Project Report

2015 Great Salt Lake Summer Ozone Study

Project Period: 15 July 2014-14 January 2016

Submitted to Patrick Barickman, Manager, Technical Analysis, Utah Division of Air Quality

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Summary

The 2014 Utah state legislative session provided funding for pilot projects led by the Utah Division of Air Quality (DAQ) to address air quality concerns facing the state. One such pilot project was the 2015 Great Salt Lake Summer Ozone Study (GSLO_3S). University researchers supplemented the DAQ project funding from other related sources in order to undertake and complete this study. Planning and preparation preceded the three-month field study undertaken during June-August 2015. The extensive ozone concentration and meteorological data collected on the basis of a novel mix of sensors deployed during the summer were analyzed as they were received and subsequent analyses have continued through the remainder of the project period.

The core objective of GSLO_3S was to examine ozone concentrations over and surrounding the Great Salt Lake in order to improve air quality forecasts along the Wasatch Front by DAQ staff. A network of 26 ozone sensors in rural and urban locations continuously monitored ozone concentrations during the summer. The current National Ambient Air Quality Standard for ozone of 70 ppb averaged over an 8-h period was exceeded at one or more of those measuring sites on 18 days (June- 15; July- 0; August- 3). The highest 8-h average concentration (83.3 ppb) at Hawthorne in the Salt Lake Valley was observed on 23 June with 10 other sites reporting 8-h average concentrations in excess of 70 ppb on that day. All available sites reported 8-h average concentrations in excess of 70 ppb on 9 June. The network of ozone monitoring sites was supplemented by additional ozone sensors deployed at times on several vehicles, a UTA light rail car, KSL traffic helicopter, tethersonde, and unmanned aerial vehicle.

The temporal and spatial evolution of ozone concentrations was placed in the context of the prevailing regional and local meteorological conditions on the basis of gridded operational analyses, the extensive network of surface weather stations available via MesoWest, and additional sensors deployed specifically for the field campaign. The high ozone concentrations during June were a result of large-scale ridging aloft that often led to clear or partly-cloudy conditions favorable for photosynthetic production of ozone. Smoke from wildfires in an arc from northern California to Washington was transported into the region during the August period of high ozone concentrations.

The Great Salt Lake influenced ozone concentrations along the Wasatch Front through several mechanisms. (1) Lake-induced wind systems modulated the transport and exchange of background ozone and ozone precursors between the lake and urban environments, with nocturnal land breezes from the Wasatch Front towards the Lake transporting ozone precursors towards the Lake; and afternoon lake breezes transporting at times air with higher ozone and precursor concentrations towards the Wasatch Front while at other times advecting cleaner air into the urban corridor. (2) Lake-modulated boundary-layer depth affecting pollutant vertical mixing over the Lake and along the Wasatch Front. For example, the relatively cool Lake surface in early June led to a shallow boundary layer over the Lake then. Other lake factors hypothesized to influence ozone concentrations include: diminished Lake level exposing highly reflective surfaces aiding ozone production photochemistry, and potential biogenic precursor sources in the wetlands surrounding the southeastern portion of the Lake.

The GSLO_3S pilot study was the most extensive field study ever undertaken related to summer air quality along the Wasatch Front. A rich data set maintained at the University of Utah (http://meso2.chpc.utah.edu/gslso3s/) is available to DAQ staff, other researchers, and the public to improve understanding of the factors affecting summer air quality along the Wasatch Front. Many questions remain regarding: the direct and secondary roles of the Great Salt Lake on ozone production; regional and local transport of ozone and anthropogenic and biogenic precursors; and the fidelity of coupled atmospheric-chemistry model simulations and forecasts of ozone concentrations for development of State Implementation Plans and daily air quality forecasts by DAQ staff.

1) Background

Utah Division of Air Quality (DAQ) field work during the 2012 summer indicated elevated ozone levels along the shores of the Great Salt Lake on the basis of a small number of ozone sensors (Arens and Harper 2013). Prior to the 2015 Great Salt Lake Summer Ozone Study (GSLO$_3$S) pilot study, no studies have assessed the areal extent of summer ozone near the Great Salt Lake in relation to that in the nearby metropolitan areas of the Wasatch Front. Such information is necessary to improve daily forecasts of ozone provided by DAQ staff as well as evaluate the performance of air quality models required for future Utah State Implementation Plans for ozone along the Wasatch Front.

The influence of warm season sea and lake breezes on the meteorology and air quality of mid-latitude coastal regions has been studied extensively both observationally and numerically (see the review by Crosman and Horel 2010). University of Utah researchers in the Department of Atmospheric Sciences have been studying during the past decade the impacts of the Great Salt Lake on atmospheric transport that affects air pollution along the Wasatch Front (Zumpfe and Horel 2007;Crosman and Horel 2009; 2010; 2012; 2015). Two National Science Foundation projects (Lake Breeze System of the Great Salt Lake 2008-2012; Persistent Cold Air Pool Study 2010-2014) have incorporated a mix of numerical studies and field work (summer 2008 in the Tooele Valley; and winter 2010-11 in the Salt Lake Valley) that have examined lake and land breeze flows associated with the Great Salt Lake.

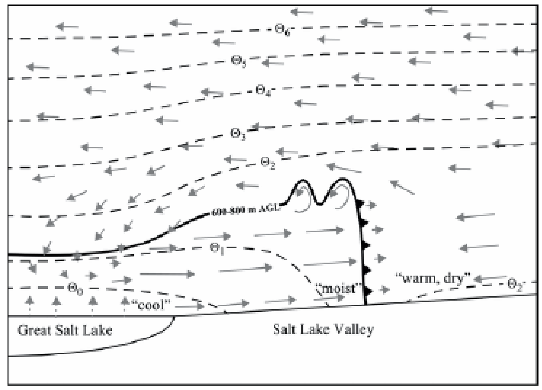

Figure 1. Schematic summary of the lake breeze system in the Salt Lake Valley on 17 Oct 2000 (Zumpfe and Horel 2007). Winds in the y–z plane (solid gray vectors), evaporation from the GSL (dashed gray vectors), potential temperature (dashed black lines) and its magnitude (indicated by subscripts), and vertical and horizontal boundaries of the lake breeze (solid black line), including the lake-breeze front (portion of solid black line annotated by triangles.

Figure 1 (Zumpfe and Horel 2007) provides a snapshot view of the structure of the lake breeze as it penetrates into the areas surrounding the lake. While the basic thermodynamic and dynamic structures of lake and land breezes are understood, how those circulations affect ozone concentrations along the Wasatch Front is not: the air trapped beneath the stable layer over the lake at times during the summer contains low concentrations of ozone while at other times exhibits very high concentrations (Arens and Harper 2013). Figure 2 attempts to summarize the physical processes affecting ozone concentrations near the Great Salt Lake, including transport of ozone precursors from the surrounding urban areas towards the lake, photochemical generation over the lake, and transport of precursors and ozone back towards the Wasatch Front by lake breezes.

The core objectives of GSLO$_3$S were to:

1. Determine the areal and vertical extent of ozone concentrations over and surrounding the Great Salt Lake during the summer
2. Improve understanding of the physical processes that control ozone concentrations near the Great Salt Lake during the summer to improve forecasts of ozone concentrations along the Wasatch Front.

The GSLO$_3$S project has been conducted in the following phases: initial testing during late summer 2014 of novel techniques to monitor ozone concentrations (e.g., deploying an ozone monitor on a UTA TRAX light rail car); preparation for the 2015 summer field study including equipment deployments during Spring 2015; June-September 2015 summer field study; and preliminary analyses of the information collected during the summer field study during the remainder of the project period. Future funding from DAQ or other agencies to continue analysis of the data would lead to improved understanding and forecasting of the complex meteorological and chemical interactions leading to poor air quality along the Wasatch Front.

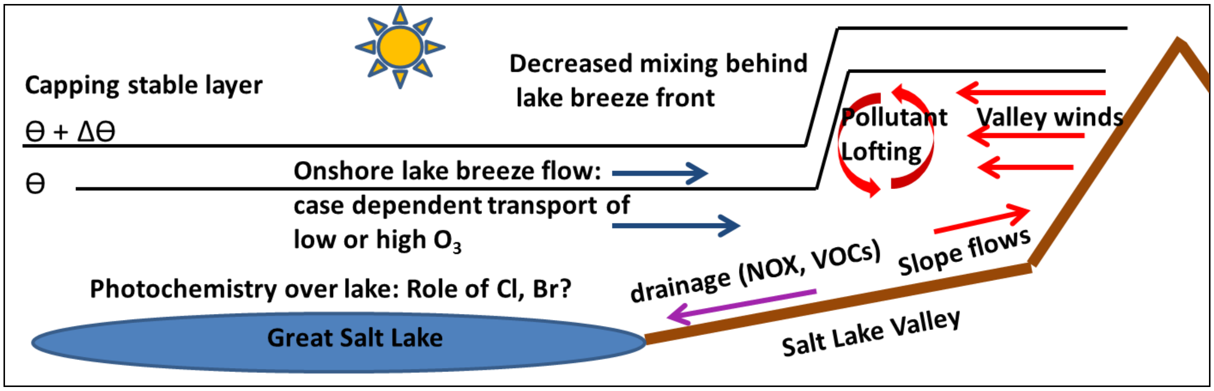

Figure 2. Schematic summary of the physical processes affecting ozone concentrations over and surrounding the Great Salt Lake (adapted from Crosman and Horel 2014).

Due to the interests of the individuals involved in this project, the limited direct funding available for GSLSO$_3$S was supplemented by other internal sources in order for DAQ, University of Utah, Utah State University, and Weber State University researchers to participate. The outcomes of this study exceeded expectations as a result of the unique mix of: (1) season-long observations of ozone, other pollutants, and surface and boundary layer meteorological conditions and (2) opportunistic observations from sensors onboard diverse mobile platforms that relied often on real-time communications to help position sensors and target areas of interest. While such real-time data collection approaches are commonplace during field experiments intended to observe severe weather episodes, they are less commonplace for air quality studies.

As summarized in Table 1, extensive information is available to DAQ staff, researchers, and the public through a web interface at the University of Utah (http://meso2.chpc.utah.edu/gslso3s/). See also the overview of the pilot study provided in a seminar at the University of Utah: meso2.chpc.utah.edu/gslso3s/GSLSO3S_Dept_Presentation_2015-10-07.pdf. Additional presentations will be made during 2016 at the annual meetings of the American Meteorological Society and the Air and Waste Management Association. As they become available these presentations will also be made available at meso2.chpc.utah.edu/gslso3s/

Table 1. Summary of Selected Online Resources for GSLSO$_3$S	
Project Home page	http://meso2.chpc.utah.edu/gslso3s/
This Final Report	http://meso2.chpc.utah.edu/gslso3s/about.html (not yet)
Ozone sensor sites	http://meso2.chpc.utah.edu/gslso3s/cgi-bin/site_metadata.cgi
Google earth kmz files of site locations and tracks of KSL helicopter, vehicle, and light rail	https://sites.google.com/site/gslso3skmlfiles/kml-files
Field Notes	https://gslso3s.wordpress.com/
Statistical summaries	http://meso2.chpc.utah.edu/gslso3s/cgi-bin/statistic_summary.cgi
Time series	http://meso2.chpc.utah.edu/gslso3s/cgi-bin/time_series.cgi
Ozone pollution and wind roses	http://meso2.chpc.utah.edu/gslso3s/cgi-bin/ozone_rose.cgi
Links to data sources from surface-based in-situ and remote sensors, numerical model analyses	http://meso2.chpc.utah.edu/gslso3s/external_links.html
Hourly analysis soundings from the High Resolution Rapid Refresh	http://meso2.chpc.utah.edu/gslso3s/hrrr_sounding_viewer.php
Satellite images from MODIS	http://meso2.chpc.utah.edu/gslso3s/satellite_image_viewer.php
Ozone, wind, and temperature analyses	http://meso1.chpc.utah.edu/uu2dvar/webGL/so3s_sens.html
Ozone analysis animations and images	http://home.chpc.utah.edu/~u0035056/summer_ozone/

MesoWest API to download ozone data	http://mesowest.org/api

2) Participants and roles

- **Utah Division of Air Quality**
  - Overall coordination for the GSLO_3S project was provided by Seth Arens.
  - Additional staff assisted with installation, calibration, and retrieval of field data.

- **University of Utah**
  - Prof. John Horel and Research Assistant Professor Erik Crosman provided the overall technical direction for the GSLO_3S study
  - Graduate students Brian Blaylock, Alex Jacques, and Ansley Long helped coordinate student participation in the field work as well as provided much technical assistance
  - Three additional graduate students, five undergraduate students, and three staff participated in field data collection or provided technical assistance
  - Assistant Research Professor Sebastian Hoch and Postdoctoral Research Susan Bush provided technical support specifically for the deployment of a wind lidar and mobile laboratory, respectively.

- **Utah State University**
  - Research Associate Professor Randal Martin and USU staff flew an unmanned aerial vehicle from Promontory Point to monitor the vertical changes in ozone
  - see Appendix A for further details
  - A separate effort was made to collect flask samples of HCl to improve understanding of the potential role of chloride on ozone photochemistry

- **Weber State University**
  - Professor John Sohl directed a team of staff and undergraduate students collecting vertical profiles of meteorological and trace gas concentrations using a tethered balloon system
  - see Appendix B for further details

3) Links to Selected Media Coverage of the GSLO_3S project (http://meso2.chpc.utah.edu/gslso3s/external_links.html)

Considerable interest in this project was exhibited by the media and the public.

