Technical Support Documentation
EPA Region 8 Review of a Flagging Demonstration by the
Wyoming Department of Environmental Quality, Division of Air Quality
Ozone NAAQS Exceedances Occurring June 14, 2012
Big Piney and Boulder Monitoring Station.

1.0 EXCEPTIONAL EVENTS RULE REQUIREMENTS

The U. S. Environmental Protection Agency promulgated the Exceptional Events Rule (EER) in 2007, pursuant to the 2005 amendment of Clean Air Act (CAA) Section 319. 42 U.S.C. §7619. The EER added 40 CFR 50.1(j), (k) and (l); 50.14; and 51.930 to the Code of Federal Regulations (CFR). These sections contain definitions, criteria for the EPA approval, procedural requirements, and requirements for air agency demonstrations, all of which must be met before the EPA can concur under the EER on the exclusion of air quality data from regulatory decisions.

Under 40 CFR 50.14(c)(3)(iv), the air agency demonstration to justify exclusion of data must provide evidence that:

A. The event satisfies the criteria set forth in 40 CFR §50.1(j) for the definition of an exceptional event;
    - The event affects air quality;
    - The event is not reasonably controllable or preventable; and
    - The event is caused by human activity that is unlikely to recur at a particular location or [is] a natural event.[1]
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.

[1] A natural event is further described in 40 CFR 50.1(k) as "an event in which human activity plays little or no direct causal role".

2.0 Background (General Discussion Prepared by the EPA)

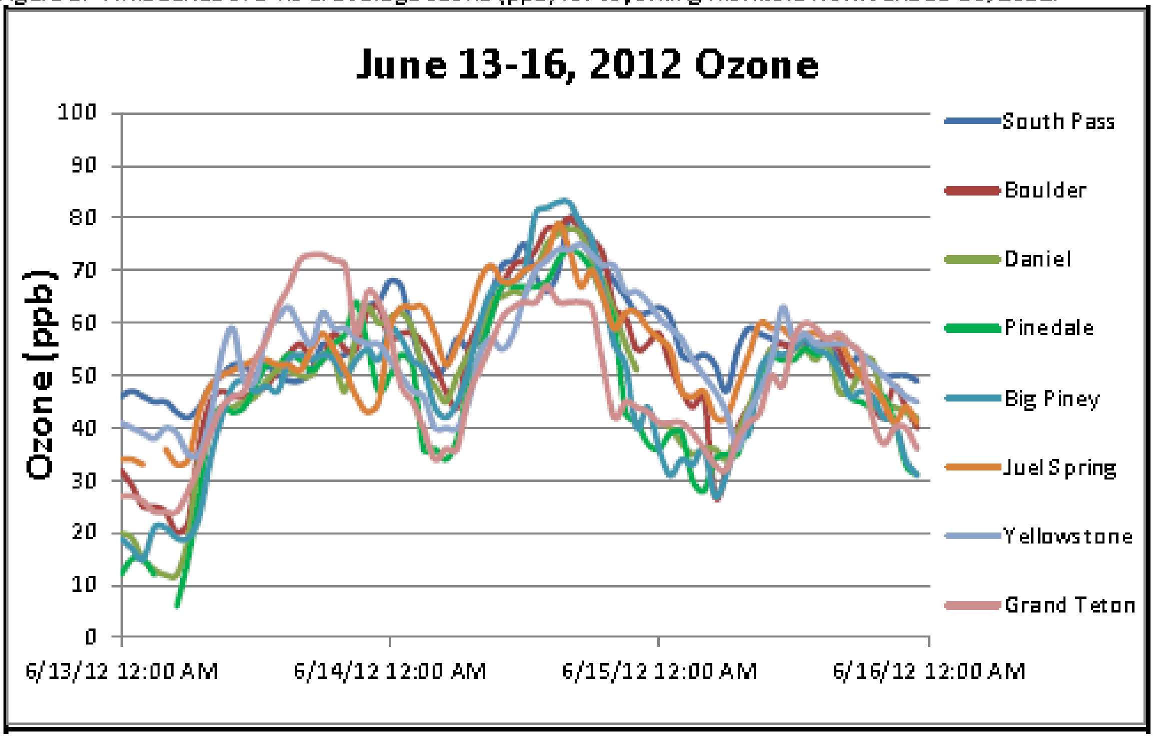
In the era of the 120 ppb 1-hour ozone National Ambient Air Quality Standard (NAAQS), stratospheric ozone intrusions impacting the NAAQS were extremely rare. Often, as in the case of an intrusion documented by Lamb, occurring in Santa Rosa, California overnight on November 19, 1972, they involved extreme weather events, and very rare circumstances which brought stratospheric concentrations of ozone (typically hundreds of ppb) directly in contact with surface ozone monitors.[2]

With the ozone NAAQS now defined as an 8-hour average of 75 ppb, stratospheric intrusions with a less distinct signature on ground level monitors can lead to exceedances of the ozone standard. For a number of reasons, stratospheric intrusion traces on surface monitors can mimic traces from local photochemical ozone production. For example, if a tropopause fold such as that in the Santa Rosa intrusion places stratospheric ozone in the mid- or lower troposphere above an ozone monitor, and that ozone is initially isolated from the ground by morning surface temperature inversions, then solar heating through the morning can lead to mixing of that ozone aloft down to the surface around mid-day, which is also when ozone concentrations typically rise due to photochemistry. For this reason, stratospheric impacts can present a monitored trace very much like that seen for a “normal” ozone day. This is illustrated in figure 1, which is figure 5 from the Wyoming Department of Environmental Quality (DEQ) demonstration for the June 14, 2012 exceptional event.

[2] Santa Rosa data does not appear in AQS until 1976, so this 1972 data is not in (or flagged in) AQS.

Figure 1 Time series of hourly ozone measurements from western Wyoming ozone monitors on June 13-16 2012. Flagged exceedances were at Big Piney and Boulder.[3]

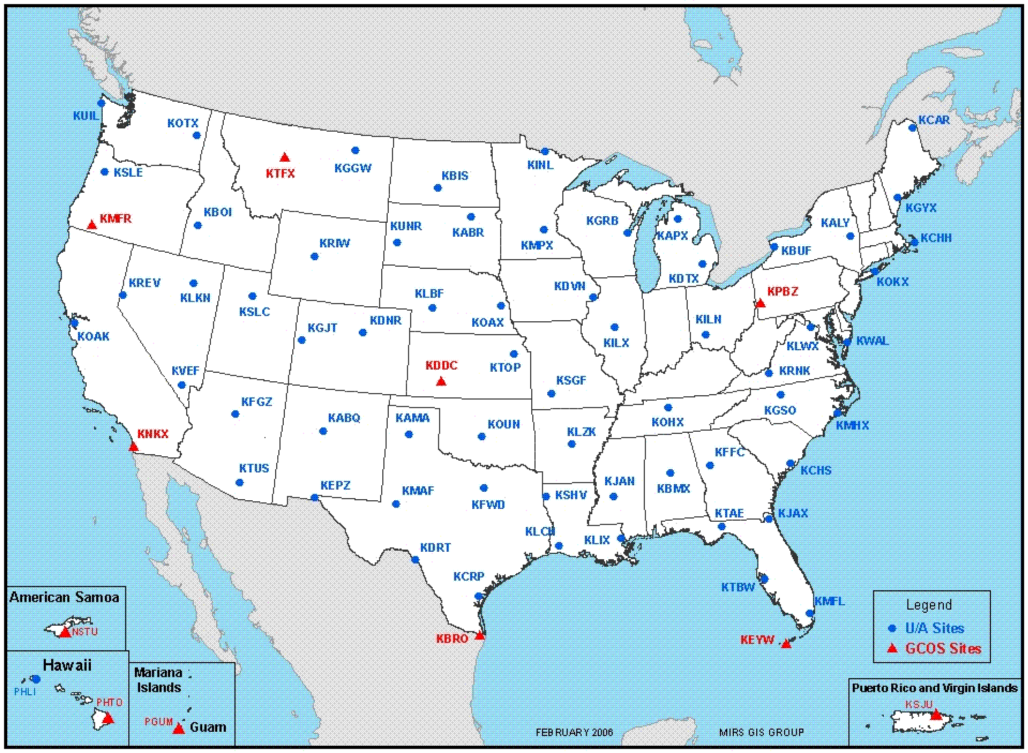
Figure 5. Time series of 1-hour average ozone (ppb) for Wyoming monitors from June 13-16, 2012.



In addition to ozone, stratospheric air is generally depleted in carbon monoxide and water vapor, relative to normal surface air. Isotopes of beryllium created from nitrogen and oxygen in the stratosphere by cosmic ray impacts can also be used as tracers for stratospheric air. Of these associated compounds, beryllium measurements are only very rarely made on a purely research basis, carbon monoxide measurements away from urban carbon monoxide sources and at the trace level sensitivities needed to detect depletions due to intrusions are very rare, and low relative humidity is often a characteristic of both the regions where stratospheric intrusion is most likely (high-elevation western locations), and can be a feature of the weather systems associated with the intrusions (dry air behind frontal passages). Vertical measurements of either ozone or the associated tracers are even rarer than surface measurements of those compounds. Vertical measurements of humidity are most common, occurring twice daily via balloon launch at midnight and noon Coordinated Universal Time at the National Weather Service Upper Air Observation Sites shown in figure 2.

[3] Exceptional Event Demonstration Package for the Environmental Protection Agency,
Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012, Wyoming DEQ, June 2013, p. 18.

Figure 2 National Weather Service Upper Atmosphere Observation Program twice daily balloon launch stations for temperature and humidity profiles



Direct vertical profile measurements of ozone concentration are much rarer. NOAA launches ozonesondes at a few sites in the U. S. approximately once per week on an intermittent or historic basis, including at Boulder, Colorado; Trinity Head, California; Hilo, Hawaii; Naragansett, Rhode Island; and Barrow, Alaska. Vertical ozone profiles are being collected on an intermittent basis using ground based differential absorption lidar (DIAL) systems at the University of Alabama, Huntsville; Boulder, Colorado; and at the Jet Propulsion Laboratory Table Mountain Observatory northeast of Pasadena on the north side of the San Bernardino Mountains in southern California. Vertical profiles of the stratosphere and upper troposphere were being generated by the High Resolution Dynamic Limb Sounder aboard the EOS Aura satellite early in its flight in 2005 and 2006, but are no longer available after instrument performance degradation.

Given the lack of direct vertical measurement of ozone, and the scarcity of vertical and surface measurement of stratospheric ozone tracers, evidence of stratospheric intrusion must generally be inferential. For this reason, the typical Wyoming DEQ intrusion demonstration begins with general background information on the atmospheric structure and meteorology most likely to lead to stratospheric intrusions impacting surface ozone measurements, and available meteorological diagnostic data available for intrusion forecasting and post event analysis. The general introductory portion of the demonstration prepared by the Wyoming DEQ is included as Appendix A of this TSD. The original Wyoming DEQ document, including active web links, can be found at http://deq.state.wy.us/aqd/Exceptional%20Events/June_14_2012BigPineyBoulder/June_14_2012_Big Piney_Boulder_SI_Package.pdf.

3.0 Evaluation of Demonstration Elements

3.1 Affects Air Quality

Figure 6 of the Wyoming demonstration, shown here as figure 3, shows the maximum ozone air quality index on June 14, 2012 for the U. S. In addition to Boulder and Big Piney, ozone exceedances were recorded on June 14 in southern and central California, at Rocky Mountain National Park in Colorado, and along the central Mississippi River in the Midwest. While not addressed in the Wyoming demonstration, the Colorado Department of Public Health and Environment (CDPHE) and the National Park Service also flagged elevated and exceedance ozone data in the Denver ozone nonattainment area with the stratospheric ozone flag on June 14, 2012. This Colorado data will be discussed briefly in Section 3.5 (No Exceedance But For the Event) portion of this TSD.

Figure 3 Peak 8-hour Ozone AQI for June 14, 2012; 8-hour ozone exceedances appear in orange.

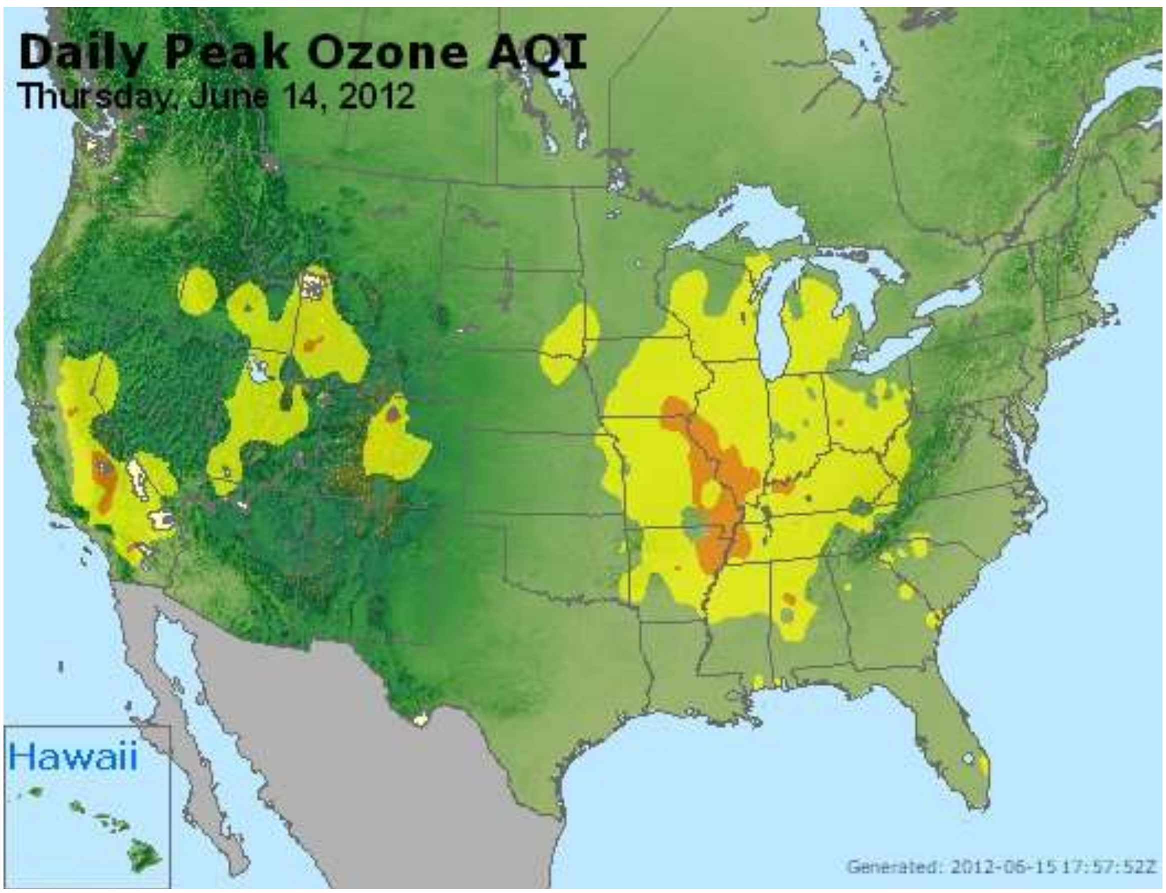


Figure 4 shows total column ozone in Dobson units, as measured by a Geostationary Operational Environmental Satellite (GOES) on June 13, 2012, with an area of enhanced total column ozone through the atmosphere extending from north central Washington southeastward through western Idaho into northeastern Nevada. On the following day, shown in figure 5 (figure 17 and 18 of the Wyoming demonstration), when the ozone exceedance was recorded at Boulder and Big Piney, total column carbon monoxide measured by satellite showed an area of minimum concentration in eastern

Idaho and western Wyoming, coincident with the area of enhanced ozone. These are suggestive of migration of ozone-enhanced (and carbon monoxide-depleted) stratospheric air downward and impacting in western Wyoming on June 14. Thus the EPA concludes that an intrusion of stratospheric air occurred over the central Rocky Mountains on June 14, 2012, and affected ozone air quality.

Figure 4 GOES Total column ozone, 11:00 a.m. June 13, 2012

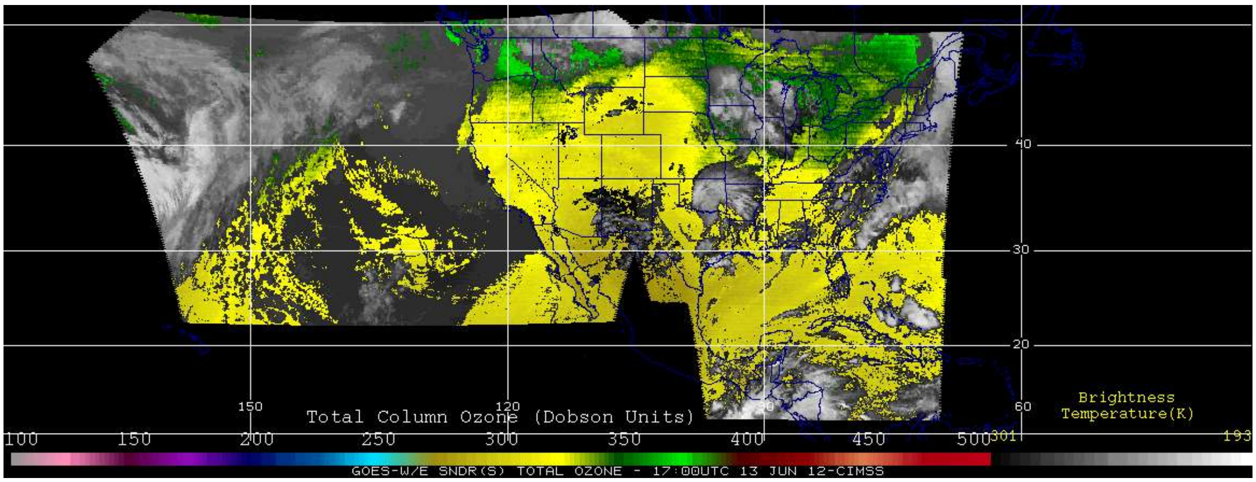


Figure 5 AIRS Total Column CO and 618 mb CO, June 14, 2012

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.

