UTAH DIVISION OF AIR QUALITY REQUEST FOR PROPOSAL
Summary Information Page

Project Title	Particulate Chloride in the Urban Environment		
Applicant Information	**Applicant:** University of Utah		
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Project Funding	Amount Requested $75,735	Matching Funds $1,500	Total Project Cost $77,235
Project Period	Start Date 07/01/2021	End Date 12/31/2022	

Particulate Chloride in the Urban Environment

Abstract

A growing body of observations and modeling studies indicate that halogen radicals, particularly the chlorine radical and related species, can play a significant role in urban atmospheric chemistry[1], Chlorine radicals can be produced by the photodissociation of chlorinated species[2], gas-phase chemical reactions involving HCl or chlorocarbons[3], or heterogeneous reactions of particulate chloride. Although chlorine in particulate matter is generally in the form of unreactive chloride, a variety of heterogeneous and multi-phase reaction processes can lead to the conversion of particulate chloride into gas-phase, reactive chlorine species[1]. The two dominant processes for this conversion include aqueous-phase chemical reactions of dissolved gases[4] and acid displacement[5,6]. Short-duration measurements made during NOAA's Utah Winter Fine Particulate Study (UWFPS) in 2017 discovered that up to 15% of the $PM_{2.5}$ mass was composed of ammonium chloride during winter air pollution events[7]. The UWFPS field experiment also indicated that significant coarse-mode particulate chloride might be present as well. The source of the fine- and course-mode particulate chloride is currently unknown.

The overall goal of this proposal is to **utilize data previously-collected by UDAQ and the PI** to characterize the prevalence and temporal variations of particulate chloride in the urban environment. A secondary goal is to use source apportionment modeling to identify potentially significant sources of particulate chloride. Although this project specifically addresses **RFP Goal #3 (Physico-Chemical PM Composition)**, it also touches on **RFP Goal #4 (Emission Inventory Improvements)** and **RFP Goal #2 ($PM_{2.5}$ Formation and Precursor Gases)** through its focus on reducing the uncertainties associated with a key halogen species (i.e., chlorine).

Specific tasks necessary to complete the project goals include:

1) Analyze available PM_{10} filters from the Hawthorne, Lindon, and Bountiful monitoring sites to determine the prevalence and temporal variations of coarse particulate chloride.
2) Use existing size-resolved elemental composition measurements to determine the temporal variation of particulate chloride particle size distributions.
3) Determine the chemical composition of road salt variants and brine solutions used by the Utah Department of Transportation (UDOT).
4) Perform source apportionment modeling of particulate chloride.

The proposed study is intended to significantly reduce uncertainties regarding the temporal, spatial, and particle size distributions of particulate chloride. It will also identify the dominant sources of this important halogen. These results will provide important emission inventory constraints for future air quality modeling efforts performed by UDAQ and others.

Basis and Rationale

The Utah Winter Fine Particulate Study (UWFPS), which took place during 2017, was one of the most comprehensive air quality studies to occur in the State of Utah[7]. UWFPS involved research groups from across the country and utilized ground-based, mobile, balloon-borne, and aircraft platforms to elucidate the complex relationships between emissions, chemical transformations, and meteorology during persistent cold air pool (PCAP) events which commonly occur along the Wasatch front and in enclosed mountain basins during the winter months. PCAPs occur 18 days per year on average and lead to poor air quality conditions which often exceed the National Ambient Air Quality Standards (NAAQS) for one or more of the criteria air pollutants. As a result of these exceedances, the US EPA declared three regions in norther Utah as non-attainment areas (NAA) for 24-hr $PM_{2.5}$ in 2009. The Salt Lake City and Provo NAAs have since been re-classified as "serious", requiring more stringent regulations to reduce $PM_{2.5}$.

Results from the UWFPS indicate that wintertime $PM_{2.5}$ was dominated by ammonium nitrate, which comprised up to 70% of $PM_{2.5}$ mass during PCAPs. Unlike many other regions of the US, sulfate-containing particles are a relatively minor contributor to $PM_{2.5}$ mass. Particulate chloride, on the other hand, comprised up to 15% of $PM_{2.5}$ mass which is unusual for inland sites but comparable to many coastal locations[8]. There was significant uncertainty regarding the contributions of organic material to the $PM_{2.5}$ mass that will require follow up study.