Sep 03, 2014 - KSL: U. researchers launch pollution monitoring project
Jun 09, 2015 - Standard Examiner: Utah Ozone Season gets started
Jun 09, 2015 - FOX 13: Pollution, hot temperatures create perfect conditions for ozone, DEQ says
Jun 14, 2015 - Press Release: DEQ and Universities Collaborate on GSL Ozone Study
Jun 15, 2015 - Standard Examiner: Scientists study solving Utah's smog problem
Jun 16, 2015 - FOX 13: Ozone study to show Great Salt Lake impact on Utahns' health
Jun 18, 2015 - FOX 13: Researchers working to determine why ozone is increasing around Great Salt Lake
Jun 19, 2015 - Herald Journal: USU, DAQ research potential ozone-Great Salt Lake link
Jun 21, 2015 - Deseret News: Groundbreaking ozone study probes pollution, role of Great Salt Lake
Jun 30, 2015 - SL Tribune: Summer Ozone Blast Threatening Utahn's Health
Aug 02, 2015 - SL Tribune: On bad day, Great Salt Lake air has 3 times more ozone than Wasatch Front
Aug 10, 2015 - IOP 3 DEQ Press Release
Aug 10, 2015 - Utah DEQ Air Quality: The Great Salt Lake Ozone Study
Aug 12, 2015 - Utah DEQ: The Best "Airheads" in Utah Work to Solve Utah's Air Quality Challenges
Aug 18, 2015 - KSL video of wildfire smoke Aug 18 6 PM
Oct 13, 2015 - Standard Examiner: Ozone researchers stretch summer funding for Salt Lake study

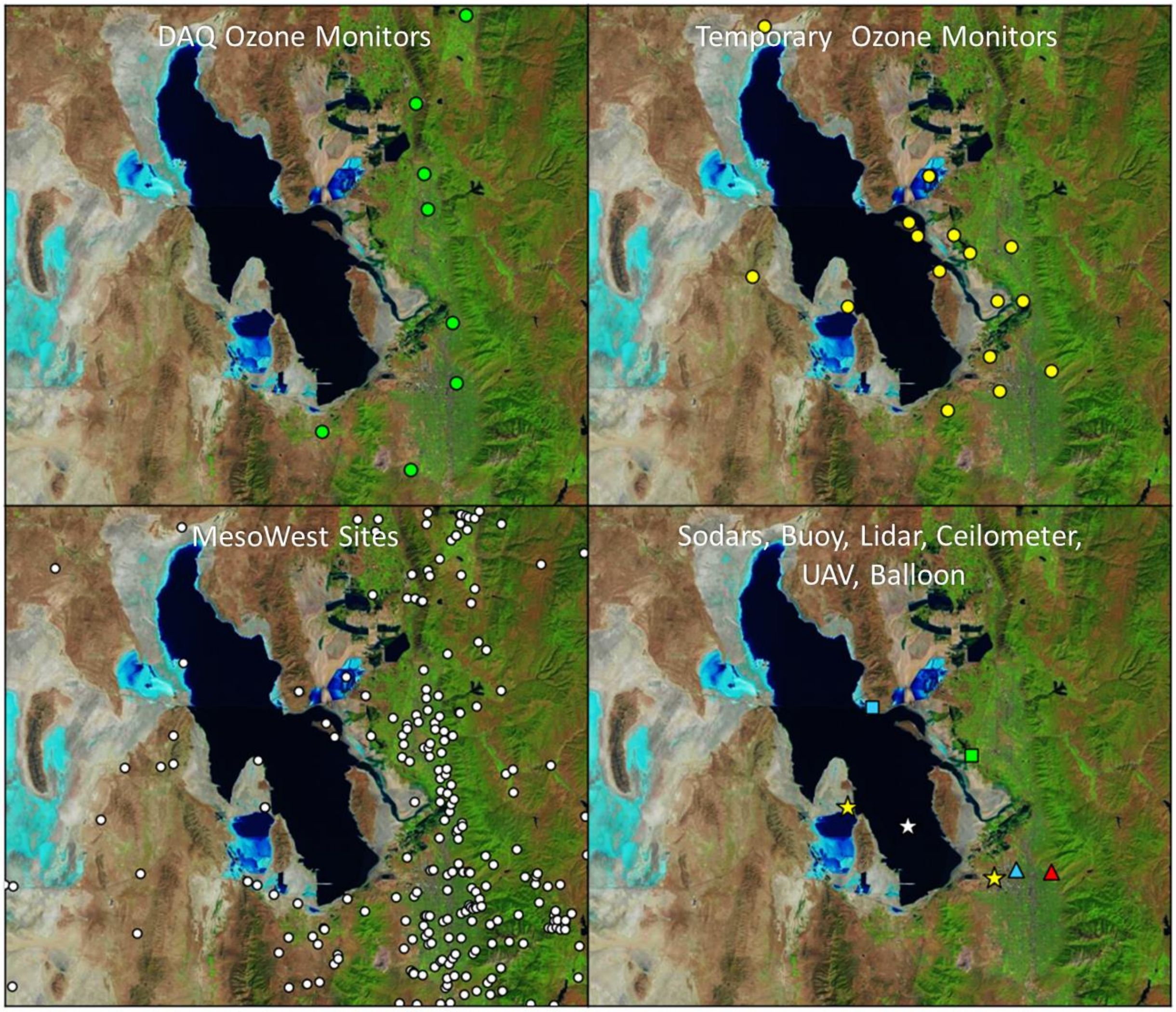

Figure 3. MODIS true-color image during June 2015 with locations of key sensors. upper left) permanent DAQ ozone monitoring sites. upper right) additional ozone monitoring sites during summer 2015. lower left) meteorological observing sites available via MesoWest (http://mesowest.utah.edu). Lower right) locations of additional sensors (NWS rawinsode- blue triangle; sodars- yellow stars; ceilometer and aethalometer- red triangle; buoy- white star; tethered balloon, lidar, sodar, ceilometer- green rectangle; UAV- blue rectangle.

5) Fixed-site instrumentation deployment

Figure 3 summarizes the locations where sensors relevant to GSLSO_3S were deployed during the 2015 summer. Ten permanently-deployed ozone monitors were in operation by DAQ during this period along the Wasatch Front (green circles in Fig. 3; two in Utah County not shown) with an additional 16 monitors deployed specifically for this project (yellow circles). See http://meso2.chpc.utah.edu/gslso3s/cgi-bin/site_metadata.cgi to query additional information regarding these sites. The ozone data were extensively quality controlled as part of this study.

The MesoWest research team at the University of Utah provides access to meteorological sensors (e.g., wind, temperature, moisture) on 3-10 m towers at over 100 locations surrounding the Great Salt Lake (white circles). See http://mesowest.utah.edu for additional details about that resource and the data collected from the in-situ sites can be downloaded using the MesoWest API (http://mesowest.org/api). Additional automated surface-based remote sensors (sodars, ceilometers, and lidar) were deployed specifically for this project (see the lower right panel and http://meso2.chpc.utah.edu/gslso3s/external_links.html). Twice-daily rawinsondes were launched routinely by the National Weather Service at the Salt Lake City International Airport as well. When conditions were favorable for intensive observations, tethersondes and UAVs were launched from the causeway entrance to Antelope Island and south end of Promontory Point, respectively (see Appendices A and B).

5) Overview of air quality during June-August 2015

Figure 4 summarizes the 8-h maximum ozone concentration at the Hawthorne DAQ site in the Salt Lake Valley during summer 2015 relative to that during the past 5 summers. High ozone concentrations were observed during June, early July and mid-late August 2015 as a result of favorable meteorological conditions for ozone formation at those times (i.e., strong ridging aloft during June as well as regional transport of wildfire smoke during August). A deeper and well-mixed boundary layer with enhanced flow speeds (contributing to reduced build-up of urban ozone precursors) tended to prevail during much of July and early August. Ozone levels exceeded the 8-h average 2015 NAAQS during 18 days, more often than during any other recent summer (e.g., 13 days in 2012).

To characterize the air quality and meteorological conditions present each day during the summer, Appendix C summarizes the air quality conditions for the Salt Lake Valley as defined by DAQ combined with a subjective characterization of factors such as ridging aloft, strong lake breezes, wildfire smoke, etc. The station identifiers used in Appendix C are defined in Appendix D and described online at http://meso2.chpc.utah.edu/gslso3s/cgi-bin/site_metadata.cgi. Field Notes (https://gslso3s.wordpress.com/) created daily during the study provide considerable information on each period of poor air quality.

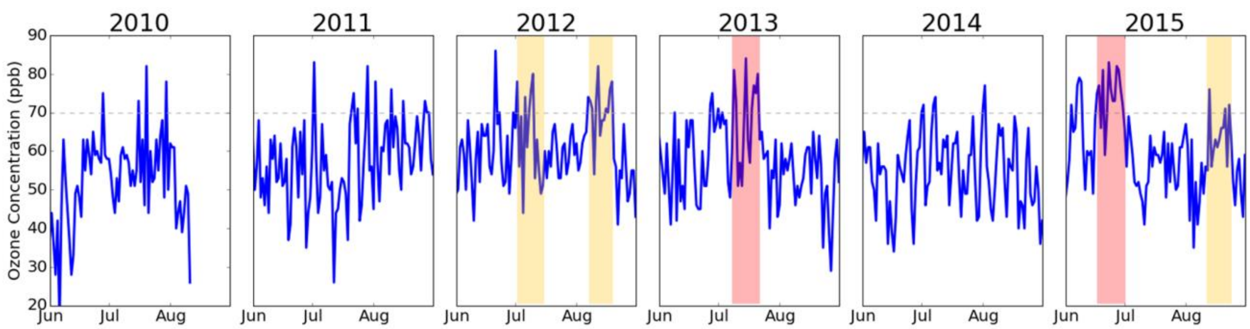

Figure 4. Daily maximum 8-h ozone concentrations at the Hawthorne (QHW) site in the Salt Lake Valley for summer months from 2010- 2015. Periods dominated by extensive meteorological ridging aloft or local and regional transport of wildfire smoke are highlighted by yellow and pink shading, respectively.

Appendix D summarizes the observations from the 26 sites continuously monitoring ozone sensors during the 2015 summer. The table at the end of the Appendix relates the station identifiers defined by MesoWest and used in the Appendix and this report. The Farmington Bay site (O3S02) recorded the most (19) exceedances of the 2015 NAAQS 8-h average standard of 70 ppb followed by Hawthorne (QHW, 18), Badger Island (BGRUT, 17), and Saltaire (QSA, 16). Those cumulative summaries highlight the multiple environments in which high ozone concentrations can occur, e.g.: western lakeshore with wide expanses of exposed Lake bed (BGRUT); urban Wasatch Front (QHW); and the interface between the Lake and urban environment immediately to the north of the Salt Lake Valley (O3S02 in the southeast corner of Farmington Bay and QSA to the northwest of the airport).

Figure 5 shows the ozone concentration time series over the summer at Badger Island and Farmington Bay. Similar time series can be generated for other stations from http://meso2.chpc.utah.edu/gslso3s/cgi-bin/time_series.cgi. Concentrations at Badger Island rarely drop below 30 ppb at night, indicating limited ozone titration where distant from urban precursor emissions. However, titration at Farmington Bay leads to ozone concentrations below 20 ppb during most nights with a greater number of afternoon peaks above 70 ppb during June, early July, and August compared to Badger Island. The pollution roses for Badger Island and Farmington Bay in Fig. 6 highlight the combined diurnal influences of photochemical destruction and production of ozone as well as local wind

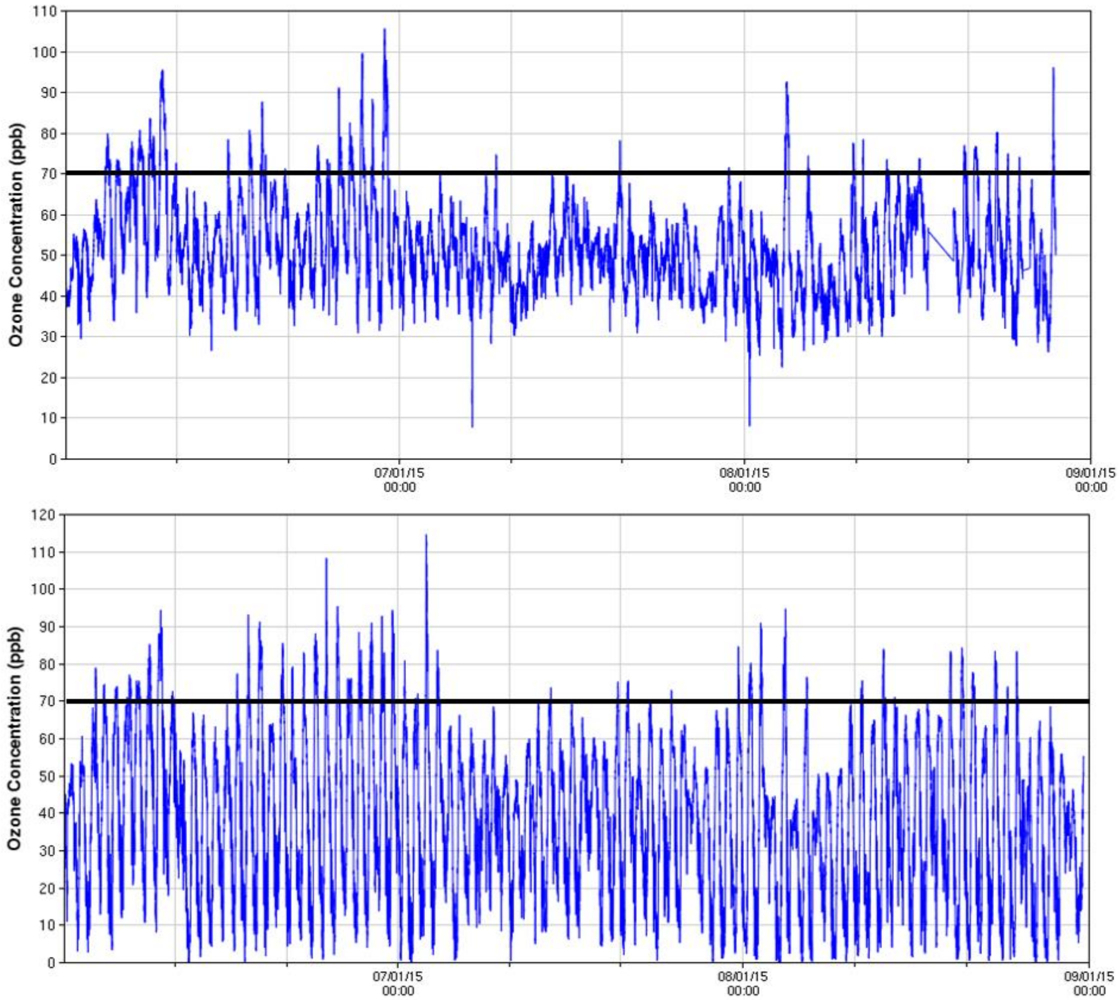

Figure 5. 5-min ozone concentration at Badger Island (BGRUT- top) and Farmington Bay (O3S02-bottom) during June-August 2015. 8-h average NAAQS denoted by the solid line.

