Characterizing Air Quality Impacts from Exceptional Events along the Wasatch Front

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1 SCOPE OF WORK

1.1 Abstract

Dust storms are exceptional events that negatively impact air quality across the Wasatch Front. These events are becoming more frequent in Utah, but their impact on ambient air quality and contribution to background particulate matter (PM) levels are unclear and need further assessment. Demonstrating the occurrence and impact of these events is important for regulatory purposes as Utah works to achieve air quality standards. Correlating dust events between source locations and impacted areas is important for determining how future land use or water diversion schemes could alter dust source regions and affect downwind populated areas along the Wasatch Front. A better understanding of source-to-sink processes could inform future planning and resulting health impacts, especially for socioeconomically disadvantaged populations. Evaluating dust sources is nearly impossible with modelling or satellite imagery alone. Dust transport models that are supported by observational data are needed to apportion dust to particular emission sources. Transport models are useful for filling in gaps in spatial resolution from discrete point measurements, to provide a more complete understanding of source to receptor processes, and for predicting future impacts from various development schemes or water development projects. Combining observations and models is a powerful new method for exploring dust emissions, transport, and deposition that has rarely been done before, and not for the Wasatch Front.

This project utilizes state-of-the-science measurements and modeling to better quantify impacts of exceptional dust events on $PM_{2.5}$ and PM_{10} concentrations along the Wasatch Front. The project will: 1) demonstrate differences between PM emissions from background sources versus exceptional events using chemical signatures; 2) identify dust source locations using isotopic "fingerprints"; 3) develop a dust modeling framework that is validated by chemistry and isotope data; and 4) use the validated dust model to predict impacts of future emissions under changing land use and climate conditions. Key project results include: a spreadsheet with trace element chemistry for 250 PM filters collected from dust events, forest fires, winter inversions, and ambient conditions; a spreadsheet with Sr isotope ($^{87}Sr/^{86}Sr$) ratios on 50 PM filters to determine dust source locations impacting the Wasatch Front over time; a validated dust modeling framework that is "transportable", i.e., can be modified for use beyond the Wasatch Front; and predicted "what-if" results for a decreased GSL water level and a new industrial dust emission source that show spatially-resolved changes in PM concentrations, including the Wasatch Front regions that are most heavily impacted by new dust sources.

1.2 Basis and Rationale

Dust storms are exceptional events that negatively impact air quality across the Wasatch Front, yet it can be difficult to demonstrate the differences in particulate matter (PM) from urban versus regional dust sources, determine dust source locations contributing to these events, and predict future impacts under various land use and climate scenarios. Our proposed research addresses the topic "Exceptional events and their impact on air quality". Exceptional events are defined as unusual or naturally occurring events that can affect air quality but are not reasonably preventable or controllable using strategies implemented to attain federal air quality standards. These events, including dust and smoke from wildfires, are becoming more frequent in Utah, but their impact on ambient air quality and contribution to background levels are unclear and need further assessment. Demonstrating the occurrence of these events is important for regulatory purposes as Utah works to achieve air quality standards.

Dust storms occur frequently along the Wasatch Front with negative impacts on air quality [Hahnenberger and Nicoll, 2012; Steenburgh et al., 2012]. The dry lakebed of Great Salt Lake (GSL) is a potent dust source located immediately adjacent to the Wasatch Front. As water levels continue to drop due to drought and diversions, dust storm events will likely increase in frequency and intensity in the future [Wurtsbaugh et al., 2017; Skiles et al., 2018]. Proposed diversions on the Bear River would reduce water flow into the GSL further accelerate lake drawdown. Ultimately, decreasing water levels could create a "dust bowl" similar to Owens Dry Lake in California, where increased dust emissions have resulted in PM_{10} exceedances and deposition of harmful metals in downwind communities [Reheis, 1997; Reheis et al., 2002, 2009]. Owens Lake bed was the largest single source of dust in the US, accounting for 5% of nationwide dust emissions, and is home to the highest atmospheric particulate and PM_{10} concentrations ever measured in the US that are 25 times higher than the federal limit [Gill and Gillette, 1991; Cahill et al., 1996]. As lake levels decline, dust emissions from the GSL lakebed will likely increase and there will be an increased need to monitor for release of metals and other contaminants during wind events.

Tracking dust events between source locations and impacted areas is important for determining how future land use or water diversion schemes could alter dust source regions and affect downwind populated areas along the Wasatch Front. A better understanding of source-to-sink processes could inform future planning and resulting health impacts, especially for socioeconomically disadvantaged populations. Evaluating dust sources is nearly impossible with modelling or satellite imagery alone. Dust transport models that are supported by observational data are needed to apportion dust to particular emission sources. Transport models are useful for filling in gaps in spatial resolution from discrete point measurements, to provide a more complete understanding of source to receptor processes, and for predicting future impacts from various development schemes or water development projects. Combining observations and models is a powerful and novel method for exploring dust emissions, transport, and deposition. In this project, we propose to: 1) demonstrate differences between PM emissions from background sources versus exceptional events using chemical signatures; 2) identify dust source locations using isotopic "fingerprints"; 3) develop a dust transport model that is validated by chemistry and isotope data; and 4) use validated transport model to predict impacts of future emissions under changing land use and climate conditions.

1.3 Technical Approach

The overall goal of this program is to provide experimental and modeling data to better quantify the impacts of exceptional dust events on air quality and assess the impacts of future dust emission scenarios on PM concentrations in the Wasatch Front. The proposed program has four objectives:

1) Demonstrate differences between PM emissions from background sources and exceptional events using chemical signatures.
2) Identify dust source locations using isotopic "fingerprints".
3) Develop a dust modeling framework that is validated by chemistry and isotope data.
4) Use the validated dust model to predict impacts of future emissions under changing land use and climate conditions.

These objectives will be achieved via the following five primary tasks.

<u>Task 1 – Demonstrate Differences in PM Composition from Background Sources and Exceptional Events</u>

Task 1.1 – Obtain existing $PM_{2.5}$ and PM_{10} filters from UDAQ

Demonstrating the occurrence of exceptional events is important for regulatory purposes as UDAQ works to achieve air quality standards. To quantify differences in chemistry between dust event days and other conditions, we will obtain approximately 50 daily PM filters from UDAQ for trace element and isotopic analyses. The samples include $PM_{2.5}$ and PM_{10} filters from existing UDAQ monitoring stations collected over the past five years. We will coordinate with UDAQ staff to identify samples that are available and not needed for regulatory purposes. We expect to obtain PM filters from major dust event days. For particular dust event days, we expect to get 3-5 samples from across northern Utah for a comparison of spatial variability. We will also request PM filters collected during ambient weather conditions, winter inversion days, and from other days of other known exceptional events such as firework displays or wildfires. Each of these events should be distinguishable by unique trace element chemistry, particularly with signatures of rare earth elements (REEs) that are unique between desert dust and urban pollution. Weather and ancillary air quality data will be documented and compared across each sample date.

Task 1.2 Collect new $PM_{2.5}$ and PM_{10} filters

To supplement the UDAQ filters from Task 1.1, we will collect additional PM samples at Provo and Salt Lake City during the study period. Using existing monitoring stations at BYU and Westminster College, we will collect weekly $PM_{2.5}$ and PM_{10} filter samples over an 18-month period beginning July 2019. At each site, two MiniVol TAS Portable Air Samplers with $PM_{2.5}$ and PM_{10} impactors, respectively, are installed on the science building roofs (the samplers were purchased as part of an earlier project). The Westminster site is operated by Dr. Frank Black (see attached Letter of Commitment). From previous experience we have determined that weekly samples provide sufficient material for chemical and isotopic analyses while also integrating a longer time period than is available from the daily UDAQ filters. Over the 18-month period, we anticipate collecting approximately 50 $PM_{2.5}$ and 50 PM_{10} filter samples at each site, for a total of 200 samples.

Task 1.3 Laboratory analyses of filter samples

The $PM_{2.5}$ and PM_{10} filters from tasks 1.1 and 1.2 will be analyzed for trace element chemistry and strontium (Sr) isotope ratios at the University of Utah (see attached Letter of Commitment from Dr. Diego Fernandez). The 250 filters are analyzed for a suite of 40+ trace and major elements (including Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, REEs, S, Sb, Se, Sr, Ti, Tl, U, V, and Zn) using an Agilent ICP-MS. To remove PM from the filters for analysis, we use a two-step sequential extraction with 1 M acetic acid and 1 M nitric acid, as described in a recent publication [Dastrup et al., 2018]. The signal from playa carbonate minerals (As, Ba, Ca, K, Li, Na, Sr, and U) is obtained from the first extraction step and the signal from urban combustion products or wildfires (Cd, Cr, Cu, Ni, Pb, REEs, Tl, V, Zn) is obtained from the second extraction step. The primary goal for measuring trace element chemistry is to develop a library of chemical signatures of PM under various meteorological conditions (i.e., dust storms versus winter inversions or wildfire smoke). A secondary goal for measuring trace element chemistry is to determine potential health impacts of harmful trace metals adsorbed to the particles. The data collected in this project is useful for collecting an initial dataset of metal concentrations in PM across the Wasatch Front.

A subset of PM filters will be analyzed for Sr isotope ratios to "fingerprint" dust from different source locations. The $^{87}Sr/^{86}Sr$ ratio is measured using a Neptune multicollector ICP-MS at the University of Utah. A minimum of 200 ng of Sr on the filter is required to make precise isotope ratio measurements. Previous experience shows that 25-50% of sample filters from UDAQ or our own filters contain sufficient Sr mass for $^{87}Sr/^{86}Sr$ measurements, particularly from filters with >5 mg of PM. As a conservative estimate, we expect to analyze 50 of our 250 filter samples for Sr isotope ratios.

Task 1.4 Evaluate differences between urban pollution and exceptional events

Using the trace element measurements of $PM_{2.5}$ and PM_{10} samples collected under different air quality conditions, we will demonstrate the difference between ambient conditions and exceptional events. Trace element concentrations on PM filters are correlated with weather behavior, i.e., background, winter inversions, wildfire smoke, fireworks, and dust storms. The chemistry shows differences in element concentrations and element ratios during exceptional events and normal or background readings. We use nonmetric multidimensional scaling (NMDS), a multivariate statistical tool that groups samples according to similar chemistries, as an exploratory tool for investigating differences between the various sample types. Further, we use the EPA Positive Matrix Factorization (PMF) 5.0 statistical model (https://www.epa.gov/air-research/epa-positive-matrix-factorization-50-fundamentals-and-user-guide) to identify contributions from each source type during specific events. PMF 5.0 is a receptor model that is used to quantify contributions from various sources. Through the combination of NMDS and PMF statistical models, we can develop a library of expected chemistry for "ambient" versus "exceptional events". We also expect to find differences in $^{87}Sr/^{86}Sr$ ratios on filters collected during dust events, fires, winter inversions, and ambient conditions, which can be used to support the results from trace element chemistry.

Task 2 – Identify Dust Source Locations Using Isotopic "Fingerprints"

Dust sources locations not identifiable from modeling or satellite imagery alone, as these methods contain considerable uncertainties. Geochemical techniques could provide an important constraint on modeling results. With two previous projects funded by the Utah Division of Forestry, Fire and State Lands (DFFSL), we developed isotopic "fingerprints" of major dust sources in western Utah including the Sevier Desert and Great Salt Lake. Sr isotope ($^{87}Sr/^{86}Sr$) ratios varied from 0.710 in the Sevier Desert to 0.715 at GSL (Fig. 1), which is a wide range in values (relative to analytical errors on the order of ±0.00001) that provides leverage for discriminating the relative importance of dust from each source. Other playas, such as Tule Valley and the Bonneville Salt Flats, contained intermediate $^{87}Sr/^{86}Sr$ ratios of ~0.712 (Fig. 1). Dust samples collected from Wasatch snowpack and the Wasatch Front had $^{87}Sr/^{86}Sr$ ratios falling within the range of the dust source locations (Fig. 1), indicating that the playas are the major source of Sr to the Wasatch Front region.

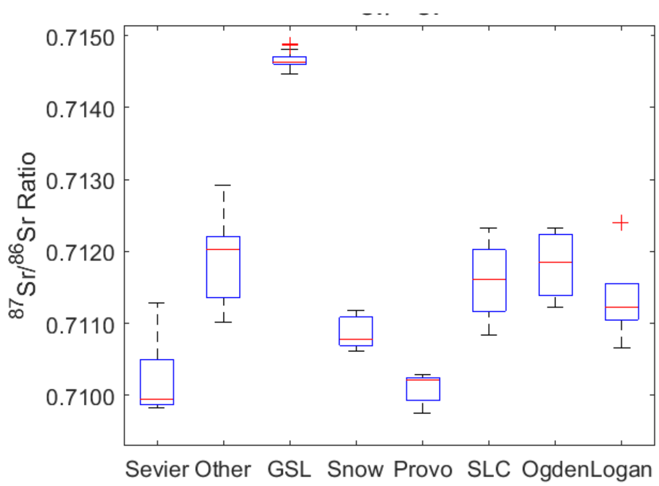


Figure 1. Sr isotope ($^{87}Sr/^{86}Sr$) ratios measured on dust samples from dust source locations in western Utah (Sevier Dry Lake, other playas, and Great Salt Lake) and dust samples collected from Wasatch snowpack and Wasatch Front urban area (Provo, Salt Lake City, Ogden, and Logan). All samples were collected as part of recent studies funded by the Utah DFFSL.

