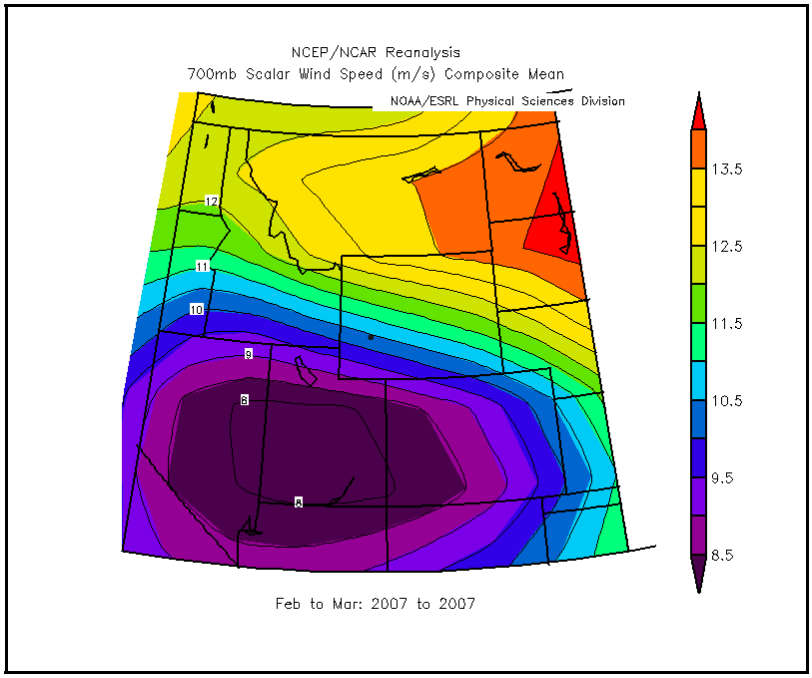

Figure 19
2007 Averaged 700 mb Wind Speed (m/s)

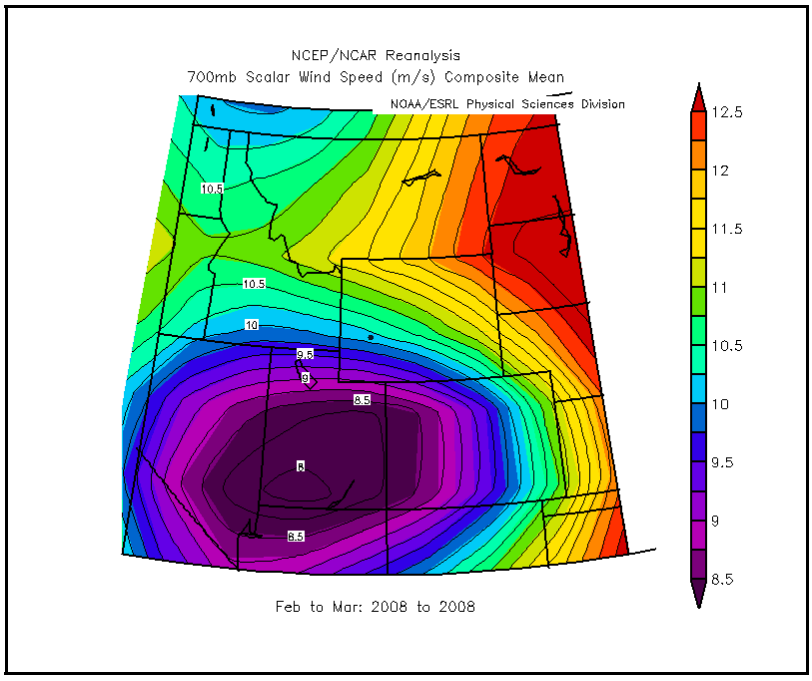

Figure 20
2008 Averaged 700 mb Wind Speed (m/s)

In summary, the surface conditions in the 2008 February/March ozone study period saw similar sea-level pressure levels compared to 2005 through 2007. However the overall averaged pattern of pressure in 2008 was more unique in that the center of high pressure was found along the California – Idaho border rather than over southwest Montana as was the case in the three previous years. Averaged surface temperatures varied considerably from year to year, with the warmest of the four years being 2007 and 2005 and the coldest being 2006 and 2008. The over all temperature pattern for the region was nearly identical with the coldest area centered over southwestern Montana into western Wyoming. Averaged surface winds over the study area ranged from 3.2 to 4.2 mps over the four years, indicating little difference from year to year. 2005 had the weakest average winds and 2007 the strongest.

At the 700 mb level, the averaged pressure height pattern for all four years was similar with a ridge centered to the west of Wyoming. 2006 was the most unique in that the ridge was located just west of the state through Idaho into Utah. At 500 mb the pattern also indicated a ridge located west of Wyoming, and in 2006 the pattern again showed the ridge was centered closest to the state. Both 700 and 500 mb levels indicated that northwesterly flow was in place over the study area in 2005, 2007 and 2008, while 2006 had more of a westerly component to the wind direction. Averaged 700 mb temperatures showed considerable differences from year to year as did the surface temperatures. 2007 had the warmest temperatures at this level and 2008 had the coldest temperatures at this level in the four year period. The wind speeds at 700 mb during the four years showed considerable differences. Both 2007 and 2008 had the strongest winds at 10.4 and 10.1 mps respectively. Weaker speeds were reported during 2005 and 2006.

MONITORING AND QUALITY ASSURANCE PLAN

for the

UPPER GREEN RIVER WINTER OZONE STUDY - 2008

Prepared for

State of Wyoming
Department of Environmental Quality, Air Quality Division
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February 15, 2008

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environmental research associates

MSI

ENVIRON

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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), 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 1995, and 1998) 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 (set at an 8-hour average concentration of 0.08 ppm) and the significantly increased federal regulatory requirements that would be associated with any potential future violation of the EPA ozone standard. The situation is made even more critical by the fact that EPA's Science Advisory Board is currently considering the need to lower the ozone standard between 0.060 and 0.070 ppm which would make a violation (currently defined as a three year average of the annual fourth highest daily maximum 8-hour ozone above 0.08 ppm) considerably more likely: preliminary measurements from the Jonah monitoring site show an average fourth highest 8-hr ozone of 0.071 ppm for 2005 – 2006.

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 during the 2007 late winter – early spring season. This study was described in detail in an original QA plan entitled *Monitoring and Quality Assurance Plan for the Upper Green River Ozone Study* written in March 2007. Atypical meteorological conditions during this initial study period resulted in only limited monitoring, and a second effort was organized using remaining funds to

conducted monitoring during the winter of 2008, during which hopefully more favorable meteorological conditions will occur. This QA plan describes the 2008 effort.

Data from this study will be used to develop a conceptual model 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

There are two levels or modes of field measurements in UGWOS: *continuous* and i*ntensive*. Continuous measurements will be ongoing from the start of the field study January 15, 2008 and continue until the scheduled end date, anticipated March 30, 2008. More extensive measurements will be conducted when the meteorological conditions are conducive to producing high ozone levels. These periods are hereafter referred to as Intensive Operational Periods (IOPs). IOPs will be initiated on a forecast basis and, as such, the field crew is committed to the project for its duration. Each IOP can last up to four days, and three such IOPs will be conducted over the study period. IOP measurements comprise the main core of the study in which the three-dimensional air quality and key meteorological features will be described. The surface ozone measurements are expanded to bound the major well field development, and measure the maximum air quality impacts.

2.1 Operational Forecasts and Readiness Protocol

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 clear skies, light winds 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. 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. 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.

Recognition of the onset and establishment of the conceptual model characteristics in advance is the key to the operational forecasting solution for

the UGWOS field measurements operations. 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 T&B Systems weather forecasters with the basis for daily long and medium range operation forecasts. An additional factor that may prove critical in operational forecasting is the presence of sufficient snow cover to provide the radiation component needed for ozone chemistry. Local observations will provide this information on a day-to-day basis.

The effects of day-to-day variability in local-scale meteorological factors on ozone levels are not clearly understood due to the limited measurements in the project area. Our knowledge and ability to refine the forecasts will improve as the program progresses. Discussions with local DEQ and BLM personnel and our initial observations suggest that high levels of ozone may occur more frequently than the current monitoring network is capable of detecting. The mesonet being deployed for the study will provide significant expanded areal ozone coverage.

A number of products and data will be routinely archived. Products include: the daily Riverton NWS rawinsondes, the GOES sounding data for Afton and Rock Springs, the Weather Modification, Inc. project soundings from Farson, and the NAM and GFS model generated simulated soundings for points within the Pinedale area. Short-term daily operational forecasts will be aided and refined as all this near real-time information is obtained. We will also be evaluating the usefulness of the Rapid Update Cycle model (RUC), the Weather Research and Forecasting model (WRF) and the RAMS model from CSU in our short-term operational forecasting mode and possibly incorporate them into our daily forecasts.

An operational forecast will be issued by 10 MST each day that will include both the short-term and long-term weather forecasts. All project participants will be required to provide any changes in their operational readiness daily to the Field Project Manager and that information will be included as well. This forecast will be posted on a project web site accessible to all participants. If conditions are developing that are conducive to the development of high ozone, an alert will be issued.

A “GO” alert will be issued at the 10 MST forecast at least 48 hrs before an IOP is to begin. Field crews will begin making preparations to debark to the field the following morning. A final GO or NO GO will be issued by 17 MST that afternoon. If the forecast remains a GO, the crews will deploy as scheduled.

The field crews will meet in Pinedale the following evening for a briefing and to coordinate setting up for the IOP. All equipment will be deployed and/or checked for readiness the following day. In this manner, an IOP can begin within 48 hours of the initial GO forecast. To aid in that critical operational forecast, we

have contingency plans to launch a rawinsonde to measure local winds, temperature and humidity the first morning in the field before the complete network is deployed.

We do not anticipate having to deploy the field crew when inclement weather hampers travel to and from the project area. It should be noted that the major characteristics of the meteorology that can lead to high ozone levels in the Pinedale-Jonah area are a stable atmosphere, clear skies, and light low-level winds. These conditions take some time (at least 48 hours after a storm frontal passage) to develop. Moreover, we expect operational conditions to occur during periods when the synoptic weather pattern in the western states is relatively stationary as opposed to short-waves of high and low pressure patterns, so it will not be necessary to start operations on the heels of a storm system.

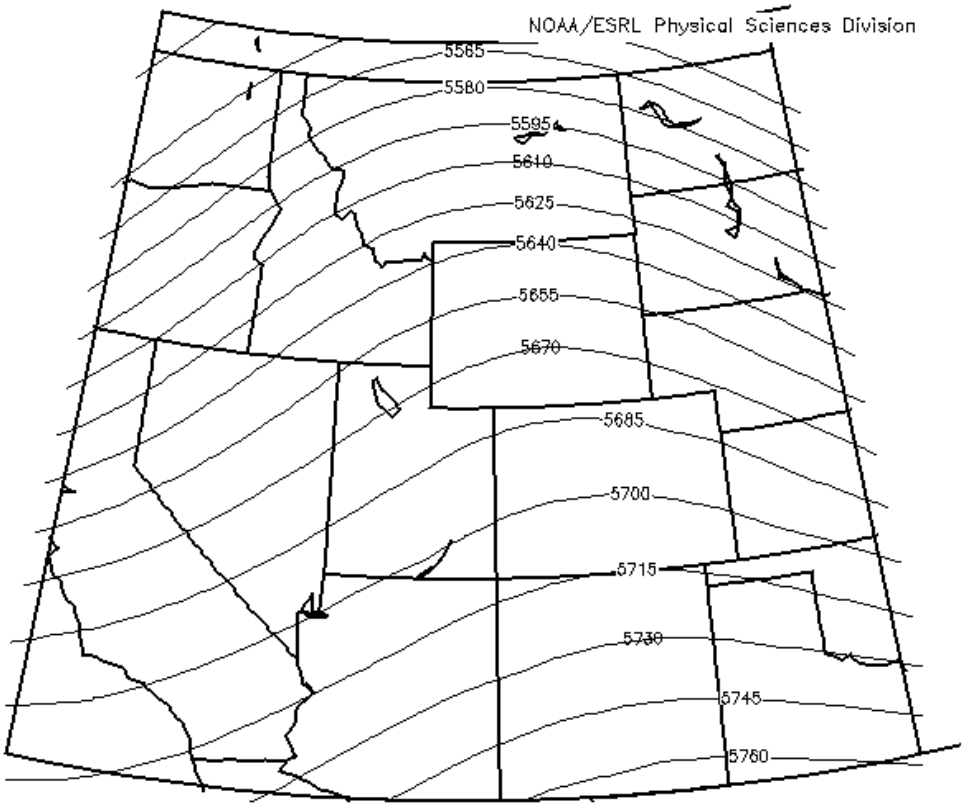


Figure 2-1 Composite 500 mb Heights During High Ozone Periods

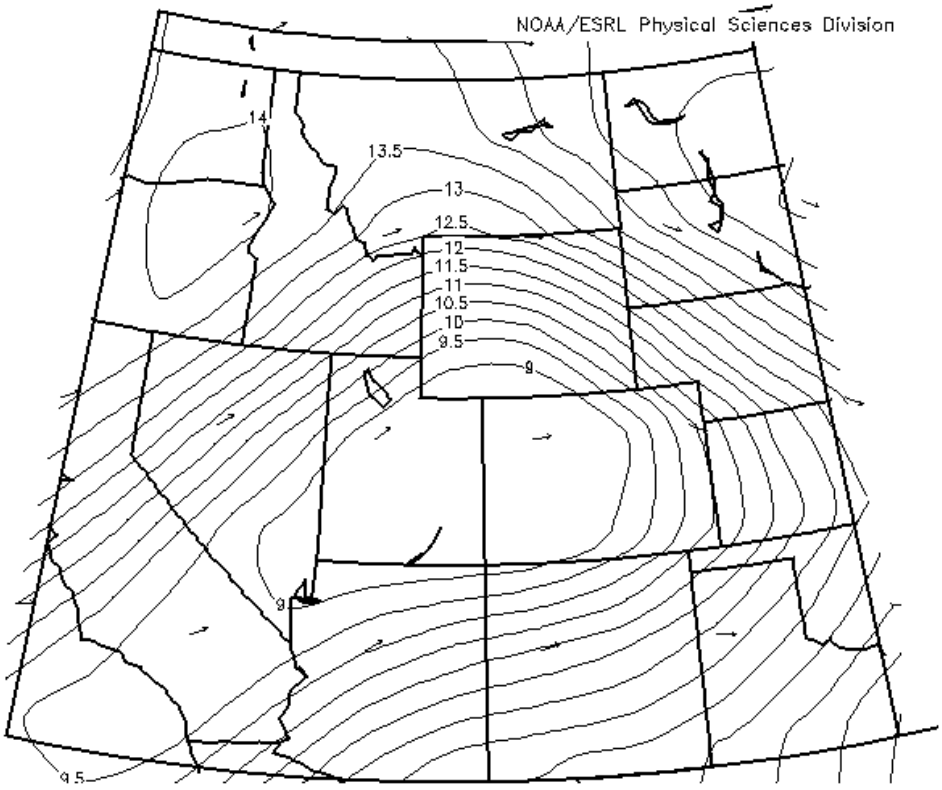


Figure 2-2 Composite 500 mb Winds During High Ozone Periods

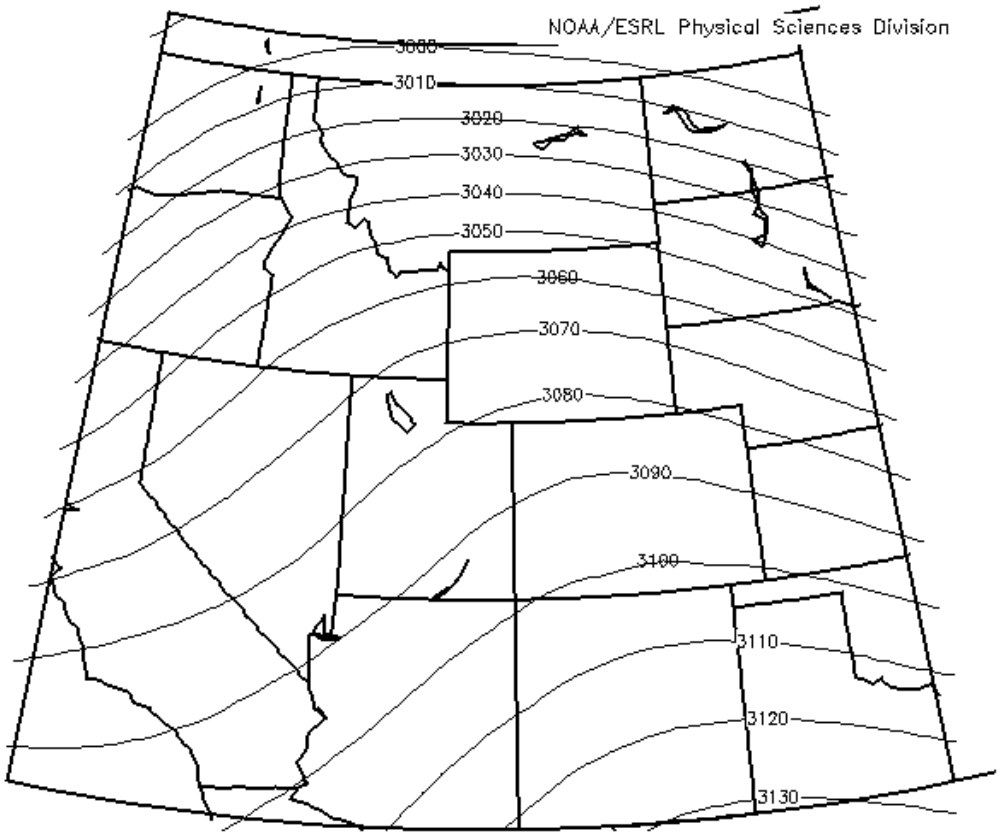


Figure 2-3 Composite 700 mb Heights During High Ozone Periods

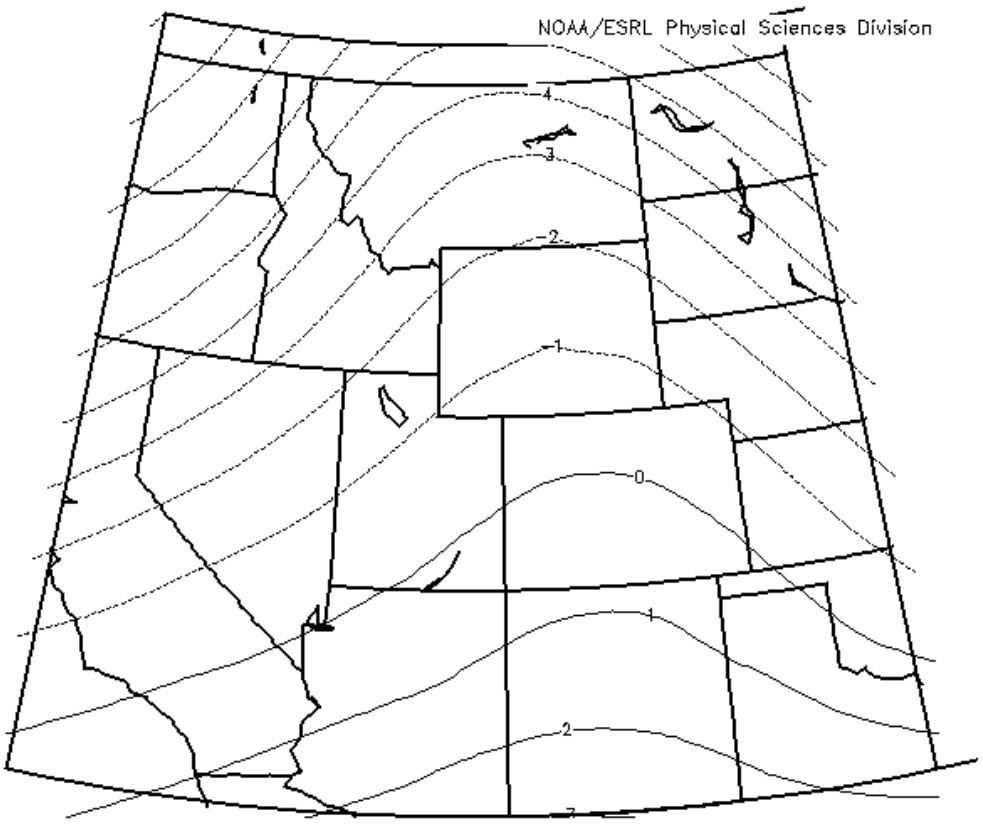


Figure 2-4 Composite 700 mb Temperature During High Ozone Periods

2.2 Continuous Measurements

Project-specific measurements to be continuously obtained over the complete field program period include surface and winds aloft, and supplemental surface ozone measurements. Surface ozone and wind measurements will be taken from a 5-site mesonetwork (mesonet) and from Wenz Field (Pinedale airport). At the latter site, continuous surface ozone measurements using a designated EPA equivalent analyzer will be made. Surface temperature and relative humidity will also be collected at the Pinedale site. At a site on the south mesa, both surface and aloft winds will be measured continuously employing a Sodar and surface meteorological station. Both incoming and reflected UV radiation will be measured using currently operating equipment at the Boulder site.

2.3 Intensive Measurements

During periods when high ozone levels are forecast, more intensive measurements will be initiated. The key components of the intensive monitoring periods (IOPs) are:

- VOC and carbonyl measurements
- Ozone/rawinsonde operations
- Aircraft measurements

2.3.1 Mesonet Ozone Measurements

Though the mesonet ozone analyzers will operate continuously over the course of the study, routine performance checks of the analyzers will only be conducted during the IOPs. MSI staff will deploy to the field from their office in Salt Lake City immediately following issuance of the final GO. The 2B ozone monitors will be span-checked prior to the first day of the IOP, if at all possible. Their operation on-site will be checked using the 2-B ozone generator and zero-scrubber, and any zero and span adjustments made. The data system time will be reset as required.

During the IOPs the sites will be visited every two to three days to download data and ensure appropriate operations. At these visits, batteries will be checked and the solar panels cleaned, as necessary. At the completion of each IOP, the ozone analyzers will be span and zero checked. All on-site operations will be documented and logged by the MSI technicians.

WDEQ will be responsible for servicing the sites in between IOPs, as time and resources allow.

2.3.2 VOC and Carbonyl Measurements

VOC and carbonyl measurements will be conducted at each of the three existing WDEQ monitoring sites within the study area – Jonah, Boulder and Daniel. The VOC and carbonyl measurements will be collocated and sampled simultaneously as three-hour integrated samples. On intensive study period days, samples will be taken from 0400-0700, 0900-1200 and 1400-1700 hours.

VOC measurements will be made using 6-liter SUMMA canisters connected to Xontech Model 910A canister samplers. Ambient air will be pumped to the canisters for a three-hour period. Carbonyl measurements will be made by pulling ambient air at 1 LPM through DNPH cartridges with an ozone scrubber inserted upstream of the cartridge. Both types of samplers are outfitted with timers that enable automatic start/stop operation. Ambient air needed for the samplers will be obtained from borosilicate glass intake manifold ports at each monitoring shelter.

Research team technicians will be responsible for loading canister/cartridge media into the samplers, confirming sample run times, removing samples and filling out the affiliated documentation. Exposed sample media will be collected at the end of each intensive study day and brought to the project field office at the Pinedale Airport for packaging and shipment to 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. A field blank will be submitted for each site during intensive study periods.

VOC/carbonyl samples will also be collected using the aircraft (see section below). Up to two samples can be collected each flight with the sample locations at the discretion of the on-board scientist based on observations during the flight. Samples will be collected during a five-minute spiral at the desired location.

While up to 150 sample pairs may be collected over the course of the 2008 study, only 100 pairs will be analyzed, based on their anticipated value for meeting study goals.

2.3.3 Aircraft Sampling

Ozone, fine particulate loading, and temperature will be measured using a single-engine airplane. A typical sampling flight will be comprised of measurements at constant levels and spiral ascents and descents to provide vertical profiles. Vertical profiles will be made from as near to ground level as safety permits to approximately 4000 ft-agl. If the daytime boundary level is shallower than 4000 ft, the spirals may be to a lower height.

Two three-hour sampling flights are planned each intensive sampling day, beginning the first day of an IOP. Preliminary flight plans will be developed prior to takeoff. The morning flight will take place approximately 07:30 -10:30 MST. The afternoon flight will take place approximately 13:30 –16:30 MST. An experienced T&B Systems air quality scientist will be onboard observing the measurements in real-time. Based on those observations and the winds aloft measurements, the flight plan may be modified. For example, if a polluted layer is observed the primary mission of that sampling flight may be to map the areal extent of the polluted layer.

Flight patterns will initially be as follows:

- The morning flights will concentrate on characterizing the near-surface ozone conditions, and will consist of a series of spiral soundings connected by relatively low level flight. Flights during both the morning and the afternoon will begin with a sounding near the radar profiler site. The study area will then be characterized by conducting a similar spiral

sounding near at least the Jonah site, with connecting legs at a constant level below 500 ft AGL (7,500 ft MSL), to characterize as best as possible concentrations at or below the inversion layer.

- The goal of the afternoon flights will be to map the extent of any plume of high concentrations. The initial spiral sounding near the radar profiler site will determine the height of maximum concentrations, determining the flight level for the remainder of the flight. As and alternative, based on available upper level wind data from the ozonesonde measurements and sodar, as well as observations from the first flight, a series of constant level traverses perpendicular to the prevailing winds could be conducted at progressively farther downwind distances.

Figure 2-5 shows a basic flight pattern. Table 2-1 describes the basic elements of the flight, including waypoints. However, the flight patterns for the aircraft measurements are intended to be dynamic in nature, with changes made as data are collected and analyzer from all of the study measurement platforms.

This task is the responsibility of T&B Systems.

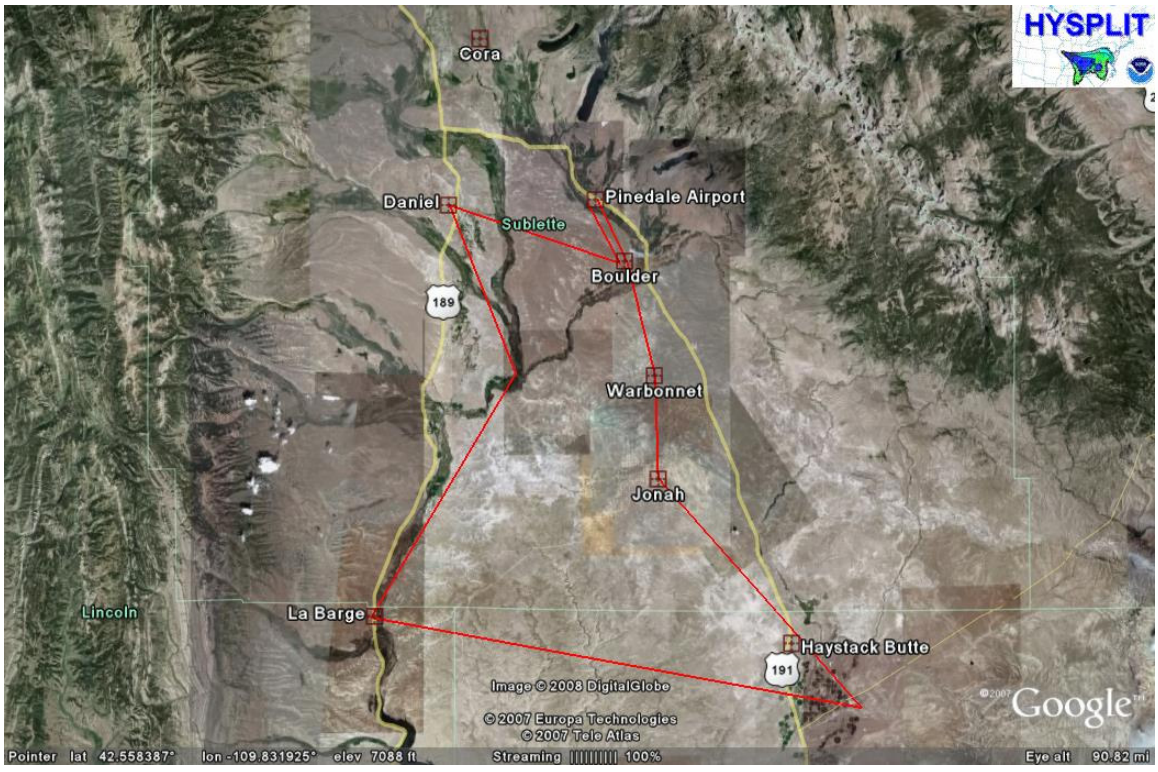


Figure 2-5. Basic Flight Pattern.