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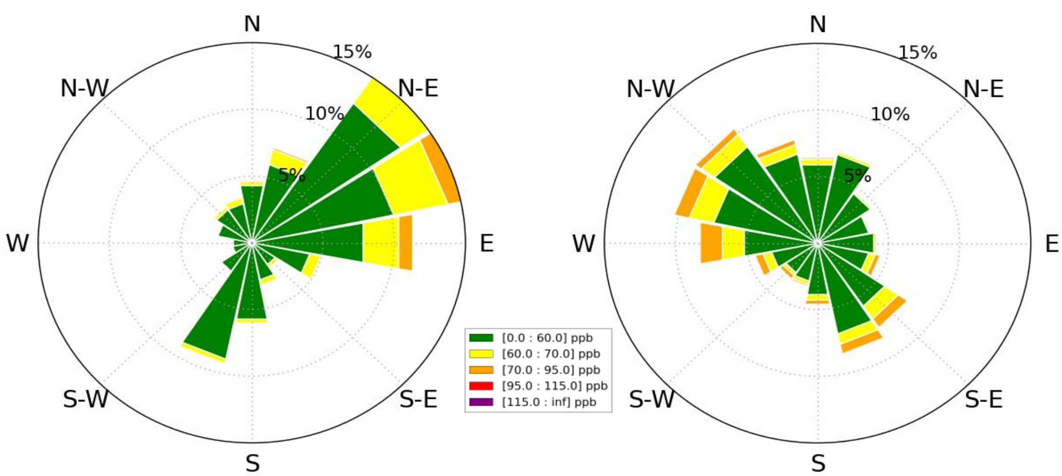

Figure 6. Pollution roses (fraction of time ozone concentrations are in range bins as a function of wind direction) at Badger Island (left) and Farmington Bay (right).

circulations. Pollution and wind roses can be generated for other stations from: http://meso2.chpc.utah.edu/gslso3s/cgi-bin/ozone_rose.cgi. Winds at Badger Island tend to be most frequent from the northeast direction (i.e., the predominant flow across the Lake is from this direction). During those times, high ozone concentrations are most likely to occur. Nocturnal land breezes from the southeast are common at Farmington Bay with afternoon lake and up-valley winds from the northwest direction. Similar pollution roses for sites surrounding the Salt Lake Valley are shown in Fig. 7. At Hawthorne (southeastern most), high ozone concentrations occur predominantly when the wind is from the north-northwest, which typically occurs in the afternoon. On the eastern bench at the University of Utah campus, nocturnal canyon drainage flows typically have lower ozone concentrations while daytime upslope flows often have higher ozone concentrations. At Neil Armstrong Academy in West Valley, Saltaire (upper left) and Bountiful (upper right), nocturnal down valley flows tend to be associated with lower ozone concentrations with higher ozone concentrations in the afternoon when the winds are blowing from the Lake from the west to northeast. Finally, at Farnsworth Peak in the Oquirrh Mountains, ozone concentrations are lower when the winds are from the prevailing westerly direction with higher concentrations when the winds are from the southeast often arising from up-slope winds during late morning. The ozone sensor at Farnsworth Peak is a critical one for the field study due to its location at high elevation (2796 m, roughly 1500 m above the Lake).

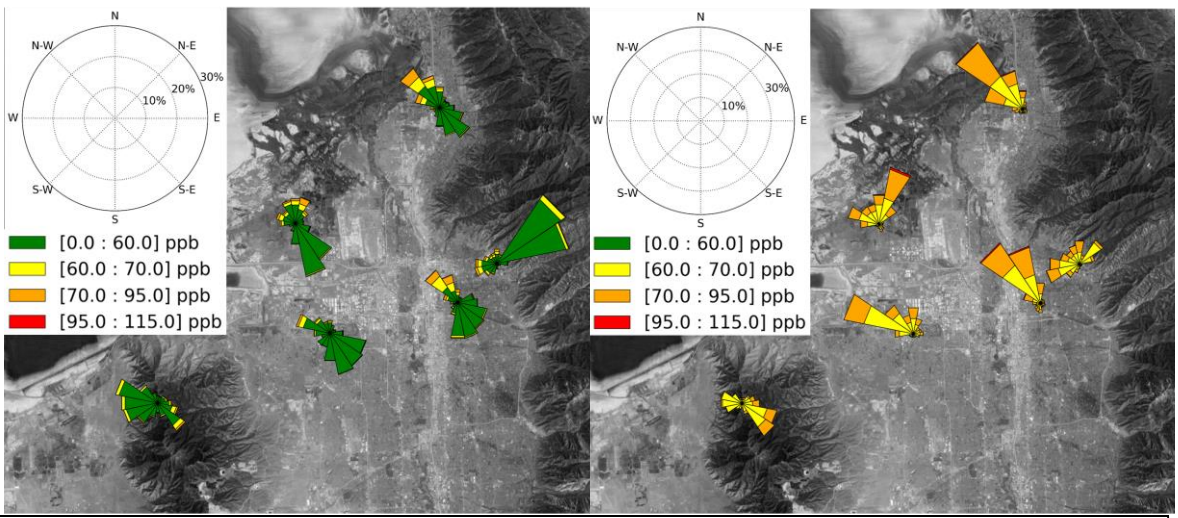

Figure 7. Pollution wind roses delineating ozone concentrations as a function of wind direction. Left: all periods. Right: restricted to periods when ozone concentration exceeded 60 ppb.

As described by Crosman and Horel (2009, 2010, 2012,2015), critical aspects of the Lake state that may affect ozone concentrations over the Lake and nearby Wasatch Front include its surface temperature as well as its areal extent. They can affect the timing, duration, and intensity of afternoon lake breezes as well as the depth of the boundary layer over the Lake. The MODIS image from June 2015 used as the background in Fig. 3 illustrates the diminished areal extent of the Great Salt Lake during summer 2015. The temperature near the Lake surface (blue line in Fig. 8) responds to the increased solar radiation both diurnally and seasonally while that near the Lake bottom remains low until enough heating has occurred to mix the Lake through its entire depth. During

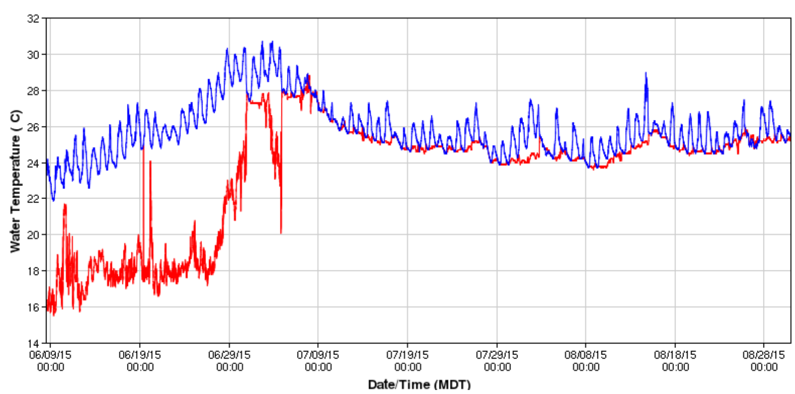

Figure 8. Lake temperature (°C) near the surface (0.4 m below; blue) and near the lake floor (1.3 m above; red) observed by the US Geological Survey buoy whose location is indicated by the white star in Fig. 4.

summer 2015, strong vertical mixing in the Lake began in mid June and the Lake became effectively isothermal by early July. Without this strong mixing, it is likely surface Lake temperatures would have been higher during this period than they were, which may have contributed to a shallower boundary layer over the Lake compared to that over nearby land surfaces.

6) Mobile instrumentation deployment

A novel mix of trace gas and meteorological sensors were deployed opportunistically as well as during planned intensive observing periods as detailed in Appendix E. Photos and information describing these deployments are provided in the seminar slides: http://meso2.chpc.utah.edu/gslso3s/GSLSO3S_Dept_Presentation_2015-10-07.pdf as well as can be explored interactively using the kmz file listed in Table 1.

Figure 9. Summary of the spatial distribution of all the observations collected during GSLSO$_3$S. The ozone sensor deployed on the KSL traffic helicopter provided many of the tracks extending away from the Wasatch Front.

Figure 9 summarizes the locations from which observations were collected at some point during the summer from both fixed sites as well as mobile instrumentation. At times, sensors onboard vehicles were used to assess conditions on the Causeway that bisects the Lake and on its western, southern, and eastern shoreline. As shown in Fig. 10, the sensor onboard the TRAX light rail car often provided valuable information on ozone concentrations within the Salt Lake Valley during the day. The data collected aloft from the sensor onboard the KSL traffic helicopter whenever it was in operation was particularly noteworthy as shown in Fig. 9. In this instance

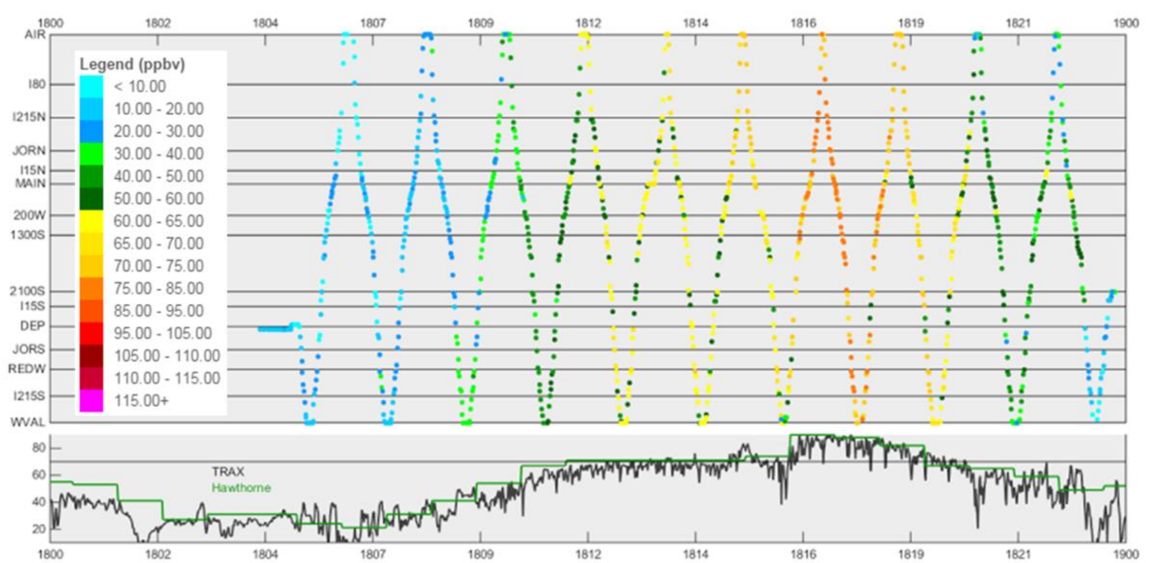

Figure 10. Top. Ozone concentration from sensor on TRAX light rail car travelling on 18 June on the Green Line from the Airport (AIR) to West Valley (WVAL). Bottom. Comparison of ozone on the light rail car (black) and at Hawthorne (green). Time in MDT.

