I. Project Title: Impacts of the Great Salt Lake on Summer Ozone Concentrations Along the Wasatch Front

II. Applicant Information:

Department of Atmospheric Sciences, University of Utah
135 S 1460 E, Rm 819
Salt Lake City, UT 84112-0110
Principal Investigator: Professor John Horel
(801) 581-7091
john.horel@utah.edu

III. Sponsored Projects/Research Office Information:

Erica Trejo
University of Utah
Office of Sponsored Projects
155 S 1452 E
SALT LAKE CITY, UT 84112
INSCC Building, Rm 350
Phone: 801 581-6232
erica.trejo@osp.utah.edu

IV. Funding Requested: $63,084
Matching Funds: 7.9% ($5,000)

V. Project Period: 1 July 2021- 31 December 2022

Abstract

We will determine the meteorological factors contributing to elevated ozone concentrations along the southern and eastern margins of the Great Salt Lake that serve as a source region for high ozone concentrations along the Wasatch Front. We hypothesize that multiple factors contribute to elevated ozone in the Farmington Bay region: (1) ozone precursors from the urban corridor (NOx and VOCs) and local biogenic precursors near freshwater ponds are transported by the nocturnal land breeze over the playa surfaces ; (2) actinic fluxes are elevated due to the high albedo over exposed playa surfaces; (3) initial development of the lake breeze concentrates precursors and ozone within the relatively shallow stable lake boundary layer; and (4) the lake breeze then transports ozone into the nearby urban regions later in the afternoon.

This study ties directly to the overarching goals of the Science for Solutions program to improve understanding of summertime ozone pollution along the Wasatch Front. The primary foci for this study are Priority I- Source Contributions to Summer-Time Ozone and Priority V- Air Exchange Processes and Pollutants Mass Transport. We will improve understanding of the summer ozone exceedances exacerbated by emission sources and processes near the southern and eastern Farmington Bay regions and how air mass exchanges affect the transport of ozone and its precursors. This will involve examining air exchanges across the Great Salt Lake and between the polluted boundary layer and free troposphere that affect transport and mixing of key ozone precursors.

The Principal Investigators have extensive experience leading field campaigns and long-term monitoring efforts for atmospheric conditions and criteria pollutants along the Wasatch Front. The proposed study will extend that work based on the extensive amount of available data resources from 2015 through the project period to address our core hypothesis. Questions will be addressed using existing observations near the Great Salt Lake and along the Wasatch Front that have been archived from in-situ sensors on fixed and mobile platforms as well as numerical weather prediction model output. A small set of additional sensors will be deployed during summer 2021 and 2022 to fill gaps in critical locations that have not been sampled adequately before. The core task for this project is to evaluate from ozone observations and meteorological observations and model analyses the timing of buildup in ozone in the southern Farmington Bay region and subsequent transport into Davis and Salt Lake counties. Completion of this task will provide resources that are likely to enhance operational air quality forecasting and provide critical information to initialize and verify air chemistry models used to identify approaches to meet federal air quality standards.

Basis and Rationale

As discussed in the RFP, the Wasatch Front experiences exceedances of the national ambient air quality standard for ozone during summer due to a complex mix of local and remote photochemical processes. The 2015 Great Salt Lake Summer Ozone Study that was supported by the Division of Air Quality was a small, yet the most comprehensive, field campaign to understand ozone concentrations in the vicinity of the Great Salt Lake (Horel et al. 2016a, b).

The 2015 Summer Ozone Study identified that the Farmington Bay region was potentially a source region for high ozone concentrations but did not fully explain why that may be the case. Figure 1 summarizes the variations in ozone concentrations during 16-30 June 2015 when ozone concentrations were high around the Great Salt Lake and along the Wasatch Front (Long 2016). Nighttime land breezes carry low ozone concentrations towards the Lake while afternoon lake breezes transport much higher ozone concentrations towards the urban corridor. The concentrations during the afternoon at Bountiful (QBV), SaltAir (QSA), and the temporary site O3SO2 were consistently some of the highest during the field campaign. Ozone concentrations in those areas built up rapidly in the late morning. Based on observational data and modeling, Blaylock et al. (2017) provided a detailed examination of how the lake breeze front then contributes to transport of high concentrations of ozone from the Farmington Bay region southward throughout the Salt Lake Valley.

Such temporal and spatial evolutions of ozone concentrations near the periphery of the Farmington Bay region are common. For example, Fig. 2 shows for the Bountiful UDAQ site, QBV, a ten-day period during August 2020 when high ozone concentrations likely developed in the Farmington Bay region and were then advected into the urban regions of Davis county. The dominant land and lake breezes are evident by the summary information in Fig. 2. However, Fig. 3 highlights that the conditions are not the same every day with the highest concentrations on 21-22 August. Fig. 3 also shows the similarity in temporal evolution between QBV and the UDAQ Rose Park site, QRP.

We hypothesize that multiple factors contribute to elevated ozone in the southern Farmington Bay region: (1) ozone precursors from the urban corridor (NOx and VOCs) and local biogenic precursors near freshwater ponds are transported by the nocturnal land breeze over the playa surfaces ; (2) actinic fluxes are elevated due to the high albedo over exposed playa surfaces; (3) initial development of the lake breeze concentrates precursors and ozone within the relatively shallow stable lake boundary layer; and (4) the lake breeze then transports ozone into the nearby urban regions later in the afternoon. VOC precursor emission sources likely include the refineries nearby in North Salt Lake City.