Table 2-1. Basic Flight Pattern

Waypoint	Latitude	Longitude	Comments
Pinedale Airport	42.7982°	-109.805°	Climb to 11,000' MSL in route to Boulder
Boulder	42.7187°	-109.754°	Spiral down to ~200' AGL, then up to 7,500' MSL (anticipated to be below inversion level)
Warbonnet	42.5702°	-109.702°	Maintain 7,500' MSL
Jonah	42.4364°	-109.696°	Proceed to Jonah at 7,500' MSL, descend to ~200' AGL, then spiral up to ~500' above inversion level
Hwy 28	42.1378°	-109.343°	Return to 7,500' MSL, and travel over Haystack Butte to Hwy 28 out of South Pass
La Barge	42.2585°	-110.194°	Maintain 7,500' MSL
Green River Drainage	42.5736°	-109.945°	As an option, fly back to any area of high readings noted along Boulder/Jonah path
Daniel	42.7914°	-110.065°	Maintain 7,500' MSL
Boulder	42.7187°	-109.754°	Maintain 7,500' MSL until approaching Boulder, then drop to ~200' AGL and spiral up to 11,000' MSL
Pinedale Airport	42.7982°	-109.805°	Descend and land

2.3.4 Ozone/Rawinsondes

Free ascending balloon-borne measurements of ozone, temperature, relative humidity, and winds will be made three-times daily from Wenz Field (Pinedale Airport) during IOPs. Scheduled rawinsonde sounding times are 07, 11, and 15 MST. The early morning sounding will document the vertical structure of the atmosphere during the most stable period over the diurnal cycle. This sounding will closely correspond to the 12 GMT world-wide sounding schedule and data set. The afternoon sounding will characterize conditions when the atmosphere is generally most unstable and the mixed layer has fully developed. The midday sounding will be document the timing of the growth of the boundary layer.

Soundings will extend to at least 500 mb or ~ 18,000 ft. Optimally, data will be gathered to 300 mb which is approximately 30,000 ft.

Ozonesondes will be incorporated for two of the soundings, most likely during the morning sounding to document initial conditions aloft, and the afternoon sounding when ozone concentrations are anticipated to be the highest.

This task is the responsibility of T&B Systems.

2.3.5 Supplemental Monitoring and Data Collection

UV Radiation

Direct and reflected UV radiation sensors (radiometers) initially installed during the 2007 effort at the WDEQ Boulder site will be an important part of the UGWOS data set. The sensors will be checked and the data downloaded at the beginning and end of each IOP. Sensor checks will consist of a zero reading and comparison of the sensors output while orientated the same. The radiometer will be operational but unattended between IOPs.

Archiving of NOAA Products

Archiving of data that is not already archived on the web and readily available will occur on a daily basis. The items that will be archived for the period from January 15 through March 31, 2008 are listed below:

- MSI routinely archives 00Z and 12Z surface and upper air maps for 700 mb, 500 mb and 850 mb.
- MSI routinely archives data from all rawinsonde sites in the United States for both 00Z and 12Z time periods.
- MSI routinely archives Visual and IR, US east and west satellite images every 15 minutes.
- Vorticity information provided by the NAM model will be archived twice daily. The 00Z and the 12Z analysis vorticity data will be archived for a 13 by 13 grid surrounding the Pinedale area. Additionally, all data from the analysis period will be archived for the data point nearest Pinedale. This will provide another point for which a sounding may be plotted.
- Vorticity graphics at 500 mb produced by NCEP from both NAM and GFS will be archived on a daily basis for the analysis runs at 00 and 12Z.
- GOES derived soundings will be archived on a daily basis. Archival will include plots and data listings.

In addition to the above, the following data are currently archived on the web and 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, Jonah and Boulder can be viewed on line at the WDEQ site, and there is also a 2 week image archive here 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. Tables 3-1 and 3-2 present coordinates and site selection rational (monitoring objectives), respectively, for each of the sites. Photographs of the sites can be found in Appendix A.

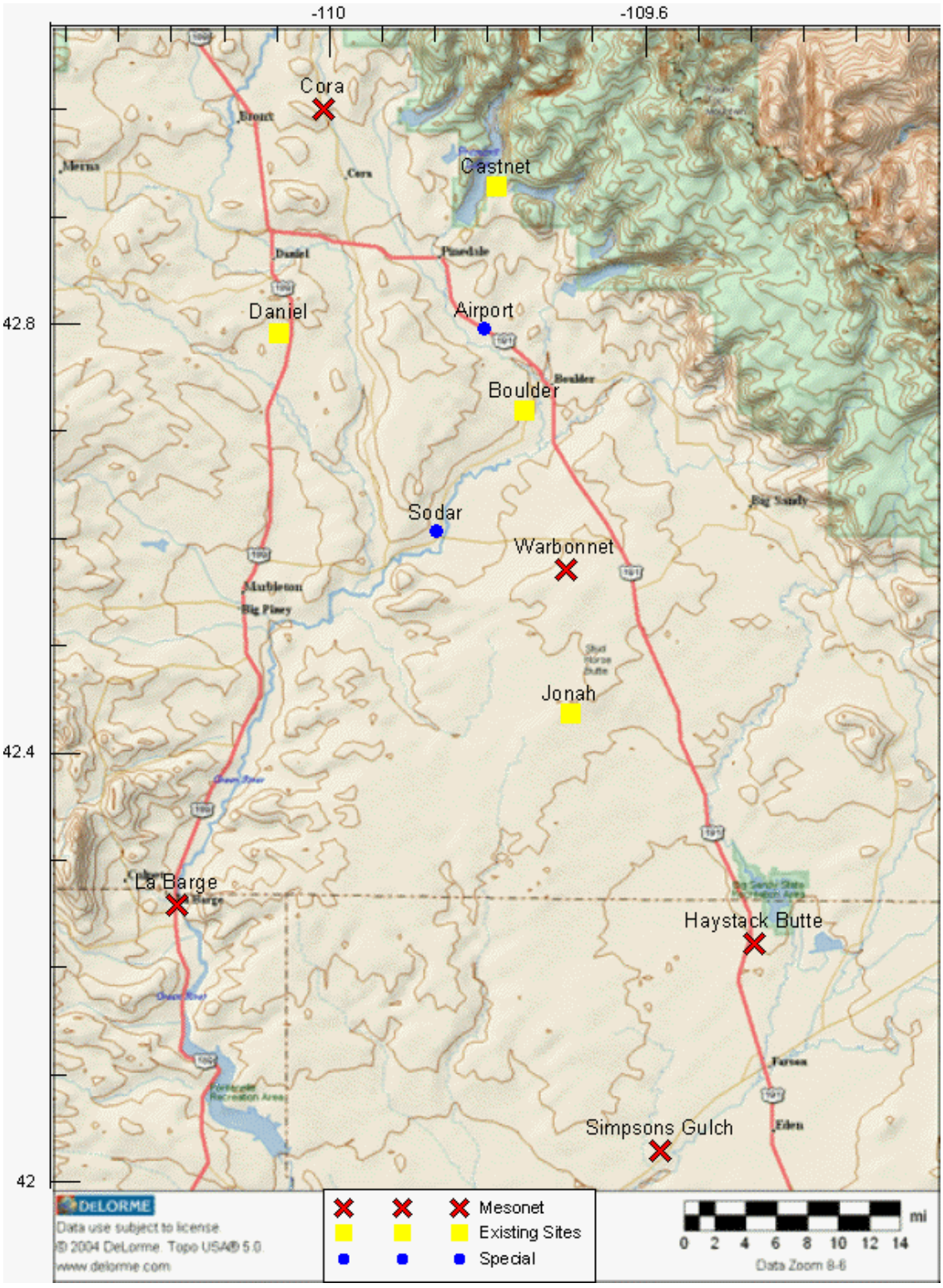


Figure 3-1. Map of UGWOS Site Locations

Table 3-1. Network Locations and Identifiers

All Lat/Longs are WGS 84	Latitude	Longitude	Elev.
OZONE/MET SITES			
Site 1: Cora Area (BLM)	43 00.399N	110 00.543W	7558’
Site 3: Warbonnet (BLM)	42 34.212N	109 42.125W	7425’
Site 4: Haystack Butte (WY)	42 13.323N	109 27.762W	6758’
Site 5: Simpson Gulch (BLM) (FAA Tower)	42 01.697N	109 34.914W	6691’
Site 8: La Barge (Private)	42 15.512N	110 11.638W	6609’
WIND PROFILER SITE			
Sodar: M&N Yard	42 36.420N	109 51.879W	6910’
SURFACE VOC/CARBONYL SITES			
Boulder	42 43.120N	109 45.225W	7078’
Daniel	42 47.484N	110 03.886W	7084’
Jonah	42 26.184N	109 41.754W	6848’
PINEDALE AIRPORT (WEINZ FIELD)			
Airport	42 47.890N	109 48.296W	7109’

Table 3-2. Major Objectives of Mesonet Sites

Cora	Northern boundary site upwind from prevailing winds
Warbonnet	Representative of middle and southern Pinedale Anticline
Haystack Butte	Southeastern boundary site. Highest readings during 2007.
La Barge	Southwestern boundary site
Simpsons Gulch	Southern boundary site

SECTION 4

MONITORING EQUIPMENT DESCRIPTION

The following section describes the monitoring equipment that will be used for UGWOS. Monitoring quality objectives (MQOs) are presented for each of the monitoring methods.

4.1 MESONET OZONE MONITORING

All equipment used at the mesonet ozone monitoring sites will be housed in a 70 to 100 quart portable cooler. This includes a 110 amp-hour deep cycle 12-Volt battery will power all equipment and allow continuous monitoring for a least one week. A small 5-watt light bulb will also be located in the cooler to provide sufficient heat to keep temperatures in the cooler within the operating ranges of all equipment.

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

2B Model 202 Ozone Analyzer

The 2B Ozone Monitor will be used for the mesonet Monitoring. This monitor has a low power consumption (12v DC, 0.33 amp, 4.0 Watt) relative to conventional instruments allowing operation with deep cycle batteries. Additionally, it does not require a temperature-controlled environment.

The 2B Technologies Model 202 Ozone Monitor™ is designed to enable accurate and precise measurements of ozone ranging from low ppb (precison of ~1 ppbv) up to 100,000 ppb (0-100 ppm) based on the well established technique of absorption of light at 254 nm. "Absorption spectroscopy" is a chemical analysis technique made possible by the phenomenon that a given molecule absorbs light at selected wavelengths. The wavelengths absorbed are characteristic of each molecule's atomic features. The amount of light radiation absorbed by a substance depends on two factors: the number of molecules in the path of the light, and the characteristics of the molecule (e.g., absorption cross-section). Measurement of changes in the light intensity as it passes through the molecules, and the use of calibration and reference data, enable the determination of the number of molecules encountered.

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

RM Young Model 05305 Wind Monitor AQ

For surface monitoring of wind speed and wind direction at the mesonet sites, we will employ an RM Young 05305 Wind Monitor AQ wind speed and direction sensors. These sensors employ a propeller anemometer. The sensors can be mounted on existing structures or on 2-meter tripods, typically on the roof of existing buildings (Figure 4-1), resulting in measurement heights ranging form 2 to 10 meters. All sensors will be oriented to true north using either the GPS walkoff method or solar alignment method for orienting wind speed sensors.

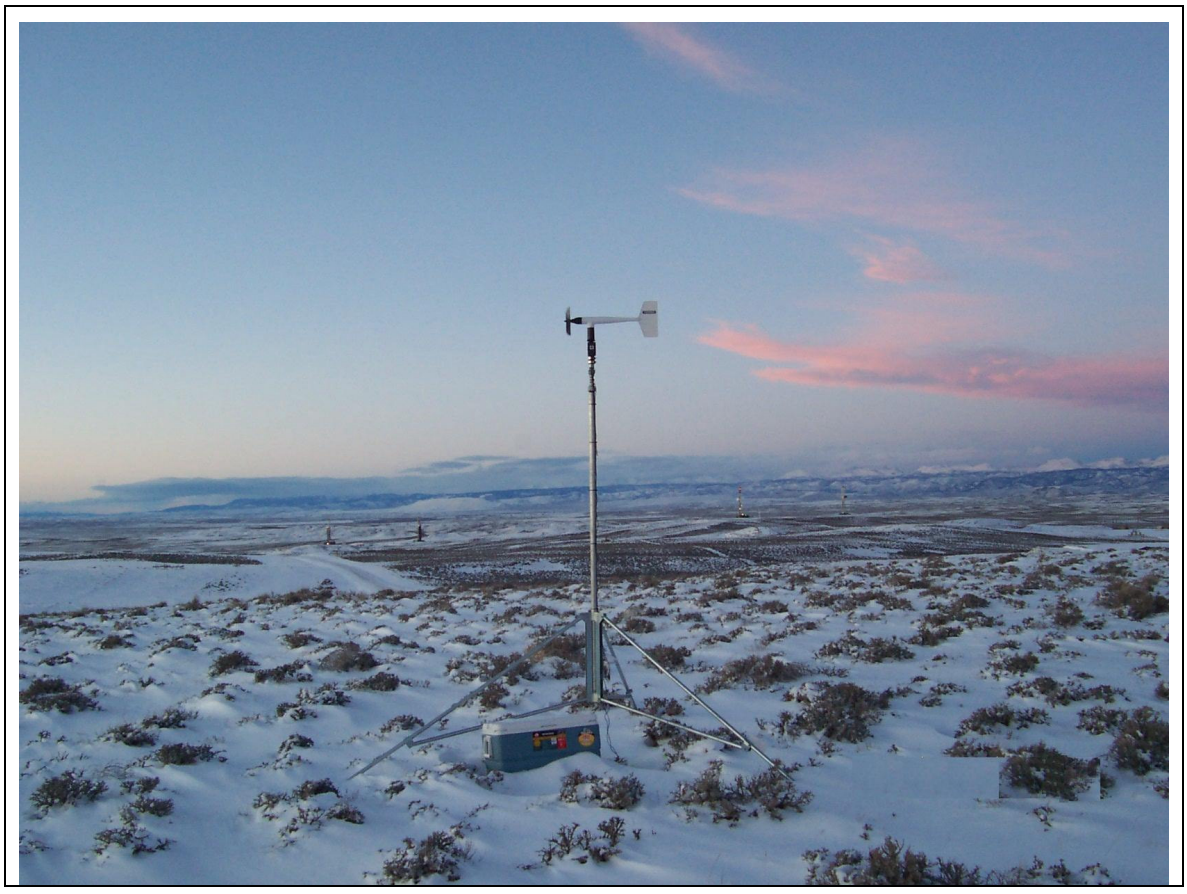


Figure 4-1. Tripod mounting of wind sensors.

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

Accuracy (instrument specifications)	
Horizontal Wind Speed	±(0.2 m/s + 5% of observed)
Horizontal Wind Direction	±5 degrees
Precision (performance checks)	
Horizontal Wind Speed	±0.1 m/s
Horizontal Wind Direction	±2 degrees
Output Resolution	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	1.0 deg.
Starting Threshold	0.5 m/s

Campbell Scientific 109-L Temperature Probe

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

Campbell Scientific CR206 Data Logger

All data will be stored using a Campbell Scientific CR206 data logger. Both 5-minute and 60-minute averages will be stored, though the 5-minute data will be used primarily for QC purposes. Based on the number of measurements an statistics being record, the CR206 can operate for a period of up to approximately two weeks before it is necessary to download data. The CR206 data logger is equipped with a 915 MHz radio, allowing remote accessing and downloading of data.

4.2 OZONE/RAWINSONDES

To profile ozone concentrations from the surface to the tropopause, we will use balloon-borne ozonesondes, with measurements placed at the Pinedale airport. The ozonesonde systems has three primary components, described below:

Sippican W-9000

The Sippican W-9000 system consists of a SIPPICAN ZEEMET W-9000 GPS based navaid receiver/data system for measuring winds and the SIPPICAN Mark II Microsondes radiosonde packages.

The SIPPICAN ZEEMET W-9000 receiving station interfaces with a personal computer and printer. This is a state-of-the-art wind finding system employing GPS technology. The UHF receiver operates in the 400 MHZ range. SIPPICAN software enables the interface with the SIPPICAN W-9000 receiver and reduces the thermodynamic pressure, temperature and humidity (PTU) and navaid/wind data. During each flight, the technician is able to monitor both raw and reduced data in near real time. The software also includes graphics and plotting capabilities that allow the technician to review results during and at the end of each flight. Both raw and reduced data are stored on the hard disk in subdirectories identified by the flight name. All data files are copied to both primary and backup diskettes immediately after each flight.

SIPPICAN Mark II Microsondes

The SIPPICAN Mark II Microsondes are 10 x 19 x 15 cm and weigh 250 grams with a water-activated 18V battery. The radiosonde UHF transmitter sends its modulated signals in the 400 MHZ range. The Microsondes are calibrated at the factory in a computer-controlled environmental chamber. Calibration coefficients are stored in read-only-memory (ROM) within each sonde and are automatically transmitted to the receiver in 1.5 sec intervals. Temperature is measured using a bead thermistor and relative humidity using a carbon hygristor. The SIPPICAN W-9000 is an automatic wind finding system that is based on tracking the sonde using the GPS satellite network. The Microsonde incorporates a low-noise integrated circuit GPS receiver. Winds aloft are calculated from the change in balloon position (determined from navaid) with time. Height is obtained directly from GPS positioning and, unlike older systems, pressure is now a derived parameter, calculated from the hydrostatic equation, using measured height, temperature, and humidity.

Accuracy (instrument specifications)	
Horizontal Wind Speed	± 0.5 ms^{-1}
Horizontal Wind Direction	Unknown
Temperature	± 0.2° C
Relative Humidity	± 2.0%

Output Resolution	
Horizontal Wind Speed	0.1 m/s
Horizontal Wind Direction	1.0°
Temperature	0.1° C
Relative Humidity	1.0%

EN-SCI Corporation KZ-ECC Ozonesondes

EN-SCI Corporation KZ-ECC ozonesonde system will be used in conjunction with the SIPPICAN W-9000 Mark II Microsondes radiosonde package. The KZ-ECC atmospheric ozone sounding system is designed for ozone measurements from balloon platforms, but for this project will be used both from balloon platforms and, in a modified package, for continuous surface sampling at fixed locations (see Section 3.2.1.4). Ozone is measured with an electrochemical concentration cell (ECC) ozonesonde coupled through an electronic interface to a SIPPICAN W-9000 Mark II radiosonde (described in detail in the meteorological measurements proposal).

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

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

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

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2. \quad (1)$$

The cell converts the iodine to iodide according to

$$I_2 + 2e \rightarrow 2I^- \quad (2)$$

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

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

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

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

As an integral part of the ozonesonde operations, a Dasibi EPA designated equivalent ozone analyzer and meteorological instrumentation will be installed at the ozonesonde launching site, within the hanger office building at the Pinedale Airport. This equipment is described below:

Dasibi Model 1000 Series Ozone Analyzer

Ozone at the Pinedale airport will be measured with either Dasibi Model 1003 or Model 1008 UV photometric ozone analyzers (EPA equivalent numbers EQOA-0577-019 and EQOA-0383-056, respectively). Sampling will made through Teflon lines, which will be of sufficiently short length to meet EPA requirements for sample residence time. Interior temperature will also be monitored.

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

RM Young Model 05103 Wind Monitor

For surface monitoring of wind speed and wind direction at the Pinedale airport site, we will employ an RM Young 05103 Wind Monitor wind speed and direction sensors. MQOs for this sensor are similar to those for the model 05305 sensor presented above with the exception of the starting threshold, which is 1.0 m/s.

4.3 AIRCRAFT SAMPLING

The sampling instrumentation for the aircraft that we are proposing is identical to that which used during the 2005 CCROPS (T&B Systems, 2006). Ozone sampling is based on the wet cell KI technique implemented by EN-SCI Corporation for tropospheric and stratospheric ozone profiling, as described in Section 4.2. The sample pump/cell system is housed in a small case with the output signal from the sampler recorded on a Campbell CR1000 data logger. This data logger allows the recording and parsing of a serial data stream from a Global Positioning System receiver as well as recording analog signals of pressure, ambient temperature, detection cell temperature and the calculated values of ozone based on the sampled parameters. Data are sampled and recorded at 2-second intervals. A set of AA batteries provides power and the capability for the entire system to measure ozone continuously for over 8 hours. The sample inlet is through a length of FEP Teflon tubing to a region of the aircraft in free airflow. The temperature probe will be placed near the sample inlet. The preparation time prior to a flight requires approximately 20 to 30 minutes to install, pre-flight and assure that the systems were operational. Figure 4-3 shows the installation of the package behind the pilot seat in the Piper Super Cub used for the 2005 CCROPS study, with the sample line is run out the open window to the mounting on the strut. For this study, we are using a Cessna 172 based out of the Pinedale airport.

In addition to sampling for ozone, $PM_{2.5}$ sampling will also be included in the aircraft measurements using a DustTrak 8520 optical light scattering instrument. Test flights of the system showed that the aircraft readings were in no way affected by the aircraft exhaust, as evidenced by $PM_{2.5}$ reading of zero.

VOC and carbonyl samples will be collected during 5-minute spirals in the desired sampling location. VOC canisters will be opened, allowing the sample to be drawn using the canister's vacuum. A Thomas 12-V portable pump operating at approximately 5 lpm will be used to draw sample air through the carbonyl cartridges. More details regarding the VOC/carbonyl sampling are discussed in the section below.

Figure 4-3. Ozone sampling package mounting in back seat of aircraft.

4.4 VOC SAMPLING

VOC samples will be collected using SUMMA canisters outfitted with flow controllers set up for 3-hour integrated samples. Carbonyl samples will be collected using DNPH-coated cartridges outfitted with ozone scrubbers and connected to constant flow pump systems over the same time period as the canisters. VOC samples will be analyzed using Method TO-14 with an expanded PAMS list of compounds (see Table 4-1). Carbonyl samples will be analyzed using Method TO-11 for the compounds listed in Table 4-2. Analysis will be performed by Environmental Analytical Services, Inc., Santa Barbara, CA.

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	

Table 4-2. Target compound list for EPA Method TO-11 volatile organic compounds.

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

4.5 UPPER AIR METEOROLOGY

An ASC Model 3000 miniSodar, and a surface-based meteorological system will be used to collect the upper air meteorology data. These instruments provide vertically and temporally resolved boundary layer winds and boundary layer depth (i.e., mixing height) data. The Sodar provides continuous (hourly or sub-hourly) wind data with a vertical resolution of 10 m at heights from about 10 m up to about 400 m 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 Figures 4-4.

As part of the operations, we will design and implement sampling strategies for the Sodar, including programming the data acquisition systems to operate the instruments under configurations that produce 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
Minimum Sampling Height	15 meters
Transmit Frequency	4500 Hz.
Averaging and Reporting Interval	1 to 60 minutes

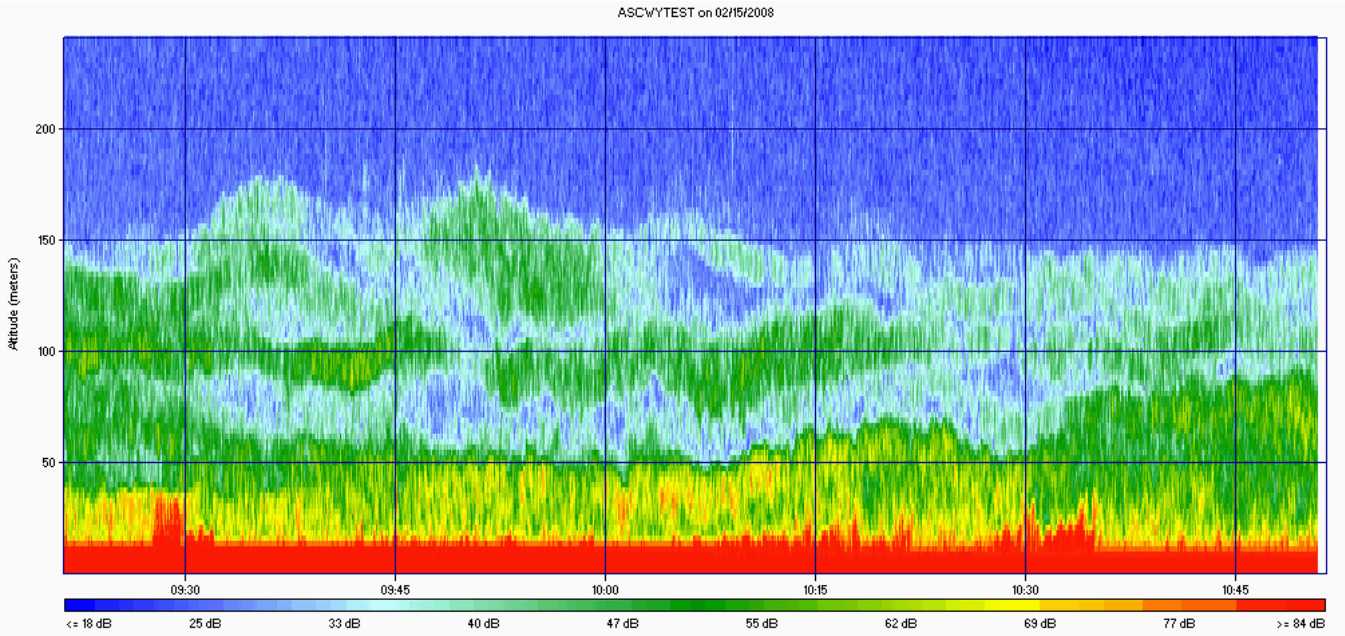


Figure 4-4. Example of sodar backscatter data capturing the daytime mixing height layers under cold wintertime conditions.

4.6 ADDITIONAL MEASUREMENTS

Total UV Radiation

UV radiation will be measured using two Eppley Total UV Radiation (TUVR) sensors – one facing upward to the sky and one facing downward to the ground. The Eppley Ultraviolet Radiometer consists essentially of a selenium barrier-layer photoelectric cell with a sealed-in quartz window, a bandpass filter to restrict the wavelength response of the photocell to the designed range, generally 295-385 nm (i.e. adhering closely to the generally accepted limits for solar ultraviolet radiation reaching the earth's surface, even at altitudes as high as l5,000 feet) and virgin Teflon diffusing disk. The purpose of this disk is twofold, - to reduce the light intensity at the filtered photocell (and thus to increase its stability with exposure time) and also to improve the adherence of the instrument to the Lambert cosine law (and is shaped with this object in view).

These sensors were installed at the Boulder site during the initial 2007 study.

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 within the desired completion time. 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.

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 flags. Flags used for UGWOS are presented in Table 6-1. 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 is 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.