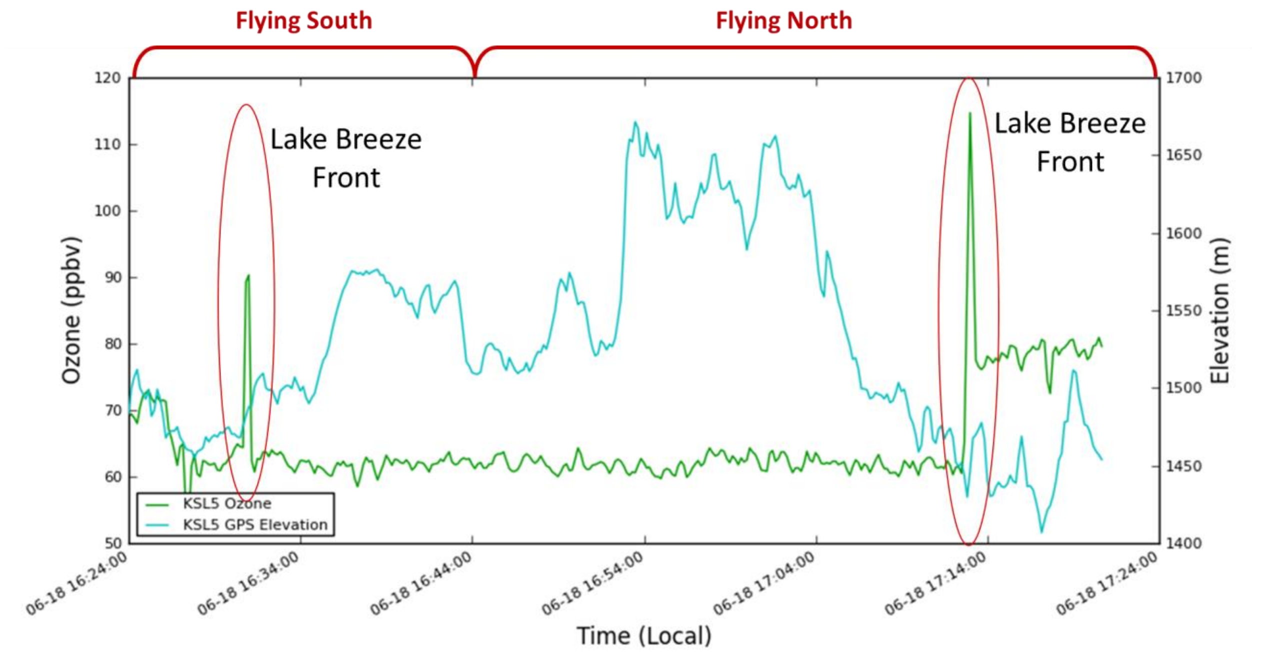

Figure 11. Ozone concentration (green line) from sensor onboard the KSL traffic helicopter (flight level in blue) indicates intersected higher ozone concentrations at the leading edge of the lake breeze front.

7) Ozone analyses

Modifications to the two-dimensional variational analysis approach of Tyndall and Horel (2012) were made to integrate all of the ozone observations available at surface sites, including those from fixed locations as well as vehicles and light rail. Background values are defined on the 1km grid separately for Lake, rural, and urban gridpoints based on medians of the available fixed site observations in each category. The Farnsworth Peak and to a lesser extent Lakeside Mountain observations are used to delineate a linear dependence of ozone concentration with elevation above 1500 m AGL (i.e., above the Wasatch Front benches). Then, all of the observations are used to adjust the background values assuming that the background error covariances decorrelate over an e-folding distance of 25 km and 250 m in the horizontal and vertical distances, respectively. This approach generally captures dominant features but, as with all objective techniques, is subject to the distribution and density of the available observations.

All of the hourly analyses are available interactively from meso1.chpc.utah.edu/uu2dvar/webGL/so3s_sens.html for surface wind as well as ozone, Images and animations for each month of ozone concentration are available from home.chpc.utah.edu/~u0035056/summer_ozone/. Figure 12 illustrates the temporal and spatial evolution of ozone concentration during the afternoon and evening of 18 June. Mobile observations from several vehicles and light rail (Fig. 10) were available at this time. High ozone concentrations remained north of the Salt Lake Valley though 1600 MDT and then the lake breeze front evident in Fig. 11 pushed southward through the Valley leading to higher ozone concentrations through much of the Valley.

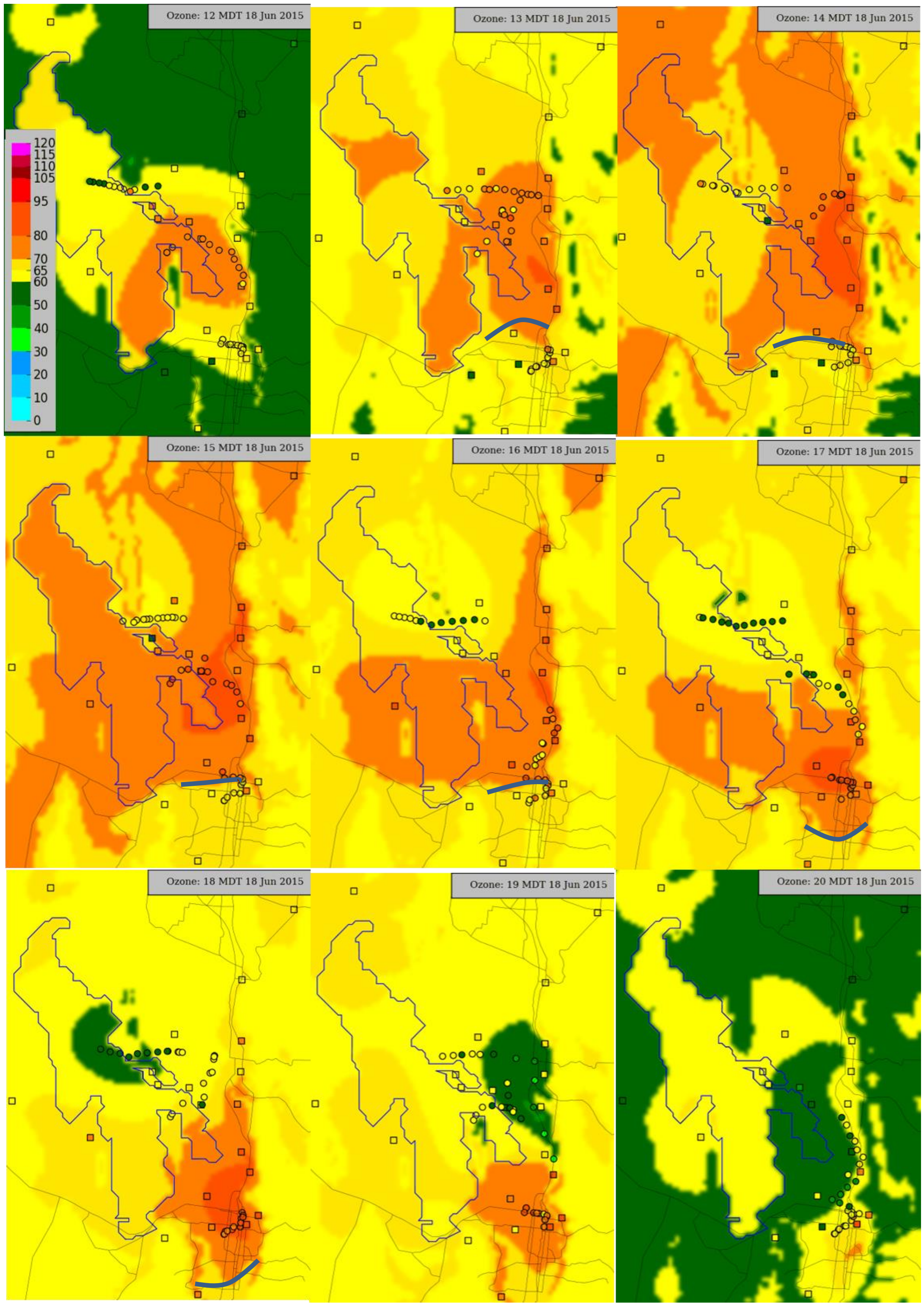

Figure 12. Hourly ozone analyses from 12-20 MDT 18 June 2015. Observations from fixed (squares) and mobile (circles) sensors are shaded according to the same scale shown in the upper right panel. Approximate position of the lake breeze front delineated by the heavy line.

8. Impacts of regional wildfire smoke transport

After the high ozone concentrations observed during June and early July, synoptically disturbed and monsoonal flows inhibited high ozone concentrations until mid-August (Fig. 4). Regional transport of smoke from wildfires throughout much of the west to the Wasatch Front may have contributed to higher ozone concentrations in mid-late August (Fig. 13). Figure 14 summarizes many of the factors contributing to the ozone concentrations observed during this period while Fig. 15 illustrates the depth of the aerool layer due to wildfire smoke during this event.

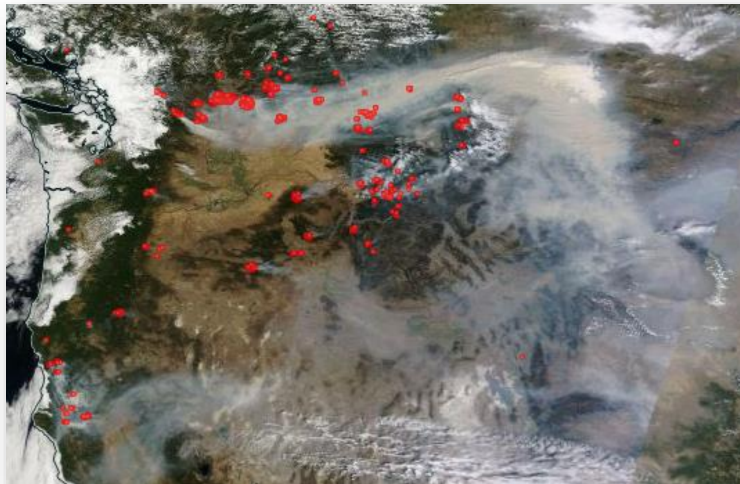

Figure 13. MODIS image of smoke transport on 20 August 2015.

An aethalometer loaned to the University of Utah researchers by Sonoma Technologies, Inc. combined with ozone and particulate sensors at the Mountain Meteorology Laboratory on the campus (MTMET) captured the sudden onset of a smoke plume during 16 August (e.g., high brown carbon concentrations as defined by the difference between light absorption in the 370 nm UV minus 880 nm BC channels, Fig. 15d). Throughout the following week, the elevated levels of ozone (Fig. 15a), PM2.5 (Fig. 15b), and black (Fig. 15c) and brown (Fig. 15d) carbon led to reduced visibility and numerous media reports of the impacts of the smoke on the general public. Complex relationships are evident in Fig. 15 arising as a result of the urban emissions of precursor chemicals for photochemical reactions, local wind circulations (e.g., north-easterly winds away from the Wasatch Mountains at this site at night and westerly winds away from the urban area towards the Wasatch Mountains during the day evident in Fig. 13e) combined with the regional smoke transport.

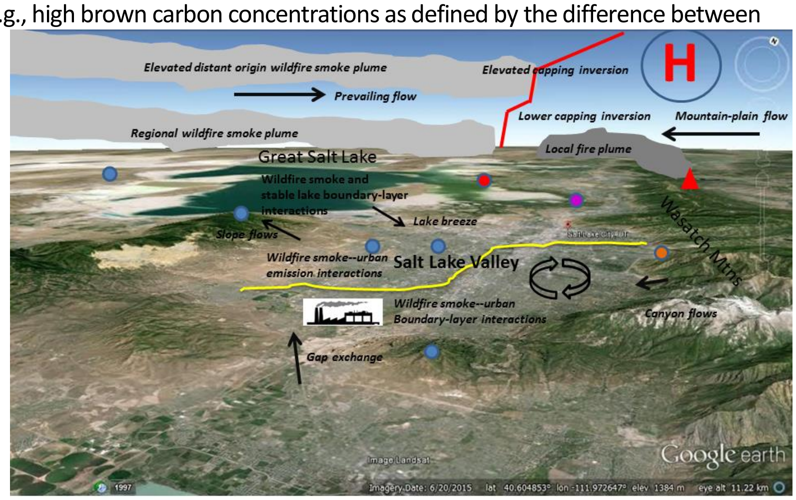

Figure 14. Schematic illustrating the relevant interactions between wildfire smoke, urban emissions, and complex terrain boundary layer interactions . Several locations of key instruments available during GSLSO$_3$S are indicated.

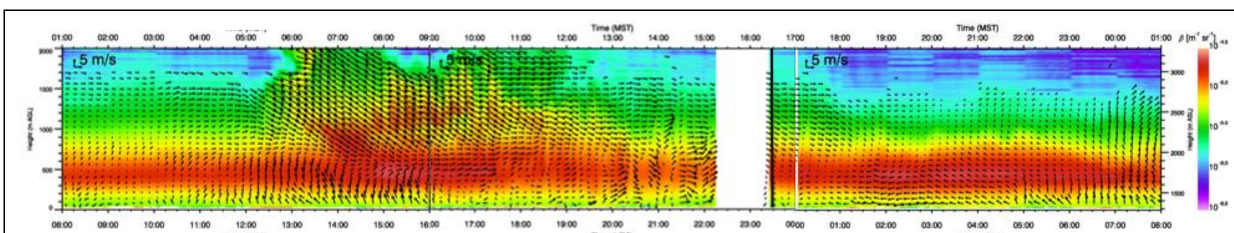

Figure 15. Lidar aerosol backscatter (shading) and horizontal winds (vectors) on 20 August, 2015 at Syracuse, UT DAQ site highlighting the presence of enhanced aerosol concentrations aloft due to the wildfire smoke.

9. Ongoing and Future Work

It is common for research to continue for several years to analyze data collected from field studies such as $GSLSO_3S$. For example, the data from the National Science Foundation supported 2010-2011 Persistent Cold-Air Pool Study continues to be examined by a number of research groups with over a dozen articles published to date. Hence, this project report serves as a preliminary evaluation after completion of the field work and a guide to the extensive information available to DAQ and other researchers through the web resources, some of which are listed in Table 1. It is premature to make recommendations as to what factors DAQ staff should focus on to improve their summer air quality forecasts.

Research will continue over the next 6-9 months using support from other sources. At the University of Utah this includes completion of M.S. thesis research by Brian Blaylock (analysis and simulation of the 18 June lake breeze case) and Ansley Long (further refinement and interpretation of the two-dimensional ozone analyses described in Section 7).. One proposal to NOAA in part to extend the analysis of the $GSLSO_3S$ data has been submitted by University of Utah researchers with other proposals likely to be submitted within the next year to extend both the data analysis as well as propose additional field work.