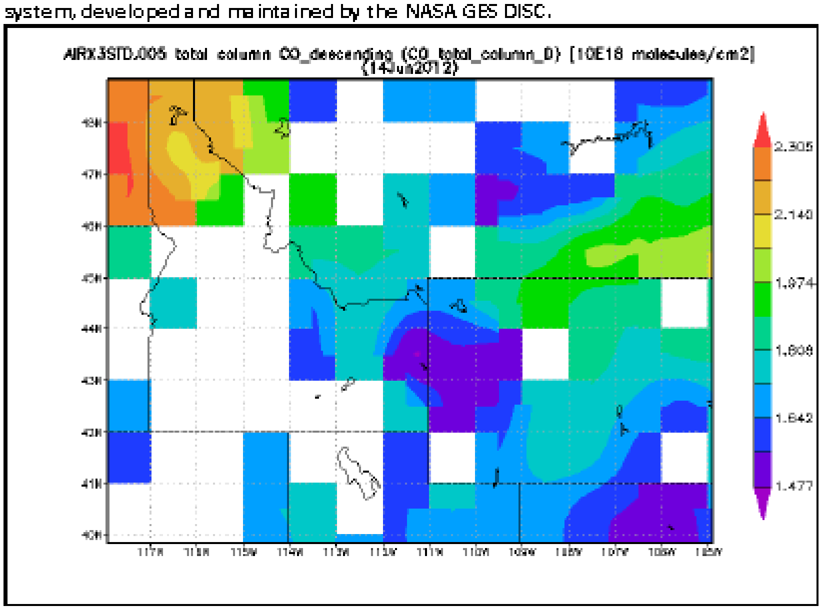
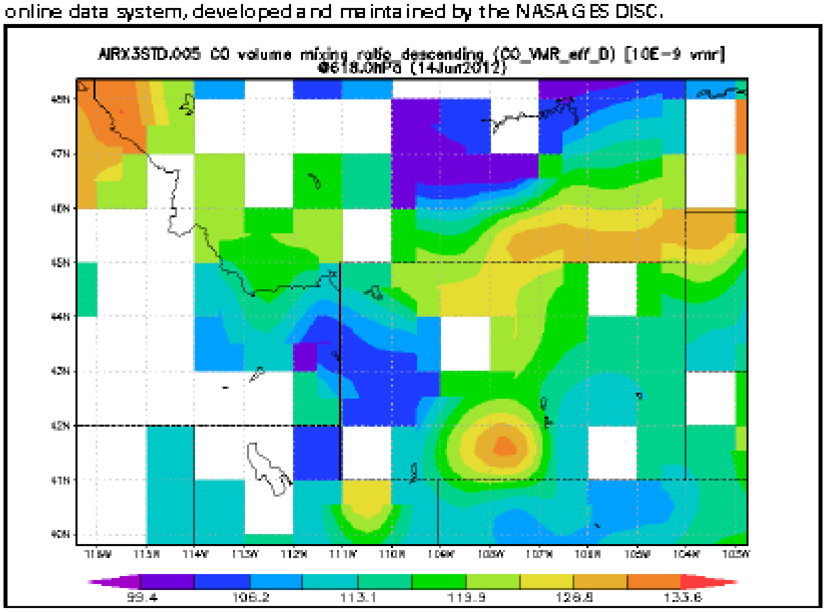


Figure 18. AIRS satellite derived CO at 618 mb (descending pass) for June 14, 2012. Figure courtesy the Giovanni online data system, developed and maintained by the NASA GES DISC.



3.2 Not Reasonably Controllable or Preventable; Natural Event

Stratospheric intrusions are clearly natural events, and are not reasonably controllable or preventable.

In addition, the two monitors impacted by this event lie within the Upper Green River 8-hour Ozone Nonattainment Area, as shown in figure 6. As a marginal ozone nonattainment area, an attainment State Implementation Plan imposing emission controls is not currently required on sources within the nonattainment area. Wyoming, however, had enrolled in the EPA Ozone Advance Program prior to the designation of the nonattainment area in 2012, and has been engaged in active emission reductions in the area since the promulgation of the 2008 ozone NAAQS. Table 2 summarizes emission reductions achieved within Sublette County (constituting the majority of the nonattainment area) through March 13, 2013, evidencing ongoing and increasing control of emission sources in the area beyond that required by its current nonattainment designation. Thus the EPA concludes that the stratospheric intrusion portion of ozone measured by the impacted monitors is not controllable, and is a natural event. In addition, local ozone precursor emissions are controlled by the emissions reduction measures in place.

Figure 6 Boulder and Big Piney Monitor Locations within the Upper Green River 8-hour Ozone Nonattainment Area

Table 2 Running Year-to-Date Emission Reductions (tons per year) Through the Upper Green River Basin New Source Review Permitting Emission Offset Demonstration Program[4]

Pollutant	2008	2008-2009	2008-2010	2008-2011	2008-2012	2008-3/13/2013
VOCs	-196.6	-1322.1	-2302.2	-3555.1	-3926.9	-4086.6
NO_x	-33.6	-606.7	-1695.2	-1545.7	-1457.2	-1484.1

[4] Letter, Steven A. Dietrich, P. E., Director, Air Quality Administrator, Wyoming DEQ to Ozone Advance, Wyoming Department of Environmental Quality – Air Quality Division's "Path Forward Letter" Submission to EPA for Ozone Advance, April 8, 2013, posted at http://www.epa.gov/ozoneadvance/participants.html, http://www.epa.gov/ozoneadvance/pdfs/Path%20Forward-Wyoming.pdf.

3.3 In Excess of Normal Historical Fluctuations

The Wyoming demonstration provided statistical analyses of historical June data for both the Boulder and Big Piney monitors, showing that June exceedances have been rare at both monitors. The demonstration provided histograms of historical 1-hour and 8-hour ozone data collected in June for the two sites, showing that the June 14, 2012 values were at the upper edge of the historical distribution. The percentile ranking of the June 14 8-hour averages relative to the entire historical data set, show that the Boulder and Big Piney values were at the 99.2958 and 100.000 (1^{st} maximum) level, respectively. Box and whisker plots of the June 8-hour data were also provided. In addition, a t-test of statistical significance when comparing the highest nine and seven hours of June 14, 2012 at Boulder and Big Piney, respectively, to all historical June data was conducted.

The requirements of 40 CFR 50.14(c)(3)(iv)(C) with respect to historical fluctuations are the same for all types of exceptional events; the demonstration must show that the event is associated with a measured concentration in excess of normal historical fluctuations, including background. In general, the additional discussion of information that might be used for this purpose in demonstrations for high wind dust events from the Interim Guidance for High Wind Dust Events[5] would also be applicable to stratospheric ozone demonstrations, and the general content provided in the Wyoming demonstration includes historical fluctuation information that is generally consistent with the type of information requested in the Guidance. In reviewing the material, however, the EPA Office of Air Quality Planning and Standards commented that the t-test of significance, in comparing the peak hours of June 14, 2012 to the mean of all data collected in all Junes when the monitors operated (2005-2012 for Boulder and 2011 and 2012 for Big Piney), neither added nor detracted from the weight of evidence of the demonstration. Given that ozone displays a diurnal pattern, generally rising in daylight hours as shown in figure 1, such a test of the high period during any June day would likely, to some degree, show a statistically significant difference from the mean of all June data. This type of test in itself does not therefore add weight to the demonstration.

A simpler presentation of data was prepared by EPA to augment the historical assessment. It emphasizes the typical nature of high ozone days in the area, and contrasts both the historical pattern in the Upper Green River Basin to the pattern in urban areas in the region, and the flagged data to the historical pattern.

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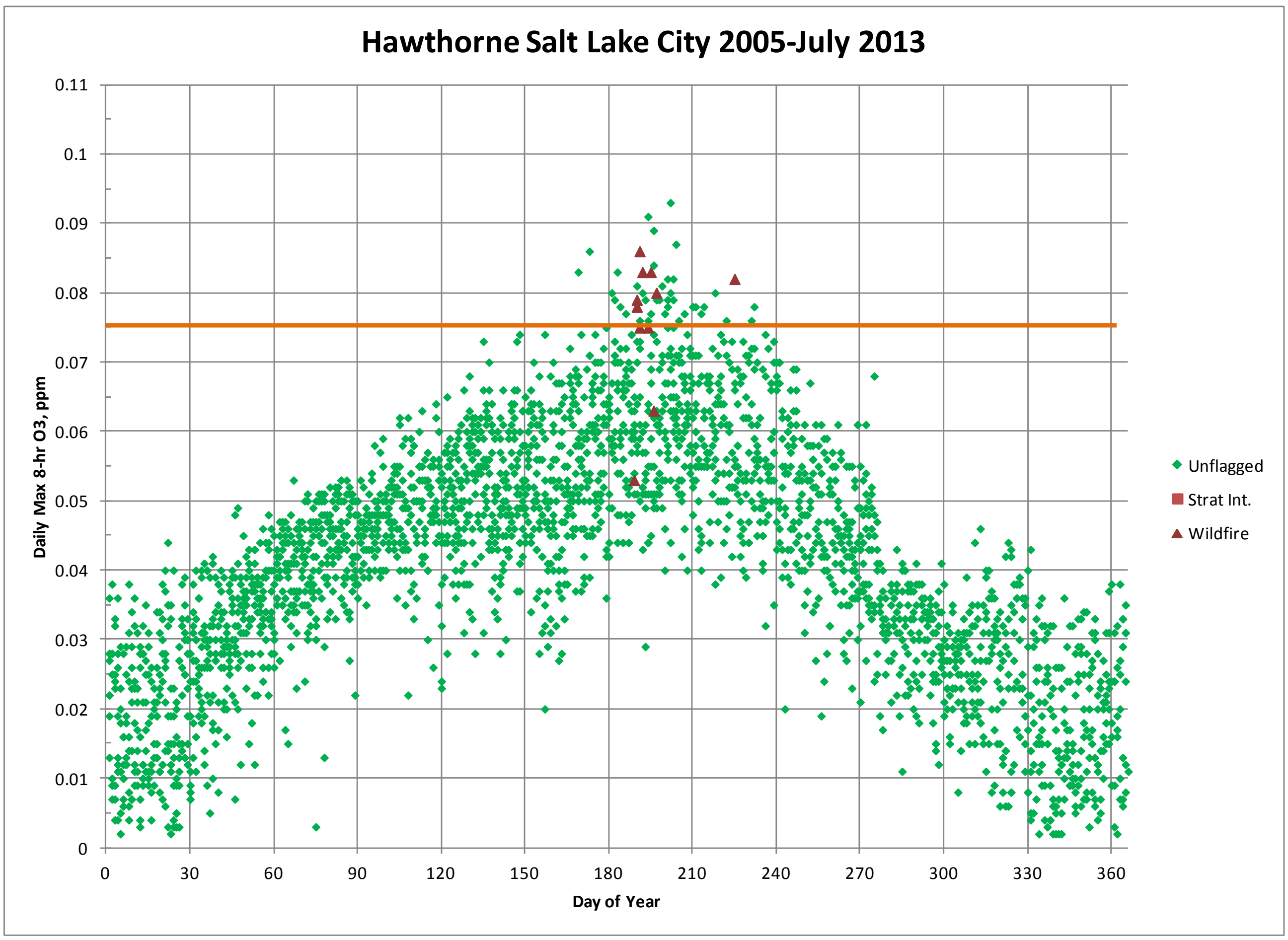
[5] Interim Guidance on the Preparation of Demonstrations in Support of Requests to Exclude Ambient Air Quality Data Affected by High Winds Under the Exceptional Events Rule, EPA, May 2013, http://www.epa.gov/ttn/analysis/docs/exceptevents_highwinds_guide_130510.pdf.

EPA Historical Data Assessment

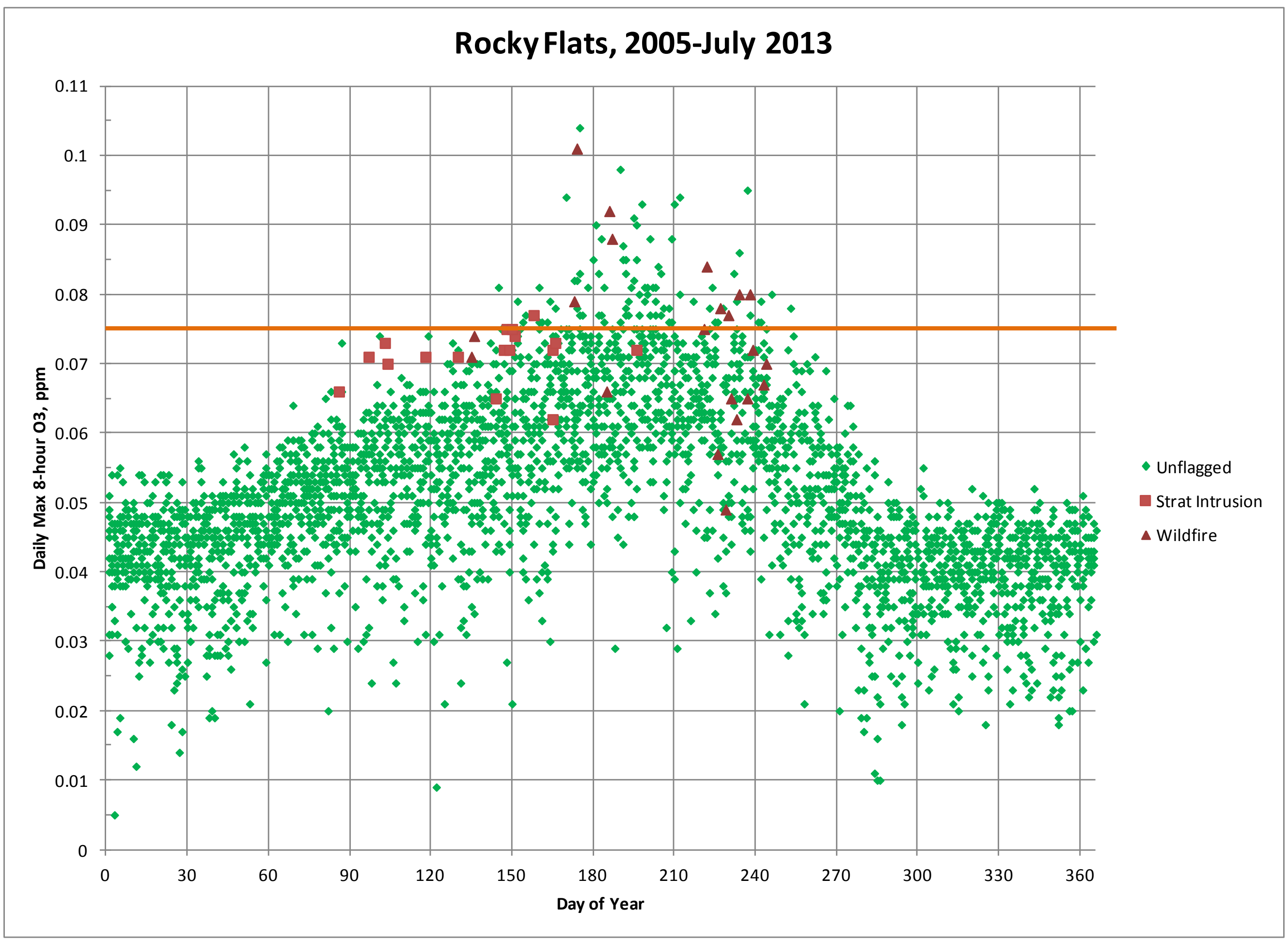
In the urban ozone areas of Region 8, local photochemical ozone production peaks in late June through August. For example, for the Hawthorne Elementary School monitor, one of two ozone monitors in the Salt Lake City Combined Statistical Area with preliminary 2011-2013 8-hour ozone design values above the NAAQS, at 76 ppb, all exceedances of the 8-hour ozone NAAQS from 2005 through July 2013 occurred in late June through August, as shown in figure 7 (in the charts, day of year 180 corresponds to June 30, or, in leap years, June 29). The majority of exceedances at Hawthorne occur during summertime stagnation conditions under regional high pressure systems. Of the three monitors that will be compared to the Wyoming flagged monitors in this EPA historical assessment of local photochemical ozone production, Hawthorne is the lowest elevation at 4,290 feet, and is the most urban, located 2.25 miles southeast of the Salt Lake City central business district.

Figure 7 Hawthorne Elementary School, Salt Lake City daily max 8-hour ozone data, 2005-July 2013; flagged data are indicated; no data has been flagged for stratospheric ozone



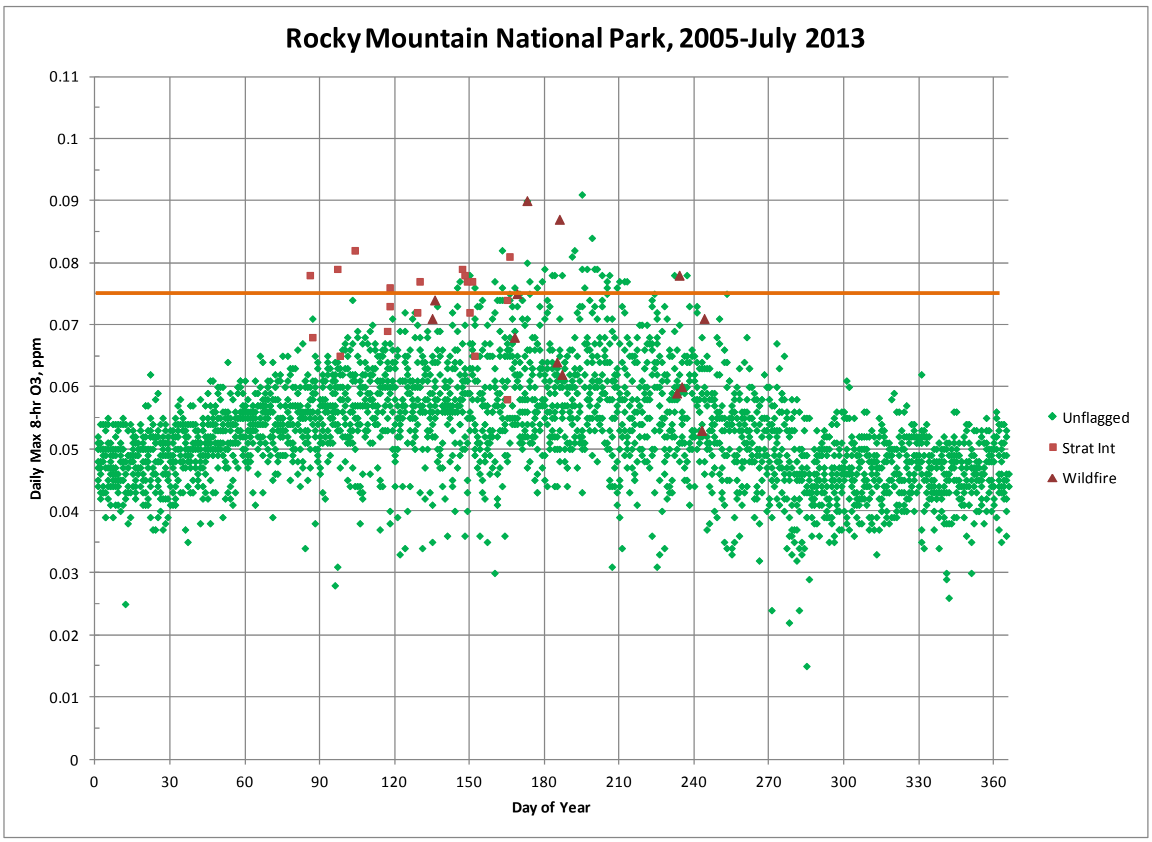
Next highest in elevation, and next in urban characteristics is one of two design value sites for the Denver 8-hour ozone nonattainment area. The Rocky Flats monitor is sited at an elevation of 5,915 feet, 13.5 miles northwest of the Denver central business district. It is about 1.4 miles west of the current edge of the nearest suburb, and about 4.5 miles east of the base of the Rocky Mountain foothills. As with Salt Lake City, the majority of exceedances occur from late June through August. Unlike Salt Lake City, however, exceedances have been observed in May and September. One exceedance day at Rocky Flats (June 7, 2011) has been flagged by CDPHE as a stratospheric ozone exceptional event. CDPHE did not begin screening data for stratospheric ozone exceptional event impacts until 2010, so at least some of the unflagged May and early June exceedances shown in figure 8 are also very likely unflagged stratospheric intrusion exceptional event exceedances, rather than exceedances caused primarily by local photochemical production. Although not an exceedance at Rocky Flats (72 ppb), CDPHE has flagged June 14, 2012 at Rocky Flats with the stratospheric ozone flag. The earlier ufflagged historical high values are no longer of regulatory significance, and flags or demonstrations are not contemplated for those values at this time. They are discussed here only in the context of historical data fluctuations.

