Summary Information Page for:

The Salt Lake regional Smoke, Ozone and Aerosol Study (SAMOZA)

A proposal to the Utah Division of Air Quality, February 2022

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Funding Requested:

We request $280,516 from the Utah Division of Air Quality to carry out this project. In addition, $65,000 in matching funds has been committed.

Project Period:

The project will begin on July 1, 2022, and end on June 30, 2023.

SCOPE OF WORK

Abstract

The Salt Lake City (SLC) region is a designated non-attainment area for the 2015 8-hour ozone (O_3) standard. Unfortunately, the annual fourth highest O_3 maximum daily 8-hour average values have shown little change in the region over the last decade, despite a significant decrease in NO_2 concentrations (Jaffe, 2021). At present, we lack a clear understanding of the chemical and meteorological controls on O_3 in the SLC area and the relationship between SLC O_3 and the increasing area of fires in the western U.S.

The University of Washington, Utah State University and the University of Montana propose to conduct a collaborative and detailed study on O_3 and $PM_{2.5}$ in the SLC area. We will measure a wide array of volatile organic compounds (VOCs) in the summer of 2022, including multiple smoke tracers. We will also measure O_3 using a scrubber-less technology to look for possible biases in existing FEM O_3 measurements during smoke events. Using these new VOC observations, plus existing measurements of NO, NO_2 ($NO+NO_2$= oxides of nitrogen or NO_x), CO and particles with an aerodynamic diameter smaller than 2.5 µm ($PM_{2.5}$), we will conduct a variety of analyses to understand O_3 formation and the sources of $PM_{2.5}$ in the SLC basin during summer. The primary goals of this work are:

1. Make new observations that can be used to support policy-relevant modeling and analyses of O_3 and $PM_{2.5}$ in the Salt Lake City region.
2. Evaluate whether existing FEM O_3 measurements show a positive bias during smoke events.
3. Evaluate and compare two different ways to identify smoke in an urban area.
4. Quantify the range of concentrations of NO_x, VOCs, CO and $PM_{2.5}$ on smoke-influenced vs non-smoke days.
5. Conduct photochemical modeling and statistical/machine learning analyses to improve our understanding of the sources of O_3 and $PM_{2.5}$, and O_3 photochemistry (NO_x vs VOC sensitivity) on both smoke-influenced and non-smoke days during the summer of 2022.

The project is a joint effort of three western universities and will be conducted from July 1, 2022–June 30, 2023. Measurements will be made at or near the SLC/Hawthorne site in August–September 2022, with the remainder of the project period used for data processing, calibration, evaluation, detailed analyses and modeling. At the completion of this project, we expect to have significant new policy-relevant insights on what controls high concentrations of O_3 in the SLC region, in both smoke-influenced and non-smoke conditions. We will also provide recommendations for future research on O_3 and $PM_{2.5}$ in the region.

Basis and Rationale

Ozone (O_3) is a key pollutant that is hazardous and shown to cause health problems for individuals, especially children and vulnerable populations. In urban areas, O_3 is formed from photochemical reactions of NO_x and VOCs. The SLC region has been designated as a non-attainment area for the 2015 8-hour O_3 standard by the U.S. EPA. To be in compliance with this standard, the annual fourth highest maximum daily 8-hour average (MDA8) O_3 concentration averaged over three years must be 70 ppb or less. Figure 1 shows the annual fourth highest MDA8 for four sites in the SLC region going back to 2006. During this time period, there has been little overall change in the fourth highest value, despite a significant reduction (~30%) in the concentration of NO_x over the same time period (Jaffe, 2021). While typical urban/industrial emissions produce sufficient NO_x and VOCs to generate O_3, wildfire smoke adds to these pollutants, especially VOCs, and is known to increase O_3 concentrations in SLC and other regions (Gong et al., 2017; Jaffe, 2021; Ninneman and Jaffe 2021).

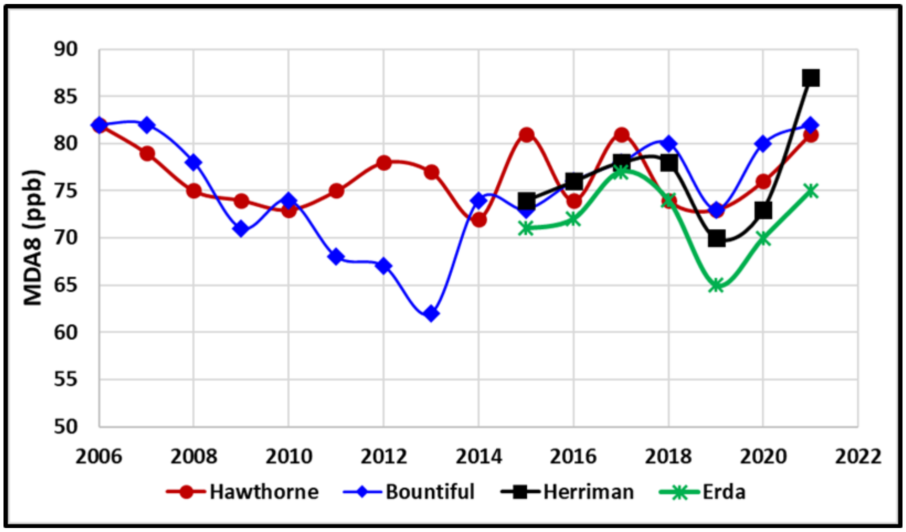

Figure 1. Annual fourth highest MDA8 value for four sites in the SLC region, 2006–2021.

Smoke from wildfires significantly impacts urban air quality in the Western U.S. The chemical composition and influence on urban air quality will likely differ for smoke that is transported from nearby vs distant fires. Figure 2 shows a map of the western U.S. with fire and smoke locations for August 4, 2021, as reported by the NOAA Hazard Mapping System (HMS). This figure also shows 48-hour backward trajectories starting from SLC for three heights (500, 1000 and 2000 meters above ground level). We have found that the HMS smoke product, developed from multiple satellite observations (Rolph et al., 2009; Kaulfus et al., 2017), is very useful for identifying fire locations and smoke transport. However, it is important to note that while the HMS product is useful, it is a measure of the column density of smoke and does not give an indication of surface smoke. Work by our team (Buysse et al., 2019) found that on days with overhead HMS smoke, $PM_{2.5}$ is enhanced at the surface on 30–70% of the days, depending on the location.

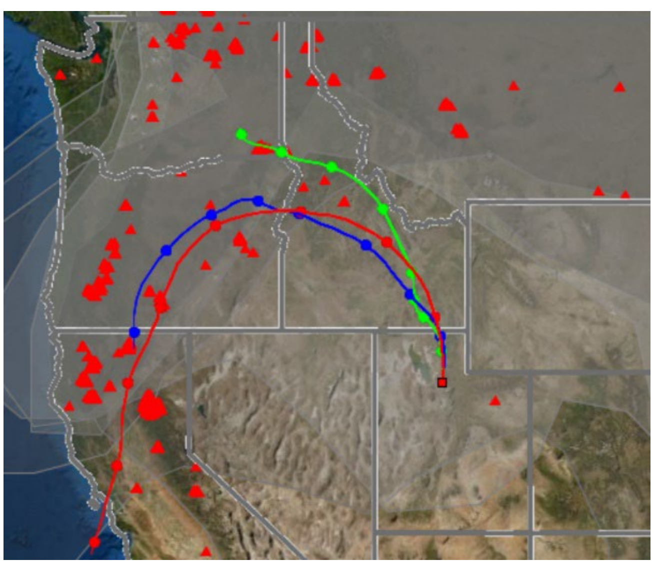

Figure 2. Hazard Mapping System smoke and fire locations on Aug. 4, 2021, along with back trajectories starting from SLC and calculated for three starting heights (500, 1000 and 2000 meters above ground level). The smoke was likely transported from multiple fires in the Pacific Northwest. On this day, the O_3 MDA8 was 86 ppb, and the $PM_{2.5}$ concentrations were 18 µg m^{-3} at the Hawthorne site.

Figure 3 shows the annual fourth highest O_3 MDA8, along with the average $PM_{2.5}$ on the top four O_3 days each year and the number of those four days that had overhead HMS smoke for the Hawthorne site.