Flag	Description
V	Valid. Data meets primary MQOs.
S	Valid, but does not meet primary MQOs. Secondary MQOs in effect.
I	Data invalid.
M	Missing. Measurement not taken.

Table 6-1. Data Flags.

Once the data have been validated to level 1, the data will be prepared for submittal to the database in a form that clearly define 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. Data flagged as invalid or missing will be given a value of -9999. In the event that data for a given measurable is either all valid (meeting primary MQOs) or all missing, participants need not supply the flag column, though this must be specifically stated.

Database Management Design

T&B Systems 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 design for the database that was implemented during the 2007 field study. 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.

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.

NMHC VOC:

SITE, DATE, HOUR, START_TIME, END_TIME, CANNISTER_ID, QC_CODE, PARAMETER1, PARAMETER2, PARAMETER3,..PARAMETERn, notes

Upper level meteorological and air quality data

The episodic rawinsonde, ozonesonde, pibal, and glider data will be stored together in a file with the following format:

SITE, DATE, TIME, HEIGHT, PRESSURE, PRESSURE_QC,

O3, O3_QC, WS, WS_QC, WD, WD_QC, TP, TP_QC, RH, RH_QC

Radar Profiler and 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 million for O3
- Meters per second for wind speed (as a general rule, metric units will be used)
- Degrees Celsius for ambient temperature
- Percent for relative humidity
- Parts per Billion Carbon for non-methanated hydrocarbon species
- Watts/m^2 for radiation

- 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

Data files of all data collected during the study will be transmitted to WDEQ by June 15, 2008.

The ENVIRON/T&B team will review the validated data collected during the field study and prepare descriptive summaries in a report format for delivery to WDEQ. We will prepare summaries of air quality and meteorological conditions during the study period. In addition, we will prepare more detailed descriptive analyses of the air quality and meteorology measured during each high ozone event captured by the intensive operating periods. As part of our Level 1 data validation procedures, we 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 shears (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 ozone, temperature, and winds;
3. Horizontal mapping of ozone, precursors, ambient temperature, and winds—both at the surface and aloft;
4. Time-height cross sections of ozone, potential temperature, winds, and mixing heights.
5. Time-height cross sections of transport statistics including scalar transport distance, vector transport distance, and recirculation factors
6. Wind roses at the surface and select levels aloft,

7. Pollution roses at the surface and select levels aloft, and
8. 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 digest format.
- A summary of field operations via tables showing the times of balloon-borne soundings, the times of ground and airplane sampling, VOC samples, and supplemental measurements. 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 presented to WDEQ by June 30, 2008. Voluminous tables and figures will be incorporated into electronic appendices as appropriate. All report materials will be made available via a project web site with access restricted in accordance with WDEQ policies and procedures.

SECTION 6

QUALITY ASSURANCE PROGRAM

6.1 PROJECT MANAGEMENT

Mr. Till Stoeckenius will serve as overall project manager and co-principal investigator. Dr. Greg Yarwood will serve as ENVIRON's Principal in Charge for the proposed project, insuring that any and all ENVIRON resources needed for the timely and on-budget completion of the project are made available.

Mr. Don Lehrman will serve as manager of all field operations and co-principal investigator, overseeing the day-to-day project activities and providing the primary interface with team members on project related issues.

Additional key staff will be assigned to each project task as shown in Figure 3-1. Quality assurance will be lead by Mr. David Bush. Mr. Bush has extensive experience in this area, having served as the external quality assurance officer for a number of large air quality studies. He will also be closely involved in field study operations. Mr. Robert Baxter will also be involved in field study operations and will lead the data archiving task. Mr. Baxter has managed numerous field studies including the Clark County (Las Vegas) CO Saturation and PM_{10} studies. Key staff from T&B Systems, MSI and STI will be responsible for the deployment, operation, and data gathering from the specific instrumentation programs they are assigned to.

Study personnel responsibilities and contact information is presented in Table 6-1.

A UGWOS study web site has been developed to assist in communications between study participants. This web site can be found at http://70.133.103.202/UGWOS. The web site contains the following web pages:

- Study Overview - This page presents a brief overview of the study, the study objectives, and study schedule.
- What's New? – This page serves as "document control" for the web site, providing a complete history of all modifications to the web site. Anytime the web pages are expanded or modified, a brief summary and the date of the modification is posted.
- Project Status – This page provides information regarding the readiness of participants' monitoring efforts. The page is particularly important during the early stages of the study period for helping to maintain the study schedule.

- Study Forecast – This page provides for the communication of study-specific information regarding forecasted ozone conditions, and serves as the alert for IOPs and episode-mode monitoring efforts.

- Monitoring Sites – This page provides a description of the CCROPS measurements and a map of the measurement locations.

- Project Participants – This page provides a list of the CCROPS participants, a summary of each participant's study responsibilities, and contact information for key individuals.

- Planning Documents – This page requests and posts measurement quality assurance documentation. This is discussed in more detail below.

- Preliminary Analysis – This page provides participants with a means to present preliminary analysis of collected data. This in turn provides study management with feedback regarding collected data versus study goals, and the means of refining the monitoring effort, if needed.

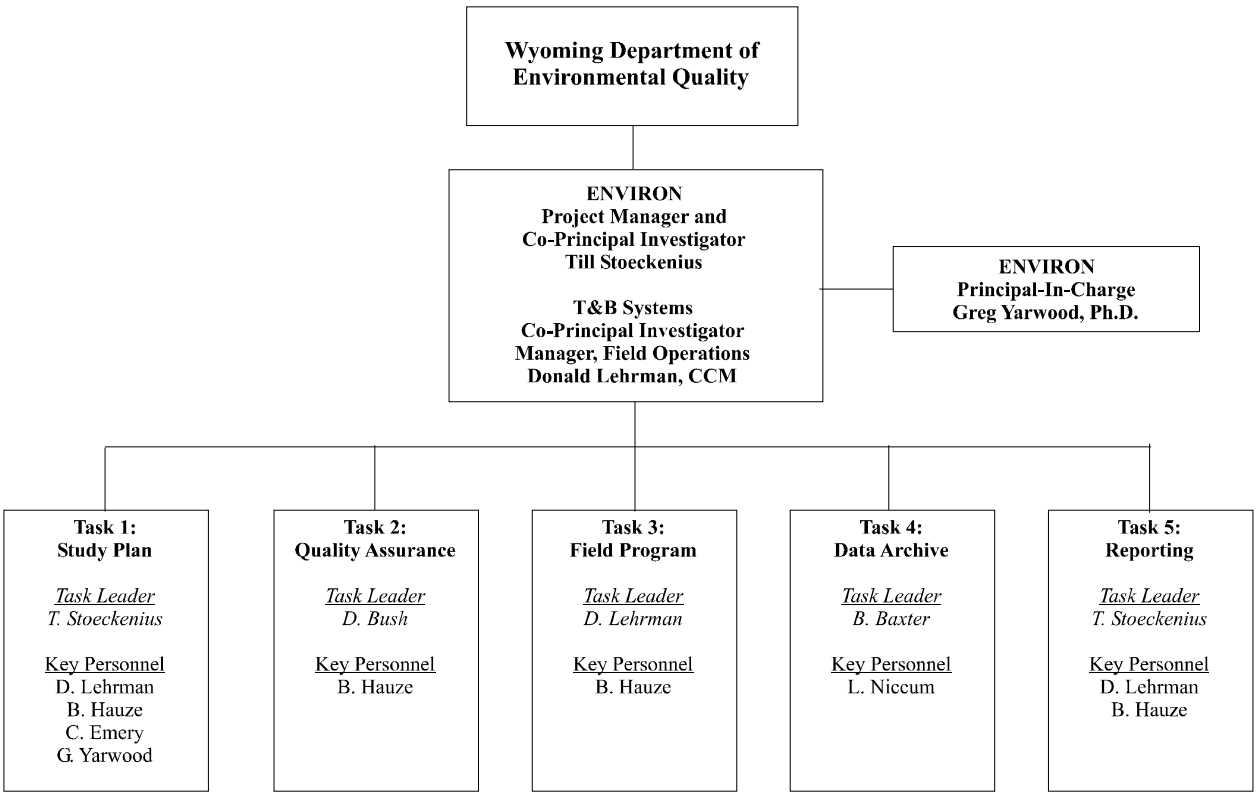


Figure 6-1. Project organization.

Table 6-2. Project Responsibilities and Contacts

Name	Organization	Key Responsibilities	Phone Numbers
Cara Keslar	Wyoming DEQ	Contract Manager	
Jennifer Frazier	Wyoming DEQ	Pinedale Support	
Till Stoeckenius	Environ	Project Manager Principal Investigator	
Don Lehrman	T&B Systems	Field Project Manager Ozonesondes Principal Investigator	
David Bush	T&B Systems	Quality Assurance Aircraft Measurements	
Bob Baxter	T&B Systems	Overall Field Measurements Support Sodar Operations	
Bill Knuth	T&B Systems	Study Setup and Teardown Ozonesondes	
David Yoho	T&B Systems	Aircraft Measurements Field Support	
Bill Hauze	MSI	Field Support	
Dan Risch	MSI	Forecasting	
Tyler Ward	MSI	Mesonet Site Checks, VOC Sampling	
Michael Butler	IML	Daniel Site Operations	
Lincoln Sherman	ARS	Boulder Site Operations	
Jim McLellan		Aircraft Pilot Pinedale Airport Support	

6.2 DATA QUALITY OBJECTIVES

Specific monitoring quality objects 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 February 16, 2008. This checkout will occur during the week prior to the start of monitoring, during setup and installation of the equipment. This includes a dry run of all measurement methods, during which operating procedures can be refined and fully documented. Standard operating procedures (SOPs) for measurements will be completed prior to the start of monitoring. SOPs can be found in Appendix B.

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

Ozone Analyzers and Samplers

All ozone analyzers and samplers will be routinely checked using a certified transfer standard, following operating procedures consistent with EPA guidelines. This will consist of zero and span checks conducted at the beginning and end of each IOP. These checks will be conducted using a transfer standard certified against T&B Systems primary standard maintained following EPA's guidelines at their office in Valencia, CA. For the mesonet equipment, a 2B model 306 (S/N 2) portable ozone calibrator will be used. Zero/span checks of the mesonet samplers will be conducted at least twice per week during the IOPS, providing precision data. A pass/fail criterion of +/-10% will be used when evaluating the span and calibration data. A zero check and ground truth comparison will be performed on all tethersonde and ozonesonde equipment prior to each flight.

Aircraft Samplers

QA/QC for the aircraft ozone sampler will be similar to that for the other ozone analyzers and samplers. This would include calibrations at the beginning and end of the study, as well as zero check and ground truth comparison each intensive day. In addition, we will periodically conduct soundings coincident with ozonesonde soundings, providing a QA comparison for both aircraft and

ozonesonde measurements. In addition, soundings at each of the tethered sounding sites will be conducted each day, providing additional QC data. The DustTrak will be subject to zero and flow checks each intensive day.

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 so that team members can use the data to assist in special monitoring and forecasting.

VOC Sampling

Field blanks totaling approximately 5% of the collected samples will be collected and analyzed. In addition, two of the samplers will be collocated periodically during the study to collect duplicate samples.

Radiation Sensors

The relative calibrations of the two radiation sensors will be periodically checked by aiming both sensors towards the sky and recording the responses. The ratio of the responses should be consistent with that obtained from the calibration certifications that accompany the sensors. In addition, the zero response of each sensor will be checked at the same time by covering the sensor with a UV blocking substance.

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 6-1.

Calibrations of the ozone instruments 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 (2B Model 306, S/N 002) certified against a local ozone standard (Dasibi Model 1003-PC, S/N 2437) maintained at the Pinedale airport. This local standard in turn has been certified against T&B System's primary standard maintained following EPA's guidelines at their office in Valencia, CA, as well as against the US EPA Region 8 primary standard

maintained at Boulder, CO prior to the initial 2007 monitoring. The two certifications showed very good agreement.

Ozone data will be adjusted if the calibration slope is off by more than ±5% or if the zero is off by more than ±5 ppb.

All meteorological sensors will be calibrated at the beginning and ending 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 30° to 45° increments. Calibration of the UV radiometers is provided by the manufacturer.

Table 6-1. Calibration methods for the monitored variables.

Measurement Variable	Calibration Method
Ozone (O_3)	Multipoint comparison of ozone concentrations with certified ozone transfer 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
Relative humidity	Collocated 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.

The principal audit tool will be system audits of the data collection operations. System audits will address the following:

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

Mr. David Bush and Mr. Bob Baxter will conduct the system audits of all measurement platforms, with audit responsibilities based on independence from the operations of the monitoring efforts. These audits will be conducted during

or before the first IOP of the study. 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.

As discussed above, to further verify the accuracy of the ozone measurements, the T&B Systems ozone transfer standard will be compared against the US EPA Region 8 primary standard located in Golden, Colorado. This comparison will consist of a six-point comparison, per US EPA guidance for ozone transfer standards, and will be conducted prior to its use for the UGWOS.

6.4 DATA VALIDATION

All data collected for UGWOS be will 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.

For the miniSodar, monthly reviews and editing will include Level 1 and Level 2 validation of wind, T_v, and mixing height data. Level 1 validation is a check of internal consistency and reasonableness for each site for each hour (or sub-hour, depending on measurement frequency). Level 2 validation is an external consistency check of the data and is achieved by comparing the data with those collected at nearby locations for each day, including comparisons of wind and temperature data to meteorological data from other sources (e.g., rawinsondes, synoptic weather charts). The final product will include electronic files containing Level 2-validated mini-sodar wind and mixing height data.

SECTION 7

REFERENCES

United States Environmental Protection Agency (1995). Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements. Document EPA/600/R-94/038d. Office of Research and Development, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina.

United States Environmental Protection Agency (1998): Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part I, Ambient Air Quality Monitoring Program Quality System Development. Office of Air Quality Planning and Standards. Draft Revision to Document EPA/600/R-94/038b.

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 Site

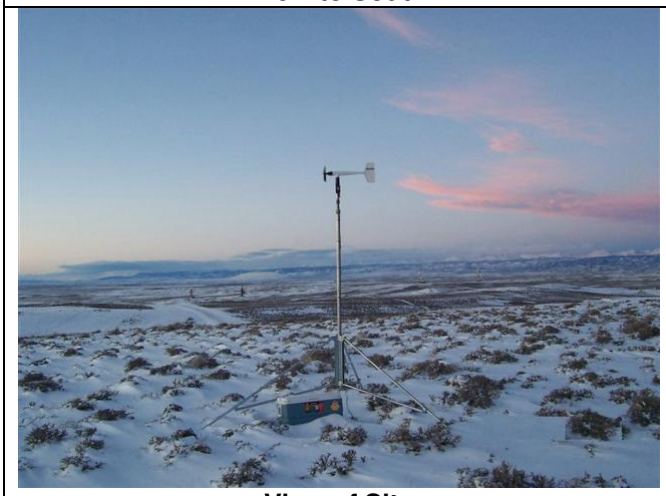
Cora

View to North

View to East

View to South

View to West



View of Site

Warbonnet

View to North

View to East

View to South

View to West

View of Site

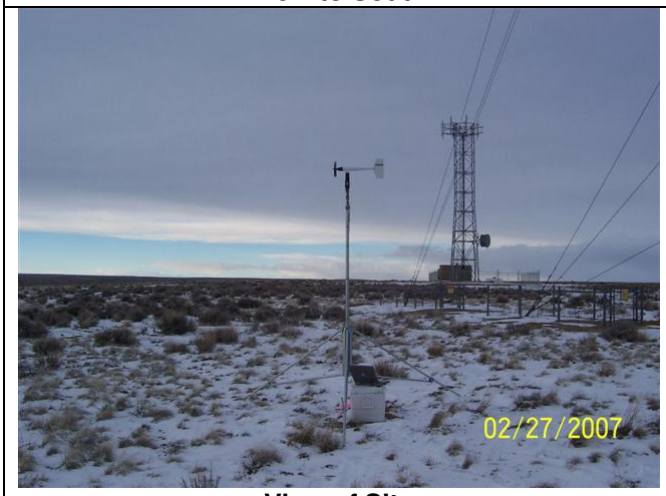
Haystack Butte

View to North

View to East

View to South

View to West



View of Site

Simpson Gulch

View to North

View to East

View to South

View to West

View of Site

La Barge

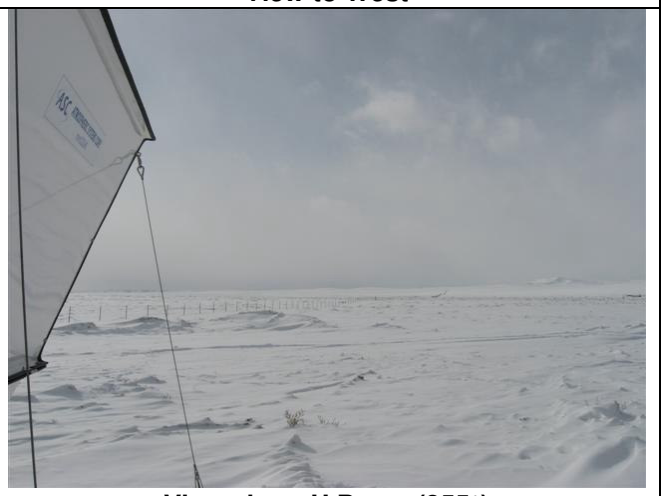
View to North

View to East

View to South

View to West

View along U Beam (345°)



View along U Beam (255°)

Mini-Sodar Site

APPENDIX B

STANDARD OPERATING PROCEDURES

1. STATION SETUP

This section to be executed only when installing equipment at a new site.

GPS Station Setup Elevation Procedures

VIZ Setup Program requires three elevation fields to be filled out. Those are:

1. DGPS Antenna Height (with reference to WGS-84 elevations)
2. Geoid Separation
3. MSL Station Height

Knowing any two of the three, the third can be determined using a variation of the following relationship:

DGPS Antenna height = MSL station height + Geoid Separation + Height of GPS antenna off ground level

Station Coordinates and MSL station height can determined from a very accurate site-specific survey.

If you know the Station Coordinates accurately before going to the field, you can obtain the Geoid Separation (from WGS-84 elevations) from the following website:

<http://www.nima.mil/GandG/egm84/intptW.html>

Otherwise the following procedure is recommended:

1. Run the program LOCATE

   To run LOCATE at the DOS prompt type "START LOCATE" (note that ground GPS antenna must be installed and W9000 system turned on). Allow the program to run for at least 10 minutes until stable readings are noted. When the "Escape" key is pressed, the resultant Latitude, Longitude, and Station Height relative to WGS-84 coordinates is shown on the monitor (which is the same as DGPS Antenna Height).

2. Using the surveyed MSL site elevation or the best estimate height with the results from LOCATE, you can calculate the DGPS antenna height in WGS-84 using the equation shown above.

3. Note that the last term in the equation is simply an estimate of the height of the GPS antenna above the ground release point (~2 meters unless mounted on a structure).

Some examples:

At Site A, we were able to determine beforehand the approximate Latitude and Longitude of the site. From the above web site, it was determined that the Geoid separation was -20 meters. Once at the site, LOCATE is run (for a minimum of 10 minutes). The height

shown in LOCATE is "-20 meters", relative to WGS-84 coordinates that must be corrected to actual using the cited relationship.

Station Height = DGPS Antenna Height - Geoid Separation - Antenna height (~2 m)
= -20 meters - (-30 meters) - 2 meters
= 8 meters

At Site B, we had no prior knowledge of its location but the site documentation gives a height of 230 meters. LOCATE is run yielding a height of 210 meters. Again the antenna is mounted on a tripod 2 meters off the ground. From the referenced relationship:

Geoid Separation = DGPS Antenna Height - Station Height - Antenna height
= 210 meters - 230 meters - 2 meters
= -22 meters

For both examples above, it is preferred to use the coordinates obtained from the LOCATE program.

NOTE: if when running the W9000 Flight Program the first time at this site, the error "Base Coordinate Error" or something to that effect, it means the software can not reconcile the height and/or location input in Setup. Run Setup again, checking the input.

Also NOTE: that the last field in the Elevation Setup, **Height Adjustment**, is no longer used.

Special Note When **Using for Audits**: A special version of the post-flight processing programs are available, call finaud.bat and audver.exe. Features of this processing program is that heights output will be meters above ground level, and virtual temperature is included in each record.

T&B Systems processing header information (all radiosonde types)

The ASCII file "SSSinput." must be edited for new sites. This information is what is output in the .DAT header record. Use the DOS or any other editor to edit. Change the fields as necessary. keeping the spacing (blanks). The edited file be must renamed so that the SSS is station ID that is used in the VIZ software.

Wind Computation Setup

GPS : Wind Interval Selection

Select Invervals by Time

	Section Start (seconds)	Smoothing Length (seconds)	Minumum Inteval Samples	Computation Interval (seconds)
1	0	1	1	1
2	6	10	5	1
3	666	20	10	10

GPS : Wind Parameter Setting

Differential GPS Curve Fit Variance 0.90
Raw Wind Sampling Interval (seconds) 1.00

LORAN: Wind Interval Selection

Select Invervals by Time

	Section Start (seconds)	Smoothing Length (seconds)	Minumum Inteval Samples	Computation Interval (seconds)
1	0	60	15	15
2	180	120	30	15
3				

LORAN: Wind Parameter Setting

Loran Curve Fit Variance 0.90
Raw Wind Sampling Interval (seconds) 3.00

2. SONDE OPERATIONS

Prepare sonde and battery; remove humidity sensor's protective cap*; remove plastic cover from thermistor arm, and orient at a 45° upwards and out from the body of the sonde; soak the battery in water for 2 minutes, then shake excess water from battery by (with label facing down assuring water will not be trapped by the wax layer) extending arm and swinging over your head to an abrupt stop at your knees, and repeat this 5 times. Then visually inspect battery for any remaining excess water.

*(Once the humidity sensor's cap is removed, close the flap and tape it down. This is also per the manual (section 5 page 4).)

Place battery in the clear plastic bag provided. Place battery into the compartment that the battery was originally packed in on the front of the sonde *with the label facing out* from sonde.

Connect battery wires to those of the sonde. Always connect the negative (ground, black) wires first when connecting the battery to the sonde. This is necessary for proper initialization. This is actually straight out of the manual (section 5, page 3), not some voodoo superstition.

Once connected, **let sonde battery warm up** *until signal begins to emit*. Not doing so will almost assuredly result in having to re-initiate the sonde (which as we know is a likelihood anyways).

Also per the manual, once the battery is hooked up and placed into it's location in the sonde (with the "TOP" label facing out), **tuck the wires into the same compartment before closing the flap and taping**. To quote the manual (section 5, page 4) "failure to put all the wire for the battery inside the battery compartment may cause radio energy to fee back into the circuits of the radiosonde."

Meanwhile, **prepare balloon** as usual (keeping in mind that an ascension rate greater than 3 meters per second is necessary for the launch to be detected), and **turn on the system computer** booting in DOS mode. (The station set-up procedure should have already been completed when first installing the site. See "station set-up notes" above). Make sure that the 403 receiver has already been turned on for at least 15 minutes before proceeded with flight (this is necessary for proper GPS coordination). Depending upon the particular launch-schedule for your project, often it is prudent to **leave the receiver on between flights** to avoid having to wait the 15 minutes each time.

From the C: prompt, type "start" to open Zeemet software. The **flight identifiers screen** should now be displayed on the system computers monitor. Enter the 6-digit sonde serial number (located on bottom of sonde), and the new flight identifier. Escape from this screen, and accept the correct values entered. **The flight preparation screen** will now open, and you will be prompted to connect the initialization cable to the sonde.

Initialize the sonde. Plug the initialization cable into the plug attached to the sonde with the words "TOP" clearly displayed from (get this) on top (above). **Wait 15 seconds** and then press "enter" and the initialization process will begin. (the 15 second delay here "allows the radiosonde microprocessors time to complete their start-up sequences").
Note: There is no pattern in the initialization process. This means that an initialization with very faint or no clicks at all may be perfectly fine (usually not); that the signal may not modulate at all

while hanging in it's static pre-flight position, but may pop in perfectly 2 minutes or 5 minutes or 30 seconds before arming for launch (or maybe not); that IN MOST CASES the sonde will need to be initiated at least twice, possibly 3 times, sometimes only once which brings up:
The 3 STRIKES YOU'RE OUT rule. The sonde may need to be re-initialized 1, 2 or 3 times, but if it hasn't happened by then, it probably will not happen; after 3 strikes (the point of diminishing returns), move onto a new sonde. 80% of the time the sonde successfully initiates on the 2nd try, but if not usually "the third time's a charm."

When initialization is complete (3-6 minutes approx.), you will be prompted that the "initialization is complete." Once the initialization is complete, the cable needs to be removed quickly and the sonde moved to it's (predetermined) static pre-flight position ***within one-and-a-half minutes*** according to the manual. The "two actions must be done quickly as they are time sensitive." (Section 5 page 4) " The radiosonde has been programmed to start acquiring satellites immediately after the initialization cable has been removed" (section 6 page 6).

A note on the "static pre-flight position": for the duration of the project, you should have selected and installed a stationary position outside of the inflation room/computer-receiver room (near the launch site) that allows you to hang the sonde from it's tie ring with the GPS antenna pointing upwards and leave it there as you proceed with other aspects of this flight's set-up. The view of the sky from here needs to be unobstructed, and **this stationary position is crucial** for the GPS capabilities of the sonde to be able to lock in to position and be of use. Also, through trial and error, Bill and I found that the static pre-flight position chosen to hang the sonde should be placed in a position that roughly forms a triangle with the two antennaes.

For more detailed information surrounding the initialization process, see Chapter 6 (page 6) "Pre-Flight and In-Flight Operating Instructions" in the GPS Supplement to the W9000 Operation Manual.

Once the sonde has been moved outside to it's stationary position, the sonde will now begin gathering and locking onto satellites. Depending on weather conditions and other variables, this process may take 10 minutes or more (but usually less). A minimum of 4 satellites need to be collected and locked onto for the GPS positioning of the sonde to be enabled.
After typing "1" from the flight preparation screen (the category of "Wind Finding Status, dgps"): the satellites will first start to appear on the "ephemeris" line, and then start to pop in along the "corrected" and "measured" lines just before finally appearing in the "in use" category (at which point also the "satellite signal quality" box will begin filling in with the satellites that are locking in**). It is only the "in use" category that we count when determining that the GPS satellites are adequately locked in.** See Figure 6-10 on the next page (copied from GPS Supplement).

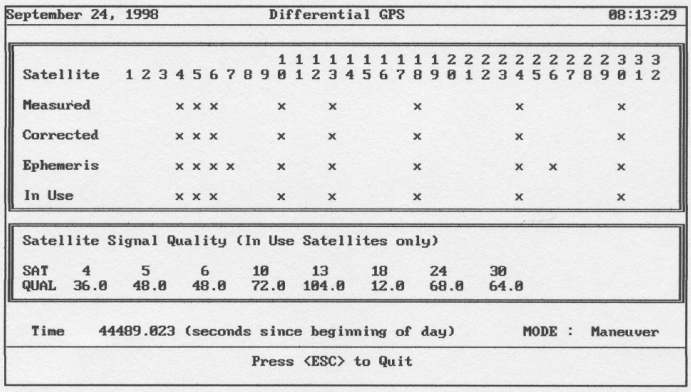


Figure 6-10. W9000 Differential GPS Screen(LOS, LOS-B, LOS High Resolution)

Note: once the satellites seem locked in while viewing this page and then you "escape"to get back to the flight preparation screen, you'll notice that the asterisk has not yet appeared or has disappeared next to the category of "Wind Finding Status, dgps." This is normal, but you'll need to now wait for a few minutes for the system to re-lock onto the satellites; for whatever reason, toggling back and forth to view the detailed satellite status information interrupts the GPS lock-up, and will thus result in delaying the launch.