With the newly developed isotopic fingerprinting tool, we can begin to identify specific dust sources that affect the Wasatch Front and monitor changes over time. These data can be used to validate dust transport models, which has never been done before in Utah. The feedback between geochemical observations and transport models will greatly improve dust apportionment studies and source tracking. For example, a recent Wasatch Front dust study by Skiles et al. [2018] would have benefited from $^{87}Sr/^{86}Sr$ measurements to validate modeling results. In that study, the authors claim that half of the dust deposited to Wasatch snowpack during the 13-14 April 2017 storm was sourced from the western playas of Bonneville Salt

Flats and Great Salt Lake. However, our unpublished $^{87}Sr/^{86}Sr$ analyses of that particular dust event suggest that 100% of the dust was from the Sevier Desert ($^{87}Sr/^{86}Sr$ ratio of ~0.711 for that dust layer, nearly identical to dust from Sevier (Dry) Lake and much lower value relative to GSL or the GSL Desert ratios of >0.713). As noted in Skiles et al. [2018], the backward trajectory dust transport models are unable to account for wet playas or playas that do not emit dust under certain conditions. Our $^{87}Sr/^{86}Sr$ data suggest that the western playas actually did not produce substantial dust during that event or that the dust did not impact the Wasatch snow sampling area. In our proposed research, we plan to use $^{87}Sr/^{86}Sr$ measurements to fine-tune the models to more closely match the observations.

Task 3 – Develop and Validate a Dust Emission and Transport Model

Task 3.1 – Develop dust emission and transport model framework

The objective of this task is to develop a dust modeling framework to predict the impact of exceptional dust events on $PM_{2.5}$ and PM_{10} concentrations along the Wasatch Front. This framework will: 1) identify significant dust emission source locations, and 2) show where dust is transported for given meteorological and land cover conditions. The framework will allow for adjustments to key emission source properties to accommodate geochemical measurements and to assess future dust event scenarios. Key elements of the dust modeling framework include dust emissions, atmospheric meteorological (wind) data, and dust particle transport.

Dust emission involves several complex and nonlinear processes that are governed by meteorology, land surface, and soil texture. Dust flux is most sensitive to wind friction velocity, with surface parameters such as roughness and vegetation most important at low to moderate wind speeds [Darmenova et al. 2009]. These factors will be accounted for using the recently completed dust emission scheme added to the Community Multiscale Air Quality (CMAQ) modeling system in version 5.2 [Foroutan et al., 2017]. This approach assumes the main physical mechanism driving dust emission is saltation. It has been shown that the dust flux due to saltation can be orders of magnitude larger than the direct aerodynamic uplifting [Loosmore and Hunt, 2000]. The physics of dust emission due to saltation can be divided into three processes: (1) the onset of saltation by movement of sand particles due to wind (calculated via the friction velocity), (2) the horizontal flux of sand particles, and (3) the vertical flux of dust due to the impact of sand particles and the surface. All of these processes are affected by wind strength, as well as surface conditions, including soil texture, soil moisture, and surface roughness.

The methodology described by Foroutan et al. [2017] for calculating friction velocity (i.e., initial saltation) and subsequent horizontal and vertical dust flux will be used in this study. This approach uses correction factors for soil moisture and surface roughness to account for uncertainties in surface properties. Surface properties, or land use data, are taken from Biogenic Emissions Landcover Database (BELD3) to determine soil (surface) erodibility. Variations in surface vegetation are represented using the fraction of absorbed photosynthetically active radiation (FPAR) based on Moderate Resolution Imaging Spectroradiometer (MODIS) observations as reported by Myneni et al. [2011] or Ran et al. [2015]. Soil type data are taken either from US State Soil Geographic (STATSGO) database [Miller and White, 1998] or from the Soil Information for Environmental Modeling and Ecosystem Management database [Mallia et al., 2017]. Depending on the soil model chosen, the dust contribution to $PM_{2.5}$ and PM_{10} will be taken from Nabat et al. [2012] or Wang et al. [2012], respectively. In either case, the $PM_{2.5}$ to PM_{10} ratio will be in the range 0.07-0.15, consistent with dust particle size distribution. Particular effort will be made to accurately represent key areas expected to contribute to Wasatch Front dust sources including the GSL Desert, GSL shoreline, Sevier (Dry) Lake, Sevier Desert, and Tule Valley playa. These locations will be partially confirmed by work done in Task 2.

The atmospheric meteorological data required for dust transport calculations will be taken from the Weather Research and Forecasting (WRF) model, version 3.7. This widely-used model provides information for wind velocities (used with a surface roughness correction to calculate friction velocity), soil moisture, and snow cover. Wind fields are generated at 12-km and 4-km resolution. Should the data from BELD3 and/or MODIS-FPAR prove too difficult to obtain or pre-process, WRF can also provide land cover data. An approach using WRF-ARW modeling similar to that described by Mallia al. [2017] will be used to calculate the meteorological data and geographic data for the Wasatch Front. This includes boundary conditions derived from the North American Regional Reanalysis (NARR) [Mesinger et al., 2006].

Particle transport and deposition will be calculated using the Eulerian approach in CMAQ. Use of an Eulerian model is preferable to a Lagrangian model for this work in order to predict transport of dust emissions from a relatively small number of sources to all grid locations in the geographical domain. This also enables predicted dust concentrations to be “filled in” between finite measurement locations. Because CMAQ also incorporates models for wet and dry dust deposition, using CMAQ with WRF meteorological and adjusted land-use data will provide “final” dust concentrations for each grid point, i.e., after emissions, transport, and wet and dry deposition. Given the national datasets that are used to develop the modeling framework, the models that we develop are “transportable” to other locations in the US for similar types of studies. Dr. Hosein Foroutan, author of the dust emission scheme in CMAQ v5.2, is a technical advisor for this project (see attached Letter of Commitment).

Task 3.2 – Adjust and validate model with measured isotope and chemistry data

Each aspect of dust event calculations has approximations based on spatial and/or temporal resolution of available emission and transport data. These contribute to inaccuracies in the overall predictions. Given the limitations associated with data from large-scale spatial and temporal databases, e.g., WRF wind velocities and land-use data, it is appropriate to identify key factors that can be used to adjust model $PM_{2.5}$ and PM_{10} calculations to better match chemistry and isotope measurements. Such adjustments serve to validate model performance and increase confidence in the model predictive capabilities.

Key approximations associated with calculations of dust emissions include data for soil type, soil moisture, surface roughness, and land cover. The key parameters to be used for tuning dust emission calculations, in order of priority, include soil type and moisture [Mallia et al., 2017], surface roughness [Foroutan et al., 2017], and dust fineness ratio. These factors can be adjusted in the individual models that comprise the dust emissions calculations. Specifically, the CMAQ moisture correction and roughness correction that feed into the friction velocity calculations can be adjusted. This reflects corrections to the amount of dry or wet soil and the available erodible soil at dust source locations. It is unlikely that approximations associated with dust transport, i.e., wind velocities (from WRF) and deposition calculations (from CMAQ), will be adjusted.

Data from three dust events will be used to adjust the dust transport model, including two benchmark Wasatch Front events that were modeled in published studies and one event that occurs during the first year of the current program. The objective of this task is to identify major dust emission source locations and PM quantities to better match the measured trends in dust concentrations. The first case is either the March or April 2010 dust event [Mallia et al., 2017] and the second case is the April 2017 dust event [Skiles et al., 2018]. Because these events have been modeled previously, input files can be checked for consistency with those values. The third case is a dust event that occurs during the first year of the current program. For each of these cases, hourly $PM_{2.5}$ and PM_{10} data from multiple Wasatch Front air monitoring stations will be used to calibrate the model. Correlating spatial correlations between the measured PM data and the modeled results is the primary focus, followed by temporal correlations. For cases two and three, trace element chemistry and $^{87}Sr/^{86}Sr$ measurements on PM filters from at least three sample locations will be used to provide additional constraints on the model. The chemistry and isotopic measurements are strictly used for spatial correlations as the filters contain the signature of the entire (24-hr) event. It is unlikely that each of these data sets will lead to the same adjustments in the model, as dust emission and transport processes vary over time, but correlating spatial PM data and geochemical data with predictions will provide a powerful new tool for modeling dust events in northern Utah.

Task 4 – Evaluate Dust Impact Scenarios

The objective of this task is to use the adjusted dust transport model to show the impact of changes to dust emission sources on Wasatch Front $PM_{2.5}$ and PM_{10} concentrations. These "what-if" studies can include impacts of increased or decreased dry lake shore from water management strategies, conversion of farmland to industrial sites, and siting of high-dust sources in populated areas. Such studies can also show the difference between PM concentrations during normal or background meteorological conditions and concentrations during exceptional event meteorological conditions.

Three evaluation scenarios are planned. Each scenario will use meteorological and land-use data from the 2017 dust event conditions identified in Task 3 as a baseline condition. The scenarios will compare predicted $PM_{2.5}$ and PM_{10} concentrations from the validated dust event conditions with PM concentrations from the specified dust emissions scenario.

Scenario 1 – Meteorological and land-use conditions representative of "normal" (non-exceptional event) conditions from April 2017 will be used to calculate $PM_{2.5}$ and PM_{10} concentrations. Results will be compared to PM measurements from the same non-event times for validation. Results will then be compared to the predicted PM concentrations from the dust event to provide a comparison of baseline or background $PM_{2.5}$ and PM_{10} concentrations from dust emissions versus PM concentrations during exceptional dust events. These results will combine with Task 1 measurements to provide UDAQ relevant data for EPA compliance assessment.

Scenario 2 – Increased erodible shoreline around the Great Salt Lake will be simulated to assess the impact of declining water levels in the Great Salt Lake due to water policy decisions or drought impacts. The baseline 2017 dust event meteorological and land-use conditions will be modified by changing CMAQ inputs, likely by changing soil properties and/or land cover values in this area. Prof. Foroutan's expertise with CMAQ will be key to making these changes. Differences in PM concentrations along the Wasatch Front will be highlighted to show impacts of declining water level on different regions.

Scenario 3 – An additional dust emission source near the Salt Lake-Utah county line along the I-15 corridor will be simulated to assess the impact of expanding a gravel mining operation in this area. As with Scenario 2, the baseline 2017 dust event meteorological and land-use conditions will be modified by changing CMAQ inputs, likely by changing soil properties and/or land cover values in this area. Differences in PM concentrations along the Wasatch Front during a dust event with this additional source will be highlighted to show impacts on residential areas in Salt Lake and Utah valleys. These results can be used to identify regions that would be disproportionately impacted by additional emission sources.

Note if UDAQ identifies a dust emission source scenario that is of greater interest than those described here, it is possible to substitute that scenario for one of those listed here during the course of the program.

All WRF and CMAQ simulations will be run on existing high performance computing resources in Prof. Adams research lab at Brigham Young University. Resources include a 24-core Xeon Gold processor with 128 GB memory, 16TB MegaRAID hard drives, 4GB NVIDIA Quadro P1000 video card; and a 28-core Xeon Gold processor with 96 GB memory, 12TB MegaRAID hard drives, 4GB NVIDIA Quadro P1000 video card.

Task 5 – Project Management

Prof. Carling will be the point of contact for the project. Project co-PIs, Prof. Carling and Prof. Adams, will be responsible for program management. Specific management tasks to be completed include:

- Coordination of project technical tasks with external collaborators (UDAQ, Black, Fernandez, Foroutan) and research students.
- Management of project budgets and coordination with university Grants and Accounting office to ensure timely invoicing to UDAQ and payment to collaborators (where appropriate).
- Timely submission of 1-2 page Quarterly Reports for the duration of the program.
- Presentation of project results at Air Quality: Science for Solutions conference
- Submission of the Final Report with 90 days of project completion.
- Coordination of Data Sharing for project results per contract requirements.

1.4 Expected Outputs and Outcomes

By the end of this program we will provide:

- A spreadsheet with trace element chemistry for 250 PM filters from dust events, forest fires, winter inversions, and ambient conditions.
- Positive matrix factorization and nonmetric multidimensional analysis of chemistry data to determine differences in chemistry among sample types and sample locations.
- A spreadsheet with Sr isotope ($^{87}Sr/^{86}Sr$) ratios on 50 PM filters to determine dust source locations impacting the Wasatch Front over time.
- A verified dust modeling framework that is "transportable", i.e., can be modified for use beyond the Wasatch Front.
- Predicted dust-based $PM_{2.5}$ and PM_{10} concentrations under baseline and exceptional event conditions, quantifying typical background concentrations due to dust.
- Predicted "what-if" results for a decreased GSL water level and an expanded industrial dust emission source that show spatially-resolved changes in PM concentrations, including Wasatch Front regions that are most impacted by increased dust emissions.

As a note to future research, wildfires are similar to dust events in that both produce particle emissions significantly greater than background concentrations and can bias PM measurements. Wildfires in the intermountain West are expected to increase both in frequency and intensity in the future with climate change [Westerling et al., 2006; Marlon et al., 2009]. The importance of wildfires as a source of "dust" in the form of ash, and the subsequent atmospheric deposition of metals associated with that ash in downwind areas, are also likely to increase. Our modeling approach is amenable to modeling wildfires but would require different inputs for particle emissions that are not included in CMAQ. Specifically, wildfire emissions would require additional pre-processing using a tool such as SMOKE, which is beyond the scope of this program. However, our chemistry data would be useful beyond this program to investigate wildfire emissions, and could also be used to adjust model emission sources in a manner similar to that described here for the dust modeling framework.