Figure 8 Rocky Flats, Denver nonattainment area daily max 8-hour ozone data, 2005-July 2013; flagged data are indicated



The Rocky Mountain National Park ozone monitor is operated by the National Park Service (NPS) within the Denver nonattainment area. It is 45 miles northwest of the Denver central business district, at an elevation of 9,010 feet. It is on the east slope (the lee slope for prevailing westerly winds) of the 14,255- foot Longs Peak, which enhances its ability to be impacted by stratospheric ozone due to springtime down-slope westerly winds.[6] Figure 9 shows exceedances flagged by the NPS for stratospheric ozone at the request of the CDPHE as early as March and continuing through mid June. Additional exceedances from mid-May to late June from 2005-2010 were not screened by CDPHE for stratospheric impacts, but may also include stratospheric intrusion events. The Rocky Mountain National Park high-elevation monitor then shows local (Denver nonattainment area) photochemical exceedances in the late June through August timeframe as do the more urban monitors examined. The June 14, 2012 exceedance recorded by the NPS, at 81 ppb, was flagged with the stratospheric ozone flag by the NPS at the request of CDPHE, as was the 77 ppb reading recorded by the collocated CASTNET ozone monitor operated by the EPA Clear Air Markets Division at the same site.

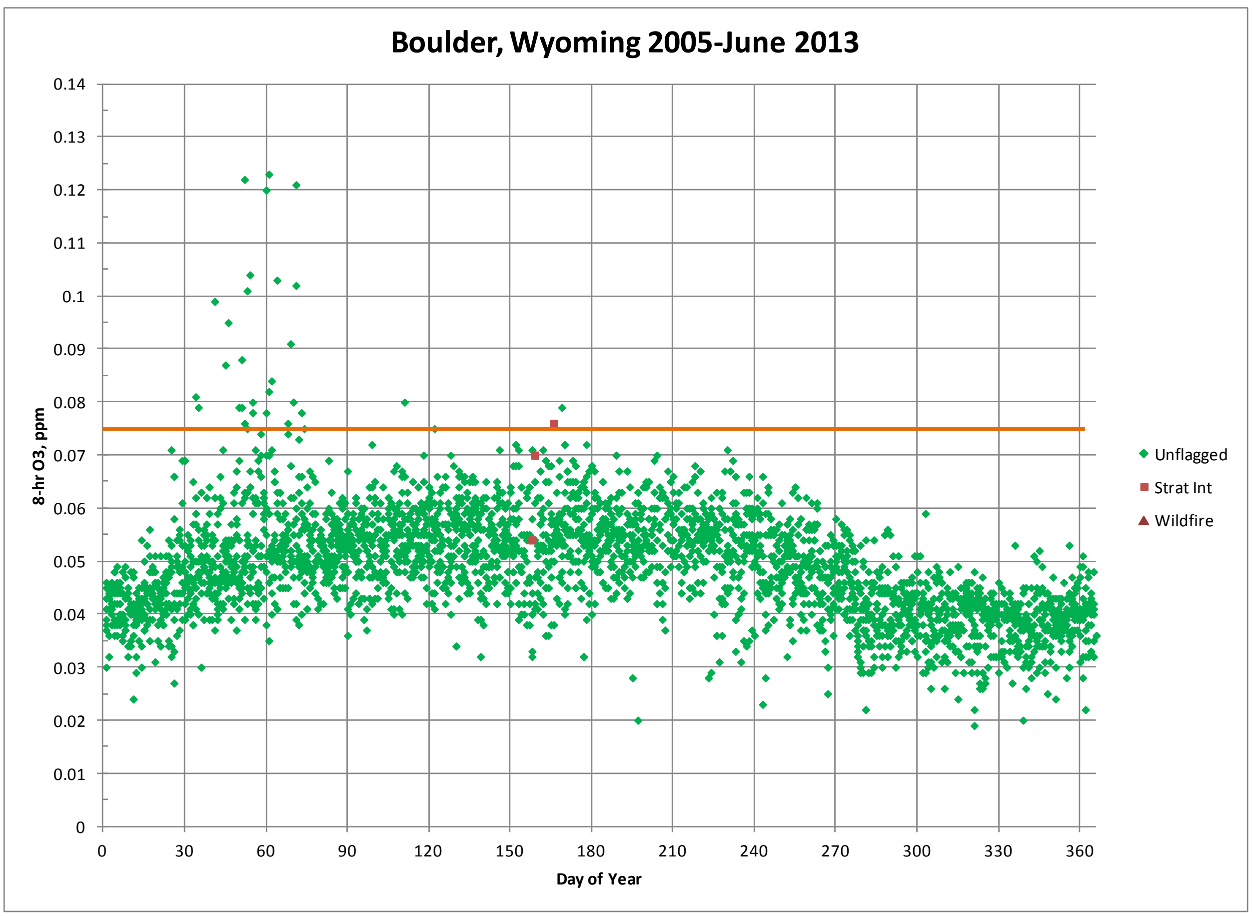
Figure 9 Rocky Mountain National Park NPS monitor, Denver nonattainment area, daily max 8-hour ozone data, 2005-July 2013; flagged data are indicated



[6] Langford, A. O., K. C. Aikin, C. S. Eubank, and E. J. Williams, Stratospheric contribution to high surface ozone in Colorado during springtime, Geophysical Research Letters, Vol. 36, L12801. While the lidar measurements found intrusions over this high elevation mountain site in all seasons, they were found to generally be shallower in summer and fall, times when deeper convective layers arrest downward motion and also provided greater dilution of any downmixed O_3. Deeper late winter and spring intrusions and downslope winds result in spring being the peak intrusion season.

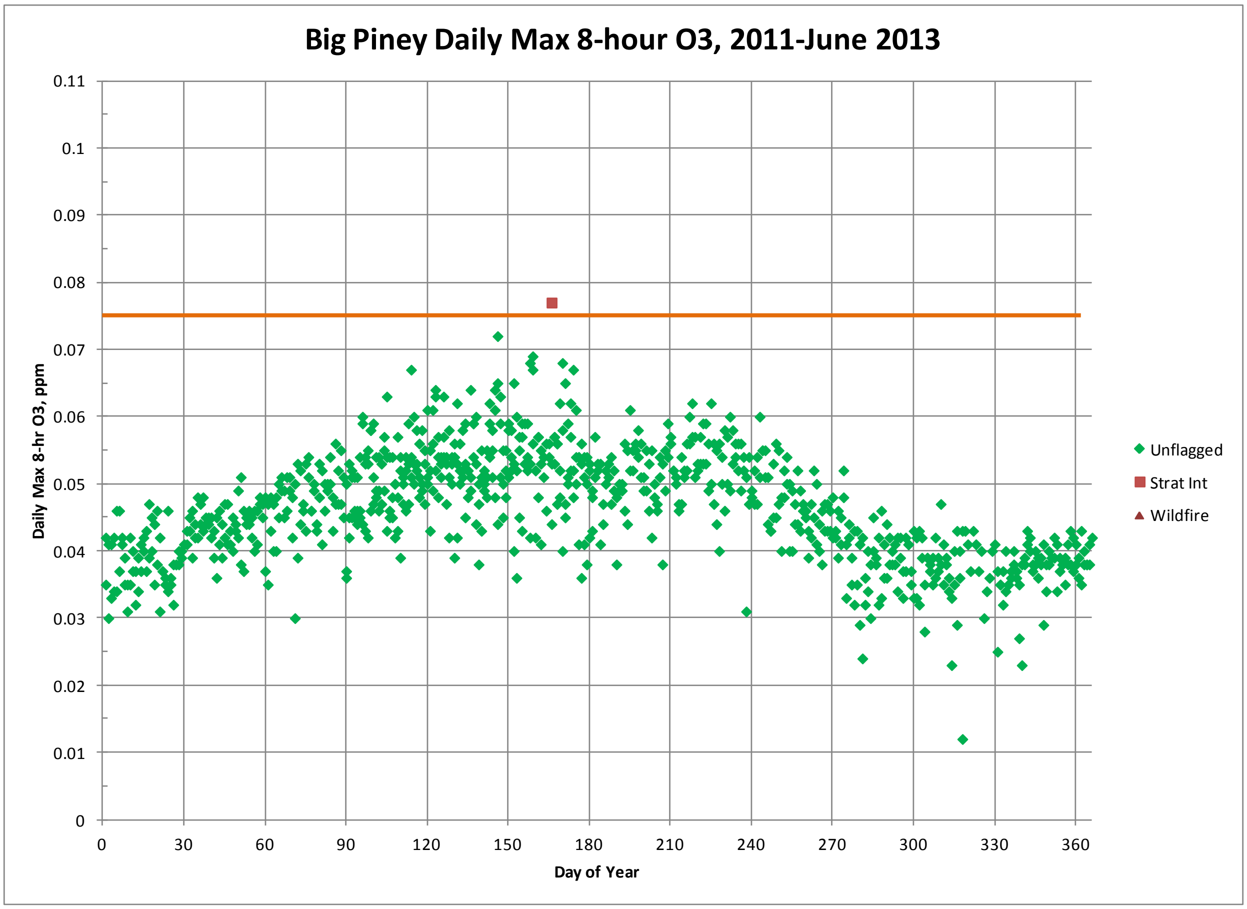
In stark contrast to the urban sites in Region 8 where peak photochemical ozone exceedances occur in late June through August, the two Wyoming sites with stratospheric ozone flags under consideration have no exceedances in July or August. For the Boulder site, one of two monitoring sites which first detected the winter ozone problem (in 2005) in what would become the Upper Green River Basin nonattainment area, the historical photochemical ozone season is February and March, as shown in figure 10. No clear ozone exceedances at Boulder due to local photochemical ozone production have occurred outside this timeframe. In addition to the June 14, 2012 exceedance flagged as stratospheric ozone for this TSD, other exceedances on April 21, 2006 and June 18, 2006 were not screened by Wyoming DEQ for stratospheric ozone impacts; given the time of year, these also could have had significant stratospheric inputs. The Boulder site is at an elevation of 7,097 feet, while the Big Piney site is at 6,820 feet. Susceptibility to stratospheric influence is expected to increase with elevation. The level of the ozone NAAQS in the first half of 2006 was 80 ppb, and the exceedances of the revised ozone standard measured in 2006 did not ultimately have regulatory significance. At this time, flags or demonstrations for these historical potential stratospheric intrusion exceedances are not anticipated, and they are mentioned here only for the purposes of the discussion of historical data fluctuations.

Figure 10 Boulder, Upper Green River nonattainment area daily max 8-hour ozone data, 2005-June 2013; flagged data are indicated



For Big Piney, less than three complete years of data have been collected through June of 2013. Big Piney began operations in 2011 only after the end of the winter ozone season, and winter ozone did not form in 2012 or 2013 due to the absence of conducive snow conditions. Consequently, the flagged exceedance of June 14, 2012 is Big Piney's only exceedance. Big Piney has seen no July or August 8-hour ozone greater than 64 ppb, considering 2011 and 2012 data in AQS and preliminary 2013 data in AIRNow, as shown in figure 11.

Figure 11 Big Piney, Upper Green River nonattainment area daily max 8-hour ozone data, 2011-June 2013



The EPA conclusion of this evaluation of historical data is that exceedances at the two flagged monitors due to local photochemical production from local emission sources appear to be very unlikely in the absence of wintertime ozone conditions (known to be the presence of relatively complete snow cover; strong, persistent temperature inversions to trap emissions for several days; and sunlight). Two unflagged exceedances from the spring and early summer of 2006 at Boulder came before Wyoming DEQ began screening data for stratospheric ozone impacts, and could represent earlier, undetected intrusion events. All other historical exceedances for the flagged monitors occurred under winter ozone conditions. No exceedances have occurred at the two monitors in July or August, when other monitors in the region with local ozone problems are most likely to exceed the NAAQS due to build up of local precursors under summer stagnation conditions associated with high pressure systems. This supports a conclusion that the June 14, 2012 exceedance was likely caused by stratospheric ozone rather than a locally produced exceedance. The EPA concludes that the flagged values on June 14, 2012 are in excess of normal historical fluctuations, including background.

3.4 Clear Causal Relationship

Given the inferential nature of the evidence, the bulk of the Wyoming demonstration is devoted to an analysis of the meteorological forcing that lead to the intrusion of stratospheric air over western Wyoming on June 14, 2012. This EPA TSD will only summarize the data from the demonstration. The Wyoming DEQ demonstration[7] provides more detailed information and explanatory discussion.

Figures 12 -14 of the Wyoming demonstration show three stills from a multiday animation of four-level meteorological maps from the North American Regional Reanalysis (NARR) model. NARR combines NOAA real time atmospheric models with global measurement data to provide archived three-dimensional math models of the historic atmosphere. The animated series of maps provided by Wyoming DEQ[8] show a strong upper level low pressure system moving across the northern U. S. from Washington at 8:00 am MST on June 13, 2012 to central Idaho at 5:00 pm, and on to the Wyoming-Montana border by 2:00 am on June 14, 2012. It is this weather system that the Wyoming demonstration shows to have provided the energy to induce the fold in the tropopause (the boundary between the troposphere and the stratosphere) that brought stratospheric air downward toward the surface south and west of the low pressure system. Figure 12 of this TSD (figure 14 of the Wyoming demonstration) shows a still from the animation, with the low pressure system over the Wyoming-Montana border at 2:00 am on June 14, 2012.

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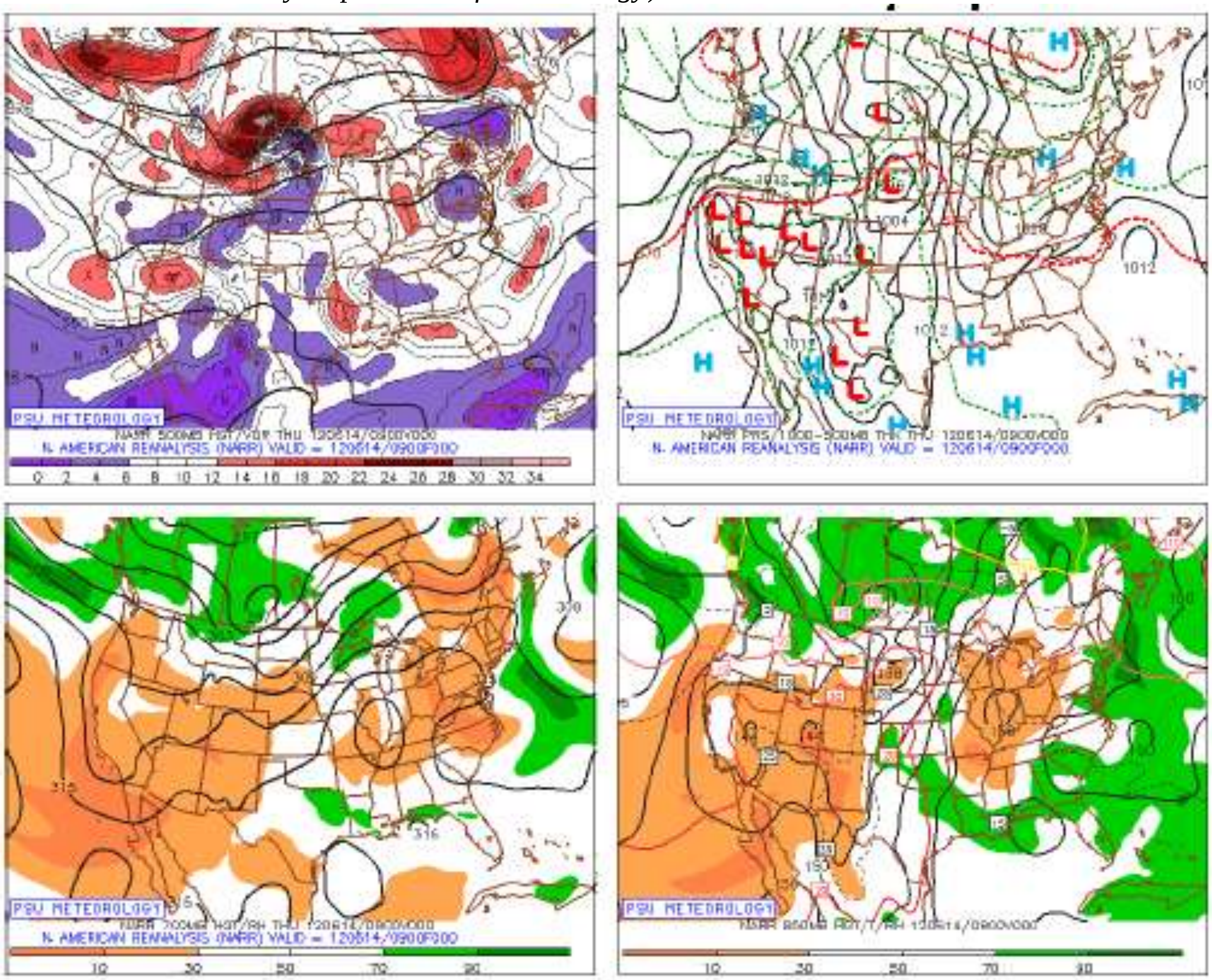
[7] http://deq.state.wy.us/aqd/Exceptional%20Events/June_14_2012BigPineyBoulder/June_14_2012_BigPiney_Boulder_SI_Package.pdf

[8] Archived on the Wyoming DEQ website at http://deq.state.wy.us/aqd/Exceptional%20Events/June_14_2012BigPineyBoulder/Animations/NARR/June13_14_2012_NARR.html

Figure 12 North American Regional Reanalysis Image for 2:00 am MST, June 14, 2012 (*figure 14 of Wyoming Demonstration; image provided by Fed Gadomski and the Penn State University Department of Meteorology*)



Satellite data in figures 4 and 5 of this TSD showed both enhancement of total column ozone and suppression of total column carbon monoxide on the trailing edge of the low pressure system; this suggests that a fold in the tropopause followed the low pressure system in its movement eastward.

