**State of Wyoming
Department of
Environmental
Quality/Air Quality
Division**

Exceptional Event Demonstration Package for the Environmental Protection Agency

Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012

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NOTES TO READER:

This document contains several electronic enhancements such as time animations and figure enlargements. Viewing this document in its electronic format will aid the reader in reaching a better understanding of the material. In addition, this document has been prepared to stand alone as a hard copy without the electronic enhancements.

All time references refer to Mountain Standard Time (MST) unless otherwise noted. EPA utilizes Mountain Standard Time (MST) consistently throughout the entire year in respect to ambient and ground based meteorological monitoring data collection and reporting.

LIST OF ACRONYMS AND TERMS

AGL	Above Ground Level
AJAX	Alpha Jet Atmospheric eXperiment
AMSL	Above Mean Sea-level
AQI	Air Quality Index
AQS	Air Quality System
$° C KM^{-1}$	Degrees Celsius per Kilometer
CFR	Code of Federal Regulations
CO	Carbon Monoxide
DALR	Dry Adiabatic Lapse Rate
DU	Dobson Unit
ECC	Electrochemical Concentration Cell
EDAS	Eta Data Assimilation System
EPA	Environmental Protection Agency
ELR	Environmental Lapse Rate
GMD	Global Monitoring Division
GOES	Geostationary Operational Environmental Satellite
h7-h5	700-500 mb layer
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory
IOP	Intensive Operational Period
IPV	Isentropic Potential Vorticity
K	Kelvin
kPA	Kilopascal
LIDAR	Light Detection And Ranging
mb	Millibar
MDT	Mountain Daylight Time
MSL	Mean Sea Level
MST	Mountain Standard Time
NAAQS	National Ambient Air Quality Standards
NAM	North American Mesoscale
NARR	North America Regional Reanalysis
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NWS	National Weather Service
O_3	Ozone
ppb	Parts Per Billion
Pphm/vol	Parts Per Hundred Million / Volume
PT	Potential Temperature
PVU	Potential Vorticity Unit
QA/QC	Quality Assurance/Quality Control
RAOB	Radiosonde observations
RAP	Rapid Refresh model
RAQMS	Realtime Air Quality Modeling System

RUC	Rapid Update Cycle model
RH	Relative Humidity
SI	Stratospheric Intrusion
SO_2	Sulfur Dioxide
START08	Stratosphere-Troposphere Analyses of Regional Transport 2008
UG	Upper Green
UGRB	Upper Green River Basin
UGWOS	Upper Green Winter Ozone Study
UTC	Coordinated Universal Time
UV	Ultraviolet
WDEQ/AQD	Wyoming Department of Environmental Quality/Air Quality Division
VOC	Volatile Organic Compound

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EXECUTIVE SUMMARY

The Wyoming Department of Environmental Quality/Air Quality Division (WDEQ/AQD) has determined that a stratospheric intrusion created elevated ozone readings resulting in an 8-hour ozone standard exceedance at the Boulder and Big Piney, Wyoming ozone monitors located in the Upper Green River Basin (UGRB) of western Wyoming on June 14, 2012 (refer to Figure 1 for monitor locations).

During the interval from late winter to late spring in the northern hemisphere, weather producing systems (i.e. tropospheric storm systems, upper level disturbances or upper level storm systems) aid in causing the tropopause to “fold” or descend into the troposphere where our weather occurs. Tropopause folding allows ozone-rich air from the stratosphere to enter the troposphere, also called a stratospheric intrusion (SI), creating the potential for ground level ozone monitors over the higher terrain of the western United States to experience elevated readings.

Throughout June 13-14, 2012, an upper level atmospheric disturbance with an associated SI moved over central Idaho injecting ozone-rich air into the troposphere. The ozone-laden air then moved over western Wyoming creating elevated ozone readings resulting in 8-hour ozone standard exceedances of 76 and 77 ppb at the Boulder and Big Piney, Wyoming ozone monitors, respectively.

Additionally, the Yellowstone and Grand Teton National Park ozone monitors as well as the AQD ozone monitors at South Pass, Daniel, Pinedale, and Juel Spring measured elevated 1-hour average ozone values from the upper 60’s to upper 70’s ppb during the SI event (refer to Figure 2). (Note to reader: the Pinedale CASTNET site was not operational during June 2012 due to a prolonged power outage).

It has been documented (T. S. ENVIRON 2008) that elevated ozone values can occur at the UGRB ozone monitors of Boulder, Big Piney, Pinedale, Daniel, and Juel Spring because of light winds, snow cover, and strong inversions during the January-March winter ozone season. However, during the June 14, 2012 period of elevated ozone, strong winds buffeted the UGRB prior to the SI event, and no snow cover or strong inversions were present. Accumulation of surface-based ozone precursors did not occur because meteorological conditions were not supportive of precursor buildup prior to elevated ozone readings.

Statistical analyses performed on the Boulder and Big Piney data show that the June 14, 2012 ozone data was statistically significantly higher than values recorded during June of each year from 2005-2012 (Boulder) and 2011-2012 (Big Piney). The AQD performed a thorough evaluation of the June 14, 2012 episode, and is confident that the Boulder and Big Piney event presented in this document is the result of a stratospheric intrusion.

Quality Assurance/Quality Control (QA/QC) checks of the Boulder and Big Piney ozone monitors during 2012 confirm that the monitors were running properly. Independent audit results for the second and fourth quarters of 2012 are consistent with 40 CFR Part 58, Appendix A, Section 3.2 and the *Quality Assurance Project Plan* for the Boulder and Big Piney monitoring projects.

With the preceding points in mind, the WDEQ/AQD submits the June 14, 2012 Boulder and Big Piney ozone exceedances as a case for the Environmental Protection Agency’s (EPA) concurrence regarding the stratospheric intrusion of ozone as being an exceptional event as outlined by the final "Treatment of Data Influenced by Exceptional Events" Final Rule. The WDEQ/AQD presents supporting evidence which clearly shows that the exceptional event passed the four required tests A-D under 40 CFR 50.14 (3)(iii). Specifically:

> **(A)** The event satisfies the criteria set forth in 40 CFR 50.1(j);
> **(B)** There is a clear causal relationship between the measurement under consideration and the event that is claimed to have affected the air quality in the area;
> **(C)** The event is associated with a measured concentration in excess of normal historical fluctuations, including background; and
> **(D)** There would have been no exceedance or violation but for the event.

Figure 1. WDEQ/AQD Air Quality Monitor Network Sites. Click to enlarge image.

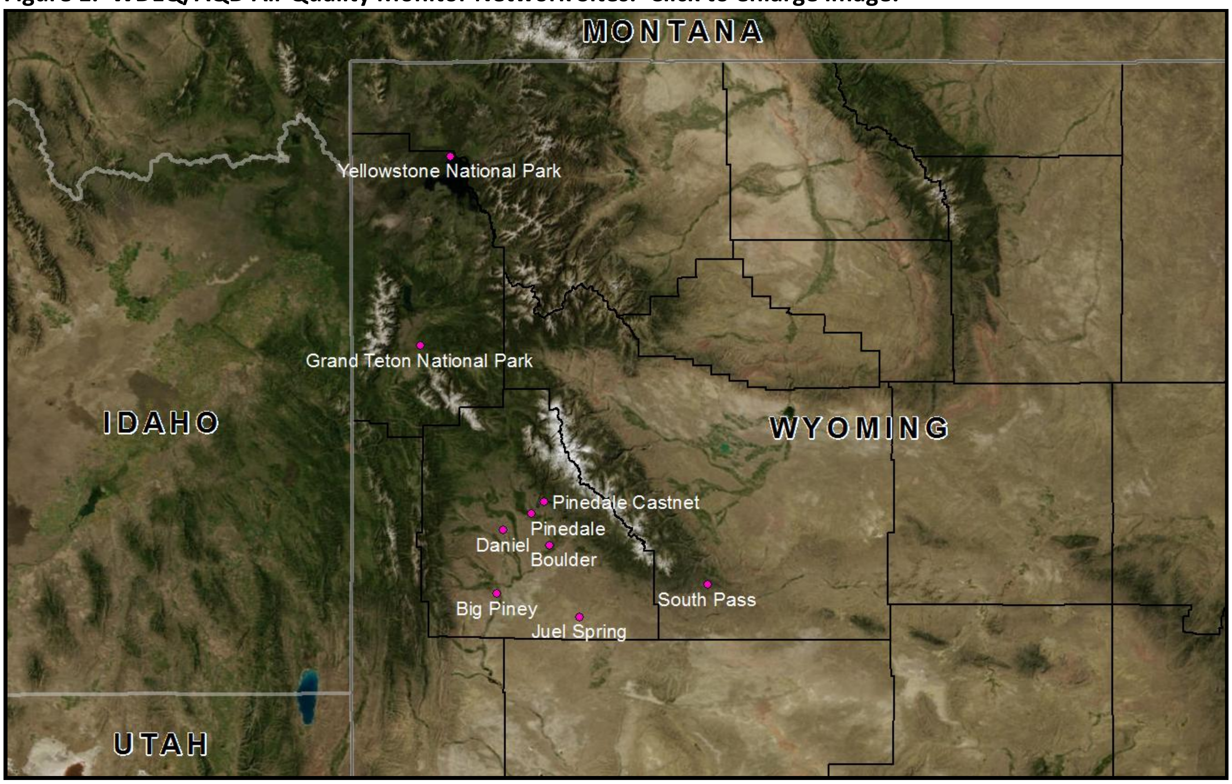
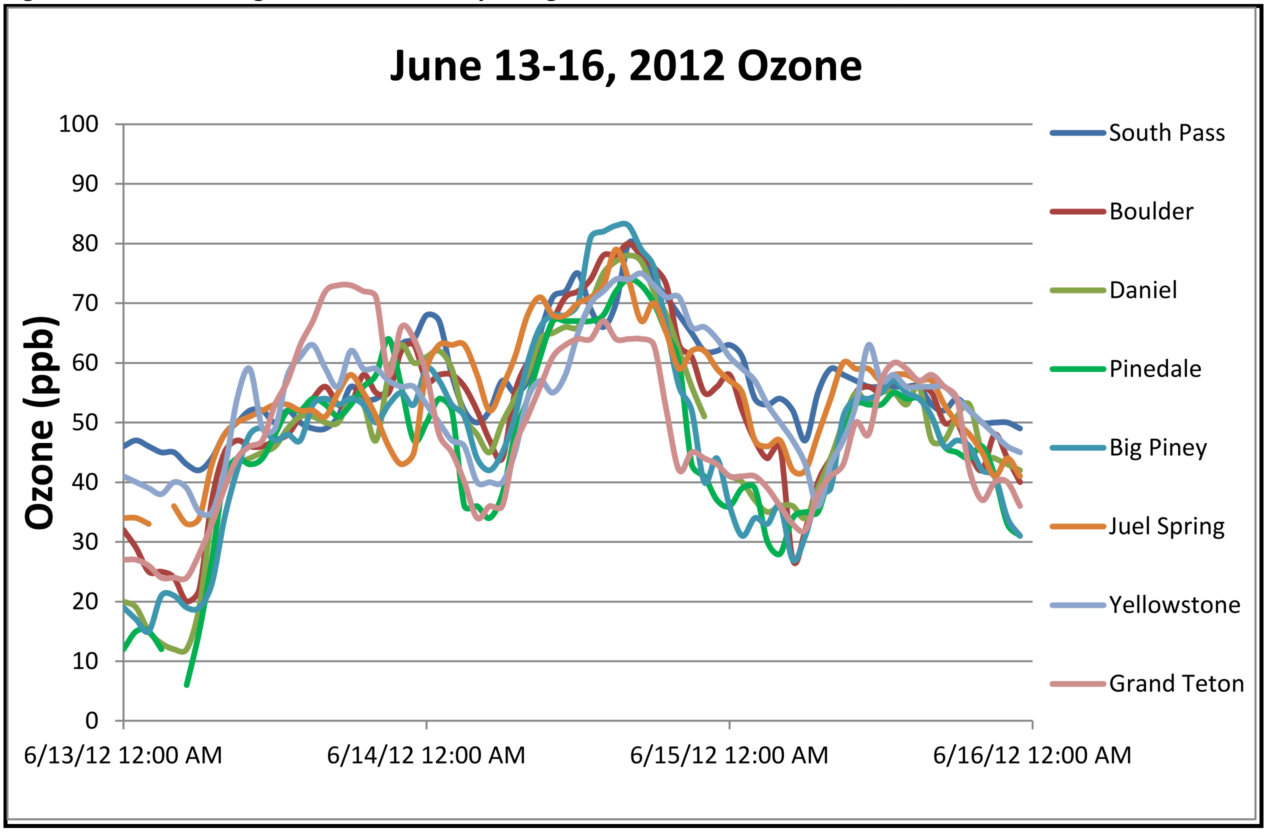


Figure 2. 1-hour average ozone data for Wyoming ozone monitors for June 13-16, 2012.



Criteria **(A)** states that "[t]he event satisfies the criteria set forth in 40 CFR 50.1(j)":

40 CFR 50.1 (j) requires that an exceptional event "affects air quality, is not reasonably controllable or preventable..." and is a "...natural event". The Exceptional Events Rule Preamble and the 40 CFR 50 Appendices I & P specifically list stratospheric intrusion of ozone as a natural event that could affect ground level ozone concentrations. This packet includes data and graphics that display a weather disturbance, and clearly show an intrusion of stratospheric air that affected ambient air quality during June 14, 2012 at the Boulder and Big Piney ozone monitors.

Criteria **(B)** states that **"**[t]here is a clear causal relationship between the measurement under consideration and the event that is claimed to have affected the air quality in the area":

The causal relationship is a basic one in which the ozone standard exceedances were caused by tropospheric folding bringing ozone-rich air down to the earth's surface. For the exceedances that occurred on June 14, 2012, an intrusion of stratospheric air occurred over central Idaho upwind of the Boulder and Big Piney monitors and injected ozone-rich air into the area above and surrounding the Boulder and Big Piney ozone monitors. The causal nature of the SI's impact on ozone values at the Boulder and Big Piney ozone monitors is further supported by the corroboration of ground-based air quality data to the spatial and temporal accuracy of the meteorological analysis.

Criteria **(C)** states that **"**[t]he event is associated with a measured concentration in excess of normal historical fluctuations, including background":

Statistical analysis of June 14, 2012 data clearly shows that the exceptional event was statistically significantly higher than data recorded during prior months of June from 2005-2012 (Boulder) and 2011-2012 (Big Piney).

Criteria **(D)** states that "[t]here would have been no exceedance or violation but for the event":

The SI allowed ozone-rich air to descend to the Boulder and Big Piney ozone monitors creating elevated 1-hour average ozone values resulting in an 8-hour ozone exceedance at both ozone monitors. The exceedances of the ozone National Ambient Air Quality Standards (NAAQS) would not have occurred "but for" the SI.

The 75th percentile hourly ozone concentrations does not exceed 55 ppb for the month of June for the years tested 2005-2012 (Boulder) and 2011-2012 (Big Piney) for statistical significance. Hourly concentrations monitored during June 14, 2012 were outliers for the months of June 2005-2012 (Boulder) and 2011-2012 (Big Piney). Statistics demonstrating that ozone levels were unusually elevated affirm that the exceedances of the ozone National Ambient Air Quality Standards (NAAQS) would not have happened "but for" the SI event having occurred during June 13-14, 2012.

In brief, the WDEQ/AQD concludes that an SI occurred during June 13-14, 2012 resulting in an exceptional event. This exceptional event has passed the four criterion tests under 40 CFR 50.14 (3)(iii). Consequently, the WDEQ/AQD is requesting EPA's concurrence that the event was exceptional and for the exclusion from the Air Quality System (AQS) database of the Big Piney and Boulder 1-hour average ozone data for the following times:

Table 1. Big Piney and Boulder times and dates for AQS data exclusion.

Site	Begin Time/Date(s)	End Time/Date(s)
Big Piney	0900 MST June 14, 2012	1900 MST June 14, 2012
Boulder	0900 MST June 14, 2012	2100 MST June 14, 2012

BACKGROUND

Document Format

The following discussion provides background information on SI's as well the methodology utilized in identifying SI's. Subsequently, the June 14, 2012 event is presented with evidence supporting the premise that an SI occurred creating a period of elevated 1-hour average ozone values resulting in ozone standard exceedances at the Boulder and Big Piney ozone monitors. The reader is encouraged to examine Appendix A, "Documented Stratospheric Intrusion Events" and Appendix B, "Diagnosis Example" to obtain further information on SI's.

Ground Level Ozone Formation

"Ozone (O_3) is a gas composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground level is created by a chemical reaction between oxides of nitrogen (NOx) [including nitrogen dioxide (NO_2)] and volatile organic compounds (VOCs) in the presence of sunlight. Ozone has the same chemical structure whether it occurs miles above the earth or at ground level and can be "good" or "bad," depending on its location in the atmosphere." (Source: EPA website). Specifically, NO_2 is split up by ultraviolet (UV) sunlight to give nitric oxide (NO) and an oxygen atom, which combines with molecular oxygen (O_2) to give ozone. Calm winds, or stagnant conditions assist the process of allowing the O_3 precursors of NO_x (NO_2) and VOCs to accumulate in order to produce O_3. Unlike ozone of stratospheric origin, ground-based ozone typically forms during the daylight hours under stagnant weather conditions (over several days in some cases) and dissipates a few hours after sunset.

Atmospheric Structure

The troposphere is the layer of air adjacent to the earth's surface and contains our weather (i.e. wind, rain, snow, thunderstorms, etc.) The troposphere also contains variable amounts of water vapor and carbon monoxide (CO), extends to a height of roughly 11 km (6.8 mi) Above Mean Sea-level (AMSL), and varies in depth from the earth's polar regions to the equator. Directly above the troposphere, the stratosphere exists with the tropopause separating the stratosphere from the troposphere. The tropopause is "...usually characterized by an abrupt change of lapse rate[1]" (American Meteorological Society 2010).

The stratosphere is the "...region of the atmosphere extending from the top of the troposphere [the tropopause], at heights of roughly 10–17 km...[and] is characterized by constant or increasing temperatures with increasing height and marked vertical stability" (American Meteorological Society 2010).

Composition of Stratospheric Air

"While the major constituents of the stratosphere are molecular nitrogen and oxygen, just as in the troposphere, the stratosphere contains a number of minor chemical species that result from photochemical reactions in the intense ultraviolet radiation environment. Chief among these is ozone..." (American Meteorological Society 2010). While the troposphere contains variable amounts of O_3, CO, and water vapor, the stratosphere lacks CO and water vapor (Pan, Randel, et

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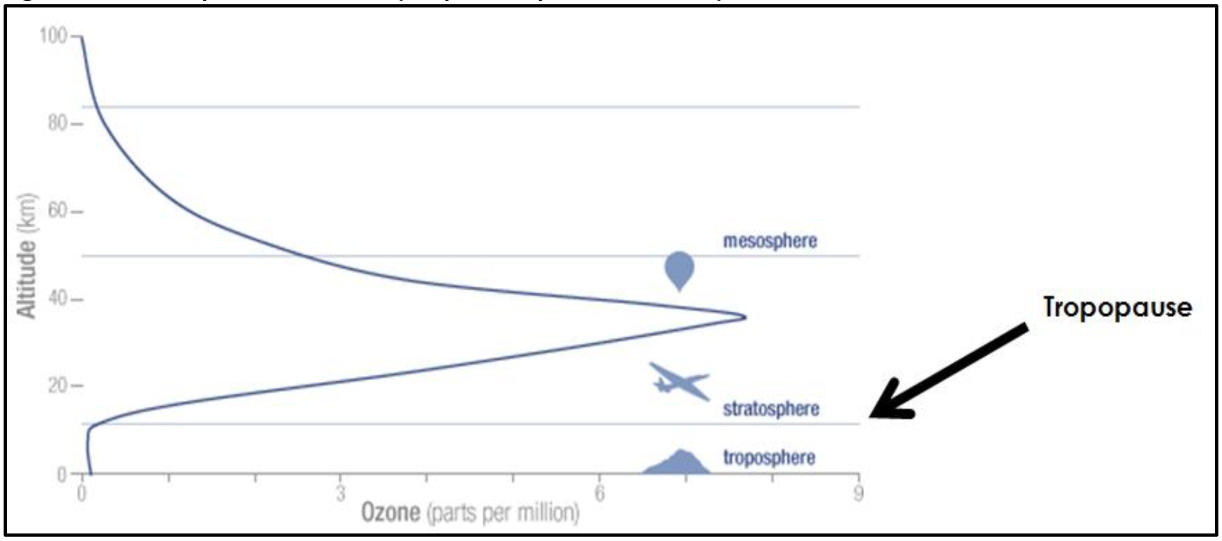
[1] Lapse rate is defined as the change of temperature with the increase of height in the atmosphere.

al. 2004; Newell, et al. 1999; Stoller, et al. 1999). Figure 3 demonstrates the typical concentration of ozone with height extending from the earth's surface through the stratosphere.

Figure 3. Vertical profile of ozone. (Graphic adapted from NASA).



Stratospheric Intrusions, Tropospheric Folding, and Identifying Stratospheric Air

Weather producing systems (i.e. tropospheric storm systems, upper level disturbances or upper level storm systems) contain atmospheric spin or vorticity, which induces vertical motion: either upward or downward motion. From late winter to late spring in the northern hemisphere, vertical motion associated with upper level disturbances aids in causing the tropopause to "fold" or descend into the troposphere where our weather occurs (Danielsen 1968). Because of tropopause folding, an intrusion of stratospheric air containing high concentrations of ozone penetrates into the troposphere (Reed 1955) releasing ozone-rich air from the stratosphere to the troposphere. As a result, the SI creates the potential for ground level ozone monitors over the higher terrain of the western United States to experience elevated ozone readings.

SI's are a tangible phenomenon. One study (Click to view press release regarding study) analyzed over 105,000 aircraft soundings, and discovered that just over 50% of the soundings contained regions of high ozone and low water vapor content occurring below the tropopause (Newell, et al. 1999). The presence of areas of high ozone concentrations and low water vapor located below the tropopause are components of an SI signature.

While the concentrations of O_3, CO, and relative humidity (RH) aid one in identifying air of stratospheric origin, additional stratospheric tracers[2] should be employed and include: isentropic potential vorticity (IPV) and potential temperature (PT). IPV is a proxy for atmospheric spin and is a conservative property[3] with values of up to two orders of magnitude [100 times] greater for stratospheric air than that of tropospheric air (Shapiro 1980). Therefore, IPV can serve as a

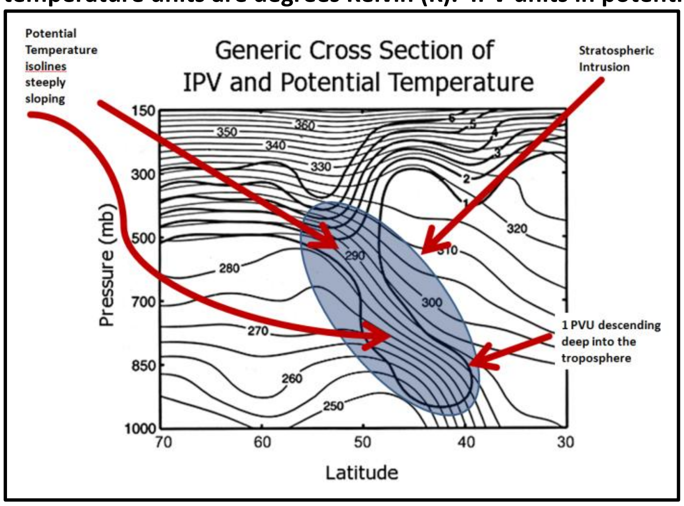
[2] "A chemical or thermodynamic property of the flow that is conserved during" air motion (American Meteorological Society 2010).

[3] "A property with values that do not change in the course of a particular series of events" (American Meteorological Society 2010). Namely, a property whose values do not change over the course of travel.

tracer of stratospheric air. One unit of IPV (1-PVU)[4] typically represents the tropopause (Shapiro 1980), and as one ascends beyond the tropopause into the stratosphere, the value of IPV increases correspondingly. However, within the last decade a study by Pan revealed that using only IPV to define the tropopause is problematic. In fact, the thermal tropopause height "...spans a broad range of..." IPV values and varies latitudinally and seasonally (Pan 2004). Therefore, based on the AQD's review of the background material regarding IPV usage, the AQD recognizes that one cannot use IPV alone in identifying air of stratospheric origin.

Potential temperature is "the temperature that an unsaturated parcel of dry air would have if brought adiabatically[5] and reversibly from its initial state to a standard pressure, p0, typically 100 kPa" (or 1000 mb) (American Meteorological Society 2010). Stratospheric air has much higher values of potential temperature than that of tropospheric air. As stratospheric air penetrates the troposphere, its potential temperature is higher than that of tropospheric air surrounding the SI. One can visualize this effect by cross-section examination of IPV and PT. The slope of isolines[6] of potential temperature increase markedly showing this effect (Reed 1955). Figure 4 shows a generic vertical cross-section of IPV and PT. Note the area of sloping isolines of PT and the 1-PVU surface juxtaposed on one another. The slope of the isolines of PT increases significantly highlighting the signature of stratospheric air descending into the troposphere.

Figure 4. Vertical cross-section of potential temperature (thin solid lines) and IPV (thick solid lines). Potential temperature units are degrees Kelvin (K). IPV units in potential vorticity units. Click image to enlarge.