Further support from DAQ to continue the analysis of the data collected by researchers at all three universities would be of great benefit to DAQ operations and planning and to the public as well. The $GSLO_3S$ pilot study was the most extensive field study ever undertaken related to summer air quality along the Wasatch Front. Many factors influencing ozone concentrations over the lake and along the Wasatch Front became apparent or were at least hypothesized to be relevant as the study evolved:

- generation of ozone during an early June thunderstorm
- impacts of a wet spring on hillside vegetation potentially leading to generation of biogenic precursors for later ozone production
- early season shallow lake thermocline potentially leading to a shallow boundary layer over the lake
- limited evidence for abnormally high ozone concentrations in the central portions of the Lake as measured along the Causeway
- enhanced ozone in the Farmington Bay region relative to other areas
- the direct and secondary roles of the Great Salt Lake on ozone production
- variations in the intensity and duration of nocturnal titration along the shores of the Great Salt Lake due to the presence of other pollutants (NOX, etc.)
- higher ozone concentrations in the upper portions of the boundary layer during the afternoon over urban areas due to titration closer to the surface
- multiple layers with differing ozone concentrations observed in vertical profiles of the boundary-layer resulting from interactions between the urban environment and complex terrain meteorology
- the relative strength, intensity, and timing of land and lake breezes compared to those of concurrent mesoscale and synoptic-scale circulations
- the impact of canyon flows and other terrain-circulations on ozone and precursor transport along the Wasatch Front
- regional transport of wildfire smoke and its impacts on particulate concentrations as well as ozone production
- regional transport of ozone produced elsewhere.

Of particular interest for improving guidance for DAQ forecasters as well as DAQ planners developing future State Implementation Plans is the extent to which numerical forecasts and simulations of ozone concentrations using coupled atmospheric-air chemistry models can be improved to capture many of the aforementioned factors affecting ozone concentrations. This will require improving emission inventories of ozone precursors, developing atmospheric modeling capabilities to resolve both the local and regional circulations, and the ability to properly simulate the generation of ozone through the various possible pathways.

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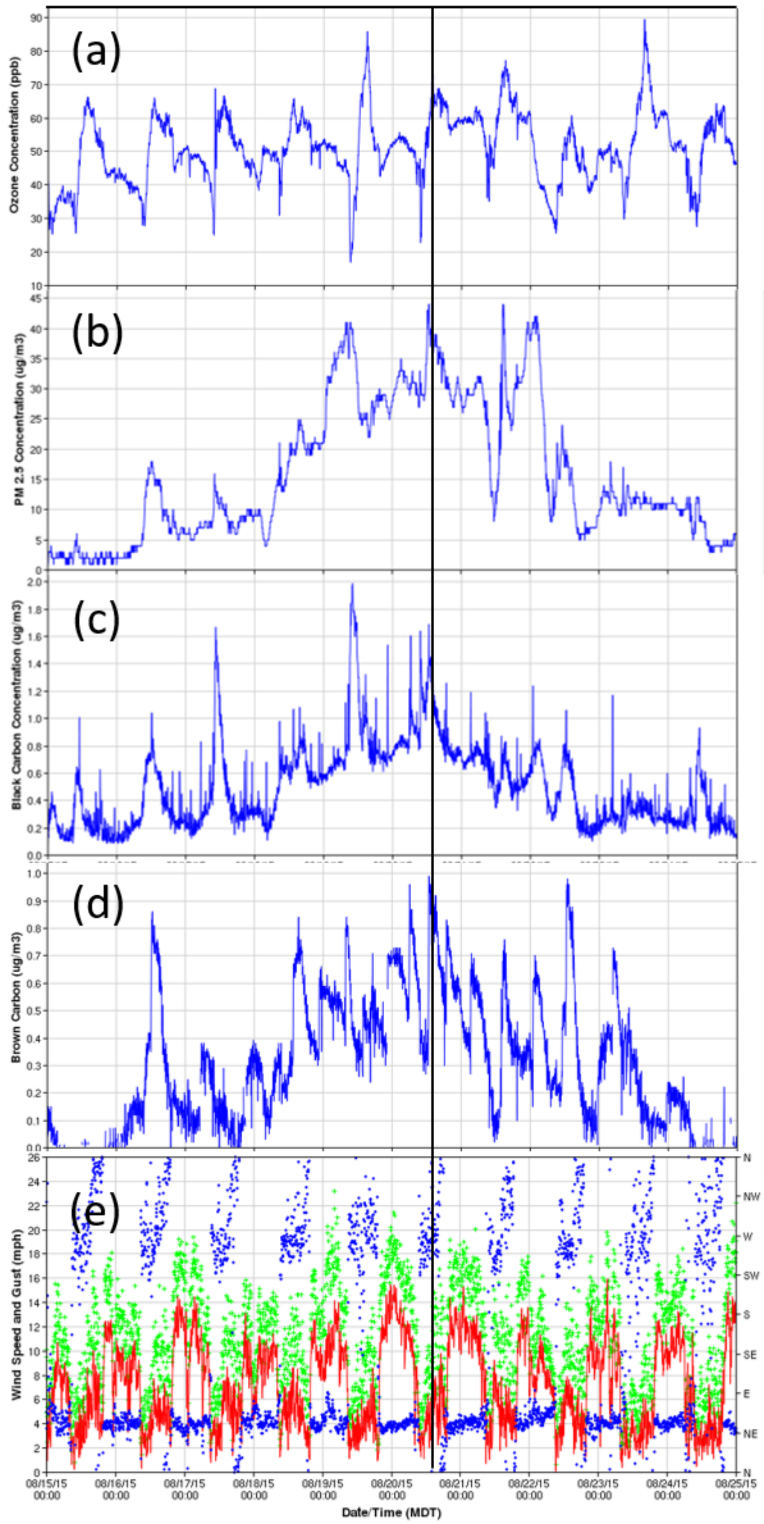


Figure 16. Conditions on the University of Utah campus from 15-24 Aug 2015 of: a) ozone; b) PM2.5; c) black carbon; d) brown carbon UV-BC; e) wind speed (red), gust (green); direction (blue). The black vertical line denotes 1730 MDT 20 August for reference.

Appendix A. Summary of Utah State University Activities

USU's vertical ozone transects ("O_3 curtains") were undertaken using a custom-modified ozone monitor (2b Technologies, Model 202) and an in-house designed UAV platform. The UAV platform used for these studies was an AggieAir Minion airframe (http://aggieair.usu.edu/node/17), a typical fixed wing platform, which has an eight foot wingspan, a takeoff weight of 6.4 kg, a payload capacity of 1.8 kg, and payload bay dimensions of approximately 13.0 cm x 13.7 cm x 29.2 cm. The single propeller engine is battery powered (16.8 v), can stay aloft for up 60 minutes, flies at average speeds of 12-18 m/s, and has typical altitudes ranging from 200-1000 m AGL. The AggieAir system can fly autonomously via preprogrammed GPS-controlled flight patterns or can be manually controlled with line of sight and a GPS-monitored information live-stream to the ground control station. Additionally, positional wind speed and direction information were derived from the UAVs aeronautics system. Ambient temperatures were coincidently logged at 1 Hz using a pair HOBO dataloggers for redundancy. For the 2015 Great Salt Lake Summer Ozone Study (GSL SO_3S) a Certificate of Authorization (COA) was obtained for the southern tip of Promontory Point, circumscribing a circle with one mile radius up to an elevation of 600 m AGL, and it is valid for a period of three years.

The COA was not approved by the FAA in time for participation in IOP1; however, it was approved in time for IOP2. The UAV/O_3 system was deployed to the Promontory Point location on July 16, 2015 (Thursday). An initial morning flight attempt (≈0930) was aborted shortly after takeoff due to unacceptably high winds aloft (> 15-20 /ms) which caused very unstable flight. A second flight attempted at 10:30, but the aircraft immediately crashed upon launch. A broken servo was found to have caused the elevator to be stuck in the "down" position and forced the plane into a nearby berm. Fortunately, the USU team brought a backup UAV aircraft, the system was reconfigured, and a third flight was initiated and was completely successful, flying from approximately 1202 to 1245 MDT. The flight path flew SE from the launch point approximately 3 km out towards the NW corner of Freemont and stair-stepped 10 transects of nominally 1367, 1417, 1467, 1517, 1567, 1617, 1667, 1717, 1817, and 1917 m above sea level (ASL) or 50, 100, 150, 200, 250, 300, 350, 400, 500, and 600 m above ground level (AGL). The base datum was considered to be the launch point which was on a bench slight above lake level. Therefore, the over water portions of the flight added roughly additional 35 m AGL. Shortly after completion of this flight, the USU team was contacted by Air Traffic Control (ATC) and was notified that the previous flight approval was suspended for the remainder of the day due to shifting wind directions and resulting changes in private and commercial aircraft approaches to area airports.

The data collected from the 16 July 2015 1202-1245 MDT flight are shown in the following figures. Figure 1 shows the vertical temperature lapse rate as determined by the paired HOBO dataloggers. The dashed line represents the ideal dry adiabatic lapse rate (Γ_d) and is typically taken as the definition "neutral stability" in air quality references. As can be seen, the lapse rate very nearly replicates neutral conditions, until perhaps around 1700 m ASL wherein the lapse rate becomes slightly more stable.

Figure 2 shows the measured overall O_3 lapse rate over the same flight. As can be derived, the ozone column concentrations were relatively constant and the column-averaged O_3 was 50.4 ppb. There appeared to be a slight increase with altitude to around 55 ppb at about 1550 m ASL, then a decrease to about 45 ppb at 1700 m ASL. This minimum is coincident with the previously mentioned temperature inflection and was also the location of the manually observed highest wind speeds (3.7 m/s as opposed to more typical 2.0 m/s). After this level, the ozone concentration appeared to recover towards the column-averaged concentrations.

Figure 3 shows a contour plot, the "O_3 curtain", of the successful flight. The contour plot shows the generalized vertical profile shown in Figure 2 was reflected along the length of the SE-NW transect with a generalized O_3 increase observed with altitude to around 1700 m ASL, followed by a slight depression and then recovery as altitude increased. Overall, during the observed time period and over the spatial coverage, although the average O_3 concentrations were only moderate, there did appear to be some discernible vertical structure, while the horizontal concentrations were essentially well-mixed within the layers.

Figures 4-7 show photographs of the UAV operation on July 16, 2015.

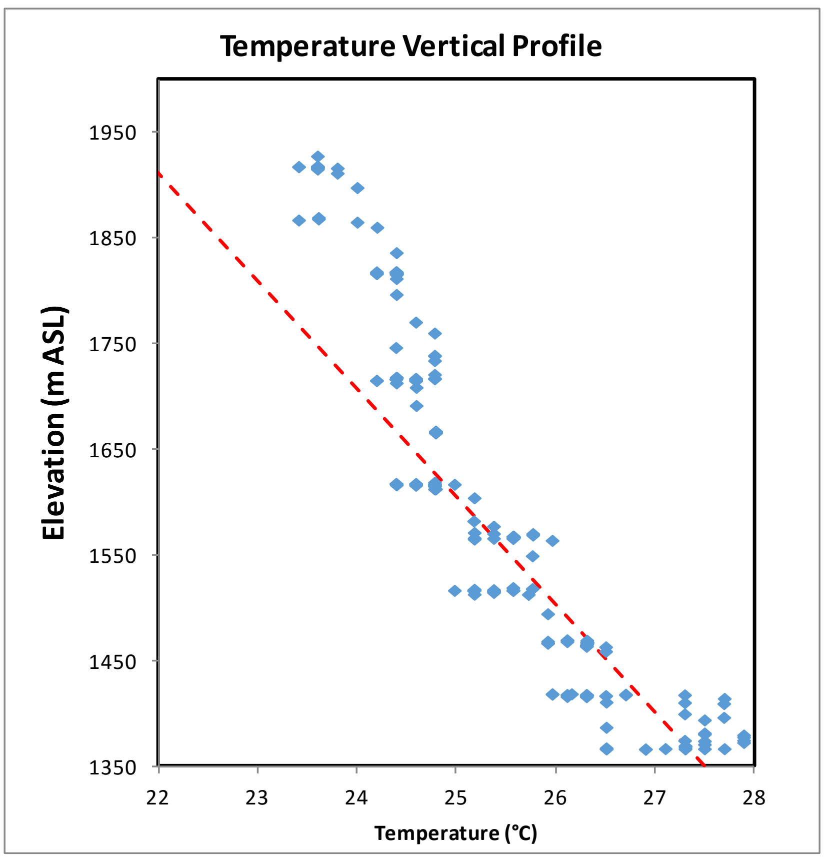


Figure 1. USU's UAV-derived vertical temperature profile, Promontory Point, 16 July 2015, 1202-1245 MDT.