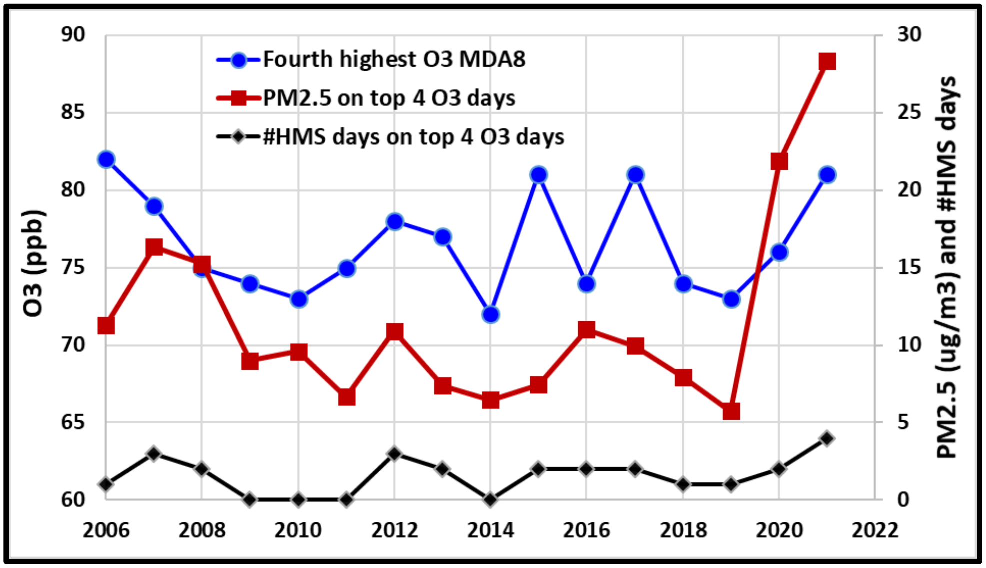

Figure 3. Annual fourth highest O_3 MDA8 value for Hawthorne site (left axis) and $PM_{2.5}$ and number of overhead HMS smoke days on the top four O_3 days each year for Hawthorne site (right axis).

Figure 3 suggests a dramatic rise in smoke influence in 2020 and 2021. In these two years, the mean $PM_{2.5}$ on the top 4 O_3 days was substantially elevated and 6 out of the 8 top days in 2020 and 2021 had overhead HMS smoke. But at the same time, it is important to note that not all high O_3 days are influenced by smoke. For example, in both 2015 and 2017, the fourth highest MDA8 at Hawthorne was significantly elevated, but the $PM_{2.5}$ concentrations and number of HMS smoke days do not suggest a particularly strong influence from smoke on those years. We note that June 2015, when most of the Hawthorne exceedance days occurred, was an unusual month due to a significantly elevated O_3 around the western U.S. (Jaffe and Zhang 2017), but this does not explain the high O_3 days in 2017. herefore, controlling O_3 in the SLC region will depend on a strong scientific understanding of the formation mechanisms for both smoke-influenced and non-smoke days.

For its FY 2023 "Science for Solutions" program, the Utah Division of Air Quality (UDAQ) has requested proposals to study O_3 and $PM_{2.5}$ in the SLC region. Specific areas of interest include:

1. VOC vs NO_x sensitivity in O_3 formation in the region.
2. Summertime Ozone Formation along the Wasatch Front.
3. Meteorology-Chemistry Coupling.
4. Wildfire emissions and Air Quality.

To address these questions, our proposal will carry out a suite of new measurements and conduct detailed modeling and analyses with data from the SLC region to address the UDAQ topics. Specific goals are:

1. Make new observations that can be used to support policy-relevant modeling and analyses on O_3 and $PM_{2.5}$ in the Salt Lake City region.
2. Evaluate whether existing FEM O_3 measurements show a positive bias during smoke events.
3. Evaluate and compare two different ways to identify smoke in an urban area.
4. Quantify the range of concentrations of NO_x, VOCs, CO and $PM_{2.5}$ on smoke-influenced vs non-smoke days.
5. Conduct photochemical modeling and statistical analyses to improve our understanding of the sources of O_3 and $PM_{2.5}$, and the O_3 photochemistry (NO_x vs VOC sensitivity) on both smoke-influenced and non-smoke days during the summer of 2022.

This project is a collaborative effort by three PIs (Jaffe: University of Washington, Lyman: Utah State University, and Hu: University of Montana). Specific tasks are given in Table 1 below, along with the lead institution for each task.

Table 1. Task list for the SAMOZA project.

	Observations (August–September 2022)	**Why**	**Lead or Co-leads**
Task 1	Observations of VOCs by proton transfer reaction mass spectrometer (PTR-MS).	Needed to identify smoke-influenced days and as input for photochemical modeling (Goals 1, 3, 4, 5)	UM
Task 2	Observations of aldehydes by dinitrophenylhydrazine (DNPH) cartridge method.	Needed as input for photochemical modeling (Goals 1, 3, 4).	USU
Task 3	Observations of O_3 using UV scrubber-less technology.	Needed to ensure standard UV measurements of O_3 are unbiased during smoke events (Goal 2).	UW
	Analyses (October 2022–June 2023)		
Task 4	QC and finalize all datasets. Compare two different methods to identify smoke-influenced days. Compare regulatory O_3 at Hawthorne with scrubber-less UV method on smoke-influenced days. Quantify VOCs, NOx, PM, CO and O_3 on smoke and non-smoke days.	Needed for Goals 2, 3, 4 and 5.	All
Task 5	Photochemical box modeling for smoke-influenced and non-smoke conditions	Goal 5.	USU/UW
Task 6	Generalized Additive Modeling	Goal 5.	UW
Task 7	Reporting and publications	Required element.	All

Technical Approach

This project will be carried out in two phases. The first will be a field measurement campaign (Tasks 1–3), which will be followed by an analysis and modeling phase (Tasks 4–6).

PHASE 1: FIELD MEASUREMENT CAMPAIGN

The three universities will partner to make key observations during August–September 2022. We will use a shared trailer that is owned by USU, which we will park adjacent to one of the existing monitoring sites, most likely the Hawthorne site. This site has some of the highest O_3 values in the region (see Figure 1) and also has routine monitoring data that will be key for our analyses (e.g., NO_x, $PM_{2.5}$, CO and hydrocarbons). We note that the Hawthorne site uses a suite of high sensitivity instruments including a trace level CO analyzer (Teledyne API 300 EU) and true NO and NO_2 measurement using a Teledyne API T200UP analyzer, which is equipped with a photolytic convertor. Data from both of these instruments are important for this work. A final decision on the site location will be made in consultation with UDAQ.

At the conclusion of the field campaign, all data will first be finalized and quality controlled. This process differs for each measurement. Details are available in published references by each PI.

Task 1: Observations of VOCs by proton transfer reaction mass spectrometer (PTR-MS)

The PTR-MS method can quantify a wide array of industrial, biogenic and wildfire VOCs that are critical to ozone production, and do so at 1-min time resolution for most species. The VOCs include many atmospherically important species and hazardous air toxics (e.g., formaldehyde, acetaldehyde, methanol, acetonitrile, acetone, formic acid, acetic acid, BTEX monoaromatics and polyaromatic hydrocarbons). A list of compounds to be measured is available at https://www.usu.edu/binghamresearch/files/PTR_compounds.xlsx. These measurements will be essential to (1) identify tracers of smoke influence, and (2) provide an adequate characterization of VOCs for photochemical box modeling and generalized additive modeling.

In the PTR-MS, sample air flows through a drift-tube reaction chamber in which all VOCs with a proton affinity higher than that of water (>165.2 kcal mol^{-1}) are ionized via proton-transfer reaction from H_3O^+ ions. The resulting protonated species are subsequently characterized by a highly sensitive quadruple or ToF mass spectrometer (m/Δm ~4000).

All sampling surfaces will be composed of heated perfluoro alkoxy (PFA) Teflon tubing (~50 °C) to minimize VOC adsorption, based on our previous work (Baasandorj et al., 2015; Hu et al., 2011; 2015; Permar et al., 2021). We will work to minimize the length of the inlet line and increase the sampling flow rate to minimize the residence time in the measurement system and reduce potential wall losses. The sampling line is 1.27 cm O.D. with a PTFE inlet filter. One pump will be used to draw ambient air at flow rates of ~20 L/min, resulting in typical < 5-second residence time from inlet to the instrument.