The presence of a significant, but poorly characterized, particulate chloride loading can complicate air quality modeling efforts because the unreactive particulate chloride can be transformed into gas-phase reactive chlorine species via a variety of heterogeneous and multi-phase reaction pathways[1]. The two dominant processes for this conversion include aqueous-phase chemical reactions of dissolved gases[4] and acid displacement[5,6], both of which are likely to occur during PCAPs. Understanding the sources and distribution of halogens is important for a variety of reasons. For example,

- the presence of halogen radicals (e.g., Cl-,ClO, BrO, etc.) can affect the lifetime of reactive hydrocarbons and reactive nitrogen, both of which play a role in ozone production[9],
- halogen radicals can participate in the catalytic destruction of ozone[10,11],
- HCl will partition to particulate matter (i.e., NH_4Cl) in the presence of excess ammonia gas, thereby increasing PM loadings and potentially altering the availability of oxidants through its interactions with reactive nitrogen[12,13].

Potential sources of halogens in the urbanized regions of the Wasatch front include, but are not limited to, the Great Salt Lake, dust from playa surfaces, industrial processes, road salt, and coal combustion. Determining the relative importance of the halogen sources was identified as a key research need in the UWFPS final report[7].

The overall goal of this proposal is to **utilize data previously-collected by UDAQ and the PI** to characterize the prevalence and temporal variations of particulate chloride in the urban environment. A secondary goal is to use source apportionment modeling to identify potentially significant sources of particulate chloride. Although this project specifically addresses **RFP Goal #5 ($PM_{2.5}$ Formation Chemical Composition and Sources)**, it also touches on **RFP Goal #2 (Emission Inventory Improvements)** and **RFP Goal #4 ($PM_{2.5}$ Formation and Precursor Gases)** through its focus on reducing the uncertainties associated with a key halogen species (i.e., chlorine).

Specific tasks necessary to complete the project goals include:

1) Analyze available PM_{10} filters from the Hawthorne, Lindon, and Bountiful monitoring sites to determine the prevalence and temporal variations of coarse particulate chloride.
2) Use existing size-resolved elemental composition measurements to determine the temporal variation of particulate chloride size distributions.
3) Determine the chemical composition of road salt variants and brine solutions used by the Utah Department of Transportation.
4) Perform source apportionment modeling of particulate chloride using Positive Matrix Factorization (PMF).

The proposed study is intended to significantly reduce uncertainties regarding the temporal, spatial, and particle size distributions of particulate chloride. It will also identify the dominant sources of this important halogen. These results will provide important emission inventory constraints for future air quality modeling efforts performed by UDAQ and others.

Technical Approach

Task #1: Analyze available PM_{10} filters from the Hawthorne, Lindon, and Bountiful monitoring sites to determine the prevalence and temporal variations of coarse particulate chloride.

The State of Utah has three Chemical Speciation Network (CSN) monitoring sites which have been operating for more than 15 years (i.e., Hawthorne, Bountiful, and Lindon). The CSN sites measure the 24-hr averaged $PM_{2.5}$ mass and elemental composition on a 1 day in 3 (Hawthorne) or a 1 day in 6 (Lindon and Bountiful) schedule. Although the CSN sites also collect filters to measure PM_{10} mass, the PM_{10} filters are not routinely analyzed for elemental composition. Thus, the composition of the coarse-mode particulate matter (i.e., 10 $\mu m < D_p < 2.5$ μm) is largely uncharacterized. I contacted UDAQ (Bo Call – personal communication) and learned that the PM_{10} filters are typically archived for a period of 1-2 years prior to disposal. I, therefore, propose to analyze all of the PM_{10} filters the 2020 calendar year for the three, previously-identified CSN sites using X-ray Fluorescence (XRF). I will work closely with UDAQ to identify a mutually-agreeable analytical laboratory which is well-versed in chain-of-custody matters. My first choice would be Crocker Nuclear Laboratory (CNL) at the University of California, Davis. They perform all of the XRF analyses for the Interagency Monitoring for Protected Visual Environments (IMPROVE) fine aerosol network as well as much of the analyses for the CSN. In addition, I worked at CNL for 4 years back in the 1990s and am very familiar with the software that they use to

deconvolute the X-ray spectra. PM_{10} filters require a different particle size correction due to the self-absorption of X-rays by the particles and most laboratories do not have much experience performing this correction. CNL spent several years in the late 1980s and early 1990s developing and testing the particle size corrections during a study of fugitive dust in the San Joaquin Valley funded by the US Department of Agriculture.