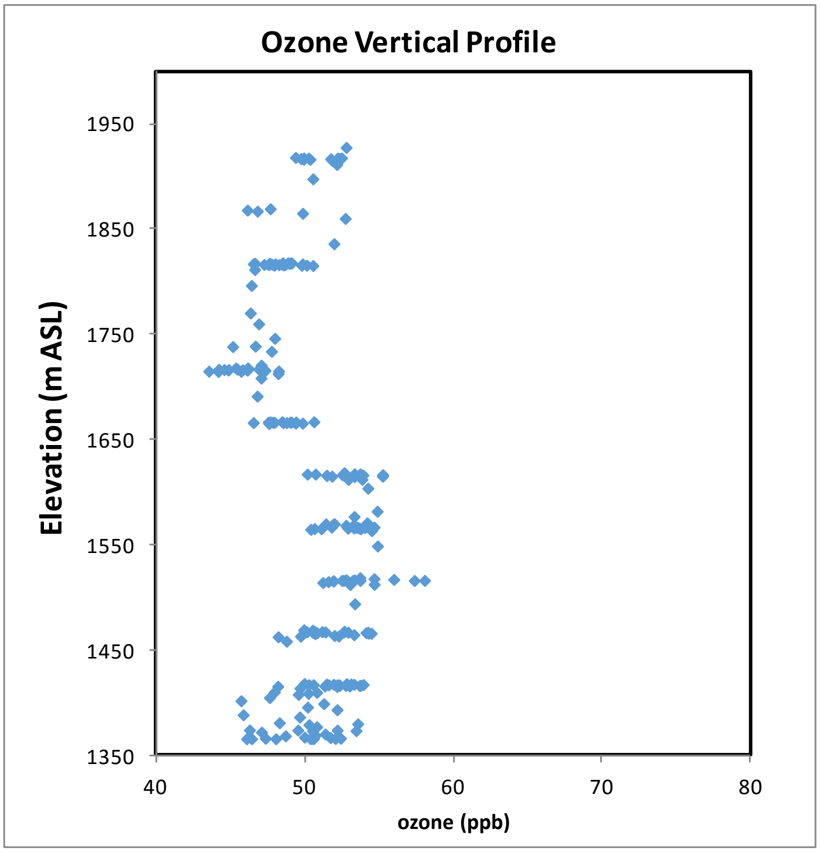


Figure 2. USU's UAV-derived vertical ozone profile, Promontory Point, 16 July 2015, 1202-1245 MDT.

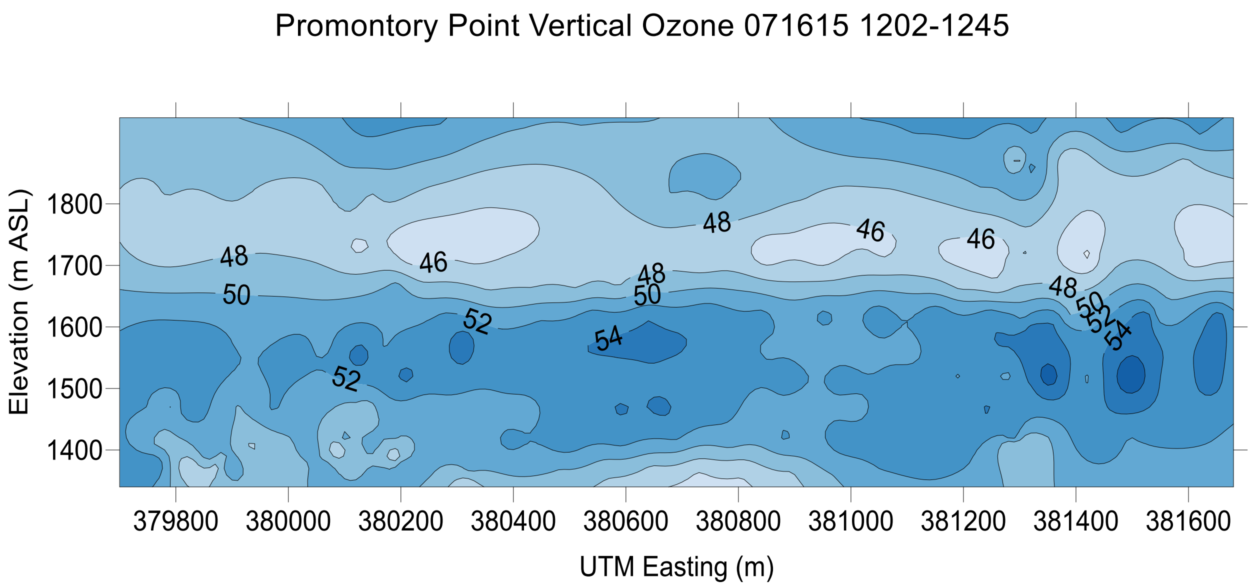


Figure 3. Contour plot of USU's UAV-derived vertical and horizontal ozone transects, Promontory Point, 16 July 2015, 1202-1245 MDT.

Figure 4. Catapult launch of the USU Minion UAV.

Figure 5. Crash shortly after launch.

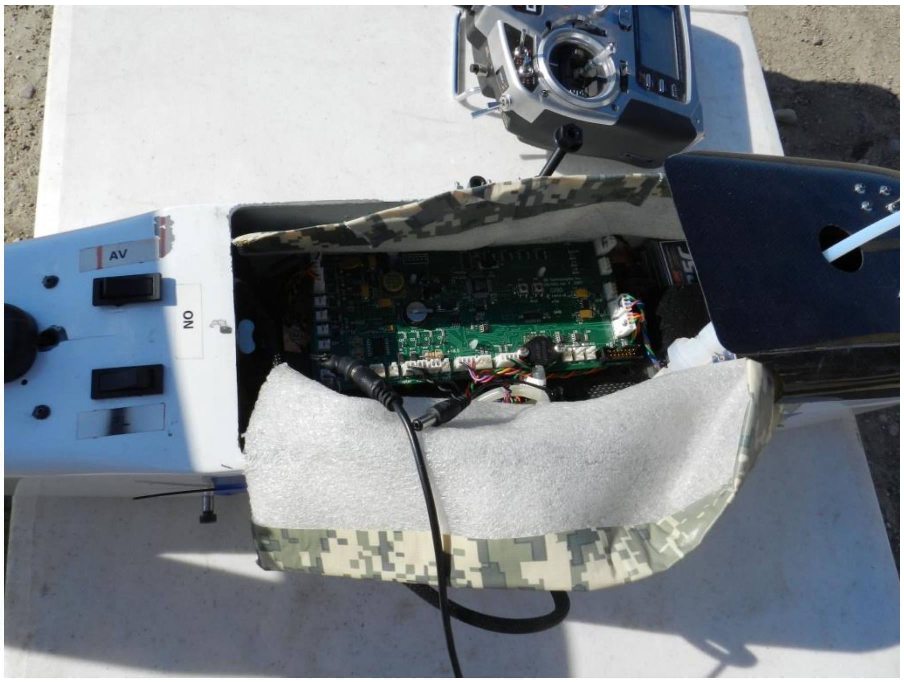


Figure 6. The modified O_3 monitor mounted in the UAV's payload bay.

Figure 7. The USU UAV coming in for a landing.

Appendix B. Weber State University Activities

DON’T TOUCH BELOW HERE

Appendix C. Daily Overview of Air Quality and Weather Conditions during June-August 2015

Date	Forecast-previous day	DAQ Morning Forecast	Max Ozone (ppb)	Location of max	8-h Avg QHW	Max 8-h Avg (SL county)	Synoptic-forcing	Thermally-forced	Rain/ Thunder-storm	Convection	Ridge	Trough	Hotter than Normal	Lake Breeze Present	Smoke
1-Jun-15			62.33	LMS			x			x	x		x		
2-Jun-15			63	QNP											
3-Jun-15			79.1	O3S02					x	x		x			
4-Jun-15			80.9	GSLM											
5-Jun-15			74.56	QSA											
6-Jun-15			80.9	GSLM					x						
7-Jun-15			81	QHW											
8-Jun-15		Unhealthy	87.4	GSLM	80.25	80.99 QSA		x			x		x		
9-Jun-15	Unhealthy	Unhealthy	99.7	QSA	78.12	90.17 QSA		x					x	x	
10-Jun-15	Moderate	Unhealthy	81.4	O3S06	61.25	63.16 QSA		x							
11-Jun-15	Moderate	Good	68.49	FWP	50	51.12 QSA			x						
12-Jun-15	Moderate	Moderate	78	QNP	60.5	60.5 QHW							x		
13-Jun-15		Moderate	85.9	MTMET	59.88	59.88 QHW							x		
14-Jun-15		Unhealthy	77.35	MTMET	60.75	60.75 QHW							x		
15-Jun-15	Good	Moderate	78.36	BGRUT	49.38	57.83 QSA	x		x	x		x	x		
16-Jun-15	Moderate	Moderate	79.44	MTMET	68.38	68.38 QHW							x		
17-Jun-15		Moderate	93.2	O3S02	75.25	75.25 QHW					x		x		
18-Jun-15	Unhealthy	Moderate	91.3	O3S02	78	78 QHW					x		x	x	
19-Jun-15	Moderate	Unhealthy	80	QSF	66.5	69.5 QH3					x		x		
20-Jun-15	Moderate	Moderate	90	QHW	81.5	81.5 QHW					x		x		
21-Jun-15		Moderate	79.16	O3S02	59.12	59.12 QHW					x		x		X
22-Jun-15	Moderate	Moderate	83	O3S02	69.62	72.88 QH3					x		x		X
23-Jun-15		Moderate	92	QBV / QHW	83.25	83.25 QHW					x		x	x	x
24-Jun-15	Moderate	Unhealthy	108.3	O3S02	76.5	76.5 QHW					x		x	x	
25-Jun-15		Unhealthy	95.4	O3S02	73.12	73.12 QHW							x	x	
26-Jun-15		Unhealthy	85.8	MTMET	75.43	75.43 QHW							x	mild	
27-Jun-15	Unhealthy	Unhealthy	116.7	MTMET	82.75	82.75 QHW					x		x	x	
28-Jun-15	Unhealthy	Unhealthy	103.9	MTMET	81.25	83.49 MTMET					x		x		
29-Jun-15		Unhealthy	105.7	BGRUT	76	77.64 QSA					x		x		
30-Jun-15	Unhealthy	Moderate	98	QSY	72.88	72.88 QHW			x	x	x		x		

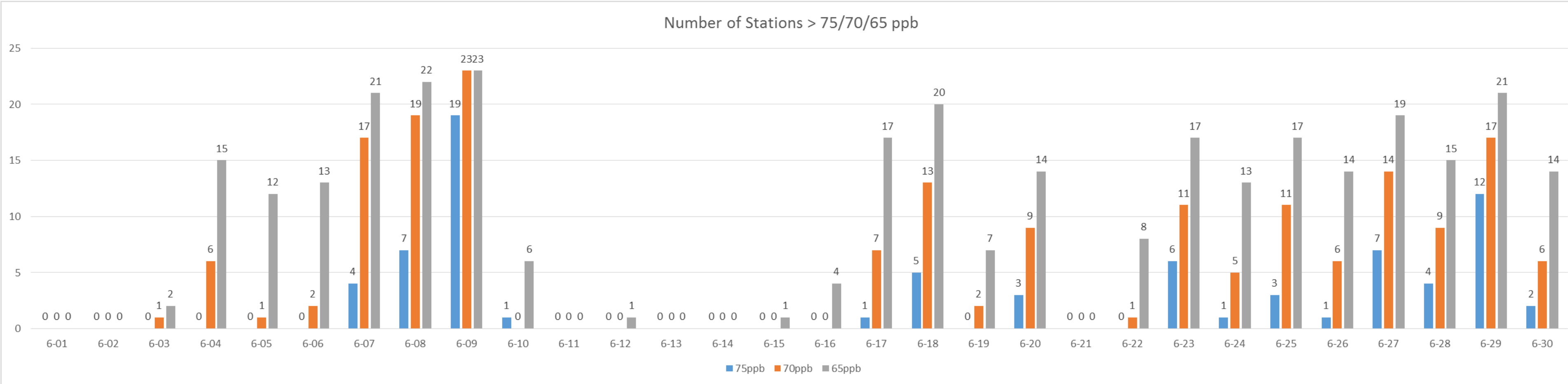
Date	Forecast-previous day	DAQ Morning Forecast	Max Ozone (ppb)	Location of max	8 Hr Avg QHW	Max 8 Hr Avg (SL county)	Synoptic-forcing	Thermally-forced	Rain/ Thunder-storm	Convection	Ridge	Trough	Hotter than Normal	Lake Breeze Present	Smoke
1-Jul-15	Unhealthy	Unhealthy	83	QSF	66.88	66.88 QHW					x		x		
2-Jul-15	Unhealthy	Unhealthy	78	QNP / QSF	56.38	58.62 QH3					x		x		
3-Jul-15	Unhealthy	Unhealthy	114.5	O3S02	69	69 QHW					x		x		
4-Jul-15		Unhealthy	84	QHV	64.38	64.38 QHW				x			x		Fireworks
5-Jul-15		Moderate	74	QL4	59.25	60 QH3			x	x					
6-Jul-15	Moderate	Good	69.22	O3S01	52.38	57.75 QH3			x	x					
7-Jul-15	Moderate	Good	66.92	MTMET	51.62	51.62 QHW				x					
8-Jul-15		Good	69.51	BGRUT	53.75	58.95 QSA			xxx	x					
9-Jul-15	Good	Good	74.79	BGRUT	49.5	52.91 QSA				x					
10-Jul-15	Good	Good	59.75	GSLM	47.25	48.38 QH3				x					
11-Jul-15	Moderate	Moderate	53.24	BGRUT	41.25	43.56 QSA									
12-Jul-15			60.62	GSLM	51.12	52.85 QSA									
13-Jul-15		Good	70.28	O3S02	52.88	52.96 QSA									
14-Jul-15	Moderate	Good	77.9	QSY	64.38	64.38 QHW				x					
15-Jul-15	Moderate	Moderate	70.28	BGRUT	56	57.88 QH3				x		x			
16-Jul-15	Moderate	Moderate	72.36	GSLM	61.62	61.62 QHW				x				x	x
17-Jul-15	Good	Moderate	70.31	MTMET	59	59 QHW									
18-Jul-15	Good	Good	64	QNP	59.5	59.5 QHW									
19-Jul-15	Good	Good	70.22	MTMET	57.5	59.88 QH3									
20-Jul-15		Good	78.1	BGRUT	59.75	62.78 QSA			x						
21-Jul-15	Good	Good	76.04	O3S03	65.12	65.12 QHW									
22-Jul-15	Good	Good	64.02	O3S02	48.88	50.88 QH3			xxx						
23-Jul-15	Moderate	Good	69.86	O3S02	61.5	62.54 QSA									
24-Jul-15	Moderate	Moderate	62.98	O3S02	52.38	52.91 QSA									
25-Jul-15		Moderate	73.08	O3S02	62.62	62.62 QHW									
26-Jul-15	Moderate	Moderate	69.84	O3S03	55.38	56.94 MTMET									
27-Jul-15		Good	60	QSF	50.75	51.01 QSA									
28-Jul-15	Good	Moderate	63.69	FWP	51.5	51.5 QHW									
29-Jul-15	Moderate	Moderate	75	QH3	61	67.88 QH3									
30-Jul-15	Moderate	Moderate	77	QSF	61.12	61.12 QHW									
31-Jul-15		Moderate	84.6	O3S02	64.88	64.88 QHW									