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[4] IPV and PVU are utilized throughout this document and are synonymous. For further information, please consult: http://www.comet.ucar.edu/class/aes_canada/04-1/html/docs/PVintro.pdf

[5] "Adiabatic process—A process in which a system does not interact with its surroundings by virtue of a temperature difference between them. In an adiabatic process, any change in internal energy (for a system of fixed mass) is solely a consequence of working. For an ideal gas and for most atmospheric systems, compression results in warming, expansion results in cooling" (American Meteorological Society 2010). Compression and expansion arise from downward atmospheric vertical motion and atmospheric upward vertical motion respectively.

[6] "... a line of equal or constant value of a given quantity, with respect to either space or time…" (American Meteorological Society 2010)

Background Summary

The stratosphere contains high concentrations of ozone compared to the troposphere. At times, from late winter until late spring in the northern hemisphere, tropospheric storm systems act synergistically with tropopause folds to inject stratospheric ozone into the troposphere via an SI. Compared to tropospheric air, stratospheric air is typically much drier, has higher values of IPV and PT, and contains lower quantities of CO.

Data from research aircraft have determined that tropopause folds (SI's) contain ample O_3, dry air, and low concentrations of CO. Mathematical calculations based on the aircraft data also verify that the SI's had greater than 1-PVU and had higher PT values compared to those of the troposphere surrounding the SI.[7]

[7] The reader is encouraged to examine Appendix A, "Documented Stratospheric Intrusion Events" and Appendix B, "Diagnosis Example" to obtain further information on SI's.

METHODOLOGY FOR DIAGNOSING SI'S AND SI EVENTS

Since the majority of SI's occur from the late winter to late spring (Danielsen 1968), elevated ozone episodes occurring during this time merit further analysis. The AQD recognizes that a combination of indicators should be employed when diagnosing an SI. One should not rely on any single indicator alone. The following offers a methodology to diagnose whether an SI has occurred:

- Summary of the synoptic scale meteorology

  An examination of the 500 mb heights and vorticity chart may indicate an SI if an upper level atmospheric disturbance occurred at some point before ground level ozone values increased. By inspecting the 500 mb pressure chart by way of the North America Regional Reanalysis (NARR)[8], one can establish whether an upper atmospheric disturbance took place.

- Employ Geostationary Operational Environmental Satellite (GOES) data

  "GOES satellites provide the kind of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which means they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to hover continuously over one position above the Earth's surface. The geosynchronous plane is about 35,800 km (22,300 miles) above the Earth, high enough to allow the satellites a full-disc view of the Earth....the main mission [of GOES satellites] is carried out by the primary instruments, the imager and the sounder. The imager is a multichannel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution." (Source: NOAA Satellite and Information Service, National Environmental Satellite, Data, and Information Service, Office of Satellite Operations website).

  Recent studies and research have shown that usage of GOES data is a useful tool in diagnosing SI's (Jin, et al. 2008). One can use the GOES total column ozone [9]data in

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[8] "The North America Regional Reanalysis (NARR) Project is a reanalysis of historical observations using a 32-km version of the National Centers for Environmental Prediction (NCEP) 1993 operational ETA model and ETA data assimilation system (EDAS)....The domain of analyses includes North and Central America...The period of the reanalyses is from October 1978 to the present and analyses were made 8 times daily (3 hour intervals). Horizontal boundary conditions are derived from the NCEP/DOE Global Reanalysis." For further information, please refer to visit this website: http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html

[9] Total column ozone (TCO) is estimated every hour using GOES Sounder data. The ozone retrieval is generated by application of a regression technique as described in Li et al 2007. Estimates are currently limited to cloud-free regions of the GOES-E (12) & -W (11) Sounder sectors. Each image is a Derived Product Image (DPI), wherein an 8-bit brightness value representing TCO is assigned within the retrieval program for each cloud-free Field-of-View (FOV). Band-8 (11.0um) is used for the DPI image background. Total column ozone is measured in Dobson Units (100 DU = 1 mm of thickness at Standard Temperature and Pressure (STP)). Features such as upper level low-pressure systems and frontal boundaries can often be identified in the TCO imagery. (Source: Data Center at the Space Science and Engineering Center (SSEC) of the University of Wisconsin – Madison)

Dobson Units (DU)[10] to locate areas of increased column ozone (Wimmers, et al. 2003; Knox and Schmidt 2005). Numerous studies have shown a positive correlation between an SI and an increase in the total column ozone. As the SI injects ozone into the troposphere, total column ozone increases (Reed 1950; Schubert and Munteanu 1988; Mote, Holton and Wallace 1991).

The GOES Band-12 channel is a water vapor channel that portrays the moisture content of the layer approximating 300-400 mb (Wimmers, et al. 2003). Use of the water vapor image helps highlight an area of substantially drier air originating from aloft mixing down to lower levels of the troposphere. Since SI's contain dry air and transverse through the 300-400 mb tropospheric layer, one can use the 6.5-micrometer GOES Band-12 water vapor channel to diagnose the presence of an SI signature.

- Employ Radiosonde observations

Another way to diagnose the existence of stratospheric air is by examining Radiosonde observations (RAOB's). RAOB's are comprised of three elements: a radiosonde (an instrument that measures and transmits pressure, relative humidity, and temperature data to a ground receiver), a parachute, and a balloon. The balloon is released into the sky carrying the radiosonde and parachute. A layer of dry air is a key signature of stratospheric air (as measured by a radiosonde) and is depicted by an increase in temperature and a decrease in dew point (moisture) with height (Newell, et al. 1999; Stoller, et al. 1999).

When coupled with a radiosonde, an ozonesonde provides direct evidence of the vertical profile of ozone concentration. An ozonesonde contains an electrochemical concentration cell (ECC) that senses ozone as is reacts with a dilute solution of potassium iodide to produce a weak electrical current proportional to the ozone concentration (partial pressure) of the sampled air.

- Employ 4-D "0-hour" Rapid Refresh (RAP) data (IPV, RH, and PT)

The RAP is a numerical weather analysis tool utilized by meteorologists to predict weather conditions. The RAP is initialized with real-time data, and the 0-hour analysis for any given hour is a very close approximation to initial actual conditions (Benjamin, et al. 2004). RAP "analysis" data can be used to illustrate the signature of an SI (refer to Figure 4) by portraying IPV, RH, and PT (Murray 2003) via a vertical cross-section or a time-height cross-section of the atmosphere.

[10] The Dobson Unit is the most common unit for measuring ozone concentration. One Dobson Unit is the number of molecules of ozone that would be required to create a layer of pure ozone 0.01 millimeters thick at a temperature of 0 degrees Celsius and a pressure of 1 atmosphere (the air pressure at the surface of the Earth). Expressed another way, a column of air with an ozone concentration of 1 Dobson Unit would contain about 2.69x1016 ozone molecules for every square centimeter of area at the base of the column. Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 millimeters thick.

- Perform trajectory analysis

  A means of tracking the path of air parcels is by employing backward and forward trajectories to demonstrate the origins of "pockets" of high ozone due to SI's. One can use the HYSPLIT software package (Draxler and Rolph n.d.) to demonstrate not only the origin of air parcels but also evolution of air parcels as they move through the troposphere. By selecting a range of altitudes and times at a specific location, one can use HYSPLIT to analyze the path air parcels took prior to arriving at a selected point (backward trajectories). Conversely, one can employ the same analysis technique to determine the eventual fate of air parcels originating from a specific point (forward trajectories). In the case of SI's, trajectory analysis is used to show how "pockets" of air containing high ozone concentrations arrived at monitors which indicated elevated ozone levels (Sørensen and Nielsen 2001; Aulerio, et al. 2005).

SUMMARY OF DIAGNOSING SI EVENTS

To review, the key features of a SI event are:

- An upper level disturbance producing a tropospheric fold and subsequent SI.
  - Depicted in cross-sections or time-height cross-sections by sloping lines of PT, by 1-PVU or greater descending into the troposphere, and by an area of dry air.
- A well-mixed or even turbulent atmosphere resulting from an upper level disturbance and creating conditions for vertical movement of SI-air to the earth's surface.

Additionally, WDEQ/AQD is a member of a national EPA SI workgroup that was formed during 2012. The primary goal of the workgroup is to diagnose past SI events, including the June 13-14, 2012 event described in this document.

JUNE 14, 2012 EXCEPTIONAL EVENT

Summary

During June 13-14, 2012, an upper level atmospheric disturbance associated with an SI moved over central Idaho injecting ozone-rich air into the troposphere. The ozone-laden air then moved over western Wyoming creating elevated ozone readings resulting in 8-hour ozone standard exceedances of 76 and 77 ppb at the Boulder and Big Piney, Wyoming ozone monitors, respectively.

Additionally, the Yellowstone and Grand Teton National Park ozone monitors as well as the AQD ozone monitors at South Pass, Daniel, Pinedale, and Juel Spring measured elevated 1-hour average ozone values from the upper 60's to upper 70's ppb during the SI event (refer to Figure 5). (Note to reader: the Pinedale CASTNET site was not operational during June 2012 due to a prolonged power outage).

Furthermore, EPA's June 14, 2012 daily peak ozone air quality index (AQI) map illustrates the effects of the SI over Idaho and western Wyoming (Figure 6). Central/southern Idaho and western Wyoming were either in the "moderate" category (yellow shade) or "unhealthy for sensitive groups" category (orange shade).

It has been documented (T. S. ENVIRON 2008) that elevated ozone values can occur at the UGRB ozone monitors of Boulder, Big Piney, Pinedale, Daniel, and Juel Spring because of light winds, snow cover, and strong inversions during the January-March winter ozone season. However, during the June 14, 2012 period of elevated ozone, strong winds buffeted the UGRB prior to the SI event, and no snow cover or strong inversions were present. Accumulation of surface-based ozone precursors did not occur because meteorological conditions were not supportive of precursor buildup prior to elevated ozone readings.

For the month of June from 2000 to 2012, Wyoming ground level, 1-hour average ozone levels at all ozone monitors ranged from 34-52 ppb (25-75% interquartile range) with a mean of 42.6 ppb. However, when an SI occurs, 8-hour average values [derived from the 1-hour average] can exceed 80 ppb on a time scale of a few hours to a few days (Mohnen and Reiter 1977). While not exceeding 80 ppb, 8-hour average ozone greater than 75 ppb occurred for three consecutive hours at Boulder and Big Piney on June 14, 2012. At 4 pm MST on June 14, 2012, the Boulder ozone monitor recorded the highest 1-hour average ozone value of 80 ppb resulting in a daily maximum rolling 8-hour average of 76 ppb. Furthermore, the Big Piney ozone monitor recorded the highest 1-hour average ozone value of 83 ppb at 3 and 4 pm MST, June 14, 2012 resulting in a daily maximum rolling 8-hour average of 77 ppb.

Public Notification and EPA's Air Quality System Data

WDEQ/AQD's Wyoming Visibility Monitoring Network (WyVisNet) website provided near real-time pollutant and meteorological data from Boulder and Big Piney and was operational during the June 14, 2012 elevated ozone event. Citizens of Wyoming have continuous access to WyVisNet via the internet, which serves as a means of public information dissemination regarding elevated ozone readings. Additionally, Boulder and Big Piney ozone data are reported to the EPA's AIRNow website.

The public also has access to EPA's Air Quality System (AQS) database that houses validated data from the AQD's monitoring stations. Figure 5 shows a time-series of 1-hour average ozone values from AQS for the period from June 13-16, 2012.

Figure 5. Time series of 1-hour average ozone (ppb) for Wyoming monitors from June 13-16, 2012.

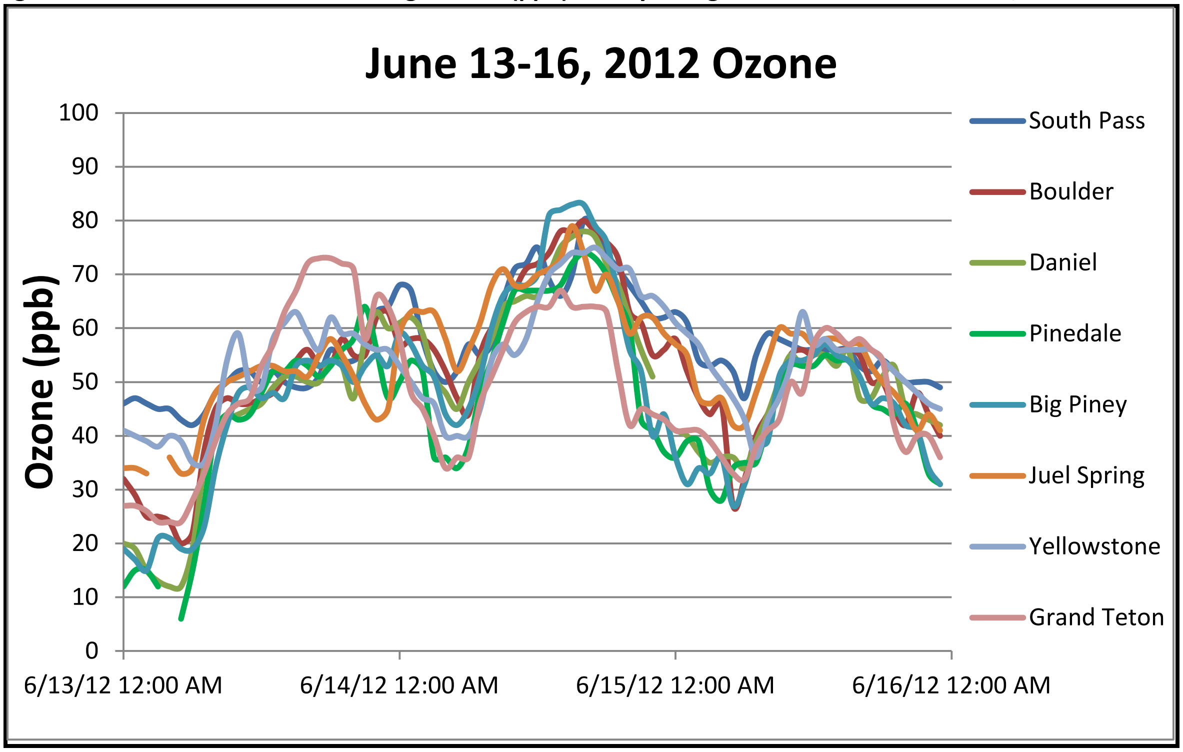
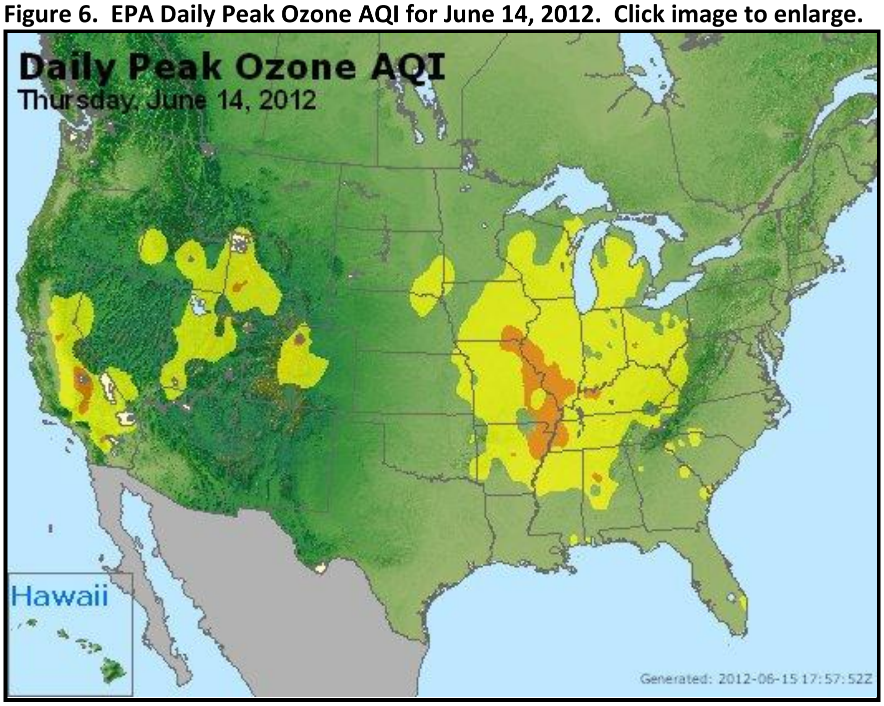


Figure 6. EPA Daily Peak Ozone AQI for June 14, 2012. Click image to enlarge.



Data QA/QC and Equipment

Quality Assurance/Quality Control procedures were followed in accordance with 40 CFR Part 58, Appendix A, Section 3.2 *Measurement Quality Checks of Automated Methods* and the *Quality Assurance Project Plan* for the Boulder and Big Piney monitoring projects.

During second and fourth quarters of 2012, Technical & Business Systems, Inc.[11] conducted independent performance audits of the ozone analyzers at Boulder and Big Piney (refer to Table 2). All tests met WDEQ/AQD specified data quality objectives, which are consistent with QA Handbook Vol II, Section 3.0, Revision No: 1.

Table 2. 2nd and 4th quarter audit statistics for 2012 for Big Piney and Boulder.

2012	**Big Piney Ozone Audit Results**			
	Slope	**Correlation**	**Y-Intercept**	**Audit Point % Difference**
April 19	0.969	0.9999	0.000	**Point 2=0.0%** **Point 3=-2.5%** **Point 4=-3.3%**
November 11	0.988	1.0000	-0.001	**Point 2=-2.7%** **Point 3=-2.4%** **Point 4=-1.6%**
2012	**Boulder Ozone Audit Results**			
	Slope	**Correlation**	**Y-Intercept**	**Audit Point % Difference**
April 17	0.950	1.0000	0.000	**Point 2=-2.9%** **Point 3=-4.9%** **Point 4=-4.9%**
November 15	0.980	1.0000	-0.001	**Point 2=-5.3%** **Point 3=-3.6%** **Point 4=-2.2%**

Statistical Analysis

A basic method for portraying the statistical significance of the June 14, 2012 elevated ozone event is via a histogram. A histogram shows the frequency of occurrence of individual values, and often it takes the shape of a "Bell Curve" or "normal distribution". Figures 7 and 8 show the 1-hour average and daily maximum 8-hour ozone for the Boulder and Big Piney ozone monitors for each June from 2005-2012 (Boulder) and from 2011-2012 (Big Piney), respectively. Note that the bell curve is elongated to the right where the June 14, 2012 Boulder and Big Piney elevated ozone concentrations reside. The daily 8-hour maximum ozone histograms clearly show that the June 14, 2012 data points represent data of statistical significance.

[11] Please refer to Appendix H for the 2nd and 4th Quarter 2012 QA Audit Reports.

Figure 7. Histograms of Junes 2005-2012 for Boulder. Click images to enlarge.

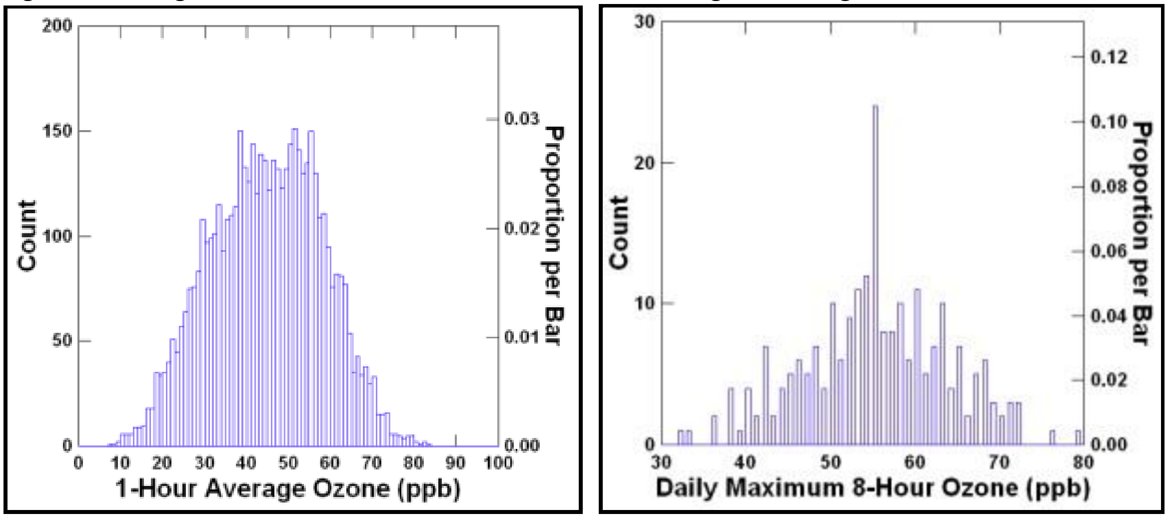
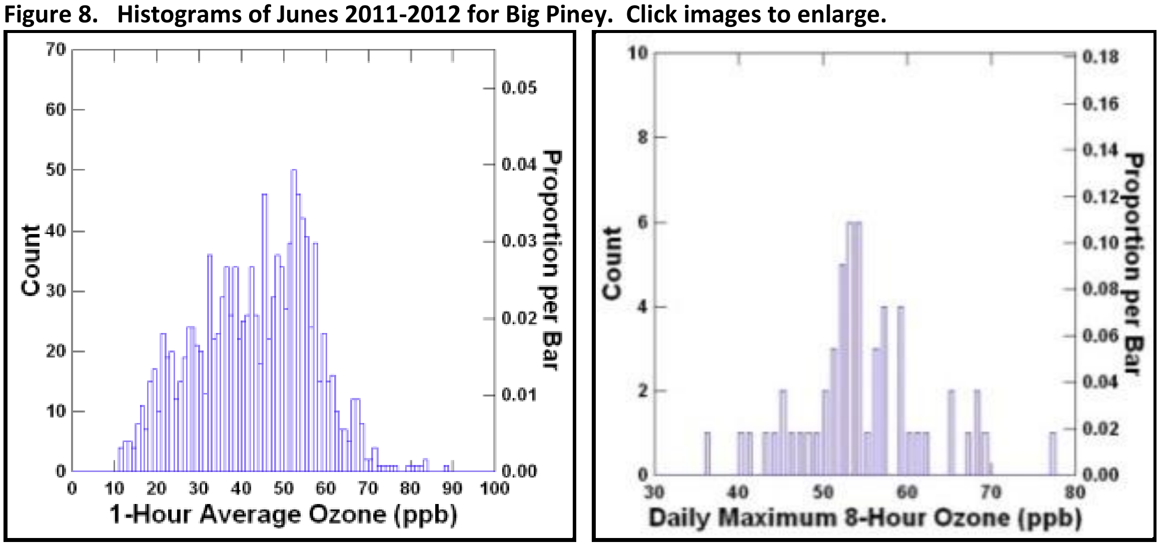


Figure 8. Histograms of Junes 2011-2012 for Big Piney. Click images to enlarge.



An additional statistical measure of the significance of the June 14, 2012 Boulder and Big Piney elevated ozone event is by means of a simple t-test[12] between two means. A high t-test score and very low p-value[13], shown in Table 3, indicate that the June 14, 2012 event was statistically significantly higher when compared to ozone values observed during Junes of other years.

If one analyzes the June 14, 2012 event from a cumulative percentage perspective, the Big Piney and Boulder daily maximum 8-hour average ozone values of 77 and 76 reside in the greater than 99th percentile for June 2005-2012 (Boulder) and 2011-2012 (Big Piney) (refer to Table 4).

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[12] For further information on t-tests, please consult: http://www.statsoft.com/textbook/basic-statistics/#t-test for independent samples. Note to reader: the WDEQ does not endorse any private business or its products. The aforementioned site is for informational purposes only.

[13] For further information on p-values, please consult: http://www.statsoft.com/textbook/elementary-concepts-in-statistics/#What is "statistical significance" (p-level). Note to reader: the WDEQ does not endorse any private business or its products. The aforementioned site is for informational purposes only.

Table 3. Boulder and Big Piney t-test and p-value statistics for 1-hour average ozone for Junes of 2005-2012 and 2011-2012, respectively.

Dates	Statistic		
	Number of Samples	Arithmetic Mean	Standard Deviation
June 2005-2012	5,181	44.30	13.30
Boulder June 14, 2012	9	75.56	3.17
	t-test=29.61		p-value=0.0000
Dates	**Statistic**		
	Number of Samples	**Arithmetic Mean**	**Standard Deviation**
June 2011-2012	1,272	42.43	13.90
Big Piney June 14, 2012	7	79.14	4.74
	t-test=20.49		p-value=0.0000

Table 4. Big Piney and Boulder 99th and greater percentile for June 14, 2012 event.

Site	Daily 8-Hour Maximum Ozone	Count	Cumulative Percent
Big Piney	77	1	100.0000
Boulder	76	1	99.2958

A final means of displaying the June 14, 2012 Boulder and Big Piney elevated ozone values as being statistically significantly higher is by a "box-and-whisker" plot. Figure 9 shows how to interpret a "box-and-whisker" plot. Figures 10 and 11 show that the June 14, 2012 Boulder and Big Piney 1-hour average and daily maximum 8-hour ozone concentrations are greater than the 75th percentile concentration value, approaching the "data outlier" range when compared to all June data from Boulder (2005-2012) and Big Piney (2011-2012). The daily maximum 8-hour ozone data for Boulder and Big Piney are statistical data "outliers" and are statistically significantly higher than the rest of the data.

Figure 9. Description of how to interpret a Box-and-Whiskers plot (Image courtesy Sonoma Technology, Inc.). Click image to enlarge.