The instrument will be checked for background levels every few hours and calibrated every other day following established protocols from our recent field campaigns. A suite of 25 VOCs will be calibrated by dynamic dilution of certified multi-component VOC standards (Apel-Riemer Environmental) into zero air generated by passing ambient air through a heated catalyst. Sticky and unstable compounds that cannot be stored in a compressed gas cylinder (e.g., formic acid, acetic acid, formaldehyde, D5-siloxane) will be calibrated using either a Liquid Calibration Unit (IONICON Analytic GmbH, Innsbruck, Austria), or a home-made permeation-based calibration system. For some species without calibration standards, quantification will be performed using a calculated mass-dependent calibration factor based on the measured instrument sensitivities following Sekimoto et al. (2017). The uncertainty is typically ≤ 15% for calibrated species and ~50% for uncalibrated species. Post-processing of the raw data will use the IONICON Analytic's Data Analyzer software to correct ion count rates, calibrate the mass axis, separate isobaric ions (for TOF) and list the *m/z* values of detected ions. In addition, this will involve baseline correction, transmission correction, mass calibration, and high-resolution peak fitting. Species identification will be based on the growing PTR peak library from literature review (Karl et al., 2018; Millet et al., 2018; Pagonis et al., 2019). The sampling and calibration systems were successfully deployed during the WE-CAN aircraft mission (https://www.eol.ucar.edu/field_projects/we-can), and during multiple ground-based experiments (e.g., the Mt. Bachelor Observatory, the Missoula long-term wildfire smoke monitoring, Toolik Field Station in Alaskan Arctic Tundra, and the Fairbanks wintertime study (https://alpaca.community.uaf.edu/)).

Task 2: Observations of aldehydes by DNPH cartridge method

Aldehydes are emitted in large amounts by wildfires and are key precursors to O_3 formation in smoke plumes (Ninneman and Jaffe, 2021). Aldehydes are also formed in photochemical reactions in typical urban pollution. Aldehydes are already measured at the Hawthorne station by UDAQ, but measurements are collected over only one 24-hr period every third day. These measurements don't provide information about temporal variability, and evidence exists that acetaldehyde and larger aldehydes are not collected quantitatively for sampling periods longer than a few hours (Herrington et al., 2007). The PTR-MS will analyze a few aldehydes, but its sensitivity to formaldehyde is humidity-dependent, and it does not measure some aldehydes that may be important in smoke plumes. We will measure aldehydes by collection on dinitrophenylhydrazine (DNPH) cartridges to provide a more comprehensive suite of compounds with better time resolution and less bias than what is currently available at the Hawthorne site.

We will collect a suite of 13 aldehydes and other carbonyls (see EPA Method TO-11A for a list of compounds; EPA, 1999) on DNPH-coated silica bead Waters Sep-Pak cartridges (P/N WAT037500) with Sep-Pak KI ozone scrubbers (P/N WAT054420). The sample path upstream of the cartridges will be composed entirely of PFA or PTFE Teflon, with a PTFE filter upstream of the sample line to exclude particles (5 µm pore size). We have two eight-cartridge automated sampling systems that can be set to any collection interval and that record the collection flow rate. We will build a third system for this project. We will collect at least two 3-hour samples on each day of the sampling campaign with sampling periods beginning at 9:00 am and 12:00 pm. We will also collect eight 3-hour samples to cover the entire 24-hr period on at least eight days during the campaign. We will strive to collect samples over at least four smoke-influenced 24-hr periods during the campaign. We will collect weekly duplicate samples and field blanks.

We will analyze DNPH cartridges following the EPA derivation method TO-11A (EPA, 1999). We will keep used and unused cartridges refrigerated or on ice, except when installed for sampling, and will analyze cartridges within 14 days of sampling. To prepare samples for analysis, we will flush cartridges with 5 mL of 75% acetonitrile and 25% dimethyl sulfoxide to release DNPH-carbonyls into solution. We will collect the solution into 5 mL volumetric flasks and bring the flasks to a volume of 5 mL using 0.5–1 mL of the acetonitrile/dimethyl sulfoxide solution. Finally, we will pipette a 1 mL aliquot from the 5 mL flask into a 1.5 mL autosampler vial for analysis by High-Performance Liquid Chromatography (HPLC). We will analyze samples using a Shimadzu LC-2040C HPLC with a Restek Ultra AQ C18 column and a diode array detector. We will use a mixture of acetonitrile, tetrahydrofuran and water as the eluent. We will prepare calibration standards by diluting commercially available carbonyl-DNPH standards, and we will calibrate the instrument on each analysis day with a five-point calibration curve. We will perform calibration checks, lab blanks and duplicate analyses on each analysis day. More information about our carbonyl analysis protocols and results are available in Lyman et al. (2021).

Task 3. Observations of O_3 using UV scrubber-less technology

As noted above, smoke and wildfire emissions can be very important in contributing to SLC regional O_3. However there have been questions about a **positive bias** from some standard UV O_3 instruments (Gao et al., 2017; Long et al., 2021; Bernays et al., 2022). This bias can be found even in FEM-approved instruments. The bias could, potentially, artificially increase the measured MDA8 values by many ppb on heavy smoke days, and is therefore **very policy relevant**. The most likely cause of the bias is the O_3 scrubber inside a standard UV instrument (Long et al., 2021; Bernays et al., 2022). We note that the Teledyne T400 UV instrument, used at the Hawthorne site (per Chris Pennell, UDAQ), has not been evaluated for this bias during any of the previous studies (Gao et al., 2017; Long et al., 2017; Bernays et al., 2022). A recent study by the EPA (Long et al., 2021) found that a scrubber-less UV design, made by 2B Technologies (model 211; https://www.twobtech.com/model-211-scrubberless-ozone-monitor.html), had essentially no bias, even in heavy smoke. The model 211 is an FEM-approved O_3 instrument. For the August–September 2022 campaign, we will deploy the model 211 O_3 instrument. Calibrations and zeroing will be done with a 2B Technologies, Model 306 O_3 calibrator that has been used in many other campaigns by the Jaffe Group and compared against a NOAA calibration standard. We will use an O_3 sampling line made of PFA Teflon with a PTFE filter (5 µm pore size) to exclude particulate matter.

PHASE 2: ANALYSES AND MODELING

Task 4: Compare multiple methods to identify smoke-influenced days. Quantify VOCs, NO_x, PM, CO and O_3 on smoke and non-smoke days.

For this task we will compare two different methods to identify smoke-influenced days:

i. **Measurements of acetonitrile (ACN) and other smoke tracers.**
ii. **PM/CO ratio.**

Background concentrations of ACN are around 0.2 ppb, and many observations show that the ACN concentrations and the enhancement ratio (ΔACN/ΔCO) are elevated by biomass burning in urban areas (Chandra et al., 2020; Huangfu et al., 2021). For this work, ACN measurements will be made by PTR-MS. We note that routine analysis of ACN and other smoke tracers may not be practical for UDAQ in the long term, but simpler sampling and analysis methods exist that could be deployed by UDAQ in the future (e.g., Chandra et al., 2020).

The ΔPM/ΔCO ratio also appears to be an excellent tracer of biomass burning influence (Laing et al., 2017; Jaffe, 2022, manuscript in preparation). This is because **this ratio** is very different in typical urban pollution (~30 µg m^{-3} per ppb) vs biomass burning (~140 µg m^{-3} per ppb; Laing et al., 2017). On this basis, we have developed a new approach that uses Monte Carlo simulations to quantify the smoke influence and the fraction of $PM_{2.5}$ that is from smoke, based on the observed concentrations of $PM_{2.5}$ and CO. Figure 4 shows results from this simulation compared to observations for a site located near Reno, NV (Sparks, NV). Figure 5 shows the estimated $PM_{2.5}$ contributions from smoke, as a function of the $PM_{2.5}$/CO ratio from the simulations.