Our objective is to investigate how meteorological processes modulate the Farmington Bay region to become a local ozone source region. We will use emission information, ozone concentrations and meteorological data from 2015-2022. We will add additional sensors in this region during late-summer 2021 and summer 2022 to adequately describe the ozone concentrations and meteorological conditions in that ozone source region.

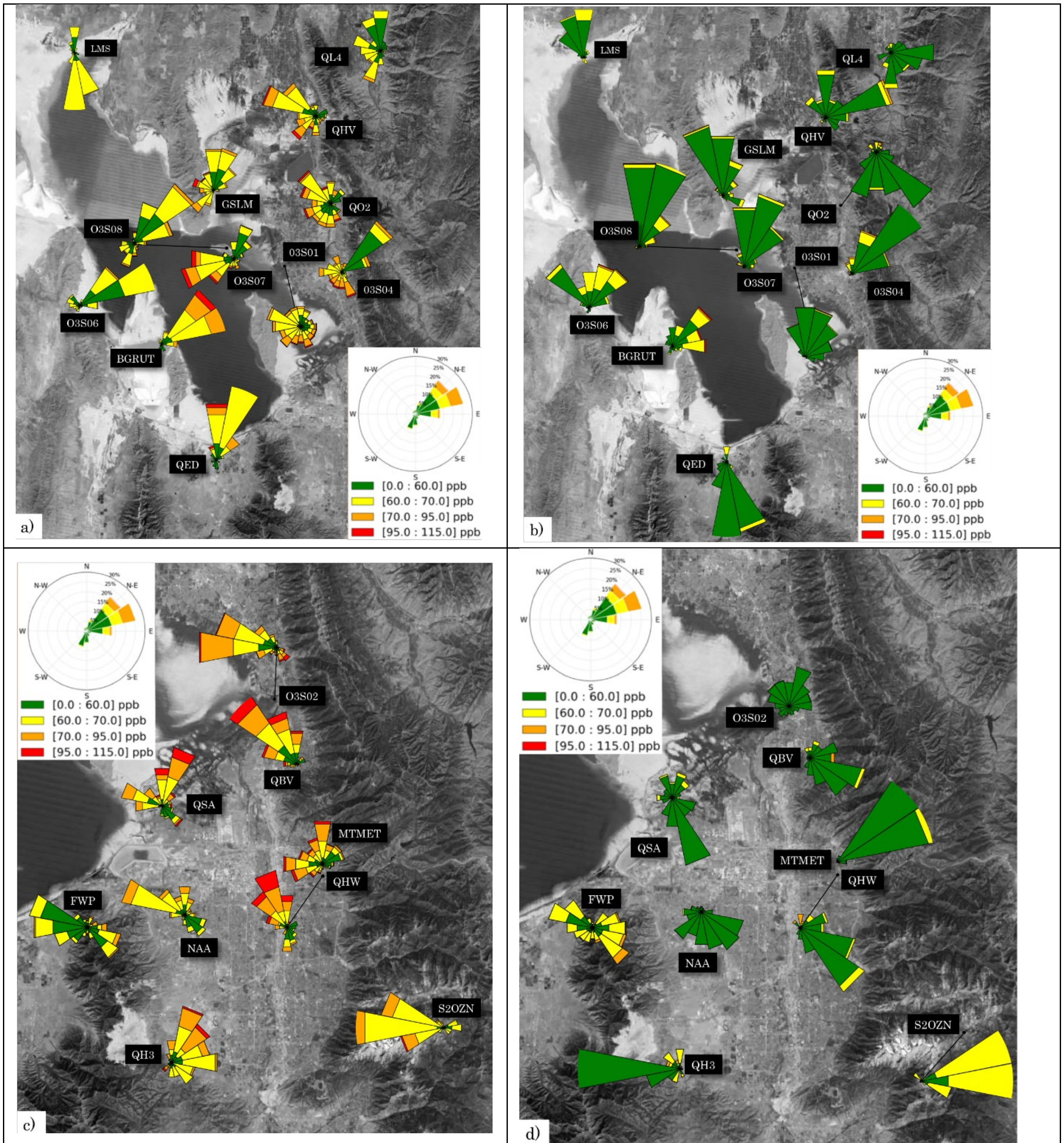

Figure 1. (a and c) Daytime (8 AM – 8 PM) ozone wind roses for 16-30 June 2015. The length of each of the 16 cardinal direction colored wedges represents the percentage of time the ozone concentrations fall within each colored range when the wind is blowing from that direction. (b and d) Nighttime (8PM-8AM) ozone wind roses. From Long (2016)

Completion of these tasks will provide a resource that is relevant to many of the objectives of the Science for Solutions program including: air exchange processes and pollutant transport; air quality modeling; and exceptional events and their impacts on air quality.

Technical Approach

a. Instrumentation and observational data sets

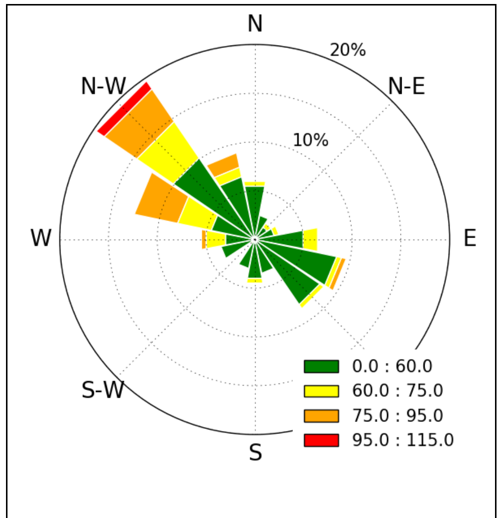

Figure 2. As in Figure 1 except for Bountiful (QBV) during all hours of the day from 20-29 August 2020.