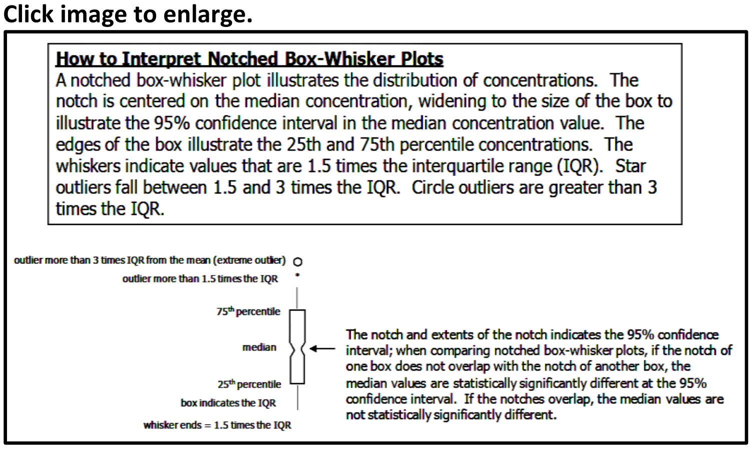


Figure 10. Box-and-whiskers plot of Junes 2005-2012 for Boulder. Click images to enlarge.

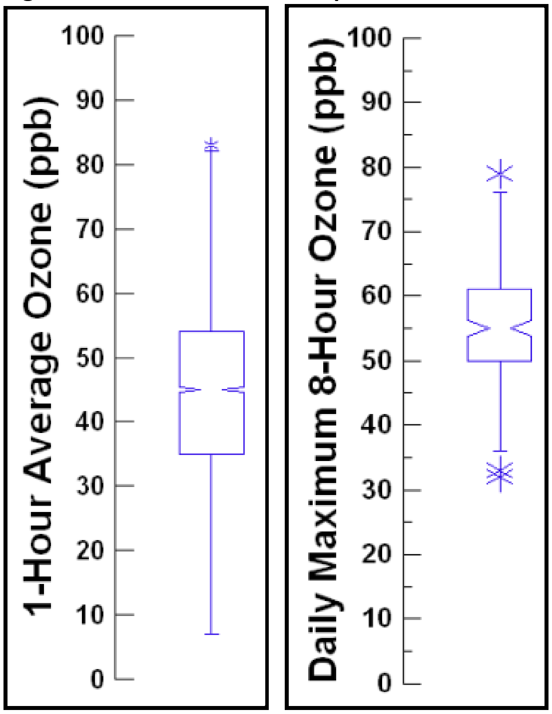
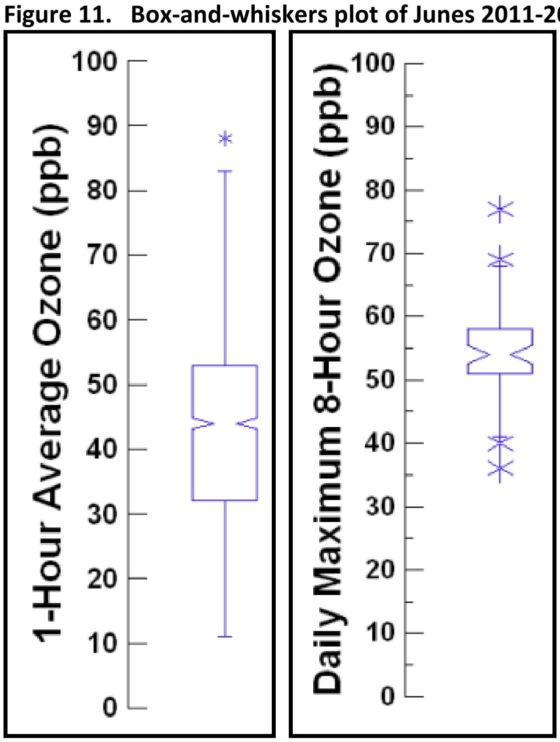


Figure 11. Box-and-whiskers plot of Junes 2011-2012 for Big Piney. Click images to enlarge.



Supporting Meteorological Data: Weather Overview

The NARR depicts[14] a vigorous upper level disturbance over Washington at 8 am MST June 13, 2012 (refer to Figure 12). Throughout June 13, 2012, the disturbance moved east and arrived at central Idaho at 5 pm on June 13, 2012 (refer to Figure 13). By 2 am MST June 14, 2012, the upper level disturbance was over the Wyoming-Montana border (refer to Figure 14).

Figure 12. North America Reanalysis valid at 8 am MST, June 13, 2012. Click image to enlarge. Click here for a time animation from 11 pm MST June 12 to 5 pm MST June 14, 2012. Graphic courtesy Fred Gadomski and the Penn State University Department of Meteorology.

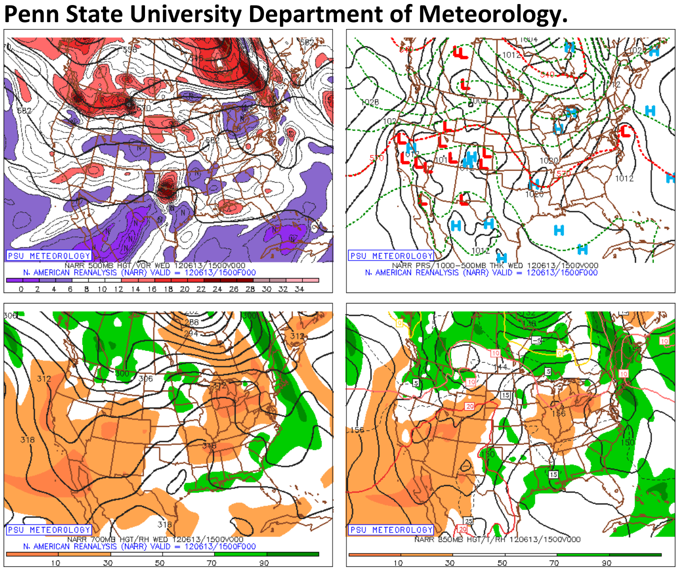
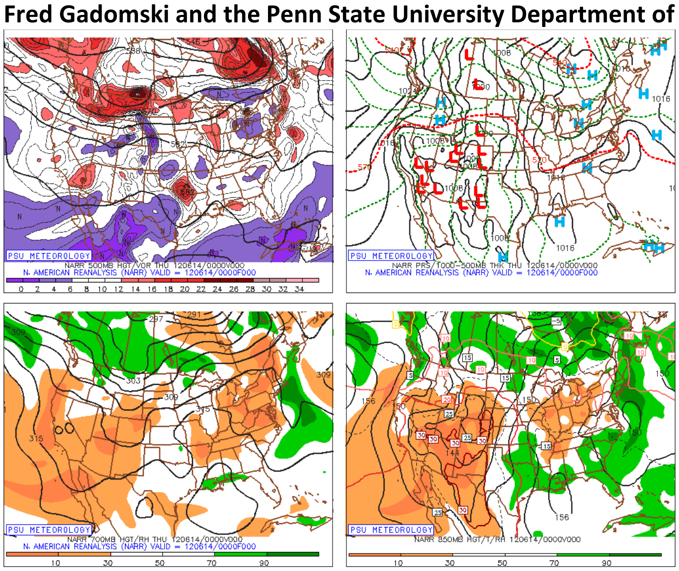
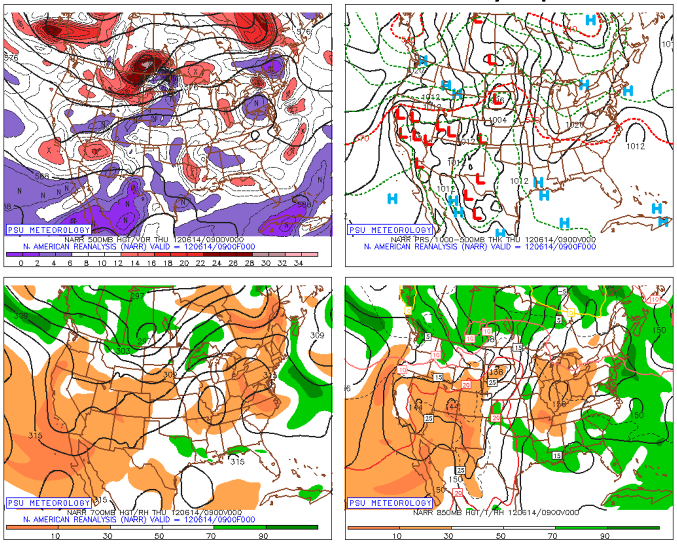


Figure 13. North America Reanalysis valid at 5 pm MST, June 13, 2012. Click image to enlarge. Graphic courtesy Fred Gadomski and the Penn State University Department of Meteorology.



[14] Please refer to Appendix C to learn how to interpret the NARR.

Figure 14. North America Reanalysis valid at 2 am MST, June 14, 2012. Click image to enlarge. Graphic courtesy Fred Gadomski and the Penn State University Department of Meteorology.



Supporting Meteorological Data: GOES Total Column Ozone Data

Because of the upper air disturbance and associated SI, an enhanced green area (increased Dobson values) can be seen in the hourly GOES total column ozone data over Washington at 11 pm MST June 12, 2012 (refer to Figure 15). Figure 16 shows a dark-green area over north central Idaho with lighter shades of green over central Idaho extending southward to northeast Nevada at 10 am MST June 13, 2012. The enhanced green areas were associated with the upper level storm system and higher Dobson values, providing additional evidence of an SI event that affected Wyoming. (Note to reader: GOES Band-12 data was unavailable during this time).

Figure 15. GOES Total Column Ozone (DU) for 11 pm MST June 12, 2012. Click to image to enlarge. Click here for a time animation from 5 am MST June 13 to 11 am MST June 14, 2012. Image courtesy of the Data Center at the Space Science and Engineering Center (SSEC) of the University of Wisconsin – Madison.

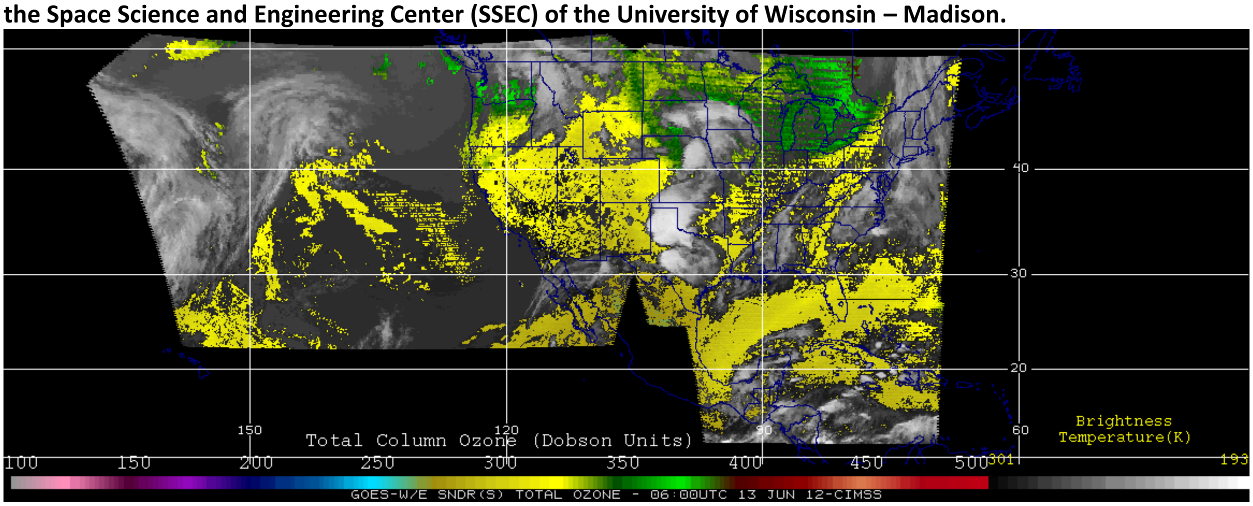
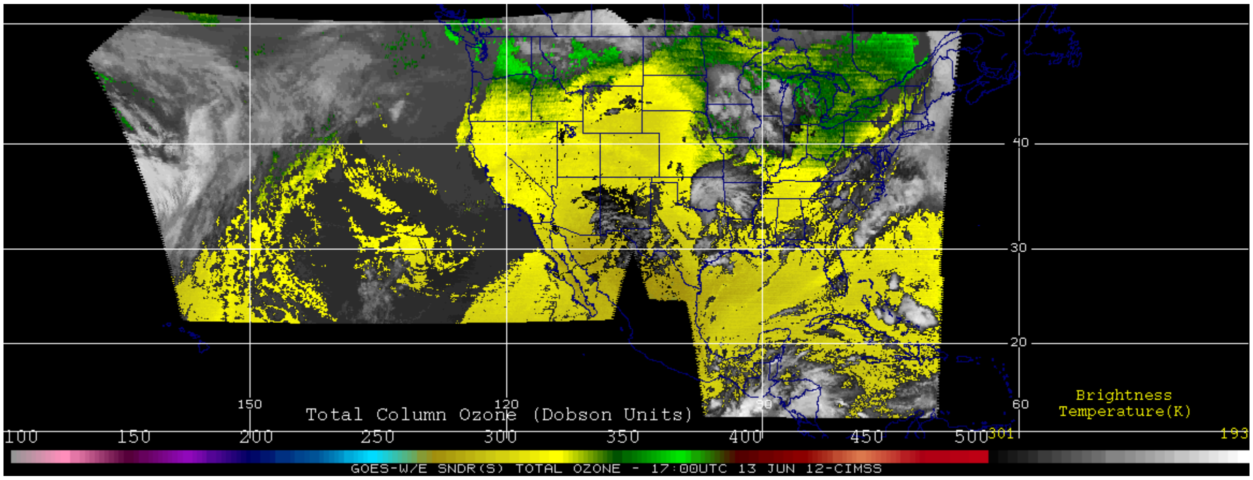


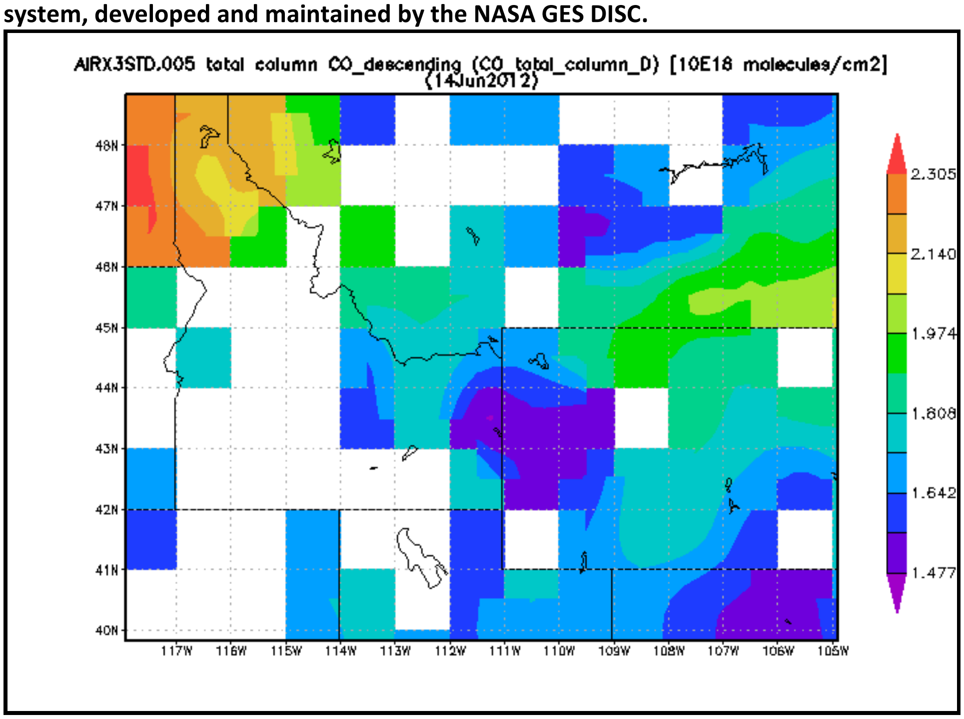
Figure 16. GOES Total Column Ozone (DU) for 10 am MST June 13, 2012. Click to image to enlarge. Image courtesy of the Data Center at the Space Science and Engineering Center (SSEC) of the University of Wisconsin – Madison.



Supporting Meteorological Data: AIRS Satellite Measurements of Carbon Monoxide

As mentioned in the introduction of this package, stratosperhic air contains little CO (Pan, Randel, et al. 2004; Newell, et al. 1999; Stoller, et al. 1999). AIRS[15] satellite measurements of total column CO and CO at 618 mb (approximate level of the SI) show lower CO concentrations over western Wyoming on June 14, 2012 (refer to Figures 17-18, respectively). The realtively lower concentration of CO over western Wyoming is another piece of evidence of an SI event having affected western Wyoming.

Figure 17. AIRS satellite derived total column CO for June 14, 2012. Figure courtesy the Giovanni online data system, developed and maintained by the NASA GES DISC.



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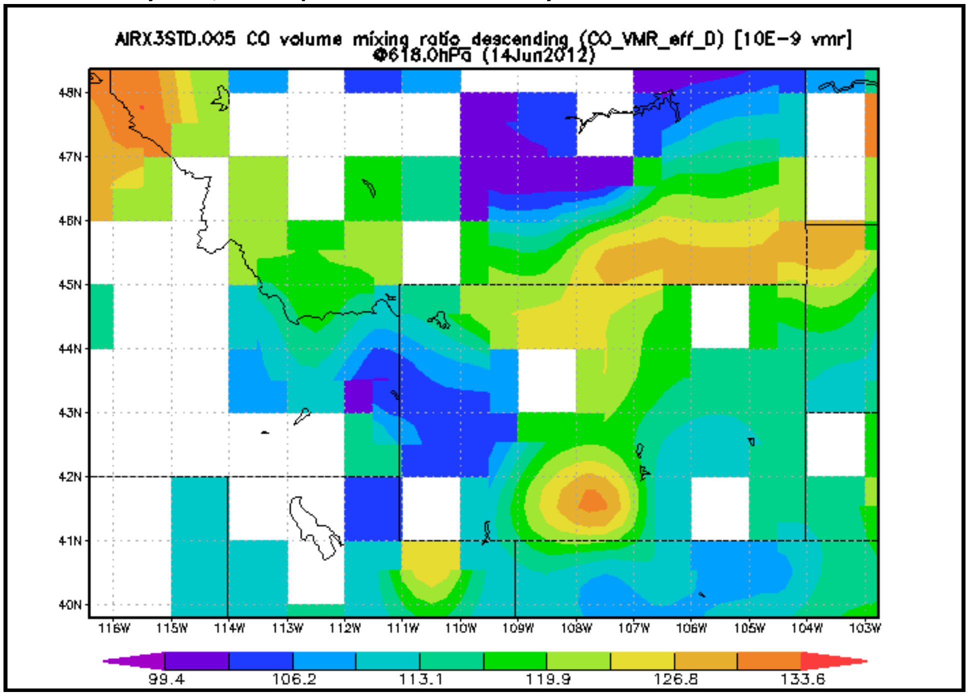
[15] For more information on AIRS satellite data, please visit this website: http://airs.jpl.nasa.gov/.

Figure 18. AIRS satellite derived CO at 618 mb (descending pass) for June 14, 2012. Figure courtesy the Giovanni online data system, developed and maintained by the NASA GES DISC.



Supporting Meteorological Data: Isentropic Potential Vorticity, Relative Humidity, and Potential Temperature Vertical Cross-Sections

Stratospheric air can be "tagged" by identifying areas characterized by approximately greater than or equal to 1-PVU, dry air, and tightly packed (and sloping) isolines of PT. Using the 20-km RAP model 0-hour analyses, a descending SI can be illustrated by examining atmospheric vertical cross-sections over a time range. One can visualize an SI approaching the earth's surface by observing the temporal and vertical evolution of the greater than 1-PVU isoline, dry air, and the pattern of PT isolines superimposed on a cross-section of the earth's terrain.

Figure 19 shows the line used to create a north-south cross-section over Idaho. As the upper level system moved over Idaho during the day, an SI descended (as shown by the descending red isoline of greater than 1-PVU, less than 15% RH area, and sloping PT isolines) over central Idaho as depicted by Figures 20-22. Note that less than 15% relative humidity air and tightly packed isolines of PT coincide with the descending 1-PVU red isoline throughout June 13, 2012. The 1-PVU isoline descended to between 3200 and 3800 mean sea level (msl) (refer to bottom graphic of Figure 22). These cross-sections provide further evidence of an SI having occurred over central Idaho during June 13, 2012.

Figure 19. Map view of terrain, IPV, RH, and PT cross-section.

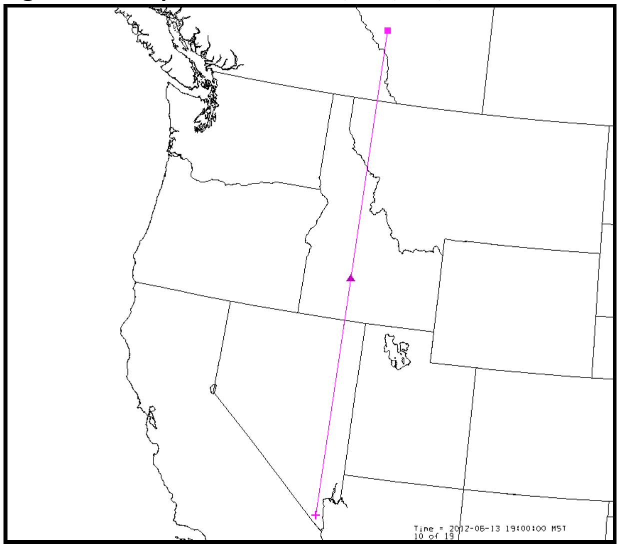


Figure 20. RAP 20-km, 0-hour analysis showing south-to-north cross-section (left-to-right) terrain (solid dark line), IPV (colored contours starting at 1-PVU), RH (shaded areas depicting RH values less than 15%), and PT (thin black contours) cross-section valid at 9 am MST, June 13, 2012. Click image to enlarge. Click here for a time animation from 5 am MST June 13 to 11 am MST June 14, 2012. Data below terrain not real.

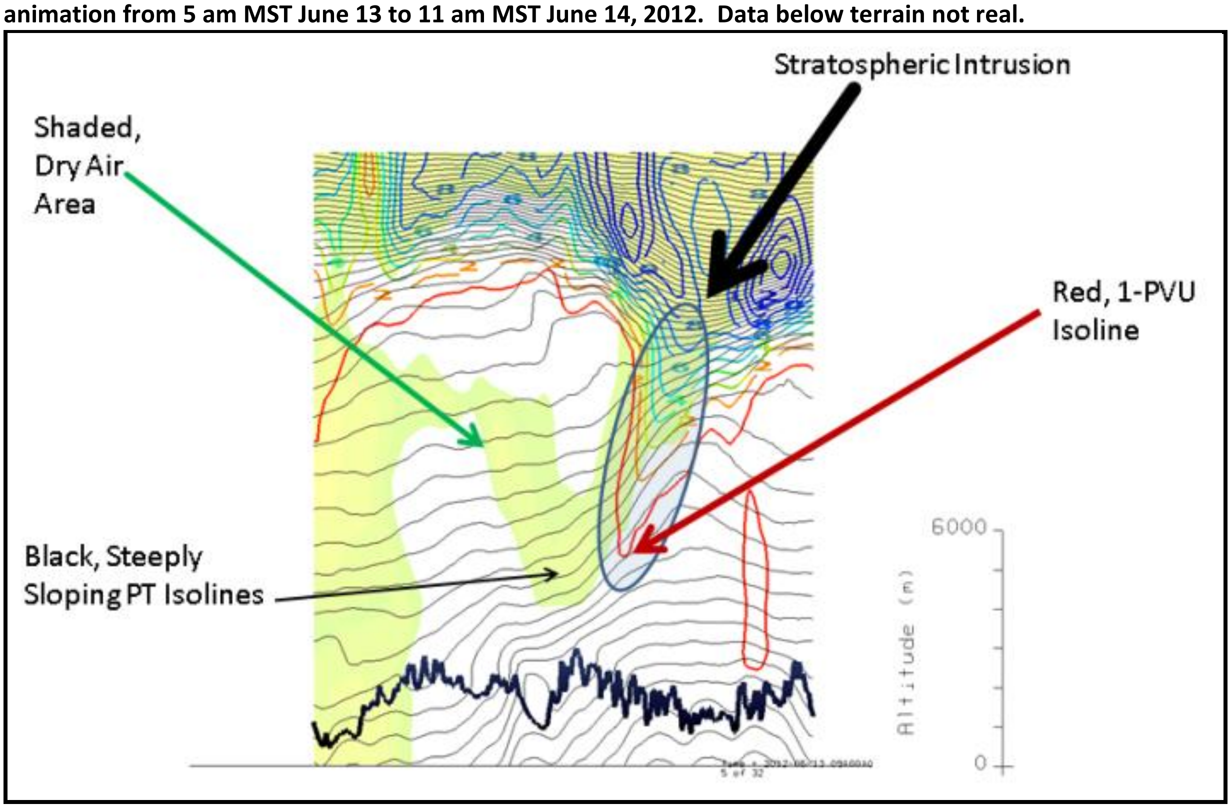


Figure 21. RAP 20-km, 0-hour analysis showing south-to-north cross-section (left-to-right) terrain (solid dark line), IPV (colored contours starting at 1-PVU), RH (shaded areas depicting RH values less than 15%), and PT (thin black contours) cross-section valid at 5 pm MST, June 13, 2012. Click image to enlarge. Data below terrain not real.