In the introduction to the Wyoming demonstration, providing the general methodology for stratospheric intrusion detection and demonstration (see Appendix A), the Wyoming DEQ described isentropic potential vorticity (IPV) and potential temperature (PT) as standard forecast model outputs which can be used as tagged tracers of stratospheric air. IPV is described as “a proxy for atmospheric spin” “with values of up to two orders of magnitude [100 times] greater for stratospheric air than for that of tropospheric air.”[9] PT is described as “the temperature that an unsaturated parcel of dry air would have if brought adiabatically and reversibly from its initial state to a standard pressure, p0, typically 100 kPa” and further states that “stratospheric air has much higher values of potential temperature than that of tropospheric air.”[10] Both quantities can be output from forecast models, and Wyoming DEQ and CDPHE have been successfully using these outputs to forecast potential stratospheric intrusions several days in the future, to the point of using the forecasts for health warnings for pending ozone impacts to the public.

Figure 13 (figure 19 of the Wyoming demonstration) shows a south to north transect along which Wyoming DEQ created an animation of relative humidity, IPV, and PT over time, beginning at 5:00 am MST on June 13 and ending at 11:00 am on June 14, 2012. A still from the animation at 9:00 am on June 13 is shown in figure 14 (figure 20 of the Wyoming demonstration). It shows a lobe of stratospheric air with very elevated IPV and PT and low relative humidity extending downward toward the surface. The entire animation is archived on the Wyoming DEQ website at this[11] location.

[9] Exceptional Event Demonstration Package for the Environmental Protection Agency, Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012, Wyoming DEQ, June 2013, p. 11, citing Shapiro, M. A. "Turbulent Mixing within Tropopause Folds as a Mechanism of Chemical Constituents between the Stratospher and Tropospher." *Journal of the Atmospheric Sciences* (American Meteorological Society) 37 (1980): 994-1004.

[10] Exceptional Event Demonstration Package for the Environmental Protection Agency, Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012, Wyoming DEQ, June 2013, p. 12, citing Shapiro, 1980.

[11] http://deq.state.wy.us/aqd/Exceptional%20Events/June_14_2012BigPineyBoulder/Animations/IPVPTRHCrossSections/June13_14_2012_IPVPTRHCrossSection.html

Figure 13 Map View of Terrain, IPV, RH, and PT Cross-Section for Animation and figure 14 (figure 19 of Wyoming Demonstration)

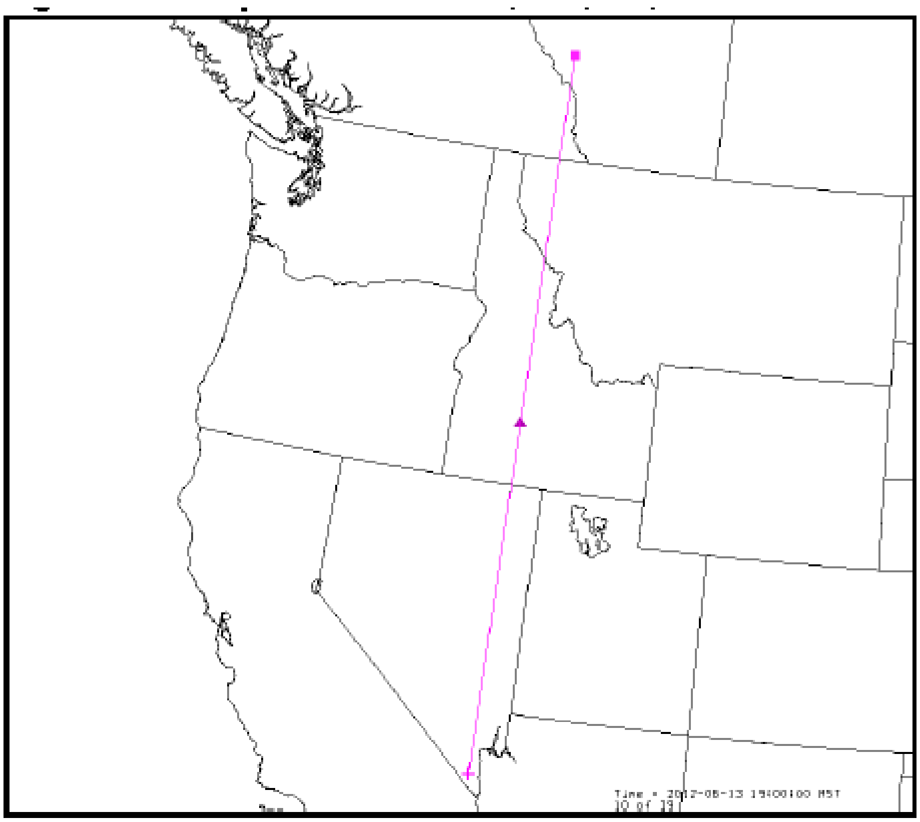


Figure 14 Rapid Refresh (RAP) Model 20-km, 0-hour analysis showing south-to-north cross-section (left-to-right) terrain (solid dark line), IPV (colored contours starting at 1-PVU), RH (shaded areas depicting RH values less than 15%), and PT (thin black contours) cross-section valid at 9 am MST, June 13, 2012. Data plotted below terrain height are model artifacts, and not physically possible.

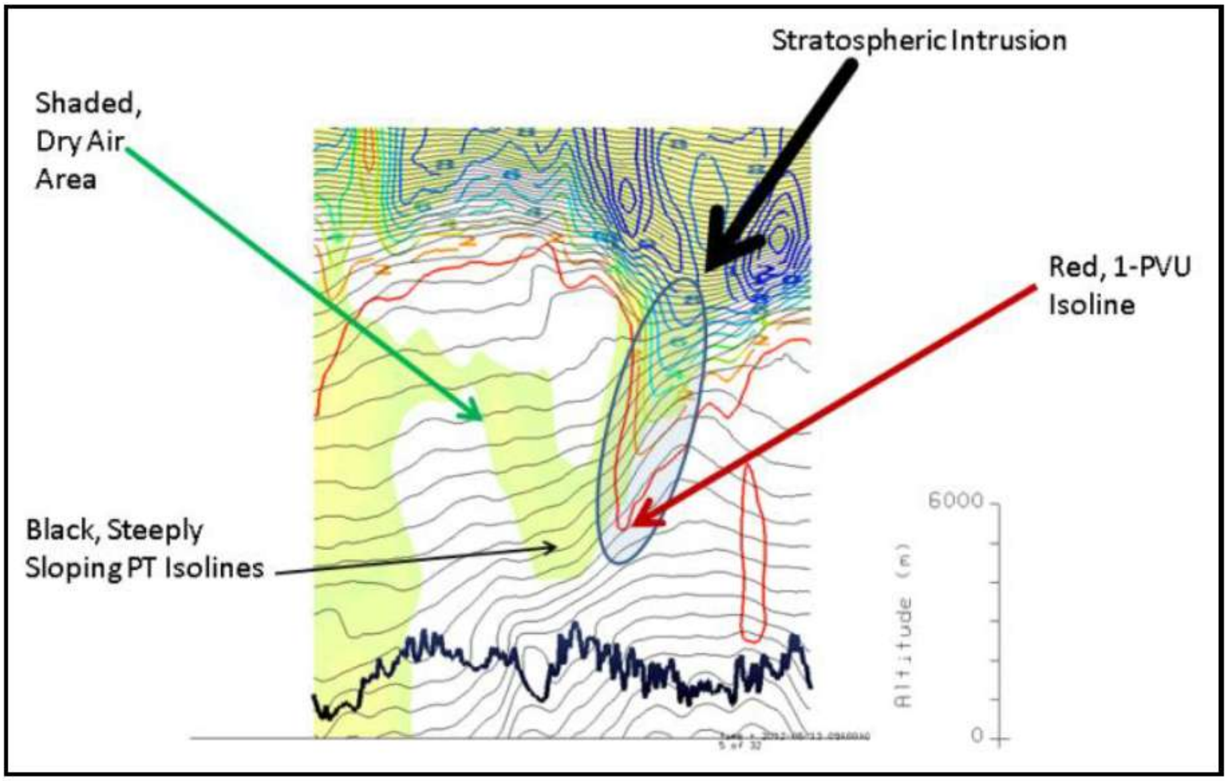
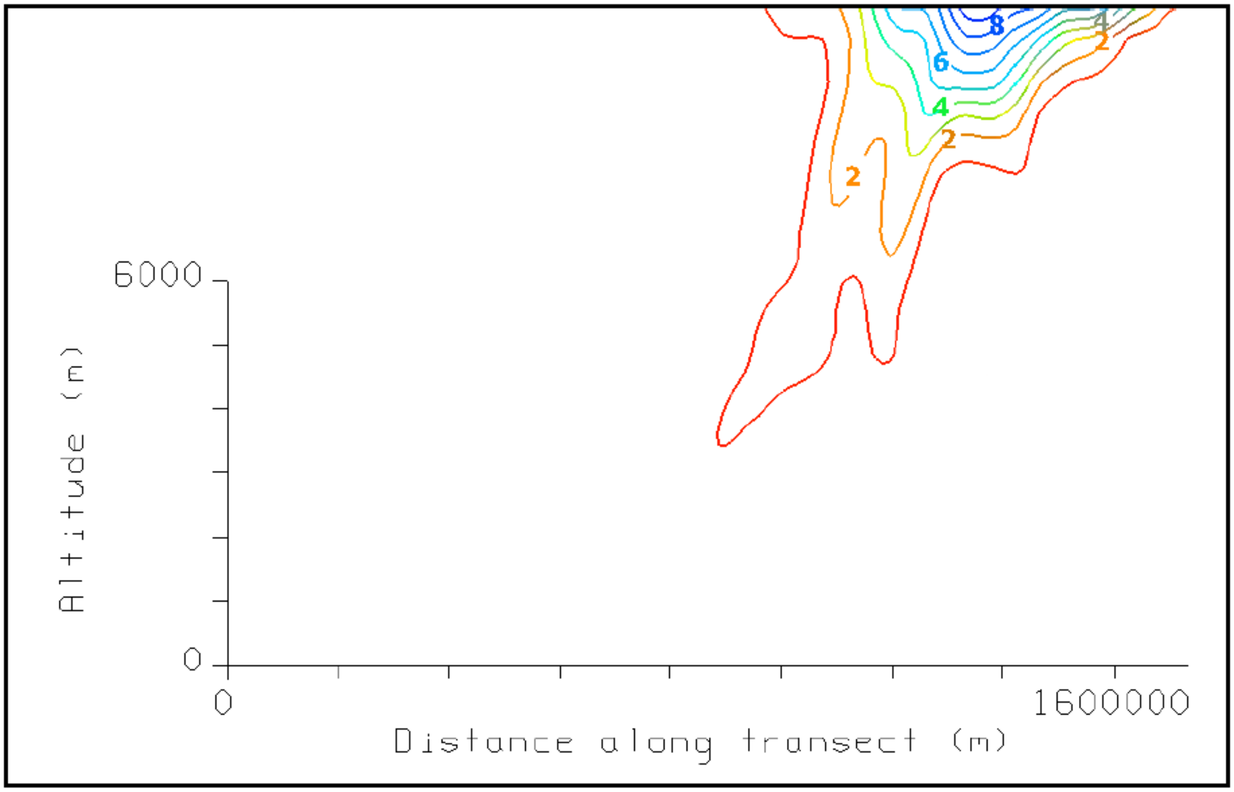


Figure 15 (from figure 22 of the Wyoming demonstration) shows the minimum modeled tropopause height along the transect shown in figure 13 at 7:00 pm MST on June 13, 2012. Defining the tropopause as an IPT of 1-PVU, the tropopause reached a minimum height of approximately 3,500 meters (11,500 feet) over central Idaho.

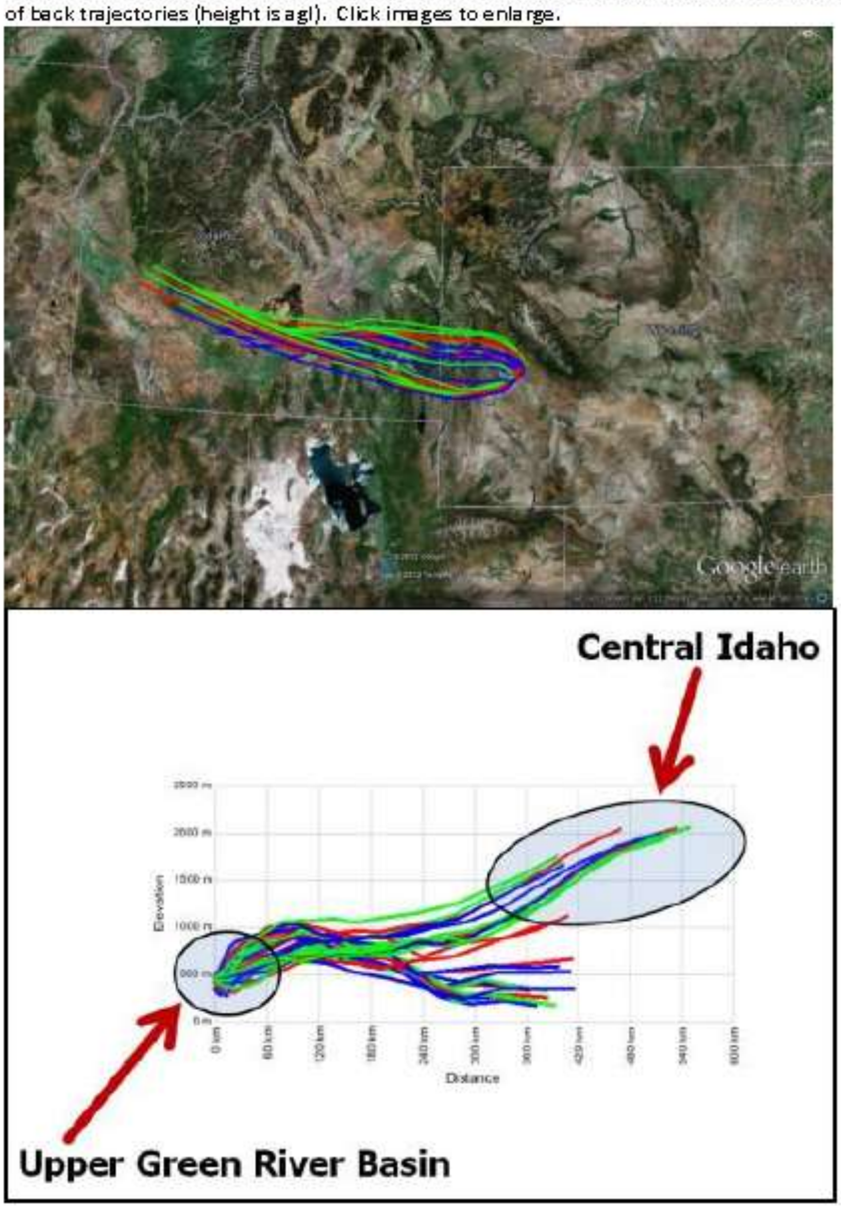
Figure 15 RAP 0-hour analysis showing IPV cross-section valid at 7 pm MST June 13, 2012 with altitude in meters above sea level on the vertical axis.



Given this modeled intrusion over central Idaho the evening of June 13, 2012, Wyoming DEQ then employed the NOAA HYSPLIT model to evaluate transport from this location to the surface monitors in Wyoming the next day, as well as back trajectories from the monitors. Figure 16 (figure 23 from the Wyoming demonstration) shows direct transport from the intrusion region to the surface at the monitor location.

Figure 16 NOAA HYSPLIT transport run, backtrajectories, showing both vertical and horizontal transport from the intrusion location the evening of June 13 to the monitor location on June 14, 2012 (*figure 23 of the Wyoming Demonstration*)

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.



Figures 17, 18, 19, 20 and 21 (figures 27-31 of the Wyoming demonstration) combine relative humidity, 500 mb height, and 600 mb IPV from the Rapid Refresh model with daily max ground based 8-hr ozone data from AQS. They show good correlation of the ground level ozone measurements on June 13, 2012 at Grand Teton National Park as the intrusion passes from west to east through Idaho into Wyoming, and again on June 14, 2012 as the intrusion proceeds to Boulder and Big Piney (as well as Yellowstone National Park, with 8-hr ozone at 72 ppb). These figures can be accessed in high resolution form through the pdf form of the Wyoming demonstration from the Wyoming DEQ web site. For these figures, ground level ozone interpolations are shown in yellow to red shading, with the concentration scale along the right hand edge of the figure (note that different scales are used for June 13 and June 14, 2012); 500 mb height in meters is shown in black contour lines; 625 mb IPV > 1 PVU are shown in blue isocontours; and areas of relative humidity less than or equal to 30% at 625 mb are shown as grey areas.