1.5 Deliverables

The following will be the key project deliverables:

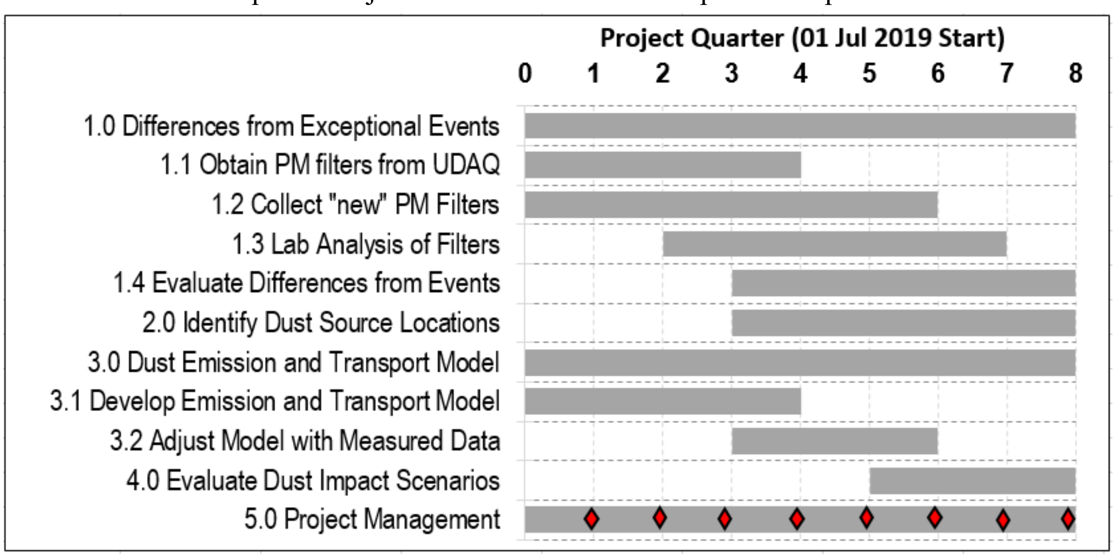
- 1-2 page quarterly reports describing the project's progress toward stated objectives.
- Project Final Report submitted within 90 days after the project completion. Report format and contents will be as outlined by the project solicitation and contract.
- Copies of slides from presentations at Air Quality: Science for Solutions conferences.
- Summary of isotope and chemical measurements from samples collected during the project. Data will be in tabular form and shared via the UDAQ website within 8 months of project completion. Measurement methodology and analysis techniques will be included in the Final Report.
- Summary of simulation results from the model adjustment/validation task. Results will be in the form of graphs, tables and color plots. The modeling approach will be described in the Final Report. Model input and output files will not be included due to their large (terabyte) size. Summaries will be shared via the UDAQ website within 8 months of the project completion.
- Summary of simulation results from the model scenarios. Results will be in the form of graphs, tables and color plots. Summaries will be shared via the UDAQ website within 8 months of the project completion.

Project managers will work with UDAQ personnel to define appropriate formats to share the measured and simulated data so they are of use to future researchers and policy makers.

1.6 Schedule

Table 1 shows the expected two-year project schedule for each of the five project tasks. The proposed project will commence July 1, 2019 and conclude June 30, 2021. Note the measurement, modeling, and management tasks will be performed in parallel. The red diamonds on the Project Management task indicate Quarterly Report milestones. The length of schedule enables more complete sampling and analysis and increases the chance to sample multiple exceptional events.

Table 1. Proposed Project Schedule. Diamonds Represent Report Milestones.



2 BUDGET

Table 2 shows the $305,733 project budget summary for the two-year program, including cost to UDAQ and significant cost-share contributed by project participants. Table 3 shows the budget breakout for each of the project tasks for the two-year program. Total UDAQ cost is $75,000 per year for two years. Cost-share is provided by donated faculty time during the fall and winter academic semesters and the reduction in university indirect rate from the normal 50% rate to the required rate of 10%.

Table 2. Proposed Project Budget Summary.

Cost Category	Year 1	Year 2	Total
Personnel	$ 54,866	$ 53,934	$ 108,800
Benefits	$ 3,911	$ 3,975	$ 7,886
Supplies	$ 1,132	$ -	$ 1,132
Lab Analyses	$ 7,000	$ 9,000	$ 16,000
Consultant	$ 2,500	$ 2,500	$ 5,000
Indirect	$ 5,591	$ 5,591	$ 11,182
UDAQ Total	$ 75,000	$ 75,000	$ 150,000
Cost-Share Total	$ 78,685	$ 77,048	$ 155,733
Program Total	$ 153,685	$ 152,048	$ 305,733

Beyond the cost-share items identified in the budget detail, additional shared contributions to the project are provided as follows:

- $PM_{2.5}$ and PM_{10} measurements and filters provided by UDAQ.
- Dust chemistry data from previous Utah DFFSL grants.
- Dust chemistry data from previous National Science Foundation grants.
- Westminster College (Dr. Frank Black) $PM_{2.5}$ and PM_{10} filter collection.
- Reduced sample analysis rate at the University of Utah laboratory (Dr. Diego Fernandez).
- Use of existing high performance computing resources at Brigham Young University.

Table 3. Detailed Project Budget and Justification.

Task Costs By Year			Year 1						Year 2			
Cost Item	Hours	$/hr	Amount	Benefits	Indirect	Total	Hours	$/hr	Amount	Benefits	Indirect	Total
Task 1 - Filter Analyses												
Carling Salary (1)	52.4	63	3,300	1,049	435	4,784	34.9	63	2,200	700	290	3,190
Carling Salary Cost-share (2)	104.8	63	6,600	3,247	4,924	14,771	69.8	63	4,400	2,165	3,282	9,847
Carling MS Student Wage	840.0	15	12,600	-	1,260	13,860	560.0	15	8,400	-	840	9,240
MS Student Tuition (3)			5,500	-	-	5,500			5,500	-	-	5,500
Supplies (4)			1,132	-	113	1,245			-	-	-	-
Lab Analyses (5)			7,000	-	700	7,700			9,000	-	900	9,900
Task 2 - Source Locations												
Carling Salary	15.9	63	1,000	318	132	1,450	36.5	63	2,300	731	303	3,335
Carling Salary Cost-share	31.7	63	2,000	984	1,492	4,476	73.0	63	4,600	2,263	3,432	10,295
Carling MS Student Wage	153.3	15	2,300	-	230	2,530	346.7	15	5,200	-	520	5,720
Task 3 - Model Development												
Adams Salary (1)	86.3	80	6,900	2,194	909	10,004	31.3	80	2,500	795	330	3,625
Adams Salary Cost-share (2)	152.5	80	12,200	6,002	9,101	27,304	55.0	80	4,400	2,165	3,282	9,847
Adams MS Student Wage	1,067	15	16,000	-	1,600	17,600	400.0	15	6,000	-	600	6,600
MS Student Tuition (3)			5,500	-	-	5,500			5,500	-	-	5,500
Consultant - Foroutan	40	62.5	2,500	-	-	2,500	-	62.5	-	-	-	-
Task 4 - Event Scenarios												
Adams Salary	-	80	-	-	-	-	55.0	80	4,400	1,399	580	6,379
Adams Salary Cost-share	-	80	-	-	-	-	97.5	80	7,800	3,838	5,819	17,456
Adams MS Student Wage	-	15	-	-	-	-	666.7	15	10,000	-	1,000	11,000
Consultant - Foroutan	-	62.5	-	-	-	-	40	62.5	2,500	-	-	2,500
Task 5 - Management												
Carling Salary	17.5	63	1,100	350	145	1,595	17.5	63	1,100	350	145	1,595
Carling Salary Cost-share	34.9	63	2,200	1,082	1,641	4,924	34.9	63	2,200	1,082	1,641	4,924
Carling MS Student Wage	44.4	15	666	-	67	733	55.6	15	834	-	83	917
Adams Salary Cost-share	20.0	80	1,600	787	1,194	3,581	20.0	80	1,600	787	1,194	3,581
Sub-Totals			$90,098	$16,015	$23,943	$130,055			$90,434	$16,275	$24,241	$130,950
Add'l University Cost-share (6)						$ 23,630						$ 21,098
Total Project Cost			$90,098	$16,015	$23,943	$153,685			$90,434	$16,275	$24,241	$152,048

Cost Detail

1) Summer salary has benefit rate of 31.8%
2) Winter salary (cost-share) has benefit rate of 49.2%
3) Graduate tuition based on 6 credit hrs for fall and winter semesters, 3 credit hrs (thesis research) for summer
4) Supplies costs are for ~150 pollution sample filters
5) Analyses of samples: 150 trace element analyses at $69/each + 75 isotope analyses at $75.33/each
6) Based on difference between standard university indirect rate of 50% and required rate of 10%

Indirect rate is 10% on all items except tuition and external consultant (pass through)

3 PERSONNEL ROLES AND RESPONSIBILITIES

Dr. Greg Carling (co-PI), Associate Professor of Geological Sciences at Brigham Young University, has ten years of experience investigating dust geochemistry in the Wasatch Front. He has published two peer-reviewed papers on dust in Wasatch snowpack (#3 and #17 on CV) and has obtained multiple grants from NSF and Utah DFFSL to investigate dust chemistry and transport processes. He has served as the primary advisor for ten geology M.S. students who each investigated water or dust chemistry in Utah. Dr. Carling will oversee the research of his graduate student and coordinate gathering of existing $PM_{2.5}$ and PM_{10} samples from UDAQ. His graduate student will primarily focus on collecting "new" filter samples in Provo and coordinating sample collection in Salt Lake City. The student will perform laboratory analyses on the filter samples, compare sample collection dates with weather conditions, and collect all publicly-available air quality data for the sampling dates. Dr. Carling will be the point of contact for the project.

Dr. Bradley Adams (co-PI), Associate Professor of Mechanical Engineering at Brigham Young University, will coordinate the research of his graduate student and Dr. Foroutan and will conduct research into modification of the CMAQ input files to model prescribed future dust emissions. His graduate student will have primary responsibility for formatting code inputs using various databases, running WRF and CMAQ codes, and post-processing results. Although Dr. Adams is relatively new to the health impacts field, he has over 25 years of experience developing and applying modeling tools to predict air pollutant formation and assess different control technologies. He has managed over $8M in R&D programs for the US Department of Defense, Department of Energy, and EPA. Dr. Adams joined the BYU faculty in 2015 after 30 years in industry.

Dr. Frank Black, Associate Professor of Chemistry at Westminster College, is an expert on chemical measurements of environmental samples with multiple years of experience with field studies in northern Utah. He will oversee $PM_{2.5}$ and PM_{10} sample collection at Salt Lake City.

Dr. Diego Fernandez, Research Associate Professor at the University of Utah, is an expert on ICP-MS and multicollector ICP-MS analyses and sample preparation. He will work with Dr. Carling's graduate student to analyze PM filters for trace element chemistry and $^{87}Sr/^{86}Sr$ ratios.

Dr. Hosein Foroutan, Assistant Professor of Biomedical Engineering and Mechanics at Virginia Tech University, is a project consultant and lead developer of the dust emissions section of the CMAQ code. He will provide support for operating CMAQ and modifying input files (e.g., soil properties) for new dust emission scenarios.

Note Letters of Commitment from Drs. Black, Fernandez, and Foroutan and CVs for Drs. Carling, Adams, and Foroutoan are included in the appendix.

4 REFERENCES

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Appendix I. Letters of Commitment

1840 South 1300 East
Salt Lake City, Utah 84105
www.westminstercollege.edu

Utah Division of Air Quality Science for Solutions Research Grant – FY 2020

UDAQ proposal review panel

Dear review panel,

I am writing in support of the proposal titled "Characterizing air quality impacts from exceptional events along the Wasatch Front" by Dr. Greg Carling and Dr. Brad Adams from Brigham Young University. The proposed research would provide important insights into the spatial and temporal variability of aspects of air quality along the Wasatch Front that have not been studied extensively previously, while also helping to elucidate the sources of atmospheric particles and pollutants along the Wasatch Front and their potential impacts on human health in the area. I look forward to collaborating with Dr. Greg Carling and Dr. Brad Adams on this project, and to using our facilities and expertise in this research area to contribute to this important research

Sincerely,

Dr. Frank Black
Associate Professor of Chemistry
Westminster College

Diego P. Fernandez, Research Associate Professor
Department of Geology and Geophysics – College of Mines and Earth Sciences

115 South 1460 East - FASB 383, Salt Lake City, UT 84112 P (801) 587-9366 F (801) 581-7250
www.earth.utah.edu/people/faculty/fernandez diego.fernandez@utah.edu

Salt Lake City, January 3rd 2019

Utah Division of Air Quality Science for Solutions Research Grant – FY 2020
UDAQ proposal review panel

Dear review panel,

I am writing in support of the proposal titled "Characterizing air quality impacts from exceptional events along the Wasatch Front" by Dr. Greg Carling and Dr. Brad Adams from Brigham Young University. My lab has analyzed PM2.5, PM10, dust and sediments for trace elements and heavy isotopes using various leaching procedures for a number of projects. The budget requested is appropriate to do a two-step sequential leaching procedure that may be useful to untangle playa versus fuel-burning sources. I am excited to help in this project providing student training opportunities and novel method development in order to advance the understanding of atmospheric aerosols in out region.

Sincerely,

Dr. Diego P. Fernandez
Research Associate Professor
Dept. Geology and Geophysics
University of Utah

Dr. Bradley Adams
Brigham Young University
360-I EB
Provo, UT 84602

December 20, 2018

RE: Support for Utah Division of Air Quality Proposal

Dr. Adams,

I am pleased to participate in the collaborative research proposal with Brigham Young University entitled *Characterizing Air Quality Impacts from Exceptional Dust Events Along the Wasatch Front*, which is being submitted to the Utah Division of Air Quality. This letter confirms that if the project is selected and funded I will provide technical support on the project for dust modeling with the CMAQ chemical transport model.

CMAQ is the premier modeling tool used by the U.S. EPA for conducting air quality model simulations. It is capable of predicting dust emissions and transport based on meteorological data, soil properties, and land cover data. I have done significant research and development in the area of dust modeling, culminating with the implementation of the dust emission model in the current version of the CMAQ. This expertise will be valuable to project researchers in their efforts to develop dust models for their region.

I understand that I will be compensated for services rendered up to $5,000 over the two-year program period. My billing rate will be $62.50/hour.

If you have any questions, please feel free to contact me at (540) 232-8400 or at hosein@vt.edu.