The estimated number of PM_{10} filters to be analyzed by XRF for this study is 243 (122 – Hawthorne, 61 – Bountiful, 61 – Lindon). Analytical laboratories using a multi-anode XRF system (such as CNL) typically report ~33 elements above the minimum detection limits (MDLs). Particulate chlorine is typically stable on the Teflon filters during storage unless the aerosol has a low pH. Under these conditions, the chloride can be lost through the process of acid displacement. These situations will be obvious and will be excluded from the analysis because the chloride concentrations will be below the MDL.

The PM_{10} elemental composition measurements will be combined with the co-located $PM_{2.5}$ elemental composition measurements to determine the concentrations of coarse chloride (and the 32 other elements measured by XRF) at the three CSN sites. Analysis of the resultant data will reveal typical concentrations and seasonal patterns. Bi-variate correlations will indicate which species have the highest covariance with the fine and coarse chloride. Spatial variations among the three CSN sites will also be investigated.

Task #2: Use existing size-resolved elemental composition measurements to determine the temporal variation of particulate chloride size distributions.

Continuous size-resolved PM elemental composition measurements with 3-hr time resolution were made by the PI at the (now retired) UDAQ Syracuse meteorological station for a period of 1.25 years. The PM samples were collected using an 8-stage rotating DRUM impactor (Fig. 1) which physically separates particulate matter into 8 size bins based on their aerodynamic diameters and then impacts them onto greased mylar substrates[14]. The substrates slowly rotate under the impaction slots to preserve a linear time series of the size-resolved particulate matter (Fig. 1). The DRUM operates at a flow rate of 16.7 lpm and was run autonomously for 6 weeks. At the end of each 6-week sampling period, the substrates were downloaded in the laboratory and replaced by a new set of sampling strips. The sampling substrates were eventually taken to the Advanced Light Source (Lawrence Berkeley National Laboratory) where the PI analyzed the elemental composition using synchrotron X-ray fluorescence (S-XRF) at beamline 10.3.1 (Fig. 2). Deconvolution of the raw X-ray spectra (Fig. 3) was performed using the Quantitative X-ray Analysis System (QXAS) X-ray peak-fitting software package that was developed by the IAEA Laboratories in Seibersdorf, Austria. Quantitative analysis was performed by calibrating the response of the system to a comprehensive set of 40 single- and multi-element NIST-traceable standards. This procedure yielded size-resolved PM elemental concentrations for elements ranging from sodium through strontium plus lead with a 3-hr time resolution[15]. This rich dataset, which has never been fully explored, will be used to determine the temporal variation of the particulate chloride concentrations in the following size bins: 10.0-5.0 μm, 5.0-2.5 μm, 2.5-1.1 μm, 1.1-0.75 μm, 0.75-0.56 μm, 0.56-0.34 μm, 0.34-0.26 μm, and 0.26-0.09 μm.