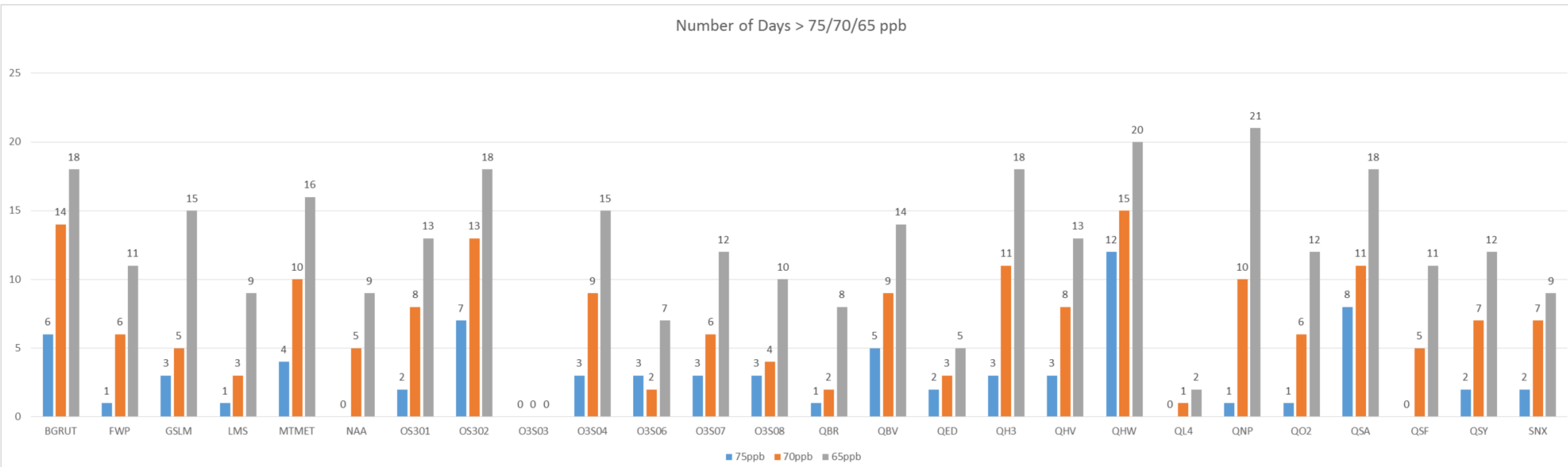
Date	Forecast-previous day	DAQ Morning Forecast	Max Ozone (ppb)	Location of max	8 Hr Avg QHW	Max 8 Hr Avg (SL county)	Synoptic-forcing	Thermally-forced	Rain/ Thunder-storm	Convection	Ridge	Trough	Hotter than Normal	Lake Breeze Present	Smoke
1-Aug-15	Moderate	Moderate	88.4	O3S03	67.88	67.88 QHW									
2-Aug-15	Moderate	Moderate	91	O3S02	61.62	61.62 QHW			x						
3-Aug-15		Good	59	QSF	42.5	46.5 QH3			x						
4-Aug-15	Moderate	Good	94.8	O3S02	63.75	77.91 QSA								x	
5-Aug-15	Moderate	Moderate	56	QH3	35.62	44 QH3						x			
6-Aug-15	Moderate	Moderate	77.06	O3S03	52.25	57.86 QSA									
7-Aug-15		Good	56.42	O3S06	40.88	43.25 QH3									
8-Aug-15	Good	Good	54	QNP	47.12	48.38 QH3									
9-Aug-15	Good	Good	66	QHW	57.38	57.38 QHW									
10-Aug-15		Moderate	77.59	BGRUT	49.38	55.74 QSA					x				
11-Aug-15	Good	Good	79	QBV	56.62	56.62 QHW			x	x	x				
12-Aug-15	Good	Good	65.88	O3S04	55.88	55.88 QHW					x				
13-Aug-15	Good	Moderate	95	QHW	76	76 QHW							x		
14-Aug-15	Moderate	Moderate	71.65	GSLM	56.12	57.99 QSA									
15-Aug-15		Good	69.94	BGRUT	60.25	61 QH3									XXX
16-Aug-15	Good	Moderate	75.34	O3S04	63.38	64.20 QSA									XXX
17-Aug-15	Moderate	Moderate	73	QSF	61	61.64 QSA									XXX
18-Aug-15		Moderate	75	QSF, QNP	63.25	66.55 QSA									XXX
19-Aug-15	Moderate	Moderate	92.1	O3S04	66.62	70.25 QH3									XXX
20-Aug-15		Moderate	89.5	O3S04	66.12	74 QH3									XXX
21-Aug-15	Moderate	Unhealthy	85.3	O3S04	71.38	71.38 QHW									XXX
22-Aug-15			80.2	O3S04	56.38	56.38 QHW									XXX
23-Aug-15			89.5	MTMET	72.88	74.76 QSA									XXX
24-Aug-15		Moderate	78.43	GSLM	63	63.78 QSA									
25-Aug-15	Good	Moderate	86.6	GSLM	52.62	52.62 QHW									
26-Aug-15	Good	Good	68.02	O3S06	46.25	49.12 QSA									
27-Aug-15	Good	Good	74	QNP	55.5	57.12 QH3									
28-Aug-15	Good	Moderate	74.54	GSLM	58.75	60.95 QSA									
29-Aug-15	Moderate		66.76	GSLM	49.75	50.45 QSA									
30-Aug-15		Good	53	QNP	43	44.50 QH3									
31-Aug-15	Good	Good	66	QHW	57	57 QHW									

Hazardous	Very Unhealthy	Unhealthy for SG	Moderate	Good

Appendix D. Statistics for June-August 2015

8 hour over 70																											
	BGRUT	FWP	GSLM	LMS	MTMET	NAA	OS301	OS302	O3S03	O3S04	O3S06	O3S07	O3S08	QBR	QBV	QED	QH3	QHV	QHW	QL4	QNP	QO2	QSA	QSF	QSY	SNX	
1-Jun																NA										NA	**0**
2-Jun												NA				NA										NA	**0**
3-Jun												NA				NA							x			NA	**1**
4-Jun	x		x													NA	x		x		x			x		NA	**6**
5-Jun	x								NA							NA										NA	**1**
6-Jun	x	x							NA							NA										NA	**2**
7-Jun	x	x	x		x	x	x	x	NA	x		x	x		x	NA	x	x	x			x	x		x	NA	**17**
8-Jun	x	x	x	x	x	x	x	x	NA	x		x	x	x	x	NA	x	x	x			x	x		x	NA	**19**
9-Jun	x	x	x	x	x	x	x	x	NA	x	x	x	x	x	x	NA	x	x	x	x	x	x	x	x	x	NA	**23**
10-Jun									NA							NA										NA	**0**
11-Jun									NA							NA										NA	**0**
12-Jun									NA							NA										NA	**0**
13-Jun									NA							NA										NA	**0**
14-Jun									NA							NA										NA	**0**
15-Jun									NA							NA										NA	**0**
16-Jun									NA							NA										NA	**0**
17-Jun	x				x			x	NA						x	NA	x	x	x								**7**
18-Jun	x				x		x	x	NA	x					x	NA		x	x		x	x	x		x	x	**13**
19-Jun									NA												x			x			**2**
20-Jun					x	x		x	NA						x		x		x		x		x	x			**9**
21-Jun									NA																		**0**
22-Jun									NA								x										**1**
23-Jun	x				x	x	x	x	NA						x		x	x	x				x			x	**11**
24-Jun					x			x	NA						x				x				x				**5**
25-Jun	x						x	x	NA	x		x						x	x		x	x			x	x	**11**
26-Jun	x								NA						NA		x		x		x			x		x	**6**
27-Jun	x	x			x		x	x	NA	x		x			NA	x	x		x		x		x		x	x	**14**
28-Jun	x				x			x	NA	x					NA	x			x		x		x			x	**9**
29-Jun	x	x	x	x			x	x	NA	x	x	x	x		NA	x	x		x		x		x		x	x	**17**
30-Jun								x	NA	x					x			x	x			x					**6**
total days	**14**	**6**	**5**	**3**	**10**	**5**	**8**	**13**	**0**	**9**	**2**	**6**	**4**	**2**	**9**	**3**	**11**	**8**	**15**	**1**	**10**	**6**	**11**	**5**	**7**	**7**	**0**





8 hour over 70

	BGRUT	FWP	GSLM	LMS	MTMET	NAA	O3S01	O3S02	O3S03	O3S04	O3S06	O3S07	O3S08	QBR	QBV	QED	QH3	QHV	QHW	QL4	QNP	QO2	QSA	QSF	QSY	SNX	
1-Jul									NA												x						**1**
2-Jul									NA																		**0**
3-Jul								x	NA						x						x						**3**
4-Jul									NA	x								x									**2**
5-Jul									NA																		**0**
6-Jul									NA																		**0**
7-Jul									NA																		**0**
8-Jul									NA																		**0**
9-Jul									NA																		**0**
10-Jul									NA																		**0**
11-Jul									NA																		**0**
12-Jul									NA																		**0**
13-Jul									NA																		**0**
14-Jul									NA																		**0**
15-Jul									NA																		**0**
16-Jul																											**0**
17-Jul																											**0**
18-Jul															NA												**0**
19-Jul															NA												**0**
20-Jul															NA												**0**
21-Jul																											**0**
22-Jul																											**0**
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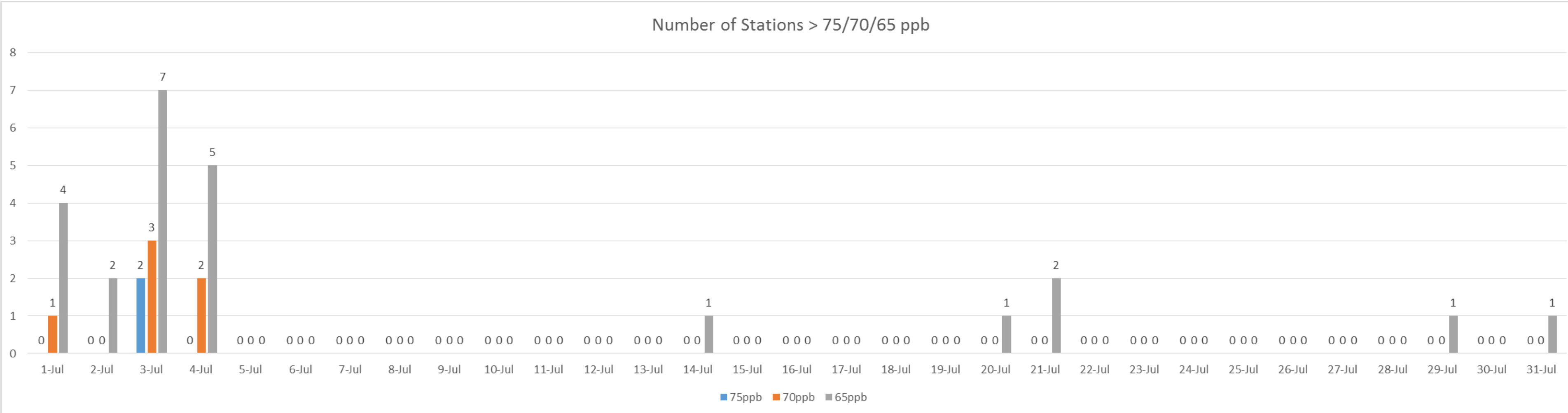
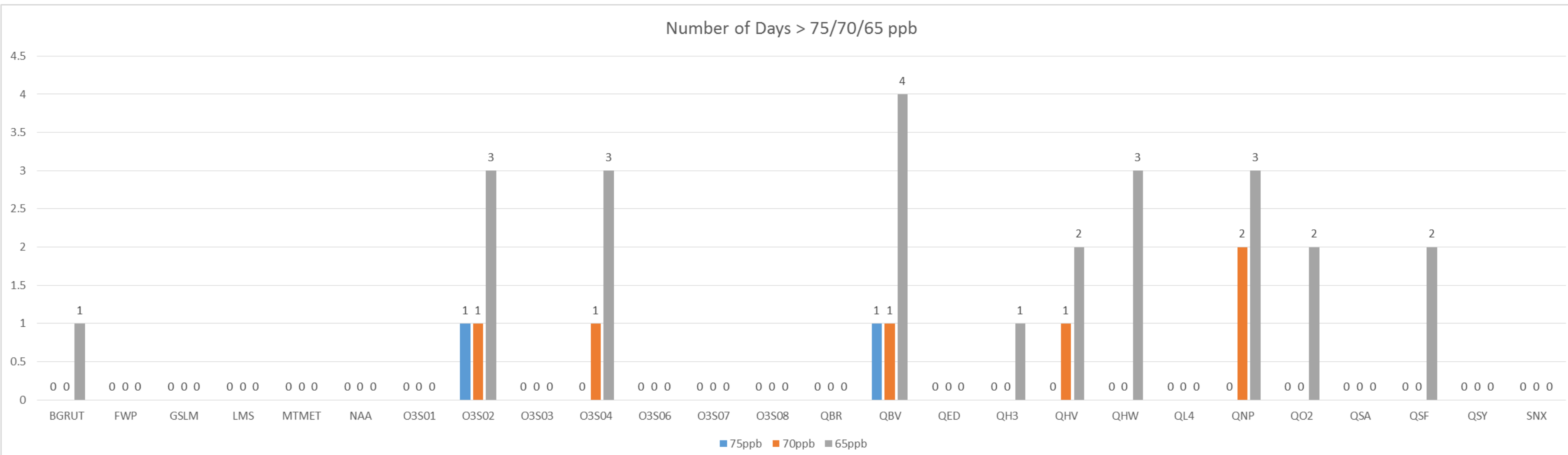
27-Jul																											**0**
28-Jul																											**0**
29-Jul																											**0**
30-Jul																											**0**
31-Jul																											**0**
total days	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**