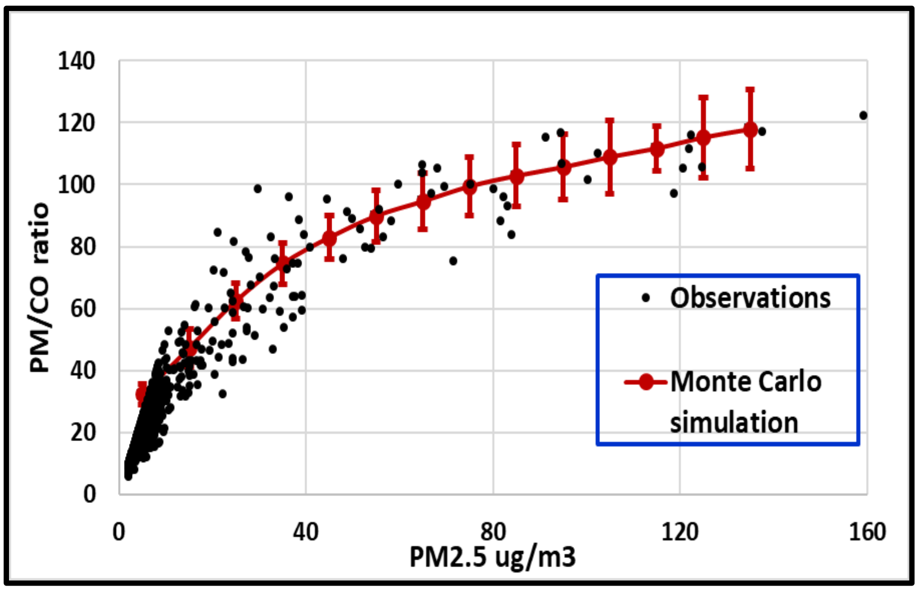

Figure 4. Observed $PM_{2.5}$/CO ratio (µg m^{-3} per ppm) vs the $PM_{2.5}$ concentration using daily observations for May–Sept. 2018–2021 from Sparks, NV (AQS id 320311005). The Monte Carlo results are computed from a simulation with 10,000 points. The simulation results are binned into 5 µg m^{-3} bins. The vertical error bars show 1 standard deviation about the mean for the points in that bin.

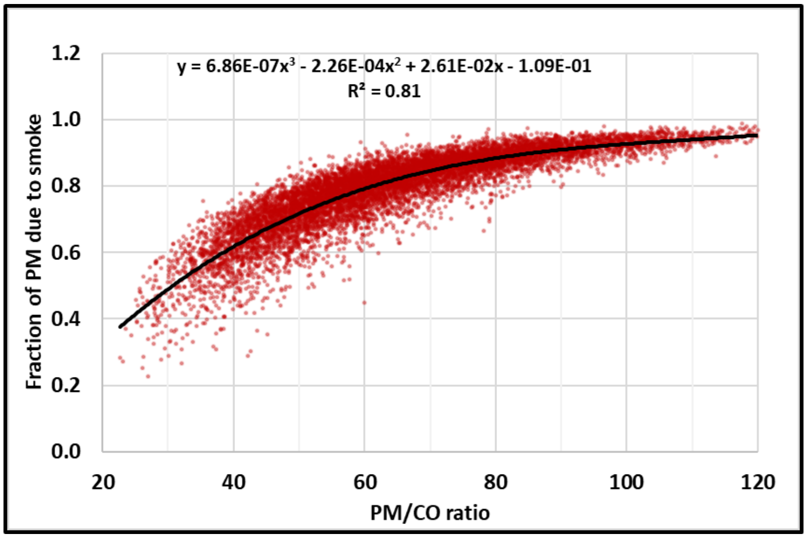

Figure 5. Fraction of $PM_{2.5}$ due to smoke vs the $PM_{2.5}$/CO ratio (µg m^{-3} per ppm) as calculated from the Monte Carlo simulations, with a cubic polynomial fit. Using this relationship, we find that at a $PM_{2.5}$/CO ratio of 31, half of the $PM_{2.5}$ is due to smoke, on average. We note that the Monte Carlo simulations give a probabilistic relationship. So, for example, at a $PM_{2.5}$/CO ratio in the range of 40–50, 97% of the points have more than half of the $PM_{2.5}$ due to smoke.

Based on these results, days with a $PM_{2.5}$/CO ratio > 40 µg m^{-3} per ppm are consistent with some degree of smoke influence, with higher ratios indicating stronger smoke influence. Comparing this ratio with the observed acetonitrile concentrations will provide an important test of this method. The PM/CO analysis and Monte Carlo simulations, shown in Figures 4 and 5, were developed using data from the Sparks, NV, site. The Monte Carlo simulations will need to be recomputed and optimized for Salt Lake City. By comparing these two approaches, we can provide important information to UDAQ on the best and most cost-effective means to routinely identify biomass burning influence.

Using our best identification of smoke-influenced vs non-smoke days, we will quantify the statistical distribution and diurnal cycles for O_3, CO, $PM_{2.5}$, NO_x, ACN, aldehydes and other VOCs (e.g., furans and their oxidation products) for each category. This step is important for assessing smoke impact on hazardous air pollutants and is also critical for photochemical modeling (Task 5).

Task 5: Photochemical box modeling for smoke-influenced and non-smoke conditions

Modeling the O_3 production in smoke using standard Eulerian transport models is a challenging problem due to the large number of VOCs involved, the varying emissions and model resolution, which tends to over-dilute smoke into model grid cells (Jaffe et al., 2020, and references therein). In contrast, box models have been successfully used to model O_3 photochemistry in smoke-influenced conditions. Most applications have used the Framework for 0-D Atmospheric Modeling system (F0AM; Wolfe et al., 2016) for biomass burning applications (e.g., Coggon et al., 2019; Decker et al., 2019; Ninneman and Jaffe, 2021).

To date, our group is the only one to apply this method to an **urban area** to understand the influence of smoke on O_3 photochemistry and why smoke days have higher O_3 concentrations (Ninneman and Jaffe, 2021). In this work, we used the observed concentrations of VOCs and NO_x on smoke and non-smoke days for Bakersfield, CA, to model the O_3 production rates and evaluate the NO_x vs VOC sensitivity on each type of day. In total, we incorporated 48 different VOCs, which results in several hundred chemical reactions. Importantly, the observations showed that while VOCs were significantly enhanced in Bakersfield on smoke days, NO_x concentrations were not. The key finding from this work is that enhanced O_3 on smoke days was driven by the significant increase in VOCs on these days, combined with pre-existing anthropogenic NO_x. More details on this analysis and the model configuration are available in Ninneman and Jaffe (2021).

For this project, we will use a similar model confirmation, but with some enhancements to improve the model results. We will use a more comprehensive VOC inventory based on the PTR-MS and DNPH cartridge-based measurements, combined with the observed concentrations of NO_x, CO and so on. We will incorporate dilution with background air that varies with smoke vs no-smoke days and consider the age of the smoke based on (1) the fire location and transport time, and (2) the VOC:VOC ratios for photochemical age (de Gouw et al., 2005). As photolysis rates are an important control on O_3 production (Baylon et al 2018; Zhao et al 2021), we will improve our simulations of the photolysis rates by using the NCAR TUV model combined with observed aerosol optical depth measurements from the MODIS instrument, which is on several satellites (https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MCD19A2). Next, we will consider the impact of the diurnal change in boundary layer height on the model results. This can be done by incorporating a time-varying parameter to increase the size of the model layer and changing the background concentrations to match observed water vapor mixing ratios and long-lived species (e.g., ethane, CO and benzene, following Edwards et al. (2014)). Finally, we will add a heterogeneous component to simulate the loss of radical species (HO_2 and RO_2) in heavy smoke. These steps will help us understand why O_3 concentrations tend not to be enhanced during heavy smoke events (Buysse et al 2019).

We will develop models for:

1. Median chemical concentrations and average observed meteorology for smoke-influenced and non-smoke days.
2. A specific 3–4 day smoke-influenced period with high O_3 and compare with a specific non-smoke period with high O_3.

We will use established model evaluation metrics, including mean absolute error (MAE) and root mean square error (RMSE), to evaluate base model performance. We will then use each of the models to investigate:

- Differences in ozone production rate and the ozone production efficiency of NO_X on smoke-influenced and non-smoke days.
- Sensitivity of ozone production to changes in concentrations of NO_x and VOC on smoke-influenced and non-smoke days. We will determine a typical speciation and magnitude of VOCs on non-smoke days and compare that to the speciation and magnitude on smoke-influenced days. We will use this information to determine sensitivity to changes in SLC VOCs separate from the VOCs introduced during wildfire smoke events. We will also determine sensitivity to classes of organic compounds (e.g., carbonyls, alkanes, alkenes, aromatics).

Utah State University and the University of Washington will co-lead on the photochemical modeling with input and assistance from the University of Montana group.