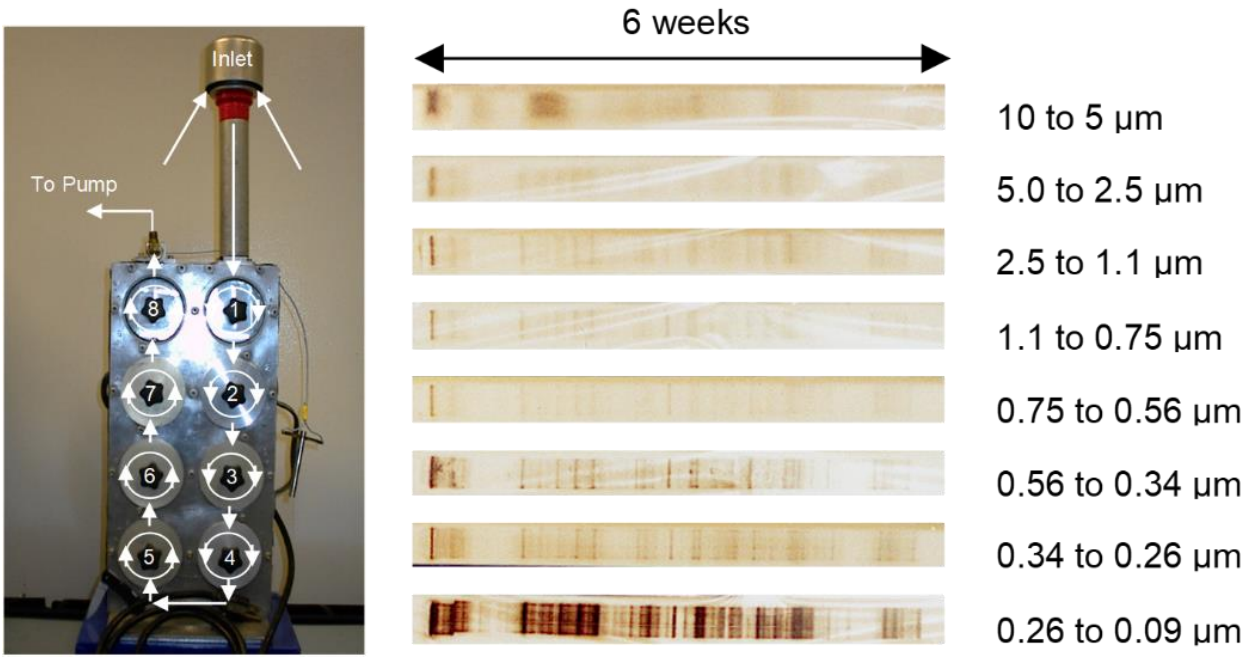

Figure 1. Image of an 8-stage rotating DRUM impactor (left) and the impaction substrates (right). The airflow through the instrument is indicated by the direction of the white arrows. Particle diameters for each stage are shown on the right. A URG PM_{10} inlet head (not shown) protects the substrates from precipitation, bugs, and provides the initial 10 µm diameter size cut.