If it becomes apparent that for whatever reason the sonde is unable to lock onto the satellites, then re-initialization will be required. However, keep the following in mind:

When you progress to the point of waiting for the satellites to start popping in, it will seem that it's taking forever with no apparent progress, but remember that **the "in use" satellites will usually *all appear at once***... that while it appears as though nothing's progressing, it actually is. It just doesn't come in incrementally. So don't give up on it too quickly…

While the sonde is hanging in it's stationary position and you are waiting for the satellites to start locking in, by now you should also have a "match" between the sonde's broadcast signal and the receiver (or to put it differently, a match between the sonde's serial number and the serial number you entered), signified with an asterik now appearing next to the "receiver" field on the flight preparation screen, in the pre-flight menu box (number 4). The signal should be modulating strongly (an unmistakable sound that you will become very familiar with)* **Most often, when it's *going* to happen, the receiver will lock onto the signal (get a match) from the sonde almost immediately**. Before or as you walk the sonde out to it's static pre-launch position, the match should just pop right in (meaning that the asterisk will appear almost immediately next to the "Receiver" status in the window). Unfortunately, this is not always the case, so you can't use it as a general rule; it may take a few minutes to lock as it often did with the loran-sondes. But to spend too much time trying to hand tune (via the "alt-t") *unless it's already locked once (and you've **already** had a "match")* is not worth the effort; you'll most likely never get a match until you re-initialize. Essentially, **It'll happen or it won't without the need for hand-tuning.**

*(keep in mind that there are times when you've got "a match" but the signal is not yet modulating, or it's going in and out, but the signal will at some point become a steady modulation before you arm for launch).

If it is necessary to re-initialize the sonde (due to the lack of a "match" or of a modulating signal, or of the inability of the sonde to lock onto satellites, or perhaps other complications): both disconnect and re-connect the battery and also toggle 403 receiver power switch off and back on.

If you are within 10 to 15 minutes of launching, now is the time to **enter the surface data** using the flight preparation screen interface. An asterisk will appear next to the "surface data" category in the pre-flight menu box (number 2) once this is complete. *Note: (to quote from the manual) "the correct surface pressure, temperature, and humidity at the release point MUST be entered in the surface data display just prior to Arm for Launch. These values are used to initialize the pressure computation for differential GPS operation…The accuracy of the in-flight pressure data is dependent upon the surface pressure measurement recorded in the Surface Data Screen. Whereas the temperature and humidity are measured by the radiosonde in flight, the pressure is calculated by the W9000 system software based on the initial pressure entered (in the Surface Data Screen)".*

Once all of the necessary satellites are locked in, an asterisk will appear next to the "wind finding status" category in the pre-flight menu box (number 1). Assuming that there is an asterisk also appearing next to the "Calibration" category in the pre-flight menu box (number 3), and next to the Receiver category (number 4) you are now ready to **Arm for Launch**.

When the weather is permitting, let the train out all the way on the derailer. The tracking software is set to compensate for the sonde oscillating along an arc based upon the full length of the line.

Special note you can take to the bank: as Bill pointed out numerous times, the sonde will either be ready to go 40 minutes early if all goes smoothly, or 30 minutes late if not. This, at least, you can count on.

3. POST-FLIGHT OPERATIONS

From main menu select option to 'End Flight' and acknowledge when prompted.
Do not change the "L" or launch point in the record as we used to do with the loran-based sondes. First of all, it isn't necessary in general because using the GPS system results in this point being remarkably accurate (almost always only 1 or at the most 2 points off, usually dead-on), and secondly, if you change the "L" even though the computer will claim to be "averaging winds up to the current time," it never will, and all data will be lost.

From the main menu selection 'Utilities', select option to 'Save Flight'. If for some reason the flight name was not entered correctly or this was a repeat sounding, you will be prompted to enter a new flight ID or overwrite the existing one. If appropriate, enter the correct flight ID new.

Escape back to main menu and exit program. You will be at the DOS prompt at this time.

Insert diskette in drive A. Type "copy c:\flights\new*.rts A:". Next type "type *.rts and inspect data file to ensure sounding was successful.

Remove diskette and add flight ID to diskette label.

Lastly wipe the snot off your nose.

Launch Information

Station Name:_____Station ID (SSS):_____

Date (mm/dd/yy): _____Flight Name (SSSmddhh): _____

Scheduled Launch Time (Local): _____Actual Launch Time (Local): _____

Radiosonde Information

Serial Number: _____Loran or GPS: _____

Sonde Frequency (MHz):_____403 Signal Strength: _____

Initial Sonde Pressure (mb):_____Pressure Offset (mb): _____

Surface Information

	Ambient Readings	Sonde Readings
Pressure (mb)	_____	_____
Temperature (C)	_____	_____
RH	_____	_____
WB Temperature (C)	_____	_____
Wind Direction	_____	_____
Wind Speed (with units)	_____	_____

Cloud Observation:_____

Current Weather Conditions:_____

Operational Information

Arm for launch Clock Time:_____

Time Launch Detected: _____

First Time Value in Edit Launch Mode (mm.ss): _____

For GPS - Number of Satellites Found: _____ Number Used: _____

Comments and Calculations Used:

The following are procedures for preparing, operating and data retrieval for the aircraft sampling systems.

Special Notes:

- First and foremost, safety is the number one priority. No operation should be performed that could pose a hazard to the operator or aircraft. If there are any questions regarding safety concerns for the flight, the Field Manger (Don Lehrman or Bob Baxter) should be contacted.
- When working with the ANODE and CATHODE solutions, take great care not to mix the syringes and solutions, otherwise all will be lost!
- When the samplers and spare cells are transported, never tip them as the fluids might leak.

1 Ozone Sampler Servicing – Laboratory Cell Preparation

- Prepare the initial sample cells. The following steps assume that the cells to be used have been previously flushed with distilled water and are dry (or been in storage since the last flushing and drying), and that the cells will be put into use within 24 hours of preparation.
    - Place an appropriate amount of CATHODE and ANODE solutions in their respective cups. As none of this solution should be returned to the original bottle, take care to only use what is necessary for the cells to be prepared.
    - Fill the CATHODE syringe and charge (fill) each of the CATHODE cells up to the bottom ridge line (approximately 1/3 of the way from the bottom of the cell).
    - Fill the ANODE syringe and charge each of the ANODE cells to the bottom ridge line on the cell. Place the cap with the short lines on the ANODE cell.
    - Using the CATHODE syringe, withdraw all CATHODE fluid from the CATHODE cell and discard. Take care not to damage or deform the platinum screen or Teflon rod. Immediately following the removal of the CATHODE fluid, fill the CATHODE cell with fresh fluid to the top ink-marked line.
    - Carefully place the cap with the long lines on the CATHODE cell. Make sure the Teflon rod on the bottom of the cell is inserted into the long tube and the long tube is not forced to deform the Platinum screen. Make sure that the long tube on top is aligned to have the arc toward the cell wires and Velcro strip.
    - Check the cell voltage. It should be positive and above about 25 mv. If the cell voltage is negative the start the preparation process over. If the repeated check is a negative voltage then the cell is bad.

- If the cells are used after 24-hours from initial preparation then the cathode solution should be replaced (anode is fine).

2 Aircraft Monitor Setup

- Install the sampling lines for ozone and $PM_{2.5}$, as well as the temperature sensor. The $PM_{2.5}$ sample line is ¼" copper tubing, providing a rigid base. Strapped to it is 1/8" Teflon tubing and the wiring leading to the temperature sensor. Using the Cessna cabin air vents, insert the tubing into the air vent such that the temperature probe and $PM_{2.5}$ sample tubing are just visible in the vent opening on the leading edge of the wing. The ozone sample tubing should bend and stick out of the vent opening about 1". Using duct tape, cover up a portion of the vent opening, leaving approximately a ¼" slit, in order to restrict the volume and velocity of the air going past the $PM_{2.5}$ inlet.
- At the beginning of each day, load fresh AA batteries (8 each) into the battery of the ozone/logger package and the GPS unit, and C batteries into the DustTrak; discard and DO NOT reuse any old batteries. Batteries will last for at least 6 hours of flight time.
- Prepare the ozone sample cell by removing the shorting clip and connecting the plug to the respective jack.
- Place ozone/logger package and DustTrak in the rear passenger area and connect the samplers to their respective sample lines. Connect the data logger plug jacks, making sure that the male and female labels match. Jacks must be connected for $PM_{2.5}$ and temperature. Connect the GPS using its cable to the serial port of the data logger and place it on the dashboard at the front of the cabin, with good exposure out the window.
- Connect the Campbell Scientific logger readout unit to the data logger and select the appropriate data screen for viewing the data.
- Connect the battery pack in the ozone/logger package and turn on the DustTrak. Using the logger readout unit, scroll to the Cessna data tables and check the ozone value. Initially, the ozone channel should be greater than 0 ppb and may fluctuate as the cell first starts sampling air. If the cell remains at 0 ppb then there is a problem. Either the cell is not connected, or the something has failed.
- Turn on the power for the DustTrak and GPS unit.
- Conduct a zero check of the ozone sampler by place a ozone scrubbing cartridge at the end of the sampling line. It should be less than 5 ppb. After removing the zero filter, compare the reading with ambient ozone readings from a reference analyzer, if available. Prior to connecting the sample line to the DustTrak, conduct a flow check and zero check of the sampler using the supplied rotameter and zero filter, respectively. The flow should be 1.7 lpm and the zero less than 5 $\mu g/m^3$. Record all check values. Verify that the temperature reading is representative of ambient conditions and that the GPS unit is reporting a location. All above checks are made using the logger readout unit.

3 In-flight Procedures

- Periodically review the logger readout unit to check for instrument performance. The ozone reading should not be noisy (variations greater than ±5 ppb). Noise may be an indication of drying cells. The spare cell can be used if problems are noted.
- Make sure that none of the GPS values (speed, heading, altitude, position) read zero or invalid. If zero or invalid readings are noted, the most likely cause is a poor cable connection most likely at the GPS unit. If bad readings are still noted after checking the cable, reposition the GPS unit in the window.
- Temperature readings should agree within a couple of degrees with the aircraft sensor.
- Extra batteries should be taken on all flights. Any of the batteries can be changed in flight if needed.

4 Procedures Following a Flight

- Verify that the pumps for the ozone sampler and DustTrak are still running.
- Turn of the DustTrak and GPS unit.
- Download the data logger as quickly as possible using the LoggerNet software version 3.3.1.
- Disconnect the battery pack in the ozone/logger package. This will prevent the data logger from continuing to log data, writing over existing data with null data.

The following are procedures for installing and operating the 2B Technologies model 202 ozone analyzers for the UGWOS Mesonet ozone monitoring network.

Ozone Analyzer Setup

1. Prior to the installation of the analyzer, condition all sample lines by drawing air with concentrations of at least 50 ppb ozone through the lines for a period of 24 hours.
2. Place the analyzer in the designate site cooler, making sure that the number on the analyzer matches the number on the cooler.
3. Connect the 47 mm filter holder, with filter, and the associated sample line onto the inlet port of the analyzer. Make sure that flow through the filter holder is in the correct direction - it should follow the arrows on the filter holder. Loop any excess line in the cooler.
4. Install a fully charged 12 V battery, with power cord adapter, in the cooler. If necessary, the 2B analyzer can be turned on its side.
5. Connect the 12 V power cord to the battery and to the 2B analyzer.
6. Turn on the analyzer and allow it to warm up for at least one hour prior to calibration in order to let internal temperatures stabilize. Note that analyzers can be powered up using a vehicle 12 V cigarette lighter receptacle in transit to the Mesonet sites in order to reduce or eliminate warm up time at the site.
7. Connect the analyzer to the Campbell Scientific CR206 data logger using the stereo jack connector labeled “1”.
8. Verify that the small heater light is connected and operating.

Ozone Analyzer Calibration

1. Position the 2B Model 306 ozone transfer standard near the station analyzer such that the calibration line reaches the sample inlet. Connect the sample inlet to the calibration line using a suitable connector.
2. Connect the calibrator’s power cord adapter to the 12 V lighter receptacle in your vehicle. Turn on the transfer standard and allow it to warm up. The calibrator display will read “Warming up …” while doing so. When the indicated delT reading is within 1°C, the display will read “Temperature Set Press Select”. The calibrator is sufficiently warmed up whenever the delT reading is within 1°C. Note that the calibrator may be kept running while in transit to the Mesonet sites in order to eliminate warm up time at the site.
3. Record the calibration “begin time” in the logbook. All calibration and check activity will influence the hourly averages, which will need to be invalidated.
4. The 2B Model 306 transfer standard has a single output port, with a venting tee contained within the transfer standard. Thus, no external vent should be used. Connect

one end of the calibration Teflon tubing to the transfer standard output port and the other to the analyzer sample inlet line, using an appropriate adapter.

5. If not already done, program the Model 306 transfer standard to produce the zero and two span points. Hold down the rotary switch until the main menu is displayed. Rotate the rotary switch to move the cursor under "Cfg" for the automatic calibration sequence configuration. Follow the menu prompts to create a five-point calibration, with points at 200, 150, 100, 50 and 0, spaced at 10-minute intervals.
6. Start the calibration sequence at approximately one minute after a five-minute clock division (e.g. 10:01, 10:06, 10:11, etc.). Since 5-minute averages are being recorded by the data logger, this will result in an approximately 4-minute stabilization period and a full 5-minute average of the calibration input for each input concentration. Start the calibration sequence by going to the main menu and selecting "Stp".
7. Using the procedures presented in the SOP "Operating Procedure for Mesonet Data Handling", connect to the data logger and download the most current 5-minute data. Record the resulting calibration values into the site logbook.
8. Contact Dave Bush for current ozone output concentrations for the 2B transfer standard settings and record these in the logbook.

Routine Station Checks

1. Station checks should be conducted every other day during IOPs, as well as at the beginning and end of each IOP.
2. Upon reaching the site, enter the date and time in the station logbook, along with the technicians initials.
3. Complete a visual inspection of the system. Note any anomalous situations both in the site's logbook.
4. If not already done, program the Model 306 transfer standard using the procedures in the Calibration section above to produce a three-point calibration sequence, with points at 200, 50 and 0, spaced at 10-minute intervals.
5. Using the procedures in the "Calibration" section above, conduct the described three-point zero/span check.
6. Using the procedures presented in the SOP "Operating Procedure for Mesonet Data Handling", connect to the data logger and download the most current data. Review the 5-minute data file and record the resulting calibration values into the site logbook.
7. Contact Dave Bush for current ozone output concentrations for the 2B transfer standard settings.
8. If either of the span checks deviated by more than 10% from the standard, or if the zero is off by more that 5 ppb, alert Dave Bush or Bob Baxter.
9. It is not anticipated that any inlet filter changes will be necessary during the study. However, if a filter change is required, use the following procedures. Record the current ozone reading from the analyzer display in the log book. Disassemble the filter holder and replace the filter. Reassemble the filter holder and record, wait approximately one minute, and record the ozone reading from the analyzer display. Note if the before and after readings change by more than 5 ppb. Note that any filter changes should be conducted after the scheduled zero/span/precision check.

10. Write down the current readings for the following measurements in the station log book: battery voltage, station temperature, ozone, WS, and WD. Verify that the WS and WD readings are consistent with current conditions.
11. Verify that the monitoring system is operating appropriately. Verify that the display on the analyzer is normal, that the red light on the Campbell Scientific Model 206 data logger is blinking, and that the heater light is on. Note in the logbook the period that the ozone analyzer was off-line for the checks.

The following are procedures for preparing, operating and data retrieval for the Mesonet monitoring network.

Special Notes:

- Data connections are made using the RF401 wireless connection module. Make sure power is provided to the module and that the serial connection is made to the proper connector on the RF401 and the antenna is connected.
- Each of the data loggers is assigned a PAKBUS address that is equivalent to the site number. You can only access the data logger by using the correct site program with the corresponding PAKBUS address, i.e., site 3 can only be accessed using the program/configuration configured for PAKBUS address 3. The following is a list of the site names/numbers:

  Cora Area – 1
  The Mesa – 2
  Warbonnet – 3
  Haystack Butte – 4
  Simpson Gulch – 5
  Speedway Pit – 6
  Big Piney – 7
  La Barge – 8

- Before proceeding to the field verify that the clock in the field computer is correct to within 1 minute of **true** Mountain Standard Time. This can be best performed using the integral Internet Time function in Windows and verifying that the time was truly set when it is complete. If not then find an appropriate time standard before leaving for the field and set the computer clock manually. Again, verify it has the proper time.
- The file naming convention for each site and data interval is critical and should not be changed. If a different computer is used for downloading data then the setup for data access and collection must be consistent with the following standard and example shown for site 3:

  Wy Site 3_min_5.dat
  Wy Site 3_min_60.dat

  Note that there is a space between 'Wy' and 'Site', as well as between 'Site' and '3'.

1.1 Data Download from Data Logger

- Enter the arrival time at the site in the site log.

- When parked within radio range of a desired site, press the “Connect” button and select the proper site.
- When connected, verify the time on the data logger is within 1 minute of the computer time. If the times differ by more than one minute then synchronize the data logger clock to the computer
- Press the “Collect Now” button and wait for the complete download. Sometimes the connection may take some time through the wireless connection.
- When the collection is complete use the view data mode for 5 minute and 60 minute files to verify all data to the present has been collected. Note the date and time of the data collection in the log.
- Review all the values for any anomalies during the period collected. In particular review the battery voltage to verify a proper battery charge. The battery voltage will read about 1.5 to 2 volts low. If you ask Bob why then be prepared for too long an explanation. However, if any values look suspicious then contact either Bob or Dave Bush regarding the operations.
- Press the “Disconnect” button, you are done at this site.

1.2 Data FTP Upload to the T&B Systems FTP Server

Special Notes: The FTP upload process should only be performed in the time window from 10 minutes past the hour to 10 minutes prior to the hour. This will minimize the chances of the server trying to process data that is in the middle of an upload. This server process will be running at the top of every hour. Additionally, any data downloads must be performed in a consistent manner. The file naming convention for the two indicated upload accounts below is critical. If a computer change is made then it is imperative that the assigned file naming convention is maintained.

- Use an appropriate FTP program such as Filezilla or you can use Internet Explorer. Be aware that FTP through Internet Explorer version 7 requires an additional step to view the FTP site in an Explorer window. This is not required in Internet Explorer version 6.
- Log into the proper account for the data uploads. If you log into the wrong account then the data may not be properly registered and a potential loss of data may occur. **Nobody else should upload data to these accounts! If you have data to be uploaded then contact Bob to set up an account and obtain the proper file naming convention. This file naming convention is critical to assure no data are lost!**
    - **Jennifer Frazier (Wyoming DEQ):**
      URL: ftp://70.133.103.202
      Username: wydeqdataup
      Password: ugwosdata
    - **MSI:**
      URL: ftp://70.133.103.202
      Username: msidataup
      Password: ugwosdata
- Copy the full files that have been downloaded from the data loggers into the FTP server. This includes both the 5-minute and 60-minute files. Do not attempt to create any new folders underneath the FTP root login, or edit, or rename the files in any way, as this will

disable the automated update process. However, it is OK to overwrite the existing files that were previously uploaded to the FTP server as those files are automatically backed up daily.

- If all goes well then the newly uploaded data will appear on the web site within an hour. Send an email to Bob (bbaxter@tbsys.com) to let him know that new data have been uploaded. He will verify that the new data have been registered properly in the database and will contact you as appropriate with any issues.

The following are procedures for checks and maintenance of the ASC miniSodar located on the M&N property. Included are the downloading notes for the surface meteorological sensor located at the same site.

Special Notes:

- The site is located on M&N property and care should be taken to not damage any of the surroundings. The minisodar Acoustic Signal Processor (ASP) and surface meteorological data logger is located in the shed adjacent to the antenna.
- Check both the minisodar and surface meteorological station cables for integrity.
- The sodar is powered by AC with an APC UPS to maintain power during short outages.
- Take care when leaving anything on the ground as there are hungry rabbits nearby. They particularly like cables and can run fast when you chase them in anger.
- There is a key hidden for entry in the shed. If you don't know the location of the key then ask Bob, Jennifer or Dwayne.
- Data downloading from the surface meteorological station should be conducted using the RF401 spread spectrum radio modem. The PakBus address is 7. If serial communications are required the data logger has a 9-pin connector cable already attached.
- The surface meteorological equipment is powered by the deep cycle battery located on the floor, below the sodar ASP.

Clearing the miniSodar antenna of snow

- Prior to the removal of the Antenna Array Box (AAB) assembly, the miniSodar must be powered off. The procedures for shutting down the system is as follows:
    - Remove the front cover from the ASP by unlatching the catches all the way around the front (8 places).
    - Press the "X" button on the front panel display and scroll using the "v" button to the "Control" menu. Select "Control" by pressing the check (√) button. Select shutdown system and again press the check (√) button. The display will ask: Power Down? "No", use the "^" to select "Yes", then press the check (√) button.
    - It is important to wait at least 30 seconds before powering down using the power switch. Wait 30 seconds before turning the power switch off (the switch is on the far left)! The power rocker switch is off when the top of the switch color is hidden. When the power is on, the top of the power switch is red
    - Turn off the front panel switch on the amplifier.
    - The system is now powered off.

- Removal of the AAB box assembly and cleaning
    - Disconnect both antenna cable connectors from the AAB taking care not to let the connectors fall in the snow. If water or snow gets into either of the connectors or the connections on the back of the array then the moisture must be removed by blowing it out.
    - Loosen each of the four Phillips head screws that hold the AAB to the enclosure. It is best to remove the bottom screws first so the array doesn't try to fall backwards. Take care in supporting the array when you loosen the screws to minimize the downward force on the screws. Don't drop the screws in the snow or you will have a fun time finding them. Also, note the orientation of the array as it must be reinstalled in the same orientation.
    - Carefully remove the AAB and lean it up against something making sure that the speakers and connectors don't fall into the snow.
    - Use a broom (at the site) to sweep all of the snow from the reflector board and the acoustic insulation to the bottom of the enclosure for removal. Be careful not to damage the insulation during the process as there may be ice formed in the foam.
- Reinstallation of the array
    - Place the array back into the enclosure in the exact orientation it was removed.
    - Start each of the four screws that hold the array into the appropriate nuts on the enclosure. It is very important and helpful to lift and support the array during the insertion and tightening of the screws, as this will prevent the threads from getting damaged.
    - Slowly tighten the four mounting screws evenly as you would lug nuts on a car so as not to deform the array mounting. The screws should only be snug, not tight, as over tightening will damage the threads. It is only necessary to make it snug so there is no air gap around the gasket.
    - Reconnect the two antenna cables making sure that both the cable and AAB connectors are dry and free of water or snow.
- Restarting the miniSodar
    - Turn the power amplifier on and wait 5 seconds.
    - Turn the ASP power switch to the on position. The boot process may take a minute or more. When booted the lights on the left of the display should cycle and the transmit pulse should be heard.
    - Replace the front cover of the enclosure to help keep heat inside and dust outside.

APPENDIX D

Monitoring and Quality Assurance Plan

APPENDIX E

The Upper Green Winter Ozone Study (UGWOS) 2008 Database

1. Introduction

This document describes the Upper Green Winter Ozone Study (UGWOS) database for 2008. 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 2008 Winter UGWOS field study included hourly measurements of surface air quality and meteorological data during the period of January through March 2008 in the upper Green River Valley region of southwestern Wyoming. Winds aloft were also measured by a mini-SODAR and are reported on an hourly basis. Additional upper level ozone data were measured along with upper level meteorology via balloon ascents during three intensive operating periods (IOP) when elevated levels of ozone were anticipated. Surface speciated volatile organic compounds (VOC) and carbonyl samples were collected during each IOP. Aircraft flights were also conducted during each IOP for collection of VOC and carbonyl samples and temperature, ozone, and PM2.5 data.

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

Wyoming Department of Environmental Quality:

- WDEQ Monitoring network data (at Daniel, Jonah, and Boulder)
  - 1-hr ozone
  - 8-hr ozone
  - 1-hr PM10
  - 1-hr NOx/NO/NO_2
  - Wind speed
  - Wind direction
  - Temperature
  - Additional met parameters (relative humidity, barometric pressure, solar radiation, sigma theta, and precipitation)
  - Daily PM 2.5 at Pinedale
  - UV Radiation at Boulder (ARS)

T&B Systems

- Rawinsonde and ozonesonde data (Pinedale Airport-Wenz Field)
  - Wind speed
  - Wind direction
  - Temperature
  - Relative Humidity
  - Ozone (ozonesondes only)

- Sodar measurements (Near Boulder)
  - Wind speed
  - Wind direction
  - Mixing heights

- Aircraft data (Cessna)
  - Temperature
  - Ozone
  - PM2.5

Meteorological Solutions, Inc.

- VOC, Carbonyl, and Carbon Monoxide Measurements (Cessna Aircraft, Daniel, Jonah, & Boulder)

- Mesonet monitoring network data (at 6 locations)
  - 1-hr ozone
  - Wind speed
  - Wind direction

Supplemental data included daily PM 2.5 data at Pinedale, hourly surface ozone and meteorological data from three CASTNET (Clean Air Status and Trends Network) sites and one industrial monitoring station near the OCI Trona facility in the Green River Valley.

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 flags used are given in Table 1 and also listed in the table QC_FLAGS in the UGWOS 2008 database. .

Table 1. Data Flags.

Flag	Description
V	Valid
S	Suspect. Data appears to be a data spike or outside normal data range
I	Data invalid.
M	Missing. Measurement not taken.
U	Invalidated Data - User is responsible for validation

3. UGWOS Database Design

T&B Systems staff assimilated the submitted data into an ACCESS 2000 database called UGWOS_2008_Database_Version?.?_MMDDYYY.mdb (where ?.? indicates version number and MMDDYYYY is the month, day and year of the version) The database is available on the T&B Systems FTP site. 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, and elevation, and a tabular list of what parameters were measured at each site and by each data source). The INSTRUMENTS and PARAMETERS tables list the instrument and parameter codes used in the data tables. The table UPDATES lists all information pertaining to modifications and versions of the data. The name of the database includes a version number and date to help users identify the most up to date 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 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 data tables for surface data include **Surface_AQ_Hourly** (hourly averages of all surface air quality parameters). **Surface_MET** (All hourly wind speed, wind direction, and temperature and additional met variables at select sites: relative humidity, solar radiation, standard deviation of wind direction, barometric pressure, dew point temperature, and precipitation), **Surface_VOC** (All Volatile Organic Compounds), **Surface_Carbonyl**, and **Ozone_8hrAvg** (All 8 hour averaged surface ozone data). The table **Additional_Lab_QC** contains quality control data pertaining to the lab analysis of the VOC data and is for reference purposes only. *Please note that proper interpretation of the VOC and carbonyl sample data requires additional information including definitions of laboratory data flags, etc. which is not provided here or in the database itself. Please refer to the UGWOS 2008 report (forthcoming) for this information. In addition, it should be noted that these data appear as reported by the analyzing laboratory: no attempt has been made to perform additional validation of the organic compound data at this time.*

The upper level met and ozone data are combined in the table **Upper_Level_Met_O3**. This table contains all of the rawinsonde and ozonesonde data. It includes ozone, pressure, wind speed, wind direction, temperature, and relative humidity. The data from the upper level wind monitoring SODAR is included in the **Upper_Level_Wind** table. The Aircraft upper level ozone, temperature, and PM2.5 data is in the **Aircraft_O3_TP** table. The table **Aircraft_VOC** contains analyzed samples of VOC taken aboard the aircraft flights. Similarly, the **Aircraft_Carbonyl** table contains the carbonyl species in air samples taken during the aircraft flights**.** Three additional data tables are **Mixed_Layer_Depth**, **Pinedale_Daily_PM25**, **Surface_CO,** and **Aircraft_CO.**

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 2000 at the bottom of the computer screen when the user is accessing the column. The exception to this is the two lab tables included for reference only: Additional_Lab_QC and Additional_Lab_QC_Summary.