Task 6: Generalized Additive Models (GAMs)

GAMs are a type of machine learning that uses observations to train a dataset to predict a key parameter. Relevant to our application, GAMS are particularly useful in that they can incorporate linear, non-linear and categorical predictors. In this case, the predicted parameter is the O_3 MDA8. In previous applications, we have used meteorological variables, such as the daily maximum temperature or geopotential height, day of week, back-trajectory distance and direction, surface chemical measurements (e.g., NO_x and VOCs) and satellite observations as predictors. Our group has used GAMs to quantify the additional O_3 associated with smoke in numerous urban areas, including SLC (Gong et al., 2017; Jaffe et al., 2020; Jaffe, 2021). In addition, we have applied this approach in several successful exceptional event demonstrations to quantify the influence of smoke on the O_3 MDA8 (LDEQ, 2018; TCEQ, 2017). Our detailed analysis methodology is described by Gong et al. (2017) and Jaffe (2021). The GAMs will provide an additional tool to quantify smoke impacts on O_3, which can be directly compared to the photochemical box modeling (Task 5). Note that GAMs are simpler to develop and compute than photochemical models. So if the GAM results are comparable to the photochemical modeling results, then it suggests that this more cost-effective approach can be applied to understanding smoke influence on O_3 in the future.

Task 7: Reporting and publications

We will provide quarterly reports that include progress to date and any obstacles to progress. We will provide a final report that details all work completed and results. We will also submit one or more scientific publications to peer-reviewed journals.

Expected Outputs and Outcomes

Outputs:

1. Quality-controlled data for all new measurements made as part of this project.
2. Model code and outputs from photochemical box modeling.
3. Results and R-code for GAMs.
4. Quarterly and final reports.
5. Peer-reviewed publication(s).

Outcomes:

1. Statistical data and diurnal cycle for key compounds on smoke-influenced and non-smoke days, including an extensive dataset on VOC concentrations on smoke-influenced and non-smoke days (Tasks 1–2).
2. Results of O_3 comparisons with standard UV measurements made by UDAQ with scrubber-less UV measurements (Task 3).
3. Discussion on best method(s) to identify smoke influence on SLC region (Task 4).
4. Improved understanding of NO_x vs VOC sensitivity on smoke-influenced and non-smoke days (Task 5).
5. Quantification and comparison of smoke contribution to the O_3 MDA8 from photochemical modeling and GAMs (Tasks 5–6).

Deliverables

Deliverables for this project will include:

- Quarterly progress reports
- A final technical report
- A final, integrated, publicly available dataset of all measurements collected
- Publicly available F0AM model scripts for each of the base models developed
- Presentations at the 2023 Air Quality: Science for Solutions conference
- A peer-reviewed publication

We will comply with UDAQ's data-sharing requirement by posting final data and final F0AM model scripts at the Utah State University Digital Commons website (https://digitalcommons.usu.edu/) within eight months of project completion. Data posted to digital commons are assigned a permanent DOI and made public in perpetuity.

Full budget by task

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	UDAQ Total	Match	Total
Personnel	**$17,942**	**$18,265**	**$18,351**	**$55,298**	**$43,915**	**$14,952**	**$29,650**	**$157,590**	**$40,783**	**$198,373**
UW	$0	$0	$18,351	$18,351	$14,952	$14,952	$14,952	$65,507	$16,051	$81,558
USU	$0	$18,265	$0	$7,070	$28,963	$0	$12,847	$50,138	$17,007	$67,145
UM	$17,942	$0	$0	$29,877	$0	$0	$1,851	$41,945	$7,725	$49,817
Fringe Benefits	**$5,817**	**$8,585**	**$4,440**	**$9,924**	**$17,291**	**$3,678**	**$10,417**	**$47,368**	**$12,784**	**$60,152**
UW (see UW budget)	$0	$0	$4,440	$4,440	$3,678	$3,678	$3,678	$15,965	$3,949	$19,914
USU	$0	$8,585	$0	$3,323	$13,613	$0	$6,038	$23,565	$7,993	$31,559
UM (see UM justification)	$5,817	$0	$0	$2,161	$0	$0	$701	$7,836	$842	$8,678
Travel	**$17,003**	**$3,200**	**$2,400**	**$0**	**$0**	**$0**	**$6,546**	**$23,149**	**$6,000**	**$29,149**
UW	$0	$0	$2,400	$0	$0	$0	$3,600	$0	$6,000	$6,000
USU	$0	$3,200	$0	$0	$0	$0	$0	$3,200	$0	$3,200
UM	$17,003	$0	$0	$0	$0	$0	$2,946	$19,949	$0	$19,949
Supplies	**$5,000**	**$11,895**	**$4,000**	**$0**	**$0**	**$0**	**$0**	**$15,462**	**$5,433**	**$20,895**
UW	$0	$0	$4,000	$0	$0	$0	$0	$0	$4,000	$4,000
USU	$0	$11,895	$0	$0	$0	$0	$0	$11,895	$0	$11.895
UM	$5,000	$0	$0	$0	$0	$0	$0	$3,567	$1,433	$5,000
Other	**$8,716**	**$0**	**$0**	**$0**	**$0**	**$0**	**$1,000**	**$9,716**	**$0**	**$9,716**
UW – Publications	$0	$0	$0	$0	$0	$0	$1,000	$1,000	$0	$1,000
UM – Tuition remission	$8,716	$0	$0	$0	$0	$0	$0	$8,716	$0	$8,716
Total Direct Costs	**$54,478**	**$41,946**	**$29,191**	**$65,222**	**$61,206**	**$18,630**	**$47,613**	**$253,285**	**$65,000**	**$318,285**
Total Indirect Costs	**$4,448**	**$4,661**	**$1,421**	**$6,891**	**$5,690**	**$2,070**	**$2,052**	**$27,232**	**$0**	**$27,232**
UW	$0	$0	$1,421	$2,532	$2,070	$2,070	$1,070	$9,164	$0	$9,164
USU	$0	$4,661	$0	$1,155	$3,620	$0	$432	$9,867	$0	$9,867
UM	$4,448	$0	$0	$3,204	$0	$0	$550	$8,201	$0	$8,201
Total Project Costs	**$58,925**	**$46,606**	**$30,612**	**$72,113**	**$66,896**	**$20,700**	**$49,665**	**$280,516**	**$65,000**	**$345,516**

Schedule

Field measurements (Tasks 1–3) will occur in August and September 2022. All other tasks will occur between October 2022 and June 2023. Table 1 provides more information about the schedule of tasks.

Budgets

University of Washington Budget by Task

	Task 3	Task 4	Task 5	Task 6	Task 7	UDAQ Total	Match	Grand Total
Personnel	**$18,351**	**$18,351**	**$14,952**	**$14,952**	**$14,952**	**$65,507**	**$16,051**	**$81,558**
Dan Jaffe, PI (1 month)	$3,352	$3,352	$3,352	$3,352	$3,352	$16,760	$0	$16,760
Post Doc (12 months)	$11,600	$11,600	$11,600	$11,600	$11,600	$41,949	$16,051	$58,000
Undergraduate Student (400 hrs @ $17/hr)	$3,399	$3,399				$6,798	$0	$6,798
Fringe Benefits	**$4,440**	**$4,440**	**$3,678**	**$3,678**	**$3,678**	**$15,965**	**$3,949**	**$19,914**
Dan Jaffe (24.6%)	$825	$825	$825	$825	$825	$4,123	$0	$4,123
Post Doc (24.6%)	$2,854	$2,854	$2,854	$2,854	$2,854	$10,319	$3,949	$14,268
Undergraduate Student (22.4%)	$761	$761				$1,522	$0	$1,522
Travel	**$2,400**				**$3,600**	**$0**	**$6,000**	**$6,000**
Field Work	$800				$1,200	$0	$2,000	$2,000
Scientific Meetings	$800				$1,200	$0	$2,000	$2,000
Planning meetings	$800				$1,200	$0	$2,000	$2,000
Supplies	**$4,000**					**$0**	**$4,000**	**$4,000**
calibration stds, regulator & nitrous oxide tank and/or other supplies	$4,000					$0	$4,000	
Other					**$1,000**	**$1,000**	**$0**	**$1,000**
Publications					$1,000	$1,000	$0	$1,000
Total UW Direct Costs	**$29,191**	**$22,791**	**$18,630**	**$18,630**	**$23,230**	**$82,472**	**$30,000**	**$112,472**
Indirect Costs	**$1,421**	**$2,532**	**$2,070**	**$2,070**	**$1,070**	**$9,164**	**$0**	**$9,164**
Total UW Costs	**$30,612**	**$25,323**	**$20,134**	**$20,700**	**$24,300**	**$91,635**	**$30,000**	**$121,635**

Included in UW budget, but no indirects charged:

Subaward – Utah State	Utah State's task breakout is located below.	$98,666	$25,000	$123,666
Subaward – Univ of Montana	Montana's task breakout is located below.	$90,215	$10,000	$100,215

Total Project Costs		**$280,516**	**$65,000**	**$345,516**

University of Washington Budget Justification

Personnel

Dan Jaffe, PI (0.274 month effort) – PI Prof. Dan Jaffe will coordinate all aspects of the work and will supervise the post-doc and student on tasks 3, 4 and 6 and co-lead on task 5. He has more 30 years of experience leading major field campaigns to study O_3, NOx, mercury and other pollutants and has published more than 200 peer-reviewed journal articles and has participated and led a number of national studies on O_3 and other pollutants. He will coordinate the experimental and modeling work and supervise a post doctoral fellow and undergraduate student on the project.