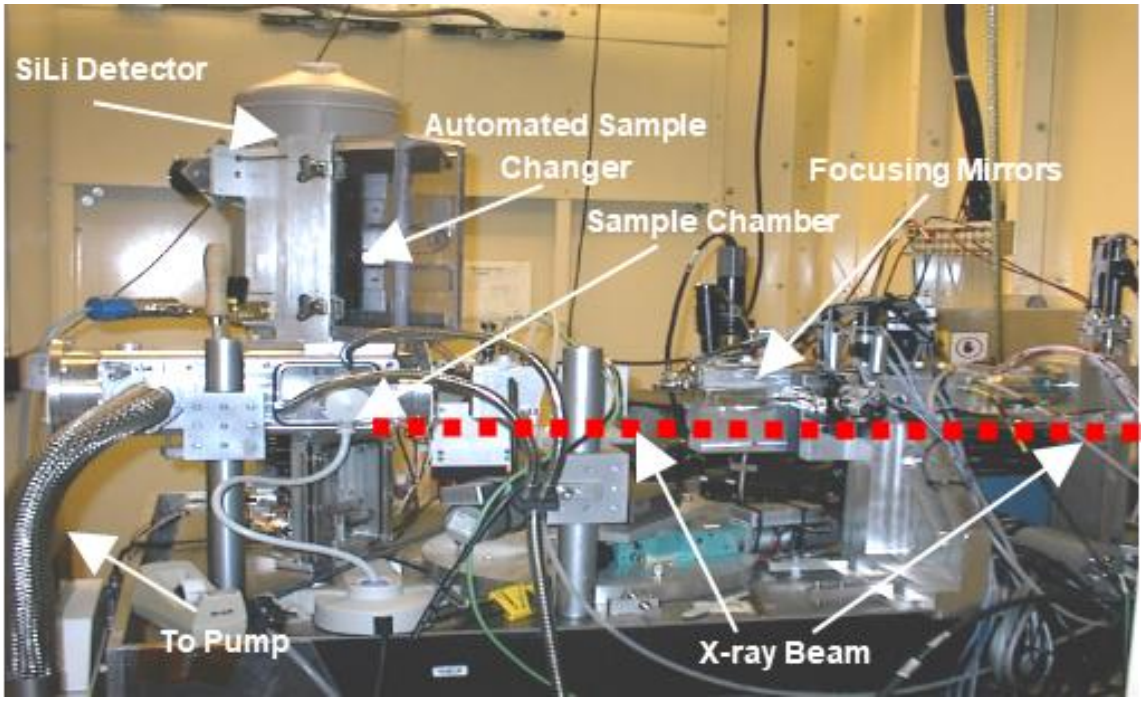

Figure 2. Picture of the S-XRF endstation (beamline 10.3.1) at the ALS. The X-ray beam from the synchrotron enters from the right, passes through the focusing mirrors and into the sample chamber. X-rays fluoresced from the sample are then detected with the SiLi detector. The sample chamber is equipped with an automated sample chamber to increase the efficiency of the analysis.

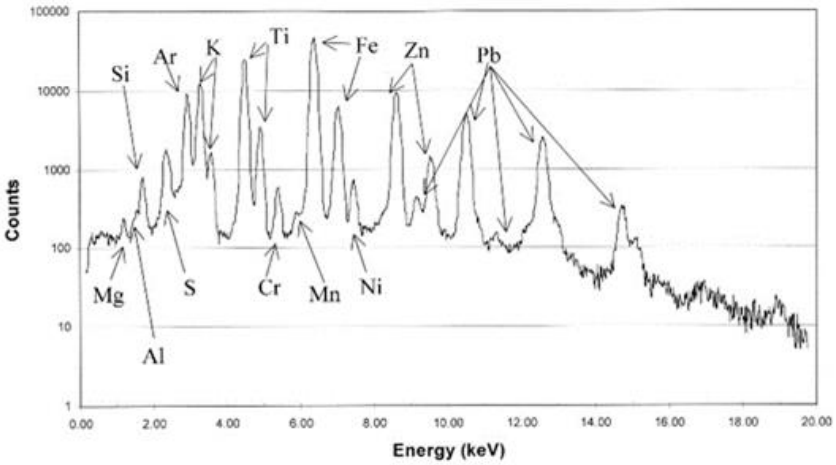

Figure 3. Raw X-ray spectra collected from a NIST-Traceable Standard (NBS 1833) using the X-ray microprobe on beamline 10.3.1 at the ALS. Note the excellent signal to background ratio on this logarithmic scale plot.

The UDAQ Syracuse meteorological station is ideally situated to capture the variations of particulate chloride from both the Great Salt Lake and the urban region abutting the Wasatch Mountains because it is subjected to alternating land/lake breezes depending on the time of day and the weather patterns. The heating differential between the lake surface and the land creates an afternoon breeze from the lake to the west (Fig. 4). At night, the temperature gradient reverses resulting in a land breeze from the east. The proximity of an urban area to the east allows for ideal monitoring of urban PM during the overnight hours.

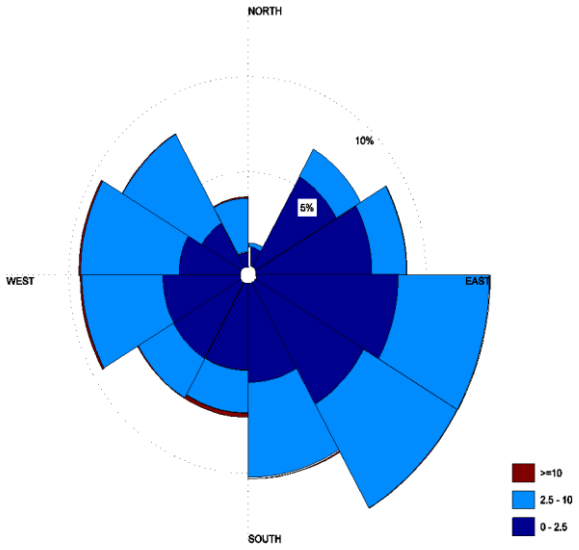

Figure 4. Wind-rose for the UDAQ Syracuse meteorological station from 07/01/2009 through 06/30/2010.