We will rely extensively on the observational resources installed by UDAQ. We have procedures in place to receive, archive, and analyze the meteorological and criteria pollutant concentration data from those sites. *We will also help facilitate access to specialized UDAQ instrumentation, the Hawthorne (QHW) Vaisala CL-51 ceilometer, that will be of benefit for other UDAQ needs.*

In addition to those foundational data assets, Table 1 summarizes some of the other instrumentation to be used in this study. *These sensors correspond to hundreds of thousands of dollars of observational resources available at no cost to the project for which the ability to acquire, archive, and analyze data from them is already in place.*

Data from two Vaisala CL-31 ceilometers have been archived by the MesoWest team for many years. Ceilometers have been of great benefit in Utah to examine aerosol layers within boundary layers (Lareau et al. 2013, Neemann et al. 2015, Whiteman and Young 2015; Foster et al. 2017). One of these ceilometers was moved from the Uintah Basin to the USDR2 site at the Salt Lake Landfill (6000 W 1300 S) in November 2020 in part for this proposed study. MTMET is located on the eastern edge of the University of Utah campus and has been used for air quality

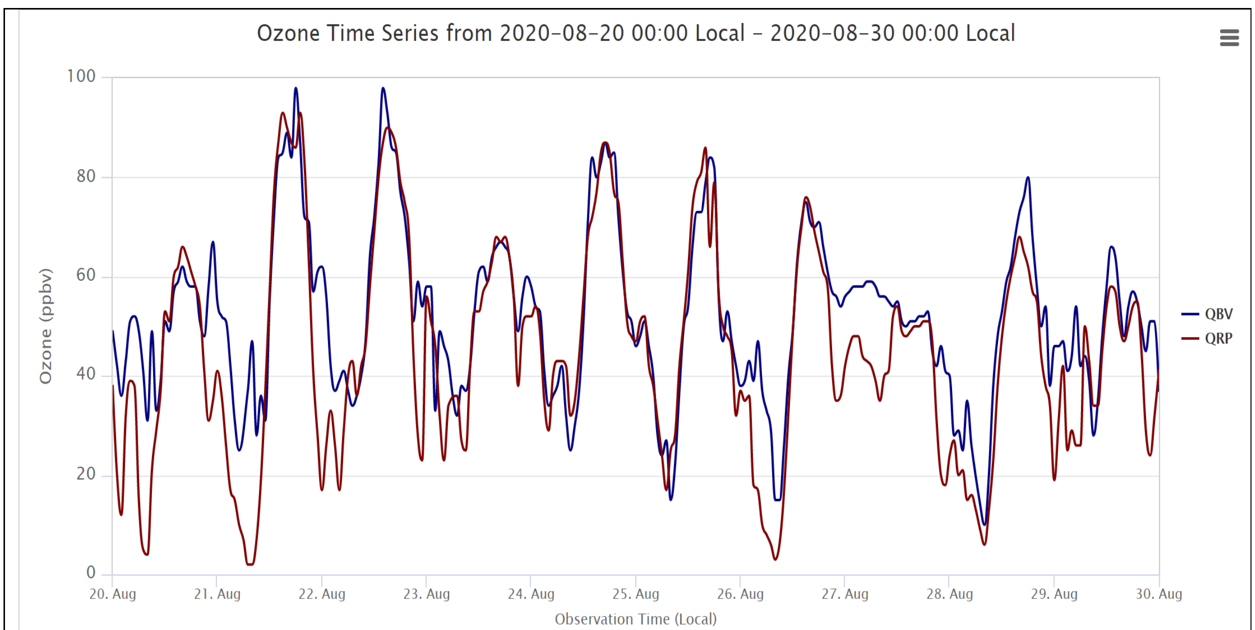

Figure 3. Ozone concentrations from 20-29 August 2020 at Bountiful (QBV; blue) and Rose Park (QRP; red).

MesoWest ID	Site Characteristics	Elevation (m)	Ceilometer	Study Period	Other Sensors	Study Period
USDR2	Salt Lake Valley Landfill	1290	Vaisala CL-31	2020-	Sodar, **O3**	2015-
MTMET	East bench	1523	Vaisala CL-31	2015-	Met/ PM2.5, O3	2015-
FBAY1	**Farmington Bay**	**1288**	**Vaisala CL-31**	**2021-2022**	**Sodar Met/O3**	**2021-2022**
FBAY2	**Farmington Bay**	**1288**	**-**	**-**	**Sodar Met/O3**	**2021-2022**
2 NSF sites	Farmington Bay playa	1288	-	-	Met/ Radiation	2021-2022
Dozens of stations in MesoWest	Sites throughout the region	Variable	-	-	Met/ some with O3	2015-
TRAX	3 Light Rail Cars	Variable	-	-	O3/PM2.5	2016-
KSL	helicopter	Variable	-	-	O3/PM2.5	2015-
KSLC	Airport	1288	-		Met/ sounding	2015-present
Terminal Doppler Weather Radar (TDWR)	West of Farmington	1288	-	-	Radial velocity, reflectivity	2015-

TABLE 1. Observing platforms relevant to the project. Bold face type denotes sensors to be installed for this study**.**

studies related to summer ozone and winter particulates (Horel et al. 2016, Baasandorj et al. 2017). Variable stratification within stable boundary layers and resulting distinct layers with higher pollutant concentrations that are evident from ceilometer data have been shown to have important impacts on basin chemistry in northern Utah (Oltmans et al. 2016, Baasandorj et al. 2017).