TBD, Post Doc (12 months effort) – The Post Doctoral fellow will play a key role in tasks 3,4, 5 and 6. Specifically the post-doc will coordinate the experimental work for task 3 and be lead for GAMs (task 6) and will work with USU on task 5.

TBD, Undergraduate Student (400 hours @ $17/hr) – They will be assigned to track all experimental data in real time and play a significant role in data processing (task 4). They will also assist with some analyses, for example calculating back-trajectories and compiling data for GAMs and photochemical modeling (tasks 5+6).

Fringe Benefits

The University of Washington has negotiated fringe benefit rates with the Department of Health and Human Services. The fringes include, based on employment position, FICA, workers' compensation, retirement and health insurance. The rates used in this proposal are faculty/post doc – 24.6% and undergraduate student – 22.4%.

Other

Publications – we are requesting funds to publish in scientific journals. ($1,000)

Indirect Costs

The University of Washington has a negotiated indirect cost rate agreement with the Department of Health and Human Services. For this proposal, we are using the sponsor required 10% of total project costs.

Match Justification

Personnel

TBD, Post Doc (2.3 months effort) – The Post Doctoral fellow will play a key role in tasks 3,4, 5 and 6. Specifically the post-doc will coordinate the experimental work for task 3 and be lead for GAMs (task 6) and will work with USU on task 5. ($16,051)

Fringe Benefits

The University of Washington has negotiated fringe benefit rates with the Department of Health and Human Services. The fringes include, based on employment position, FICA, workers' compensation, retirement and health insurance. The rates used in this proposal are faculty/post doc – 24.6%. ($3,949)

Materials and Supplies

A laptop is requested for field data collection. In addition, software, calibration standards, regulator and nitrous oxide tank and/or other supplies will be needed on this project. ($4,000)

Travel

Purpose	# people	# trips	# days	# nights	Lodging	Per diem	Airfare	Other	Total
Field work (2 trips x 1 person x 3 days each trip) = 4 person days, Airfare @424x2	1	2	6	6	$128/night x 6 nights = $768	$64 x 6 days = $384	$424/trip x 2 trips =$848		2000
Planning/project meetings 2 trips x 1 person x 3 days each trip) = 4 person days, Airfare @424x2	1	2	6	6	$128/night x 6 nights = $768	$64/day x 6 days = $384	$424/trip x 2 trips = $848		2000
Scientific meetings (e.g. AGU, San Francisco)	1	1	3	3	$288 x 3 nights = $864	$79/day x 3 days = $237	$299	Reg = $600	2000

Utah State University Budget–

Table 3 shows the project budget for Utah State University. Notes about the budget include:

- We calculated benefits at 47% of salary costs. The technician may accrue overtime during this project.
- Field maintenance and repair costs are maintenance and upkeep of the trailer and sampling equipment. We calculated repair costs as 5% of replacement costs annually.
- Laboratory consumables and repair costs include compressed gases, calibration standards, and maintenance and repair costs for laboratory equipment.
- Costs to build the DNPH sampler include valves, tubing, a flow meter, pumps, and a datalogger.
- The mileage rate is the actual cost to USU per mile for ten trips from Vernal to SLC.
- Hotel and per diem costs are based on the assumption that an overnight stay will be required for 5 of the trips to SLC.
- We have included indirect costs at 10% of total costs.
- Matching funds will come to USU in the form of gifts from Chevron and Big West Oil, rather than as a contract, so indirect costs will not be charged for these matching funds, in keeping with USU policy. Chevron funds will be used for part of the cost of Task 7, and Big West Oil funds will be used for part of the cost of Task 5. Indirect costs in Table 3 are reduced appropriately

	Task 2	Task 4	Task 5	Task 7	Total to be paid by UDAQ	Matching Funds Chevron	Matching Funds Big West Oil	Grand Total
PERSONNEL								
Seth Lyman 214h@$63/h	8426		2515	3058	10999	3000		13999
Research Professor 466h@$76/h			26448	7546	21191	6000	6803	33994
Research Scientist 378h@$42/h	6987	7070		1664	14517	1204		15721
Technician 119h@$29/h	2852			579	3431			3431
BENEFITS @ 47%	8585	3323	13613	6038	23565	4796	3197	31559
SUPPLIES								0
Field maint. and repair	1000				1000			1000
Lab consum. and repair	6895				6895			6895
DNPH sampler build	4000				4000			4000
TRAVEL								0
3600 miles@$0.60/mile	2160				2160			2160
5 hotel stays @$130 ea.	650				650			650
10 days per diem @$39 ea.	390				390			390
TOTAL DIRECT COSTS	41946	10393	42576	18884	88799	15000	10000	113800
TOTAL INDIRECT @10%	4661	1155	3620	432	9867	0	0	9867
TOTAL PROJECT COST	46606	11548	46196	19316	98666	15000	10000	123666

Budget Justification: University of Montana

PI: Lu Hu

Period of Performance: 7/1/2022-6/30/2023

- U of M calculate 24.8% fringe benefits plus insurance for the PI, 31.3% plus insurance for postdoc, 11.8% for summer students, and 4% for grad student during academic months.
- Field maintenance and repair costs are maintenance and repair of the PTR-MS system. It also includes materials for the sampling inlets, Teflon tubing, fittings, pumps, filters, etc.
- Laboratory consumables and repair costs include compressed gases, calibration standards, chemicals, and maintenance and repair costs for laboratory equipment.
- The field trip and project meeting trip cost are based on US GSA guidelines for lodging in SLC, meal per diem per UMT travel guide.
- U-Haul truck rental for moving instruments between MSO and SLC is based on UHaul reservation and an estimated gas cost. Rental car cost is estimated per UMT travel guide via contract companies.
- Tuition is requested for the graduate student.
- We have included indirect costs at 10% of total direct costs.
- Matching funds will come to UM as the third party cost share, so indirect costs will not be charged for matching funds, in keeping with UM policy.

	Task 1	Task 4	Task 7	Total to be paid by UDAQ	Matching funds	Grand Total
PERSONNEL						
Lu Hu, 178 h@$52/h*	3,702	3,702	1,852	9,256		9,256
Graduate student, 1yr@$30,900/yr	7,725	23,175		23,175	7,725	30,900
Postdoc, 240h @ $27/h	6,515			6,515		6,515
Undergrad, 200h@$15/h		3,000		3,000		3,000
BENEFITS @ various % see text	5,817	2,161	701	7,836	842	8,678
SUPPLIES						
Field maint. And repair	2,000			567	1,433	2,000
Lab consum. And repair	3,000			3,000		3,000
TRAVEL						0
1 person 60 days (w.2 person rotating), lodging @$128/night, per diem @$50/day	10,680			10,680		10,680
Uhaul truck + gas; 2 trips@$740/trip	1,480			1,480		1,480
Rental car + gas; 60 days; 15 mi/day	3,097			3,097		3,097
1 person trip to SLC, 7 days, @$500 airfare, $128 loging, $50 per diem	1,746			1,746		1,746
2 person trips for 1 project meeting, 4 days			2,946	2,946		2,946
OTHER						
Tuition remission	8,716			8,716		8,716
TOTAL DIRECT COSTS	54,478	32,038	5,499	82,014	10,000	92,014
TOTAL INDIRECT COSTS @10%	4,448	3,204	550	8,201	0	8,201
TOTAL PROJECT COST	58,925	35,241	6,049	90,215	10,000	100,215

Personnel Roles and Responsibilities–

Daniel Jaffe, University of Washington: Prof. Jaffe is a Professor in the UW Bothell School of STEM and UW Seattle Department of Atmospheric Sciences. He has more 30 years of experience leading major field campaigns to study O_3, NOx, mercury and other pollutants and has published more than 200 peer-reviewed journal articles and has participated and led a number of national studies on O_3 and other pollutants. He will coordinate the experimental and modeling work and supervise a post doctoral fellow and undergraduate student on the project.