Task #3: Determine the chemical composition of road salt variants and brine solutions used by the Utah Department of Transportation (UDOT).

According to the UDOT website[16], they use 236,000 tons of regular (white) salt and three types of high performance salt each year. They also use 1.8 million gallons of salt brine each year to pre-treat for ice on state roads. As a result, the application of salt (in its various forms) to Utah roadways has the potential to be a significant source of particulate chloride to the atmosphere. It is impossible to determine the magnitude of this chloride source if the compositions of the various salts/brine solutions are unknown. Thus, the goal of this task is to characterize the chemical composition of the PM_{10} fraction of the different types of rock salt and brine solutions used by UDOT. The PI will work with UDOT to obtain representative samples of each type of salt/rock salt/brine solution that they use. The particulate salt samples will be disaggregated and then sieved to obtain particles with diameters <75 μm. These particles will then be resuspended in a specially-designed chamber using compressed air, passed through a URG inlet at a flow rate of 16.7 lpm to provide a PM_{10} 50%-cutpoint, and then collected onto 25 mm Teflon filters. The filters will then be analyzed by XRF and Inductively-Coupled Plasma Mass Spectrometry (ICP-MS) to determine the elemental composition of each sample. Together, XRF and ICP-MS are capable of quantifying 53 elements. The brine solution will be analyzed in a similar manner. The only difference is that the salt from the brine solution will need to be crystalized first. The data generated by this task will provide source fingerprints which can be used during the source apportionment phase of this project (i.e., Task #4).

Task #4: Perform source apportionment modeling of particulate chloride.

This task will apply state-of-the-art receptor models such as EPA Unmix and EPA positive matrix factorization (PMF) to the data from the three, long-term, CSN network sites in Utah to quantitatively apportion the particulate chloride to various source types. The EPA Unmix receptor model is based on a form of Factor Analysis, but it imposes physically-meaningful constraints to remove the ambiguity of the multiple solutions that are characteristic of ordinary Factor Analysis[17]. Unmix estimates the number of sources, the source compositions, and source contributions to each observation. This approach is particularly useful when the number of contributing source types is unknown or when source profiles are not available for important contributing sources. PMF[18] is a least squares formulation of Factor Analysis originally developed by Dr. P. Paatero (Dept. of Physics, University of Helsinki) (*Paatero and Tapper* 1994; *Xie et al*. 1999; *Lee et al.* 1999; *Paatero et al.* 2002). It has since been modified by the EPA Office of Research and Development (ORD) to provide more realistic uncertainty estimates. PMF assumes the ambient aerosol concentrations at one or more sites can be explained by the linear product of a source matrix and contribution matrix. No a priori knowledge regarding the contributing source types is required in this type of analysis. Instead, PMF creates individual source profiles for species that exhibit temporal collinearities. The resultant source profiles can then be compared to measured source profiles for positive identification. One disadvantage of PMF is that there is no universally accepted methodology for identifying the most appropriate number of source types to retain in the analysis.

Expected Outputs and Outcomes

Task #1: Completion of this task will provide crucial information on the prevalence, temporal variations, and spatial variations of coarse particulate chloride in the urban environment along the Wasatch Front. Although particulate chloride is thought to play a significant role in wintertime secondary aerosol formation through its contribution to the halogen budget, little is known about the coarse-mode chloride concentrations and the sources which produce it. This project will clearly establish whether particulate chloride is generally partitioned in the accumulation or coarse mode. If significant coarse-mode chloride is present, then future air quality research experiments will need to take this into account when planning the measurement strategies.

Task #2: The 3-hr resolution measurements of the size-resolved PM chloride concentrations will shed light on both the sources of particulate chloride and the processes which affect its prevalence. The measurements were collected near the shore of the Great Salt Lake at a location with distinct lake/land breezes. Thus, the data from this single site will provide information about particulate chloride sources from both the lake and the adjacent urbanized region. A quick look at some of the data revealed that there is almost an order of magnitude more chlorine mass in the coarse mode than there is in the accumulation mode. Thus, the particle size distributions will likely be heavily skewed toward the larger particles. This also means that the measurement campaigns which focus solely on fine (i.e., $PM_{2.5}$ particles) likely miss an important contributor to the halogen budget.