The flat format for each table is described below:

Surface_MET (Surface Hourly Meteorological Data)

SITE_CODE, DATE, HOUR, WS, WS_QC, WD, WD_QC,VWS, VWS_QC,UWD,UWD_QC, WGUST, WGUST_QC, TP, TP_QC, RH, RH_QC, DP, DP_QC, TP10M,TP10M_QC,DELTATP, DELTATP_QC, SIGTH,SIGTH_QC,SOLRD,SOLRD_QC, PRESS,PRESS_QC, PRECIP,PRECIP_QC

Ozone-8hrAvg (Ozone 8-hour averaged)

SITE_CODE, DATE, HOUR, INSTRUM, O3_8HR, O3_8HR_QC

Surface_Hourly_AQ (Hourly Surface Air Quality)

SITE_CODE, DATE, HOUR, O3, O3_QC, NO, NO_QC, NO2, NO2_QC, NOx, NOx_QC, PM10, PM10_QC

Surface_VOC (Non Methanated Hydrocarbons Volatile Organic Compounds):

SITE_CODE, DATE, HOUR, TIME, END_HOUR, END_TIME, SDG, SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_UGM3, REPOLIMIT_UGM3, MDL_UGM3, MDL_UGM3, RESULT_PPBV, REPOLIMIT_PPBV, MDL_PPBV, and additional lab parameters. The table Surface_CO has the same format as Surface_VOC.

Surface_Carbonyl:

SITE_CODE, DATE, HOUR, TIME, END_HOUR, END_TIME, SDG, SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_UGM3, MDL_UGM3, MDL_UGM3, RESULT_PPBV, MDL_PPBV, and additional lab parameters

Surface_VOC_Summary: (Percentages of VOC specie groups in sample)

SITE_CODE, DATE, HOUR, TIME, END_HOUR, END_TIME, SDG, SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_PCNT, RESULT_PPBC, and additional lab parameters

Upper level meteorological and air quality data

(he episodic rawinsonde and ozonesonde are stored together in a file with the following format:

**SITE, DATE, TIME, HEIGHT, PRESSURE, PRESSURE_QC,
O3, O3_QC, WS, WS_QC, WD, WD_QC, TP, TP_QC, RH, RH_QC**

Upper Level Wind Data:

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

Aircraft_O3_TP

**SITE_CODE, DATE, TIME, HOUR, HEIGHT, LATITUDE, LONGITUDE, O3,
O3_QC, PRESS, PRESS_QC, TP, TP_QC, PM25, PM25_QC**

Aircraft_VOC:

**SITE_CODE, DATE, HOUR, TIME, HEIGHT, LATITUDE, LONGITUDE, SDG,
SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_UGM3,
REPOLIMIT_UGM3, MDL_UGM3, MDL_UGM3, RESULT_PPBV,
REPOLIMIT_PPBV, MDL_PPBV, and additional lab parameters.** The table Aircraft_CO has the same format as Aircraft_VOC.

Aircraft_Carbonyl:

**SITE_CODE, DATE, HOUR, TIME, HEIGHT, LATITUDE, LONGITUDE, SDG,
SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_UGM3, MDL_UGM3,
MDL_UGM3, RESULT_PPBV, MDL_PPBV, and additional lab parameters**

Aircraft_VOC_Summary:

**SITE_CODE, DATE, HOUR, TIME, HEIGHT, LATITUDE, LONGITUDE, SDG,
SAMPNO, FIELDSAMPID, CASNO, PARAMETER, RESULT_PCNT,
RESULT_PPBC, and additional lab parameters**

The data have the following general unit configurations:

Parts per billion for O3, NOx, NO, and NO2
Meters per second for wind speed (as a general rule, metric units are used)
Degrees Celsius for ambient temperature and dew point temperature
Watts per meter squared for solar radiation and ultra violet radiation
Micrograms per cubic meter for PM10 and PM2.5 mass

Percent for relative humidity

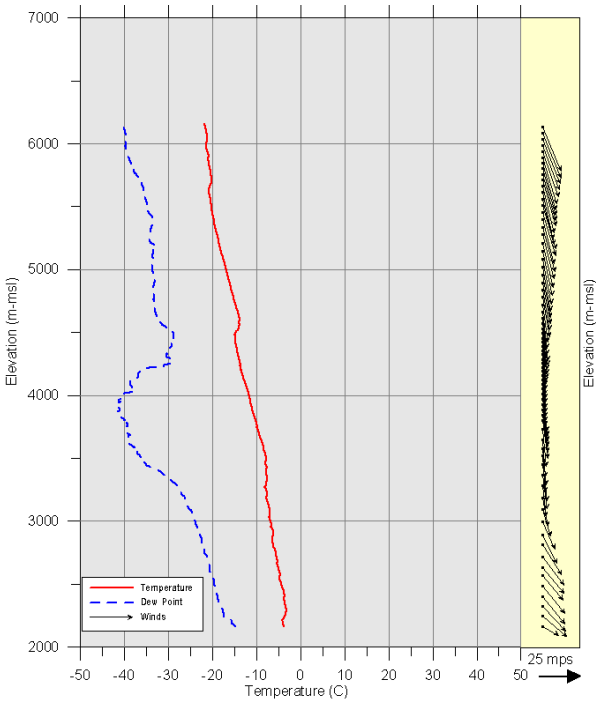
All additional field names are described in the PARAMETERS table. The level 1 database is available for download on the T&B Systems FTP server in a zip file with a name reflecting the current the version number and date of the database. Users wishing to be notified of updates to the database can send their e-mail address to the UGWOS Data Manager at lniccum1@msn.com.

4. Summary

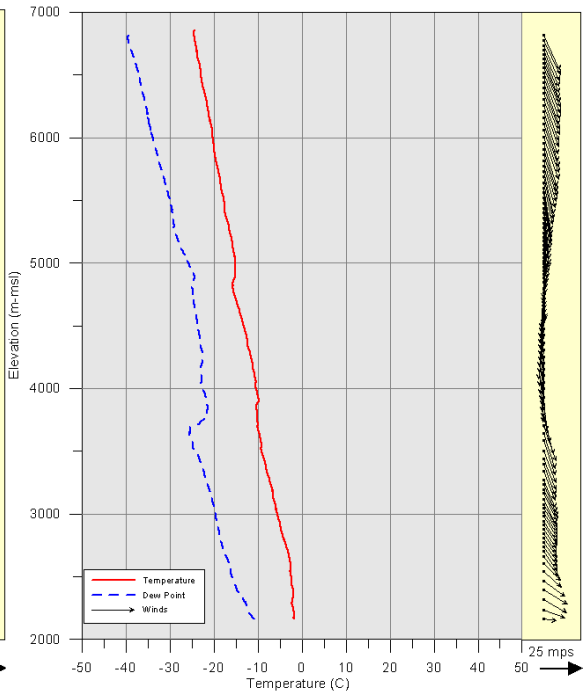
This document describes the 2008 UGWOS database. Feedback from study participants concerning this document and the database is requested and any suggestions for improvement are highly encouraged and appreciated.

APPENDIX F

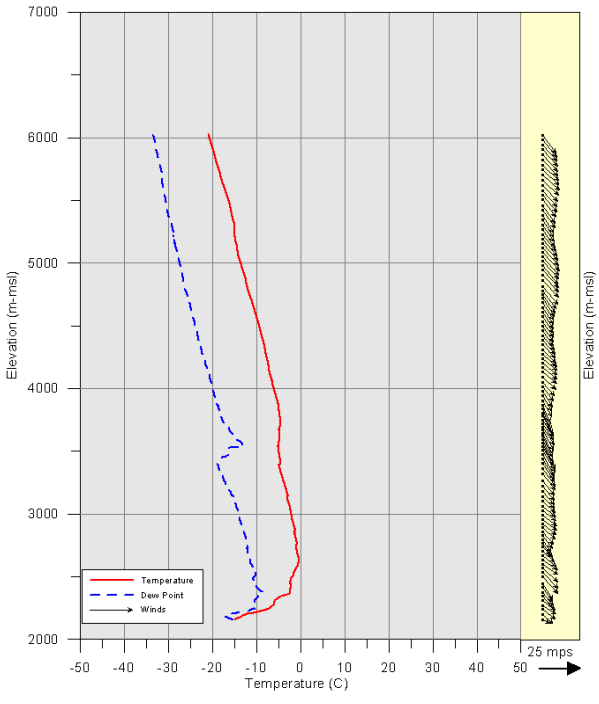
Free Ascent Balloon Sounding (Rawinsonde and Ozonesonde) Plots



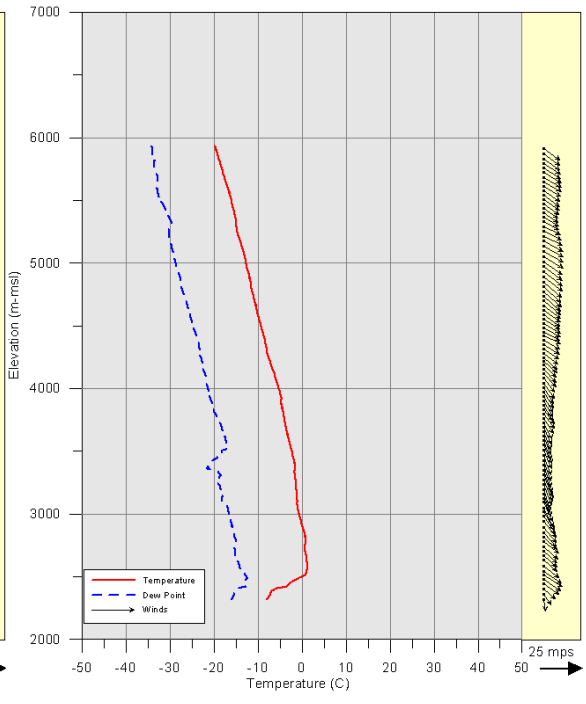
Wenz Field - February 18,2008 at 11 MST



Wenz Field - February 18, 2008 at 16 MST



Wenz Field- February 19, 2008 at 7 MST



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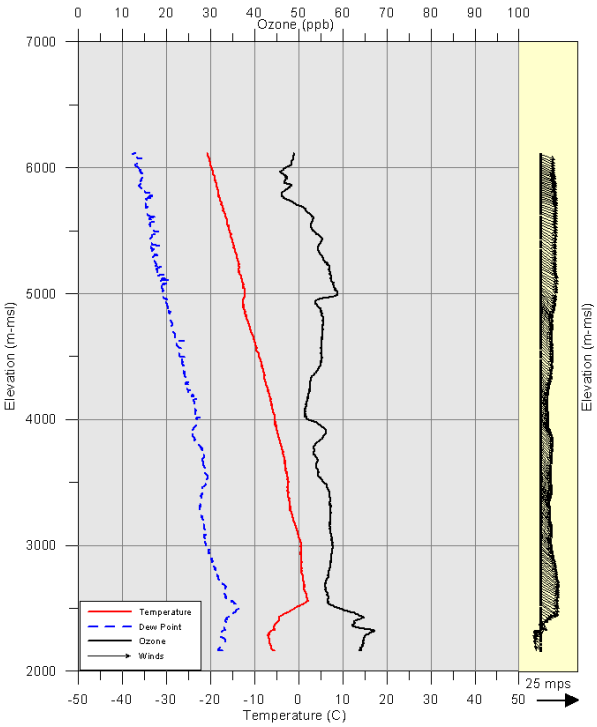

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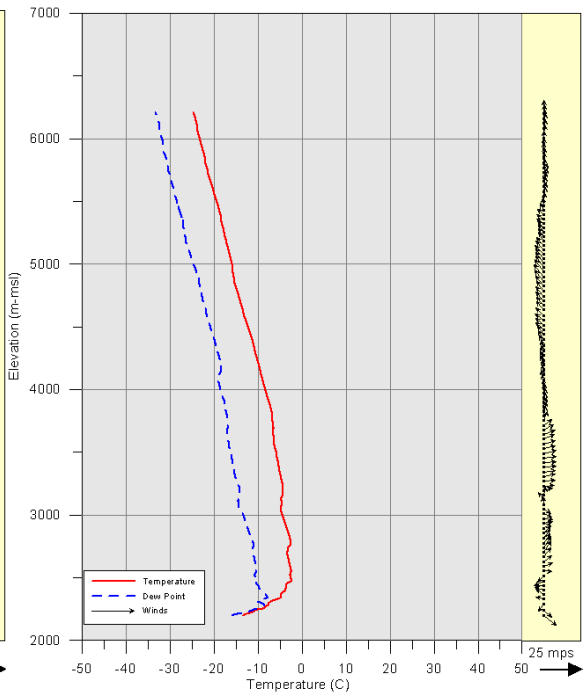

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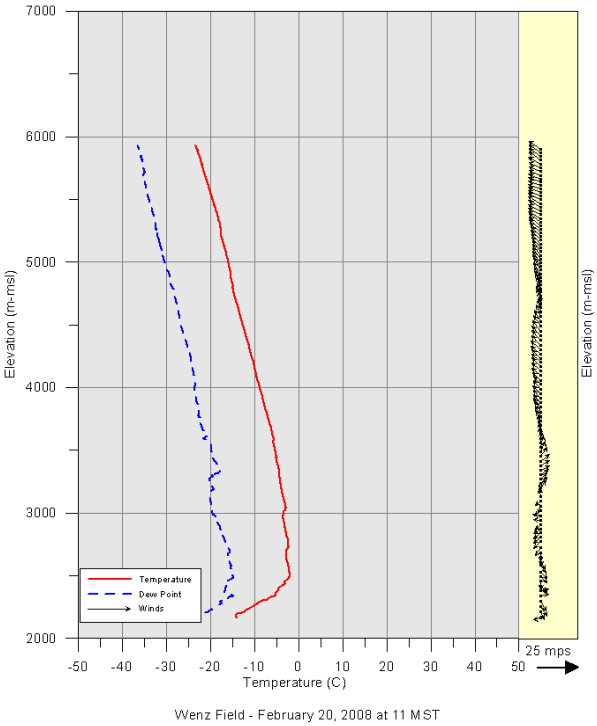
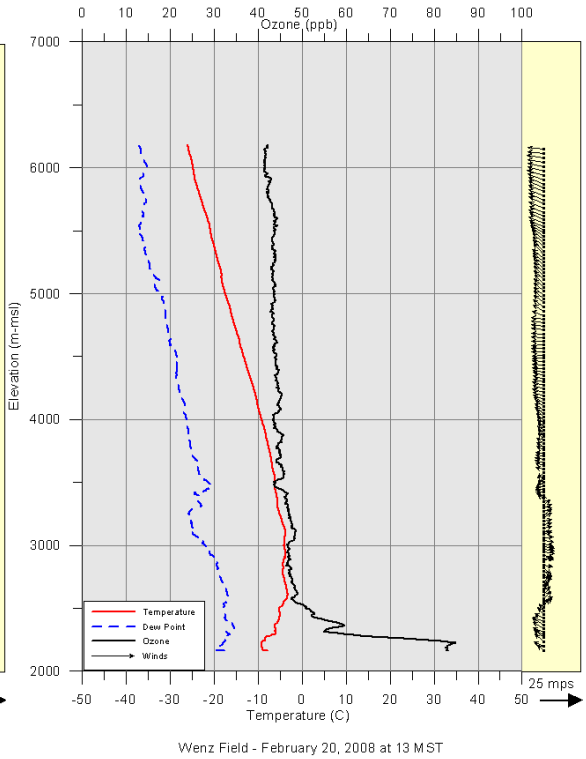


Wenz Field - February 20, 2008 at 11 MST



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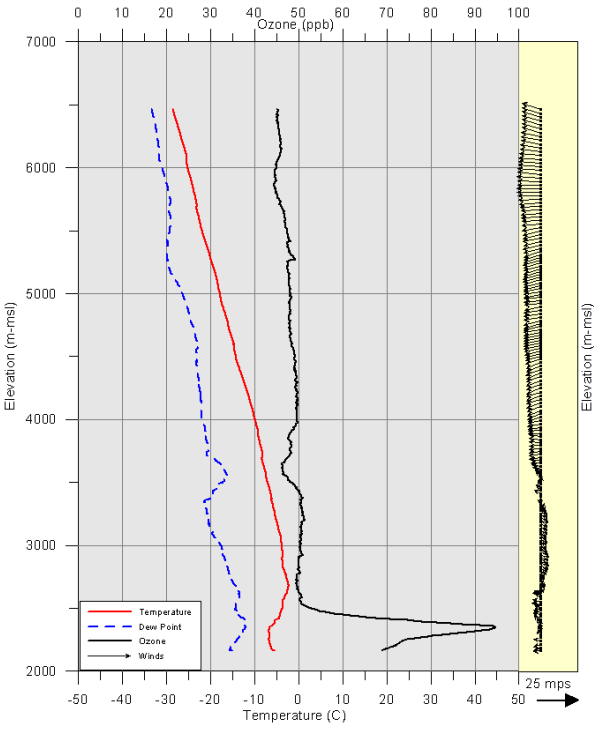

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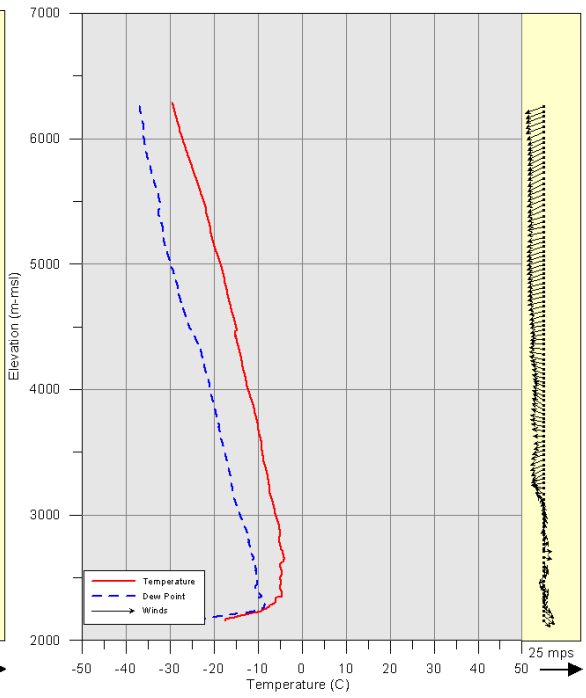

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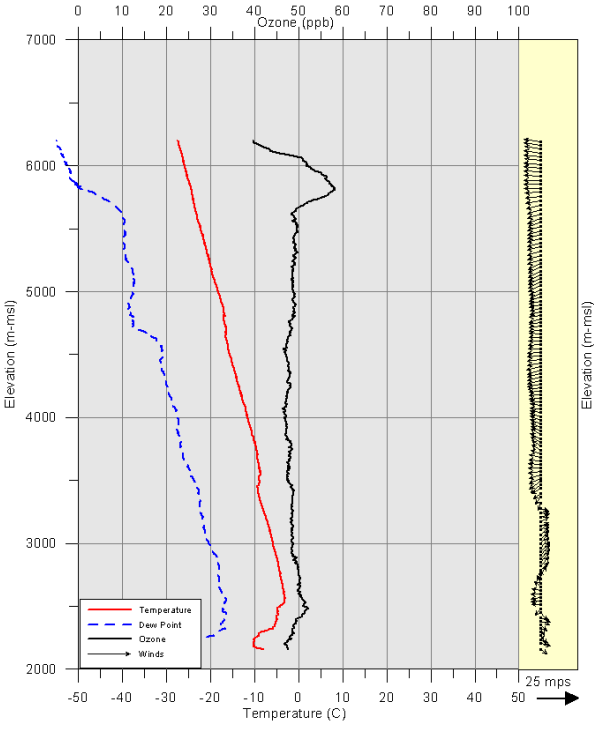
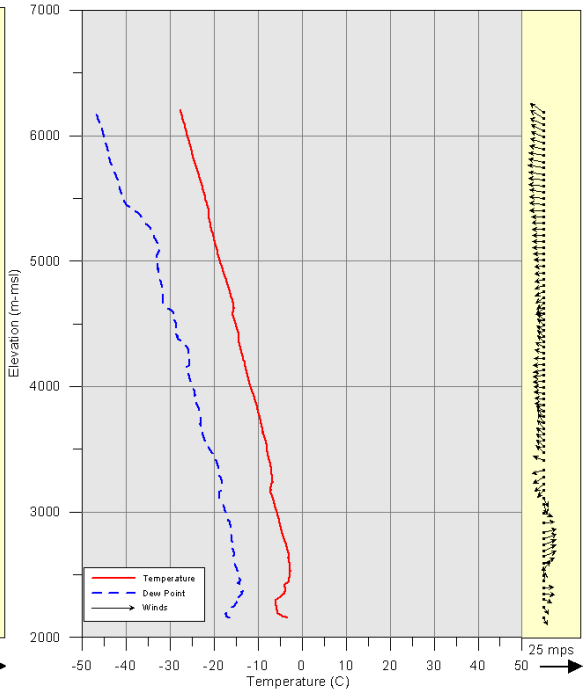


Wenz Field - February 21, 2008 at 11 MST



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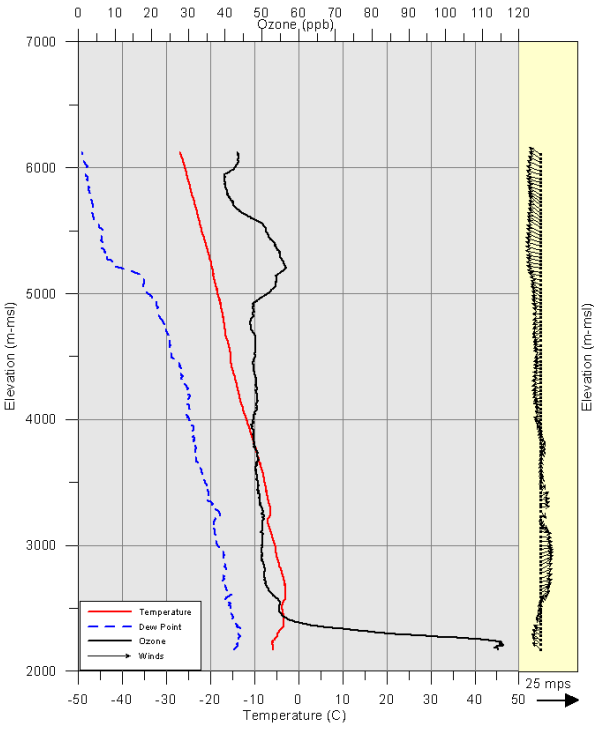

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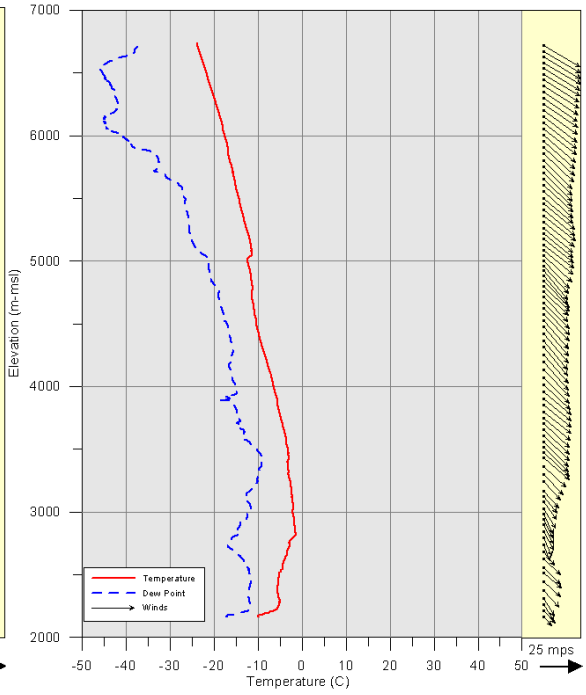

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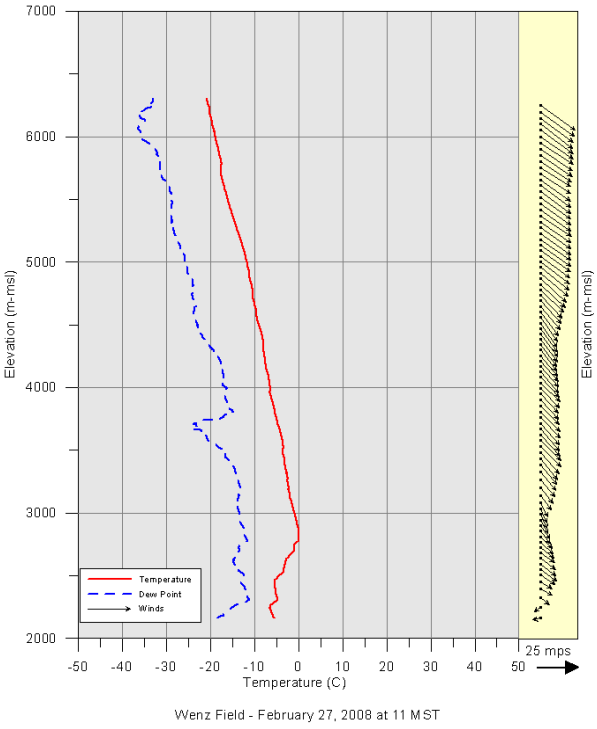

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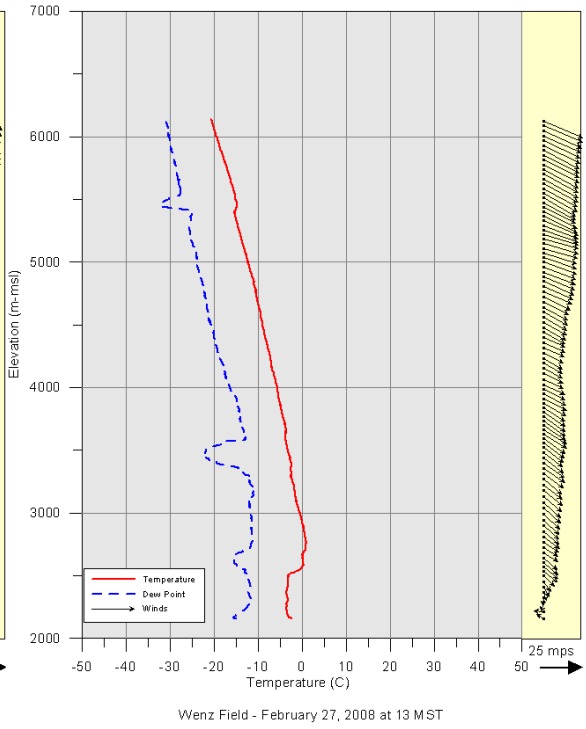

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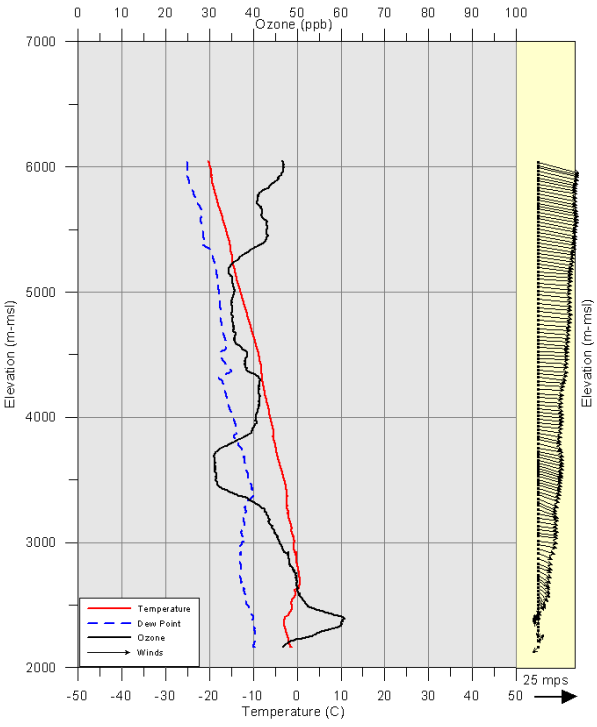