Two sites on the periphery of Farmington Bay will be identified to deploy equipment during late-summer 2021 and summer 2022 periods. Each site will have an ozone monitor, meteorological sensors, and sodar to sample winds below 150 m. One of those sites will require power to deploy the ceilometer. The locations of USDR2 and estimated locations of the two FBAY sites are shown in Fig. 4. The objective is to build a "picket fence" of critical observations between the Farmington Bay region and urban regions in Salt Lake and Davis counties. A fallback location for deploying the ceilometer is at an existing trailer of the Department of Atmospheric Sciences with power located at the entrance to the Antelope Island causeway. We have sited instrumentation at this site for prior field work and it is adjacent to the decommissioned UDAQ Syracuse site. That site may turn out to be appropriate as it would allow evaluation of conditions to extend into Weber County.

Two additional sites on the Farmington Bay playa will be installed before summer 2021 by Col Hoch as part of a separate NSF-funded study on the impacts of dust from playa surfaces on the Wasatch Front region. Those sites will have meteorological towers and radiation budget sensors from which to estimate playa surface albedo and actinic flux. The radiation budget data from these sites will be invaluable for helping to evaluate enhancement of photochemical production of ozone on the playa surfaces.

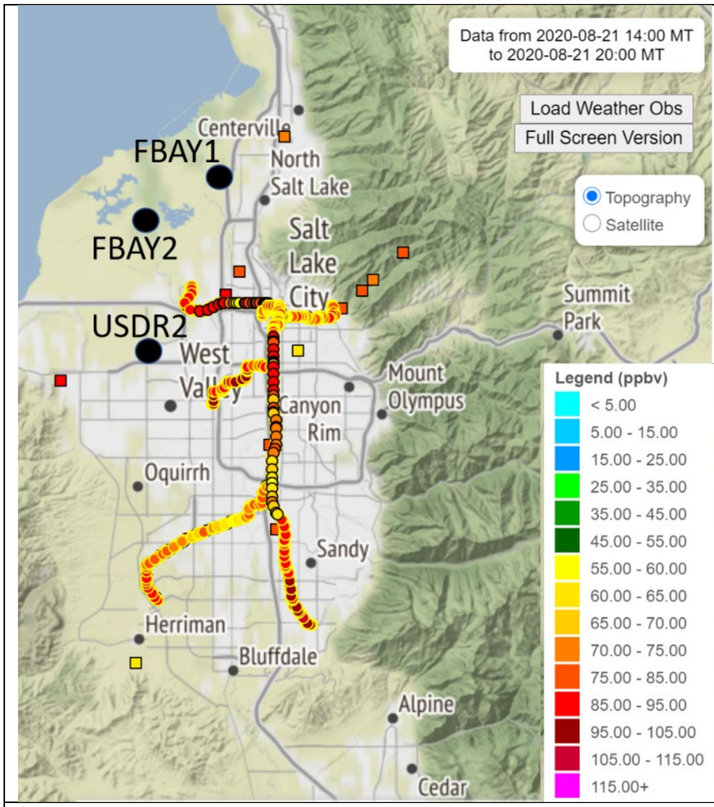

Figure 4. Ozone observations available on 21 August 2020. Location of existing USDR2 site and possible Farmington Bay sites.

We will rely on extensive in situ meteorological and criteria pollutant data in northern Utah that are part of the MesoWest data archive (Lin et al 2018). These resources have been used in many air quality studies. The PM2.5 and ozone sensors onboard three TRAX light rail cars provide pollutant transects within the Salt Lake Valley (see Fig. 4; Mitchell et al. 2018). The temperature, PM2.5, and ozone sensors onboard the KSL helicopter are particularly useful for sampling vertical profiles of temperature and ozone and particulate concentrations when the helicopter is in flight (Crosman et al. 2017). We have data from hundreds of summer helicopter flights since 2015.

The Salt Lake City twice-daily rawinsonde profiles are of considerable importance for characterizing wind, temperature, and moisture and for validating the HRRR model output. In addition, reflectivity and radial velocity data from the Terminal Doppler Weather Radar (TDWR) located west of Farmington and oriented to look directly south over and beyond the Salt Lake City airport will also be invaluable to characterize lake and land breeze circulations. The TDWR has excellent coverage of the Farmington Bay region with the capability to see through much of the Salt Lake Valley as well.

b. High Resolution Rapid Refresh model analyses

We have extensive experience working with output from the operational High Resolution Rapid Refresh (HRRR) model. The HRRR has the highest spatial (3km) and temporal (hourly) resolution of any operational numerical weather prediction model and has been used extensively by us for air quality studies. We have developed and maintain a public archive of HRRR model output beginning in 2015 that is now used by hundreds of other researchers (Blaylock et al. 2017, 2018; Blaylock and Horel 2020). That archive is now duplicated and accessible publicly through the Amazon Web Services (AWS) Open Data program. HRRR model output is archived for both near-surface fields and for 3-dimensional fields at pressure levels and in terrain following coordinates.