Seth Lyman, Utah State University: Professor Lyman leads USU's Bingham Research Center in Vernal, Utah. He has extensive experience with measurements and analysis of atmospheric pollutants, including many projects funded by UDAQ. Seth and others at the Bingham Center will conduct sampling and analysis of aldehydes and other carbonyls and will lead F0AM box modeling work. He will also supervise other USU students/staff that will be involved in the project.

Lu Hu, University of Montana: Professor Lu Hu is an Assistant Professor of Chemistry and leads a research group that does experimental and modeling research on atmospheric VOCs and ozone chemistry. He is an expert in wildfire emissions and has participated in numerous experimental campaigns to understand the VOC emissions from western U.S. wildfires. Lu will coordinate all aspects of the PTR-MS observations of VOCs at the Hawthorne and contribute to all of the modeling and analyses. He will also supervise a University of Montana student that will be involved in the project.

References

Angot, H., McErlean, K., Hu, L., et al., 2020. Biogenic volatile organic compound ambient mixing ratios and emission rates in the Alaskan Arctic tundra. Biogeosciences 17, 23, 6219-6236, doi: 10.5194/bg-17-6219-2020.

Baasandorj, M., Millet, D.B., Hu, L., et al., 2015. Measuring acetic and formic acid by proton-transfer-reaction mass spectrometry: sensitivity, humidity dependence, and quantifying interferences. Atmos Meas Tech 8, 3, 1303-1321, doi: 10.5194/amt-8-1303-2015.

Baylon, P., Jaffe, D.A., Hall, S.R., et al., 2018. Impact of biomass burning plumes on photolysis rates and ozone formation at the Mount Bachelor Observatory. J Geophys Res-Atmos 123, 4, 2272-2284, doi: 10.1002/2017jd027341.

Bernays, N., Jaffe, D., Petropavlovskikh, I., and Effertz, P.: Comment on "Comparison of ozone measurement methods in biomass burning smoke: an evaluation under field and laboratory conditions" (Long et al. 2021), Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2022-11, in review, 2022.

Buysse, C.E., Kaulfus, A., Nair, U., and Jaffe D.A.: 2019. Relationships between particulate matter, ozone, and nitrogen oxides during urban smoke events in the western US. Environ Sci Technol 53, 21, 12519-12528, doi: 10.1021/acs.est.9b05241.

Chandra, B.P., McClure, C.D., Mulligan, J., and Jaffe D.A.: 2020. Optimization of a method for the detection of biomass-burning relevant VOCs in urban areas using thermal desorption gas chromatography mass spectrometry. Atmosphere 11, 3, 276, doi: 10.3390/atmos11030276.

Coggon, M.M., Lim, C.Y., Koss, A.R., et al., 2019. OH chemistry of non-methane organic gases (NMOGs) emitted from laboratory and ambient biomass burning smoke: evaluating the influence of furans and oxygenated aromatics on ozone and secondary NMOG formation. Atmos Chem Phys 19, 23, 14875-14899, doi: 10.5194/acp-19-14875-2019.

de Gouw, J.A., Middlebrook, A.M., Warneke, C., et al., 2005. Budget of organic carbon in a polluted atmosphere: Results from the New England Air Quality Study in 2002. J Geophys Res-Atmos 110, D16, doi: 10.1029/2004JD005623.

Decker, Z.C.J., Zarzana, K.J., Coggon, M., et al., 2019. Nighttime chemical transformation in biomass burning plumes: a box model analysis initialized with aircraft observations. Environ Sci Technol 53, 5, 2529-2538, doi: 10.1021/acs.est.8b05359.

Edwards, P.M., Brown, S.S., Roberts, J.M., et al., 2014. High winter ozone pollution from carbonyl photolysis in an oil and gas basin. Nature 514, 7522, 351-354, doi: 10.1038/nature13767.

Gao, H.L., Jaffe, D.A., 2017. Comparison of ultraviolet absorbance and NO-chemiluminescence for ozone measurement in wildfire plumes at the Mount Bachelor Observatory. Atmos Environ 166, 224-233, doi: 10.1016/j.atmosenv.2017.07.007.

Gong, X., Kaulfus, A., Nair, U., Jaffe D.A.: 2017. Quantifying O_3 impacts in urban areas due to wildfires using a Generalized Additive Model. Environ Sci Technol 51, 22, 13216-13223, doi: 10.1021/acs.est.7b03130.

Herrington, J.S., Fan, Z.-H., Lioy, P.J., et al., 2007. Low acetaldehyde collection efficiencies for 24-hour sampling with 2,4-dinitrophenylhydrazine (DNPH)-coated solid sorbents. Environ Sci Technol 41, 2, 580-585, doi: 10.1021/es061247k.

Hu, L., Millet, D.B., Baasandorj, M., et al., 2015. Emissions of C_6–C_8 aromatic compounds in the United States: Constraints from tall tower and aircraft measurements. J Geophys Res-Atmos 120, 2, 826-842, doi: 10.1002/2014JD022627.

Hu, L., Millet, D.B., Mohr, M.J., et al., 2011. Sources and seasonality of atmospheric methanol based on tall tower measurements in the US Upper Midwest. Atmos Chem Phys 11, 21, 11145-11156, doi: 10.5194/acp-11-11145-2011.

Huangfu, Y., Yuan, B., Wang, S., et al., 2021. Revisiting acetonitrile as tracer of biomass burning in anthropogenic-influenced environments. Geophys Res Lett 48, 11, e2020GL092322, doi: 10.1029/2020GL092322.

Jaffe, D.A., 2021. Evaluation of ozone patterns and trends in 8 major metropolitan areas in the U.S. Final project report for CRC Project A-124. Coordinating Research Council, Alpharetta, GA. Available at http://crcao.org/wp-content/uploads/2021/04/CRC-Project-A-124-Final-Report_Mar2021.pdf.

Jaffe, D.A., O'Neill, S.M., Larkin, N.K., et al., 2020. Wildfire and prescribed burning impacts on air quality in the United States. J Air Waste Manage Assoc 70, 6, 583-615, doi: 10.1080/10962247.2020.1749731.

Jaffe, D. A., and L. Zhang (2017), Meteorological anomalies lead to elevated O3 in the western U.S. in June 2015, Geophys. Res. Lett., 44, doi:10.1002/2016GL072010.

Karl, T., Striednig, M., Graus, M., et al., 2018. Urban flux measurements reveal a large pool of oxygenated volatile organic compound emissions. P Natl Acad Sci USA 115, 6, 1186-1191, doi: 10.1073/pnas.1714715115.

Kaulfus, A.S., Nair, U., Jaffe, D., et al., 2017. Biomass burning smoke climatology of the United States: implications for particulate matter air quality. Environ Sci Technol 51, 20, 11731-11741, doi: 10.1021/acs.est.7b03292.

Laing, J.R., Jaffe, D.A., Slavens, A.P., Li W., and Wang W.: 2017. Can ΔPM2.5/ΔCO and ΔNOy/ΔCO enhancement ratios be used to characterize the influence of wildfire smoke in urban areas? Aerosol Air Qual Res 17, 10, 2413-2423, doi: 10.4209/aaqr.2017.02.0069.

Long, R. W., Whitehill, A., Habel, A., Urbanski, S., Halliday, H., Colón, M., Kaushik, S., and Landis, M. S., 2021. Comparison of ozone measurement methods in biomass burning smoke: an evaluation under field and laboratory conditions, Atmos. Meas. Tech., 14, 1783–1800, https://doi.org/10.5194/amt-14-1783-2021.

Louisiana Department of Environmental Quality (LDEQ), 2018. Louisiana Exceptional Event of September 14, 2017: Analysis of Atmospheric Processes Associated with the Ozone Exceedance and Supporting Data. Available at https://www.epa.gov/sites/production/files/2018-08/documents/ldeq_ee_demonstration_final_w_appendices.pdf.

Lyman, S.N., Holmes, M.L., Tran, H.N.Q., et al., 2021. High ethylene and propylene in an area dominated by oil production. Atmosphere 12, 1, 1, doi: 10.3390/atmos12010001.

Millet, D.B., Alwe, H.D., Chen, X., et al., 2018. Bidirectional ecosystem–atmosphere fluxes of volatile organic compounds across the mass spectrum: How many matter? ACS Earth Space Chem 2, 8, 764-777, doi: 10.1021/acsearthspacechem.8b00061.

Ninneman, M., Jaffe, D.A., 2021. The impact of wildfire smoke on ozone production in an urban area: Insights from field observations and photochemical box modeling. Atmos Environ 267, 118764, doi: 10.1016/j.atmosenv.2021.118764.