Sincerely,

H. Foroutan

Hosein Foroutan, PhD

Appendix II. CVs

Gregory T. Carling

Associate Professor
Dept. of Geological Sciences, Brigham Young University
Provo, UT 84602 (801) 422-2622
greg.carling@byu.edu

Academic History

2018-	Associate Professor, Geological Sciences, Brigham Young University
2012-18	Assistant Professor, Geological Sciences, Brigham Young University
2012	Ph.D., Geology, University of Utah Trace element cycling in Great Salt Lake wetlands, Wasatch snowpack, and mining-impacted rivers of southern Ecuador. Advisor: W.P. Johnson
2007	M.S., Geology, Brigham Young University The rate and timing of direct mountain front recharge in an arid environment, Silver Island Mountains, Utah. Advisor: A.L. Mayo
2005	B.S., Geology, Brigham Young University
2001	A.S., General Studies, Adams State College

Peer-Reviewed Publications

18) *Smith, K. M**.**, McBride, J. H., Nelson, S. T., Keach, R. W., II, Hudson, S., Tingey, D. G., Key, K., and **Carling, G.T.**, 2019, An Integrated High-Resolution Geophysical and Geological Visualization of a Lake Bonneville Shoreline Deposit (Utah, USA), *Interpretation*, in press.

17) *Dastrup, D.B., **Carling, G.T.**, Collins, S.A., Nelson, S.T., Fernandez, D.P., Tingey, D.G., Hahnenberger, M., Aanderud, Z.T., 2018. Aeolian dust chemistry and bacterial communities in snow are unique to airshed locations across northern Utah, USA. *Atmospheric Environment* 193:251-261.

16) *Selck, B.J., **Carling, G.T.**, Kirby, S.M., Hansen, N.C., Bickmore, B.R., Tingey, D.G., Rey, K., Wallace, J., Jordan, J.L., 2018. Investigating anthropogenic and geogenic sources of groundwater contamination in a semi-arid alluvial basin, Goshen Valley, Utah, USA. *Water, Air, and Soil Pollution* 229:186.

15) Spackman Jones, A., Aanderud, Z.T., Horsburgh, J.S., Eiriksson, D.E., Dastrup, D., Cox, C., Jones, S.B., Bowling, D.R., Carlisle, J., **Carling, G.T.**, Baker, M.A., 2017. Designing and implementing a network for sensing water quality and hydrology across mountain to urban transitions. *Journal of the American Water Resources Association (JAWRA)* 53:1095-1120.

14) **Carling, G.T.**, Rupper, S.B., Fernandez, D.P., Tingey D.G., *Harrison, C.B., 2017. Effect of atmospheric deposition and weathering on trace element concentrations in glacial meltwater at Grand Teton National Park, Wyoming, USA. *Arctic, Antarctic, and Alpine Research* 49:427-440.

13) *Goodsell, T.H., **Carling, G.T.**, Aanderud, Z.T., Nelson, S.T., Fernandez, D.P., Tingey, D.G., 2017. Thermal groundwater contributions of arsenic and other trace elements to the middle Provo River, Utah, USA. *Environmental Earth Sciences* 76:268.

12) South, J.V., McBride, J.H., **Carling, G.T.**, Mayo, A.L., Tingey, D.G., Rey, K.A., Nelson, S.T., 2016. Imaging the margins of Pleistocene lake deposits with high-resolution seismic reflection in the eastern Basin and Range: Pilot Valley, Utah (USA), p. 526-548, in *Lake Bonneville: A scientific update*, J. Oviatt, J.F. Schoder, Jr. (eds).

11) Rihosek, J., Bruthans, J., Masin, D., Filippi, M., **Carling, G.T.**, Schweigstillova, J., 2016. Gravity-induced stress as a factor reducing decay of sandstone monuments in Petra, Jordan. *Journal of Cultural Heritage* 19:415-425.

10) **Carling, G.T.**, Tingey, D.G., Fernandez, D.P., Nelson, S.T., Aanderud, Z.T., *Goodsell, T.G., *Chapman, T.R., 2015. Evaluating natural and anthropogenic trace element inputs along an alpine to urban gradient in the Provo River, Utah, USA. *Applied Geochemistry* 63:398-412.

9) **Carling, G.T.**, Radebaugh, J., Saito, T., Lorenz, R., Dangerfield, A., Tingey, D.G., Keith, J.D., South, J.V., Lopes, R.M., Diniega, S., 2015. Temperatures, thermal structure, and behavior of eruptions at Kilauea and Erta Ale volcanoes using a consumer digital camcorder. *GeoResJ* 5:47-56.

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7) Naftz, D.L., **Carling, G.T.**, Angeroth, C., Freeman, M., Rowland, R., Pazmiño, E., 2014. Density-stratified flow events in Great Salt Lake, Utah, USA: Implications for mercury and salinity cycling. *Aquatic Geochemistry* 20:547-571.

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5) **Carling, G.T.**, Diaz, X., Ponce, M., Perez, L., Nasimba, L., Pazmino, E., Rudd, A., Fernandez, D.P., and W.P. Johnson, 2013. Particulate and dissolved trace element concentrations in three southern Ecuador rivers impacted by artisanal gold mining. *Water, Air, and Soil Pollution* 224:1415.

4) **Carling, G.T.**, Richards, D., Hoven, H., Miller, T., Fernandez, D.P., Rudd, A., Pazmino, E., and W.P. Johnson, 2013. Relationships of surface water, pore water, and sediment chemistry in wetlands adjacent to Great Salt Lake, Utah, and potential impacts on plant community health. *Science of the Total Environment* 443:798-811.

3) **Carling, G.T.**, Fernandez, D.P., and W.P. Johnson, 2012. Dust-mediated loading of trace and major elements to Wasatch Mountain snowpack. *Science of the Total Environment* 432:65-77.

2) **Carling, G.T.**, Mayo, A.L., Tingey, D.G., and J. Bruthans, 2012. Mechanisms, timing, and rates of arid region mountain front recharge. *Journal of Hydrology* 428-429:15-31.

1) **Carling, G.T.**, Fernandez, D.P., Rudd, A., Pazmino, E., and W.P. Johnson, 2011. Trace element diel variations and particulate pulses in perimeter freshwater wetlands of Great Salt Lake, Utah. *Chemical Geology* 283:87-98.

Publications in Progress

1. **Carling, G.T.**, Jin, L., Fernandez, D.P., Tingey, D.G., Romanowicz, E., *Goodsell, T.G. Trace elements dynamics in surface water and shallow groundwater at Red Canyon, Wyoming, USA. In prep.
2. *Randall, M.C., **Carling, G.T.**, Dastrup, D.B., Miller, T., Nelson, S.T., Rey, K., Hansen, N., Bickmore, B.R., Aanderud, Z.T. Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake. Submitted to *PLOS ONE*.
3. Munroe, J.S., Norris, E., Carling, G.T., Beard, B., Satkoski, A., Ji, J. Sr and Nd isotope fingerprinting of modern eolian dust in the alpine zone of the Uinta Mountains, Utah, USA. Submitted to *Aeolian Research*.

* *indicates student author*

Research Funding

Awarded Funding – Principal Investigator (External Grants)

5/2018-19 South Davis Sewer District, $30,300, "Characterizing nutrient fluxes and Fe-P dynamics in Utah Lake sediment"

7/2017-18 State of Utah DFFSL, $29,770, "Understanding environmental impacts of Great Salt Lake dust: Using isotopic "fingerprints" to determine dust sources and quantifying changes in trace metal concentrations from source to deposition"

7/2015-18 NSF Hydrologic Sciences, $269,796 ($338,324 including U of U), "Collaborative Research: Investigation of the fate and transport of dust-borne trace metals and solutes during snowmelt"

7/2016-17 Provo City Water Resources, $5,760, "Literature review of arsenic geochemistry and remediation options in groundwater"

8/2015-17 South Davis Sewer District, $56,638, "Characterizing phosphorus mineralogy, chemistry, and speciation in Utah Lake sediments"

7/2015-16 State of Utah DFFSL, $39,717, "Characterizing harmful effects of dust emissions from the dry lakebed of Great Salt Lake relative to other regional dust sources"

5/2015-16 NSF EPSCoR iUTAH Traineeship award, $16,140, "Assessing urban stormwater quantity and quality in Heber City"

9/2014-15 Utah Geological Survey, $24,472, "Groundwater resources in Goshen Valley, Utah: Assessing water quality impacts from agriculture, legacy mining, playa soils, septic tanks, and geothermal waters"

4/2013-14 UW/NPS Research Center, $5,000, "Melting glaciers: A source of mercury and other trace elements to high elevation ecosystems in Grand Teton National Park?"

Total value of external funding: $477,567

Awarded Funding – Principal Investigator (Internal Grants)

8/2018-20 Graduate Mentoring Assistantship, $13,125, "Water quality downstream of the world's largest hyperacidic lake, Kawa Ijen volcano, Indonesia"

1/2017-19 BYU Mentoring Environment Grant, $20,000, "Characterizing nutrient fluxes from sediment to the water column in Utah Lake"

11/2014-15 CPMS High Impact Teaching Stipend, $3,900, "Redesigning Geology 435 (Groundwater) to utilize online hydrologic data sources and state-of-the-art software programs"

1/2014-15 BYU Mentoring Environment Grant, $20,000, "Melting glaciers as a source of mercury and other trace metals to high elevation ecosystems in the Wind River Range, Wyoming"

Total value of internal funding: $57,025

Student Advising

Graduate Students

Sheena Smithson—advisor—M.S. Geology expected 2020.

Natalie Barkdull—advisor—M.S. Geology expected 2019. Thesis titled: "Impact of glaciers on water chemistry and discharge in Dinwoody Creek, Wyoming"

Michael Goodman—advisor—M.S. Geology expected 2019. Thesis titled: "Using isotopic fingerprints to determine dust sources for the Wasatch Front"

Colin Hale—advisor—M.S. Geology, August 2018. Thesis titled: "Using isotopic tracers to determine the effects of dust on water quality"

Brian Packer—advisor—M.S. Geology, August 2018. Thesis titled: "Mercury concentrations in the Provo River during snowmelt"

Hannah Checketts—advisor—M.S. Geology, August 2018. Thesis titled: "Trace metal transport in the Provo River during snowmelt". Currently employed full-time as a geologist with Anderson Engineering, Saratoga Springs, UT.

Matt Randall—advisor—M.S. Geology, August 2017. Thesis titled: "Characterizing phosphorus chemistry and mineralogy in Utah Lake". Currently employed full time as a geologist for PBS Engineering and Environmental Inc. in Portland.

Dylan Dastrup—advisor—M.S. Geology, December 2016. Thesis titled: "Impact of aeolian dust on water quality in mountain streams". Employed full-time at BYU as a hydrological technician for iUTAH after graduation. Currently employed as a hydrologist with CUWCD in Duchesne, UT.

Brian Selck—advisor—M.S. Geology, December 2016. Thesis titled: "Arsenic distribution and sources in surface water of Goshen Valley, Utah". Employed full time with Provo City Water Resources after graduation. Currently employed at ECS Mid-Atlantic as a project hydrogeologist in Charlottesville, VA.

Timothy Goodsell—advisor—M.S. Geology, April 2016. Thesis titled: "Effects of urban and agricultural runoff in the middle Provo River, Utah". Currently employed full-time as a geologist for Environmental Resources Management in New Orleans.

Committee member for Erin Jones (Ph.D. Plant & Wildlife Sciences 2014-), Ben Godwin (M.S. Geology 2016-), Joel Barker (M.S. Geology 2016-), Kerri Russell (M.S. Plant & Wildlife Sciences 2016-18), Katelynn Smith (M.S. Geology 2016-18), Sam Hillam (M.S. Geology 2014-17), Michelle Meadows (M.S. Geography at U. of Utah 2015-16), Riley Rackliffe (M.S. Biology 2013-14), McLean Carpenter (M.S. Geology 2013-14)

Courses Taught

Introduction to Geology	Geol 101	Winter 2014, 2015, 2017, 2018
Geological Communications	Geol 230	Fall 2013-2017
Geological Field Methods	Geol 420	Spring 2013-2018
Groundwater	Geol 435	Fall 2012-2018
Contaminant Hydrogeology	Geol 535	Winter 2014, 2017
Advanced Hydrogeology	Geol 635	Winter 2013, 2018
Advanced Hydrogeochemistry	Geol 636	Winter 2015

External Leadership/Service

- Academic Editor for PLOS ONE (since 2017)
- Member of Utah Lake Science Panel (since 2018). Involves monthly meetings or phone calls. Some meetings last multiple days.
- Peer reviewer for JGR-Biogeochemistry (2018x2), Journal of Hydrometeorology (2018), Journal of Geochemical Exploration (2017), Environmental Research Letters (2017), Geosciences (2017), Catena (2017), Geochimica et Cosmica Acta (2017), North American Symposium on Landslides (2017), Toxics (2017x2), Sustainability (2017), Euro-Mediterranean Journal for Environmental Integration (2016), Scientific Reports-Nature (2016), Water (2016x2), Chemosphere (2016,2015), PLOS ONE (2016, 2015x2), IJERPH (2017,2015), Science of the Total Environment (2015x2), Atmospheric Environment (2015, 2014), Applied Geochemistry (2015), Journal of Hydrology (2015, 2013x2), Geosciences (2017,2015), Limnology and Oceanography (2014), Journal of Arid Land (2014), Elementa (2014), Resources (2014), Journal of Applied Remote Sensing (2013)
- Ad hoc reviewer for NSF EAR Postdoctoral Fellowship (2018,2014), NSF Geomorphology and Land Use Dynamics (2015), RCSA Cottrell College Science Award (2013).
- Co-authored op-ed on Utah Lake in the Deseret News: https://www.deseretnews.com/article/900012461/op-ed-the-present-future-and-past-of-utah-lake.html
- Participation in local and state water quality meetings (since fall 2015):
    - Nov 10, 2015—Utah Lake planning meeting with Utah DWQ
    - Feb 4, 2016—meeting with Provo City drinking water engineers
    - Mar 23, 2016—meeting with Provo City drinking water engineers
    - Apr 25, 2016—Provo River Watershed Council meeting
    - May 12-13, 2016—GSL Issues Forum sponsored, Friends of Great Salt Lake
    - May 24, 2016—Utah Lake/Provo River meeting with Utah DWQ
    - Jun 28, 2016—field trip with Provo River Watershed Users Association including a stop and lecture at Soapstone research site
    - Jul 15, 2016—iUTAH Annual Symposium and stakeholder meeting
    - Jul 19, 2016—public hearing on 2016 Utah DWQ integrated report
    - Aug 23, 2016—meeting with Provo City drinking water engineers
    - Sep 6, 2016—Provo City council work meeting regarding sewage treatment plant discussion
    - Nov 4, 2016—iUTAH all hands meeting
    - Nov 16, 2016—Salt Lake County Watershed Symposium
    - Dec 5, 2016—meeting with Provo City drinking water engineers