We will rely on HRRR model output for all summer seasons from 2015-2022. The HRRR model data will be critical for this study to characterize thermodynamical and dynamical processes within the boundary layer and the evolution of land/lake breezes. For example, Fig. 5 illustrates the weak flows in the Farmington Bay region typically observed during the late morning after the land breezes terminate earlier in the morning. The progression of the lake breeze boundary then progresses in the

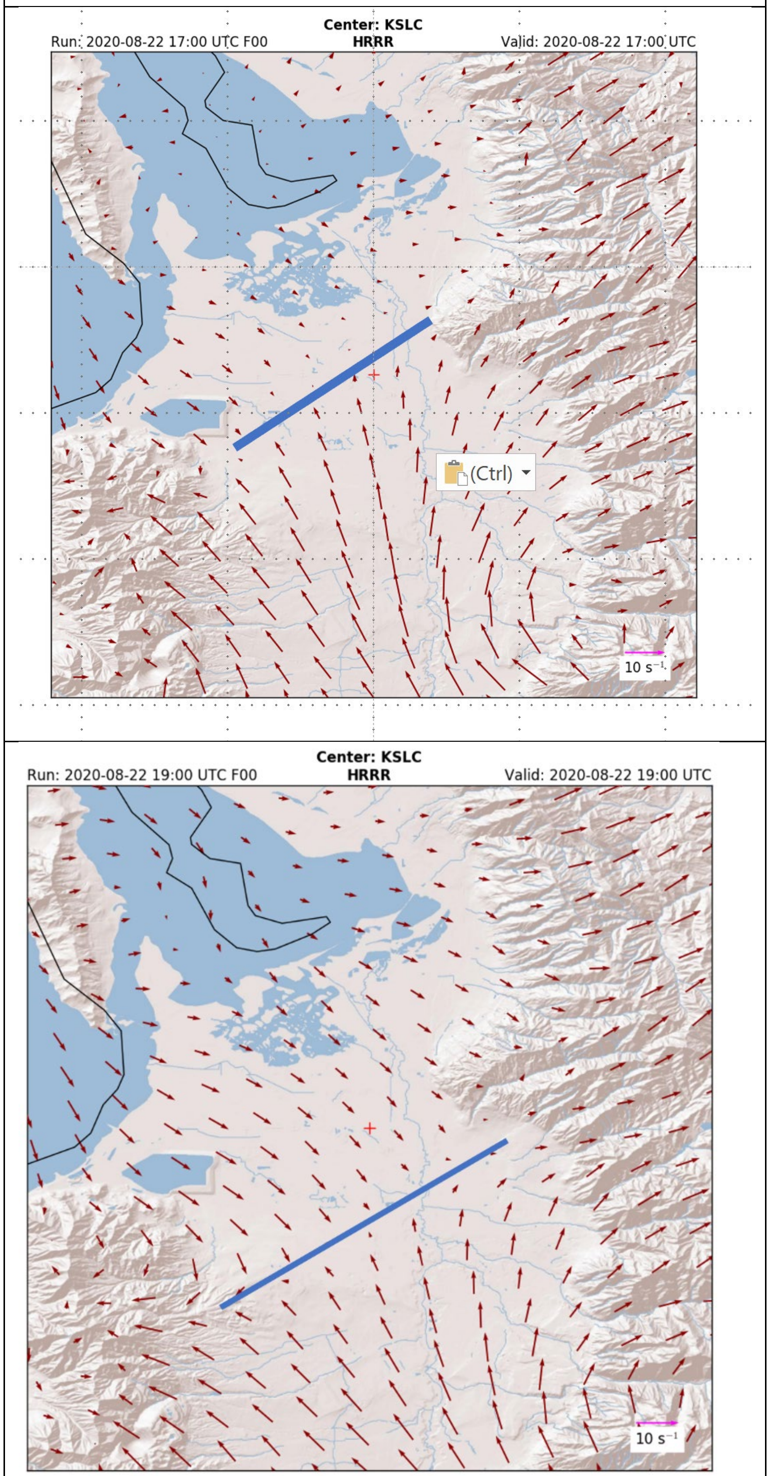

Figure 5. HRRR analysis of 80 m AGL winds at 11 AM MDT (top) and 1 PM (bottom) 22 August 2020. Formation region over Farmington Bay at 11 AM and lake breeze boundary (blue line) progressing by 1 PM down the Salt Lake Valley.

early afternoon into the urban corridor of Davis County and northern section of the Salt Lake Valley.

c. Task 1: Examine ozone concentrations during 2015-2020 summer seasons

The objective of this phase of the study is to diagnose the times within the summer season that are most influenced by land/lake breeze processes in the Farmington Bay region. We will use the data collected during the 2015 Summer Ozone Study to provide context for the conditions during subsequent summer seasons. The duration and characteristics of periods of ozone concentration exceedances at UDAQ sites will be identified in Davis and Salt Lake counties during 2016-2022 summers. Periods will be identified that appear to be heavily influenced by regional transport (e.g., regional transport and wildfire smoke) vs. local processes. Other sources for ozone concentration data (U/Utah fixed sites, TRAX, KSL helicopter) will be evaluated as well to help fill gaps in the UDAQ ozone network.

We suspect that ozone precursors are pooled in the Farmington Bay region after the land breeze weakens. Weak turbulence and the shallow depth of the boundary layer at this time of day also likely helps to confine the precursors. Under clear skies, the incoming solar radiation increases rapidly during the morning leading to potentially enhanced photochemical production of ozone. Enhancement of actinic flux resulting from the high albedo of the playa surfaces may also contribute to rapid ozone production.