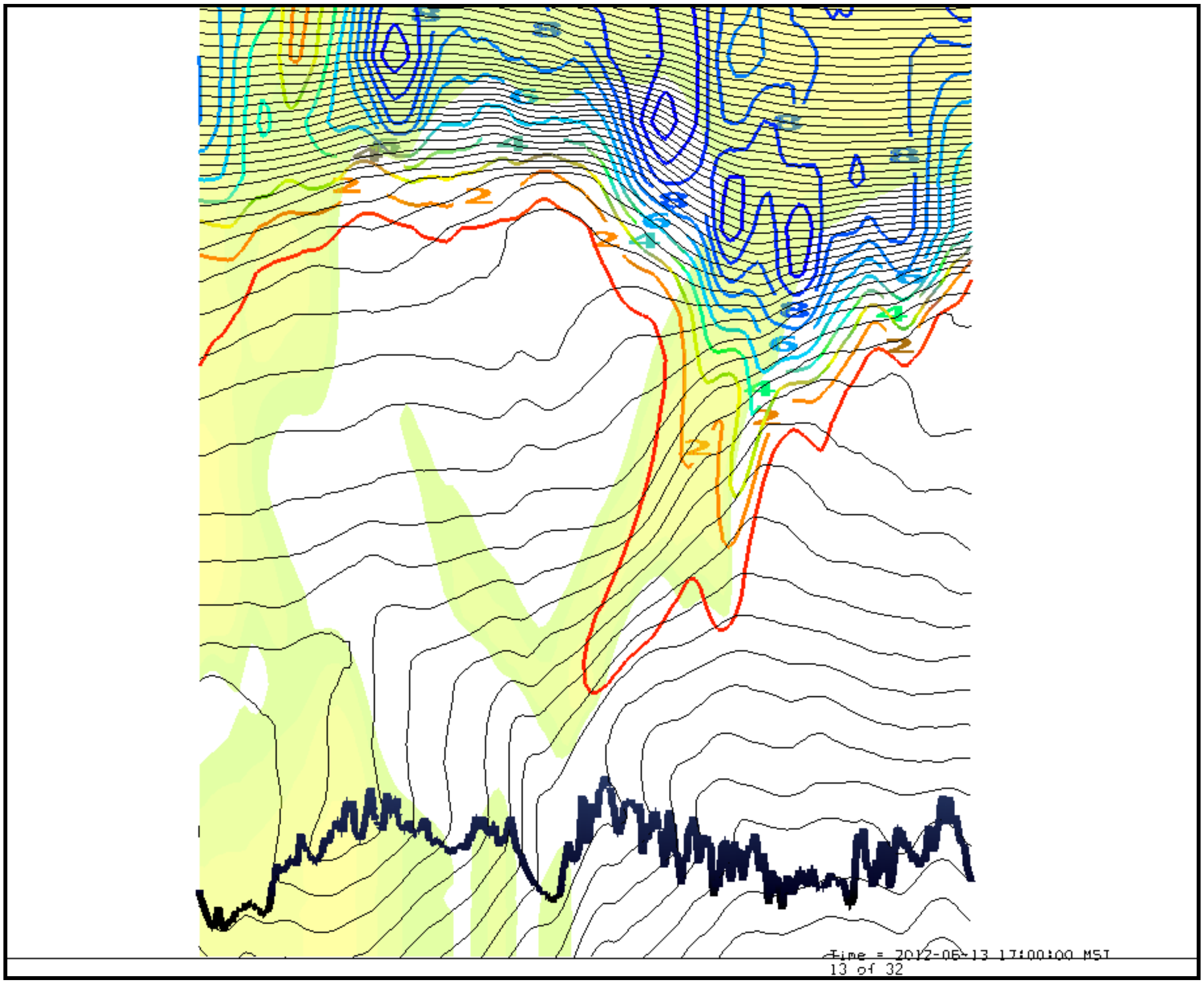
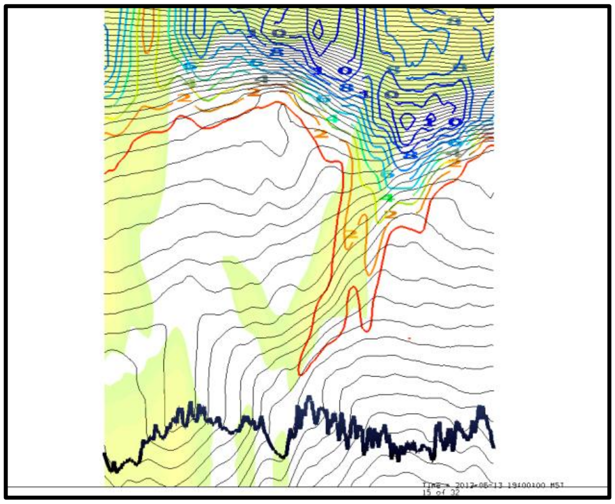
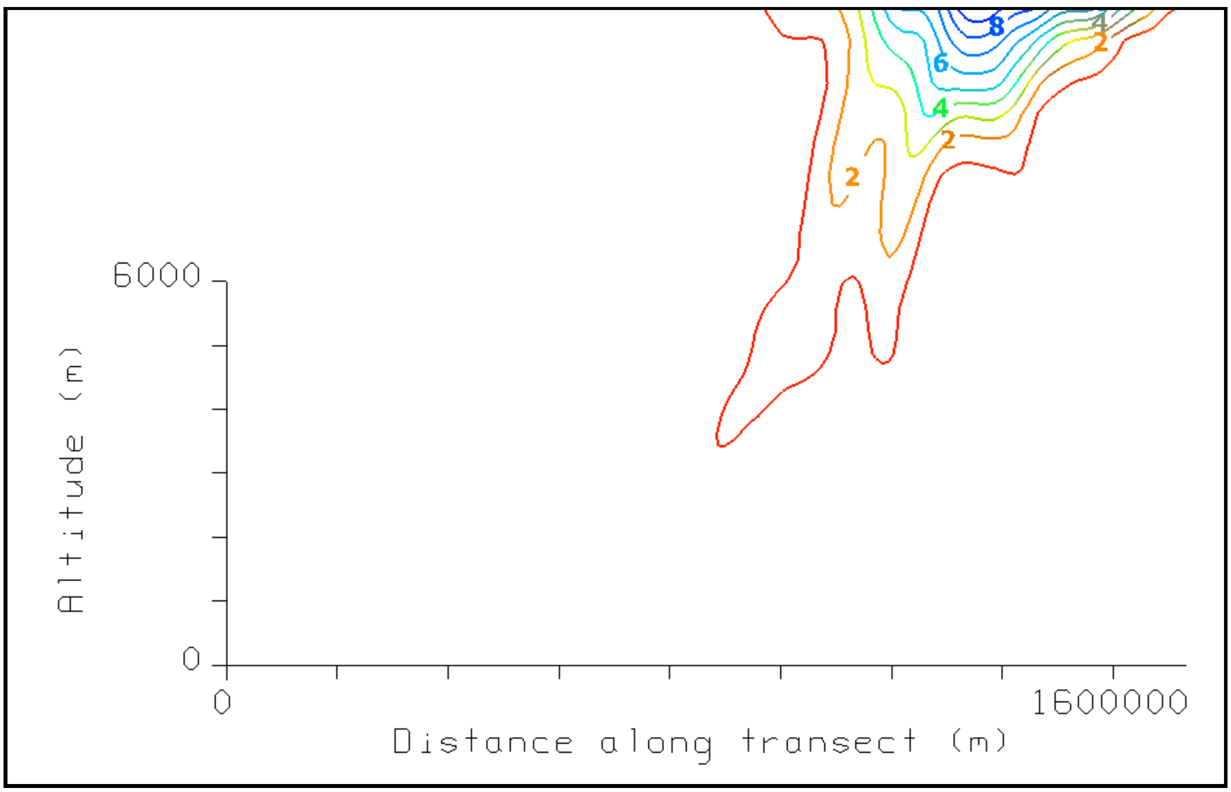


Figure 22. Top: RAP 20-km, 0-hour analysis showing south-to-north cross-section (left-to-right) terrain (solid dark line), IPV (colored contours starting at 1-PVU), RH (shaded areas depicting RH values less than 15%), and PT (thin black contours) cross-section valid at 7 pm MST, June 13, 2012. Bottom: RAP 0-hour analysis showing IPV cross-section valid at 7 pm MST June 13,2012 with altitude in msl on the vertical axis. Click top image to enlarge. Data below terrain not real.





Supporting Meteorological Data: Back Trajectory Analysis

While cross-section analysis confirms an SI having occurred over central Idaho, a trajectory analysis is warranted to examine the path the ozone-rich air took from the SI to the UGRB. As already shown by Figure 22, the SI descended to between 3200 and 3800 msl over central Idaho. Therefore, a trajectory analysis was performed using the central Idaho location as a start/endpoint of air parcel trajectories.

Forward and backward trajectory analyses occurred using the HYSPLIT program with archived NAM 12-km data from June 13-14, 2012. Instead of analyzing one trajectory, the option of using HYSPLIT in ensemble mode was chosen to provide a more realistic likelihood of the air's pathway. Figure 23 shows backward trajectories emanating at 2600 msl over the UGRB for 11 am MST June 14, 2012 and ending over central Idaho near the SI at 5 pm MST June 13, 2012. Figure 23 is further evidence of air originating from the SI and arriving at the UGRB around the same time elevated ozone values were observed.

Figures 24-25 portray forward trajectories starting at 3600 and 3200 at 5 pm MST June 13, 2012 over central Idaho and ending at 10 am MST June 14, 2012, respectively. Figure 26 shows forward trajectories starting at 3700 msl at 6 pm MST June 13, 2012 and ending at 10 am MST June 14, 2012. From Figures 24-26, it is apparent that air parcels emanating from the SI over Idaho arrived at the UGRB approximately the same time 1-hour average ozone values started to increase; further evidence of air of SI origin having affected ozone monitors in the UGRB.

Figure 23. Top: map view of ensemble of back trajectories starting at the middle of the UGRB at 11 am MST June 14, 2012 and ending at 5 pm MST June 13, 2012. Starting trajectories height: 2600 msl. Bottom: vertical profile of back trajectories (height is agl). Click images to enlarge.

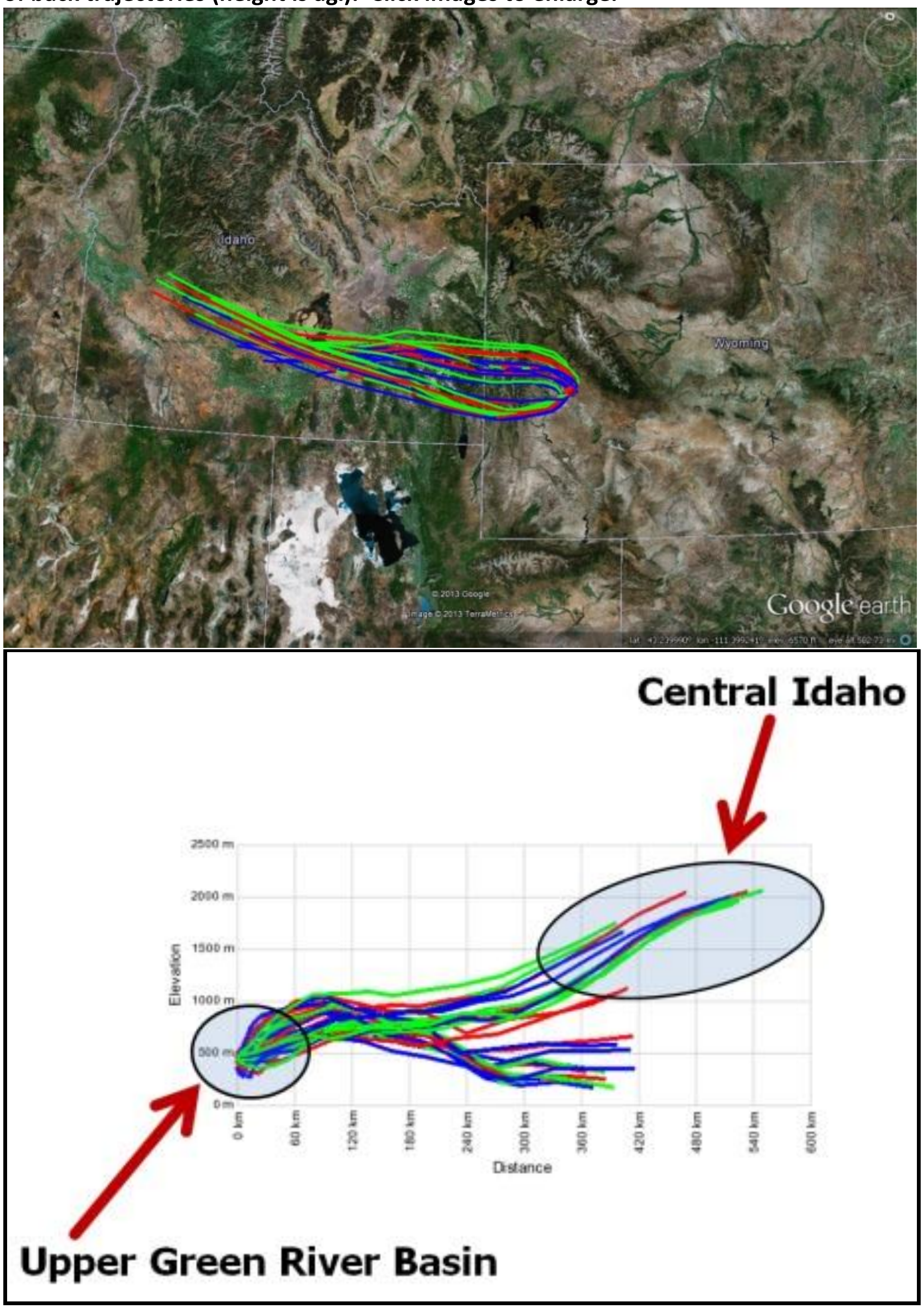


Figure 24. Top: map view of central Idaho ensemble of forward trajectories emanating from 3600 msl starting at 5 pm MST June 13, 2012 and ending at 10 am MST June 14, 2012. Bottom: vertical profile of back trajectories. (height is agl) Click images to enlarge.

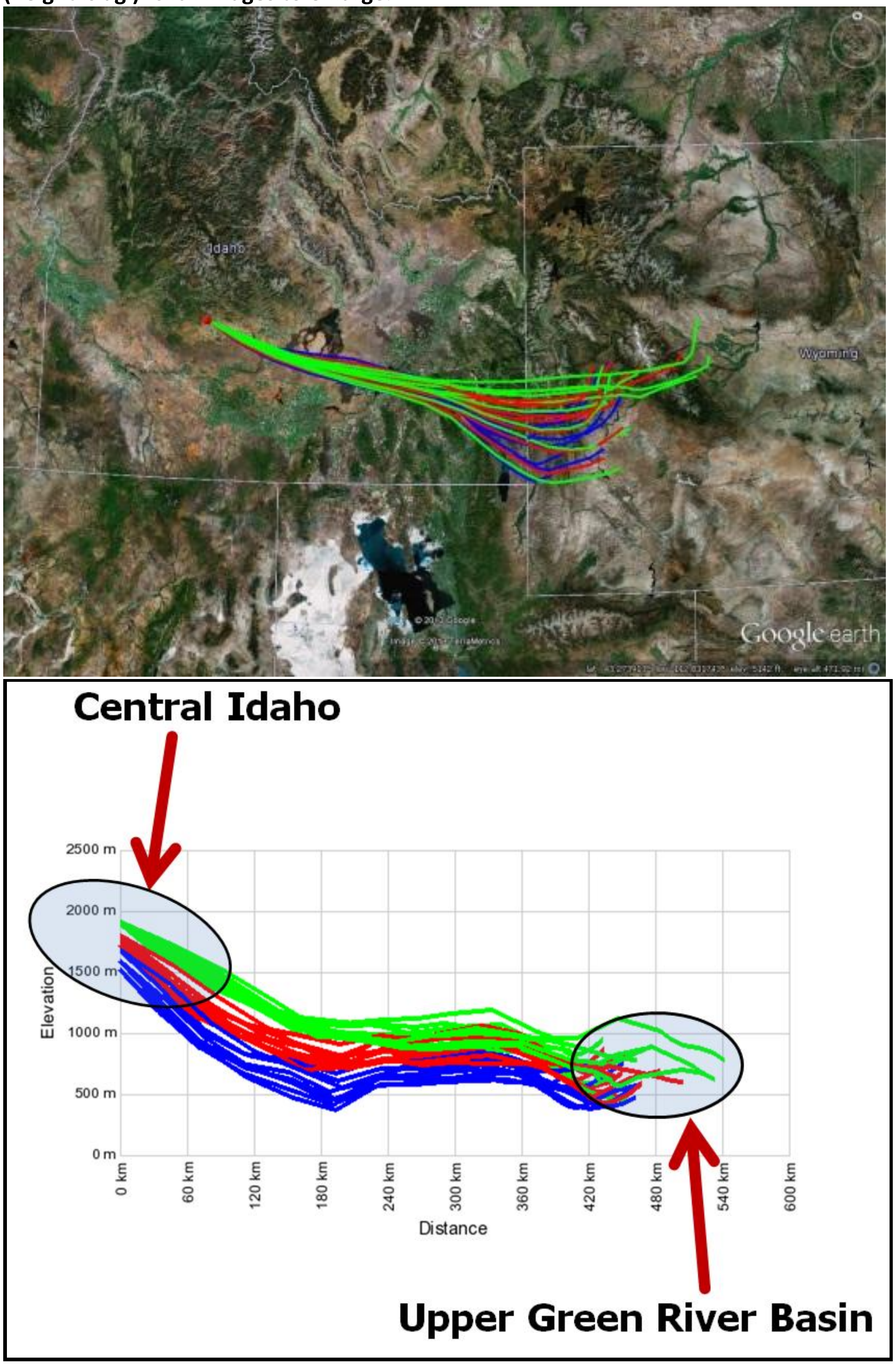


Figure 25. Top: map view of central Idaho ensemble of forward trajectories emanating from 3200 msl starting at 5 pm MST June 13, 2012 and ending at 10 am MST June 14, 2012. Bottom: vertical profile of back trajectories. (height is agl) Click images to enlarge.

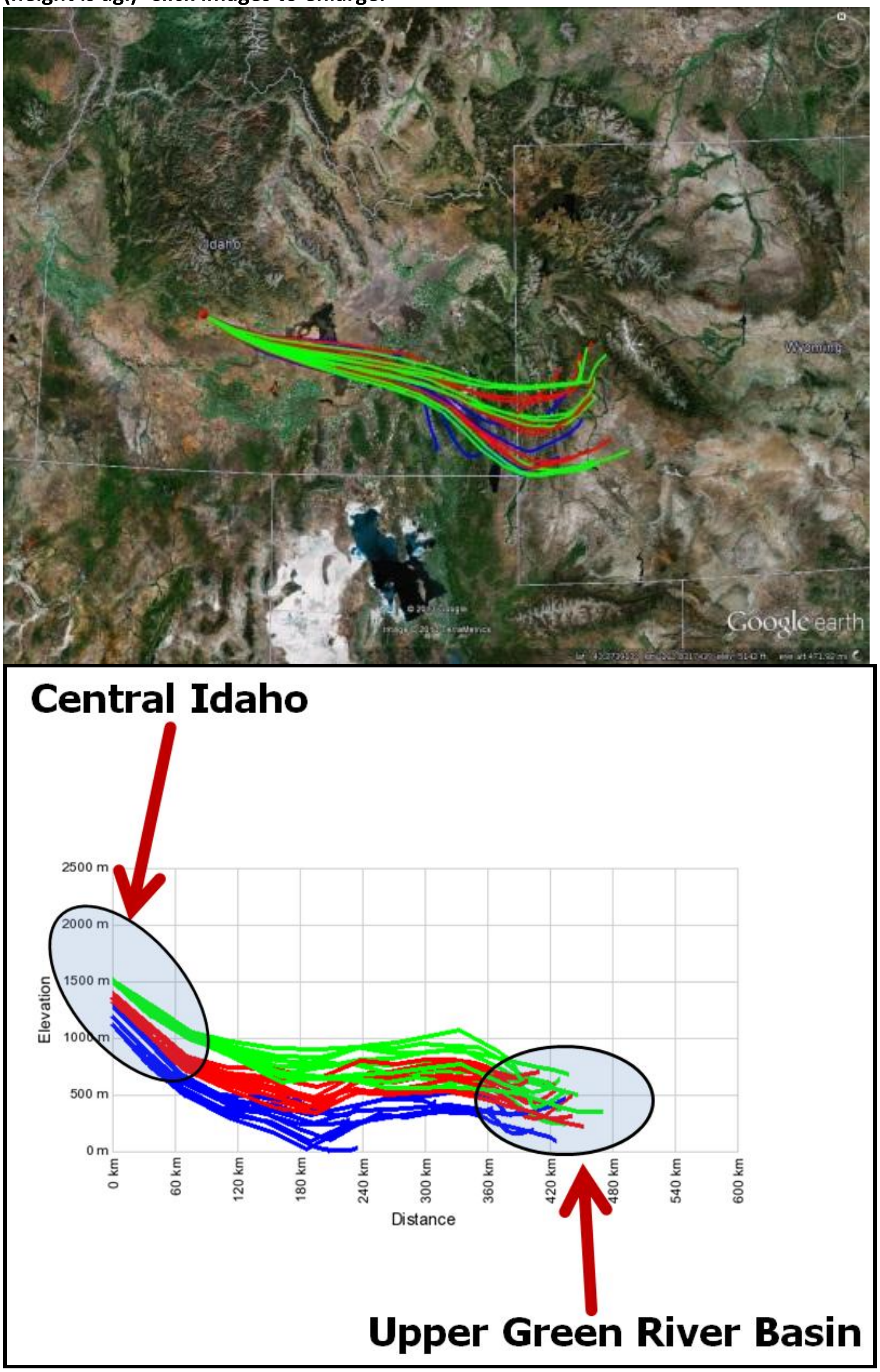
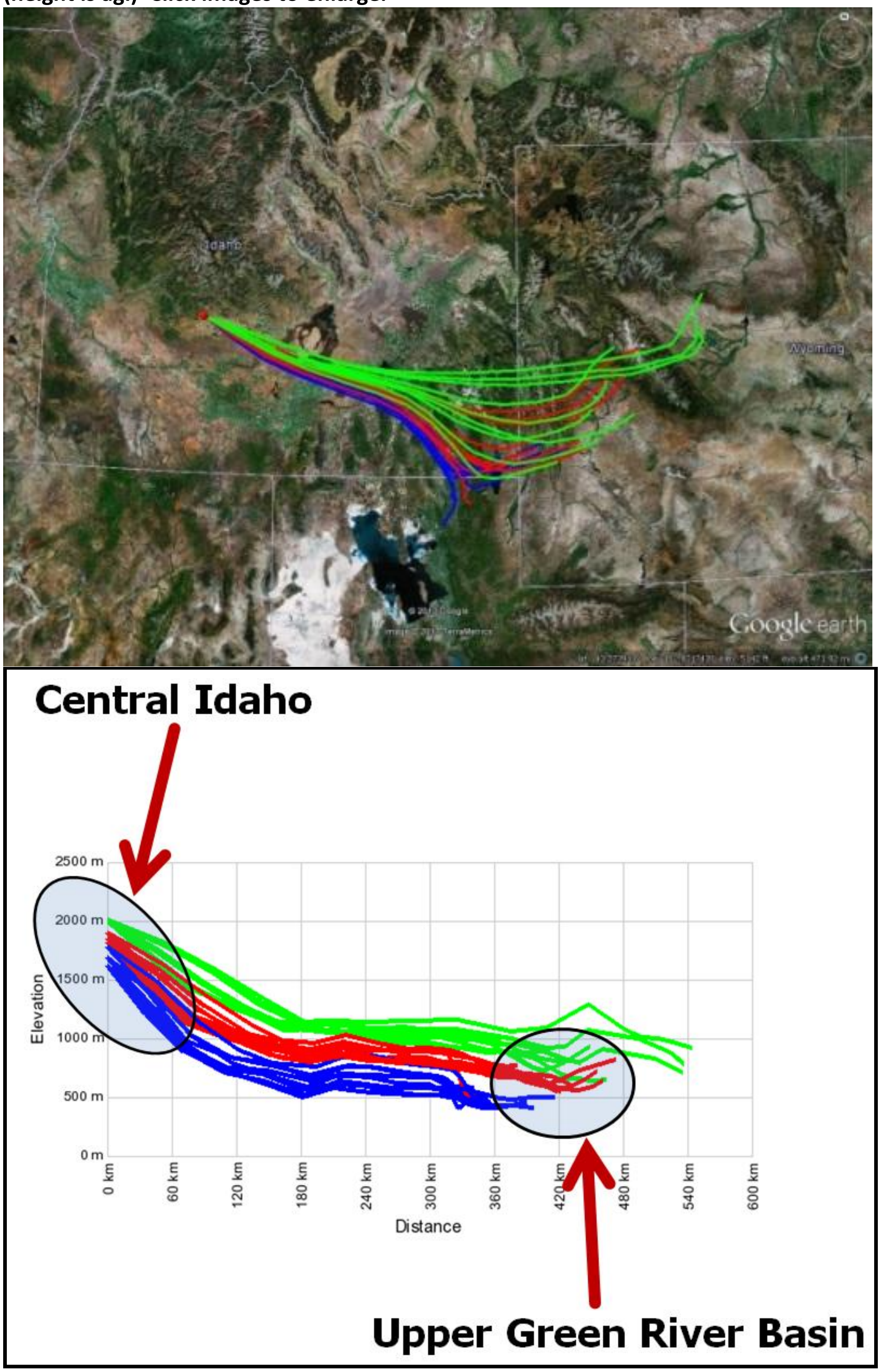


Figure 26. Top: map view of central Idaho ensemble of forward trajectories emanating from 3700 msl starting at 6 pm MST June 13, 2012 and ending at 10 am MST June 14, 2012. Bottom: vertical profile of back trajectories. (height is agl) Click images to enlarge.