- Jan 10, 2017—Provo River Watershed Council meeting
    - Mar 14, 2017—Great Salt Lake Technical Team meeting
    - Mar 30, 2017—Utah Lake Education Half-Day meeting
    - Mar 31, 2017—iUTAH Broader Impacts Forum
    - May 23, 2017—Utah Lake Summit
    - Jul 13-14, 2017—iUTAH Annual Symposium
    - Sep 13, 2017—Utah Lake field trip with state legislators
    - Nov 15, 2017—Salt Lake County Watershed Symposium
    - Jan 4, 2018—Utah Lake steering committee meeting
    - Feb 15, 2018—Utah Lake commission meeting
    - Feb 27, 2018—Meet with Sandy Wingert, DWQ
    - May 9-10, 2018—Great Salt Lake Issues Forum
    - May 30-31, 2018—Utah Lake science panel meeting
    - Nov 14, 2018—Salt Lake County Watershed Symposium
- Hosted iUTAH undergraduate research iFellows from Salt Lake Community College and BYU during summers of 2015—2017. Kyle Ahn investigated mercury concentrations in Utah Lake water and sediments. Greta Hamilton investigated water chemistry in the Provo River during snowmelt runoff. Andrew Luymes investigated soil composition in the Provo River watershed.
- iUTAH Summer Institute 2015 field trip in Heber Valley, led inquiry-based project "Hot and Heavy Metals" to investigate water chemistry in hot springs for over 30 K-12 teachers, high school and undergraduate students
- Session chair at International Conference on Atmospheric Dust, Italy, 6-13-2016. Session titled: "Interdisciplinary study of dust in mountain environments".
- Session chair at Geological Society of America annual meeting in Vancouver, British Columbia, 10-20-2014. Session titled: "Hydrogeology of arid region endorheic basins: groundwater flow, geochemical evolution, and hydrostratigraphy".
- Professional affiliations: American Geophysical Union (AGU), Geological Society of America (GSA)
- Campus representative for Geological Society of America
- Judge for outstanding student presentation award, AGU Fall Meeting 2013, 2017, 2018
- K-12 outreach: Gave a tour of geology laboratories to two Webelos Scout groups during summer 2016. Science fair judge 2008-2012 (Salt Lake City School District) and 2013, 2016, 2018 (Central Utah Regionals). Presented talk entitled "Groundwater Contamination" at Lakeridge Junior High Sustainability Conference during October 2012.
- Organized dust interest workgroup at University of Utah that involved students and faculty from Geology & Geophysics, Atmospheric Sciences, Biology, and Geography. Bi-weekly meetings were held during February, March, and April 2012
- Participated in collaboration through Great Salt Lake Institute to engage undergraduate students from Westminster College in cutting-edge research at the University of Utah. Involved two Westminster students in mercury research, including field and laboratory work (https://www.westminstercollege.edu/pdf/great_salt_lake_institute/April_2010_Newsletter.pdf)

Invited Lectures and Seminars

Invited speaker, iUTAH Annual Symposium, 7-13-2017, "From PhD to tenure track: becoming a leader in hydrology through iUTAH experiences"

Invited speaker, Utah Lake Summit meeting, 5-23-2017, "Phosphorus in Utah Lake sediments"

Invited speaker, Intermountain Section AWWA 2017 Midyear Conference, 4-5-2017, "Trace metals in the upper Provo River watershed"

Invited speaker, Utah Lake Half Day Education meeting, 3-30-2017, "Phosphorus in Utah Lake sediments"

Guest lecture, Geochemistry class (B. Bickmore), BYU, 3-27 and 3-29-2017

Invited speaker, Great Salt Lake Technical Team meeting, 3-14-2017, "Differentiating Great Salt Lake dust from other regional sources"

Invited speaker, Utah Geological Association monthly luncheon meeting, 3-13-2017, "Trace element and nutrient cycling in northern Utah: windblown dust, snowmelt runoff, and harmful algal blooms"

Invited speaker, Great Salt Lake Technical Team meeting, 7-1-2015, "Characterizing harmful effects of dust emissions from the dry lakebed of Great Salt Lake relative to other regional dust sources"

Seminar, Dept. of Geological Sciences, BYU, 2-12-2015, "Trace element cycling from mountain snowpack to streams and wetlands"

Invited speaker, Utah Geological Association monthly luncheon meeting, 12-10-2012, "Trace elements and nutrients in Great Salt Lake wetlands: Is past accumulation more important than current loading?"

Seminar, Earth Science Dept., Utah Valley Univ., 10-30-2012, "Trace elements and nutrients in Great Salt Lake wetlands: Is past accumulation more important than current loading?"

Seminar, Dept. of Geological Sciences, BYU, 2-23-2012, "Using hydrogeochemistry to explore practical problems in the Great Salt Lake watershed and beyond"

Guest lecture, Aqueous geochemistry class (W.P. Johnson), U. of Utah, 11-9-2011

Guest lecture, Geophysics class (J. Radebaugh), BYU, 3-31-2008

Media Interviews

March 2017. Interview with Fox 13 news about dust issues in Great Salt Lake. http://fox13now.com/2017/03/25/dusty-conditions-at-great-salt-lake-could-impact-air-water-quality-along-wasatch-front/.

March 2017. Follow-up interview with Leia Larsen from Standard Examiner (Ogden, Utah) about dust issues in Great Salt Lake. http://www.standard.net/Environment/2017/03/22/Dust-study-provides-clues-about-air-pollution-coming-from-dry-Great-Salt-Lake.html.

August 2016. Graduate student Matt Randall interview with KSL 5 news about nutrients in Utah Lake. http://live.ksl.com/?_v=4328/#/v/4328?_k=1dgdl9.

October 2015. Interview with Leia Larsen from Standard Examiner (Ogden, Utah) about dust issues in Great Salt Lake. http://www.standard.net/Environment/2015/10/11/As-Great-Salt-Lake-dries-up-Utah-air-quality-concerns-blow-in.html.

Conference Presentations

Carling, G.T., Hale, C., Nelson, S., Aanderud, Z., Fernandez, D., Brooks, P., 2018. Using $^{87}Sr/^{86}Sr$ ratios to investigate flow pathways during snowmelt runoff in an alpine catchment, upper Provo River, Utah, USA. Abstract H53H-1694, AGU Fall Meeting, Washington, DC.

Carling, G.T., Randall, M., Nelson, S., Aanderud, Z., Miller, T., 2018. Phosphorus mobility in legacy sediments of shallow, eutrophic Utah Lake. Geological Society of America Abstracts with Programs 50(6), Indianapolis, IN.

Carling, G.T., Randall, M., Nelson, S., Rey, K., Hansen, N., Bickmore, B., Miller, T., 2017. Characterizing the fate and mobility of phosphorus in Utah Lake sediments. Abstract B53G-07, AGU Fall Meeting, New Orleans, LA.

Carling, G.T., Selck, B.J., Kirby, S., Hansen, N.C., Bickmore, B.R., Rey, K.A., Tingey, D.G., Wallace, J., and Jordan, J.L., 2017. Natural and anthropogenic sources of arsenic and nitrate in a semi-arid alluvial basin; Goshen Valley, Utah, USA. Geological Society of America Abstracts with Programs 49(6), Seattle, WA.

Carling, G.T., Fernandez, D.G., Nelson, S.T., Aanderud, Z.T., Tingey, D.G., Checketts, H.N., and Dastrup, D.B., 2016. Investigating transport of dust-borne trace elements from snowpack to snowmelt runoff in the Provo River, Utah. Geological Society of America Abstracts with Programs 48(7), Denver, CO.

Carling, G.T., Dastrup, D.B., Fernandez, D.G., Aanderud, Z.T., Nelson, S.T., and Tingey, D.G., 2016. Geochemistry and mineralogy of mountain dust in Utah and Nevada, USA. Scientific Research Abstracts vol. 5 p. 30, International Conference on Atmospheric Dust, Castellaneta Marina, Italy.

Carling, G.T., Dastrup, D.B., Fernandez, D.G., Tingey, D.G., Aanderud, Z.T., Nelson, S.T., 2015. Fate and transport of dust-borne trace metals during snowmelt runoff in the Provo River, Utah. Abstract A33L-0363, AGU Fall Meeting, San Francisco, CA.

Carling, G.T., Johnson, W.P., Richards, D.C., Miller, T.G., Hoven, H., Fernandez, D.P., 2015. Trace metals in Great Salt Lake wetlands and potential impacts on plant community health. SETAC North America 36th Annual Meeting, Salt Lake City, UT.

Carling, G.T., Dastrup, D.B., Tingey, D.G., Fernandez, D.P., Nelson, S.T., Aanderud, Z.T., 2015. $^{87}Sr/^{86}Sr$ as a tracer of aeolian dust from snowpack to snowmelt runoff Goldschmidt Abstracts 467, Prague, Czech Republic.

Carling, G.T., Tingey, D.G., Fernandez, D.P., Packer, B.N., and Selck, B.J., 2015. Trace metals in glacial meltwater and proglacial streams at Grand Teton National Park, Wyoming: Contributions from atmospheric deposition and other sources. Geological Society of America Abstracts with Programs 47(4), Anchorage, AK.

Carling, G.T., Fernandez, D.P., and Tingey, D.G., 2014. Trace elements in glacial meltwater at Grand Teton National Park, Wyoming: Contributions from atmospheric deposition and other sources. Abstract H13K-1236, AGU Fall Meeting, San Francisco, CA.

Carling, G.T., Jin, L., Fernandez, D.P., Romanowicz, E.A., Tingey, D.G., Fernandez, D.P., and Goodsell, T.H., 2014. Trace element dynamics in surface water and shallow groundwater at Red Canyon, Wyoming. Geological Society of America Abstracts with Programs 46(6), Vancouver, British Columbia.

Robertson, P., Kerswell, B., Walther, S., Wang, W., **Carling, G.T.**, Rey, K., and Nelson,

S.T., 2014. Investigating human impact on the Jordan River using sedimentary and stable isotopic records. Geological Society of America Abstracts with Programs 46(6), Vancouver, Canada.

Radebaugh, J., **Carling, G.T.**, Saito, T., Dangerfield, A., Tingey, D., Lorenz, R.M.C., Lopes, R., Howell, R., Diniega, S., Turtle, E.P., 2014. Temperature and structure of active eruptions from a handheld camcorder. American Astronomical Society, DPS meeting 46, 411.06, Tucson, AZ.

Carling, G.T., Jin, L., Fernandez, D.P., Romanowicz, E.A., 2013. Influence of groundwater-surface water interactions on trace element concentrations in a semiarid mountain catchment (Red Canyon, Wyoming). Abstract H33F-1447, AGU Fall Meeting, San Francisco, CA.

Carling, G.T., Tingey, D.G., Fernandez, D.P., Nelson, S.T., Johansen, W.J., and Goodsell, T.H., 2013. Trace element concentrations and isotopic trends along a mountain to urban transition in the Provo River, Utah. Geological Society of America Abstracts with Programs 45(7), Denver, CO.

Carling, G.T., Johnson, W.P., Miller, T., Hoven, H., 2011. Surface water, pore water, and sediment chemistry of wetlands adjacent to Great Salt Lake. Water Environment Association of Utah (WEAU) Mid-year Conference, West Valley City, Utah.

Carling, G.T., 2010. Trace element particulate pulse and diel (24-hr) variations in a wetland adjacent to Great Salt Lake. Great Salt Lake Issues Forum, Salt Lake City, Utah.

Carling, G.T., Johnson, W.P., Naftz, D.L., 2009. Diel variations in particulate Hg and other trace elements in a temperate wetland adjacent to Farmington Bay, Great Salt Lake, Utah. Geological Society of America Abstracts with Programs 41(7), Portland, OR.

Rudd, A., Johnson, W.P., Fernandez, D.P., **Carling, G.T.**, Naftz, D., 2009. Spatial variation of mercury methylation potential in sediments and overlying water column in Farmington Bay of Great Salt Lake. Geological Society of America Abstracts with Programs 41(7), Portland, OR.

Naftz, D.L., Krabbenhoft, D.P., Cederberg, J.R., Beisner, K.R., **Carling, G.T.**, 2009. Diurnal trends in methyl mercury concentration in a wetland adjacent to Great Salt Lake, Utah, USA. Geological Society of America Abstracts with Programs 41(7), Portland, OR.

Carling, G.T., Johnson, W.P., Naftz, D.L., 2008. Diel variations in particulate Hg and other trace metals in a temperate wetland adjacent to Farmington Bay, Great Salt Lake, Utah. 237th American Chemical Society National Meeting and Exposition, Abstract GEOC 125, Salt Lake City, UT.

Mayo, A.L., **Carling, G.T.**, Tingey, D. 2008. The rate and timing of direct mountain front recharge in an arid environment. 33rd International Geological Congress, Oslo, Norway.

Carling, G.T., Mayo, A., Tingey, D., 2007. Quantifying recharge in an arid environment: Pilot Valley, UT-NV. Geological Society of America Abstracts with Programs 39(5), St. George, UT.

Carling, G.T., Saito, T., Dangerfield, A., Radebaugh, J., Tingey, D., Keith, J., South, J., 2007. Measuring lava eruption temperatures with a digital camcorder at Kilauea volcano, Hawaii, USA. European Geosciences Union Geophysical Research Abstracts 9:09039, Vienna, Austria.