Figure 17 6:00 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 (*figure 27 of the Wyoming Demonstration*)

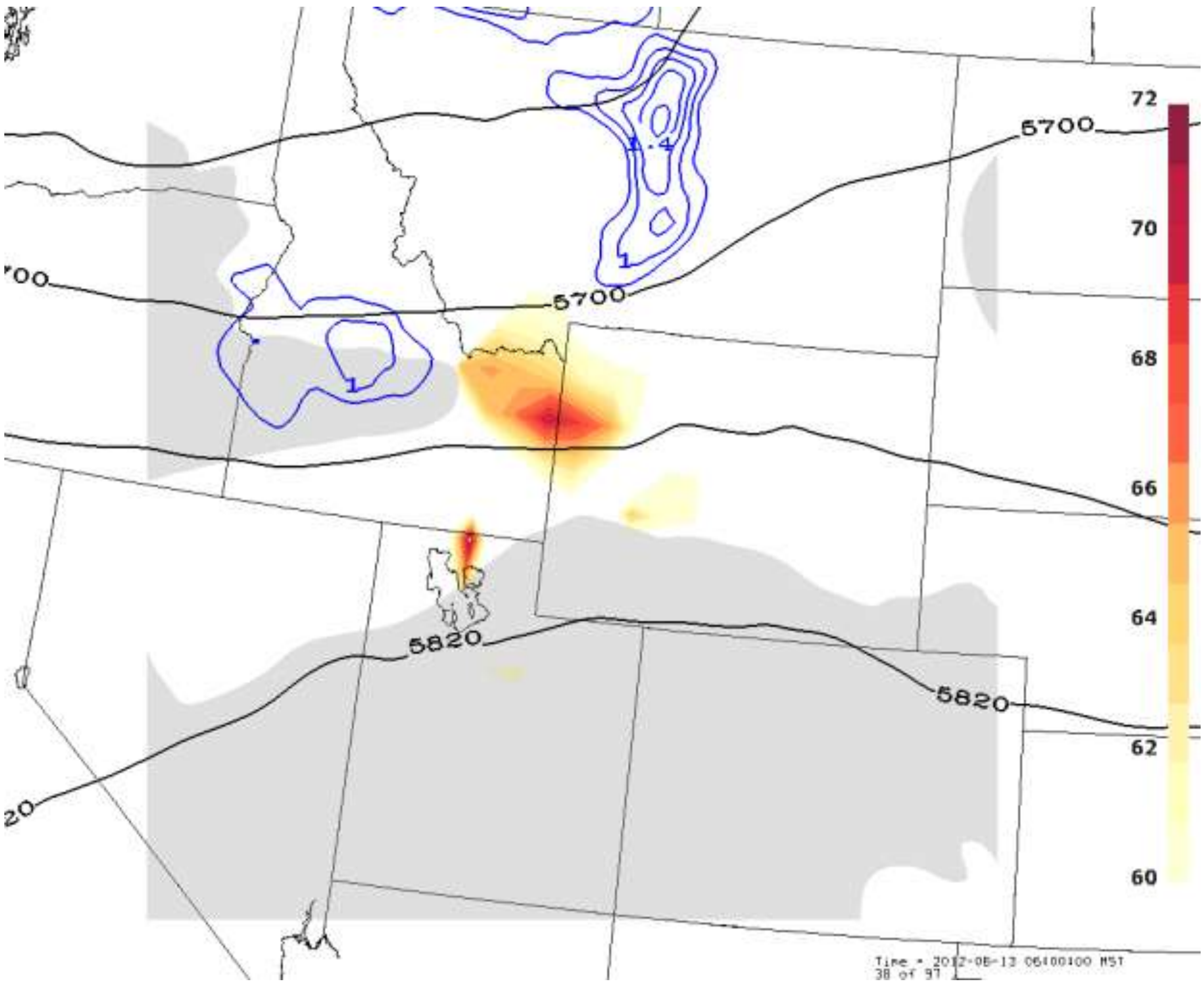


Figure 18 10:00 am MST, June 13, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading (*figure 28 of the Wyoming Demonstration*)

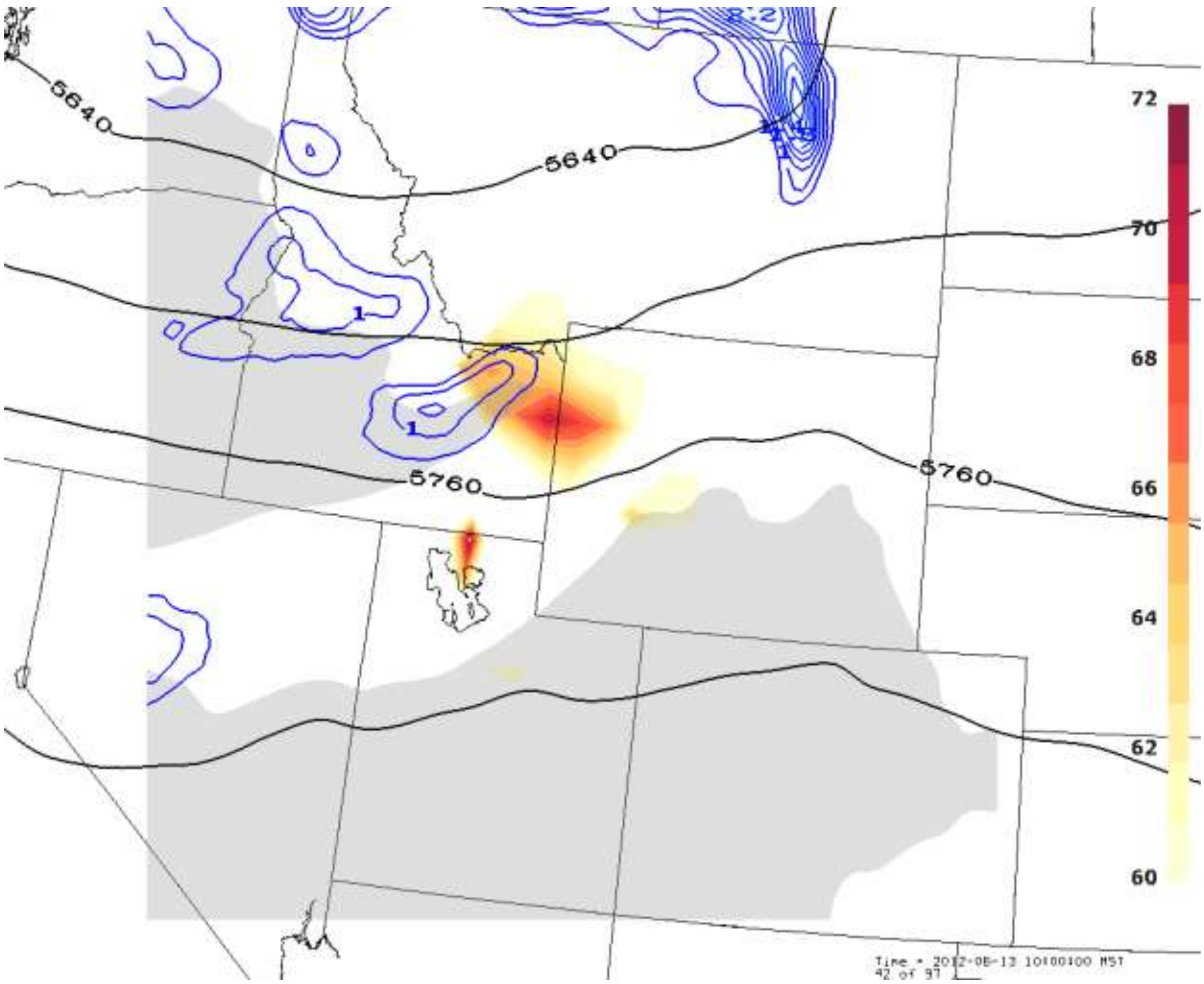


Figure 19 12:00 pm MST, June 13, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading (*figure 29 of the Wyoming Demonstration*)

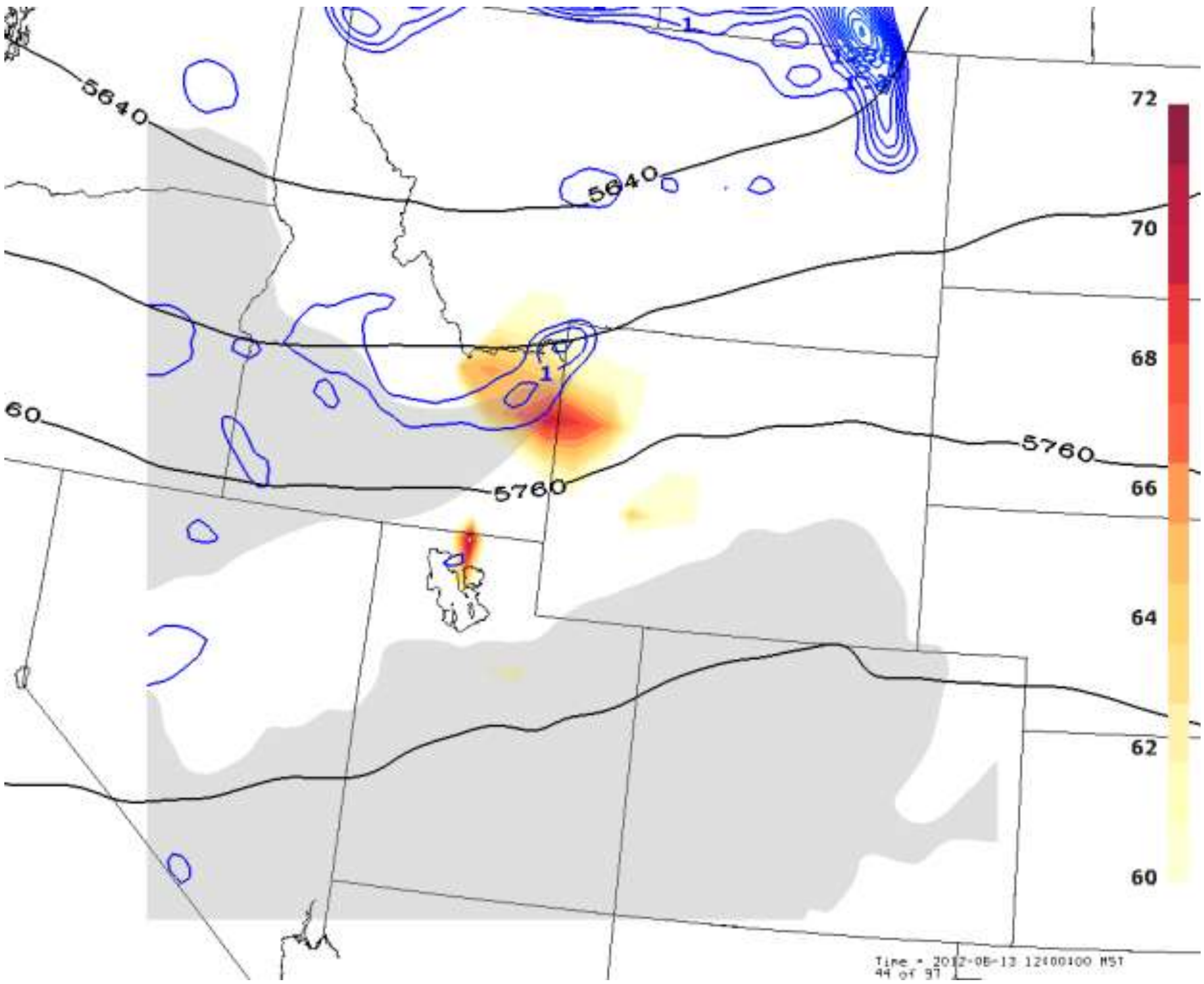


Figure 20 4:00 am MST, June 14, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading; **Note: Color Scale for figure 20 and 21 Different from figures 17-19**. (*figure 30 of the Wyoming Demonstration*)

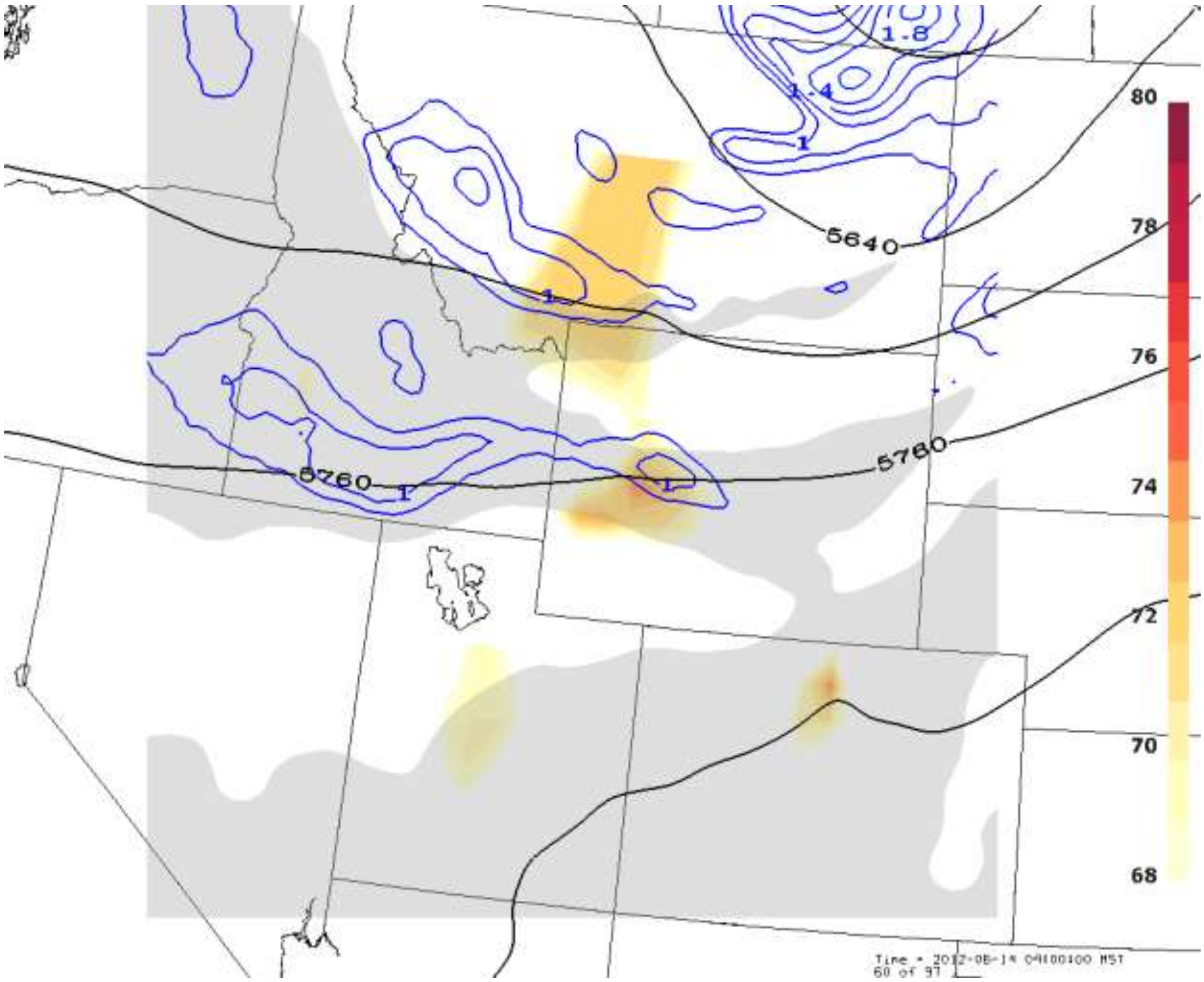


Figure 21 11:00 am MST, June 14, 2012 RAP 20-km, 0-hour analysis of 500 mb heights in meters (solid black), 625 mb IPV >= 1-PVU blue isolines, 625 mb RH <= 30% in grey, and EPA AQS Daily Max 8-hour O3 in ppb >= 60 ppb in colored shading; **Note: Color Scale for figure 21 and 22 Different from figures 17-19**. (*figure 31 of the Wyoming Demonstration*)

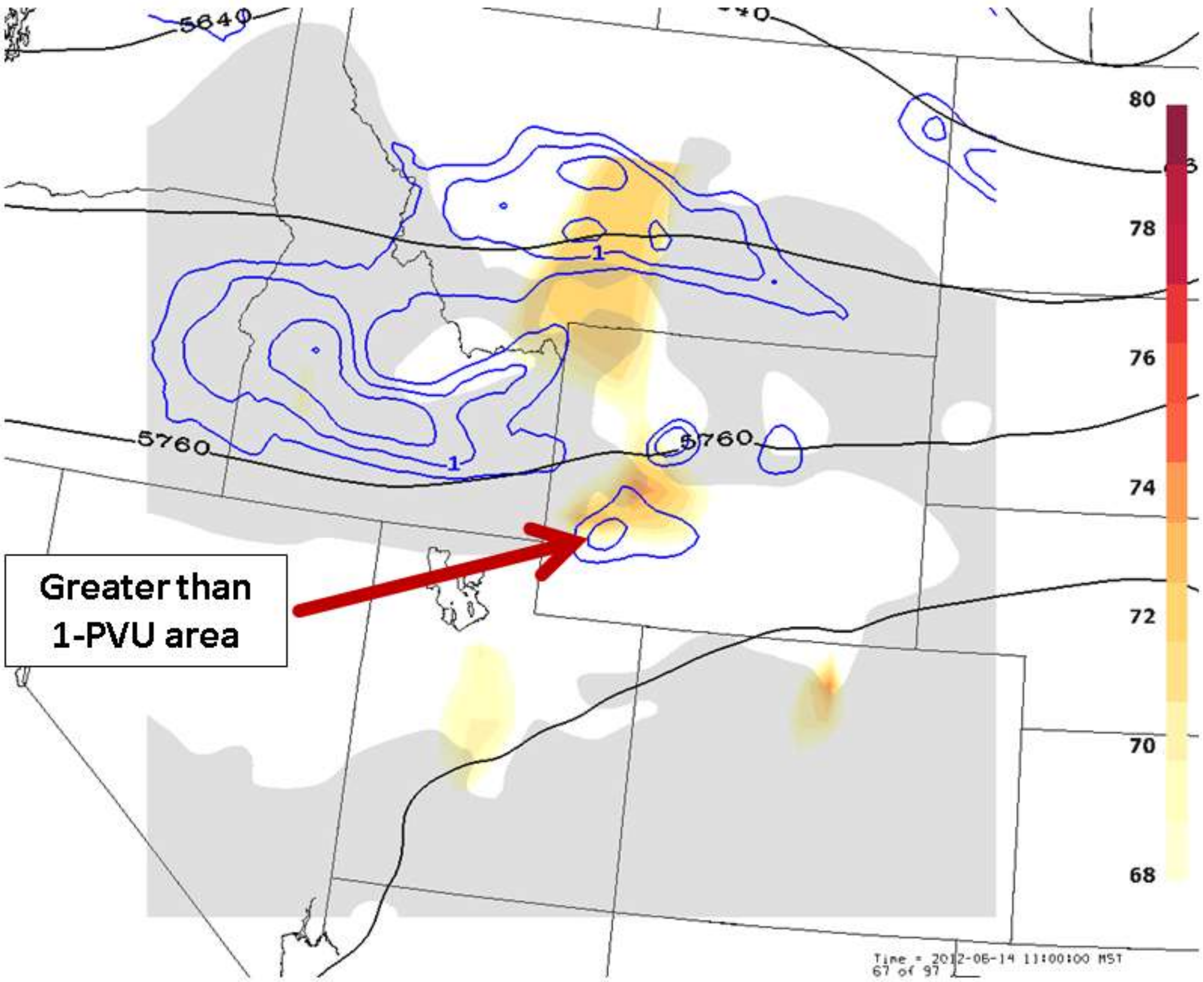
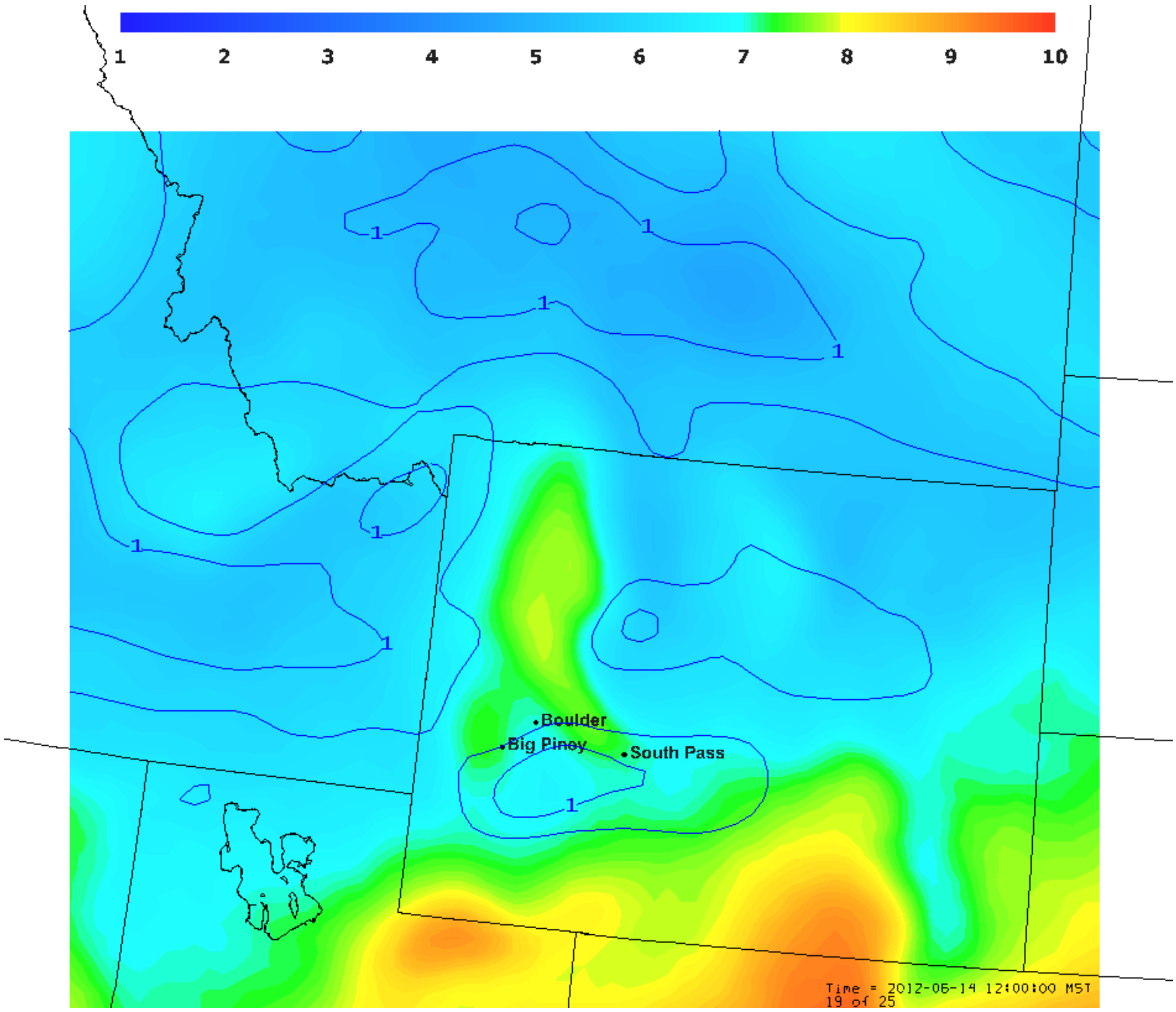