Supporting Meteorological Data: SI-Composite Chart

Another means of showing the SI event is by showing an "SI composite chart" of IPV, RH, and daily maximum 8-hour surface ozone data. This "quick look chart" is an easy way to visualize IPV, RH, and surface ozone on one chart. Figure 27 shows the 0-hour RAP 20-km analysis of the 500 mb height pattern, greater than 1-PVU, and relative humidity less than 30% at 625 mb (approximate height of the SI) valid at 6 am MST, June 13, 2012. Superimposed on the chart is EPA's AQS daily maximum 8-hour ozone greater than 60 ppb. Figure 28 displays the same aforementioned parameters valid at 10 am MST, June 13 2012 while Figure 29 shows the same information valid at 12 pm June 13, 2012. The noteworthy aspect of the "SI composite chart" is that at 10 am MST, June 13, 2012 and 12 pm June 13, 2012, all of the parameters are juxtaposed on one another. Specifically, the greater than 1-PVU area is coincident with RH values less than 30% aiding in producing the greater than 70 ppb maximum ("bulls-eye") over eastern Idaho and extreme western Wyoming. Coincident with the aforementioned juxtaposition, the ozone monitor at Grand Teton National Park (located in northwestern Wyoming) experienced elevated 1-hour average ozone as shown in Figure 5.

On June 14, 2012, the SI-composite charts valid at 4 am and 11 am MST (Figures 30 and 31) show the same pattern as was mentioned in the previous paragraph: a greater than 1-PVU area with less than 30% RH juxtaposed on a "bulls-eye" of greater than 75 ppb.

The "SI composite chart" provides further evidence of an SI causing an increase in surface ozone.

Figure 27. 6 am MST, June 13, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading. Click image to enlarge.

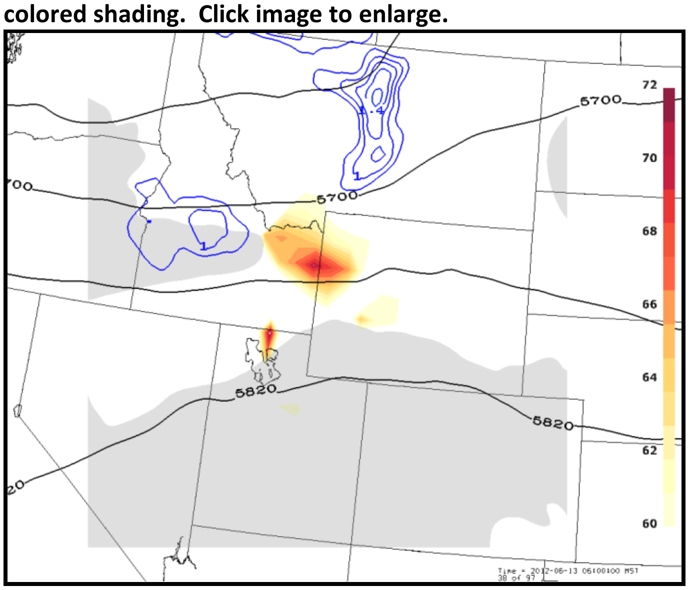


Figure 28. 10 am MST, June 13, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading. Click image to enlarge.

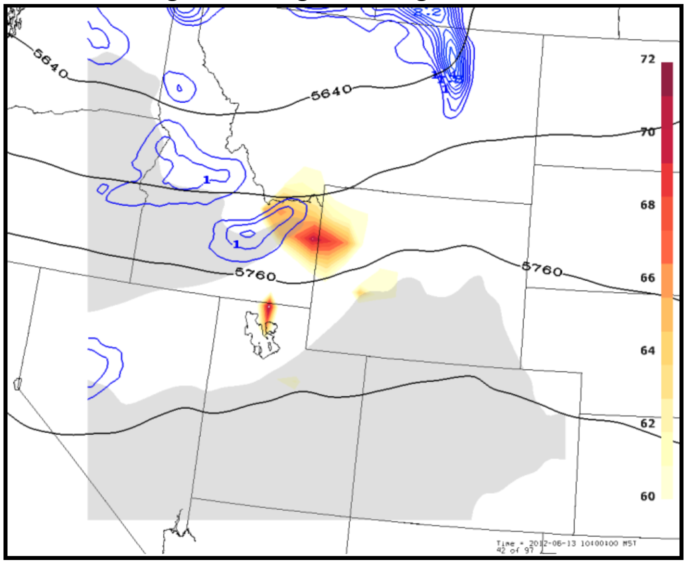


Figure 29. 12 pm MST, June 13, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading. Click image to enlarge.

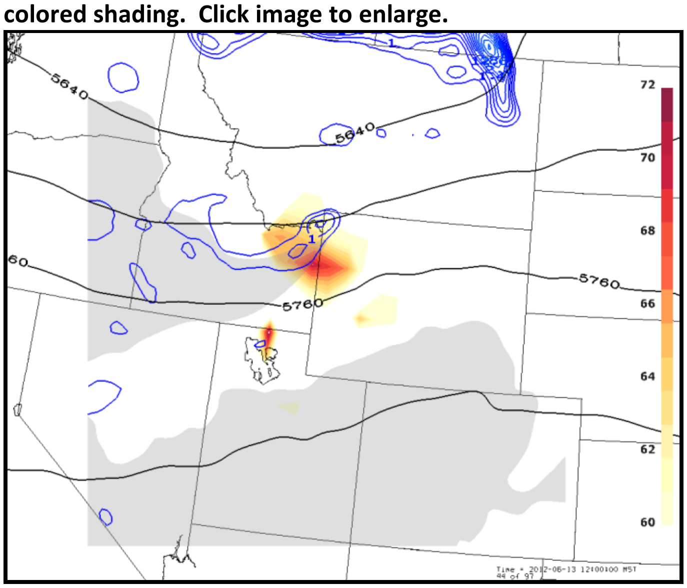


Figure 30. 4 am MST, June 14, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading. Click image to enlarge.

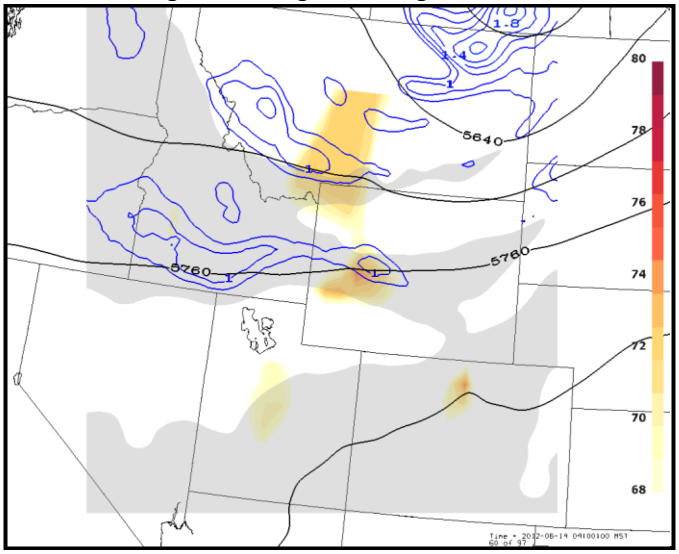
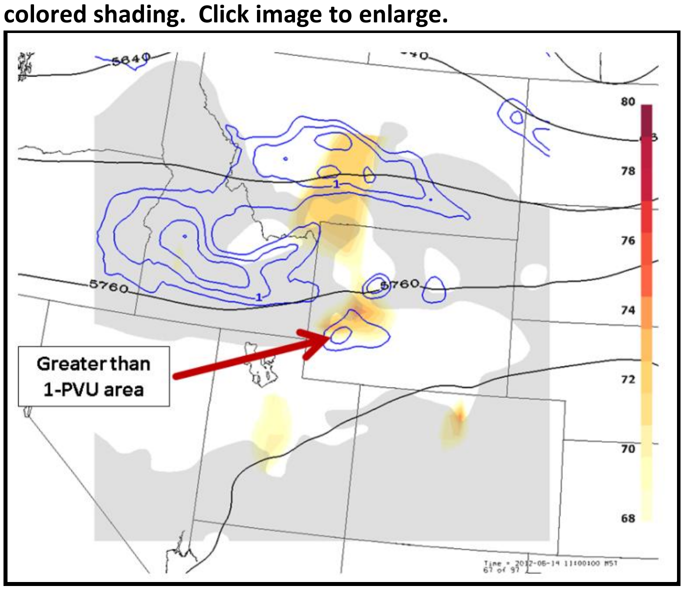


Figure 31. 11 am MST, June 14, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading. Click image to enlarge.



Supporting Meteorological Data: Vertical mixing as shown by lapse rates

An additional method for depicting a well-mixed atmosphere supportive of vertically transporting air of SI origin to the earth's surface is by means of mid-tropospheric lapse rate analysis. By showing the juxtaposition of 700-500 mb environmental layer lapse rates (ELR's) and greater than 1-PVU at 625 mb, one can visualize conditions conducive for vertical mixing up to the SI. As the magnitude of the ELR starts to approach the dry adiabatic lapse rate of 9.8º C km-1 (DALR), the atmosphere is better able to mix in the vertical. Figure 32 shows an axis (blue isolines) of greater than 1-PVU over southern Idaho and a "bulls-eye" of greater than 1-PVU over west central Wyoming at 3 am MST June 14, 2012. At 11 am MST June 14, 2012, Figure 33 shows two "bulls-eyes" over western Wyoming of greater than 1-PVU superimposed with ELR's ranging from 6 to 8º C km-1. At 12 pm MST June 12, 2012, a greater than 1-PVU "bulls-eye" was near Big Piney and Boulder coincident with ELR's from 6 to 8 º C km-1 (refer to Figure 34). From early morning to midday of June 14, 2012, the ELR increased in magnitude and assisted the SI air to reach the vicinity of the Boulder and Big Piney ozone monitors. This is additional evidence of ozone rich air from the central Idaho SI having been able to mix to the ground creating elevated ozone values.

Figure 32. 700-500 mb lapse rate and 625 mb IPV image at 3 am MST, June 14, 2012 RAP 20-km, 0-hour analysis. Lapse rate units are degrees C km-1. IPV units are potential vorticity units. Click image to enlarge. Click here for a time animation from 2 am to 1 pm MST June 14, 2012.

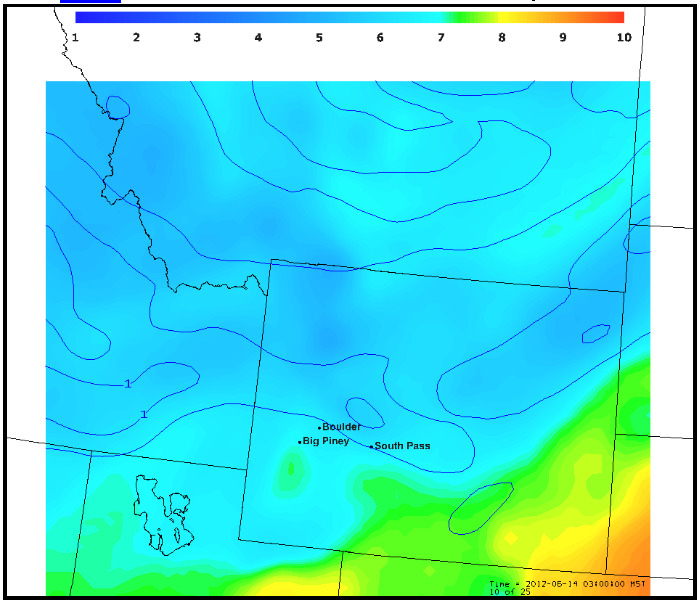


Figure 33. 700-500 mb lapse rate and 625 mb IPV image at 11am MST, June 14, 2012 RAP 20-km, 0-hour analysis. Lapse rate units are degrees C km-1. IPV units are potential vorticity units. Click image to enlarge.

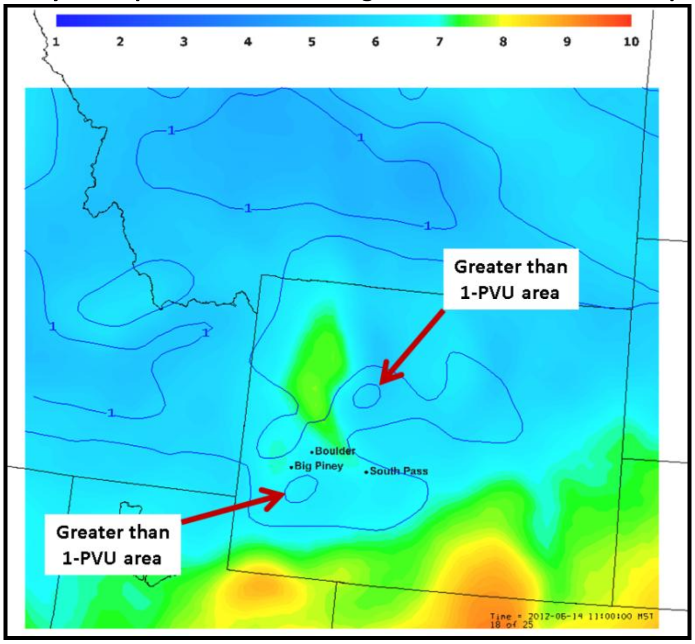
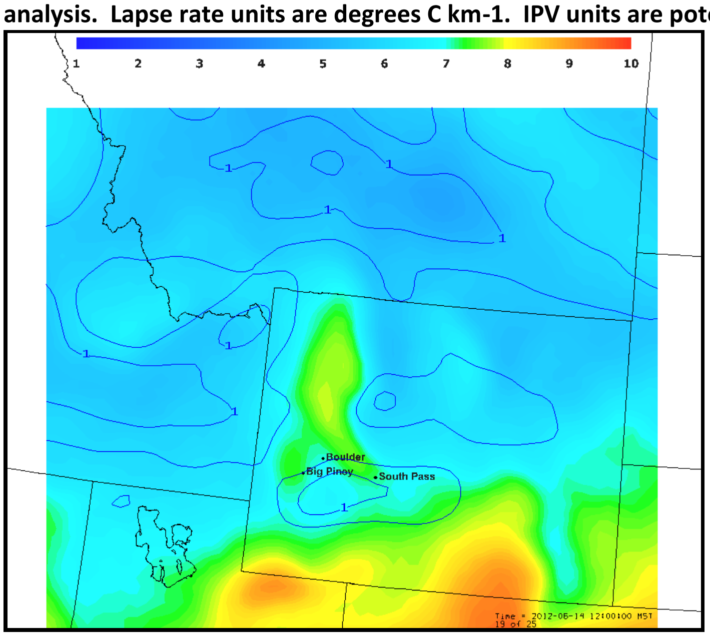


Figure 34. 700-500 mb lapse rate and 625 mb IPV image at 12 pm MST, June 14, 2012 RAP 20-km, 0-hour analysis. Lapse rate units are degrees C km-1. IPV units are potential vorticity units. Click image to enlarge.



Supporting Meteorological Data: Upper Air RAOB's

Recall that a lowering of the tropopause or the existence of a dry air layer is another indication of a stratospheric air. By examining the June 13-14, 2012 RAOB's from Boise, Idaho, Great Falls, Montana, and Riverton, Wyoming, one can detect the presence of SI-air. The 5 am MST June 13, 2012 Boise RAOB shows a dry air layer from 600 to 500 mb (Figure 35). At 5 pm MST June 13, 2012, the Boise RAOB shows that the dry air layer was between 675 and 575 mb (Figure 36). Meanwhile, the 5 am MST June 14, 2012 Riverton RAOB portrays the dry air layer between 650 and 550 mb as shown by Figure 37. By 5 pm MST June 14, 2012, the Great Falls and Riverton RAOB's show the dry air layer between 650-600 mb and 700-500 mb, respectively (Figures 38 and 39).

Figures 36 and 38-39 show that the atmosphere was well-mixed (as shown by the dry adiabatic lapse rate (DALR)) vertically up to the ozone-laden, dry air layer providing another piece of evidence that supports air from an SI having vertically mixed to the earth's surface.

Figure 35. Boise, Idaho RAOB at 5 am MST, June 13, 2012. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

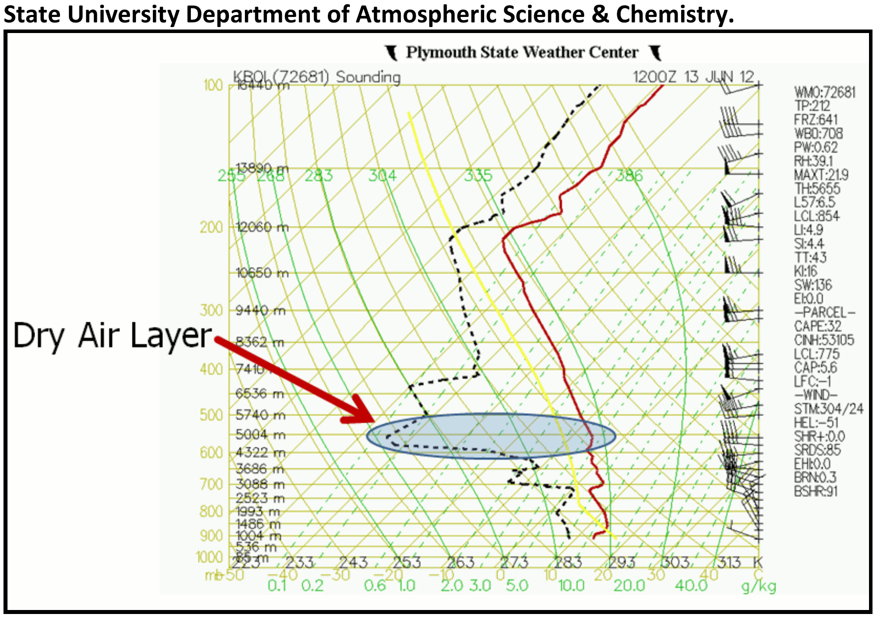


Figure 36. Boise, Idaho RAOB at 5 pm MST, June 13, 2012. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

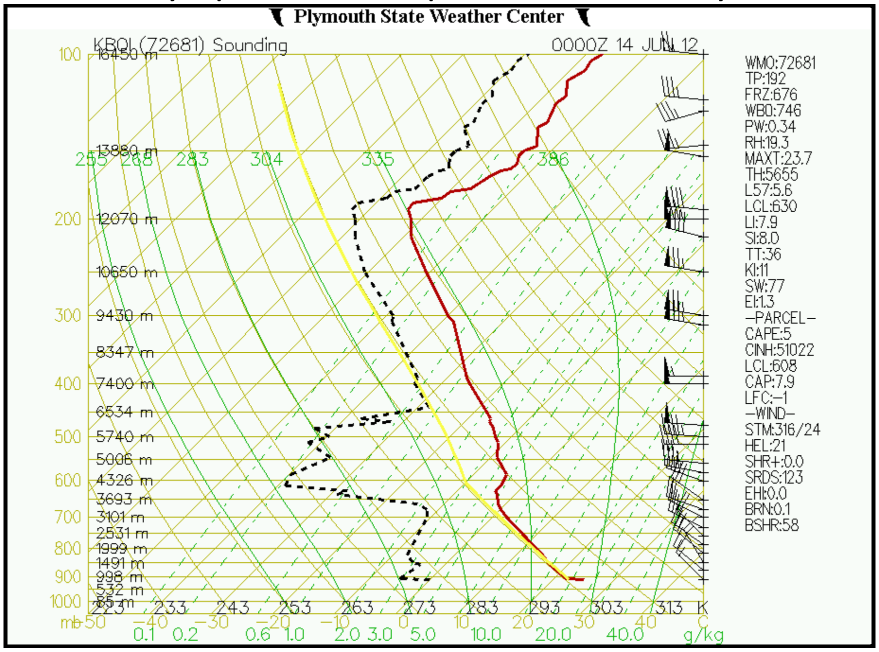


Figure 37. Riverton, Wyoming RAOB at 5 am MST, June 14, 2012. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

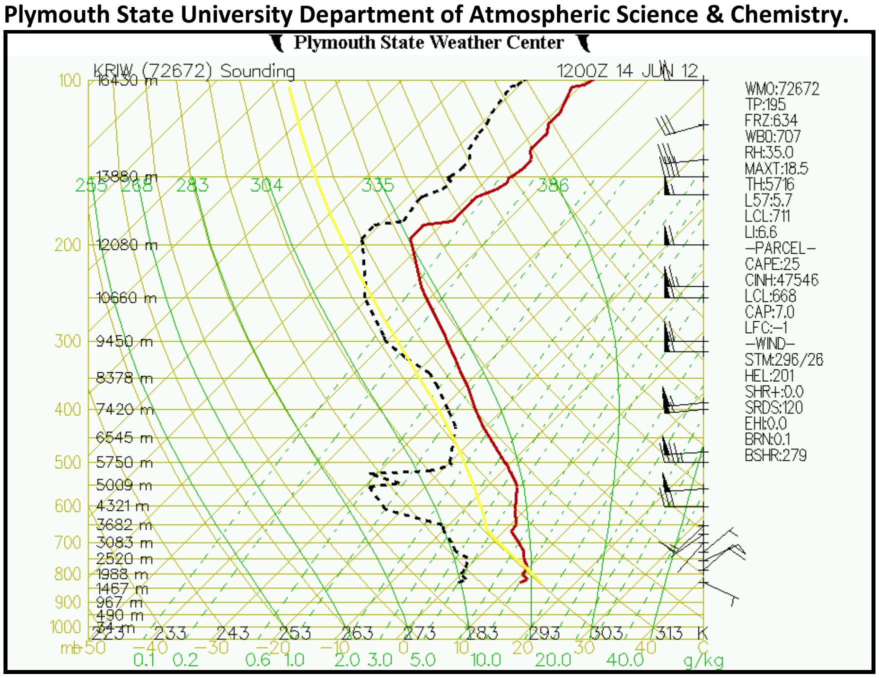


Figure 38. Great Falls, Montana RAOB at 5 pm MST, June 14, 2012. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

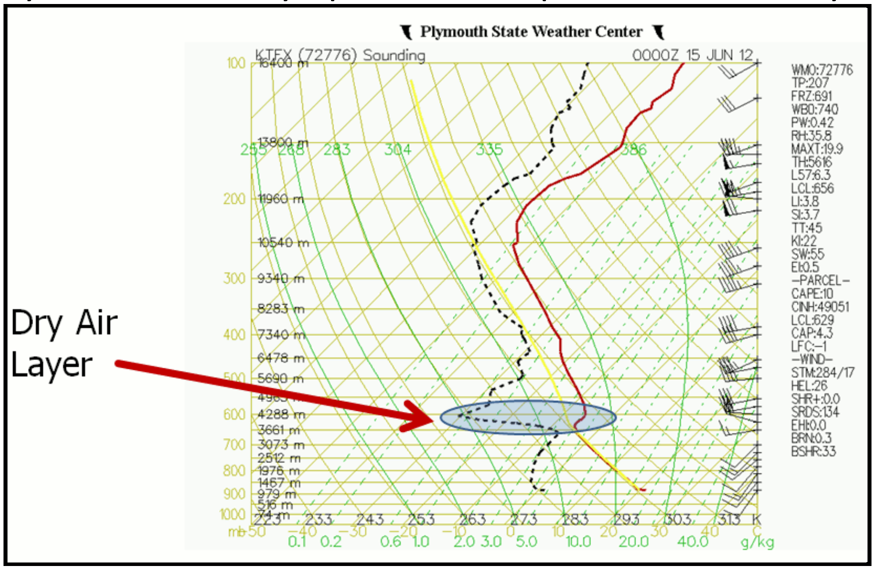
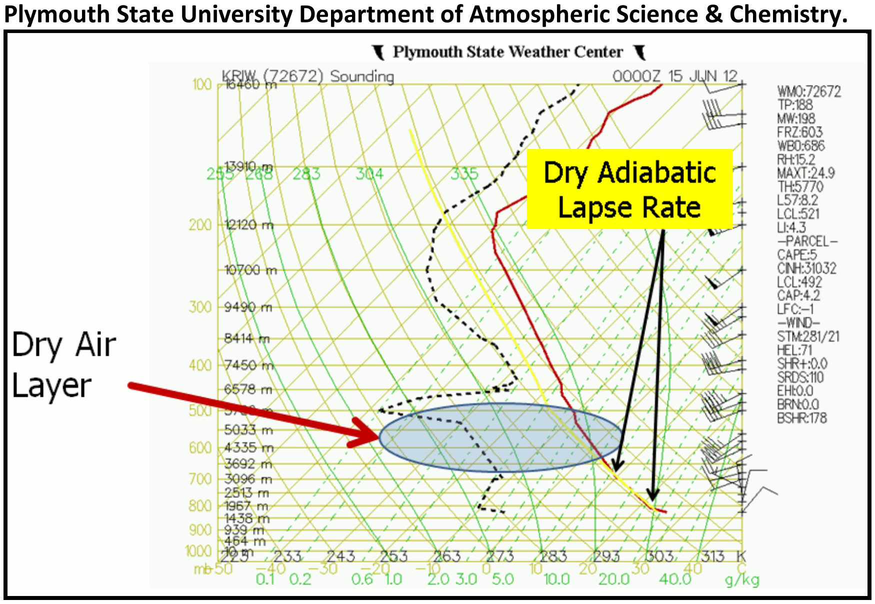


Figure 39. Riverton, Wyoming RAOB at 5 pm MST, June 14, 2012. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

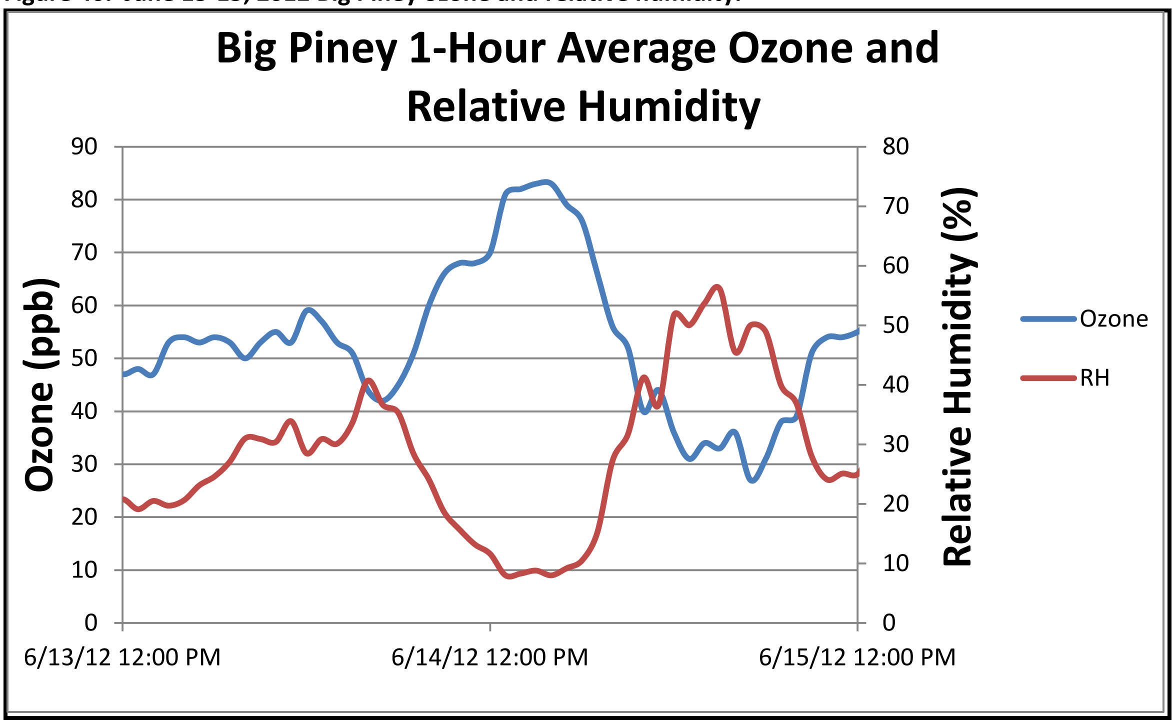


Supporting Meteorological and Ambient Data: Surface-based data

Figures 40-41 show the June 13-15, 2012 1-hour average ozone and hourly relative humidity data for the Big Piney and Boulder monitors. The data show a decrease in relative humidity that coincided with an increase in 1-hour average ozone values. Recall that air of stratospheric origin is dry as depicted by very small relative humidity values. An increase in ozone concentration and a decrease in relative humidity at Big Piney and Boulder is further evidence of an SI event having occurred on June 14, 2012[16].