Dangerfield, A., Radebaugh, J., **Carling, G.T.**, Tingey, D., Keith, J., South, J., 2007. Accuracy of MODIS on Kilauea eruption temperatures. European Geosciences Union Geophysical Research Abstracts 9:05099, Vienna, Austria.

Student Presentations

Barkdull, N., **Carling, G.T.**, 2018. Impacts of glacier meltwater on water chemistry and discharge in Dinwoody Creek, Wind River Range, Wyoming, USA. Abstract C43C-1806, AGU Fall Meeting, Washington, DC.

Misuraca, T., **Carling, G.T.**, 2018. Phosphorus in legacy sediments of shallow, eutrophic Utah Lake. Abstract H53N-1773, AGU Fall Meeting, Washington, DC.

Taylor, T., **Carling, G.T.**, 2018. Dust composition in the urban Wasatch Front, Utah, and comparison with nearby desert playas. Geological Society of America Abstracts with Programs 50(6), Indianapolis, IN.

Cordner, C., **Carling, G.T.**, 2018. Concentration-discharge relationships reveal trends in geogenic contaminant input to the upper Provo River, Utah, USA. Geological Society of America Abstracts with Programs 50(6), Indianapolis, IN.

Barkdull, N., **Carling, G.T.**, 2018. Mercury contamination in four Indonesian watersheds affected by small-scale artisanal gold mining. BYU CPMS Student Research Conference.

Bentz, A., **Carling, G.T.**, 2018. Tracing dust deposition along the Wasatch Front. BYU CPMS Student Research Conference.

Cordner, C., **Carling, G.T.**, 2018. Utility of rhizon samplers in low conductivity soils. BYU CPMS Student Research Conference.

Goodman, M., **Carling, G.T.**, 2018. Using $^{87}Sr/^{86}Sr$ ratios of carbonate minerals in dust to quantify contributions from desert playas to the urban Wasatch Front, Utah, USA. BYU CPMS Student Research Conference.

Hale, C., **Carling, G.T.**, 2018. Using $^{87}Sr/^{86}Sr$ ratios to investigate changes in stream chemistry during snowmelt in the Provo River. BYU CPMS Student Research Conference.

Misuraca, T., **Carling, G.T.**, 2018. Phosphorus flux in Utah Lake. BYU CPMS Student Research Conference.

Packer, B., **Carling, G.T.**, 2018. Mercury and dissolved organic matter dynamics during snowmelt in the upper Provo River, Utah, USA. BYU CPMS Student Research Conference.

Goodman, M., **Carling, G.T.**, 2017. Using $^{87}Sr/^{86}Sr$ ratios of carbonate minerals in dust to quantify contributions from desert playas to the urban Wasatch Front, Utah, USA. Abstract A33F-2422, AGU Fall Meeting, New Orleans, LA.

Hale, C., **Carling, G.T.**, 2017. Using $^{87}Sr/^{86}Sr$ ratios to investigate changes in stream chemistry during snowmelt in the Provo River, Utah, USA. Abstract H41H-1551, AGU Fall Meeting, New Orleans, LA.

Packer, B., **Carling, G.T.**, 2017. Mercury and dissolved organic matter dynamics during snowmelt in the upper Provo River, Utah, USA. Abstract H51H-1378, AGU Fall Meeting, New Orleans, LA.

Hale, C., **Carling, G.T.**, 2017. Using $^{87}Sr/^{86}Sr$ ratios to investigate changes in stream chemistry. Salt Lake County Watershed Symposium, Salt Lake City, UT.

Barkdull, N., **Carling, G.T.**, 2017. Mercury contamination in four Indonesia watersheds affected by artisanal and small scale gold mining. Geological Society of America Abstracts with Programs 49(6), Seattle, WA.

Goodman, M., Hale, C., **Carling, G.T.**, 2017. Dust in northern Utah and impacts on air and water quality. Seminar, Utah Valley University.
Dastrup, D., **Carling, G.T.**, 2017. Composition of aeolian dust deposition to mountains in northern Utah and Nevada. 2017 iUTAH Annual Symposium.
Hale, C., **Carling, G.T.**, 2017. Tracing changes in water chemistry during spring runoff using $^{87}Sr/^{86}Sr$ in the upper Provo River. 2017 iUTAH Annual Symposium.
Randall, M., **Carling, G.T.**, 2017. Characterizing the fate and mobility of phosphorus in Utah Lake sediments. Spring Runoff Conference, Utah State University.
Hale, C., **Carling, G.T.**, 2017. Tracing changes in water chemistry during spring runoff using $^{87}Sr/^{86}Sr$ in the upper Provo River. Spring Runoff Conference, Utah State University.
Packer, B., **Carling, G.T.**, 2017. Mercury transport during snowmelt in the upper Provo River. Spring Runoff Conference, Utah State University.
Checketts, H., **Carling, G.T.**, 2017. An analysis of trace element chemistry in Uinta snowpack and subsequent changing of trace element water chemistry in the upper Provo watershed. Spring Runoff Conference, Utah State University.
Barkdull, N., **Carling, G.T.**, 2017. Mercury methylation and artisanal gold mining in Indonesia. BYU CPMS Student Research Conference.
Goodman, M., **Carling, G.T.**, 2017. Wet and dry atmospheric deposition of phosphorus and nitrogen on Utah Lake, Utah. BYU CPMS Student Research Conference.
Pallo, G., **Carling, G.T.**, 2017. Phosphorus loading to Utah Lake from groundwater springs. BYU CPMS Student Research Conference.
Misuraca, T., **Carling, G.T.**, 2017. Characterizing emissions from the dry lakebed of Great Salt Lake relative to other regional dust sources. BYU CPMS Student Research Conference.
Randall, M., **Carling, G.T.**, 2017. Characterizing the fate and mobility of phosphorus in Utah Lake sediments. BYU CPMS Student Research Conference.
Hale, C., **Carling, G.T.**, 2017. Effects of windblown dust onto the Uinta Mountain Snowpack and upper Provo River. BYU CPMS Student Research Conference.
Packer, B., **Carling, G.T.**, 2017. Mercury transport during snowmelt in the upper Provo River, Utah. BYU CPMS Student Research Conference.
Checketts, H., **Carling, G.T.**, 2017. An analysis of trace element chemistry in Uinta snowpack and subsequent changing of trace element water chemistry in the upper Provo watershed. BYU CPMS Student Research Conference.
Packer, B., **Carling, G.T.**, 2016. Mercury transport during snowmelt in the upper Provo River, Utah, USA. Abstract B33D-0645, AGU Fall Meeting, San Francisco, CA.
Randall, M., **Carling, G.T.**, 2016. Characterizing the fate and mobility of phosphorus in Utah Lake sediments. Abstract B51H-0503, AGU Fall Meeting, San Francisco, CA.
Checketts, H., **Carling, G.T.**, 2016. Investigating transport of dust-borne trace elements from snowpack to snowmelt runoff in the upper Provo River, Utah. Abstract A21E-0105, AGU Fall Meeting, San Francisco, CA.
Meadows, M., Rupper, B., Forster, R., **Carling, G.T.**, 2016. High frequency variability in glacier meltwater patterns in the Rhone Watershed, Switzerland. Abstract C41D-0701, AGU Fall Meeting, San Francisco, CA.
Randall, M., Packer, B., **Carling, G.T.**, 2016. Mercury in the Provo River and phosphorus in Utah Lake. UVU Department of Earth Sciences seminar.

Randall, M., **Carling, G.T.**, 2016. Characterizing phosphorus mineralogy, chemistry, and speciation in Utah Lake sediments. Organic Phosphorus Workshop 2016, Lake District, England.

Checketts, H.N., **Carling, G.T.**, 2016. Evaluating dust contributions to the solute chemistry of mountain streams in northern Utah, USA. Scientific Research Abstracts vol. 5 p. 173, International Conference on Atmospheric Dust, Castelleneta Marina, Italy.

Hale, C., **Carling, G.T.**, 2016. Dust emissions from the dry lakebed of Great Salt Lake and potential impacts on the Wasatch Front urban area. Scientific Research Abstracts vol. 5 p. 191, International Conference on Atmospheric Dust, Castelleneta Marina, Italy.

Packer, B.N., **Carling, G.T.**, 2016. Mercury transport during spring runoff in the Provo River, Utah. Spring Runoff Conference, Utah State University.

Checketts, H.N., **Carling, G.T.**, 2016. Evaluating dust contributions to the solute chemistry of mountain streams in northern Utah. Spring Runoff Conference, Utah State University.

Randall, M., **Carling, G.T.**, 2016. Characterizing phosphorus mineralogy, chemistry, and speciation in Utah Lake sediments. Spring Runoff Conference, Utah State University.

Packer, B.N., **Carling, G.T.**, 2016. Mercury transport during spring runoff in the Provo River, Utah, USA. BYU CPMS Student Research Conference.

Checketts, H.N., **Carling, G.T.**, 2016. Effects of windblown dust on the upper Provo River during snowmelt. BYU CPMS Student Research Conference.

Randall, M., **Carling, G.T.**, 2016. Characterizing phosphorus mineralogy, chemistry, and speciation in Utah Lake sediments. BYU CPMS Student Research Conference.

Brabazon, J., **Carling, G.T.,** 2016 Heber City canals: an update on flow monitoring stations. Spring Runoff Conference, Utah State University.

Brabazon, J., **Carling, G.T.,** 2016. Flow rates in Heber City canals: assessing impact of urbanization and agricultural runoff on stream hydrology. BYU CPMS Student Research Conference.

Hale, C., Goodman, M., **Carling, G.T.**, 2016. Characterizing harmful effects of dust emissions from the dry lakebed of Great Salt Lake relative to other regional dust sources. BYU CPMS Student Research Conference.

Rodriguez, B., Barton, B., **Carling, G.T.**, 2016. Total and methylmercury analysis of Dinwoody and Gannett Glaciers as well as Swiss Alps. BYU CPMS Student Research Conference.

Packer, B., **Carling, G.T.**, Tingey, D.G., 2015. Mercury transport during snowmelt in three mountain watersheds in northern Utah, USA. Abstract B11D-0465, AGU Fall Meeting, San Francisco, CA.

Selck, B., **Carling, G.T.**, Kirby, S., Wallace, J., Jordan, J., and Tingey, D., 2015. Evaluating sources and transport of arsenic in a semiarid alluvial basin aquifer, Goshen Valley, Utah. Geological Society of America Abstracts with Programs 47(4), Anchorage, AK.

Packer, B., **Carling, G.T.**, 2015. Mercury concentrations in snowpack and snowmelt in northern Utah and Great Basin National Park in eastern Nevada. BYU CPMS Student Research Conference.

Sowards, K., **Carling, G.T.**, 2015. Local meteoric water line of Lindon, Utah. BYU CPMS Student Research Conference.

Brabazon, J., **Carling, G.T.**, 2015. Differentiation of Goshen Valley springs: a possible insight into source waters and flow-pathways. BYU CPMS Student Research Conference.

Chapman, T., **Carling, G.T.**, 2015. The impact of Snake Creek on the Provo River watershed chemistry. BYU CPMS Student Research Conference.

Godwin, B., **Carling, G.T.**, 2015. Lead-210 geochronology of Jordan River sediments. BYU CPMS Student Research Conference.

Randall, M., **Carling, G.T.**, 2015. Attenuation of nitrate and phosphate in Utah Lake wetlands that receive inputs from urban runoff and treated wastewater. BYU CPMS Student Research Conference.

Selck, B., **Carling, G.T.**, 2015. Evaluating sources and transport of arsenic in a semiarid alluvial basin aquifer, Goshen Valley, Utah. BYU CPMS Student Research Conference.

Dastrup, D., **Carling, G.T.**, 2015. The impact of aeolian dust on trace element chemistry of snowpack and runoff. BYU CPMS Student Research Conference.

Goodsell, T., **Carling, G.T.**, 2015. Potential for water quality impacts due to agriculture and urban runoff in the middle Provo River, Utah. BYU CPMS Student Research Conference.

Harrison, C., **Carling, G.T.**, 2014. Melting glaciers: A source of mercury and other trace elements to high elevation ecosystems at Grand Teton National Park? Utah Conference on Undergraduate Research.

Chapman, T., **Carling, G.T.**, 2014. Identifying sources of arsenic and salinity in groundwater and surface water in the Snake Creek watershed, Utah. Geological Society of America Abstracts with Programs 46(6), Vancouver, British Columbia.

Randall, M., **Carling, G.T.**, 2014. Attenuation of nitrate and phosphate in Utah Lake wetlands that receive inputs from urban runoff and treated wastewater. Geological Society of America Abstracts with Programs 46(6), Vancouver, British Columbia. *Outstanding undergraduate presentation award for the GSA Environmental and Engineering Geology Division Student Research Competition*

Goodsell, T., **Carling, G.T.**, 2014. Water quality impacts due to agriculture and urban runoff in the middle Provo River, Utah. Geological Society of America Abstracts with Programs 46(6), Vancouver, British, Columbia.

Dastrup, D., **Carling, G.T.**, 2014. The impact of aeolian dust on the trace element chemistry of snowpack and snowmelt runoff in high alpine watersheds of Utah and Nevada. Geological Society of America Abstracts with Programs 46(6), Vancouver, British, Columbia.

Harrison, C., **Carling, G.T.**, 2014. Melting glaciers: A source of mercury and other trace elements to high elevation ecosystems at Grand Teton National Park? BYU CPMS Student Research Conference.

Chapman, T., **Carling, G.T.**, 2014. Trace element trends along the Provo River. BYU CPMS Student Research Conference.

Chapman, T., **Carling, G.T.**, 2014. Trace element concentrations showing signs of urbanization along Provo River, Utah. Utah Conference on Undergraduate Research.

Randall, M., **Carling, G.T.**, 2014. Nitrogen inputs to Utah Lake from urban runoff, treated wastewater, and other sources. BYU CPMS Student Research Conference.