Figure 22 (figure 34 of the Wyoming demonstration) shows a combination of 625 mb IPV and 700 to 500 mb lapse rate at 12:00 pm on June 14, 2012. As described in the Wyoming demonstration, as the 700-500 mb environmental layer lapse rate (ELR) approaches the dry adiabatic lapse rate (9.8°C/km), with the surface pressure at Boulder approximately 700 mb, the atmosphere from the surface to the height of the intrusion becomes better mixed. By 12:00 pm MST, the lower troposphere near the monitors was becoming well mixed up to the height of the intrusion.

Figure 22 700-500 mb lapse rate (color scale) and 625 mb IPV (blue isocontours) image at 12 pm MST, June 14, 2012 RAP 20-km, 0-hour analysis. Lapse rate units are degrees C/km; IPV units are potential vorticity units (*figure 34 of the Wyoming Demonstration*)



In addition to the essentially inferential data used in this section thus far, direct measurement of dry air aloft provides confirmation of the modeled result. The Wyoming demonstration presents balloon sounding data from Boise, Idaho; Riverton, Wyoming; and Great Falls, Montana, included here as figures 23 through 27, confirming that a layer of dry, stratospheric air was above the north central Rocky Mountains on June 13 and 14, 2012, and that lapse rates measured both at 5:00 am and 5:00 pm at the balloon launch sites generally showed good mixing conditions up to the level of the dry air which was likely to have contained enhanced levels of stratospheric ozone. In these figures, temperature is indicated by the red trace, while humidity is indicated by the dashed black trace. The dry adiabatic lapse rate is indicated by a yellow curve, and is the theoretical temperature trace a parcel of air would follow if allowed to rise and expand with no heat transfer. If the red temperature trace follows the yellow dry adiabat, in a layer of the atmosphere, that layer can be considered well mixed.

Figure 23 Boise, Idaho National Weather Service (NWS) Upper Air Sounding at 5 am MST, June 13, 2012. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry. (*figure 35 of the Wyoming Demonstration*)

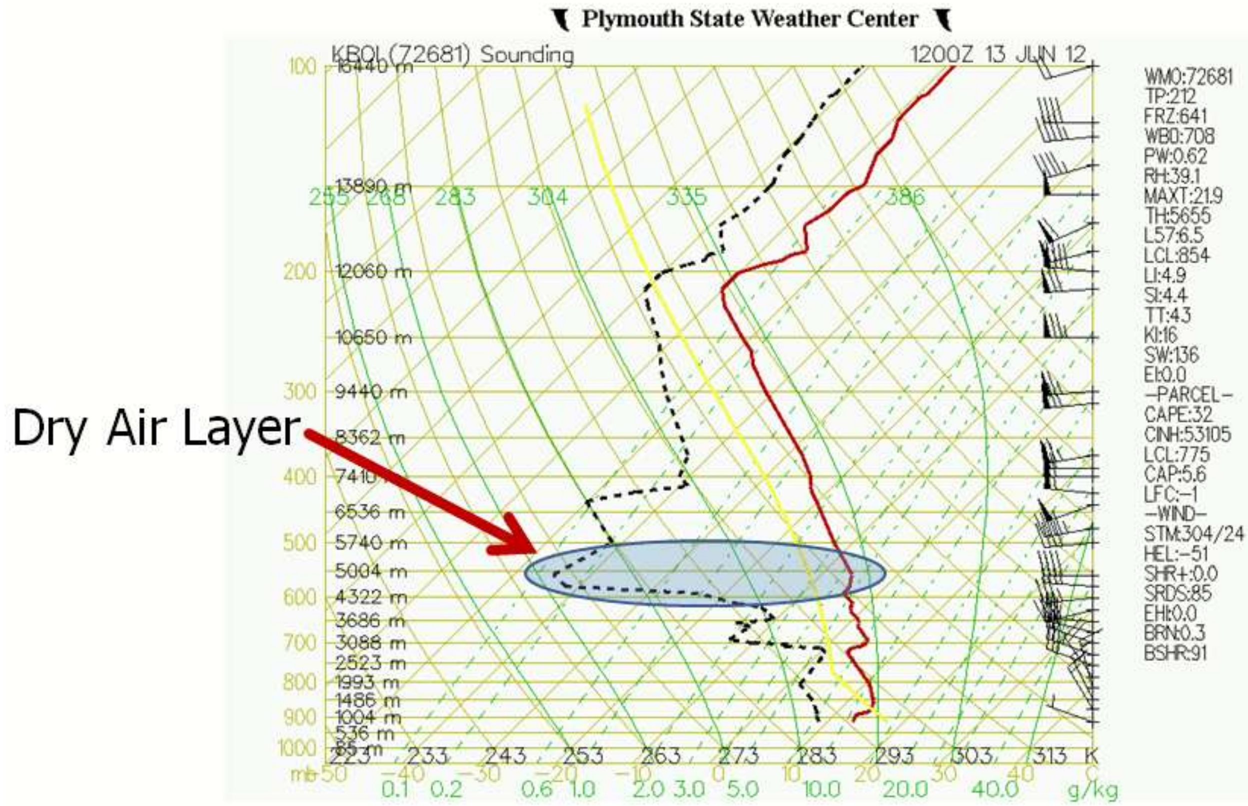


Figure 24 Boise, Idaho NWS Upper Air Sounding at 5 pm MST, June 13, 2012. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry. (*figure 36 of the Wyoming Demonstration*)

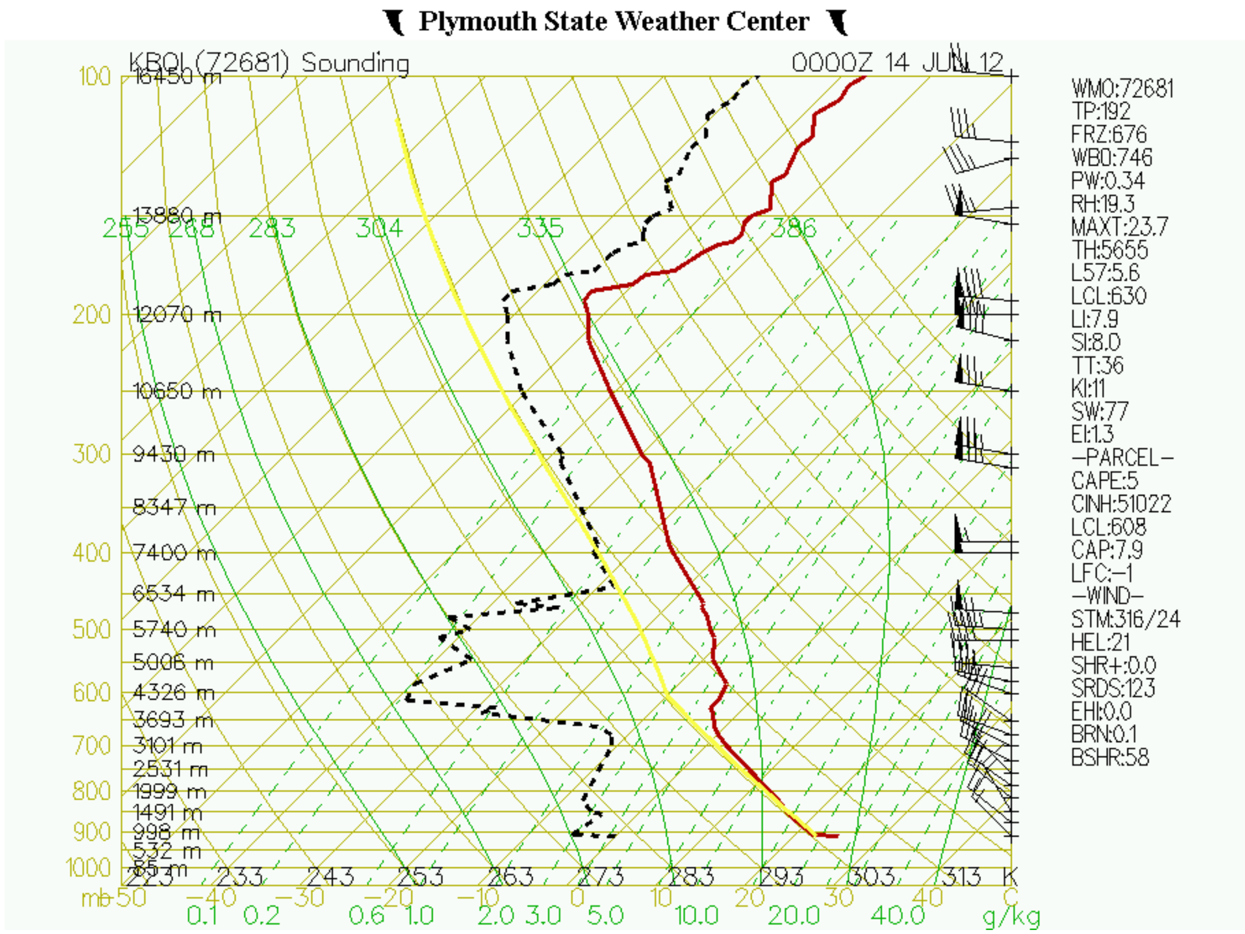


Figure 25 Riverton, Wyoming NWS Upper Air Sounding at 5 am MST, June 14, 2012. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry. (*figure 37 of the Wyoming Demonstration*)

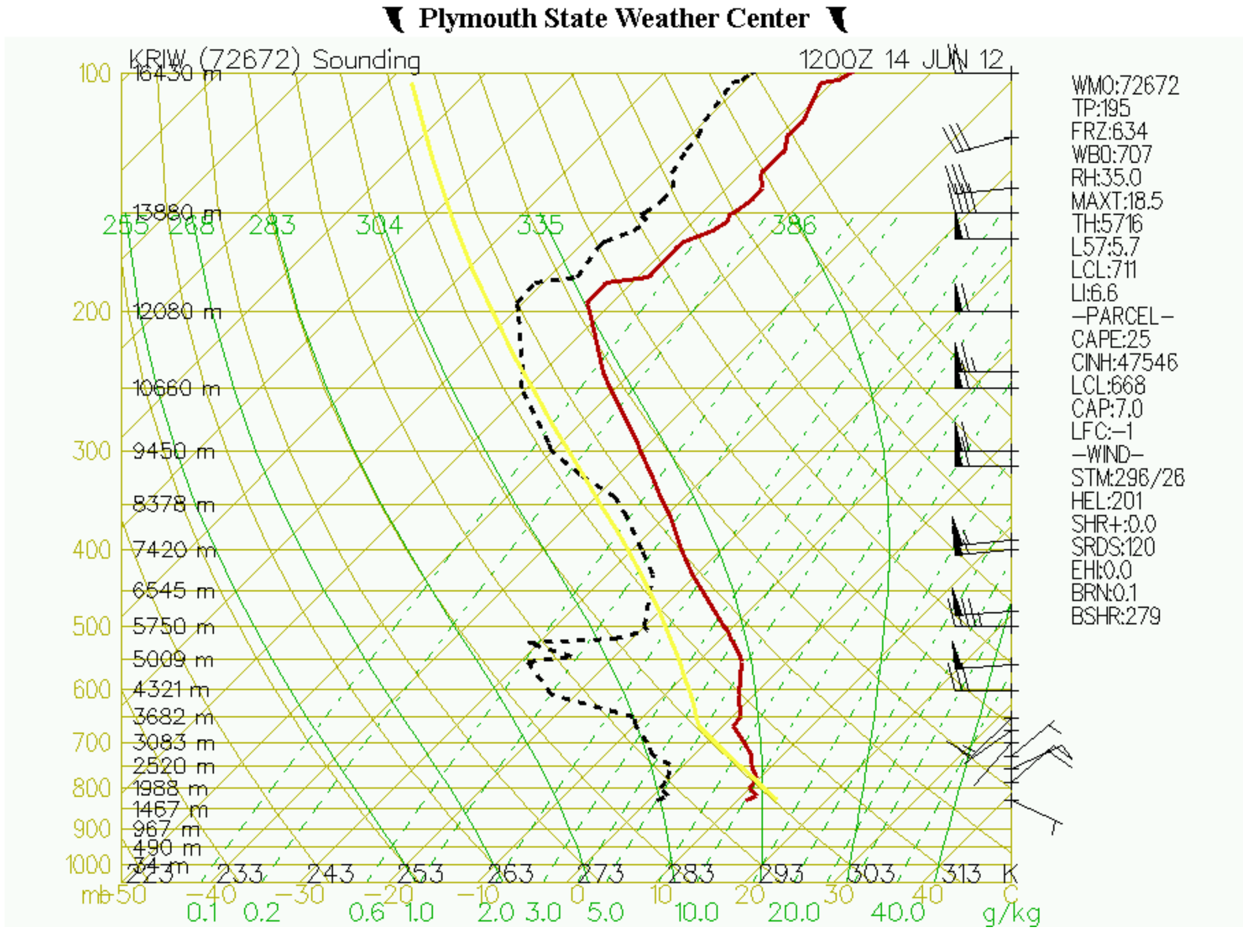


Figure 26	Great Falls, Montana NWS Upper Air Sounding at 5 pm MST, June 14, 2012. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry. (*figure 38 of the Wyoming Demonstration*)

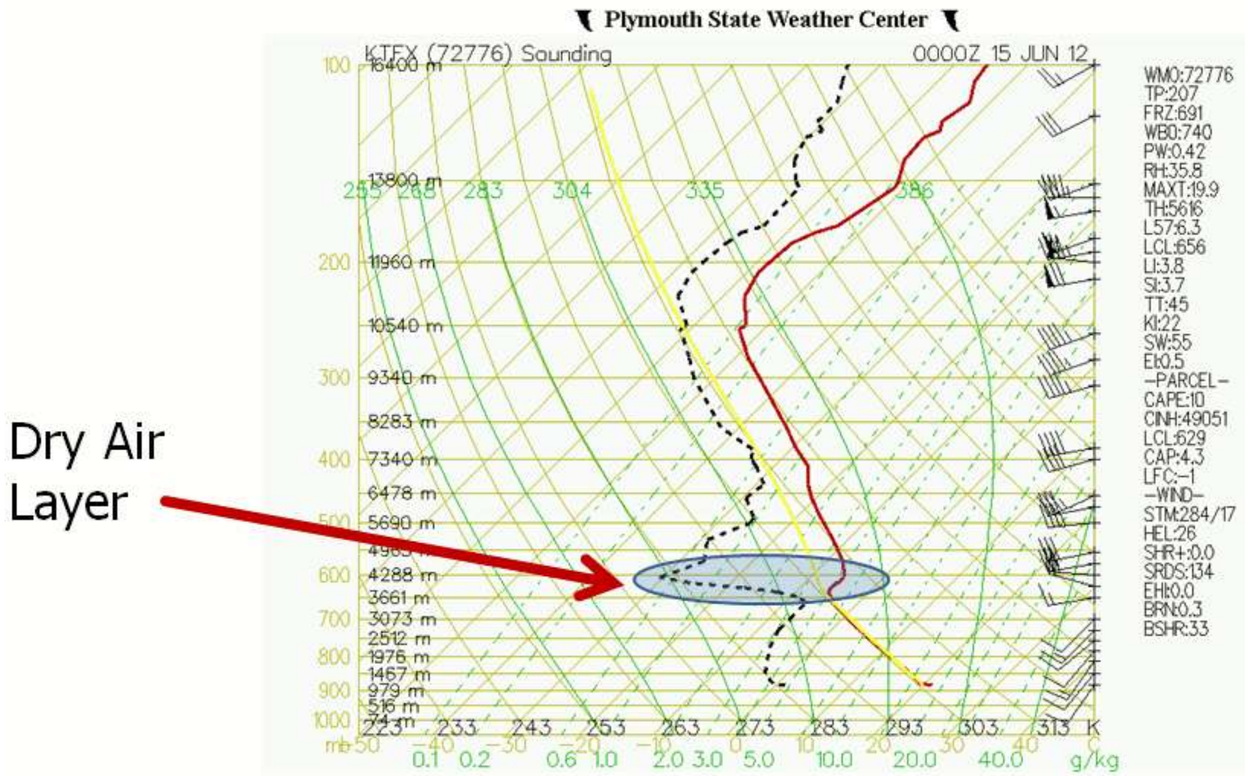
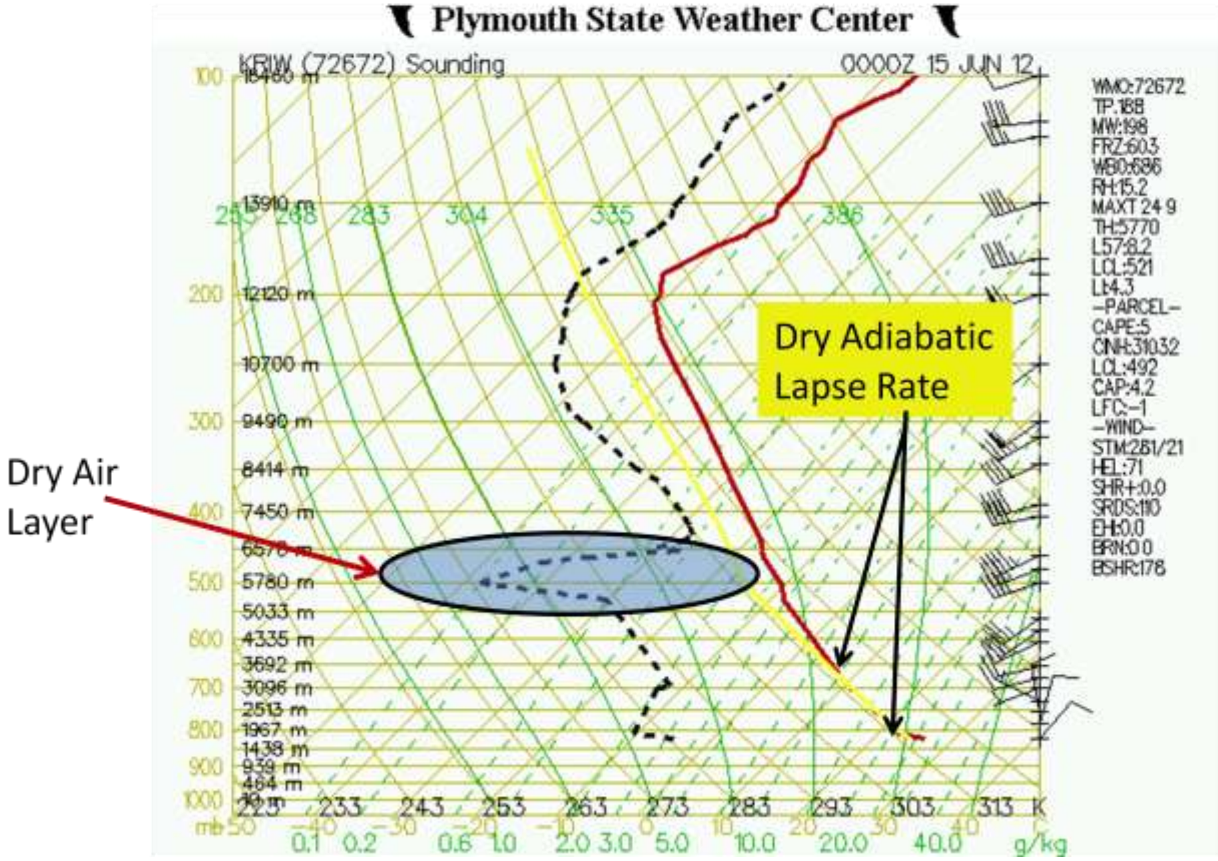