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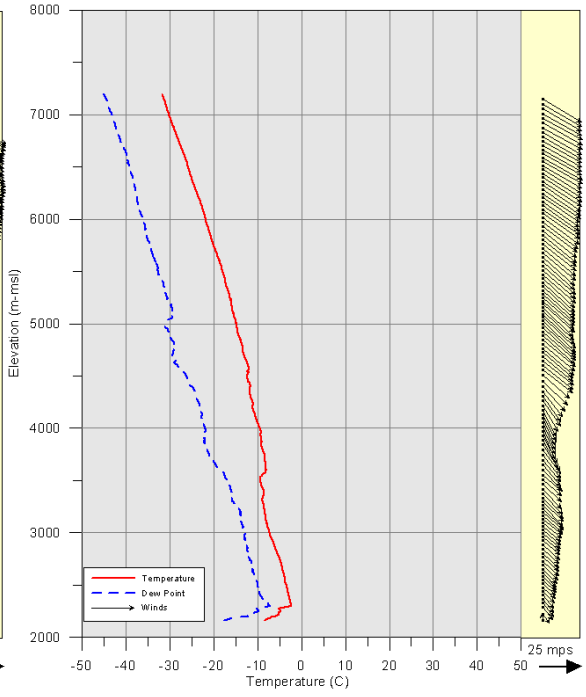

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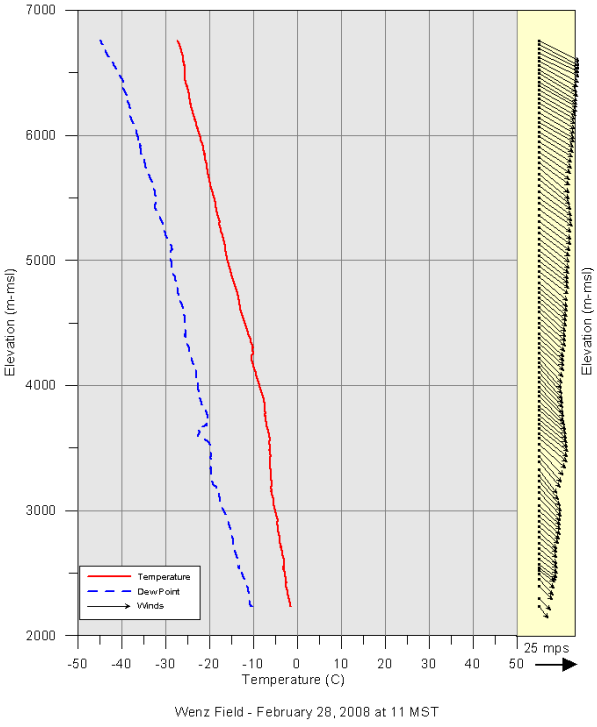

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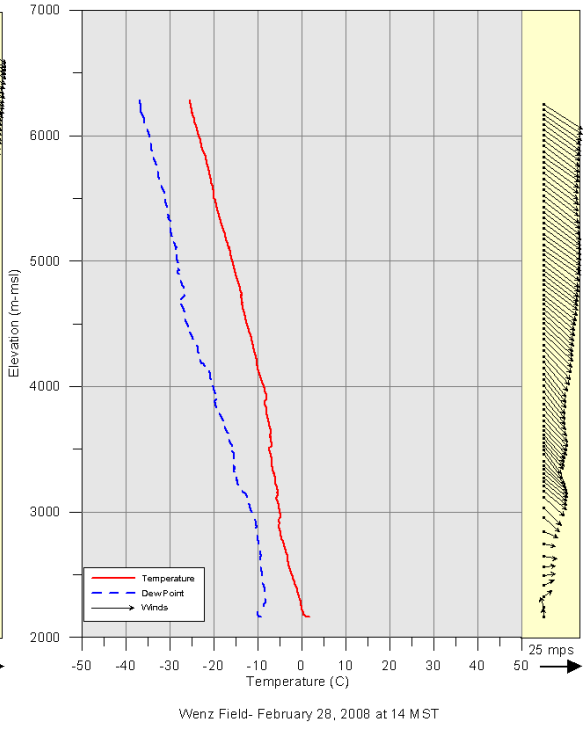

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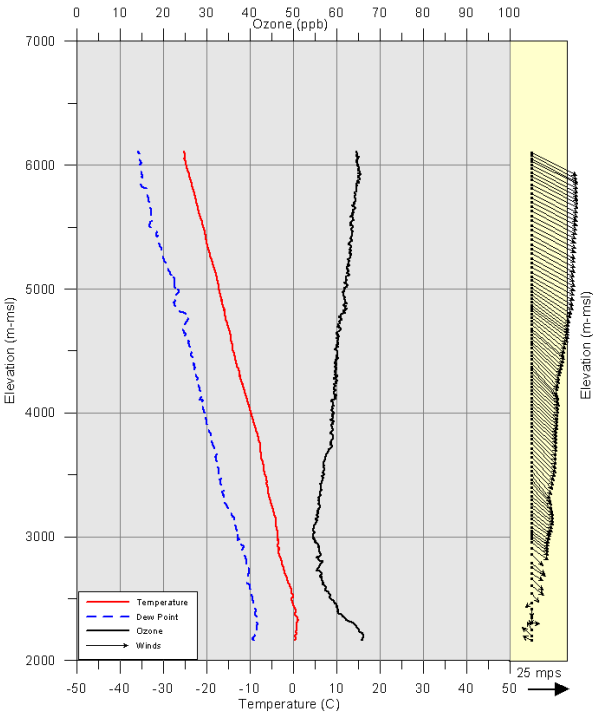

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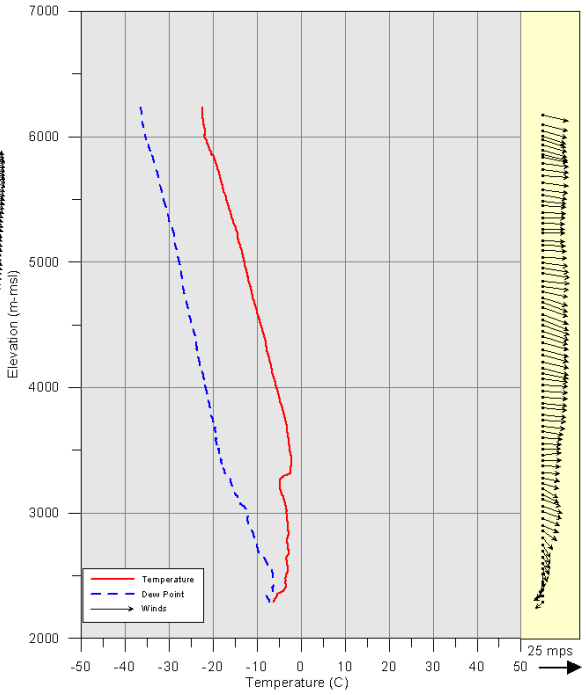

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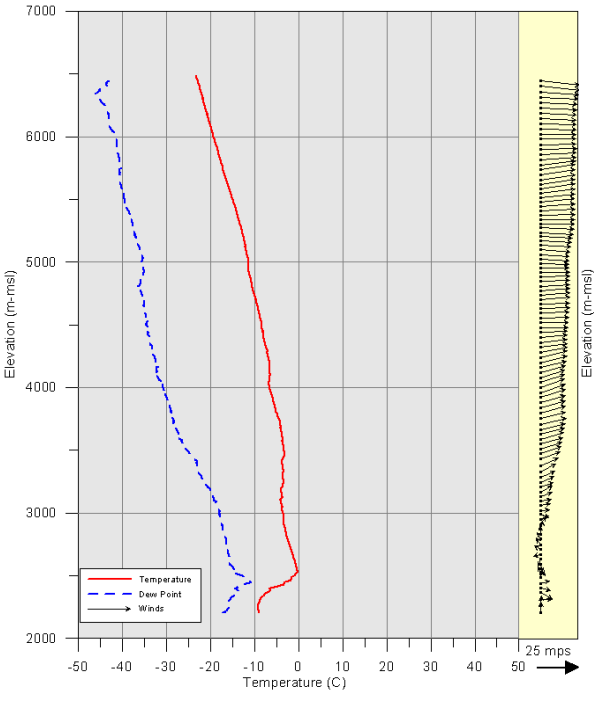

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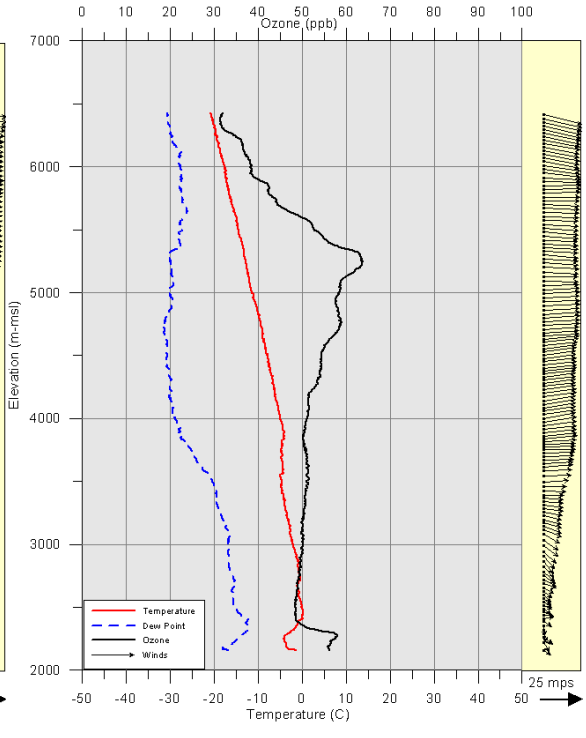

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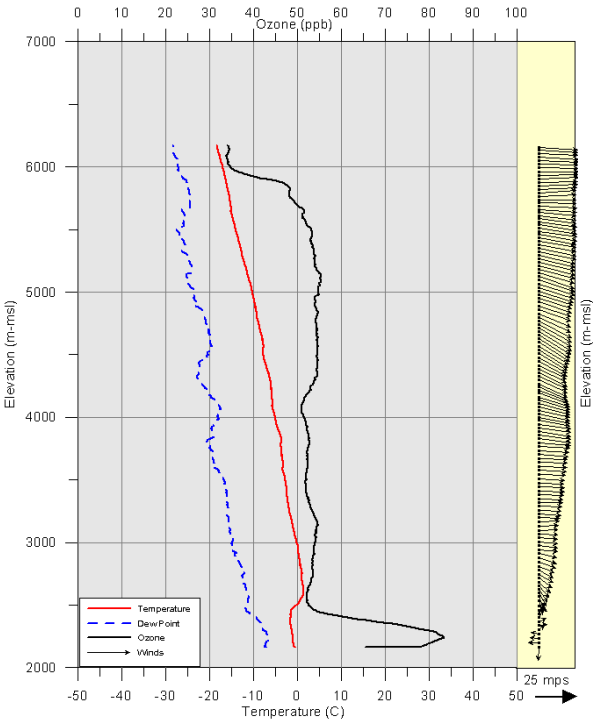

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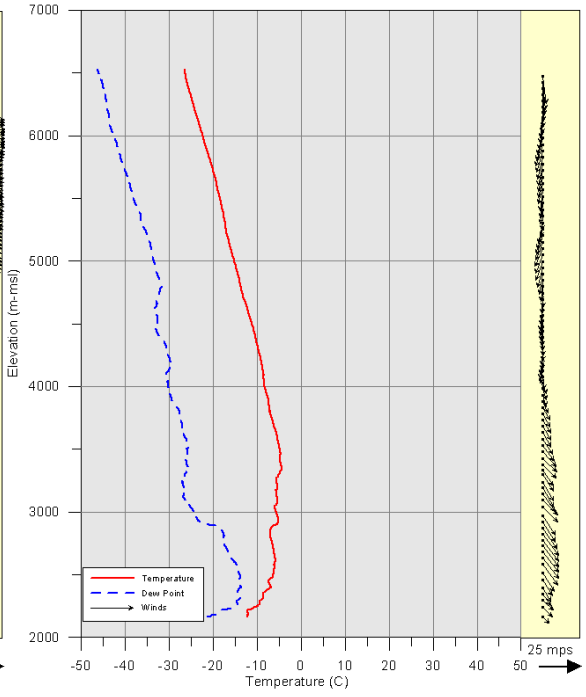

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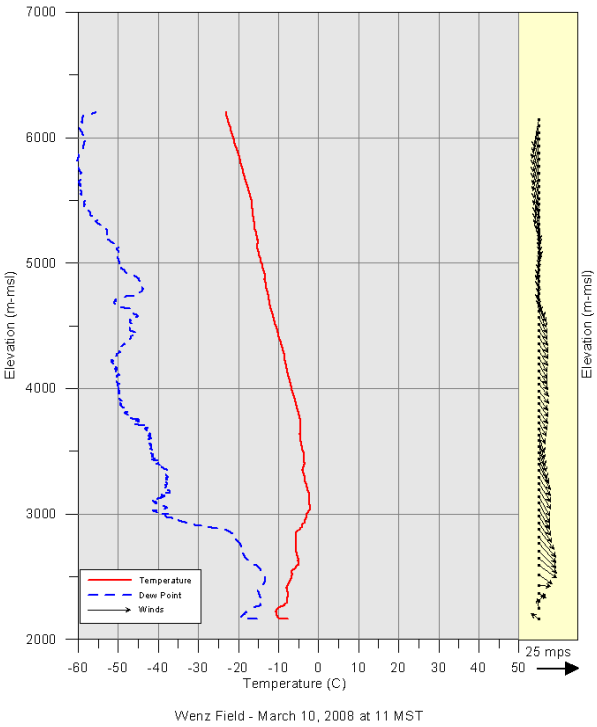

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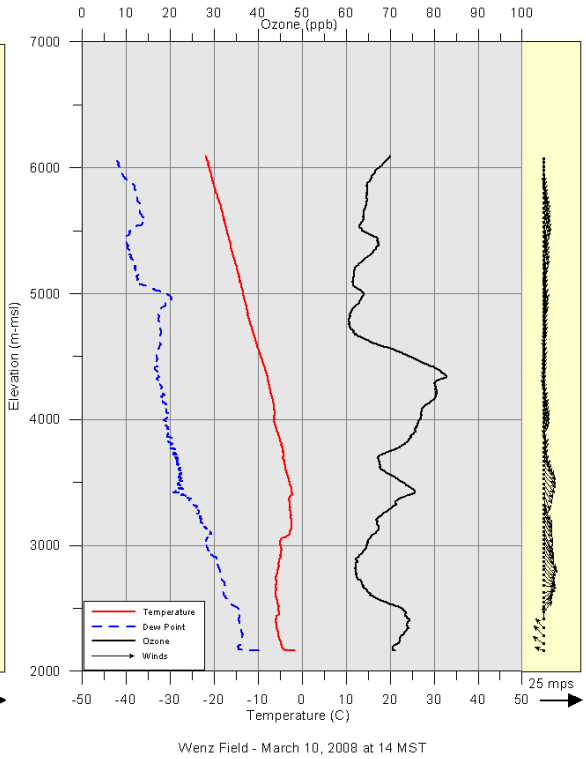

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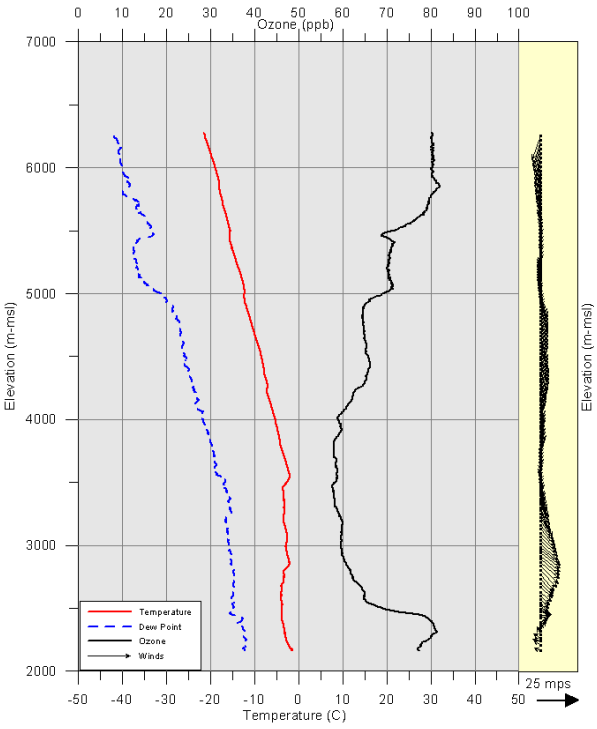

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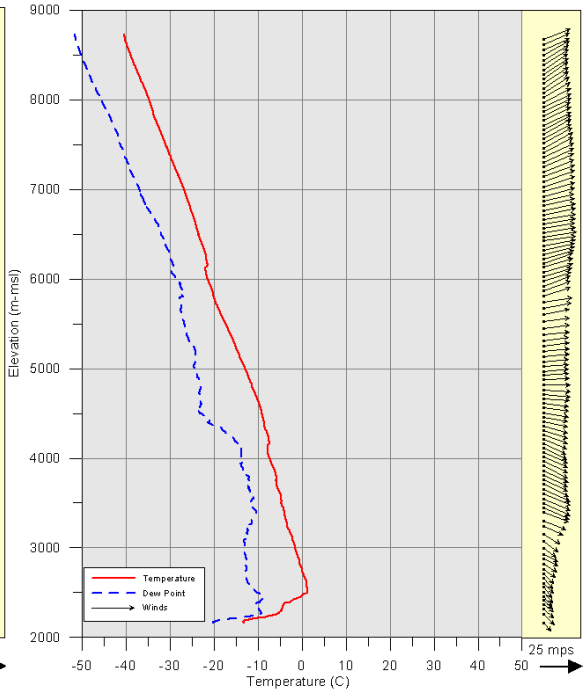

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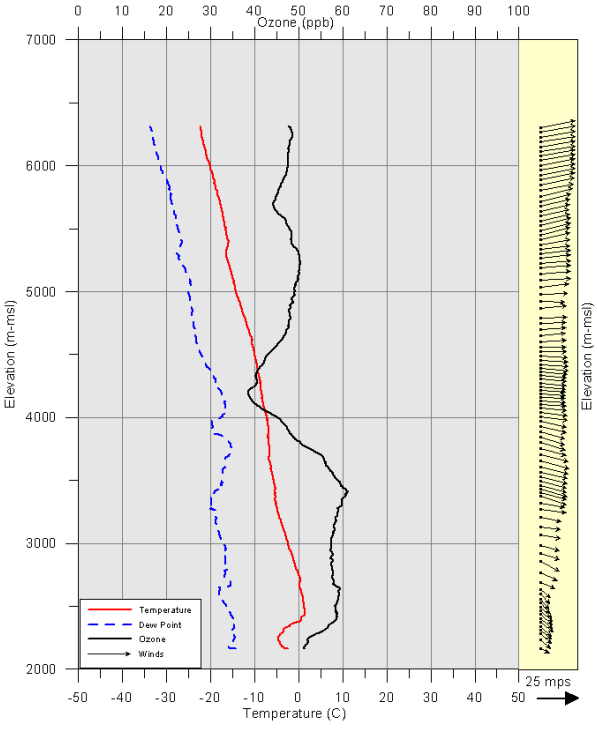

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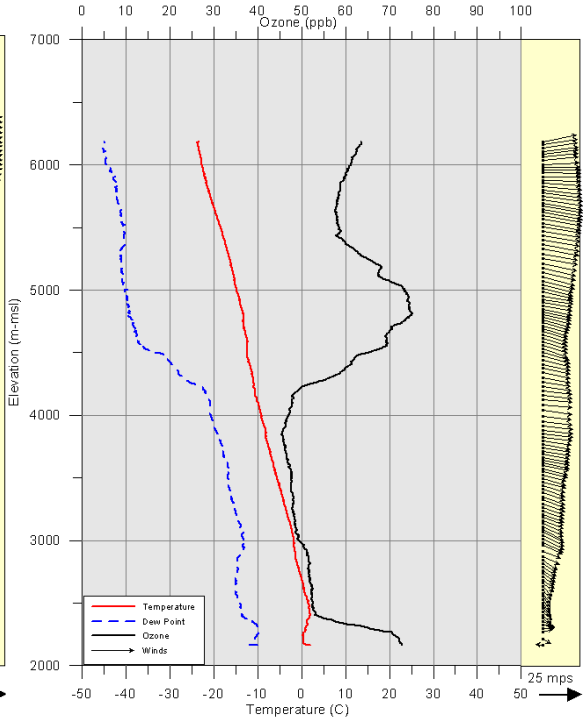

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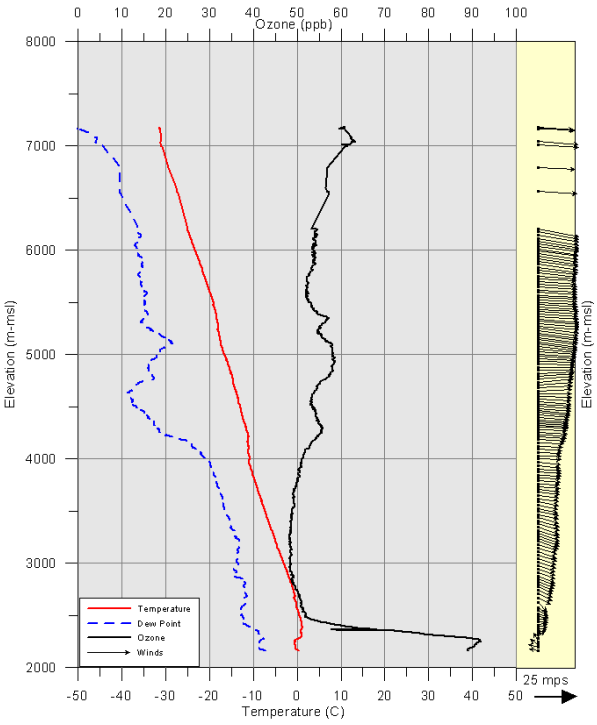

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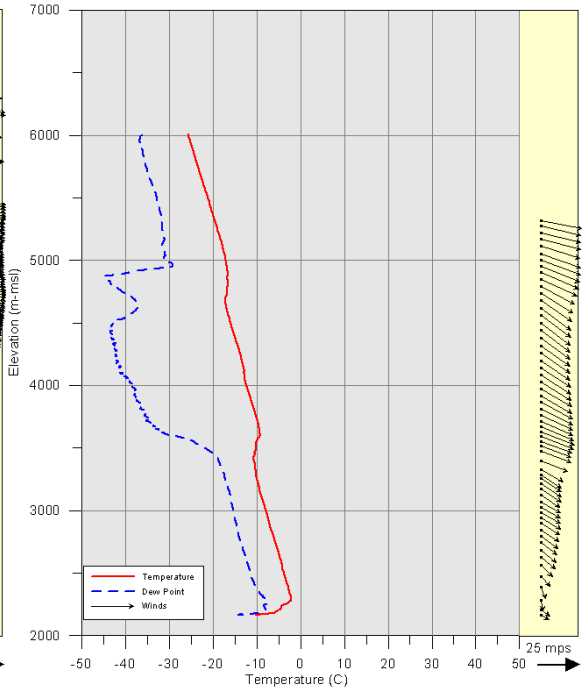

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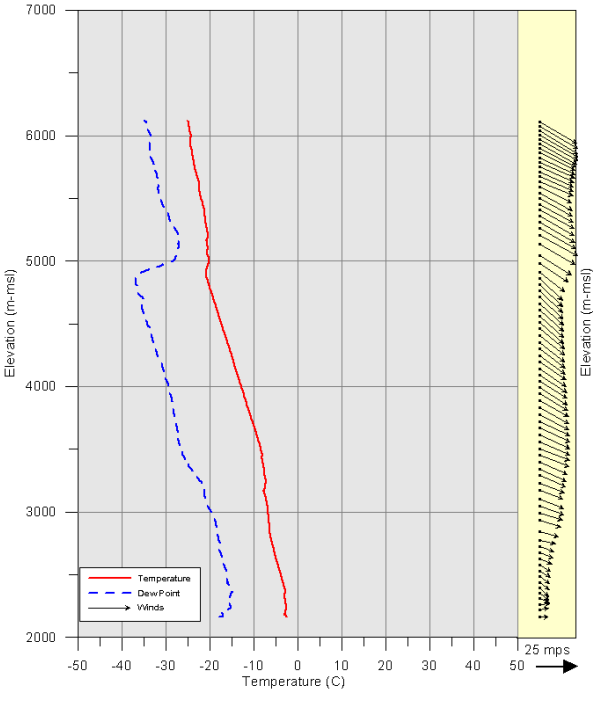
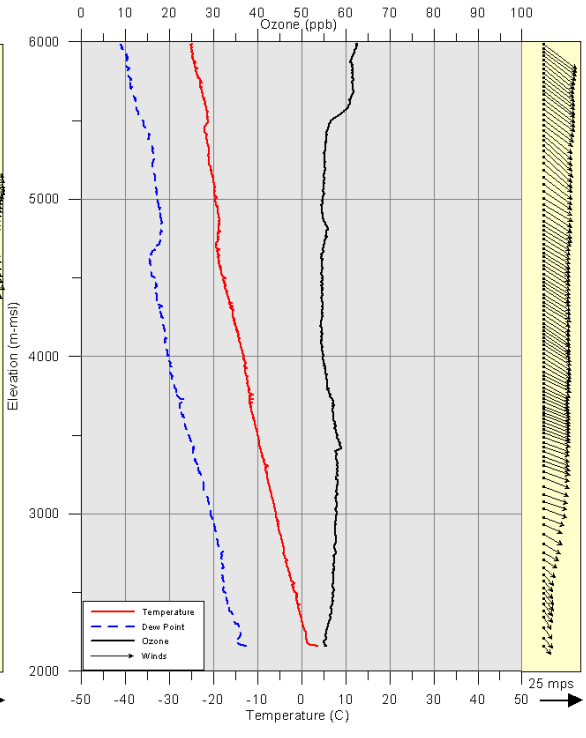


Wenz Field - March 12, 2008 at 11 MST



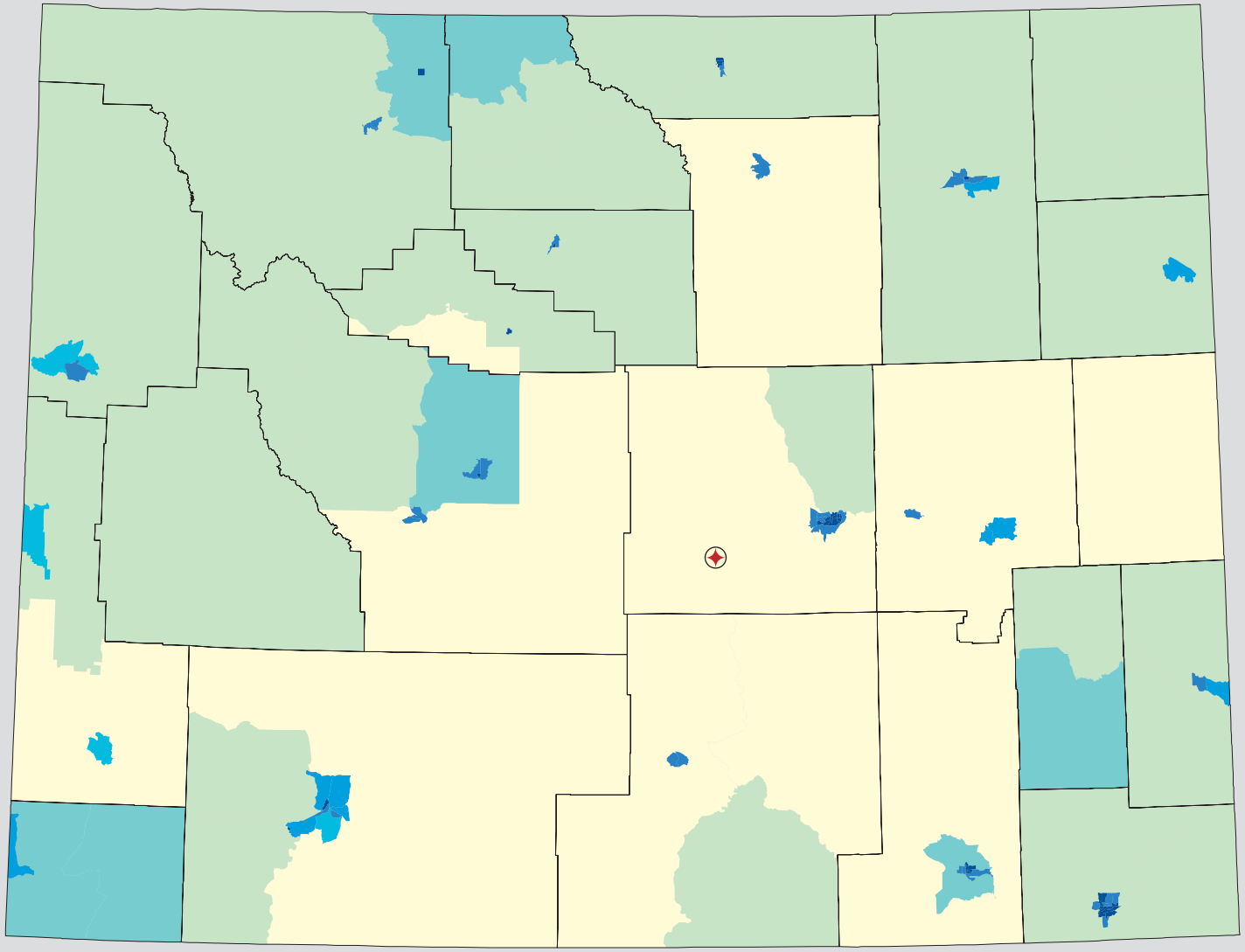
Wenz Field - March 12, 2008 at 15 MST

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

Appendix S.3
Population Density by Census Tract

Census 2000: Wyoming Profile

Population Density by Census Tract



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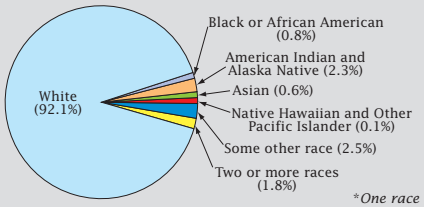
0 10 20 40 60 Kilometers

0 10 20 40 60 Miles

State Race* Breakdown

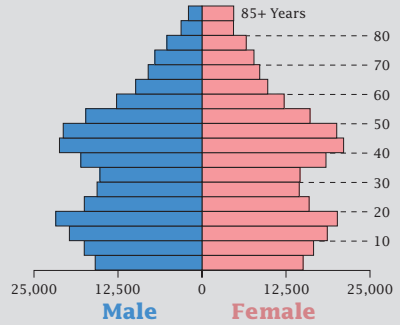


*One race

Hispanic or Latino (of any race) makes up **6.4%** of the state population.