Surface meteorological data (wind, etc.) at dozens of sites, Salt Lake rawinsonde, TDWR and HRRR model output will be used to evaluate the conditions during high ozone cases likely dominated by land/lake breeze interactions. Not all situations are as clear cut as that examined by Blaylock et al. (2017) or that evident in Fig. 5. The diurnal evolution of the boundary layer during those cases will be examined using all available resources, including the data collected potentially from the KSL copter when it is flying. Of particular interest will be to characterize the depth of the boundary layer over the Lake/playa surfaces in the morning vs. that in the afternoon. In addition, we will document the time evolution of the land/lake breeze evolution over Farmington Bay with heavy reliance on the velocity and reflectivity data from the TDWR radar. We have found that it is possible to qualitatively discriminate between the diffuse reflectivity and radial velocity patterns during the late morning from nocturnal land breeze and afternoon lake breeze boundaries.

This work will facilitate future UDAQ modeling studies that require meteorological model input for air chemistry simulations. We expect this work may help identify UDAQ modeling cases for ozone exceedance episodes and provide validating data sets for those efforts. It will also be highly relevant for those responsible for forecasting summer ozone situations. Recently, Wang et al. (2020) summarized the impact on Weather Research and Forecast atmospheric model coupled with chemistry (WRF-Chem) simulations to understand the impacts on ozone concentration of a large shallow lake within an urban region. They concluded that in regions with spatially extensive shallow lakes, it is important to accurately represent the lake-atmosphere exchange for ozone pollution simulations, especially under high-temperature and light-wind conditions, in which ozone high concentration events occur frequently and effects of the local lake breeze dominate.

d. Task 2: Examine ozone concentrations during 2021-2022 summer seasons

At the outset of the study, we will identify locations to deploy existing equipment to two sites near the southern end of Farmington Bay (Table 1 and Fig. 4). We have sited equipment in this region before and will identify at least 1 site with power to operate a ceilometer there. As mentioned earlier, a fallback location for the ceilometer is at the trailer of the Department of Atmospheric Sciences with power located at the entrance to the Antelope Island causeway that is adjacent to the decommissioned UDAQ Syracuse site. That site may turn out to be appropriate as it would allow evaluation of conditions to extend into Weber County.

Ozone monitors at these sites will help to characterize the diurnal evolution of ozone during high ozone concentration episodes as they develop in the region. Nearby emission sources will be characterized, e.g., VOCs from the nearby refineries and vegetation from satellite imagery. Solar radiation sensors will be used to estimate albedo in combination with playa soil data measurements to estimate the areal extent of enhanced actinic flux. Simulating albedo correctly over the playas may be a particularly critical factor for future UDAQ model simulations Craft and Horel (2019).

We will be able to deploy instrumentation soon after the project is funded in mid-late summer 2021. We will redeploy the equipment in May 2022 to obtain data throughout the summer 2022 season. The site selection, setting up the sensors, and establishing real-time communications with them will be straightforward.

The meteorological data from these additional sites will be combined with the sensors already in place throughout Davis and Salt Lake counties to characterize more completely the atmospheric conditions overnight and early morning. The strength of the land breeze and boundary layer depth will be monitored to establish the preconditions leading to rapid ozone formation.

We will then establish the timing and location of initial lake breeze circulations and its evolution into the urban areas through the rest of the afternoon. The ceilometer and sodars will help to characterize the morning boundary layer depth and land breeze circulations and when those weaken and later form lake breezes. Hourly and 15 minute HRRR analyses of surface winds and winds throughout the boundary layer will help define the boundary layer in conjunction with the Terminal Doppler Weather Radar velocity and reflectivity scans. When conditions warrant and the pilot can do so, we can ask for KSL helicopter flights to penetrate the lake breeze circulation to obtain critical validation information aloft.

Expected Outputs and Outcomes

1. We have extensive web pages in place to monitor data and model output collected in real time as well as provide access to archived data that will be accessible throughout the project to all interested:
    a. Air Quality: http://utahaq.chpc.utah.edu/
    b. MesoWest meteorological data: https://mesowest.utah.edu/
    c. Ceilometer: http://meso1.chpc.utah.edu/ceilometer/
    d. High Resolution Rapid Refresh model output: http://hrrr.chpc.utah.edu/

2. We will develop a project web page for preliminary results like that developed for the 2015 Summer Ozone Study: http://meso2.chpc.utah.edu/aq/cgi-bin/gslso3s_home.cgi

3. Task 1: Cases of ozone exceedances in Davis and Salt Lake counties dominated by local factors vs. regional transport will be identified during 2015-2022 summers

4. Task 1: Characteristics of the boundary layer conditions near the Farmington Bay ozone source region will be developed in the context of land/lake breezes during 2015-2022 summers

5. Task 2: Sensors will be deployed during late-summer 2021 and summer 2022 to fill gaps in the present observing network for ozone and meteorological conditions.

6. Task 2: The contribution to ozone exceedances in Davis and Salt Lake counties from meteorological and photochemical processes in the Farmington Bay region will be examined.

7. Task 2: Provide validation data sets and information on boundary layer and radiative-transfer processes for future UDAQ ozone chemistry simulations.

Deliverables

We will supply all the expected deliverables listed as part of the requirements for the Science for Solutions program, including:

- quarterly and final reports
- all data will be publicly accessible either via API services or web pages
- participation in the Science for Solutions conference
- We expect to publish journal articles to be paid for by funds external to this project.