Selck, B., **Carling, G.T.**, 2014. Methyl mercury inputs into the South Arm of Great Salt Lake, Utah. BYU CPMS Student Research Conference.

Dastrup, D., **Carling, G.T.**, 2014. The effect of aeolian dust on the trace element and nutrient

chemistry of snowpack and snowmelt runoff in high alpine watersheds in Utah and Nevada. BYU CPMS Student Research Conference.
Goodsell, T., **Carling, G.T.**, 2014. Water quality impacts due to agricultural and urban runoff in the middle Provo River, Utah. BYU CPMS Student Research Conference.
Goodsell, T., **Carling, G.T.**, 2013. Groundwater flow in closed-basin playas: an investigation of Pilot Valley playa, near Wendover, UT-NV. BYU CPMS Student Research Conference.
Johansen, J., **Carling, G.T.**, 2013. Elemental trends along the Provo River and the effects of Jordanelle and Deer Creek reservoirs. BYU CPMS Student Research Conference.
Olson, M., **Carling, G.T.**, 2013. Quantifying groundwater recharge rates, residence times, and water quality in sandstone aquifers. BYU CPMS Student Research Conference.
Robinson, J., **Carling, G.T.**, 2013. The fate of dust-derived trace elements after deposition to Wasatch Mountain snowpack. BYU CPMS Student Research Conference.

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Education

Ph.D., Mechanical Engineering	University of Utah	1993
Dissertation: *Computational Evaluation of Mechanisms Affecting Radiation in Gas- and Coal-fired Industrial Furnaces*; Advisor: Philip J. Smith		
M.S., Mechanical Engineering	Brigham Young University	1985
B.S., Mechanical Engineering	Brigham Young University	1984
Minor: Mathematics		

Employment

- ***Associate Professor**, Dept. Mechanical Engineering, Brigham Young University, (2015 - present)*

  Taught undergraduate courses in Heat Transfer and Professional Skills, graduate course in Compressible Flow. Served on department course committees and External Relations committee. Mentored undergraduate and graduate student researchers in radiative heat transfer and CFD modeling of advanced gas- and coal-fired combustion systems, air quality modeling.

- ***President**, Reaction Engineering International, Salt Lake City, Utah (2000 - 2015)*

  Led a technical consulting firm with an internationally recognized expertise in combustion and environmental solutions, ~$4M in annual revenues. Managed $8M in combustion-related R&D programs for US DOE, DOD, EPA, and NSF. Coordinated R&D programs and consulting projects for commercial clients in the power generation, petrochemical and material processing industries. Projects focused on using computer simulations and/or pilot-scale testing to evaluate combustion performance and air pollutant control strategies for large-scale furnaces. Oversaw development and application of new simulation tools for prediction of ultra-low NOx emissions in pyrolysis furnaces, mercury speciation in coal-fired power plants, and heat transfer and steam circuit behavior in combustion systems.

- ***Vice President**, Engineering Analysis, Reaction Engineering Intl., Salt Lake City, UT (1998-2000)*

  Managed REI analysis/modeling division with responsibility for Environmental Technologies and Performance Optimization groups.

- ***Manager**, Applied Technologies, Reaction Engineering Intl., Salt Lake City, Utah (1997-1998)*

  Managed projects for modeling industrial combustion applications including work for power generation, chemical process and metallurgical industries; responsible for project proposals, schedules, budgets and technical results.

- ***Senior Engineer**, Reaction Engineering International, Salt Lake City, Utah (1992-1997)*

  Conducted R&D to improve REI simulation tools with an emphasis on heat transfer, NOx predictions and balance of plant impacts in coal-fired combustion systems; used CFD modeling tools to improve performance, reduce air-borne emissions and assess technology impacts in industrial combustion systems.

- ***Instructor**, Department of Chemical Engineering, University of Utah, Salt Lake City, Utah (1992)*

  Taught undergraduate heat transfer course, ranked in top 20% of Engineering College instructors in student evaluations.

- ***Consultant**, Reaction Engineering International, Salt Lake City, Utah (1991)*

  Analyzed differences in deposition and NOx levels between slurry-fired and dry coal-fired turbine combustor; evaluated effects of multiple burners and urea injection on NOx levels in a gas-fired utility boiler.

- ***Research Assistant**, Computational Fluid Dynamics Laboratory, University of Utah (1991-1992)*

  Conducted research of radiative heat transfer mechanisms in industrial gas- and coal-fired furnaces including turbulence-soot-radiation interaction; implemented domain decomposition techniques to improve computational efficiency of combustion software.

- ***Consultant**, Los Alamos National Laboratory, Los Alamos, New Mexico (1990)*

  Analyzed transient heat transfer characteristics of materials in a waste storage container to determine possibility of explosion and solid waste combustion.

- ***Research Assistant**, Combustion Computations Laboratory, Brigham Young Univ. (1989-1990)*

  Conducted research of radiative heat transfer mechanisms in industrial furnaces including improved radiation property models; implemented and evaluated vectorization techniques to improve computational efficiency of combustion software.

- ***Staff Member**, Optical Systems Engineering, MIT Lincoln Laboratory, Lexington, MA (1987-1989)*

  Led projects to analyze the thermal performance of a high-energy laser system, aircraft-based cryogenic cooling system and satellite-based electronics package using experimental prototypes and CFD-based simulations; served as Group Representative on committees responsible for procurement of division mini-supercomputer and workstations; evaluated and procured heat transfer and CFD analysis codes for Group use.

- ***Engineer**, Corporate Mechanical Engineering, GenRad, Concord, Massachusetts (1984-1986)*

  Responsible for structural, thermal and acoustical analysis of three new products; developed computer codes for optimizing acoustical and thermal packaging of electronics systems.

Professional Associations and Awards

- Member American Society of Mechanical Engineers (ASME)
- Senior Member American Institute of Chemical Engineers (AIChE)
- Member American Flame Research Committee (AFRC)
- ASPACC-99 (Combustion Institute) "Most Important, Original, and High Quality Paper"
- Advanced Combustion Engineering Research Center (ACERC) Fellowship

Journal Articles (at Brigham Young University)

Adams, B., Hosler, T. (2019) "Pressure and particle property impacts on radiation in oxy-coal combustion," *Fuel* 239, 667–676.

Tree, D., Tobiasson, J., Egbert, S., **Adams, B.** (2019) "Measurement of Radiative Gas and Particle Emissions in Biomass Flames," *Proc. Combust. Inst*. 37 (4), 4337-4344.

Tobiasson, J., Egbert, S., **Adams, B.**, Tree, D. (2018) "An Optical Method for the Measurement of Combustion Gas Temperature in Particle Laden Flows," *Exp. Therm. Fluid Sci.* 98, 704-711.

Adams, B., Tobiasson, J., Egbert, S, Tree, D. (2018) "Determining Total Radiative Intensity in Combustion Gases Using an Optical Measurement," *Energy Fuels* 32 (2), 2414–2420.

Smith, J., **Adams, B.,** Jackson, R., Suo-Anttila, A. (2017) "Use of RANS and LES Turbulence Models in CFD Predictions for Industrial Gas-fired Combustion Applications," *Industrial Combustion, Journal of the International Flame Research Foundation*, Article 201607, ISSN 2075-3071.

Other Articles and Conference Proceedings (at Brigham Young University)

Gunnarsson, A., Andersson, K., **Adams, B.** (2018) "Full Scale 3D-Modelling of the Radiative Heat Transfer in Rotary Kilns with a Present Bed Material," Paper #50, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Hosler, T., **Adams, B.** (2018) "Particle Property Impacts on Radiation in a Pressurized Oxy-Coal Combustor," Paper #49, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Schroedter, T., **Adams, B.** (2018) "Modeling Transport of Pressurized Dense Phase Coal," Paper #48, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Gunnarsson, A., Andersson K., **Adams, B.** (2018) "3D-Modelling of the Radiative Heat Transfer in Rotary Kilns with a Present Bed Material," *Eurotherm 110, Computational Thermal Radiation in Participating Media VI*, Cascais, Portugal. (peer reviewed)

Adams, B. (2017) "Mitigation of Airborne Pollutants in Coal Combustion, Use of Simulation," *Fossil Fuels*, *Encyclopedia of Sustainability Sci. Technol.*, 2nd Ed., Springer, ISBN 978-1-4939-2775-3, DOI 10.1007/978-1-4939-2493-6_959-1. (invited)

Smith, J., **Adams, B.,** Jackson, R., Suo-Anttila, A. (2017) "RANS vs LES CFD for Gas-fired Combustion Equipment Analysis," *AFRC 2017 Industrial Combustion Symposium*, Houston, TX.

Hosler, T., **Adams, B.** (2017) "Impact of Particle Properties on Radiative Heat Flux in an Oxy-Coal Reactor," Paper # 29OT-0033, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Schroedter, T., **Adams, B.** (2017) "Modeling a Pressurized Coal Feed System," Paper # 29OT-0031, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Williams, T., **Adams, B.** (2017) "A Fast-Running Simulation Tool for Axisymmetric Oxy-Coal," Paper # 29CC-0032, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Adams, B., Fry, A., Tree, D. (2017) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Program Overview," *The 42nd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Sperry, R. (2017) "Impact of Computational Mesh on CFD Combustion Predictions," *2017 AIChE Spring Meeting*, San Antonio, TX.

Conference Presentations (at Brigham Young University)

Houghton, L., **Adams, B.,** Fry, A., Gunnarsson, A., Andersson, K. (2018) "Radiometer Measurements in High Pressure Flames: System Design, Sensors and Calibration," Abstract #78, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Fry, A., Tree, D. (2018) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Year 1 Update," Abstract #47, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Tobiasson, J., Egbert, S., Tree, D. (2018) "Total Radiation Intensity from Combustion Gas Measurement," Abstract #130, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Green, A., **Adams, B.** (2018) "Simulating Coal Transport with Carbon Dioxide," University Conference on Undergraduate Research, Cedar City, Utah.

Adams, **B.**, Hosler, T., Fry, A. (2018) "Impact of Particle Properties on Radiative Heat Flux in a Pressurized Oxy-Coal Combustor," 2nd International Workshop on Oxy-Fuel Combustion, February 14-15, Bochum, Germany.

Houghton, L., **Adams**, **B.**, Fry, A., Gunnarsson, A., Andersson, K. (2018) "Measuring Radiation From High Pressure Oxy-Coal Flames," 2nd International Workshop on Oxy-Fuel Combustion, February 14-15, Bochum, Germany.

Research Grants and Contracts (at Brigham Young University)

"Modeling Impacts of Exceptional Dust Events on Wasatch Front Air Quality," BYU College of Engineering SEED Funding, $12,500, Jan 1, 2019 – Dec 31, 2019.

"Development of Enabling Technologies for a Pressurized Dry Feed Oxy-Coal Reactor," DOE Contract DE-FE0029157, $1.41M ($1.1M DOE), Co-PI with Andrew Fry, Oct 1, 2016 – Sep 30, 2019.

Graduate Student Advisement (at Brigham Young University)

Taylor Schroedter	MS	Brigham Young University	Graduated 2018
Todd Williams	PhD	Brigham Young University	2016 – present
Ty Hosler	MS	Brigham Young University	2019 – present

Undergraduate Student Advisement (at Brigham Young University)

Ryan Sperry	BS	Brigham Young University	2016 – 2017
Ty Hosler	BS	Brigham Young University	2017 – 2018
Ariel Green	BS	Brigham Young University	2017 – 2018
Cole Thatcher	BS	Brigham Young University	2018 – present
Scott Gardner	BS	Brigham Young University	2018 – present

Thesis/Dissertation Committee Advisement (at Brigham Young University)

Alex Josephson	PhD (David Lignell, Chemical Engineering)	Graduated 2018
Brent Reichman	PhD (Kent Gee, Physics)	Graduated 2018
John Tobiasson	MS (Dale Tree, Mechanical Engineering)	Graduated 2017
Michael Farnsworth	MS (Scott Thomson, Mechanical Engineering)	Graduated 2018
Aaron Skousen	MS (Dale Tree, Mechanical Engineering)	2017 – present
Cody Carpenter	MS (Dale Tree, Mechanical Engineering)	2017 – present
Scott Egbert	MS (Dale Tree, Mechanical Engineering)	2017 – present
Ashton Jessup	MS (Dale Tree, Mechanical Engineering)	2018 – present

Professional Service (at Brigham Young University)

- Reviewer for *ASME IMECE, Combustion Science and Technology, Energy & Fuels, Fuel, Fuel Processing Technology, Heat and Mass Transfer, International Journal of Heat and Mass Transfer, Journal of Thermal Science and Engineering* (2015 – present)
- Conference Committee, The International Technical Conference on Clean Energy ("Clearwater Clean Energy Conference") (2013 – present)
- Academic Liaison, American Petroleum Institute (API) Subcommittee on Heat Transfer Equipment (SCHTE) Fired Heater Consensus Group (2015 – present)
- API Fired Heater Research Consortium (2016 – present)
- Chair, Session on Radiative Heat Transfer, The 43rd International Technical Conference on Clean Energy (June 2018)
- Reviewer, Proposed Alternative NOx Control Technologies, PacifiCorp (August 2017)
- Chair, Session on Coal and Biomass, Western States Section of the Combustion Institute (WSSCI) Fall Technical Meeting (October 2017)

- Chair, Session on Solid Combustion/Flame Spread, Western States Section of the Combustion Institute (WSSCI) Fall Technical Meeting (October 2015)
- Chair, Session on Ignition, Ash Deposition, Trace Elements Partitioning, 5^{th} Oxyfuel Combustion Research Network Meeting, Wuhan, China (October 2015)

University Service (at Brigham Young University)

- Member, External Relations Committee, Mechanical Engineering Department (2015-present)
- Member, ME EN 340 Heat Transfer Course Committee (2015-present)
- Chair, ME EN 393 Professional Skills Course Committee (2016-present)
- Member, ME EN 422 Applied Thermodynamics Course Committee (2015-present)
- Member, PhD Program Outcomes Subcommittee, Mechanical Engineering Department (2017)
- Reviewer, Engineering and Technology College ORCA proposals (2017)
- Executive Committee, Advanced Combustion Engineering Research Center (ACERC) (2016-present)

Courses Taught (at Brigham Young University)

- Graduate Compressible Flow (ME EN 510) – F15, F16, F17
- Undergraduate Heat Transfer (ME EN 340) – W16, W17, W18, F18
- Undergraduate Professional Skills (ME EN 393) – F16, W17, F17, W18, F18
- Mentored Projects (497R) – F16, W17, F17, W18, F18
- Capstone Senior Design – F18

Invited Lectures and Seminars (at Brigham Young University)

- "Combustion Research Opportunities in the Petrochemical Industry," API 2015 Fall Refining and Equipment Standards Meeting, SCHTE Fired Heater Consensus Group, November 16, 2015.
- "Result of High-Flame Temperature Oxy-Combustion Tests at the 15 MW_{th} Test Facility and its Application to Refineries" (with Jupiter Oxygen Corp) at 5th Oxyfuel Combustion Research Network Meeting, Wuhan, China, October 28, 2015.

