The Red Butte Canyon Ozone Network: leveraging existing infrastructure to probe background concentrations, canyon flows and stratospheric oxidant exchange

In Response to the Utah Division of Air Quality's Science for Solutions Research Grant-FY 2020

Department of ATMOSPHERIC SCIENCES
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Scope of Work

Abstract

The Salt Lake Valley (SLV) experiences frequent prolonged pollution episodes impacting the health of the ~1 million residents of the valley. These health effects include an array of respiratory and pulmonary problems, chiefly among susceptible populations and those participating in outdoor activities (*Devin et al.*, 1997; *Parmet et al.*, 2003). The unique topography of the SLV results in two distinct air quality seasons, with elevated fine particulate matter ($PM_{2.5}$) in the winter, and significantly elevated ozone (O_3) levels in the summer. These pollution episodes commonly exceed the Environmental Protection Agencies (EPA) National Ambient Air Quality Standards (NAAQS) and as a result the SLV has been declared a nonattainment area for both $PM_{2.5}$ and O_3 standards. Recent studies have identified O_3 as the critical oxidant driving the formation of wintertime $PM_{2.5}$ (*Baasandorj et al.*, 2017, *Womack et al.*, submitted). Thus, O_3 serves as a key pollutant during both the summer and winter months.

Despite the importance of O_3 as both a pollutant and an oxidant, many questions remain regarding its formation, transport and roles in secondary chemical reactions. In particular, transport of O_3 through the mountain canyons surrounding the SLV is poorly understood. This project would deploy a transect of reliable and accurate O_3 monitoring stations throughout the Red Butte Canyon the is adjacent to the University of Utah. The Red Butte Canyon is a United States Forest Service designated Research Natural Area and already has significant monitoring resources deployed in it that this project will leverage. This network will produce a dataset with several applications ranging from: (a) probing the role of canyon flows in the transport of O_3 during stratospheric injections in the summer (b) examining the exchange of O_3 from the free troposphere with stagnant air in persistent cold air pools in the winter (c) the potential for using the site to assist in understanding and monitoring background O_3 concentrations, and (d) examining the impact of anthropogenic activities on O_3 formation,. A better understanding of these outstanding questions is central in the implementation of successful O_3 mitigation policies.

Basis and Rationale

The urbanized Wasatch front is bounded by mountains that have deep canyons incised across them. In the summertime, deep convection associated with strong thunderstorms passing over the mountains can inject stratospheric air with elevated levels of ozone (O_3) down the canyons and directly into the urbanized area leading to O_3 exceedances of National Ambient Air Quality Standards (NAAQS). In the winter, long-lived thermal inversions cause Persistent Cold Air Pools (PCAPs) within the valleys along the Wasatch mountains. Within PCAPs, O_3 plays an important role in the oxidant budget leading to the secondary formation of fine particulate matter ($PM_{2.5}$). Daily thermally driven canyon flows can provide a mechanism for injecting O_3 rich air from the free troposphere above PCAPs down into PCAP air masses. Currently there is a lack of a monitoring network to observe how these two processes in these different seasons contribute to NAAQS exceedances within the urban areas adjacent to the Wasatch Mountains.

Red Butte Canyon is a major tributary canyon that flows into the Salt Lake Valley's East side directly above the University of Utah (Figure 1). The canyon runs ~8 km west to east with an elevation gradient of ~800 meters. The canyon is unique in several ways that make it an excellent location for a canyon ozone monitoring network. First, it is a United States Forest Service designated Research Natural Area, which means that it is free from human activities that include fossil fuel combustion or development. Second, as a research area the canyon is host to multiple ongoing research projects and observational networks that span an array of objectives that include climate and water quality issues. Adding air quality measurement sites would further enhance the value of this already unique area. Third, being directly situated above the University of Utah, canyon flows from Red Butte influence existing air quality and meteorological infrastructure at the University (*Baasandorj et al*., 2017; *Bares et al*., 2016; *Bares et al*., 2018). Lastly, Red Butte Canyon directly lines up with the Utah Division of Air Quality's measurement site at Hawthorne Elementary (HW), thus a straight transect can be drawn from HW through the University of Utah and up the canyon spanning a range of human activities and elevations.