It has been documented (T. S. ENVIRON 2008) that elevated ozone values can occur at the UGRB ozone monitors of Boulder, Big Piney, Pinedale, Daniel, and Juel Spring because of light winds, snow cover, and strong inversions during the January-March winter ozone season. However, during the June 14, 2012 period of elevated ozone, strong winds (refer to Figure 42) buffeted the UGRB prior to the SI event, and no snow cover or strong inversions were present. Accumulation of surface-based ozone precursors did not occur because meteorological conditions were not supportive of precursor buildup prior to elevated ozone readings.

Figure 40. June 13-15, 2012 Big Piney ozone and relative humidity.



[16] Please refer to Appendices D-G for the complete AQS dataset including all air quality and meteorological parameters for June 13-16, 2012.

Figure 41. June 13-15, 2012 Boulder ozone and relative humidity.

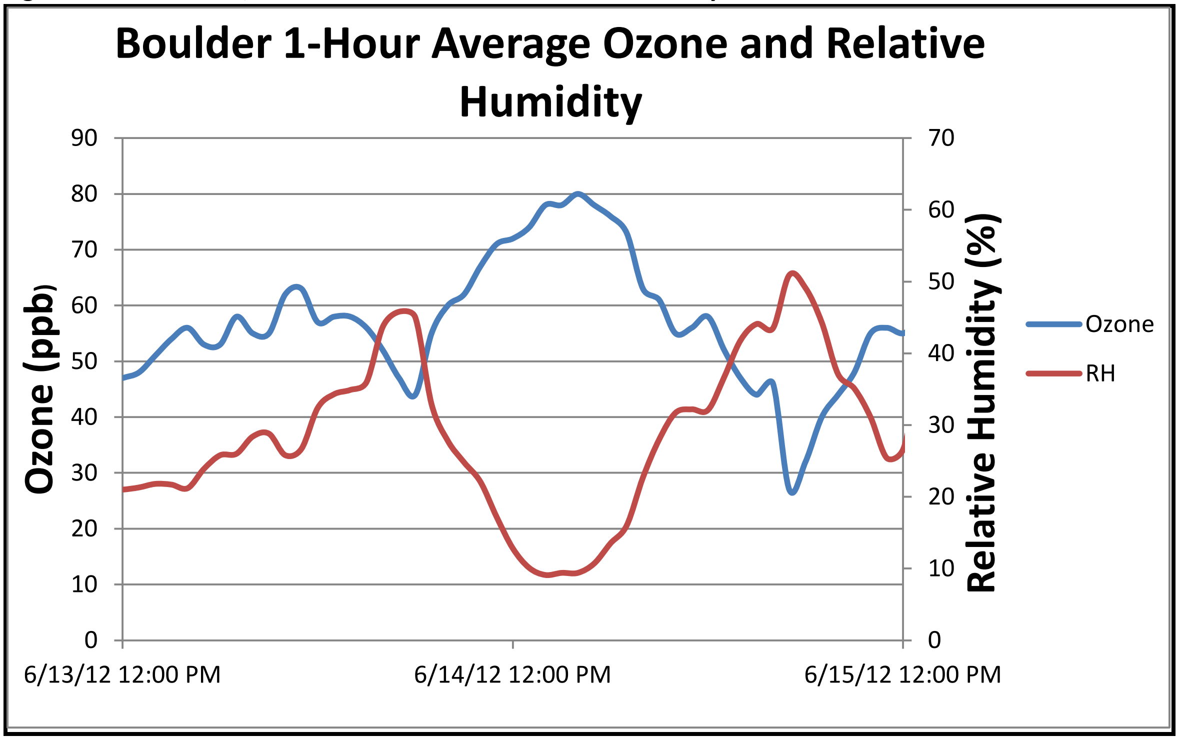
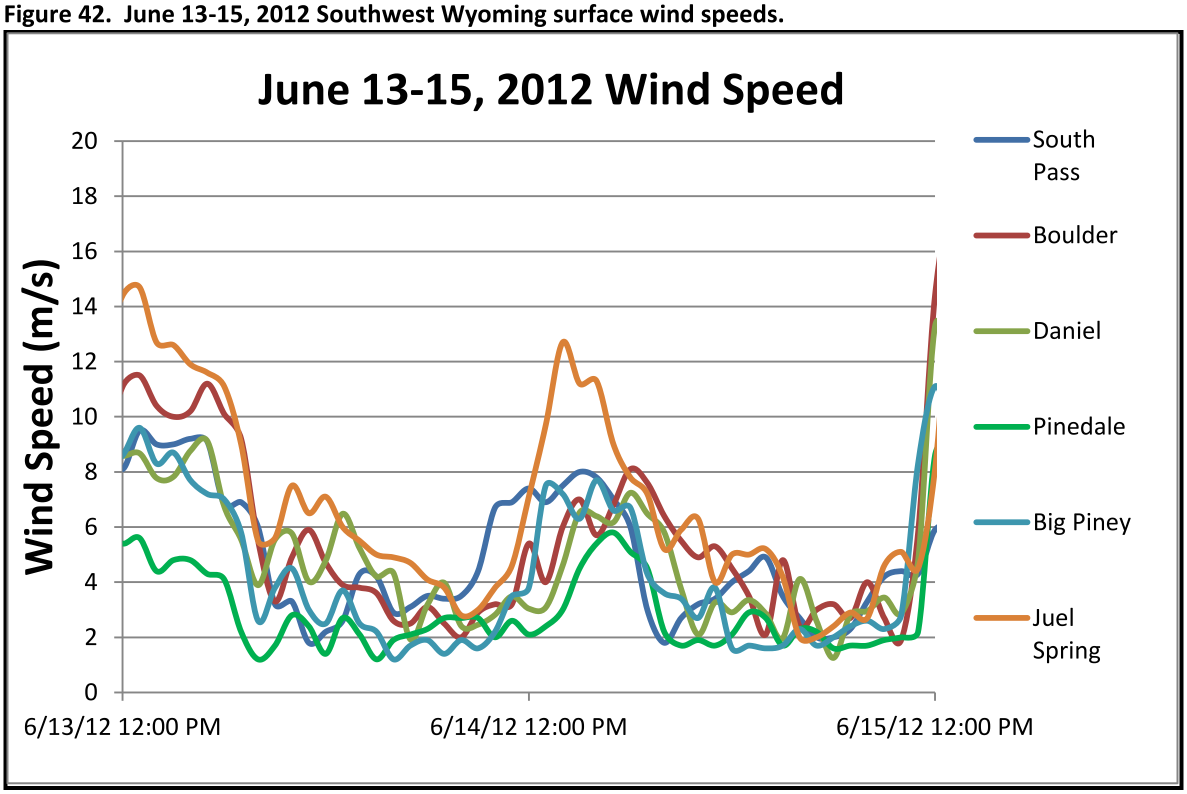


Figure 42. June 13-15, 2012 Southwest Wyoming surface wind speeds.



Lastly, NO_2 plays an important role in ozone formation. Without attempting to quantify NO_2 levels as they pertain to resultant ozone levels, a relative comparison of NO_2 levels can be made. Figure 43 depicts June 13-15, 2012 NO_2 for South Pass, Boulder, Daniel, Pinedale, Big Piney, and Juel Spring. With the exception of Pinedale, 1-hour average NO_2 levels ranged between 0 and 2 ppb; near the detection level of the instrument.

Figures 44 and 45 present the month of June 2012 and June 14, 2012 Pinedale hourly NO_2, respectively. June 14, 2012 is representative of the diurnal cycle observed during the entire month of June. Furthermore, Figures 46 and 47 show the distribution (Box-and-whiskers plots) of 2009-2012 and June 2012 Pinedale hourly NO_2 values from midnight to 11 pm MST, correspondingly. On both box-and-whiskers plots, NO_2 concentration increases during the early morning hours, decreases late in the morning, and increases during mid-evening. The June 14, 2012 hourly NO_2 displays a similar pattern compared to Figures 46 and 47.

Figure 43. June 13-15, 2012 Southwest Wyoming NO_2.

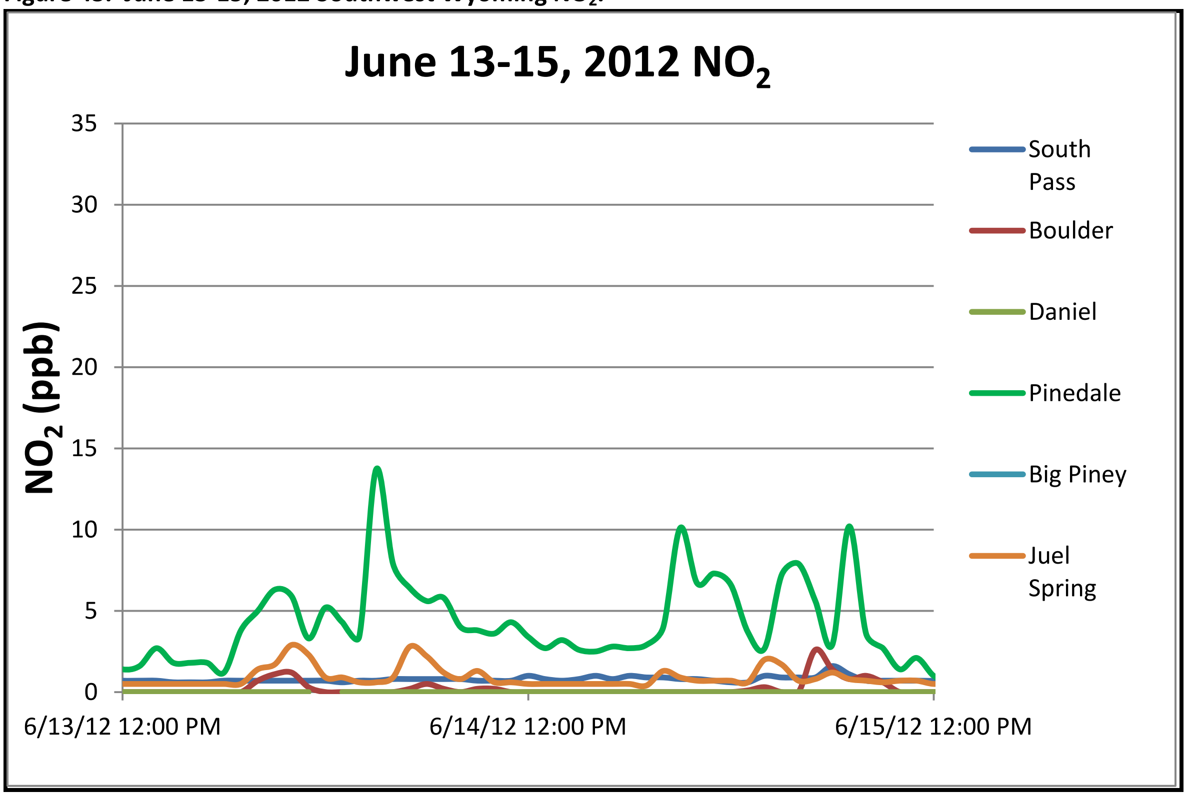


Figure 44. June 2012 Pinedale hourly NO_2.

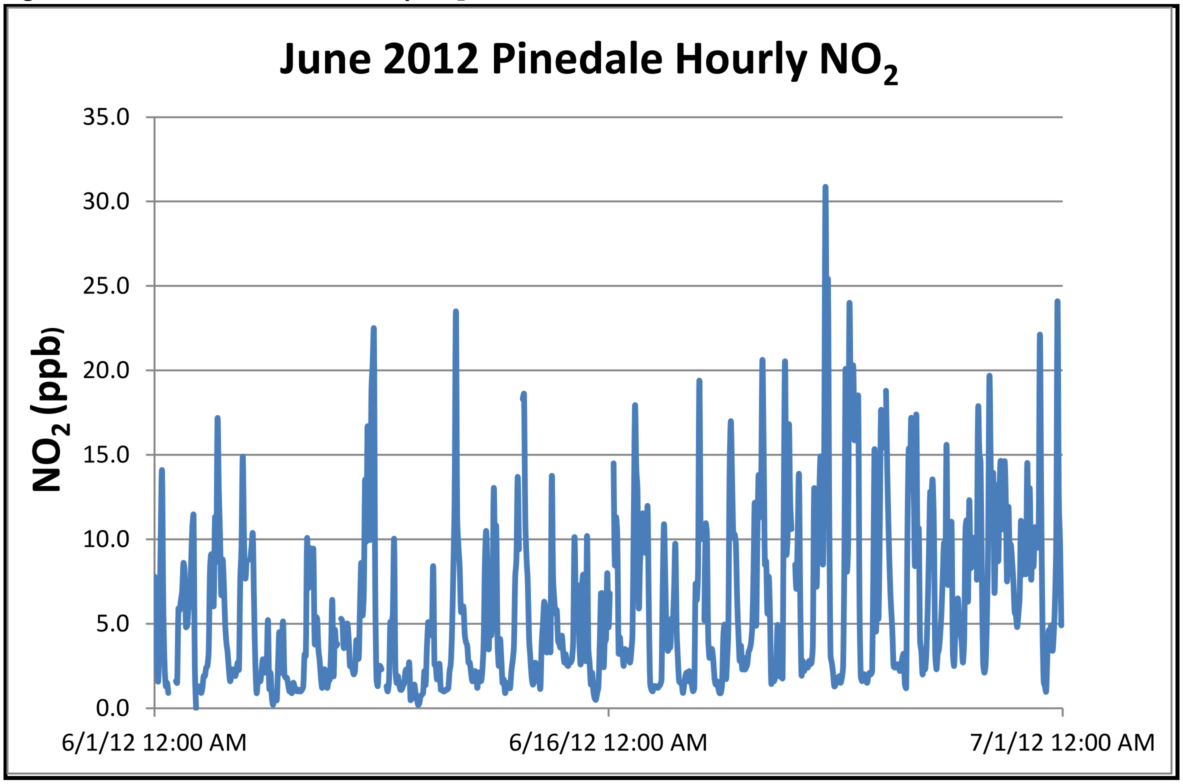


Figure 45. June 14, 2012 Pinedale hourly NO_2.

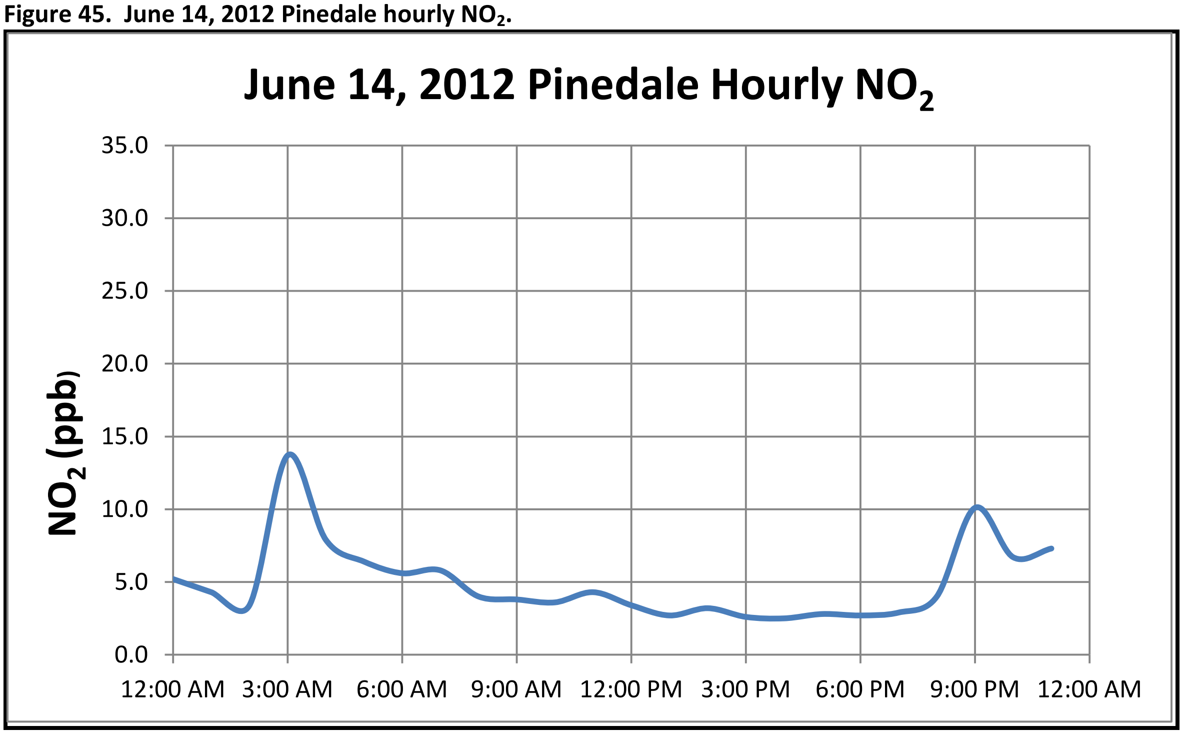


Figure 46. 2009-2012 Pinedale box-and-whiskers plots of hourly NO_2 values from midnight to 11 pm MST. Click image to enlarge.

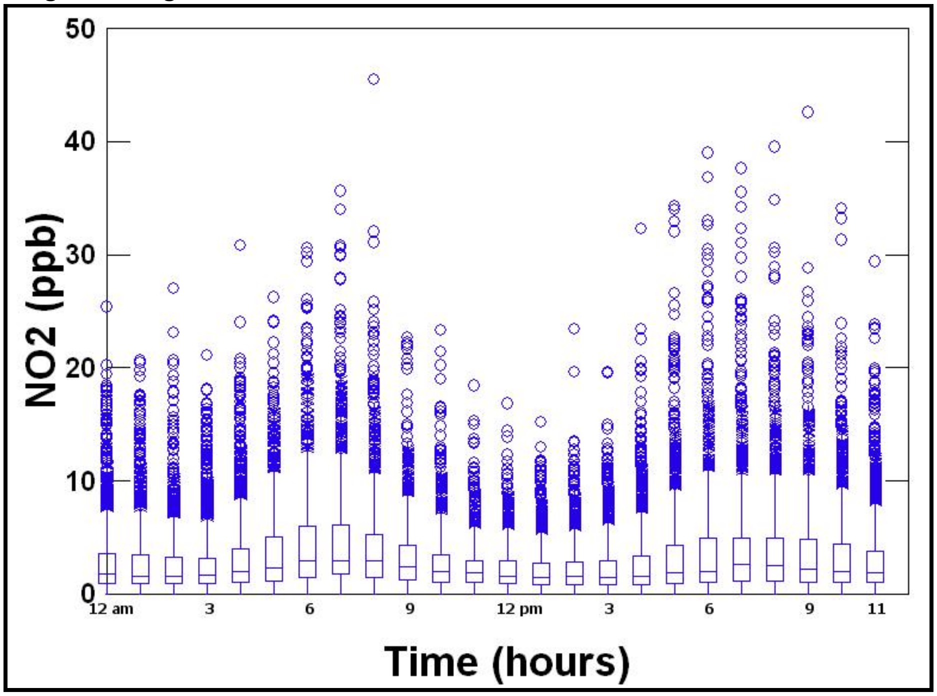
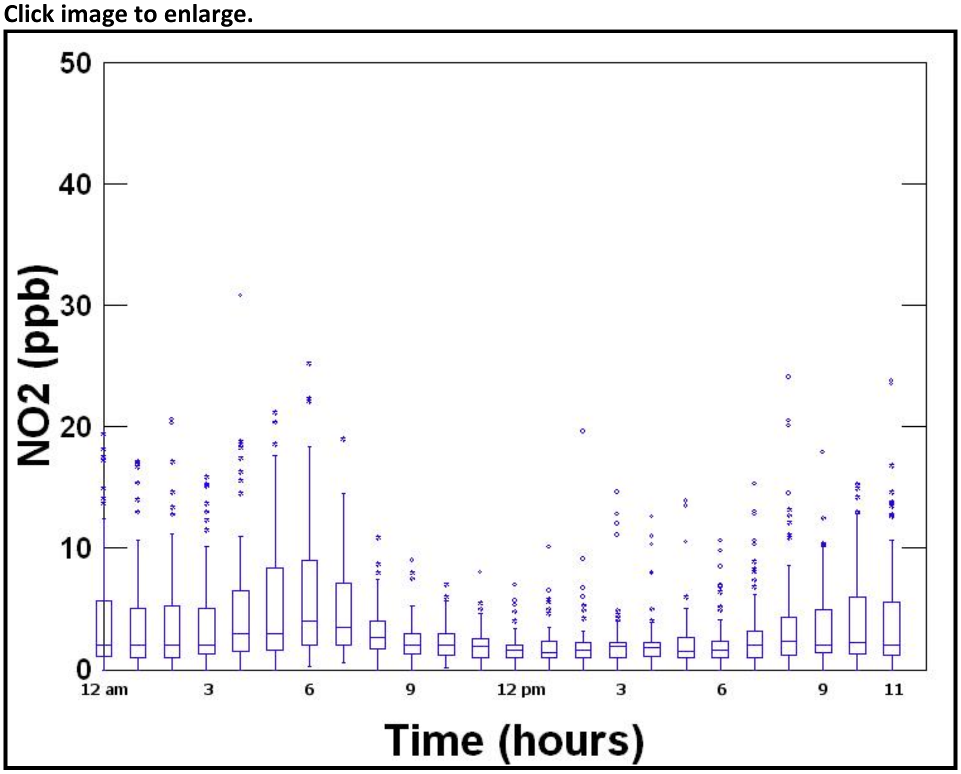


Figure 47. June 2010-2012 Pinedale box-and-whiskers plots of hourly NO_2 values from midnight to 11 pm MST. Click image to enlarge.



SUMMARY AND CONCLUSIONS

During the interval from late winter to late spring in the northern hemisphere, weather producing systems (i.e. tropospheric storm systems, upper level disturbances or upper level storm systems) aid in causing the tropopause to "fold" or descend into the troposphere where our weather occurs. Tropopause folding permits ozone-rich air from the stratosphere to enter the troposphere, also called a stratospheric intrusion (SI), creating the potential for ground level ozone monitors over the higher terrain of the western United States to experience elevated readings.

Throughout June 13-14, 2012, an upper atmospheric disturbance associated with an SI moved over central Idaho injecting ozone-rich air into the troposphere. The ozone-laden air then moved over western Wyoming creating elevated ozone readings resulting in 8-hour ozone standard exceedances of 76 and 77 ppb at the Boulder and Big Piney, Wyoming ozone monitors respectively.