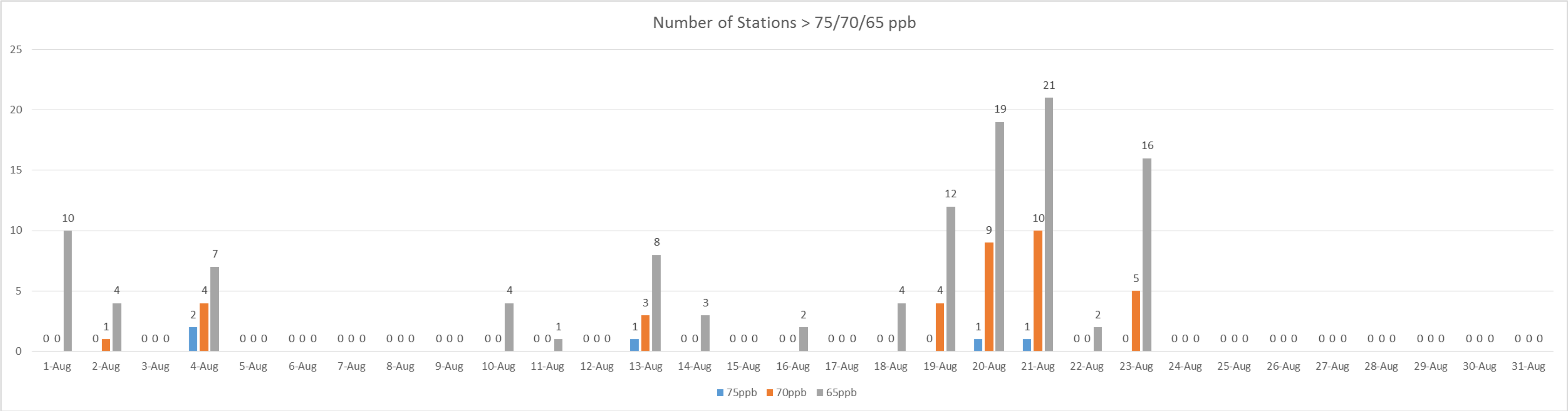


Number of Stations > 75/70/65 ppb
75ppb
70ppb
65ppb

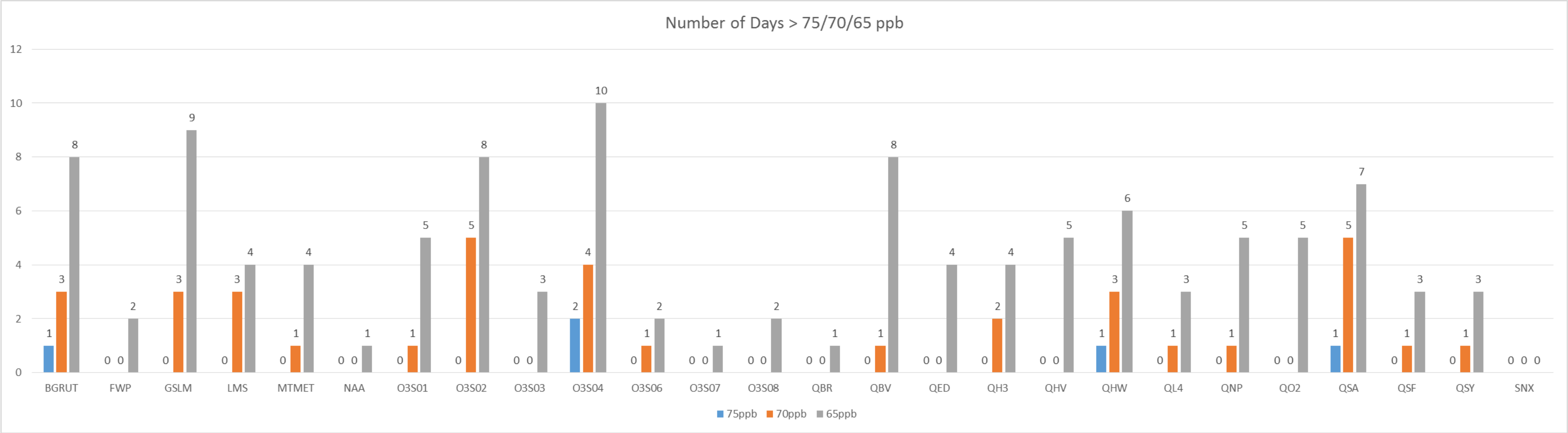


Number of Days > 75/70/65 ppb
BGRUT
FWP
GSLM
LMS
MTMET
NAA
O3S01
O3S02
O3S03
O3S04
O3S06
O3S07
O3S08
QBR
QBV
QED
QH3
QHV
QHW
QL4
QNP
QO2
QSA
QSF
QSY
SNX
75ppb
70ppb
65ppb

8 hour over 70																											
	BGRUT	FWP	GSLM	LMS	MTMET	NAA	O3S01	O3S02	O3S03	O3S04	O3S06	O3S07	O3S08	QBR	QBV	QED	QH3	QHV	QHW	QL4	QNP	QO2	QSA	QSF	QSY	SNX	
1-Aug																											**0**
2-Aug								x																			**1**
3-Aug																											**0**
4-Aug	x				NA			x							x								x				**4**
5-Aug					NA																						**0**
6-Aug					NA																						**0**
7-Aug					NA																						**0**
8-Aug																		NA									**0**
9-Aug																		NA									**0**
10-Aug																		NA									**0**
11-Aug																		NA									**0**
12-Aug																		NA									**0**
13-Aug					x														x				x				**3**
14-Aug																											**0**
15-Aug										NA																	**0**
16-Aug										NA																	**0**
17-Aug																											**0**
18-Aug	NA																										**0**
19-Aug			x	x					NA	x							x										**4**
20-Aug	x		x	x				x		x							x				x		x	x			**9**
21-Aug	x		x				x	x		x	x								x	x			x		x		**10**
22-Aug																											**0**
23-Aug				x				x		x									x				x				**5**
24-Aug							NA			NA																	**0**
25-Aug	NA						NA			NA																	**0**
26-Aug	NA						NA			NA																	**0**
27-Aug	NA						NA			NA																	**0**
28-Aug	NA						NA			NA																	**0**
29-Aug	NA						NA			NA																	**0**
30-Aug	NA						NA			NA																	**0**
31-Aug	NA						NA			NA																	**0**
total days	**3**	**0**	**3**	**3**	**1**	**0**	**1**	**5**	**0**	**4**	**1**	**0**	**0**	**0**	**1**	**0**	**2**	**0**	**3**	**1**	**1**	**0**	**5**	**1**	**1**	**0**	**0**



Number of Stations > 75/70/65 ppb
75ppb
70ppb
65ppb



Number of Days > 75/70/65 ppb
75ppb
70ppb
65ppb

Create a table defining all 26 stations and mention NA means no observations.

Appendix E. Summary of mobile observations

	June						
Date	KSL5	TRAX	UUTK1	UUTK2	UUTK3	UNERD	UUPOM
1-Jun	NA	Green Line		FWP			
2-Jun	NA	Green Line	UNERD Route				
3-Jun	NA	Red Line					
4-Jun	NA	Red Line					
5-Jun	NA	Red Line	BGRUT				
6-Jun	NA	Green Line					
7-Jun	NA	South Salt lake Train Yard					
8-Jun	NA	Green Line					
9-Jun	NA	Red Line	BGRUT				
10-Jun	NA	Red Line					
11-Jun	NA	Green Line					
12-Jun	NA	Red Line					
13-Jun	NA	Green Line					
14-Jun	NA	South Salt lake Train Yard					
15-Jun	NA	Red Line					
16-Jun	NA	Red Line					
17-Jun	Lake/Valley Transects	Red Line	Causeway	BGRUT		UNERD Route	
18-Jun	Farmington/Vernon/Eagle Mountain	Green Line	Causeway	NA		UNERD Route	
19-Jun		Green Line		NA			
20-Jun		Red Line		NA			
21-Jun		Red Line		NA			
22-Jun		Red Line	QSY	NA			
23-Jun		Red Line		NA			
24-Jun	2100 S. & I-15	South Salt lake Train Yard		NA			
25-Jun	Twin Paeks/South Jordan/Mill Creek	South Salt lake Train Yard		NA			
26-Jun	Trenton	South Salt lake Train Yard		NA			
27-Jun		Red Line		NA	South Valley		
28-Jun	*Little Cottonwood Canyon	South Salt lake Train Yard/ Red Line		NA	400 S. 600 E.		
29-Jun	*Charleston/Vernon/Provo	Green Line		NA	Flight Park/Suncrest		
30-Jun		Green Line		NA			

	July					
Date	KSL5	TRAX	UUTK1	UUTK3	UNERD	UUPOM
1-Jul		South Salt Lake Train Yard	LMS			
2-Jul		Red Line				
3-Jul		Red Line		Southern Utah		
4-Jul		Red Line				
5-Jul		Red Line		Southern Utah		
6-Jul		Green Line		Southern Utah		
7-Jul		Red Line				
8-Jul		Red Line				
9-Jul		Green Line				
10-Jul	Little Cottonwood/Brigham City	Red Line				
11-Jul		Red Line				
12-Jul		South Salt Lake Train Yard/ Red Line				
13-Jul	Mill Creek/South Jordan/ Provo	Red Line				
14-Jul	I-80 Exit 41	Red Line	Causeway		UNERD Route	
15-Jul	Kennecott	Red Line		Causeway		
16-Jul	South Jordan/Little Cottonwood/Lehi	Red Line	BGRUT/Tooele	Causeway	UNERD Route	QSY/ Causeway
17-Jul	West Valley/Rockport Lake	South Salt Lake Depot				
18-Jul		South Salt Lake Train Yard				
19-Jul		South Salt Lake Train Yard				
20-Jul		Red Line				
21-Jul		Red Line				
22-Jul		Red Line				
23-Jul	Bountiful	Red Line				
24-Jul	Lehi/Olympic Park/Salt Lake City	Red Line				
25-Jul		Green Line				
26-Jul		Blue Line				
27-Jul	Forest Lake/Santaquin	South Salt Lake Train Yard				
28-Jul	Clearfield/Park City	South Salt Lake Train Yard				
29-Jul	Bountiful/ParkCity/Lehi	Green Line				
30-Jul	Salt Lake City/Farmington	Red Line				
31-Jul	*Richfield	Red Line				Chris' Flight

	August					
Date	KSL5	TRAX	UUTK1	UUTK3	UUNERD	UPOM
1-Aug	Ogden Airport/Morgan	Red Line				
2-Aug		South Salt Lake Train Yard/ Red Line				
3-Aug	Kaysville/Farmington	Green Line				
4-Aug	*Park City/Grand View Peak	South Salt Lake Train Yard				
5-Aug	South Salt Lake/ Weber Canyon	Green Line				
6-Aug	Wasatch near Bountiful	Green/Red Line				
7-Aug	Big Cottonwood Canyon	Green Line				
8-Aug	Riverton	Red Line				
9-Aug		South Salt Lake Train Yard				
10-Aug	QSA/Provo	Green Line	BGRUT		UNERD Route	
11-Aug		Red Line	BGRUT/Tooele		UNERD Route	
12-Aug		Red Line	I-80 Transects		UNERD Route	
13-Aug	*Kennecott/Provo	Red Line				Hat Island
14-Aug	Payson/Big Cottonwood/Brighton	South Salt Lake Train Yard				
15-Aug		South Salt Lake Train Yard				
16-Aug		South Salt Lake Train Yard				
17-Aug		Red Line		BGRUT		
18-Aug	Grand View Peak/Tooele	Red Line				
19-Aug	Salt Lake City/Grand View Peak	Red Line	Bountiful Peak	I-80 Transects		
20-Aug	*Draper/North Ogden	Red Line				
21-Aug	*Day Break/Farmington	Green Line				
22-Aug		Green Line				
23-Aug	Paradise Park Reservoir	South Salt Lake Train Yard				
24-Aug	Paradise Park Reservoir/Santaquin	Red Line				
25-Aug	Bountiful	Red Line				
26-Aug	Day Break/West Valley/Orem	Red Line				
27-Aug	Spanish Fork	South Salt Lake Train Yard				
28-Aug	Heriman/Spanish Fork	South Salt Lake Depot				
29-Aug		South Salt Lake/Jordan Train Yard				
30-Aug		South Jordan Train Yard				
31-Aug	Along Wasatch Front to Draper	South Jordan Train Yard				