Population by Sex and Age

Total Population: 493,782



Housing Tenure

Total Occupied Housing Units: 193,608

70.0% Owner Occupied	30.0% Renter Occupied

Average Household Size of Owner-Occupied Units:	Average Household Size of Renter-Occupied Units:
2.58 people	2.25 people

Population Per Square Mile by Census Tract

U.S. density is 79.6

- 1,000.0 to 6,652.7
- 200.0 to 999.9
- 79.6 to 199.9
- 20.0 to 79.5
- 5.0 to 19.9
- 1.0 to 4.9
- Less than 1.0
- County Boundary
- Wyoming Mean Center of Population

Appendix S.4.A.
2007 Vehicle Miles on State Highways By County

2007 VEHICLE MILES ON STATE HIGHWAYS BY COUNTY

County	Highway Miles	DVMT*	DVMTT**
Albany	311.1	1,080,321	404,489
Big Horn	290.9	365,776	42,943
Campbell	336.6	1,051,147	152,704
Carbon	513.0	1,399,506	631,073
Converse	258.6	691,232	116,302
Crook	290.8	503,667	89,832
Fremont	507.2	979,546	103,255
Goshen	236.6	304,008	41,347
Hot Springs	118.6	142,872	19,877
Johnson	313.8	586,183	111,209
Laramie	416.4	1,889,076	494,858
Lincoln	337.2	615,113	136,039
Natrona	348.4	1,242,470	181,043
Niobrara	174.4	193,226	40,894
Park	349.6	587,977	41,815
Platte	265.0	568,186	110,224
Sheridan	274.5	629,637	79,014
Sublette	229.2	447,953	74,001
Sweetwater	568.7	2,667,117	1,110,817
Teton	144.2	622,356	30,613
Uinta	218.4	1,013,595	356,875
Washakie	149.8	175,856	19,954
Weston	205.8	186,103	27,167
Statewide	6,859	17,942,923	4,416,345

* Daily Vehicle Miles Traveled

**Daily Vehicle Miles Traveled by Trucks

Appendix S.4.B.
Commuting Patterns in Sublette County

http://doe.state.wy.us/LMI/commuter_flow_2007.pdf

Introduction

The purpose of the commuting pattern project is to ***estimate*** worker and wage flows between counties and to study flow patterns using a variety of demographic and economic variables such as industry, sex, tenure, age, residency status and state of origin. This document contains general information regarding the methods used to build the commuting pattern data model. The commuting pattern data model consists of several components as follows:

1. Wage records file[1]
2. Wyoming Department of Transportation (WYDOT) Driver License file
3. Department of Employment employer master file[2]
4. Other administrative datasets as deemed necessary

The goal of the model is to link where people live to where they work using administrative datasets.

Determination of Residence Location

Residence location is determined from the WYDOT driver license file. Each time a person renews or applies for a Wyoming driver license, a new record is created in the file. Some individuals may not have updated their license data for several years or left the state. In these cases, residence location is interpolated between known data points and extrapolated before the first data point and after the last data point in the file. Residence locations are assigned by processing drivers' physical addresses through Residency Assignment Software (RAS). RAS, sponsored by the Department of Labor's Bureau of Labor Statistics, processes each physical address supplied on the file and assigns each record a state and county code in addition to latitude and longitude coordinates. People who list Post Office (PO) boxes as a physical address do not receive latitude and longitude assignments; however, a county code is assigned to those records. Social Security Numbers (SSNs) are removed from the file prior to shipment to ensure confidentiality. SSNs are then used to re-link the WYDOT driver license file to wage records following RAS processing.

Determination of Work Location

---

[1] Wage Records is an administrative database. Each employer in the State who has employees covered under Unemployment Insurance, by law, must submit quarterly tax reports to the State showing each employee's Social Security Number (SSN) and wages earned in the quarter. Wage Records has a two-quarter time lag (e.g., wage information for first quarter 2001 employees is generally not available until third quarter 2001). For more information, see Wayne M. Gosar, "Insurance Wage Record Summary: A New Way to Look at Wyoming," *Wyoming Labor Force Trends*, May 1995, pp. 4-8.

[2] For a definition of the data contained in the employer master file, see http://www.bls.gov/cew/cewover.htm

Many Wyoming businesses operate at multiple locations and break their employment and wages paid by each location. While the employer master file contains detailed information on business units (if reported), the wage records file does not; it only tells us which company employed the workers. In these cases, the commuting pattern data model assigns workers using statistical techniques to the most likely employer location based on distance, county of employer unit and county of residence, among other variables. Since latitude and longitude coordinates for employer physical addresses are contained in the master file, we can calculate distances between residence and likely work locations. In cases where two locations have an equal probability of assignment, a random sorting variable is used to break ties. The random variable is most often used when latitude and longitude coordinates could not be assigned to employer physical addresses.

Results

The results of the model are shown in the accompanying tables. For each county, estimates of inflowing and out flowing commuters are shown on a quarterly basis. Workers commuting between counties are identified as "Intercounty Commuters". In the same manner, the average wages for workers in those categories are also shown. The third component of commuting flows is people who work and live in the same county, who are identified as "Intracounty Commuters".

Limitations

The commuting data model is not without its limitations. First, persons with PO boxes for physical addresses may actually live a considerable distance from the PO locations. Second, people who move and fail to update their records also introduce noise into the system. Third, people with out-of-state driver licenses but working in Wyoming are reported has having an "Unknown" residence location. Fourth, persons commuting from Wyoming to another state for work are not included in the model.

		2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Inflow	(to Sublette)												
	Fremont	14	22	26	19	16	21	56	22	14	18	22	12
	Lincoln	109	113	116	108	107	120	126	116	101	117	107	99
	Sweetwater	51	66	76	56	58	78	99	107	66	82	88	78
	Teton	38	50	53	53	41	54	55	56	30	55	54	39

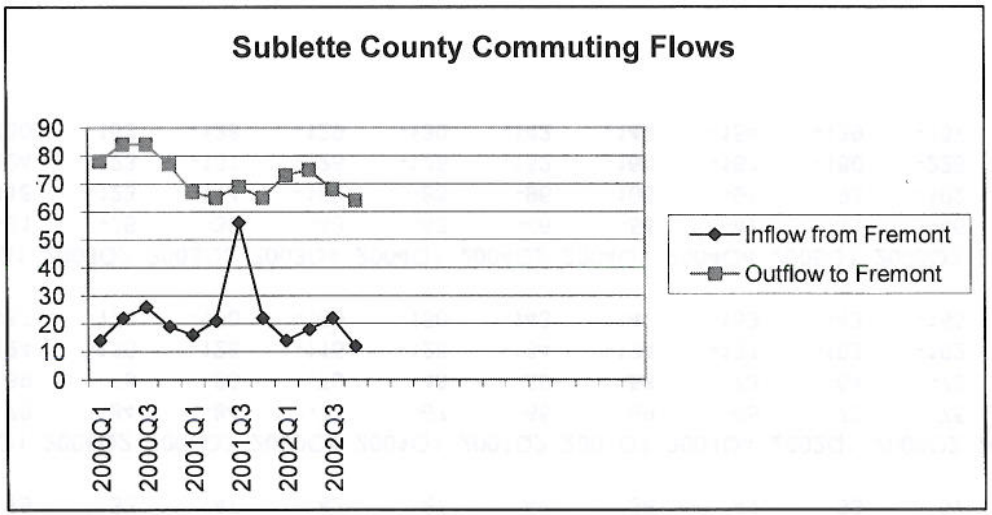
		2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Inflow	(to Sublette)												
	Fremont	18	29	30	28	28	38	47	50	42	47	52	48
	Lincoln	70	93	92	82	90	98	104	107	104	120	149	137
	Sweetwater	55	80	88	86	93	102	132	117	137	186	218	200
	Teton	19	33	47	42	27	44	38	41	33	57	53	51

		2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Outflow	(from Sublette)												
	Fremont	-78	-84	-84	-77	-67	-65	-69	-65	-73	-75	-68	-64
	Lincoln	-69	-78	-80	-79	-48	-59	-56	-73	-64	-73	-81	-86
	Sweetwater	-124	-136	-128	-115	-128	-134	-124	-131	-103	-102	-117	-114
	Teton	-167	-178	-170	-169	-150	-143	-147	-153	-143	-155	-147	-153

		2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Outflow	(from Sublette)												
	Fremont	-31	-36	-39	-43	-43	-46	-54	-47	-41	-46	-42	-47
	Lincoln	-118	-123	-114	-102	-88	-96	-108	-95	-93	-102	-92	-85
	Sweetwater	-104	-123	-131	-125	-128	-152	-164	-161	-180	-226	-226	-202
	Teton	-130	-152	-128	-129	-130	-142	-142	-154	-139	-137	-126	-117

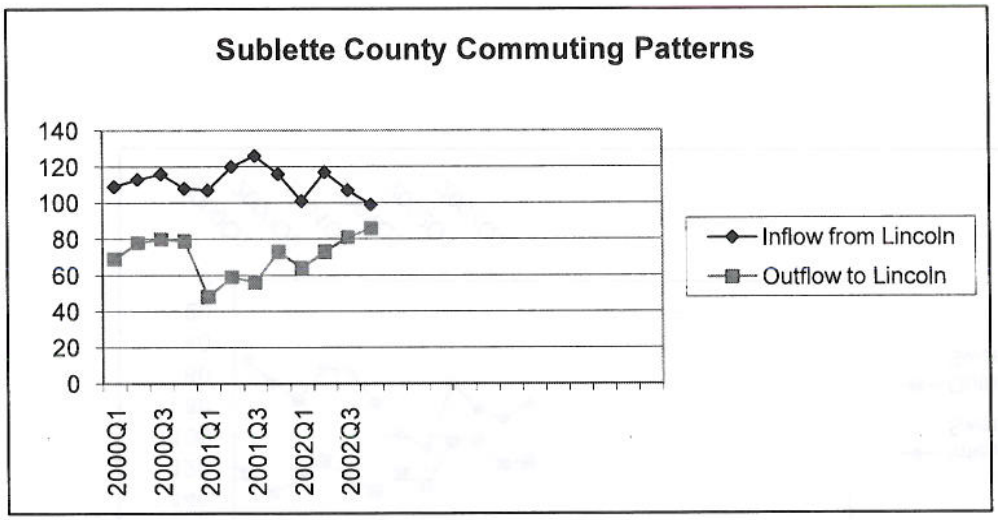
	2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Inflow from Fremont	14	22	26	19	16	21	56	22	14	18	22	12
Outflow to Fremont	78	84	84	77	67	65	69	65	73	75	68	64

Inflow from Fremont	2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Outflow to Fremont	18	29	30	28	28	38	47	50	42	47	52	48
	31	36	39	43	43	46	54	47	41	46	42	47



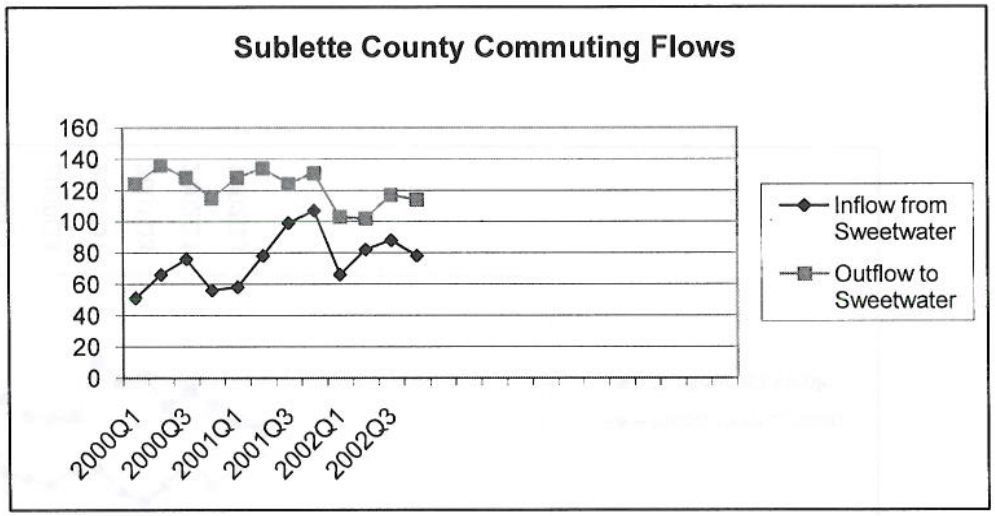
	2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Inflow from Lincoln	109	113	116	108	107	120	126	116	101	117	107	99
Outflow to Lincoln	69	78	80	79	48	59	56	73	64	73	81	86

Inflow from Lincoln	2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Outflow to Lincoln	70	93	92	82	90	98	104	107	104	120	149	137
	118	123	114	102	88	96	108	95	93	102	92	85



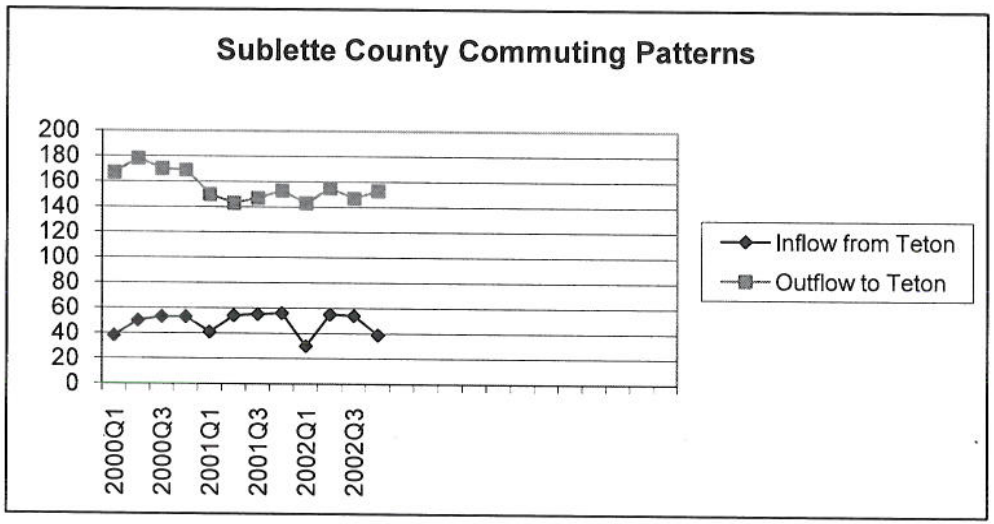
	2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Inflow from Sweetwater	51	66	76	56	58	78	99	107	66	82	88	78
Outflow to Sweetwater	124	136	128	115	128	134	124	131	103	102	117	114

Inflow from Sweetwater	2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Outflow to Sweetwater	55	80	88	86	93	102	132	117	137	186	218	200
	104	123	131	125	128	152	164	161	180	226	226	202



	2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
Inflow from Teton	38	50	53	53	41	54	55	56	30	55	54	39
Outflow to Teton	167	178	170	169	150	143	147	153	143	155	147	153

	2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
Inflow from Teton	19	33	47	42	27	44	38	41	33	57	53	51
Outflow to Teton	130	152	128	129	130	142	142	154	139	137	126	117



Appendix.
Glossary

GLOSSARY

agl	Height above ground level
AMSL	Above mean seal level
AQD	Air Quality Division
BACT	Best Available Control Technology
Bbls	Barrels
BLM	Bureau of Land Management
BFWA	Bridger and Fitzpatrick Wilderness Areas
ºC	Degrees Centigrade
CAA	Clean Air Act
CALMET	Diagnostic wind model
CASTNET	Clean Air Status and Trends Network
CBM	Coal Bed methane
CBSA	Core Based Statistical Area
CSA	Combined Statistical Area
DEQ	Wyoming Department of Environmental Quality
DOE	Wyoming Department of Employment
DVMT	Daily vehicle miles traveled
EDAS	NCEP Eta Data Assimilation System
EDIS	North Carolina's Economic Development Intelligence System
EGU	Electric Generating Unit
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
FEM	Federal Equivalent Method - (method that is equivalent to FRM)
FRM	Federal Reference Method - (EPA approved method)
FTA	Forward Trajectory Analyses
GRBVS	Green River Basin Visibility Study
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory
IOPs	Intensive Operating Periods
JPA	Jonah-Pinedale area
JPAD	Jonah Pinedale Anticline Development
JPDA	Jonah-Pinedale Development Area
m/S	Meters per second
Mb	millibar
Mcf	Thousand cubic feet
Mesonet	Network of temporary, battery powered, tripod mounted measurement stations
miniSODAR	A low power SODAR
Mmcf	Million cubic feet
MPOs	metropolitan planning organizations
MQOs	Measurement Quality Objectives
MSA	Metropolitan Statistical Area
msl	Height above mean sea level
MST	Mountain standard time

NAAQS	National Ambient Air Quality Standard
NCEP	National Center for Environmental Prediction
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Oxides of Nitrogen ($NO + NO_2$)
NPS	National Park Service
NSR	New Source Review
O&G	Oil and gas
Ozonesonde	Similar to rawinsonde but for measuring the ozone as a function of height
ppb	Parts per billion
ppbC	For an organic compound, the mixing ratio of the compound in ppbV multiplied by the number of carbon atoms in the compound
ppbV	Parts per billion by volume
ppm	Parts per million
ppmV	Parts per million by volume
PSD	Prevention of Significant Deterioration
QA/QC	Quality assurance / quality control
Rawinsonde Instrument	system based on use of a helium balloon to measure winds, temperature, and dew point temperature as a function of height
RUC	Rapid Update Cycle
SEIS	Supplemental Environmental Impact Statement
SODAR	Sound Detection and Ranging: a technique for using sound waves as in a radar to remotely probe the vertical structure of the lower atmosphere
Tethersonde	Similar to rawindsonde but using a balloon that remains tethered to the surface rather than a free ascending balloon; can also be used to measure vertical profiles of ozone or other contaminants
TPY	Tons per year
UGRB	Upper Green River Basin
UGWOS	Upper Green River Winter Ozone Study
USFS	United States Forest Service
UTC	Coordinated universal time
UV	ultraviolet
Vertical wind sheer,	A (generally rapid) change of wind direction with height
VMT	Vehicle miles traveled
VOCs	Volatile Organic Compounds
WAQS&R	Wyoming Air Quality Standards and Regulations
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WYDOT	Wyoming Department of Transportation
WYNSR	Wyoming's new source review program

STATE OF WYOMING

Technical Support Document II
For Recommended 8-Hour Ozone Designation
For All Areas of the State Outside the
Upper Green River Basin

March 26, 2009

The Wyoming Department of Environmental Quality
Air Quality Division
Herschler Building, 122 West 25th Street
Cheyenne, Wyoming 82002

The State of Wyoming recommended that all areas outside of the Upper Green River Basin under the jurisdiction of the Wyoming Department of Environmental Quality (exclusive of tribal lands) be designated as attainment/unclassifiable. This recommendation is based on the quality assured and certified ozone monitoring presented in the following tables.

Design Values for Wyoming Ambient Ozone Monitors							
Site Name	AQS ID	Year				3-Year Average 2005-2007 (ppm)	3-Year Average 2006-2008[1] (ppm)
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1-Q3[1] (ppm)		
Daniel South	56-035-0100	0.067[2]	0.075	0.067	0.074	N/A	0.072[1]
Boulder	56-035-0099	0.080[3]	0.073	0.067	0.101	0.073[3]	0.080[1]
Jonah	56-035-0098	0.076	0.070	0.069	0.082	0.072	0.074[1]
Yellowstone (NPS)	56-039-1011	0.060	0.069	0.064	0.065	0.064	0.066[1]
Thunder Basin	56-005-0123	0.063	0.072	0.072	0.074	0.069	0.073[1]
Campbell County	56-005-0456	0.063[4]	0.065	0.072	0.060	0.067[4]	0.066[1]

[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in July 2005
[3] Incomplete year; began operation in February 2005
[4] One quarter with less than 75% data completeness

4th Maximum 8-Hour Ozone Values for Ambient Monitors without 3 years of data					
Site Name	AQS ID	Year			
		2005 (ppm)	2006 (ppm)	2007 (ppm)	2008 Q1-Q3[1] (ppm)
Murphy Ridge	56-041-0101	---	---	0.070	0.061
South Pass	56-013-0099	---	---	0.071[2]	0.065
OCI[3]	56-037-0898	---	0.071[3]	0.066	0.072
Wamsutter	56-005-0123	---	0.067[4]	0.064	0.064
Atlantic Rim	56-007-0099	---	---	0.047[5]	0.064

[1] Data collected and validated through 3rd quarter 2008
[2] Incomplete year; began operation in March 2007
[3] Site operated by industry. Incomplete year; began operation in May 2006
[4] Incomplete year; began operation in March 2006
[5] Incomplete year; began operation in October 2007

2008 Primary and Secondary NAAQS 8-Hour Primary and Secondary Ozone Standard
Wyoming Recommendations for Ozone Designations
For Areas Not Under The Jurisdiction of Tribal Authority

Region	8-hour Ozone Designation
Casper, WY: Natrona County (part)..... The portion within the City of Casper	Attainment/Unclassifiable
Cheyenne, WY: Laramie County (part) ..... The portion within the City of Cheyenne	Attainment/Unclassifiable
Evanston, WY: Uinta County (part)..... The portion within the City of Evanston	Attainment/Unclassifiable
Gillette, WY: Campbell County (part) ..... The portion within the City of Gillette	Attainment/Unclassifiable
Jackson, WY: Teton County (part) ..... The portion within the City of Jackson	Attainment/Unclassifiable
Lander, WY: Fremont County (part) ..... The portion within the City of Lander	Attainment/Unclassifiable
Laramie, WY: Albany County (part)..... The portion within the City of Laramie	Attainment/Unclassifiable
Riverton, WY: Fremont County (part)..... The portion within the City of Riverton	Attainment/Unclassifiable
Rock Springs, WY Sweetwater County (part)..... The portion within the City of Rock Springs	Attainment/Unclassifiable
Sheridan, WY Sheridan County (part) ..... The portion within the City of Sheridan	Attainment/Unclassifiable
Albany County (remainder)	Attainment/Unclassifiable
Big Horn County	Attainment/Unclassifiable
Campbell County (remainder)	Attainment/Unclassifiable
Carbon County	Attainment/Unclassifiable
Converse County	Attainment/Unclassifiable
Crook County	Attainment/Unclassifiable
Fremont County (remainder)	Attainment/Unclassifiable
Goshen County	Attainment/Unclassifiable
Hot Springs County	Attainment/Unclassifiable
Johnson County	Attainment/Unclassifiable
Laramie County (remainder)	Attainment/Unclassifiable
Lincoln County (remainder)	Attainment/Unclassifiable
Natrona County (remainder)	Attainment/Unclassifiable
Niobrara County	Attainment/Unclassifiable
Park County	Attainment/Unclassifiable
Platte County	Attainment/Unclassifiable
Sheridan County (remainder)	Attainment/Unclassifiable
Sweetwater County (remainder)	Attainment/Unclassifiable
Teton County (remainder)	Attainment/Unclassifiable

Region	8-hour Ozone Designation
Uinta County (remainder)	Attainment/Unclassifiable
Washakie County	Attainment/Unclassifiable
Weston County	Attainment/Unclassifiable
Upper Green River Basin Area: Sublette County: (all) Lincoln County: (part) The area of the county north and east of the boundary defined by a line starting at the point defined by the intersection of the southwest corner Section 30 Range (R) 115 West Township (T) 27N and the northwest corner of Section 31 R 115 West T 27N of Sublette County at Sublette County's border with Lincoln County. From this point the boundary moves to the west 500 feet to the Aspen Creek. The boundary follows the centerline of Aspen Creek downstream to the confluence of Aspen Creek and Fontenelle Creek (in R 116 W T26N, Section 1). From this point the boundary moves generally to the south along the centerline of Fontenelle Creek to the confluence of Fontenelle Creek and Roney Creek (in R115W T24N Section 6). From the confluence, the boundary moves generally to the east along the centerline of Fontenelle Creek and into the Fontenelle Reservoir (in R112W T24N Section 6). The boundary moves east southeast along the centerline of the Fontenelle Reservoir and then toward the south along the centerline of the Green River to where the Green River in R111W T24 N Section 31 crosses into Sweetwater County. Sweetwater County: (part) The area of the county west and north of the boundary which begins at the midpoint of the Green River, where the Green River enters Sweetwater County from Lincoln County in R111W T24N Section 31. From this point, the boundary follows the center of the channel of the Green River generally to the south and east to the confluence of the Green River and the Big Sandy River (in R109W R22 N Section 28). From this point, the boundary moves generally north and east along the centerline of the Big Sandy River to the confluence of the Big Sandy River with Little Sandy Creek (in R106W T25N Section 33). The boundary continues generally toward the northeast long the centerline of Little Sandy Creek to the confluence of Little Sandy Creek and Pacific Creek (in R106W T25N Section 24). From this point, the boundary moves generally to the east and north along the centerline of Pacific Creek to the confluence of Pacific Creek and Whitehorse Creek (in R103W T26N Section 10). From this point the boundary follows the centerline of Whitehorse Creek generally to the northeast until it reaches the eastern boundary of Section 1 R103W T 26North. From the point where Whitehorse Creek crosses the eastern section line of Section 1 R103W T 26North, the boundary moves straight north along the section line to the southeast corner of Section 36 R103W T27N in Sublette County where the boundary ends.	Non-attainment

R = Range, T = Township, N = North, W = West

carol CA
OPRA — B-P-AR

Department of Environmental Quality

To protect, conserve and enhance the quality of Wyoming's environment for the benefit of current and future generations.