Additionally, the Yellowstone and Grand Teton National Park ozone monitors as well as the AQD ozone monitors at South Pass, Daniel, Pinedale, and Juel Spring measured elevated 1-hour average ozone values from the upper 60's to upper 70's ppb during the SI event (refer to Figure 5). (Note to reader: the Pinedale CASTNET site was not operational during June 2012 due to a prolonged power outage).

It has been documented (T. S. ENVIRON 2008) that elevated ozone values can occur at the UGRB ozone monitors of Boulder, Big Piney, Pinedale, Daniel, and Juel Spring because of light winds, snow cover, and strong inversions during the January-March winter ozone season. However, during the June 14, 2012 period of elevated ozone, strong winds (refer to Figure 39) buffeted the UGRB prior to the SI event, and no snow cover or strong inversions were present. Accumulation of surface-based ozone precursors did not occur because meteorological conditions were not supportive of precursor buildup prior to elevated ozone readings.

Statistical analyses performed on the Boulder and Big Piney data show that the June 14, 2012 ozone data was statistically significantly higher than values recorded during June of each year starting from 2005-2012 (Boulder) and 2011-2012 (Big Piney). The AQD performed a careful evaluation of the June 14, 2012 episode, and is confident that the Boulder and Big Piney event presented in this document is the result of a stratospheric intrusion.

The "Supporting Meteorological Data" sections of this document clearly show that an upper atmospheric disturbance and its attendant SI carried ozone-rich air from the stratosphere over central Idaho to the area around the Boulder and Big Piney ozone monitors during the June 13-14, 2012. Due to the disturbance, tropospheric conditions were conductive for vertical mixing over the Boulder and Big Piney area as evidenced by the "Backward and Forward Trajectory Analyses", "Vertical mixing as shown by lapse rate analysis", and "Upper Air RAOB's" sections of this document. As a result, 1-hour average ozone values at the Boulder and Big Piney ozone monitors increased during June 14, 2012.

The SI meets the definition of a stratospheric intrusion as outlined in the preamble to "Treatment of Data Influenced by Exceptional Events" 40 CFR Parts 50 and 51 section IV(D)(5)(e). Specifically, air originated in the stratosphere and was transported directly to the earth's surface via an upper level disturbance causing the Boulder and Big Piney June 14, 2012 exceptional event. This event meets the specific criterion established in 40 CFR 50.14 (3)(iii) as described below.

Criteria **(A)** states that "[t]he event satisfies the criteria set forth in 40 CFR 50.1(j)":

40 CFR 50.1 (j) requires that an exceptional event "affects air quality, is not reasonably controllable or preventable..." and is a "...natural event[s]". The Exceptional Events Rule Preamble and the 40 CFR 50 Appendices I & P specifically list stratospheric intrusion of ozone as a natural event that could affect ground level ozone concentrations. This packet includes data and graphics that display a weather disturbance, and clearly show an intrusion of stratospheric air that affected ambient air quality during June 14, 2012 at the Boulder and Big Piney ozone monitors.

Criteria **(B)** states that **"**[t]here is a clear causal relationship between the measurement under consideration and the event that is claimed to have affected the air quality in the area":

The causal relationship is a basic one in which the ozone standard exceedance was caused by tropospheric folding resulting in an SI. For the exceedances that occurred on June 14, 2012 an intrusion of stratospheric air occurred over central Idaho upwind of the Boulder and Big Piney monitors, and injected ozone-rich air into the area above and surrounding the Boulder and Big Piney ozone monitors. The causal nature of the SI's impact on ozone values at the Boulder and Big Piney ozone monitors is further supported by the corroboration of ground-based air quality data to the spatial and temporal accuracy of the meteorological analysis.

Criteria **(C)** states that **"**[t]he event is associated with a measured concentration in excess of normal historical fluctuations, including background":

Statistical analysis of June 14, 2012 data clearly shows that the exceptional event was statistically significantly higher than data recorded during prior months of June from 2005-2012 (Boulder) and 2011-2012 (Big Piney).

Criteria **(D)** states that "[t]here would have been no exceedance or violation but for the event":

The SI allowed ozone-rich air to descend to the Boulder and Big Piney ozone monitors creating elevated 1-hour average ozone values. The exceedances of the ozone National Ambient Air Quality Standards (NAAQS) would not have occurred "but for" the SI.

The 75^{th} percentile hourly ozone concentrations does not exceed 55 ppb for the month of June for the years tested (2005/11-2012) for statistical significance. Hourly concentrations monitored during June 14, 2012 were outliers for the months of June 2005-2012 (Boulder) and 2011-2012 (Big Piney). Statistics demonstrating that ozone levels were unusually elevated affirm that the exceedances of the ozone National Ambient Air Quality Standards (NAAQS) would not have happened "but for" the SI event having occurred during June 14, 2012.

In brief, the WDEQ/AQD concludes that an SI occurred during June 13-14, 2012 resulting in an exceptional event. This exceptional event has passed the four criterion tests under 40 CFR 50.14 (3)(iii). Consequently, the WDEQ/AQD is requesting for EPA concurrence that the event was exceptional and for the exclusion from the Air Quality System (AQS) database of the Big Piney and Boulder 1-hour average ozone data for the following times:

Table 5. Big Piney and Boulder times and dates for AQS data exclusion.

Site	Begin Time/Date(s)	End Time/Date(s)
Big Piney	0900 MST June 14, 2012	1900 MST June 14, 2012
Boulder	0900 MST June 14, 2012	2100 MST June 14, 2012

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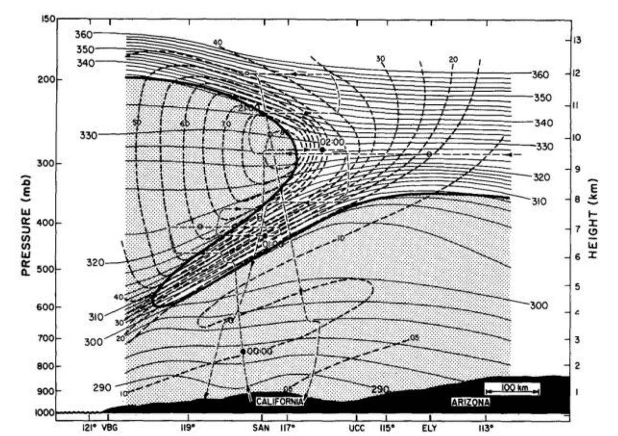
APPENDIX A - Documented Stratospheric Intrusion Events

March 12, 1978

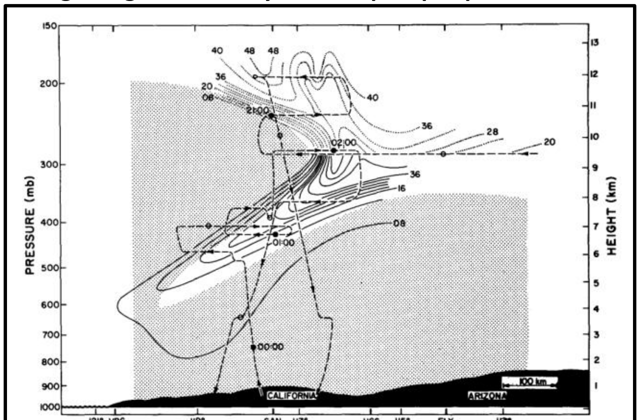
Much of the literature regarding SI's refers to Shapiro's May 1980 paper outlining the results of a research flight that flew through an SI on March 12, 1978 (Shapiro 1980). Equipped with a "fast-response ozone" analyzer, a research plane flew several transects through an SI over California. Shapiro produced vertical cross-sections of IPV, PT, and O_3 concentration from the flight data. Figures A and B portray cross-sections of IPV, PT, and the flight track and clearly show that the O_3 concentration increased when the plane flew through the SI.

Figure A. Cross-section through the 5 pm MST March 13, 1978 tropopause folding event. Potential temperature (K) thin solid lines; wind speed (meters per second) heavy dashed lines; flight track, thin dashed lines; the 100 x 10-7 K mb-1 s-1 potential vorticity Tropopause (1-PVU), heavy solid line; troposphere, stippled area. Click image to enlarge. Figure courtesy Mel Shapiro per personal communication.



Cross section through the 0000 GMT 13 March 1978 tropopause folding event. Potential temperature (K) thin solid lines; wind speed (m s^{-1}) heavy dashed lines; Sabreliner flight track, thin dashed lines; the 100 × 10^{-7} K mb^{-1} s^{-1} potential vorticity tropopause, heavy solid line; troposphere, stippled area.

Figure B. Cross-section through the 5 pm MST March 13, 1978 tropopause folding event. Ozone concentration analysis, parts per hundred million by volume (pphm/vol). Analysis for upper flight track data, dotted lines; lower flight track analysis, solid lines; tropopause, interfaces between stipple and clear area. Click image to enlarge. Figure courtesy Mel Shapiro per personal communication.



Ozone concentration analysis, parts per hundred million by volume (pphm/vol) Analysis for upper flight track data, dotted lines; lower flight track analysis, solid lines; tropopause, interfaces between stippled and clear area.

November 7-8, 1999

During 1999, the Mesoscale Alpine Programme captured an SI event over northern Italy from evidence obtained by using remote optical sensing technology known as the Raman Light Detection And Ranging (LIDAR) sensor (Aulerio, et al. 2005). The Raman LIDAR measures water vapor concentration, and combined with back trajectory analyses, an SI was detected which descended to 4 km AMSL and was ~500 meters thick in 1999 over northern Italy. In other words, the SI lowered to within 16,000 feet of the earth's surface and extended over the length of five football fields upward.

April 28, 2008

During 2008, the Stratosphere-Troposphere Analyses of Regional Transport (START08) field project utilized a research aircraft to measure a multitude of ambient air quality and meteorological parameters (L. L. Pan 2010). On April 28, 2008, Research Flight 4 penetrated the upper portion of an SI, which occurred over northern Missouri (refer to Figure C). Data from the flight reveals more direct evidence that O_3 concentrations increased as the plane entered the SI. Figure D shows the height of the flight path, and a cross-section with corresponding flight times, IPV, and PT as the plane entered the SI. As the plane penetrated the SI, the O_3 concentration increased to over 400 ppb, CO decreased, PT increased, and the RH decreased providing further evidence of an SI as evidenced by Figures E and F.

Figure C. Thin red line in plan-view is the flight path. Click image to enlarge.

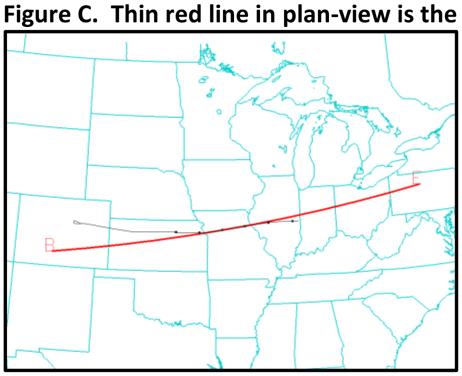


Figure D. Cross-section of flight path and IPV. Times are in MDT. Click image to enlarge.

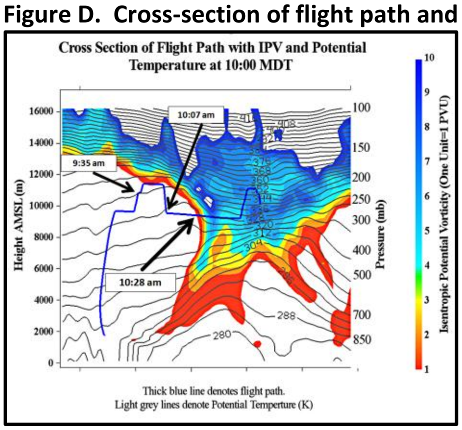


Figure E. Time series of ozone, carbon monoxide, and relative humidity during flight. Times are in MDT. Click image to enlarge.

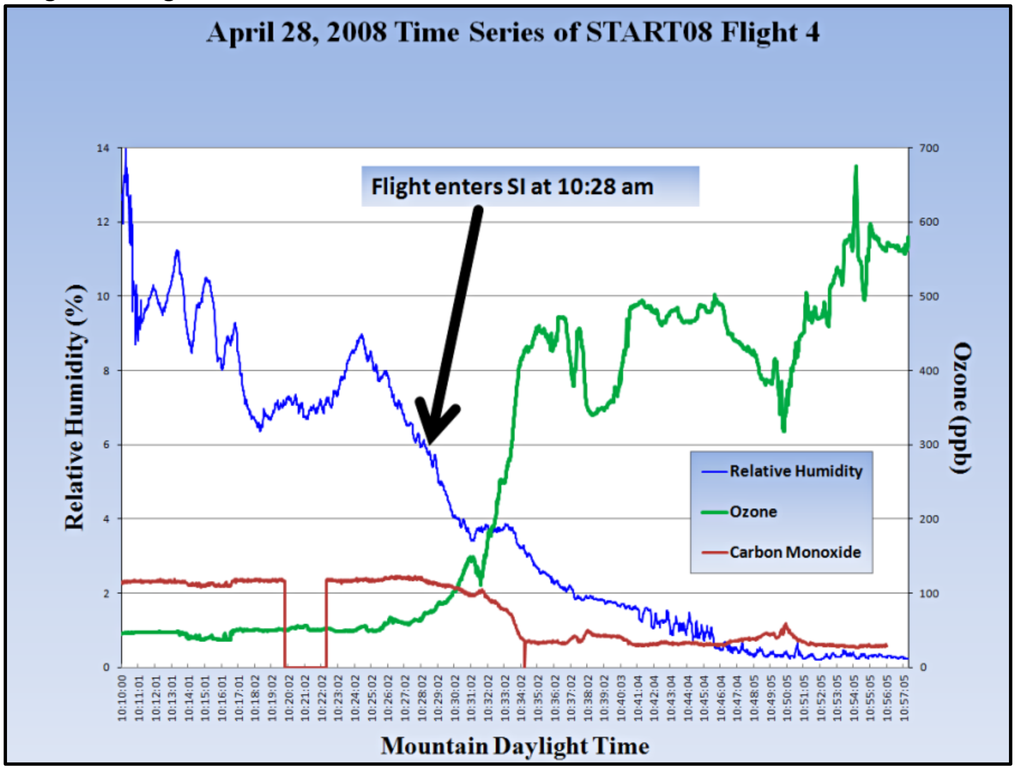
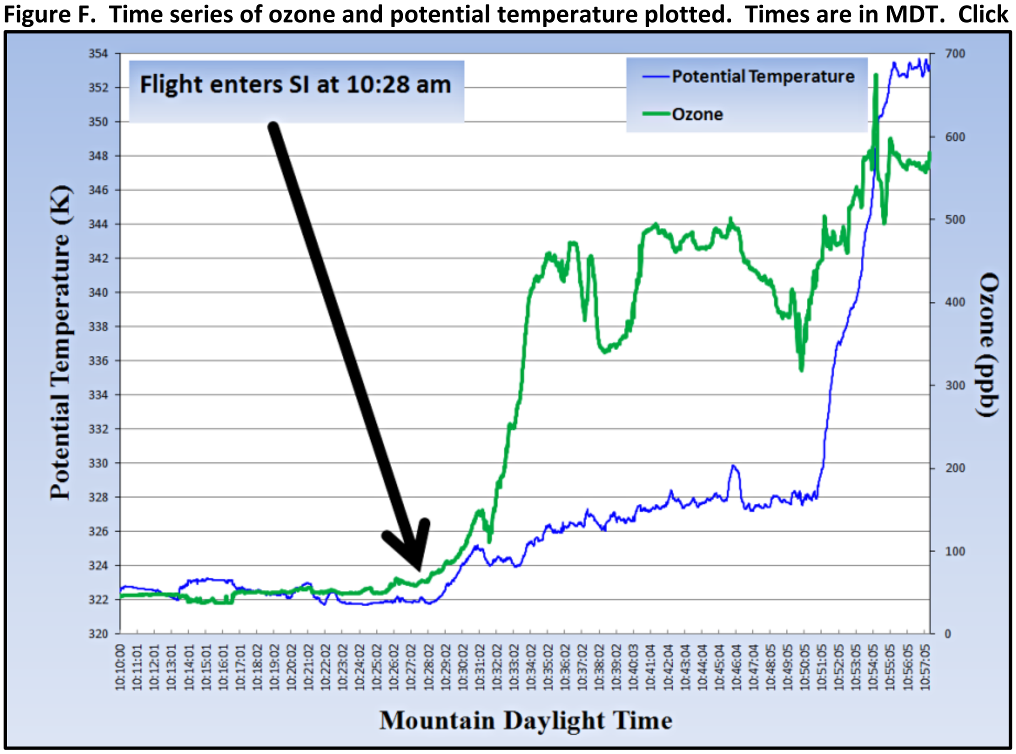


Figure F. Time series of ozone and potential temperature plotted. Times are in MDT. Click image to enlarge.

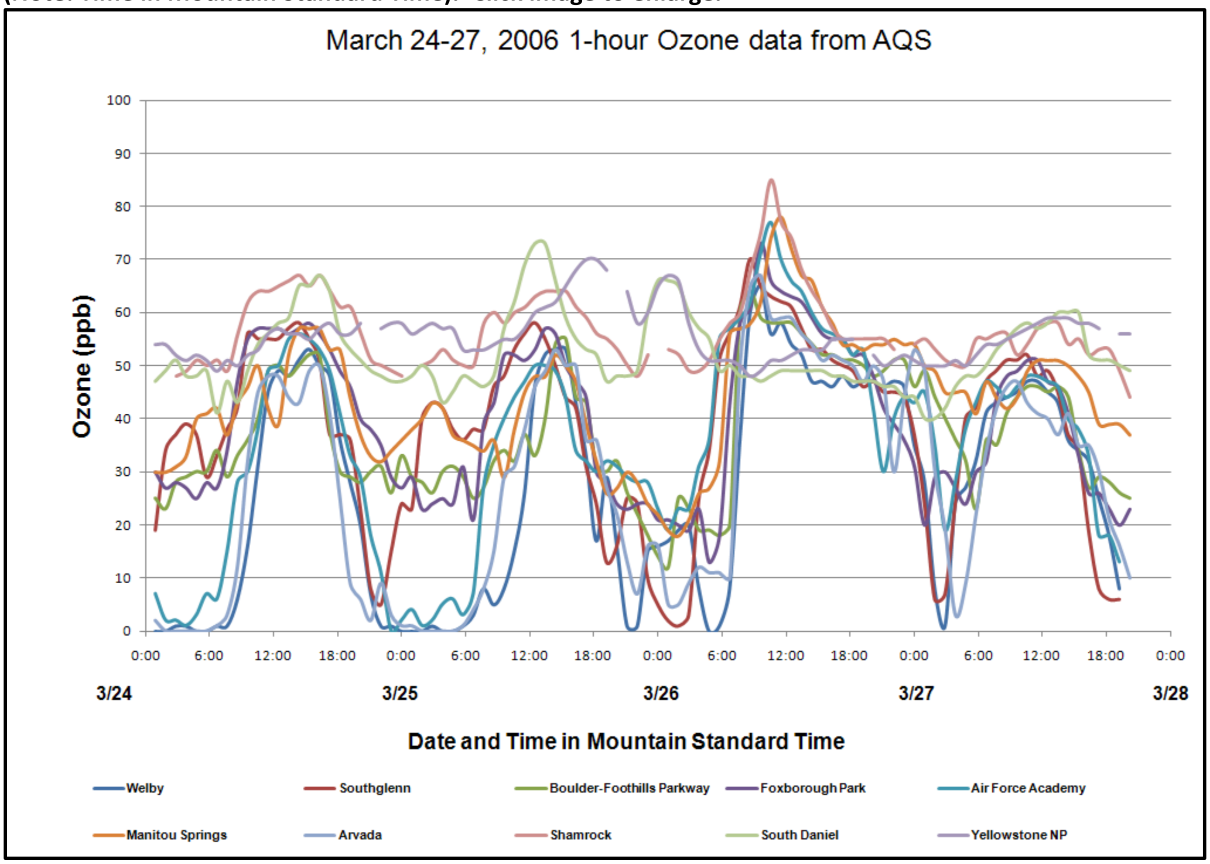


APPENDIX B - Diagnosis Example

Event: March 26, 2006 SI moving over Colorado ground based ozone monitors.

Between March 25, 2006 and March 27, 2006, a strong upper level system moved over Colorado and Wyoming. Air closest to the ground was well mixed due to winds associated with the movement of the weather system across the region. A well-mixed environment enhances the likelihood that stratospheric air can "mix-down" to the surface. In this instance, an SI associated with the passing weather disturbance injected ozone-rich air into the area resulting in abnormally high hourly ozone readings. Figure A shows several Colorado ozone monitors "spiking" well into the 70's and lower 80's ppb during the morning of March 26, 2006 for 1-hour average ozone.

Figure A. Various Colorado and Wyoming 1-hour average Ozone concentrations (ppb) from March 24-27, 2006 (Note: Time in Mountain Standard Time). Click image to enlarge.

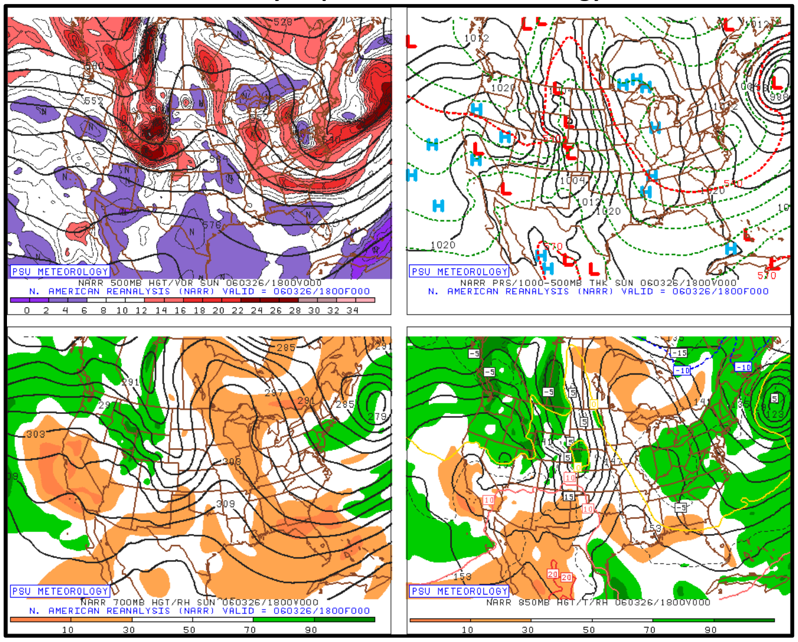


Supporting Meteorological Data: Weather Overview

The NARR for March 25-27, 2006 shows that an upper level weather system moved over Colorado. Figure B is a 4-panel graphic of 500 mb heights and vorticity, 700 mb heights and relative humidity, 850 mb heights/temperatures/relative humidity, and the surface pressure pattern at 11 am MST on March 26, 2007 (Please refer to Appendix C for a further explanation on how to interpret the NARR charts). Note the 500 mb circulation center over Colorado and Wyoming. Recall that upper level weather systems aid in tropopause folding, or the descent of ozone-rich air into the troposphere. Time stamps on the NARR charts are in Universal

Coordinate Time (UTC). To convert to Mountain Standard Time, subtract 7 hours from UTC (e.g. 18 UTC equates to 11 am MST).

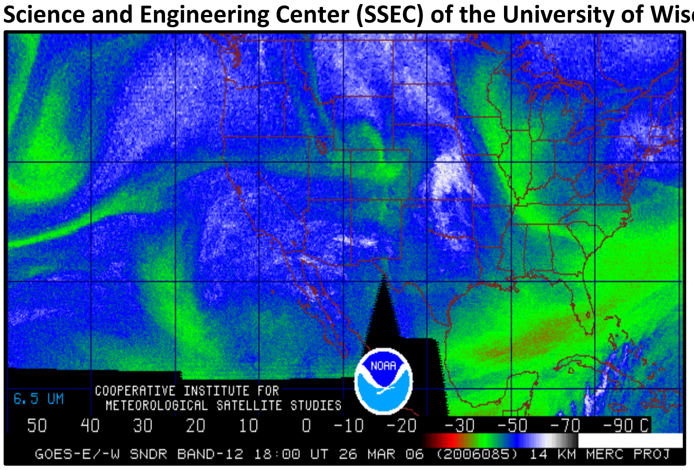
Figure B. North America Reanalysis valid at 11 am MST, March 26, 2006. Click image to enlarge. Click here for a time animation from 11 am March 25, 2007 to 11 am March 27, 2006. Graphic courtesy Fred Gadomski and the Penn State University Department of Meteorology.



Supporting Meteorological Data: GOES Band-12 Data[17]

In Figure C, GOES Band-12 data shows an upper level weather disturbance located over Colorado and Wyoming at 11 am MST on March 26, 2006. Note the dry air, depicted by the light green color in the 400 to 300 mb layer over southern Wyoming and northern Colorado. The same time convention of UTC applies for the GOES Band-12 images as in the case for the NARR graphics.

Figure C. 11 am MST, March 26, 2006 GOES Band-12 image. Click image to enlarge. Click here for a time animation from 5 pm March 25, 2006 to 4 pm March 26, 2006. Image courtesy of the Data Center at the Space Science and Engineering Center (SSEC) of the University of Wisconsin-Madison.



[17] GOES total column ozone data was unavailable during this SI event.

Supporting Meteorological Data: Upper Air RAOB's

RAOB's taken at the Denver airport on March 26, 2006 at 5am and 5pm, portray the lowering of the tropopause associated with the passing upper air disturbance and attendant dry air intrusion. Figures D and E show that the tropopause was approximately at the 200 mb level at 5 am (1200Z), and lowered to 450 mb at 5 pm (0000Z)[18]. To understand this comparison, note in Figure D the red line veering steeply to the right toward the top of the graphic. This represents the tropopause at 200 mb because air above the tropopause will start to warm with height. Figure E depicts the lowering of the tropopause to 450 mb. Note that the warming of air occurs closer to the bottom of the graphic representing a "lowering of the tropopause". One can determine the lack of moisture in the air by the increasing distance between the red contour and dashed black contour when comparing both graphics.