Data Sharing Plan

All the raw data will be archived and accessible and available in near-real time as much as possible. Processed data and summary data will be available through web pages such as those listed in Table 2. While the raw data will remain accessible, quality control of the data will also be undertaken. Summary data and results will be accessible for 10 or more years through the University of Utah Hive archive managed by the University of Utah Marriott Library (https://hive.utah.edu/). We have already used that resource for other projects (see https://hive.utah.edu/concern/datasets/47429912h).

Schedule

We intend to complete the project during the 18-month period: July 1, 2021- December 31, 2022. The specific timeline for project elements is detailed below including the project personnel who will complete those tasks.

Tasks	Expected Completion Date	Responsible Personnel
Deploy Farmington Bay sites	July 15, 2021 - September 30, 2021	CoI Hoch, graduate student
Access data from UDAQ Hawthorne ceilometer	Initially by September 30, 2021 and then continuing until the end of the project	PI Horel
Quarterly Report	September 30, 2021	PI Horel, CoI Hoch
Evaluate ozone exceedances from 2015-2021	December 31, 2021	PI Horel, graduate student
Quarterly Report	December 31, 2021	PI Horel, CoI Hoch
Evaluate preliminary results from summer 2021	March 31, 2022	PI Horel, graduate student
Quarterly Report	March 31, 2022	PI Horel, CoI Hoch
Present preliminary results at Science for Solutions conference	Spring 2022	Research Team
Deploy Farmington Bay site	May 1, 2021 - September 30, 2021	CoI Hoch, graduate student
Quarterly Report	June 30, 2022	PI Horel, CoI Hoch
Evaluate and complete analyses for summer 2022 season	September 30, 2020	PI Horel, graduate student
Quarterly Report	September 30, 2022	PI Horel, CoI Hoch
Submit Final Report	December 31, 2022	PI Horel, CoI Hoch

Budget

	Task 1	Task 2	Total	Matching Funds	Grand Total
PERSONNEL					
J. Horel	2,687	2,687	5,374	0	5,374
S. Hoch	3,545	3,545	7,090	0	7,090
Graduate Student	15,000	15,000	30,000	0	30,000

FRINGE BENEFITS (@37% staff; 10% student)	3,806	3,806	7,612	0	7,612
SUPPLIES					
EQUIPMENT					
2B Technologies 205 ozone monitor				5000	5,000
TRAVEL	0	0	0	0	0
CONTRACTURAL	0	0	0	0	0
OTHER: TUITION	4,000	4,000	8,000	0	8,000
TOTAL DIRECT COSTS	29,038	29,038	58,076	5,000	63,076
TOTAL INDIRECT COSTS	2,504	2,504	5,008		5,008
TOTAL PROJECT COSTS	31,542	31,542	63,084	5,000	68,084

Budget Explanation

This will be a fixed price contract with all the work to be completed as specified in the timeline. The funding will support personnel costs of CoIs Horel (0.2 FTE month) and Hoch (0.75FTE month) and a graduate student who are fully capable to complete the tasks within the project period. The Schedule above highlights those members of the team involved in each aspect of the project. A benefit rate of 37% for faculty and 10% for graduate students is estimated.

PI Horel will provide overall project direction and be involved in data analysis. CoI Sebastian Hoch will help manage the project and be involved in the deployment of instrumentation and analysis of the data. The graduate student, who is not assigned at this time to the project, will help during summer 2021 with deploying instrumentation and preliminary analyses followed by greater involvement with the data collection and analysis of the conditions during summer 2022. Tuition costs of $8000 are requested that are not subject to indirect costs.
Matching funds in the amount of $5000 will be provided by the Department of Atmospheric Sciences. Those funds will be used towards the purchase of a 2B Technologies Model 205 ozone sensor and is not subject to indirect costs. University of Utah indirect costs are calculated at a rate of 10% of a Modified Total Direct Cost (MTDC).

Personnel Roles and Responsibilities

Personnel	Responsibilities	Qualifications
PI John Horel	Overall project management and data analysis	34 years of project-based research
CoI Sebastian Hoch	Project management and data analysis	Extensive collaboration with UDAQ staff on Utah air quality projects
Graduate Student	Data analysis	Will help with installation of equipment and use existing software to process and analyze project data

References

Baasandorj, M., S. W. Hoch, R. Bares, J. C. Lin, S. S. Brown, D. B. Millet, R. Martin, K. Kelly, K. J. Zarzana, C. D. Whiteman, W. P. Dube, G. Tonnesen, I. C. Jaramillo, and J. Sohl, 2017: Coupling between chemical and meteorological processes under persistent cold-air pool Conditions: Evolution of wintertime PM2.5 pollution events and N2O5 observations in Utah's Salt Lake Valley. *Environmental Science & Technology*, **51**, 5941-5950. doi: 10.1021/acs.est.6b06603

Blaylock, B., J. Horel, E. Crosman, 2017: Impact of Lake Breezes on Summer Ozone Concentrations in the Salt Lake Valley. *J. Appl. Meteor. Clim.*56, 353-370. http://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-16-0216.1

Blaylock, B., J. Horel, S. Liston, 2017: Cloud archiving and data mining of High Resolution Rapid Refresh Model Output. Computers and Geosciences, 109, 43-50. doi.org/10.1016/j.cageo.2017.08.005