Pagonis, D., Sekimoto, K., de Gouw, J., 2019. A library of proton-transfer reactions of H3O+ ions used for trace gas detection. J. Am. Soc. Mass Spectrom. 30, 7, 1330-1335, doi: 10.1007/s13361-019-02209-3.

Permar, W., Wang, Q., Selimovic, V., et al., 2021. Emissions of trace organic gases from western U.S. wildfires based on WE-CAN aircraft measurements. J Geophys Res-Atmos 126, 11, e2020JD033838, doi: 10.1029/2020JD033838.

Rolph, G.D., Draxler, R.R., Stein, A.F., et al., 2009. Description and verification of the NOAA Smoke Forecasting System: the 2007 fire season. Weather Forecast 24, 2, 361-378, doi: 10.1175/2008waf2222165.1.

Sekimoto, K., Li, S.-M., Yuan, B., et al., 2017. Calculation of the sensitivity of proton-transfer-reaction mass spectrometry (PTR-MS) for organic trace gases using molecular properties. Int J Mass Spectrom 421, 71-94, doi: 10.1016/j.ijms.2017.04.006.

Texas Commission of the Environment (TCEQ), 2017. El Paso Ozone Exceptional Event: June 21, 2015, Addendum 4: Update, May 17, 2017.

U.S. Environmental Protection Agency (EPA), 1999. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Compendium Method TO-11A: Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC), 2nd ed. U.S. Environmental Protection Agency, Cincinnati, OH. Available at https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-11ar.pdf.

Wolfe, G.M., Marvin, M.R., Roberts, S.J., et al., 2016. The Framework for 0-D Atmospheric Modeling (F0AM) v3.1. Geosci Model Dev 9, 9, 3309-3319, doi: 10.5194/gmd-9-3309-2016.

Zhao, S., Hu, B., Liu, H., et al., 2021. The influence of aerosols on the NO2 photolysis rate in a suburban site in North China. Sci Total Environ 767, 144788, doi: 10.1016/j.scitotenv.2020.144788.

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Re: **Commitment for Salt Lake Regional Smoke, Ozone and Aerosol Study project funding**

Dr. Jaffe,

Rio Tinto Kennecott Utah Copper, LLC (RTK) supports the goals of the Salt Lake Regional Smoke, Ozone and Aerosol Study (SAMOZA) that has been proposed by Dr. Seth Lyman (Utah State University), Dr. Dan Jaffe (University of Washington) and Dr. Lu Hu (University of Montana). RTK believes this project will significantly improve our understanding of ozone and aerosols in the Salt Lake City basin and will improve Utah Division of Air Quality's (UDAQ) ability to regulate emissions utilizing the best available science.

If SAMOZA is awarded the contract by UDAQ, RTK will make a financial commitment of $15,000 to the project. RTK supports the full participation of all three university PIs, however, for logistical reasons, RTK will contribute directly to the work of the University of Washington.

Should you have any questions about this commitment, please contact me at (801) 569-6494, or Jenny.Esker@riotinto.com.

Regards,

Jenny Esker

Jenny Esker
Principal Advisor, Air Quality

Salt Lake City Refinery

Tesoro Refining & Marketing Company LLC

474 West 900 North
Salt Lake City, UT 84103-1494

Dr. Dan Jaffe
Physical Sciences Division, School of Science, Technology, Engineering, and Math
Discovery Hall 452E
University of Washington-Bothell
18115 Campus Way NE
Bothell, WA 98011-8246
djaffe@uw.edu

Re: Tesoro Refining & Marketing Company LLC
Commitment for Salt Lake Regional Smoke, Ozone and Aerosol Study project funding

Dr. Jaffe,

Tesoro Refining & Marketing Company, LLC, Salt Lake City Refinery supports the goals of the Salt Lake Regional Smoke, Ozone and Aerosol Study (SAMOZA) that has been proposed by Dr. Seth Lyman (Utah State University), Dr. Dan Jaffe (University of Washington) and Dr. Lu Hu (University of Montana). Tesoro believes this project will significantly improve our understanding of ozone and aerosols in the Salt Lake City basin and will improve Utah Division of Air Quality's (UDAQ) ability to regulate emissions utilizing the best available science.

If SAMOZA is awarded the contract by UDAQ, Tesoro will make a financial commitment of $15,000 to the project. Tesoro supports the full participation of all three university Principal Investigators (PIs), however, for logistical reasons, Tesoro will contribute directly to the work of the University of Washington.

Should you have any questions about this commitment, please contact Michelle Bujdoso at (801)366-2036, or mdbujdoso@marathonpetroleum.com.

Regards,

Wesley J. Waida

Wesley J. Waida, P.E.
Manager Environmental Safety and Security, Salt Lake City Refinery

cc: Michelle Bujdoso
Chris Kaiser
Brad Shafer
Greg Myers

HOLLYFRONTIER.

HollyFrontier Woods Cross Refining LLC
1070 W. 500 S, West Bountiful, Utah 84087
Tel: 801-299-6600
hollyfrontier.com

January 24, 2022

Director Kyle Unruh
University of Montana
Office of Sponsored Programs
32 Campus Drive 4104
Missoula, MT 59812-4104

Sent electronically via email

RE: **Funding Commitment Letter – University of Montana**

Director Unruh,

My company, HollyFrontier Woods Cross Refining LLC, HFWCR, fully supports the goals of the Salt Lake regional Smoke, Ozone, and Aerosol Study (SAMOZA) that has been proposed by Dr. Seth Lyman (Utah State University), Dr. Dan Jaffe (University of Washington), and Dr. Lu Hu (University of Montana). We believe this project will significantly improve our understanding of ozone and aerosols in the Salt Lake City basin and will improve UDAQ's ability to regulate emissions best on the best available science. Our company will make a financial commitment of $10,000 to the project. While we support the full participations of all three university PI's, for logistical reasons, our contribution will go towards the work of the University of Montana.

If you have any questions about this commitment please contact me at (801) 299-6623 or via email at Eric.Benson@hollyfrontier.com.

Sincerely,

Eric Benson

Eric Benson
Environmental Manager

c: lu.hu@mso.umt.edu

Big West Oil LLC 333 W. Center Street • North Salt Lake Utah 84054 • 801.296.7700 • www.bigwestoil.com

January 25, 2022

Dr. Seth Lyman
Bingham Research Center
Utah State University
320 N Aggie Blvd
Vernal, UT 84078

RE: Salt Lake Regional Smoke, Ozone and Aerosol Study (SAMOZA)

Dear Professor Lyman:

Big West Oil LLC supports the goals of the Salt Lake Regional Smoke, Ozone and Aerosol Study (SAMOZA) that has been proposed by Dr. Seth Lyman (Utah State University), Dr. Dan Jaffe (University of Washington) and Dr. Lu Hu (University of Montana). My company believes this project will significantly improve our understanding of ozone and aerosols in the Salt Lake City basin and will improve Utah Division of Air Quality's (UDAQ) ability to regulate emissions utilizing the best available science. If SAMOZA is awarded the contract by UDAQ, we will make a financial commitment of $10,000 to the project. My company supports the full participation of all three university PIs, however, for logistical reasons, we will contribute directly to the work of Utah State University.

Should you have any questions about this commitment, please feel free to contact me.

Sincerely,

Orson Thornton
Technical Manager
Big West Oil LLC
333 West Center Street
North Salt Lake, Utah 84054

Blair Blackwell
Corporate Affairs Manager

Seth Lyman
Bingham Center Director and Research Associate Professor
320 N Aggie Blvd
Vernal, UT 84078-8330

Dear Dr. Lyman,

Chevron was pleased to learn of the joint application by yourself, Dr. Dan Jaffe (University of Washington) and Dr. Lu Hu (University of Montana) to the Utah Division of Air Quality's Science for Solutions Research Grant.

Chevron supports the goals of the Salt Lake regional Smoke, Ozone and Aerosol Study (SAMOZA) and believes this project will significantly improve the understanding of ozone and aerosols in the Salt Lake City basin and support UDAQs ability to regulate emissions based on the best available science.

Improving air quality requires both a data-driven approach and collaboration across the region. We have been pleased to support a variety of initiatives at USU over many years, and can confirm a financial commitment of at least $15,000 to the project to be provided to Utah State University.

Please let me know if you have any questions about this commitment. I may be reached at blair.blackwell@chevron.com.

With best regards,

Blair Blackwell

Chevron U.S.A. Inc.
685 S. Chevron Way, North Salt Lake, UT 84054