Figure D. Denver, Colorado upper air sounding at 5 am MST, March 26, 2006. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

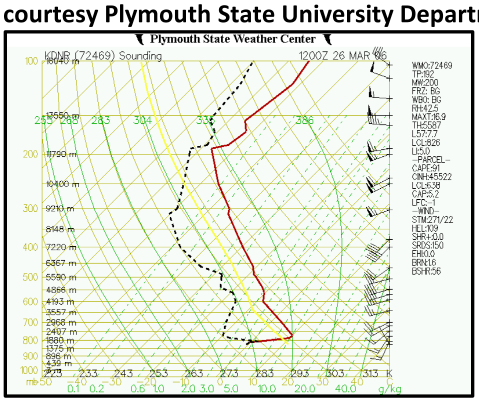
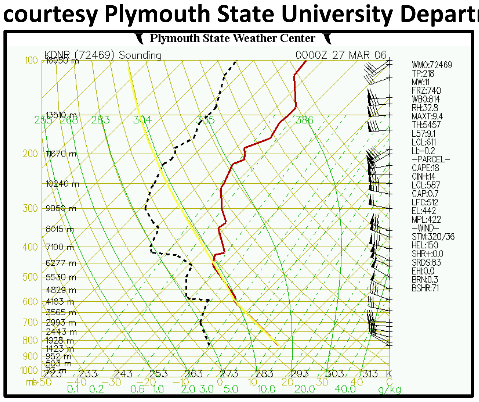


Figure E. Denver, Colorado upper air sounding at 5 pm MST, March 26, 2006. Click image to enlarge. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry.

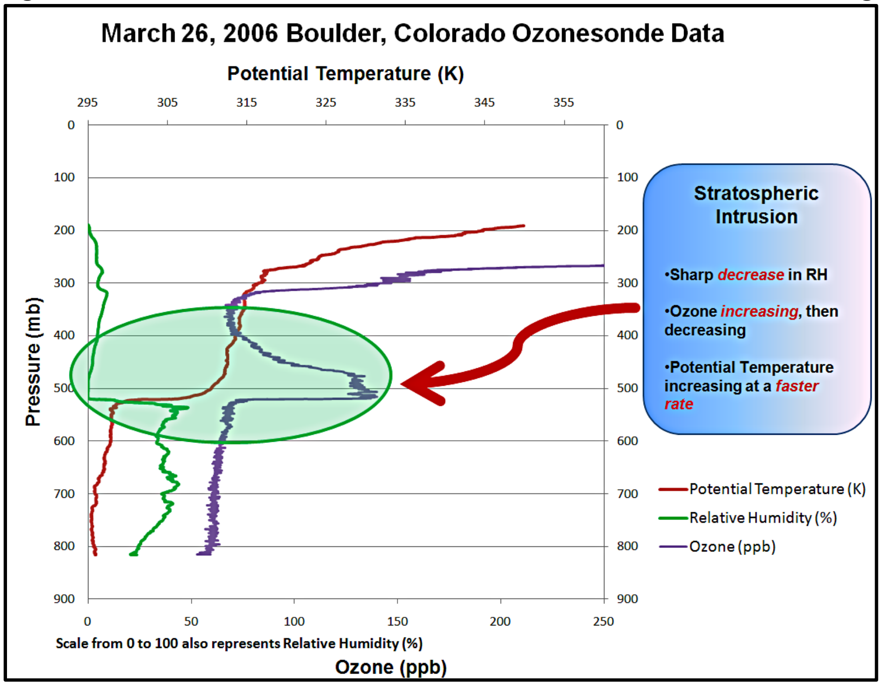


Additional evidence of an SI having occurred on March 26, 2006 comes from the Global Monitoring Division (GMD) of the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration. The GMD released weekly ozonesondes that provide ozone, relative humidity, and potential temperature data from an instrument package attached to a balloon. An ozonesonde is like a RAOB but geared specifically toward capturing ozone concentrations. The GMD launched an ozonesonde on March 26, 2006 at 12:56 pm MST from Boulder, Colorado while an SI passed overhead. Figure F depicts the instrument flight data in

[18] Atmospheric pressure increases with altitude. When one descends in the atmosphere, pressure values increase.

the vertical. The SI is identified by its signature: a layer of dry air, higher ozone concentrations, and a potential temperature contour that steepens sharply indicating a fast rate of increase.

Figure F. Boulder, Colorado ozonesonde data from March 26, 2006. Click image to enlarge.



Supporting Meteorological Data: Isentropic Potential Vorticity, Relative Humidity, and Potential Temperature Cross-Sections

Using the 20-km RUC 0-hour analysis in time series, one can view the lifecycle of an SI. Figure G shows a map view where the cross-section was taken for use in this analysis.

Figure G. Map view of analysis cross-section. Click image to enlarge.

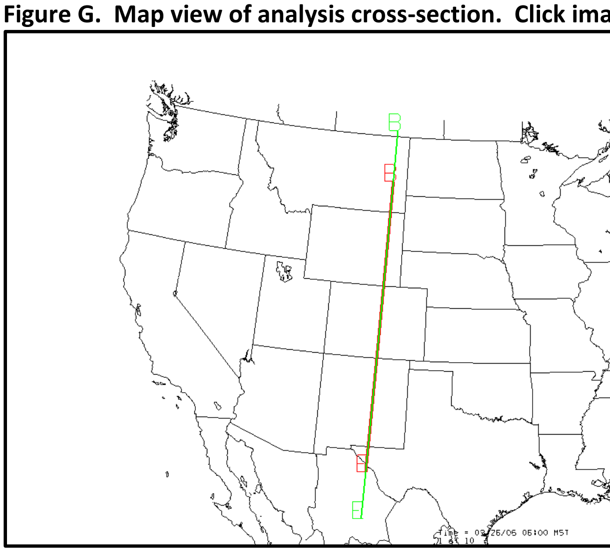


Figure H depicts IPV and PT along with a map view of the 500 mb heights and vorticity at 11 am March 26, 2006. The Denver-Colorado Springs I-25 corridor is approximately in the middle of the cross-section. The animated loop illustrates the 1-unit IPV surface descending along with the steeply sloping potential temperature surfaces, a clear SI signature. The right side of Figure H reveals that the passage of the 500mb storm system vorticity core over the Denver-Colorado Springs I-25 corridor corresponds to the 1-unit IPV surface having reached its lowest altitude.

Figure H. 11 am March 26, 2006 cross-section of IPV and potential temperature (left panel). 500 mb heights (black)/vorticity (blue-red) (right panel). Click image to enlarge. Click here for a time animation from 6 am to 3 pm, March 26, 2006.

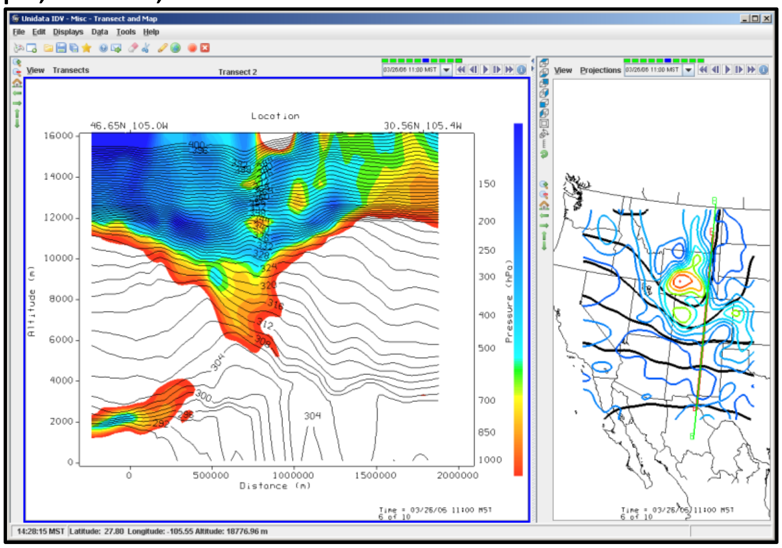
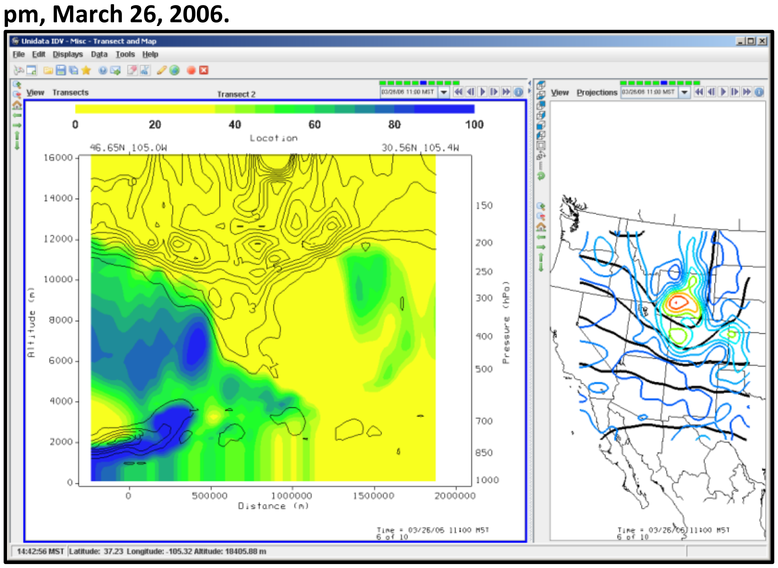


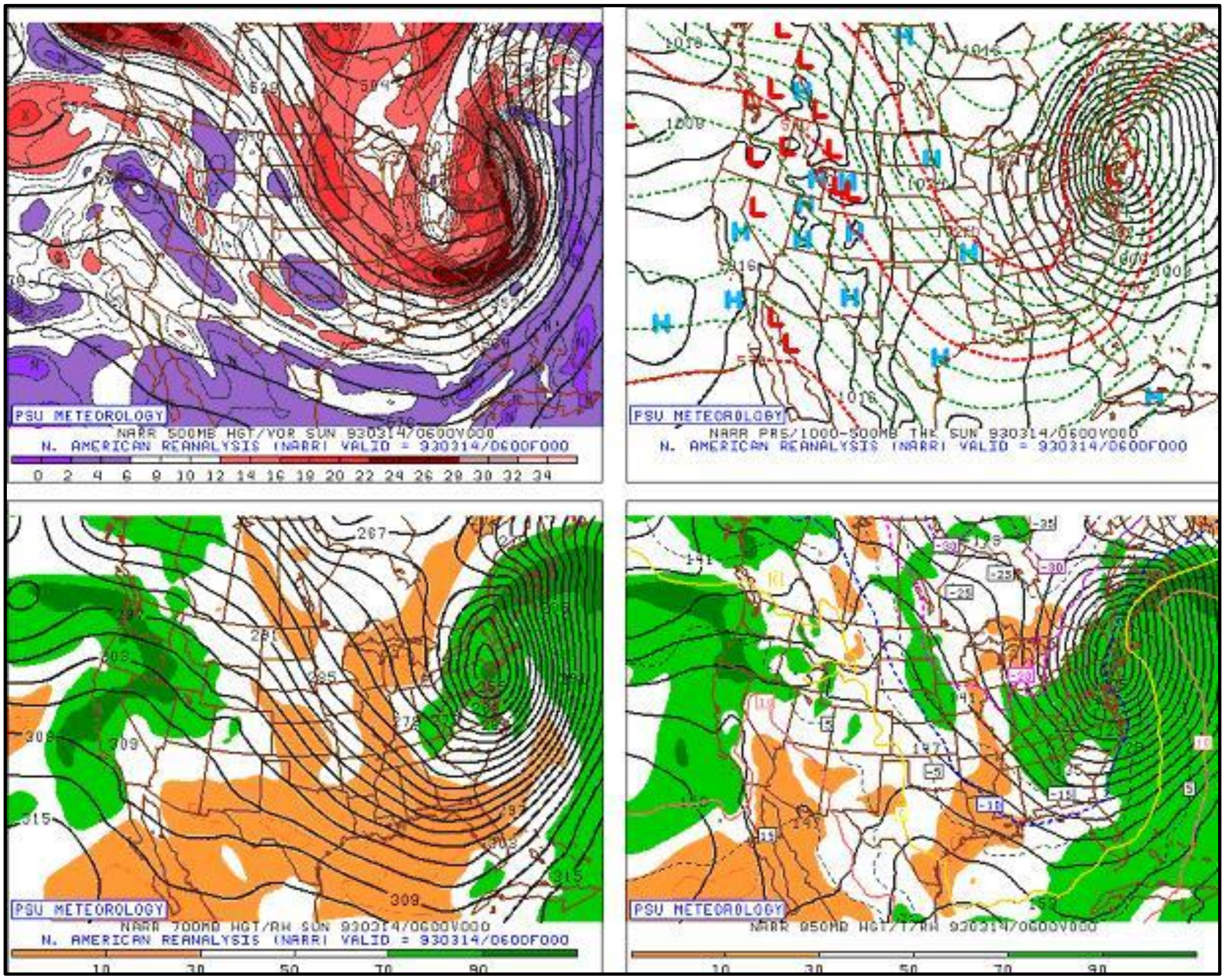
Figure I depicts IPV and RH along the same Denver-Colorado Springs I-25 corridor as in Figure 16. In the area where 1-unit of IPV descended to its lowest altitude, the air entrained was significantly drier than the air surrounding the intrusion. The combination of descending IPV and low RH air is another aspect supporting the presence of an ozone-rich stratospheric intrusion.

Figure I. 11 am MST March 26, 2006 cross-section of IPV and relative humidity (left panel). 500 mb heights (black)/vorticity (blue-red) (right panel). Click image to enlarge. Click here for a time animation from 6 am to 3 pm, March 26, 2006.



APPENDIX C - NARR Explained

Example of the 4-panel NARR plot of 500 mb heights and vorticity, 700 mb heights and relative humidity, surface pressure and 1000-500 mb thickness, and 850 mb heights, temperature, and relative humidity. Explanation on how to interpret this chart follows. Graphic and NARR description courtesy Fred Gadomski and the Penn State University Department of Meteorology.



NARR 500mb Heights and Vorticity Panel – Top Left

The 500mb Heights and Vorticity Panel can be used to describe the steering flows of the atmosphere. These steering flows are located about 20,000 feet up (about halfway through the atmosphere) and generally direct major weather systems across the country. The black contours are isohypse (lines of constant height), and are contoured every 6 dm (the values on the isohypse are in decameters, i.e. 570 would actually be 5700m). The height of the 500mb level is how far you would have to go up in the atmosphere before the pressure drops to 500mb. Lower heights are usually found to the north while higher heights are usually found off to the south.

The red and purple shading on the map indicate areas of vorticity in the atmosphere. Vorticity is a measure of rotation throughout the atmosphere. Vorticity can either strengthen or weaken storm systems. Areas of red shading on the panel indicate positive vorticity, while areas of purple shading indicate negative vorticity. The darker the shading is, the stronger the vorticity. Areas of positive vorticity can strengthen areas of low pressure, and are sometimes referred to as "upper-level disturbances" or "upper-level energy". The numbers on the map near areas of vorticity indicate the magnitude of the vorticity.

NARR 700mb Heights and Relative Humidity Panel – Bottom Left

The 700mb Heights and Relative Humidity Panel is an important panel used by meteorologists. The black contours are isohypse at the 700mb level (roughly 10,000ft), and are contoured every 3dm (the isohypse are in decameters, so 300dm is actually 3000m). The height of the 700mb level is how far you would have to go up in the atmosphere before the pressure drops to 700mb. The green and brown shading indicates the amount of relative humidity in the atmosphere at 700mb. (NOTE: This is NOT the relative humidity found at the surface). The green shading represents areas with a 700mb RH greater than 70% as indicated by the legend below the panel. Darker green shaded regions represent areas that have a 700mb RH greater than 90%. Light brown areas are regions where 700mb RH is less than 30%, with dark brown areas less than 10%. White areas on the map indicated regions where the RH is between 30% and 70%.

NARR Surface Pressure and 1000-500mb Thickness Panel – Top Right

The Surface Pressure and 1000-500mb Thickness Panel is useful when predicting where storm systems are moving and the type of precipitation that may fall from them. The black lines on this panel are isobars, (lines of constant pressure), and are contoured every four millibars (mb). Some of the isobars are labeled with numbers that usually range from 960mb (a strong low-pressure system), to 1050mb (a strong high pressure system). Low pressure systems are denoted by a red "L" while high pressure systems are denoted by a blue "H".

The red and green dashed contours on the map are 1000-500mb thickness contours. The 1000-500mb thickness is the average depth of a column of air from 1000mb (surface level) to 500mb. The thickness can also be inferred to be the average temperature of a column of air from 1000mb to 500mb. The red dashed thickness contours are primary thickness contours (contoured every 30dm, the value on the thickness contours is in decameters), while the green dashed contours are secondary thickness contours (contoured every 6dm). The three primary thickness contours on the panel above are 510dm, 540dm, and 570dm. Thickness values lower than 510dm usually represent a dry, arctic air mass found in Canada or along the northern portion of the United States during winter, while thickness values higher than 570dm usually represent a warm and moist tropical air mass from the south. Thickness values can also be very useful in forecasting the different precipitation types from winter storm systems. More information on this can be found here.

850mb Temperature, and Relative Humidity

The 850mb Temperature and Relative Humidity panel is used by forecasters to get a general sense of what is going on in the lower-levels of the atmosphere just above ground level. The 850mb level is about 1500m above ground level, and is a valuable level to use when forecasting different the precipitation types associated with major winter storms.

The 850mb relative humidity (like the 700mb relative humidity), is scaled from 0% to 100%, with low humidity values shaded in a dark brown, and high humidity values shaded in a dark green. The difference between the relative humidity at 700mb and the relative humidity at 850mb is that the 850mb RH samples the lower-levels of the atmosphere and can be used to determine if low clouds such as stratus will form. It can also be used to give an estimate of the low level moisture in the atmosphere if you know the temperature of the air.

The other contours on the map are isotherms. The yellow contour on the map labeled with a 0 is the 850mb 0°C isotherm. Isotherms in intervals of 5°C are shown as well, with the -10°C isotherm shown as a blue dashed line, the -20°C shown as a pink dashed line, the 10°C isotherm shown as a solid orange line, and the 20°C isotherm shown as a solid red line.

APPENDIX D - AQS Data – AMP 350, Raw Data Report for Big Piney, Boulder, South Pass, Daniel, Pinedale, Juel Spring, Yellowstone and Grand Teton National Parks 1-hour average ozone for June 13-16, 2012 (Click image to read report).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

User ID: RBN

RAW DATA REPORT

Report Request ID: 1090534 | Report Code: AMP350 | Apr. 26, 2013

GEOGRAPHIC SELECTIONS

Tribal Code	State	County	Site	Parameter	POC	City	AQCR	UAR	CBSA	CSA	EPA Region	Method	Duration	Begin Date	End Date
	56	035	0700												
	56	035	0099												
	56	013	0099												
	56	035	0100												
	56	035	0101												
	56	035	1002												
	56	039	1011												
	56	039	0008												

PROTOCOL SELECTIONS

Parameter Classification	Parameter	Method	Duration
CRITERIA	44201		

SELECTED OPTIONS

Option Type	Option Value
RAW DATA EVENTS	INCLUDE EVENTS
DAILY STATISTICS	MAXIMUM
UNITS	STANDARD
MERGE PDF FILES	YES
INCLUDE NULLS	YES

SORT ORDER

Order	Column
1	STATE_CODE
2	COUNTY_CODE
3	SITE_ID
4	PARAMETER_CODE
5	POC

GLOBAL DATES

Start Date	End Date
2012 06 13	2012 06 16

APPLICABLE STANDARDS

Standard Description
Ozone 1-hour Daily 2005

Selection Criteria Page 1

APPENDIX E - AQS Data – AMP 350NW, Raw NAAQS Ozone Average Data Report for Big Piney, Boulder, South Pass, Daniel, Pinedale, Juel Spring, Yellowstone and Grand Teton National Parks for June 13-16, 2012 (Click image to read report).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

User ID: RBN

RAW DATA NAAQS AVERAGES

Report Request ID: 1090537 Report Code: AMP350NW Apr. 26, 2013

GEOGRAPHIC SELECTIONS

Tribal Code	State	County	Site	Parameter	POC	City	AQCR	UAR	CBSA	CSA	EPA Region	Method	Duration	Begin Date	End Date
	56	035	0700												
	56	035	0099												
	56	013	0099												
	56	035	0100												
	56	035	0101												
	56	035	1002												
	56	039	1011												
	56	039	0008												

PROTOCOL SELECTIONS

Parameter Classification	Parameter	Method	Duration
CRITERIA	44201		

SELECTED OPTIONS

Option Type	Option Value
SINGLE EVENT PROCESSING	INCLUDE EVENTS
DAILY STATISTICS	MAXIMUM
MERGE PDF FILES	YES

SORT ORDER

Order	Column
1	STATE_CODE
2	COUNTY_CODE
3	SITE_ID
4	PARAMETER_CODE
5	POC

GLOBAL DATES

Start Date	End Date
2012 06 13	2012 06 16

APPLICABLE STANDARDS

Standard Description
Ozone 8-Hour 2008

Selection Criteria Page 1

APPENDIX F - AQS Data – AMP 350, Raw Data Report for Big Piney, Boulder, South Pass, Daniel, Pinedale, Juel Spring, Yellowstone and Grand Teton National Parks all air quality and meteorological parameters for June 13-16, 2012 (Click image to read report).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

User ID: RBN

RAW DATA REPORT

Report Request ID: 1090541 Report Code: AMP350 Apr. 26, 2013

GEOGRAPHIC SELECTIONS

Tribal Code	State	County	Site	Parameter	POC	City	AQCR	UAR	CBSA	CSA	EPA Region	Method	Duration	Begin Date	End Date
	56	035	0700												
	56	035	0099												
	56	013	0099												
	56	035	0100												
	56	035	0101												
	56	035	1002												
	56	039	1011												
	56	039	0008												

PROTOCOL SELECTIONS

Parameter Classification	Parameter	Method	Duration
ALL			

SELECTED OPTIONS

Option Type	Option Value
RAW DATA EVENTS	INCLUDE EVENTS
DAILY STATISTICS	MAXIMUM
UNITS	STANDARD
MERGE PDF FILES	YES
INCLUDE NULLS	YES

SORT ORDER

Order	Column
1	STATE_CODE
2	COUNTY_CODE
3	SITE_ID
4	PARAMETER_CODE
5	POC

GLOBAL DATES

Start Date	End Date
2012 06 13	2012 06 16

APPLICABLE STANDARDS

Standard Description
CO 1-hour 1971
Lead 3-Month 2009
Lead 3-Month PM10 Surrogate 2009
Lead Quarterly 1978
NO2 Annual 1971
Ozone 1-hour Daily 2005
PM10 24-hour 2006
PM25 24-hour 2006
SO2 1-hour 2010

Selection Criteria Page 1

APPENDIX G - AQS Data – AMP 350, Raw Data Report for the State of Idaho all air quality and meteorological parameters for June 13-16, 2012 (Click image to read report).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

User ID: RBN

RAW DATA REPORT

Report Request ID: 1090520 Report Code: AMP350 Apr. 26, 2013

GEOGRAPHIC SELECTIONS

Tribal Code	State	County	Site	Parameter	POC	City	AQCR	UAR	CBSA	CSA	EPA Region	Method	Duration	Begin Date	End Date
	16														

PROTOCOL SELECTIONS

Parameter Classification	Parameter	Method	Duration
ALL			

SELECTED OPTIONS

Option Type	Option Value
RAW DATA EVENTS	INCLUDE EVENTS
DAILY STATISTICS	MAXIMUM
UNITS	STANDARD
MERGE PDF FILES	YES
INCLUDE NULLS	YES

SORT ORDER

Order	Column
1	STATE_CODE
2	COUNTY_CODE
3	SITE_ID
4	PARAMETER_CODE
5	POC

GLOBAL DATES

Start Date	End Date
2012 06 13	2012 06 16

APPLICABLE STANDARDS

Standard Description
CO 1-hour 1971
Lead 3-Month 2009
Lead 3-Month PM10 Surrogate 2009
Lead Quarterly 1978
NO2 Annual 1971
Ozone 1-hour Daily 2005
PM10 24-hour 2006
PM25 24-hour 2006
SO2 1-hour 2010

Selection Criteria Page 1

APPENDIX H - 2012 2nd and 4th Quarter QA Audit Reports (Click images to read reports).

SECOND QUARTER 2012 QUALITY ASSURANCE AUDIT REPORT

for the

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY AIR MONITORING NETWORK

Prepared for

Wyoming Department of Environmental Quality
Air Quality Division
Herschler Building
122 W. 25th St.
Cheyenne, WY 82002

JUNE 2012

Prepared by

TECHNICAL & BUSINESS SYSTEMS, INC.

26074 AVENUE HALL, UNIT 9

VALENCIA, CA 91355

(661) 294-1103

FOURTH QUARTER 2012 QUALITY ASSURANCE AUDIT REPORT

for the

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY AIR MONITORING NETWORK

Prepared for

Wyoming Department of Environmental Quality
Air Quality Division
Herschler Building
122 W. 25th St.
Cheyenne, WY 82002

JANUARY 2013

Prepared by

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