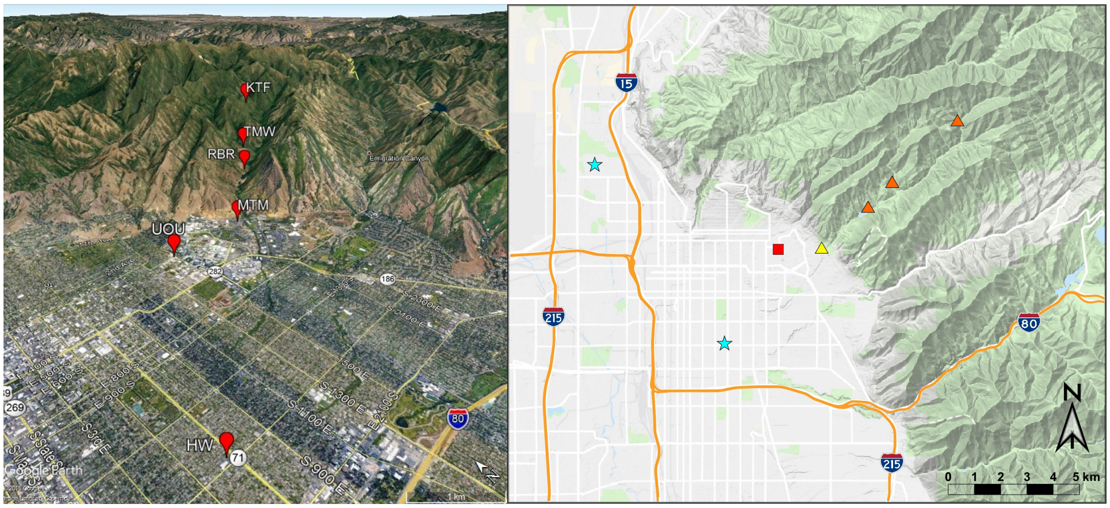

Figure 1. Map of proposed Red Butte Canyon stations. The left panel shows a Google Earth image looking at the transect that goes up the Red Butte Canyon. The Right panel shows an overhead view. The orange triangles indicate the new Red Butte Canyon sites that will be installed. The yellow triangle indicates the MTM site that will be refurbished. The red square indicates the UOU site. The cyan stars indicated the Hawthorne and Rose Park UDAQ sites.

Currently, Red Butte Canyon hosts the Gradients Along Mountain to Urban Transitions network (GAMUT), which continuously monitors the climate and water quality of the canyon and its creek at 13 sites from the headwaters to the confluence with the Jordan River. This network contains four fully instrumented climate stations dispersed along an elevation gradient in the canyon (Figure 1). Climate stations measure: temperature, precipitation, wind speed/direction, relative humidity, barometric pressure, soil moisture/temperature (5, 10, 20, 50, 100cm), snow depth, incoming/outgoing shortwave radiation, incoming/outgoing longwave radiation, and incoming/outgoing photosynthetically-active radiation. Data from these sites are archived and made publicly available in near real-time at www.hydroshare.org. In addition to the GAMUT network, Red Butte Canyon is also part of the National Ecological Observatory Network (NEON; https://www.neonscience.org/field-sites/field-sites-map/REDB).

For this project, we propose to build a network of four O_3 monitoring sites along the Red Butte canyon. Three of the sites will be at GAMUT climate stations (Figure 1): Above Red Butte Reservoir (RBR), Todd's Meadow (TMW) and Knowlton Fork (KTF). The fourth sites will be at the University of Utah's Mountain Meteorology Lab (MTM) located at the mouth of the canyon. This transect of O_3 monitors paired with the extensive meteorological measurements already being made at these sites will facilitate the quantification of O_3 concentrations within canyon flows during both winter and summer months. This network will directly address UDAQ's goal of understanding ***"air exchange processes and pollutant transport within mountain canyon flows."***

In addition, the transect down the Red Butte Canyon will be able to detect air masses as they pass through the canyon during summertime deep convection events that have the ability to inject stratospheric air with high O_3 concentrations into the SLV. Stratospheric air also has much lower relative humidity associated with it, making the meteorological variables already measured at the GAMUT sites an essential component of the measurement capabilities. This measurement capacity will directly address UDAQ's goal of understanding ***"stratospheric intrusions of ozone into the urbanized regions adjacent to the Wasatch mountain range."***