Task #3: Characterizing the composition of the salt variants and brine solutions used by UDOT is a necessary first step in determining whether their application to roadways is a significant source of particulate chloride during the winter months. Creating a source elemental and particle size fingerprint will provide crucial information for subsequent source apportionment modeling efforts.

Task #4: Source apportionment using EPA Unmix and EPA Positive Matrix Factorization should be able to identify the dominant primary sources of particulate chloride in the urbanized areas along the Wasatch Front. These sources can then be targeted to develop a detailed emissions inventory for use in future air quality modeling efforts.

Deliverables

The primary deliverables for this project will be quarterly reports, the final report, and resultant publications. Results of this project will also be presented at the Science for Solutions annual conference and published in peer-reviewed journal articles. Data sets generated by this project will include:

- PM_{10} elemental composition measurements from the Hawthorne, Bountiful, and Lindon CSN sites for 2019.
- Size-resolved PM composition measurements for the UDAQ Syracuse meteorology station from 06/16/2009 through 10/15/2010.
- PM_{10} elemental composition measurements of salt variants and brine solutions used by the UDOT.

The data sets described above will be submitted to Mendeley Data for permanent archival within 6 months of the conclusion of the project. Mendeley Data is an open research data repository, where researchers can upload and share their research data (https://data.mendeley.com/). Published datasets are archived with Data Archiving and Network Services (DANS). DANS is a long-term archiving provider, which is an institute of the Dutch Academy KNAW, and NWO, the Netherlands' national research council. Mendeley Data has a contract with DANS to archive all valid, published datasets in perpetuity. The agreement ensures that the DOIs provided by Mendeley Data will always resolve to a web page, where the dataset metadata and files will be available. I would also be willing to have the data shared through the UDAQ website if there is interest.

Schedule

Activity	Quarter					
	1	2	3	4	5	6
Task #1						
Work with UDAQ to identify a mutually-acceptable XRF laboratory	X					
Ship filters to XRF laboratory with appropriate chain of custody documentation		X				
Receive XRF results and perform QA checks of the data			X			
Merge the PM10 and PM2.5 elemental composition data for the CSN sites				X		
Perform temporal and spatial analysis of particulate chloride data				X	X	
Task #2						
Perform QA and add timestamps to the size-resolved PM composition data	X	X				
Merge data files into a single continuous time series		X				
Calculate particle size distributions of particulate chloride			X	X		
Investigate temporal patterns in the particulate chloride data				X	X	
Task #3						
Contact UDOT to secure salt and brine samples		X	X			
Prepare and sieve samples			X			
Resuspend sieved samples and extract PM10 portion onto filters			X			
Perform XRF and ICP-MS analysis of samples			X	X		
Create elemental fingerprints for each source					X	
Task #4						
Download PM2.5 speciation data for CSN sites	X					
Format speciation data for EPA Unmix and PMF models		X				
Perform source apportionment of fine particulate chlorine			X			
Merge coarse and fine particulate chlorine data for CSN sites				X		
Perform source apportionment of coarse + fine particulate chlorine					X	
Reports						
Quarterly reports	X	X	X	X	X	
Final report					X	X
Science for Solutions conference Presentation						X

Budget

	Task 1	Task 2	Task 3	Task 4	Total
A. PERSONNEL					
1. Dr. Kevin Perry (PI) - University of Utah	5889	5889	11778	5889	29444
2. Undergraduate Research Assistant	0	600	600	0	1200
Total Personnel =	5889	6489	12378	5889	30644
B. FRINGE BENEFITS					
A1 (34%)	2002	2002	4004	2002	10011
A2 (10%)	0	60	60	0	120
Total Fringe Benefits =	2002	2062	4064	2002	10131
C. EQUIPMENT	0	0	0	0	0
D. TRAVEL					
1. Fleet Vehicle (@0.65/mile)	0	0	325	0	325
Total Travel =	0	0	325	0	325
E. OTHER DIRECT COSTS					
1. XRF Analysis	18750	0	1500	0	20250
2. ICPMS Analysis	0	0	2000	0	2000
3. Particle Size Analysis	0	0	500	0	500
3. Lab Supplies	0	0	2000	0	2000
4. Computer Hardware	500	500	500	500	2000
5. Publication Page Charges	250	250	250	250	1000
Total Other Direct Costs =	19500	750	6750	750	27750
F. TOTAL DIRECT COSTS	27391	9301	23517	8641	68850
G. INDRECT COSTS	2739	930	2352	864	6885
H. TOTAL REQUEST (=DIRECT AND INDIRECT COSTS - 10%)	30130	10231	25869	9505	75735
I. COST SHARE (Publication Page Charges)	341	341	341	341	1364
Indirect on Cost Share (10%)	34	34	34	34	136
Total Cost Share =	375	375	375	375	1500
J. TOTAL PROJECT	30505	10606	26244	9880	77235