Figure 27 Riverton, Wyoming NWS Upper Air Sounding at 5 pm MST, June 14, 2012. Image courtesy Plymouth State University Department of Atmospheric Science & Chemistry. (*figure 39 of the Wyoming Demonstration*)



The EPA concludes that the combined evidence provided in the Wyoming demonstration from both atmospheric models and from atmospheric soundings on June 13 and 14, 2012 provide evidence of a clear causal relationship between the intrusion of stratospheric air over southwestern Wyoming on June 14 and the ozone exceedances recorded on that day.

3.5 <u>No Exceedance But For the Event</u>

The Boulder ozone monitor began operations on February 1, 2005, and Big Piney began collecting ozone data on April 1, 2011. A total of 121 months of ozone data have been collected by the two monitors, including 30 exceedances of the 75 ppb 8-hour ozone standard. Of the 30 exceedances, all but four have been winter ozone exceedances in February or March at the Boulder monitor. Of these four, two are the June 14, 2012 exceedances (one at Boulder and one at Big Piney) that are the subject of the Wyoming demonstration and this TSD; the remaining two occurred at Boulder on April 21, 2006 and June 18, 2006. No exceedances have occurred in the typical peak photochemical months of July and August.

There should be no expectation that the Wyoming demonstration would evaluate the April 21 and June 18, 2006 events in detail for stratospheric contribution, as the NAAQS at that time of these exceedances was 80 ppb, and the maximum ozone concentrations measured at Boulder on those two dates were 80 and 79 ppb, respectively (and thus were not exceedances of the NAAQS). At least superficially, however, April 21 and June 18, 2006 share some of the same meteorological characteristics with those of June 14, 2012. Both of the 2006 events had low pressure systems located over the north central states or southern Canada by late in the afternoon. Figures 28-29 show 5:00 pm MST meteorological maps for these two days. On April 21, 2006 there was a low pressure system over Minnesota and a low was similarly situated over southwest Ontario on June 18, 2006.

Figure 28 April 21, 2006, 5:00 pm MST Upper Air Meteorology Chart, Showing Strong Low Pressure System in Minnesota and an 850 mb Height Minimum over the Four Corners

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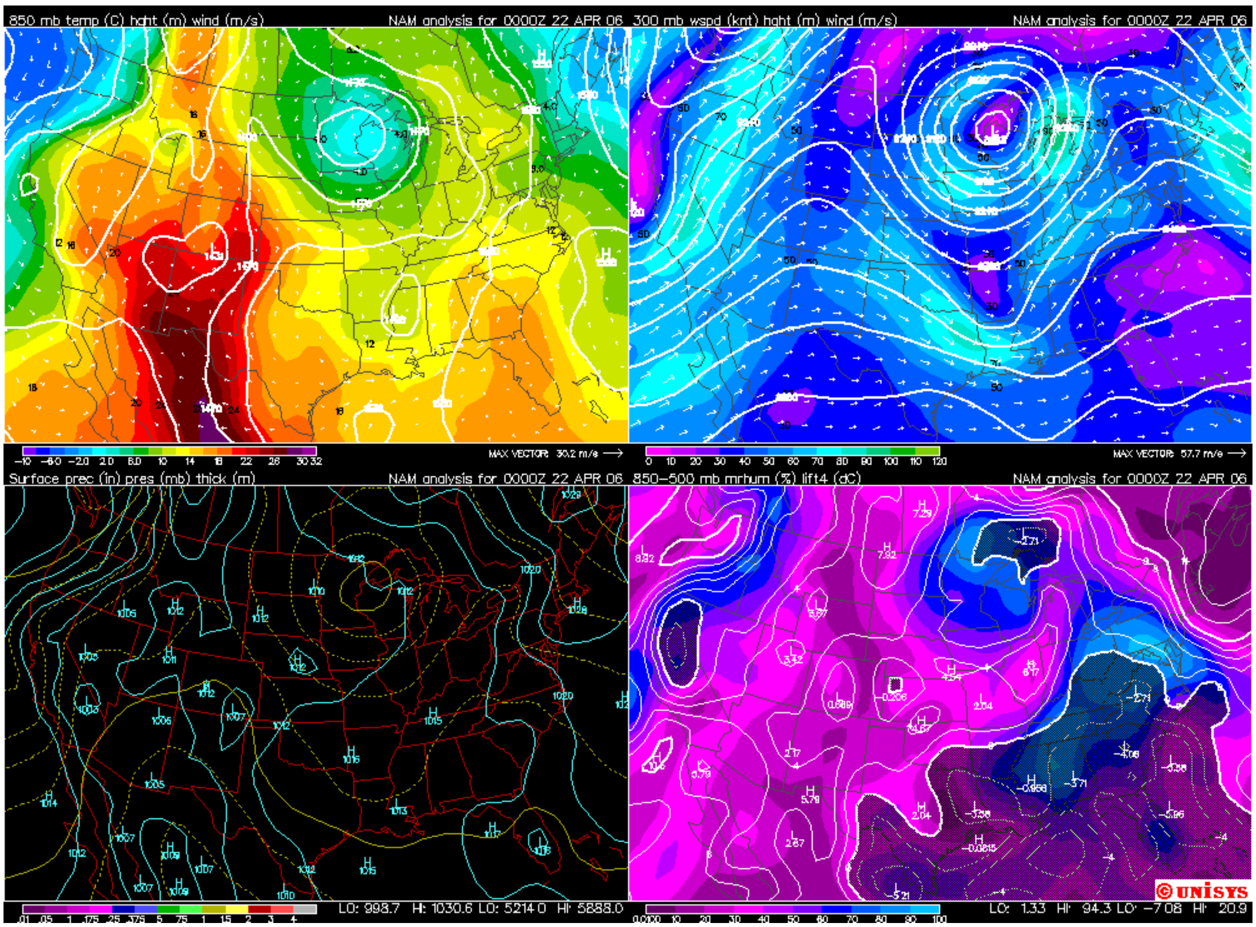
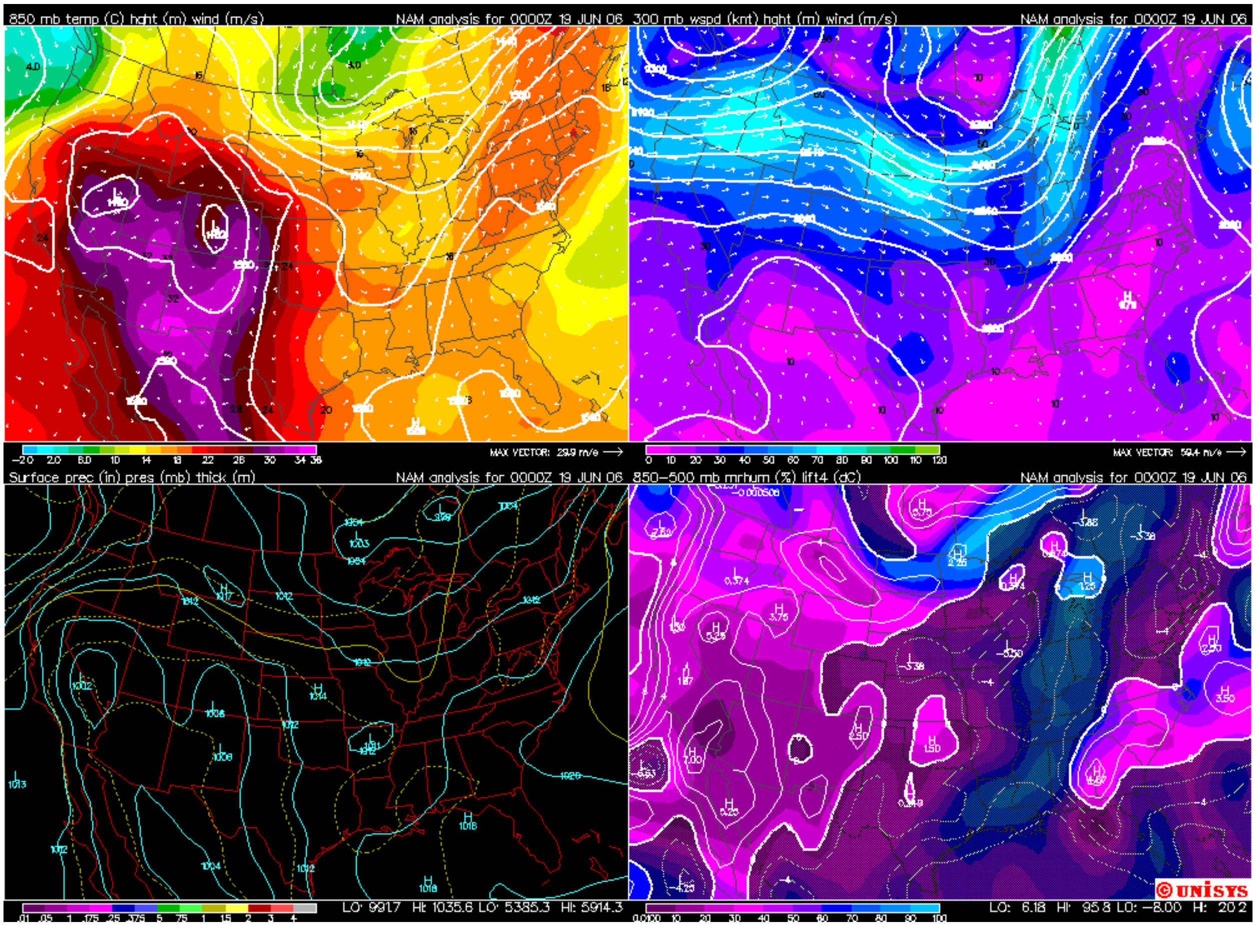
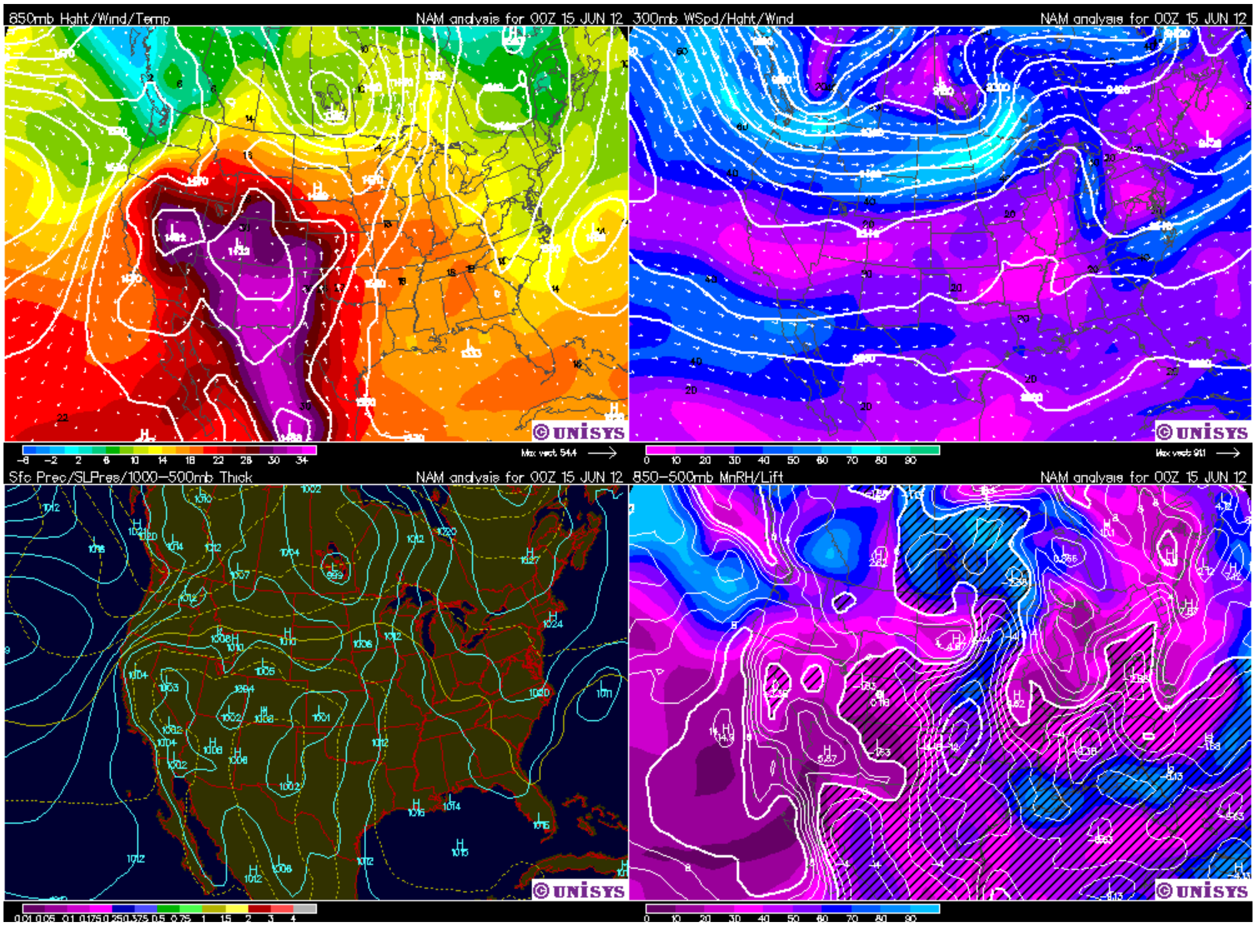


Figure 29 June 18, 2006, 5:00 pm MST Upper Air Meteorology Chart, Showing Low Pressure System in Southwestern Ontario and 850 mb Height Minimum over Central Colorado



In the case of the June 14, 2012 event addressed by the Wyoming demonstration, the low pressure system occurred over southern Manitoba. Figures 30 shows the similarity of the synoptic pattern relative to Wyoming, including low zones in the 850 mb surface over the Rocky Mountains or the Colorado Plateau, on these three days of high ozone concentrations. The similarities at least suggest that all three may have had similar potential for stratospheric intrusion from passing low pressure systems.

Figure 30 June 14, 2012, 5:00 pm MST Upper Air Meteorology Chart, Showing Low Pressure System in Southern Manitoba and 850 mb Height Minimum over SW Wyoming and the Central Rockies



Even though ozone monitoring stations are not concentrated in the central Rockies, it is reasonable to compare data from various locations to evaluate the possibility of a regional stratospheric ozone intrusion. One other ozone exceedance was detected in EPA Region 8 on June 14, 2012. This measurement occurred at the 9,010-foot elevation Rocky Mountain National Park monitoring site in the Denver ozone nonattainment area. Figure 31 plots all 8-hour ozone data for June 14, 2012 from all reporting Colorado and Wyoming monitors on June 14, 2012 and shows a weak trend for increasing ozone with elevation, as might be expected with a regional stratospheric ozone impact. The sites exceeding the NAAQS are Big Piney and Boulder, and the two collocated monitors at the Rocky Mountain National Park site.