Blaylock, B., J. Horel, C. Galli, 2018: High-Resolution Rapid Refresh Model Data Analytics Derived on the Open Science Grid to Assist Wildfire Weather Assessment. Journal of Atmospheric and Oceanic Technology, 35, 2213-2227. https://journals.ametsoc.org/doi/abs/10.1175/JTECH-D-18-0073.1

Blaylock, B., J. Horel, 2020: Comparison of Lightning Forecasts from the High-Resolution Rapid Refresh Model to Geostationary Lightning Mapper Observations. Wea. Forecasting. 35, 401-416. https://journals.ametsoc.org/doi/abs/10.1175/WAF-D-19-0141.1

Craft, K., J. Horel, 2019: Variations in surface albedo arising from flooding and dessication cycles on the Bonneville Salt Flats, Utah. J. Appl. Meteor. Clim., 58. 773-785. https://journals.ametsoc.org/doi/ full/10.1175/JAMC-D-18-0219.1

Crosman, E., A. Jacques, J. Horel, 2017: A Novel Approach for Monitoring Vertical Profiles of Boundary-Layer Pollutants: Utilizing Routine News Helicopter Flights. *Atmospheric Pollution Research.* 8, 828-835. http://dx.doi.org/10.1016/j.apr.2017.01.013

Foster, C., E. Crosman, J. Horel, 2017: Simulations of a Cold-Air Pool in Utah's Salt Lake Valley: Sensitivity to Land Use and Snow Cover. *Boundary Layer Meteorology*. 164, 63-87. http://dx.doi.org/10.1007/s10546-017-0240-7

Crosman, E., J. Horel, 2017: Large-eddy simulations of a Salt Lake Valley cold-air pool. *Atmospheric Research.* 193, 10–25. http://10.1016/j.atmosres.2017.04.010

Foster, C., E. Crosman, J. Horel, 2017: Simulations of a Cold-Air Pool in Utah's Salt Lake Valley: Sensitivity to Land Use and Snow Cover. *Boundary Layer Meteorology*. 164, 63-87. http://dx.doi.org/10.1007/s10546-017-0240-7

Horel, J., E. Crosman, R. Martin, J. Sohl, S. Arens, 2016a: *2015 Great Salt Lake Summer Ozone Study.* Final Report to the Utah Division of Air Quality. 38 pp.

Horel, J., E. Crosman, A. Jacques, B. Blaylock, S. Arens, A. Long, J. Sohl, R. Martin, 2016b: Influence of the Great Salt Lake on summer air quality over nearby urban areas. *Atmospheric Science Letters*, **17**, 480-486. doi: 10.1002/asl.680

Lareau, N., E. Crosman, C. Whiteman, J. Horel, S. Hoch, W. Brown, T. Horst, 2013: The Persistent Cold-Air Pool Study. *Bull Amer. Meteor. Soc*. **94**, 51–63. doi: dx.doi.org/10.1175/BAMS-D-11-00255.1

Lin, J., L. Mitchell, E. Crosman, D. Mendoza, M. Buchert, R. Bares, B. Fasoli, D. Bowling, D. Pataki, D. Catharine, C. Strong, K. Gurney, R. Patarasuk, M. Baasandorj, A. Jacques, S. Hoch, J. Horel, J. Ehleringer, 2018: CO2 and carbon emissions from cities: linkages to air quality, socioeconomic activity and stakeholders in the Salt Lake City urban area. Bull Amer. Meteor. Soc. 2325-2339. https://doi.org/10.1175/BAMS-D-17-0037.1

Long, A., 2016: Analysis of Summer Ozone Concentrations in the Salt Lake Valley. M.S. Thesis University of Utah. 70 pp.

Mitchell, L., E. Crosman; A. Jacques; B. Fasoli, L. Leclair-Marzolf, J. Horel, D. Bowling, J. Ehleringer, J. Lin, 2018: Monitoring of greenhouse gases and pollutants across an urban area using a light-rail public transit platform. Atmospheric Environment. 187, 9-23. https://doi.org/10.1016 /j.atmosenv.2018.05.044

Neemann, E., E. Crosman, J. Horel, L. Avey, 2015: Simulations of a cold-air pool associated with elevated wintertime ozone in the Uintah Basin, Utah. *Atmos. Chem. Phys.*, **15**, 135-151. doi:10.5194/acp-15-135-2015 154, 2, 291-316.

Oltmanns, Oltmans, S. J. et al., 2016:, O3, CH4, CO2, CO, NO2 and NMHC aircraft measurements in the Uinta Basin oil and gas region under low and high ozone conditions in winter 2012 and 2013, *Elem. Sci. Anthr.*, **4:132**. doi:10.12952/journal.elementa.000132.

Wang, F., Q. Li, Y. Wang, 2020: Lake-atmosphere exchange impacts ozone simulation around a large shallow lake with large cities. *Atm. Environ*. In press. https://doi.org/10.1016/j.atmosenv.2020.118086

Whiteman, C. D., S. W. Hoch, J. D. Horel, and A. Charland, 2014: Relationship between particulate air pollution and meteorological variables in Utah's Salt Lake Valley. *Atmospheric Environment*, **94**,742-753. doi:10.1016/j.atmosenv.2014.06.012

Young, J.S., and C. D. Whiteman, 2015: Laser ceilometer investigation of persistent wintertime cold-air pools in Utah's Salt Lake Valley. *J. Appl. Meteor. Climatol*., **54**, 752–765. doi: doi.org/10.1175/JAMC-D-14-0115.1