Budget Justification

A. Personnel

Dr. Kevin Perry (PI) – A total of 2.5 months of summer salary support are requested for this project. The effort distribution will be 0.5 months for Task #1, Task #2, and Task #4 and 1.0 month for Task #3. The summer salary is calculated as 1/9 of the academic (9-month) salary as per University regulations.

Undergraduate Research Assistant - $1,200 is requested to hire an undergraduate student to assist with Task#2 and Task #3. The effort distribution will be divided equally between the two tasks. This equates to 80 hrs @ $15/hr.

B. Fringe Benefits

All fringe benefits are calculated in accordance with University policies. University of Utah fringe benefits are 34% for faculty and 10% for students.

C. Equipment

No funds are requested for permanent equipment.

D. Travel

Task #3 (total = $325)

- Truck Fleet Mileage (500 miles @ $0.65/mile = $325). Travel to various UDOT facilities to obtain rock salt and brine solution samples and to observe loading/application operations.

E. Other Direct Costs

Task #1 (total = $19,500)

- XRF Analysis (250 filters x $75/filter = $18,750)
- Computer hardware ($500) – 1/4 of a laptop and a desktop monitor
- Publication charges ($250)

Task #2 (total = $750)

- Computer hardware ($500) – 1/4 of a laptop
- Publication charges ($250)

Task #3 (total = $6,750)

- XRF Analysis (20 filters @ $75/filter = $1,500)
- ICPMS Analysis (20 filters @ $100/filter = $2,000)
- Particle size analysis (20 samples @ $25/sample = $500)
- Laboratory Supplies (filters, tubing, forceps, cleaning supplies, glove box, etc) - $2,000
- Computer hardware ($500) – 1/4 of a laptop and a desktop monitor
- Publication charges ($250)

Task #4 (total = $750)

- Computer hardware ($500) – 1/4 of a laptop
- Publication charges ($250)

F. Indirect Costs

Indirect costs ($7,021) are capped at the maximum allowable rate of 10% of the Total Direct Costs as per the RFP instructions.

I. Cost Share

The Department of Atmospheric Sciences at the University of Utah will contribute $1,500 for publication page charges (including 10% indirect cost on the publication page charges).

Personnel Roles and Responsibilities

Principal Investigator: Dr. Kevin Perry (University of Utah)

Dr. Perry is an Associate Professor in the Department of Atmospheric Sciences at the University of Utah and served as Department Chair from 2011 to 2018. He has more than 25 years of management and research experience in the areas of ambient air quality monitoring, instrumentation/analytical technique development, source apportionment, atmospheric dry deposition, and the climatic and health effects of particulate matter. His experience includes management and participation in ~20 ambient air monitoring projects ranging from local-scale pollution events (e.g. plumes from the World Trade Center collapse, smoke from pyrotechnic displays) to the intercontinental transport of pollutants (e.g., Aerosol Characterization Experiment – ACE-Asia, International Transport and Chemical Transformation Experiment – ITCT2K2). Dr. Perry has deployed ambient air monitoring equipment at ground-based, ship-based, airborne, and high-altitude mountain observatories around the globe. He also developed a technique using the Advanced Light Source (ALS) Synchrotron at Lawrence Berkeley National Laboratory (LBNL) to use Synchrotron-Xray Fluorescence (S-XRF) to characterize the size- and time-resolved elemental composition of atmospheric particulate matter. As PI, Dr. Perry will be responsible for ensuring that the goals and timelines are met and that the deliverables are produced on schedule. Dr. Perry will personally perform the data analysis for all task and will generate all of the required reports.

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