Finally, our highest elevation site (KTF) may be able to assist in the quantification of high altitude background O_3 concentrations. Background O_3 results from the O_3 concentrations from natural sources everywhere in the world outside of Utah, in addition to the precursor emissions from outside of Utah that are transported into Utah and contribute to O_3 locally. This definition of background conditions includes stratospheric intrusions since these air masses are derived from natural sources (*U.S. EPA*, 2013). The KTF site will primarily sample free tropospheric air masses that are more indicative of background O_3 levels than sites within the urbanized area, but the network will also be able to detect stratospheric injection events. These measurements could then be compared to modeled estimates of background O_3. This would assist in UDAQ's goal of understanding ***"background ozone as well as how ozone formation is affected by Wasatch front emissions sources."***

Several years ago, the UDAQ funded the Great Salt Lake Summer O_3 Study (SO_3S) that examined O_3 around the Great Salt Lake and across the Wasatch front (*Horel et al.*, 2015). That study included sites on top of Farnsworth Peak and the MTM site and discussed the importance of canyon flows. However, that project did not deploy instruments within a single canyon to understand the timing and processes controlling canyon flows in depth. This monitoring network would build on this prior work and allow for the detailed examination of O_3 within canyon flows in much greater detail going into the future.

While the timeline for this measurement campaign is scheduled to end in August of 2020, it is the intention of our research group to continue to operate and maintain this equipment into the future by leveraging available resources at that time. We expect that this network will play a key role in planned upcoming aircraft and ground-based field campaigns that will examine O_3, NO_x, and $PM_{2.5}$ concentration along the Wasatch front in both summer and wintertime.

This proposal is independent of, but synergistic with, the proposal "The Red Butte Canyon Air Mass Exchange and Pollution Transport Study" submitted by PI Hoch and Co-I Crosman that will focus on observing wind fields and pollutant concentrations at the Red Butte Canyon mouth. The wind field observations at the Red Butte Canyon mouth would provide very interesting additional information, but are not required for the successful completion of this project. Similarly, this proposed network of O_3 monitoring sites along Red Butte Canyon would be an additional asset that could be utilized by PI Hoch and Co-I Crosman in their proposed project.

Technical Approach

The 2B Technologies Dual Beam O_3 Monitors (Model 205, 2B Technologies, Boulder CO) are an ideal analyzer for the proposed project as they are stable, precise, accurate, reliable in the field, low power, and relatively low cost. We propose purchasing four Model 205's, three of which would be deployed in the canyon at GAMUT climate stations. The fourth instrument will be calibrated at the Utah-Atmospheric Trace Gas and Air Quality Lab, and swapped with one of the analyzers in the field during regular field visits. The analyzer brought out of the field will then be re-calibrated and swapped again at with another site. By having a fourth calibrated instrument available to swap, we can remove any potential bias in the dataset that originates from a single instrument, and minimize uncertainty by guaranteeing a well-calibrated network of analyzers. Currently the MesoWest group at the University of Utah operates a Model 205 at their MTM site at the mouth of the Red Butte. This analyzer needs some repairs, thus if funded we will opt to send this instrument back to the manufacture to have the necessary repairs at significant savings compared to purchasing a new instrument.

Upon purchase of the new instruments, all analyzers will be calibrated and tested for precision and accuracy in a laboratory setting. Span, zero, flows, temperature measurements and the accuracy of observations in the presence of water vapor will all be tested in the Utah-Atmospheric Trace gas and Air Quality lab (U-ATAQ) at the University of Utah. Span and zero tests will be performed using the labs Teledyne T700U Dynamic Dilution Calibrator with O_3 photometer and generator, and the labs Teledyne T701 Zero Air Generator. Flow and temperatures will be independently verified by flow meters and temperature measurements. Water vapor DewLines will be verified by running a gas of known O_3 concentration form the T700U through a Li-610 (LI-COR, Lincoln, NE) portable dew-point generator while varying the concentration of H_2O. Each of these testes will be conducted every time an instrument is brought back from the field prior to redeployment.

After all Model 205 instruments have been verified to be performing within an acceptable range, they will be installed at the selected field sites. To accommodate the increased power demands of the O_3 sensors, solar arrays will be upgraded from 40 Watt panels to 60 Watt panels and additional 100aH batteries will be installed. The 205 analog outputs will be wired to existing CR3000 dataloggers (Campbell Scientific, UT) that are on site for GAMUT meteorological measurements.

Using the existing radio telemetry network installed for GAMUT, data will be ingested directly to a database at the University of Utah's Center for Higher Performance Computing hourly where it will be incorporated into two existing publicly available data displays and portals: MesoWest (http://utahaq.chpc.utah.edu/) and the U-ATAQ webpage (air.utah.edu). Here data will be displayed in near-real time and available for download.