Dave Freudenthal, Governor

John Corra, Director

March 30, 2009

Ms. Carol Rushin
Acting Regional Administrator
USEPA Region 8
Mail Code: 8RA
1595 Wynkoop Street
Denver, CO 80202-1129

RE: Wyoming Technical Support Documents for Recommended 8-Hour Ozone Designations - Errata March 30, 2009

Dear Ms. Rushin:

The Technical Support Document (TSD) sent to you on March 27, 2009, has some incorrect references to figures. Attached is an Errata sheet and replacement pages for the document. The AQD has posted the corrected TSD to the DEQ/AQD website. A copy of the revised TSD has been sent to Callie Videtich, Monica Morales, and Kerri Fiedler. Please contact me with any questions at 307-777-7032.

Sincerely

Janet L. Lydigsen

Janet L. Lydigsen
Air Quality Division
Wyoming Department of Environmental Quality

Enclosures: Errata
Corrected TSD pages: 61, 68, 72, 74, 76, and 78

cc: Christine Anderson, AQD
Callie Videtich, Director, Air and Radiation Program, EPA Region 8 w/o Enclosures
Monica Morales, EPA Region 8 w/o Enclosures
Kerri Fiedler, EPA Region 8 w/o Enclosures

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APR 06 2009
USEPA RA'S OFFICE

Herschler Building • 122 West 25th Street • Cheyenne, WY 82002 • http://deq.state.wy.us

ADMIN/OUTREACH	ABANDONED MINES	AIR QUALITY	INDUSTRIAL SITING	LAND QUALITY	SOLID & HAZ. WASTE	WATER QUALITY
(307) 777-7937	(307) 777-6145	(307) 777-7391	(307) 777-7369	(307) 777-7756	(307) 777-7752	(307) 777-7781
FAX 777-3610	FAX 777-6462	FAX 777-5616	FAX 777-5973	FAX 777-5864	FAX 777-5973	FAX 777-5973

ERRATA

Page 61. The last sentence on the page states that a forward trajectory analysis from the Utah, Idaho, and Wyoming border is shown in Figure S.7-28. This is incorrect. The last sentence on the page should be deleted.

Page 68. The first paragraph states: "The trajectory analysis in Figure S.7-30 shows all modeled trajectories from Moxa Arch not entering the proposed nonattainment area." This should read: "The trajectory analysis in Figure S.7-30 shows all modeled trajectories from Naughton not entering the proposed nonattainment area."

Page 72. The first two sentences on the page state: "As shown in Figure S.7-34, the trajectory analyses for the LaBarge area exhibit several possible air parcel paths to the northwest on February 21, 2008. Figure S.7-35 shows the trajectory analysis for the Moxa Arch area, which exhibits a few trajectories initially moving into the southernmost portion of the UGRB, but the strong northerly winds in the UGRB dominate the flow." The figure numbers are incorrect. The sentences should read: "As shown in Figure S.7-33, the trajectory analyses for the LaBarge area exhibit several possible air parcel paths to the northwest on February 21, 2008. Figure S.7-34 shows the trajectory analysis for the Moxa Arch area, which exhibits a few trajectories initially moving into the southernmost portion of the UGRB, but the strong northerly winds in the UGRB dominate the flow."

Page 74. The last sentences states: "The trajectory analysis in Figures S.7-37 and S.7-38 shows all modeled trajectories from OCI and Bridger not entering the proposed nonattainment area." The figure references are incorrect. The sentence should read: "The trajectory analysis in Figures S.7-36 and S.7-37 shows all modeled trajectories from OCI and Bridger not entering the proposed nonattainment area."

Page 76. The last sentence on the page states: Terrain blocking and channeling effects can also be seen in Figure S.7-43 in the forward trajectories originating from the OCI Trona plant. This should state: Terrain blocking and channeling effects can also be seen in Figure S.7-42 in the forward trajectories originating from the OCI Trona plant.

Page 78. The last sentence on the page references a forward trajectory analysis in Figure S.7-39 and a back trajectory analysis in Figure S.7-40. This is incorrect, the sentence should read: "The back trajectory analysis in Figure S.7-41 shows a limited potential for sources outside the recommended nonattainment area to affect ozone measured at the Boulder monitor."

Replacements for pages 61, 68, 72, 74, 76 and 78 are attached.

CalDESK Forward Trajectory Analyses for February 19, 2008 are shown in Figures S.7-23 through S.7-29.

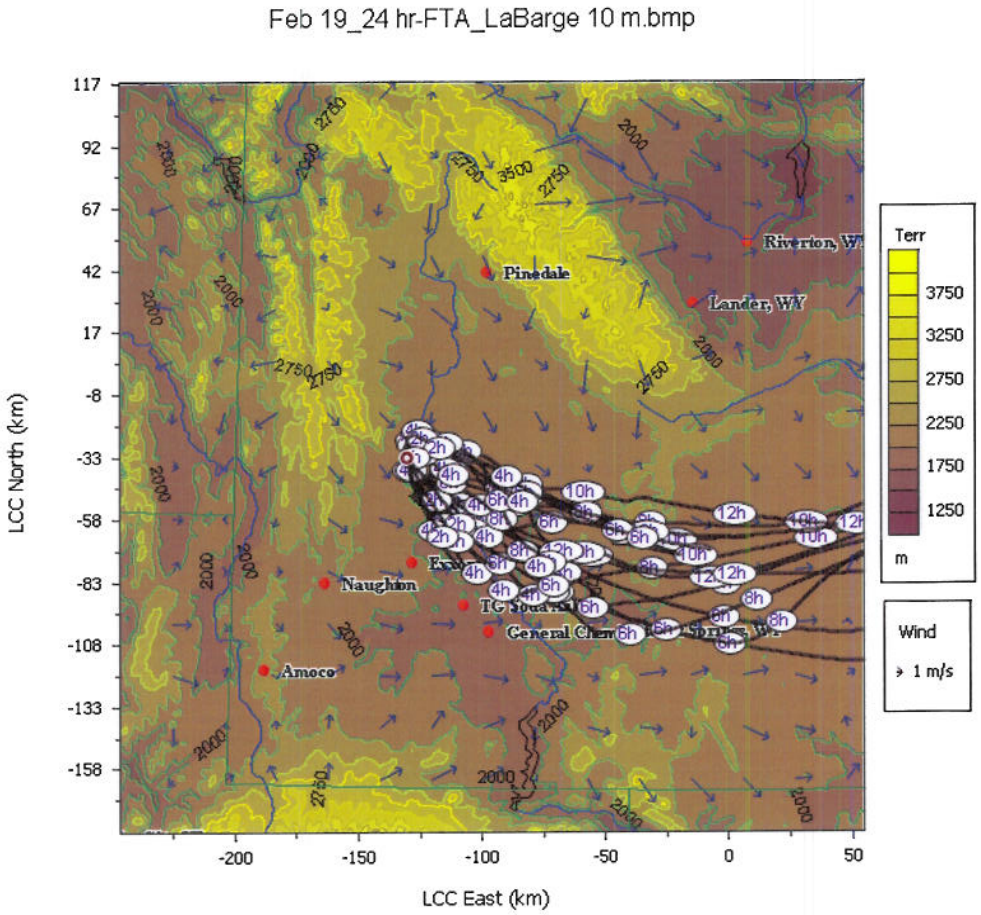

Figure S.7-23. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 19, 2008.

As shown in Figures S.7-23 through S.7-27, the prevailing northwest winds on February 19th continue to limit air parcel transport into the UGRB from the south, which is reflected in the trajectory analysis for the LaBarge and Moxa Arch areas, the Naughton power plant, the OCI Trona processing facility, and the Bridger power plant.

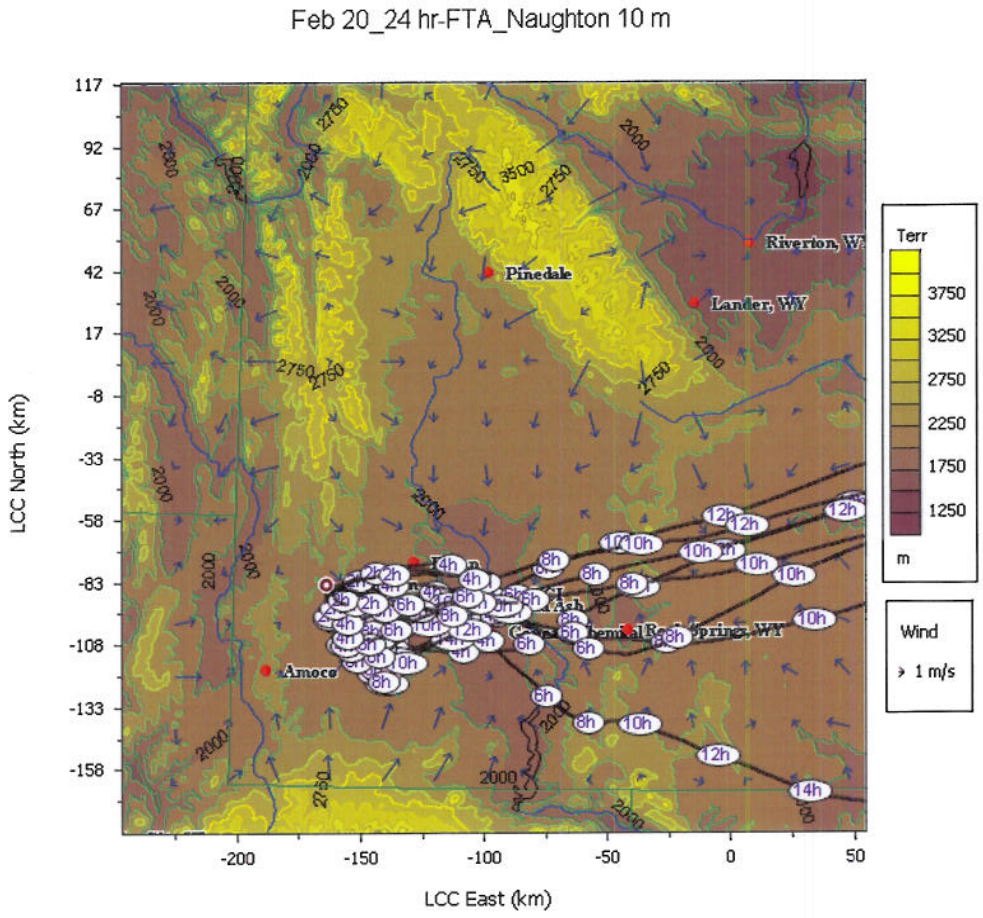

Figure S.7-30. 24-hour forward trajectory analysis at Naughton power plant on February 20, 2008.

The trajectory analysis in Figure S.7-30 shows all modeled trajectories from Naughton not entering the proposed nonattainment area.

As shown in Figure S.7-33, the trajectory analyses for the LaBarge area exhibit several possible air parcel paths to the northwest on February 21, 2008. Figure S.7-34 shows the trajectory analysis for the Moxa Arch area, which exhibits a few trajectories initially moving into the southernmost portion of the UGRB, but the strong northerly winds in the UGRB dominate the flow. This limits northward air parcel transport into the UGRB, and the vast majority of the trajectories continue to travel south out of the UGRB. The trajectory start point at Moxa Arch is approximately fourteen (14) miles south of the LaBarge trajectory start point, where the dominant northwest wind influence in the UGRB valley is tapering off, and mixes with prevailing westerly winds.

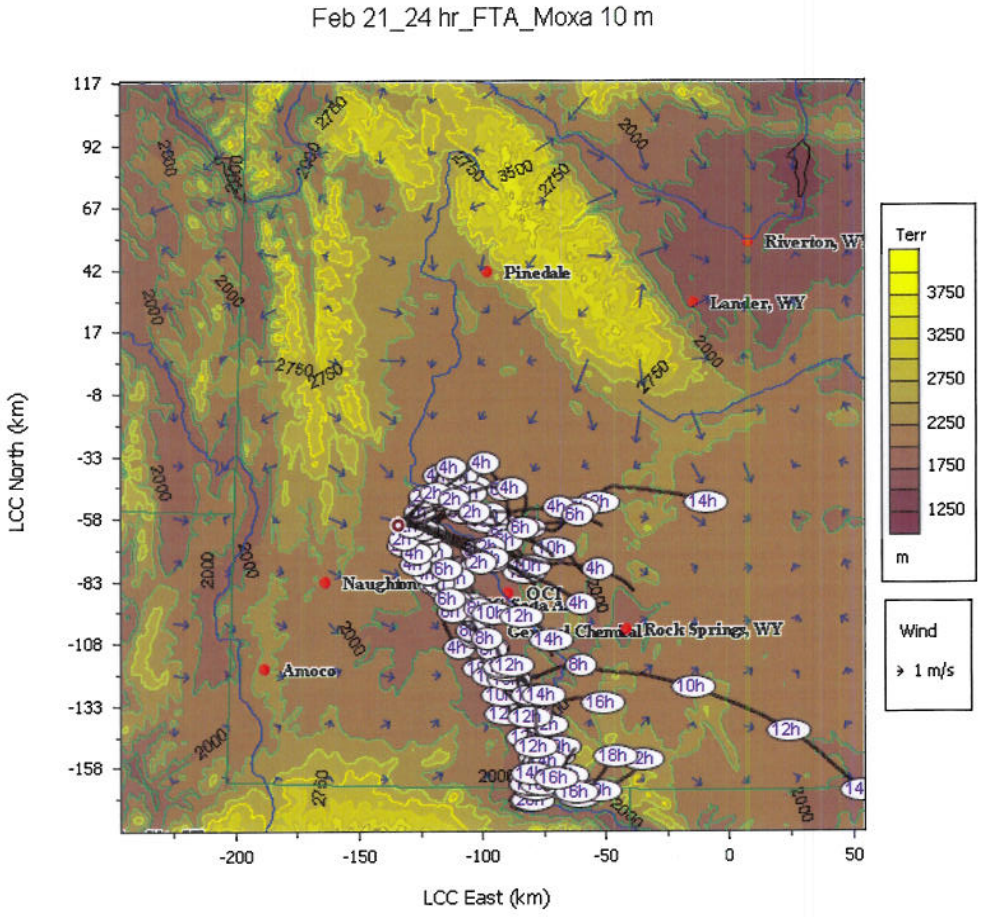

Figure S.7-34. 24-hour forward trajectory analysis in the Moxa Arch area on February 21, 2008.

Figures S.7-36 and S.7-37 show the prevailing westerly winds at the OCI Trona plant and the Bridger power plant, with the air parcels moving eastward and then northward. As noted with the forward trajectory paths from Naughton power plant, the strong northwest winds in the UGRB and the terrain blocking effects of the Uinta Range to the south continue to influence the trajectory paths as they move from the OCI and Bridger trajectory start points. The trajectory analysis in Figures S.7-36 and S.7-37 shows all modeled trajectories from OCI and Bridger not entering the proposed nonattainment area.

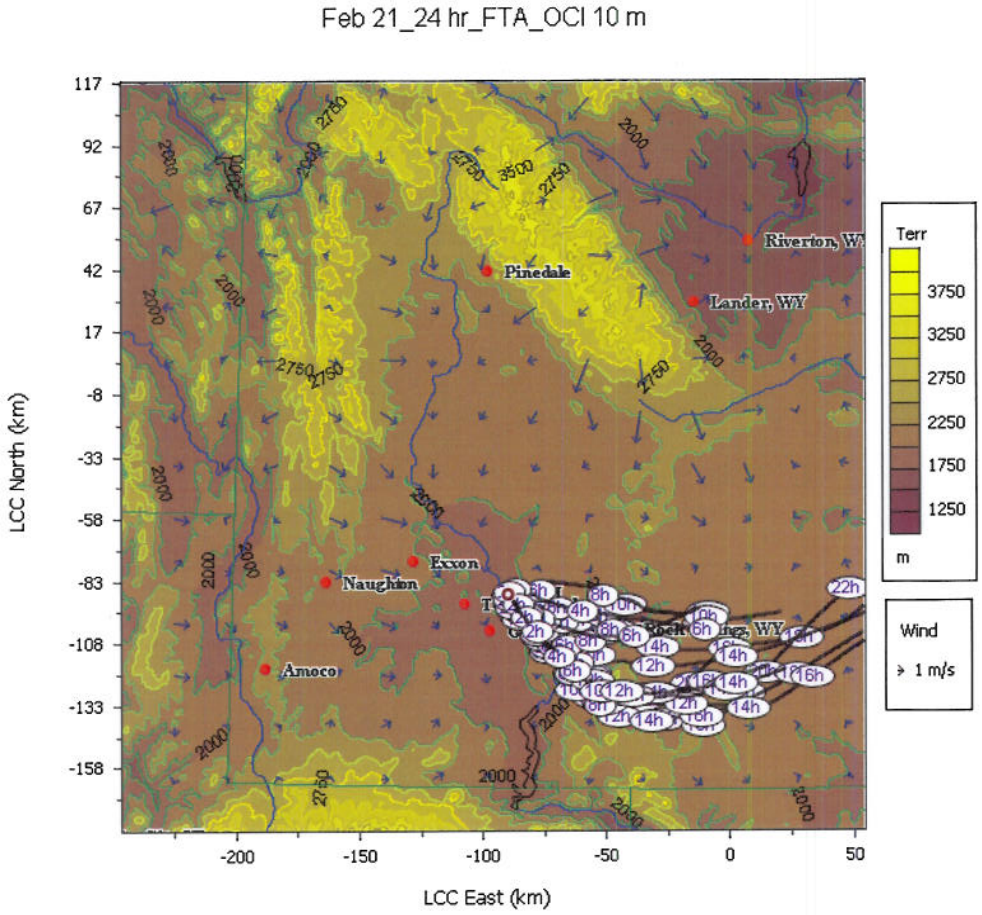

Figure S.7-36. 24-hour forward trajectory analysis at OCI Trona plant on February 21, 2008.

CalDESK Forward Trajectory Analyses for February 22, 2008 are shown in Figures S.7-38 through S.7-42.

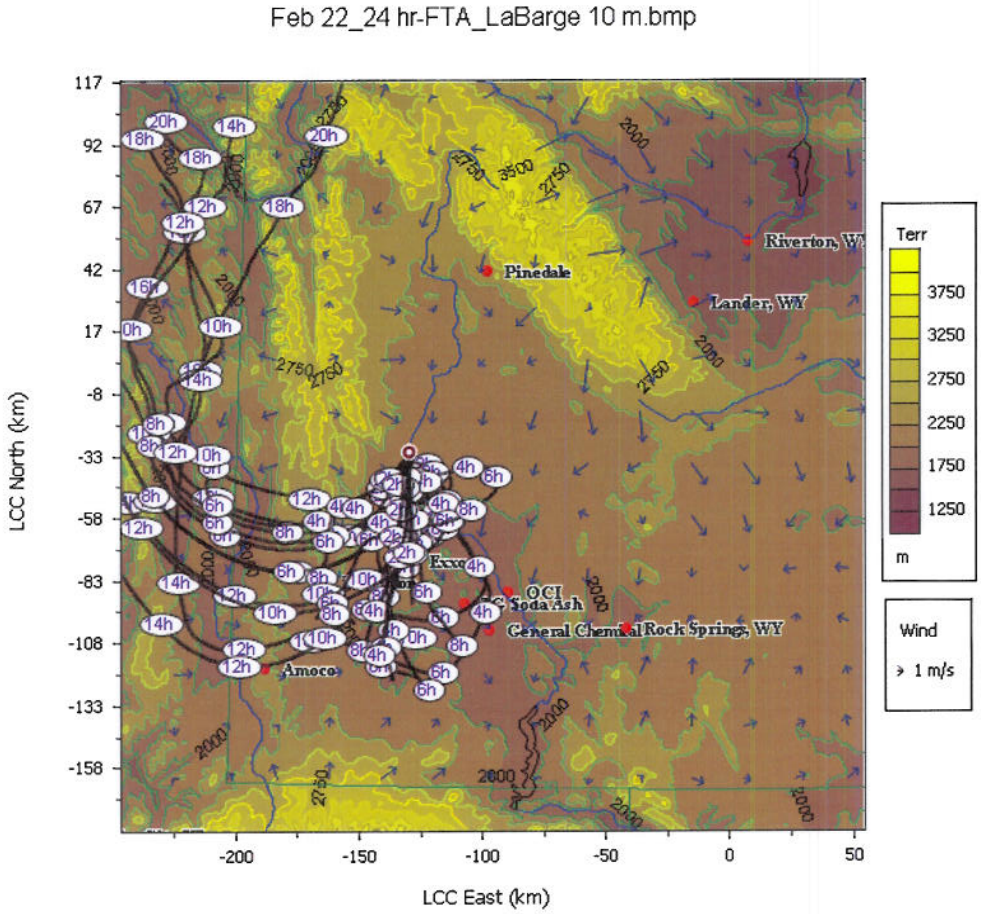

Figure S.7-38. 24-hour forward trajectory analysis at LaBarge, Wyoming on February 22, 2008

The high pressure ridge continued to weaken during February 22, 2008, while a shortwave low pressure trough approached southwestern Wyoming from the northwest. Skies became mostly cloudy during the morning hours and light precipitation spread over the area later in the afternoon. However, the low level inversion stayed intact well into the afternoon, and ozone concentrations remained high during most of the day. No IOP operations were conducted this day because it was anticipated that the stable layer would be mixed-out by the trough by early morning and, therefore, trapped emission would be dispersed. Instead, the late arrival of the trough allowed one more day of high ozone concentrations.

As shown in Figure S.7-38, the trajectory analysis for the LaBarge area shows that most of the possible forward trajectory paths are now moving away from the UGRB during February 22nd. Figures S.7-38 through S.7-40 show air parcels tend to be blocked and channeled westward and then northward around the Wyoming Range, with limited air parcel movement into the UGRB. There are 1-2 trajectory paths showing air parcel movement from the Moxa Arch and Naughton areas into the UGRB, however, the vast majority of the air parcel trajectories do not enter the UGRB, due to the significant terrain blocking and channeling effects of the terrain that make up the Wyoming Range and the Wasatch Range. Terrain blocking and channeling effects can also be seen in Figure S.7-42 in the forward trajectories originating from the OCI Trona plant.

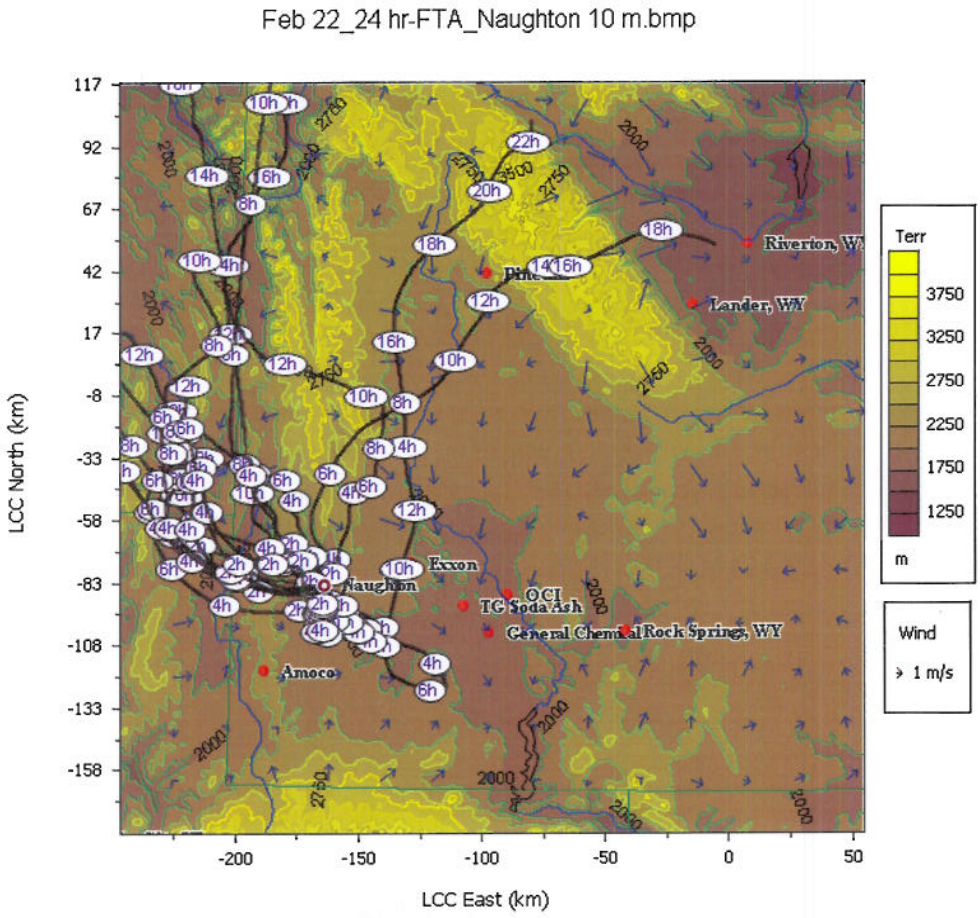

Figure S.7-40. 24-hour forward trajectory analysis at Naughton power plant on February 22, 2008.

There are two forward trajectory paths (2 am and 6 am) which show possible air parcel transport from the Naughton power plant into the UGRB. A 12-hour back trajectory analysis was performed at the Boulder monitor location (2 am – 2 pm) for February 22, 2008 to evaluate potential air parcel trajectories that could reach the Boulder monitor during this same time period (2 am and 6 am). The results of this back trajectory analysis are shown in Figure S.7-41.

Figure S.7-41 shows the calculated back trajectories of air parcels at the Boulder monitor tend to originate from within the UGRB, with very little air parcel movement occurring outside of the UGRB; the air parcels tend to stay within the UGRB during this 12 hour period (2 am – 2 pm) largely due to localized meteorological conditions in the UGRB. The back trajectory analysis in Figure S.7-41 shows a limited potential for sources outside the recommended nonattainment area to affect ozone measured at the Boulder monitor.