Figure 31 Colorado and Wyoming 8-hour Ozone Readings, June 14, 2012, Plotted Against Monitoring Site Elevation

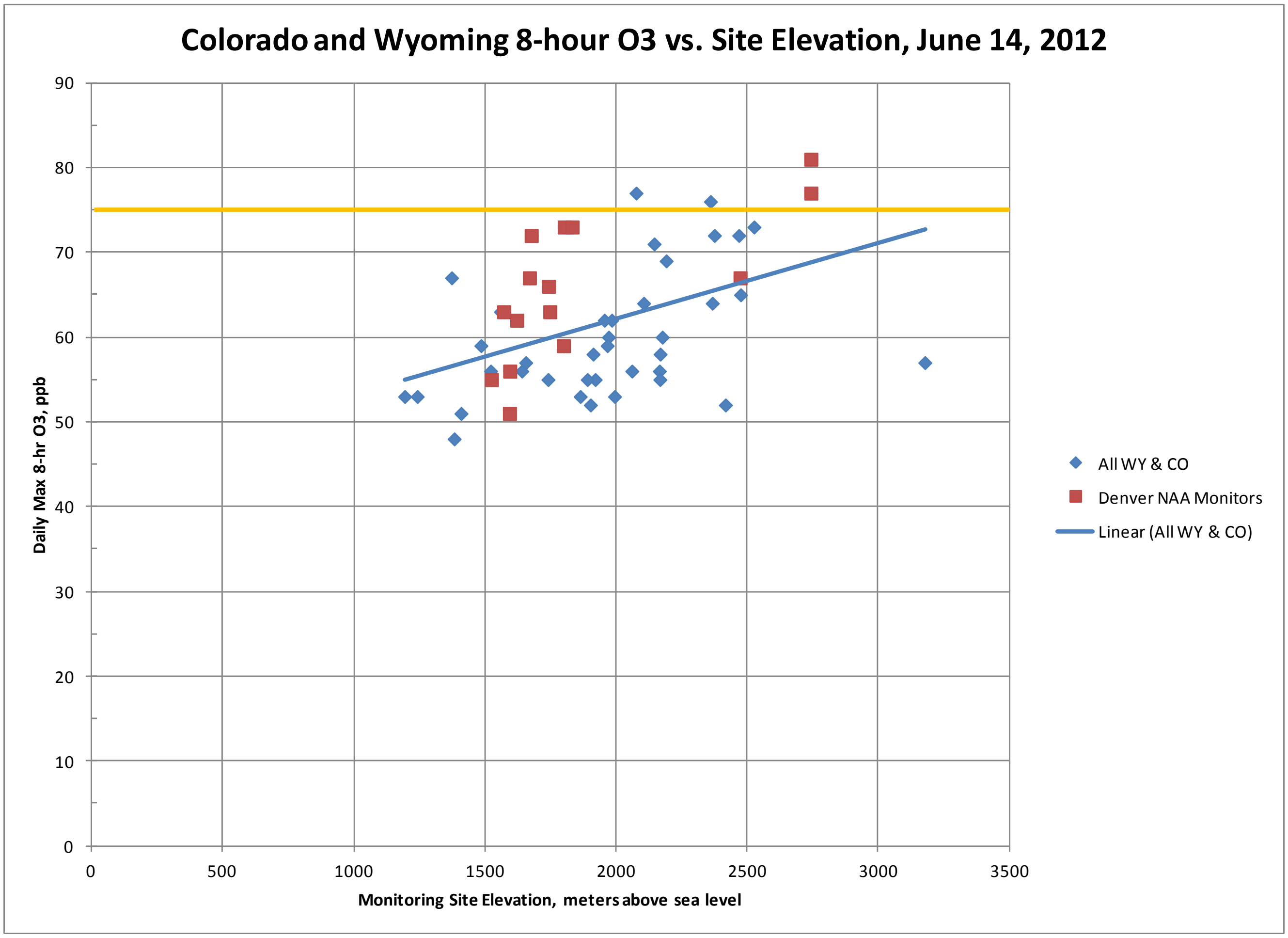
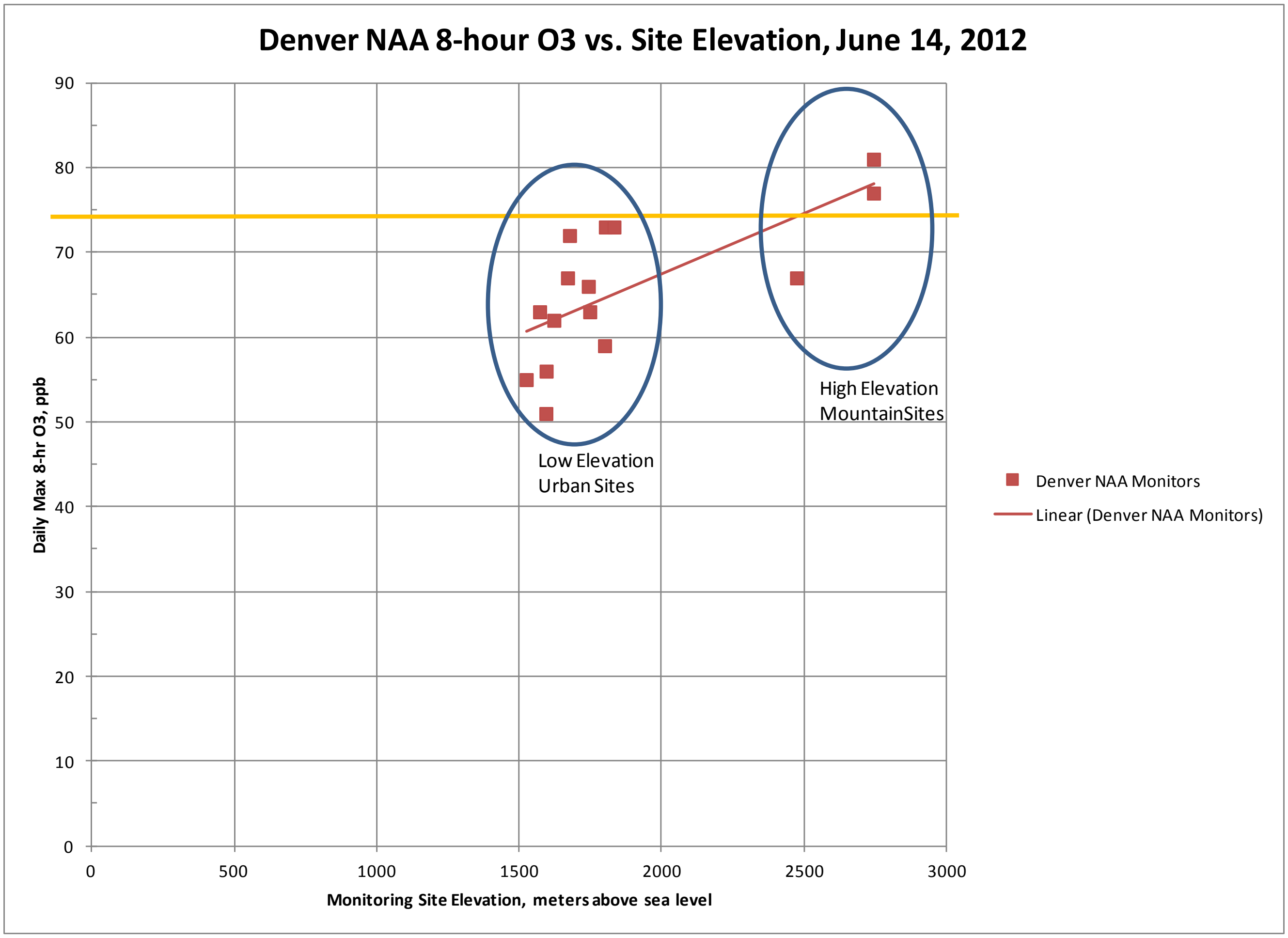


Figure 32 shows just the subset of the data of figure 31 collected within the Denver nonattainment area. The Wyoming demonstration does not extend analysis of IPV and PT east of the Big Piney and Boulder monitors to show potential stratospheric impacts in Colorado. Colorado data have been flagged, but CDPHE has not yet determined whether the June 14, 2012 data will have regulatory significance justifying eventual demonstration development. Therefore, the depth of data presented for the Boulder and Big Piney impacts is not currently available for the Denver and Rocky Mountain National Park monitors. Nevertheless, the only monitors exceeding the NAAQS in the Denver nonattainment area on June 14, 2012 were the two collocated ozone monitors at a high-elevation site in the mountains above the urbanized area. This would be much more consistent with ozone reaching the monitors through downward mixing than with formation from precursors emitted at low elevations below the exceeding monitors and then moving upslope to the high-elevation sites.

Figure 32	Denver Nonattainment Area 8-hour Ozone Readings, June 14, 2012, Plotted Against Monitoring Site Elevation



Given the absence of historical ozone exceedances in the area of the flagged Wyoming data in the peak summer ozone months, and the similarity in meteorology for the three exceedance days in April-June over the nine year monitoring record, it is unlikely that local production of ozone from local precursor emissions would have led to an exceedance of the NAAQS at the Boulder or Big Piney ozone monitors on June 14, 2012 in the absence of significant contribution to the local ozone concentration from down-mixing of stratospheric ozone. The available preliminary data suggesting that the exceedances in the Denver nonattainment area on the same day were also consistent with a source of ozone aloft in the atmosphere. The EPA concludes that no exceedance would have occurred at the Big Piney and Boulder monitors on June 14, 2012 but for the intrusion of stratospheric ozone on that day.

3.6 Schedule and Procedural Requirements

Wyoming DEQ applied the stratospheric ozone flag to the June 14, 2012 ozone data from the Boulder and Big Piney monitors on October 9, 2012 and April 26, 2013, along with an initial description, well before the date of July 1, 2013 required by 40 CFR 50.14(c)(2)(iii). The demonstration was made available for 30 days of public comment on May 7, 2013, with the public comment period closing

June 10, 2013; no comments on the package were received. Wyoming DEQ submitted the package to EPA Region 8 by letter dated June 20, 2013 and it was received by Region 8 on June 26, 2013, in advance of the June 30, 2015 deadline allowed by 40 CFR 50.14(c)(3).

4.0 Conclusion

EPA has reviewed documentation provided by Wyoming DEQ to support claims that intrusion of stratospheric ozone resulted in exceedances of the 8-hour ozone standard at the Boulder and Big Piney ozone monitors in the Upper Green River ozone nonattainment area of Wyoming on June 14, 2012. Based on that demonstration and additional analysis conducted by EPA, EPA concurs that the flagged exceedances meet the definition of an exceptional event: the exceedances affected air quality, were not reasonably controllable or preventable, and meet the definition of a natural event. Furthermore, EPA has determined that there is a clear causal relationship between the event and the measured exceedances, there would have been no exceedance at the monitors but for the event, and the measured exceedances were in excess of normal historical fluctuations, including background.

40 CFR 50.14(a)(1) states:

> A State may request EPA to exclude data showing exceedances or violations of the national ambient air quality standard that are directly due to an exceptional event from use in determinations by demonstrating to EPA’s satisfaction that such event caused a specific air pollution concentration at a particular air quality monitoring location.

EPA finds that the weight of evidence is sufficient to concur on the flagged data for the NAAQS exceedances of 76 ppb at the Boulder station and 77 ppb at the Big Piney station on June 14, 2012. These concurrences do not constitute final EPA action regarding any matter on which EPA is required to provide an opportunity for public comment, such as determinations regarding the attainment status, area redesignations, or reclassification of nonattainment areas. Final actions will take place only after EPA completes notice and comment rulemaking on those determinations.

Appendix A

Wyoming DEQ Background Information on Stratospheric Ozone Intrusions and Diagnostic Methodology

Extract from the Demonstration for the June 14, 2012 Stratospheric Ozone Exceptional Event
http://deq.state.wy.us/aqd/Exceptional%20Events/June_14_2012BigPineyBoulder/June_14_2012_BigPiney_Boulder_SI_Package.pdf

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[A1]" (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).

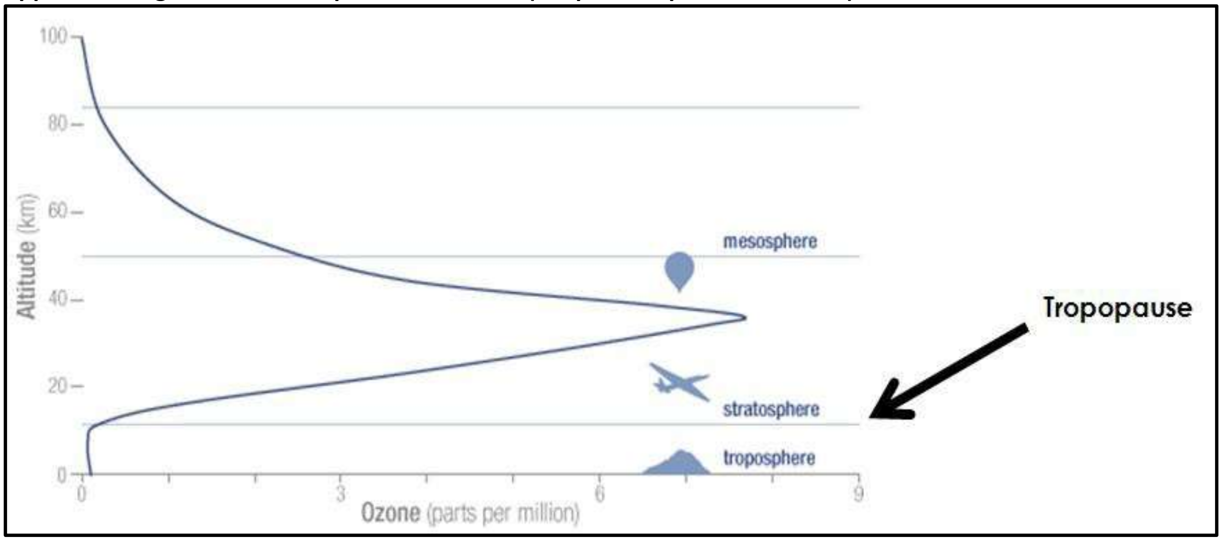
Composition of Stratospheric Air

"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

[A1] 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.

Appendix A 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[A2] 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[A3] 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

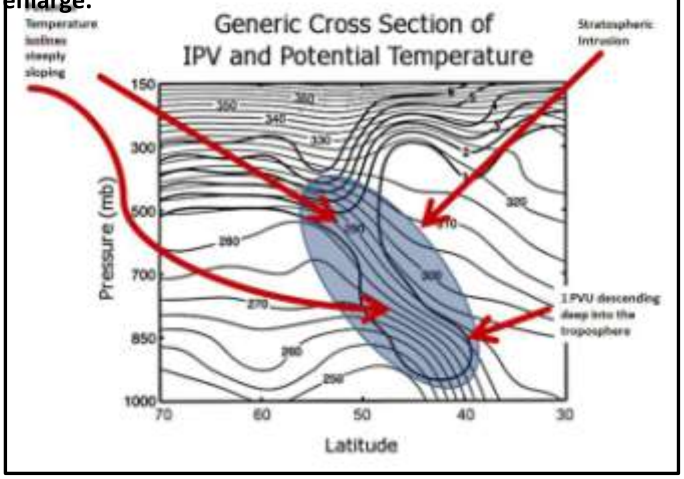
[A2] "A chemical or thermodynamic property of the flow that is conserved during" air motion (American Meteorological Society 2010).

[A3] "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)[A4] 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[A5] 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[A6] 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.

Apendix A 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.



[A4] 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

[A5] "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.

[A6] "... 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.[A7]

[A7] The reader is encouraged to examine Appendix A [of the Wyoming Demonstration], "Documented Stratospheric Intrusion Events" and Appendix B [of the Wyoming Demonstration], "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)[A8], 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 [A9]data in

[A8] "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

[A9] 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)[A10] 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.

[A10] 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 $2.69x10^{16}$ 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.

Appendix B EPA Region 8 Exceptional Events Documentation Review Sheet

Station Name(s)	AQS Identification Number	Date	8-hr O_3 Concentration, ppb
Big Piney	56-035-0700	June 14, 2012	77
Boulder	56-035-0099	June 14, 2012	76

A. GENERAL - This section is intended to gather general event information and should be used for any event regardless of the type of event.

1. What type of event occurred?
   a. □ Wildland Fire
   b. □ Prescribed Burn
   c. □High Wind
   d. □ Fireworks
   e. □ Construction
   f. ☒ Other

2. What parameter(s) was affected?
   a. □ PM_{10}
   b. □ $PM_{2.5}$
   c. ☒ Ozone
   d. □ Other_______________

Did an exceedance of the NAAQS occur? ☒ Yes □ No (no action) Data Values:_76 & 77 ppb, 8-hour average ozone

3. Were the data flagged and an initial description loaded into AQS by July 1 of the following year?
   Event Dates: _June 14, 2012
   Date Flags Appeared in AQS:_ October 9, 2012
   Is the description adequate (event location, direction from monitor, wind direction, etc)?
   Follow-up Notes: __"Possible exceptional event, under evaluation by AQD"_

4. Does the demonstration contain all required elements
   a. Meets definition of 40 CFR 50.1 (j)?
      i. ☒ The event affected air quality?
      ii. ☒ The event is not reasonably controllable?
         1. □ Were anthropogenic sources involved?
         2. □ Are those sources controlled?
         3. □ Are controls described?
            a. Controls: No controls available for Strat O3 Intrusion; sources in area have more controls than required for marginal O3 NAA
      iii. □ If human activity, is it unlikely to recur at the location, or
      iv. ☒ Was a natural event (natural sources of emissions)?
      v. □ Was air stagnation or temperature inversion involved?
      vi. □ Was the event caused by high temperature or lack of precipitation?
      vii. □ Were any sources in non-compliance?
   b. ☒ Shows a clear causal relationship between the event and the flagged measurement?
   c. ☒ The measurement is in excess of normal historical fluctuation at the monitor?
      i. ☒ Are historical data presented?- YES How far back? 2011 (Big Piney) & 2005
      ii. ☒ Are the data analyzed by season? YES
   d. ☒ Shows there would have been no exceedance, but for the event?
   e. ☒ Documents that the public comment process was followed?
      i. ☒ Was public given an opportunity to comment?
      ii. ☒ Were 30 days of comment time provided?

iii. □ Were any public comments received? NO
iv. □ Was the demonstration revised to reflect the comments? N/A
v. □ Were the comments received provided with the demonstration submittal? N/A

f. ⊠ Was the demonstration received either
i. ⊠ Within 3 years of the quarter containing the event, or
ii. □ At least 12 months prior to a regulatory action using the data?

5. What data are included in demonstration?

a. Mandatory
i. ⊠ Historical data for same time of year
ii. ⊠ Sampling dates for affected monitor
iii. ⊠ Meteorological Data
1. ⊠ Wind Speed and direction
iv. □ Area map detailing emission sources and affected area
v. □ Sources controls and activities/emissions in area upwind during event

b. Optional, as applicable
i. □ Filter analysis (or STN/speciation data) (2010, 2011)
ii. ⊠ Meteorological Data
1. ⊠ Weather Maps
2. □ Inversion/stagnation data
iii. ⊠ Modeling, receptor or back trajectory analysis
iv. ⊠ Videos and/or photos of the event and resulting emissions
v. □ News accounts of the event
vi. □ Reliable eyewitness accounts
vii. ⊠ Satellite data imagery
viii. ⊠ Elevation of plume
ix. □ Fire information (acreage, dates, hours burning, etc)
x. ⊠ Other

6. Specific Considerations by Event Type

a. High Winds
i. □ Did the documentation of high winds show unusual winds for time and location?
Follow-up Notes:

b. Prescribed Fire
i. □ Has the State certified to the EPA that it has adopted and is implementing a Smoke Management Program?
ii. □ If not, did the State ensure that the burner employed basic smoke management practices?
1. □ Did the State undertake a review of its approach to ensure public health is being protected & include consideration of development of a Smoke Management Plan?