In addition to the Model 205's in the field, the U-ATAQ lab will continue to operate a Teledye T400 Photometric Ozone Analyzer. This will provide accurate data adjacent to the mouth of the canyon and providing a measure of O_3 that is not within the path of canyon air flows.

After the measurement campaign has been completed, time periods during the winter and summertime will be identified for a case study analysis. We will aim to examine the timing, O_3 concentrations, associated meteorologic conditions of O_3 transport throughout the Red Butte Canyon during different seasons. In this analysis we will use O_3 concentrations, relative humidity, temperature, wind direction and wind speed. Additionally, the appropriateness of KTF as a high-altitude background site will be examined. Time series analysis, diurnal plots, wind vectors and pollution roses are some of the potential tools that will be employed in this case study. Programming will be conducted in R and Python.

This project leverages significant existing resources that will facilitate the success of the project. In addition to the operation of the O_3 monitoring site at the U-ATAQ lab supported by the University of Utah's Sustainable Campus Initiative fund (estimated ~$4,500), the U-ATAQ lab will perform the 2B 205 instrumentation calibrations (estimated ~$5,000) and the Wasatch Environmental Observatory (WEO) will provide 0.25 FTE for the two key personnel, Research Associate Ryan Bares and Research Associate David Eiriksson, who will install and service the instrumentation in the field and contribute to the case study analysis and final report (estimated at ~$18,750 for each person, or ~$37,500 total contribution to the project).

Expected Outputs and Outcomes

The two main expected outputs for this proposal are a high quality O_3 dataset, and a final report that includes a case study that utilizes this data. The dataset will have a high enough spatial density to accurately detect down canyon flows and produce precise enough measurements to have a high degree of confidence in the results of any analysis conducted with the data. Thus, a minimum of three site distributed throughout the canyon spanning the maximum feasible elevation gradient, and a measurement precision of ~1 ppbv O_3 throughout the measurement campaign will be required.

Additionally, the proposed case study to be included in the final report will need to accurately identify the transport of O_3 rich air throughout the canyon, as well as O_3 depleted air as PCAP layers expand up the canyon in winter. These events will be specifically examined during both wintertime and summer time NAAQS exceedances to qualitatively examine to role of canyon transport during these. While the quantification of the influence of stratospheric injections during exceptional events that lead to NAAQS exceedances is beyond the scope of this study, the dataset produced by this proposal could serve as a critical tool that could be utilized for this purpose in future work.

Deliverables

The final deliverables for this project are as follows:

- An accurate and continuous O_3 dataset throughout Red Butte canyon and at the mouth of the canyon that spans a minimum of one year.
  - This dataset will have the spatial density, elevation gradient and low measurement uncertainty required to examine questions of background concentrations, the role of human activities on the formation of tropospheric O_3, the role of canyon flows in the transport and injection of stratospheric rich O_3 air, and the exchange of oxidants between PCAP's and the free troposphere.
- A near-real time data displays for public outreach and education hosted by MesoWest and air.utah.edu.
  - Data can be downloaded through these portals at any point during the campaign and will be permanently housed there for future use for a minimum of 10 years.
- A high-altitude background site for continuous monitoring of O_3 concentrations.
- Quarterly progress reports outlining the progress of the project, achieved milestones, problems and solutions, and any proposed updates to the schedule as outlined in Table 1.
- Presentation of the project and results at Science for Solutions Conference and at least one additional conference.
- A final report outlining the background and significance of the project, the purpose, methods, any deviations from the original plan, the future direction of the project and data management. Additionally, the results of wintertime and summertime case studies will be presented that will use wind speed and direction, temperature, relative humidity and O_3 concentrations to examine canyon transport during isolated events in the summer and winter that correspond with NAAQS exceedance events using data from HW, UOU, MTM, and all three sites in Red

Butte Canyon. Lastly, the report will discuss the appropriateness of KTF as a background site.

Schedule

The proposed timeline of this project is 14 months, starting on July 1st of 2019 and running until October 1st of 2020 and is outlined in Table 1. The purchasing of equipment will begin and end in July of 2019 and the relevant lab testing and validation of that equipment will be completed by the end of August. Instrumentation installation will begin in the field as equipment passes laboratory-testing beginning in August and will be fully completed by the end of that month. The measurement campaign will run from August 2019 to the end of August 2020, thus capturing one full summer and winter season. Lastly, the final report including a limited case study will begin as the measurement campaign is entering its last month, August of 2020. This report will be completed by the end of October 2020.

Table 1: Project Schedule. X in the final report task rows indicate when quarterly reports will be submitted

Task	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Nov 2019	Dec 2019	Jan 2020	Feb 2020
Purchase Equipment								
Laboratory Testing								
Instrument Install								
Measurement Campaign								
Final Report			X			X		

Task	Mar 2020	Apr 2020	May 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020
Purchase Equipment								
Laboratory Testing								
Instrument Install								
Measurement Campaign								
Final Report	X			X			X	

It should be noted that while the timeline for this project indicates that the measurement campaign will end in August of 2020, it is the intention of the authors to continue to run the equipment at these sites well after this time by leveraging other available resources once the equipment has been purchased and is in place.

Budget

The total funding requested from UDAQ is $39,833.

The budget justification is provided below, and also shown in Table 2.

Instrumentation:

The main bulk of the budget is for the purchase of new equipment to establish three O3 monitoring sites in Red Butte Canyon, a spare 2B 205 analyzer, and to refurbish the 2B 205 at the MTM site at the mouth of Red Butte Canyon. Each new site consisting of the analyzer and the equipment needed to install the site will cost $8,811, and with three sites installed the subtotal will be $26,433. The spare 2B 205 analyzer is $7,300. Refurbishing the 2B 205 analyzer at the MTM site is estimated to cost $1,000. The refurbishing costs are subject to 10% overhead on the $1,000, so that leads to $100 overhead costs.

Salary and benefits:

We request 0.743 months of salary for Research Assistant Professor Logan Mitchell (PI) who has an annual salary of $53,560. This amounts to $3,317, has a 37% benefit rate ($1,228), and a F&A of 10% ($455) for a total salary cost of $5,000. The Department of Atmospheric sciences will match these salary funds to provide an additional 0.743 months for Dr. Logan Mitchell's salary for a total time commitment of 1.49 months to oversee and direct the project, conduct the case study analysis, and write the final report.

Table 2. Budget for the Red Butte Canyon Ozone Monitoring project.

New Sites:	
2B Tech. Model 205	$7,300
Spare pumps	$425
Filter housings	$175
PTFE tubing	$100
Enclosures and mounting hardware	$451
Sunsaver charge controller	$50

Batteries 100 amph	$250	
Filters	$60	
Subtotal per site:	$8,811	
Number of sites:	3	
Subtotal for new sites:	***$26,433***	
Spare 2B Tech. Model 205	$7,300	
Subtotal for spare instruments:	***$7,300***	
Repairs of MTM 2B Tech. Model 205	$1,000	
F&A (10%)	$100	
Subtotal for MTM repairs:	***$1,100***	
Faculty salary	$3,317	
Benefits (37%)	$1,228	
F&A (10%)	$455	
Subtotal for salaries	***$5,000***	
Matching Funds:		Matching entity
PI Mitchell Salary	$5,000	UofU Atmos. Sci.
Subtotal Matching funds:	***$5,000***	
Total project costs	***$44,833***	
Total Matching funds	***$5,000***	
Amount requested from UDAQ	***$39,833***	

Personnel Roles and Responsibilities

PI Mitchell is a Research Assistant Professor in the Atmospheric Sciences Department at the University of Utah. He is currently leading several air quality related measurement projects, including the TRAX air quality project that is monitoring air pollutants across the Salt Lake Valley. Mitchell will oversee all aspects of the project, including oversight of the budget and all purchasing and spending decisions. He will also lead the analysis of the case study, and will lead the writing of the quarterly and final reports.

Ryan Bares (MS) is a Senior Laboratory Specialist with the Utah-Atmospheric Trace gas and Air Quality at the University of Utah. His responsibilities on this project will include initial laboratory testing and validation of new equipment, assisting in the installation of equipment at field sites, monitoring incoming data and identifying problems as they arise, laboratory calibrations of 2B analyzers as they rotate out of the field and the operation, calibration and maintenance of the University of Utah's Teledyne T400 O_3 analyzer. He will also assist in the analysis and writing of the quarterly and final reports.

Dave Eriksson (MS) is the Senior Red Butte Field Technician and Red Butte Creek GAMUT data manager. His responsibilities on this project will include the initial equipment installation and power upgrades, assisting in laboratory calibration and testing of analyzers, monitoring data for problems as they arise, swapping inlet filters, and rotating instruments from field sites with extra laboratory calibrated instrument on a regular basis.

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