Major Research Grants and Contracts (before Brigham Young University)

"Characterizing Impacts of High Temperatures and Pressures in Oxy-Coal Combustion Systems," DOE Contract DE-FE0001247, $1.57M, ($1.25M DOE), June 2015 (left before completion).

"CFD Modeling of Oxy-coal Combustion in a New Modular Boiler Concept," Jupiter Oxygen Corporation, $80K, January 2014.

"Characterization of Oxy-combustion Impacts in Existing coal-fired Boilers," DOE Contract DE-NT0005288, $3.9M ($3.1M DOE), October 1, 2009 – September 30, 2013.

"Development of a Graphics-based Convection Design Package," Shaw Energy and Chemicals, $340K, April 2011.

"Radiation Modeling in Oxy-Coal Fired Boilers," Vattenfall R&D, $58K, March 2010.

"CFD Modeling Study of MPCRF Combustor," EPA Contract EP08C000261, $40K, August 2008.

"Development of a Corrosion Management Methodology for Coal-fired Boilers," Ohio Coal Development Office Grant CDO-D-01-15, $654K, 2003 – 2005.

"Scramjet Combustor Simulations Using Reduced Chemical Kinetics For Practical Fuels," AFRL/PRKA Contract F33615-01-2124, $726K, May 2001 – March 2004.

Professional Service (before Brigham Young University)

- Chair, Session on Air Toxics, The 39th International Technical Conference on Clean Coal & Fuel Systems, June 2014
- Chair, Session on Mercury Control, The 38th International Technical Conference on Clean Coal & Fuel Systems, June 2013
- Chair, Session on Use of Modeling Tools for Technology Assessment, The 37th International Technical Conference on Clean Coal & Fuel Systems, June 2012
- Chair, Session on Oxy-Fuel Technology IV – Understanding Oxy-Combustion Impacts, The 36th International Technical Conference on Clean Coal & Fuel Systems, June 2011
- Co-Chair (with Karen Eriksson), Session 05C on CFD Modeling and Experimental Validation, 1st International Oxyfuel Combustion Conference, Germany, September 2009
- Organizing Committee, AFRC 2008 Spring Meeting, May 2008
- Chair, Session on Utility Industry Combustion Research and Development Needs, AFRC 2008 Spring Meeting, May 2008
- Organizing Committee, Applied Combustion Technology: Problem Solving for the Utility and Process Industries, Brigham Young University, May 2005

Professional Short Courses Taught (before Brigham Young University)

- "SO_3 and Hg Emission Mitigation Strategies from Coal-fired Boilers," Reaction Engineering International, Salt Lake City, Utah, (with Connie Senior, Jost Wendt, Scott Evans, Volker Schmid) March 2006.
- "Emissions Mitigation from Coal-Fired Boilers: Strategies for SO_3 Control," Clean Air Engineering, Palatine, Illinois, (with Connie Senior, Scott Evans, Jim Wright) November 2006.
- "Emissions Mitigation from Coal-Fired Boilers: Strategies for Hg Control," Clean Air Engineering, Palatine, Illinois, (with Connie Senior, Scott Evans, Jim Wright) November 2006.
- "VFURN CFD Modeling," Chinese Petroleum Corporation, Chiayi, Taiwan, March 1999.

Invited Lectures and Seminars (before Brigham Young University)

- "Current Trends in the U.S. Power Generation Industry," Pusan National University Combustion Seminar, University of Utah, Salt Lake City, Utah, June 28, 2013.
- "Challenges for U.S. Power Generation Industry," Korean Electric Power Research Institute, Daejeon, Korea, June 13, 2008.
- "The State of Computer Simulation Capabilities for Coal-Fired Systems," US-China Conference on Combustion Technology, Park City, Utah, May 7-9, 2007.
- "Emissions Mitigation from Coal-Fired Boilers Strategies for SO_3 and Hg Control," REI Environmental Compliance Seminar, Chicago, Illinois, November 14-16, 2006.
- "Mercury Emissions and Controls for U.S. Coal-fired Utility Boilers," Conference on Mercury Emissions Control Technologies for Stationary Pollution Sources, Taipei, Taiwan, November 19, 2003.
- "NOx Modeling Overview," HuaDian Power International, Jinan, China, November 21, 2003.
- "Career Seminar - Preparing for Work after Graduation," University of Utah Department of Chemical & Fuels Engineering, November 13, 2001.

Journal Articles (before Brigham Young University)

Fry, A., **B. Adams**, A. Paschedag, P. Kazalski, C. Carney, D. Oryshchyn, R. Woodside, S. Gerdemann, and T. Ochs (2011) "Principles for Retrofitting Coal Burners for Oxy-combustion," *International Journal of Greenhouse Gas Control*, Vol. 5, Supp. 1, pp. S151-S158.

Fry, A., **B. Adams**, K. Davis, D. Swensen, S. Munson, and W. Cox (2011) "An Investigation into the Likely Impact of Oxy-coal Retrofit on Fire-side Corrosion Behavior in Utility Boilers," *International Journal of Greenhouse Gas Control*, Vol. 5, Supp. 1, pp. S179-S185.

Tang, Q., Denison, M., **Adams, B**., and Brown, D. (2009) "Towards Comprehensive Computational Fluid Dynamics Modeling of Pyrolysis Furnaces With Next Generation Low NOx Burners Using Finite-rate Chemistry," *Proceedings of Combustion Institute*, Volume 32, Issue 2, pp. 2649-2657.

H-P Wan, C-S Yang, **B.R. Adams**, S.L. Chen (2008) "Controlling LOI From Coal Reburning In A Coal-Fired Boiler," *Fuel*, 87, pp. 290–296.

Wu, K.-T., H.T. Lee, C.I. Juch, H.P. Wan, H.S. Shim, **B.R. Adams**, S.L. Chen (2004) "Study of Syngas Co-Firing and Reburning in a Coal Fired Boiler," *Fuel*, Vol. 83, pp. 1991-2000.

Harding, N.S., **Adams, B.R**. (2000) "Biomass as a reburning fuel: a specialized cofiring application," *Biomass and Bioenergy,* Vol. 19, Elsevier, pp. 429-445.

Adams, B.R., Harding, N.S. (1998) "Reburning Using Biomass for NOx Control," *Fuel Processing Technology*, Vol. 54 (1-3), pp. 249-263.

Adams, B.R. and Smith, P.J. (1995) "Modeling Effects of Soot and Turbulence-Radiation Coupling on Radiative Transfer in Turbulent Gaseous Combustion," *Combust. Sci. Technol.,* 109, 1-6, p. 121.

Adams, B.R. and Smith, P.J. (1993) "Three-dimensional Discrete-ordinates Modeling of Radiative Transfer in a Geometrically Complex Furnace," *Combust. Sci. Technol.*, 88, pp. 293-308.

Ma, K-L., Sikorski, K., Smith, P.J. and **Adams, B.R**. (1993) "Distributed Combustion Simulations," *Energy Fuels*, Vol. 7, No. 6, pp. 902-905.

Major Technical Reports (before Brigham Young University)

B. Adams, K. Davis, C. Senior, H. Shim, B. Van Otten, A. Fry, J.O.L. Wendt, A. Paschedag, C. Shaddix, W. Cox, D. Tree, "Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers," Final Technical Report, U.S. Department of Energy Cooperative Agreement DE-NT0005288, December 2013.

B. Adams, A. Fry, C. Senior, H. Shim, H. Wang, J. Wendt, C. Shaddix, "Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers," DOE Topical Report, U.S. Department of Energy Cooperative Agreement DE-NT0005288, July 31, 2009.

Adams, B.R., "CFD Modeling of Syngas Reburning in the EPA MPCRF Pilot-Scale Coal Combustor," Final Report U.S. EPA, C_EP08C000261_0_0_RCI, April 2009.

C. Montgomery, A. Sarofim, **B. Adams**, E. Eddings, J. Bozzelli, V. Katta, "Multifunctional Fuel Additives for Reduced Jet Particulate Emissions," Final Report AFRL-PR-WP-TR-2006-2212, AFRL, June 2006.

B. Adams, M. Cremer, C. Montgomery, W. Zhao, D. Eklund, C. Tam, J.-Y. Chen, "Scramjet Combustor Simulations Using Reduced Chemical Kinetics for Practical Fuels," Final Technical Report AFRL-PR-WP-TR-2004-2011, Air Force Research Laboratory, December 2003.

C. Senior, B. Shiley, **B. Adams**, R. Afonso, P. Amar, "Summary of Emissions Controls Available for NO_x and PM from Large Stationary Sources in the Western United States," Report to the Western Governors' Association, April 25, 2003.

Trade Publications (before Brigham Young University)

B. Adams, M. Cremer, A. Chiodo, C. Giesmann, K. Stuckmeyer, J. Boyle, "Layered NOx Reduction on a 500-MW Cyclone-Fired Boiler," *Coal Power*, pp. 2733, January/February, 2007.

C. Senior, **B. Adams,** "Dynamic Duo Captures Mercury," *Power Engineering*, February, 2006.

B. Adams, C. Senior, "Curbing the Blue Plume: SO3 Formation and Mitigation," *Power*, May, 2006.

B. Adams, "CFD Modeling of Boiler Performance and Emissions," *Power*, pp. 57-60, April 2004.

Conference Proceedings (before Brigham Young University)

Adams, B., Cremer, M., Murphey, J., "Use of CFD in Evaluating Pyrolysis Furnace Design," 2015 Spring Meeting & 11th Global Congress on Process Safety, AIChE, ISBN 978-0-8169-1089-2, Paper 2b, April, 2015.

Adams, B., Cremer, M., Olver, J., "Impact of High-Emissivity Coatings on Process Furnace Heat Transfer," 2015 Spring Meeting & 11th Global Congress on Process Safety, AIChE, ISBN 978-0-8169-1089-2, Paper 85b, April, 2015.

Adams, B., Van Otten, B., "Evaluation of Mercury Control Strategies in the Presence of SO_3," Paper #18, Power Plant Pollutant Control "MEGA" Symposium, Baltimore, MD, August 19-21, 2014.

Adams, B., Cremer, M., "Use of CFD in Evaluating Pyrolysis Furnace Design," AFRC 2014 Industrial Combustion Symposium, Houston, Texas, September 7-10, 2014.

Adams, B., Denison, M., Olver, J., "Impact of High-Emissivity Coatings on Process Furnace Heat Transfer," AFRC 2014 Industrial Combustion Symposium, Houston, Texas, September 7-10, 2014.

Van Otten, B., Davis, K., **Adams, B**., Fry, A., "Evaluation of Mercury Control Technologies Under Oxy-Fired Conditions in a 1.5MW Pilot Scale Furnace," Air Quality IX, Arlington, Virginia, October 21-23, 2013.

Adams, B., Shurtz, T., "Evaluating High Temperature Oxy-Natural Gas Retrofit of a Coal-fired Boiler," AFRC 2013 Industrial Combustion Symposium, Kauai, Hawaii, September 22-23, 2013.

Adams, B., Davis, K., Wang, H., Valentine, J., Smith, B., Shi, L., Pozzobon, E., "Ash Deposition Modeling Incorporating Mineral Matter Transformations Applied to Coal and Biomass Co-firing," AFRC 2013 Industrial Combustion Symposium**,** Kauai, Hawaii, September 22-23, 2013.

Van Otten, B., **Adams, B**., Fry, A., "Pilot-scale Testing of Mercury Control Technologies Under Oxy-fired Conditions," The 38th International Technical Conference on Clean Coal & Fuel Systems (Clearwater Clean Coal Conference), Clearwater Florida, June 2-6, 2013.

Adams, B., A. Fry, T. Shurtz, “Modeling Furnace Performance and Impacts of Coal-to-Gas Conversion,” presented at Reinhold Environmental Coal to Gas Conference, Chattanooga, Tennessee, October 23, 2012.

Fry, A., **B. Adams**, T. Fout, “Carbon, Sulfur and Nitrogen Behavior during Pilot-Scale Testing of Oxy-Coal Combustion,” Paper #49, DOE-EPRI-EPA-A&WMA Power Plant Air Pollutant Control "Mega" Symposium, Baltimore, MD, Aug. 20-23, 2012.

Fry, A., **B. Adams**, K. Davis, D. Swensen, W. Cox, “Fire-Side Corrosion of Heat Transfer Surface Materials with Air- and Oxy-coal Combustion,” Paper #51, DOE-EPRI-EPA-A&WMA Power Plant Air Pollutant Control "Mega" Symposium, Baltimore, MD, Aug. 20-23, 2012.

Adams, B., A. Fry, B. Van Otten, M. Cremer, “SteamGen Expert Process Modeling for Boiler Combustion Modifications,” The 37th International Technical Conference on Clean Coal & Fuel Systems, Paper #105, Clearwater, Florida June 3 - 7, 2012.

A. Fry, **B. Adams**, K. Davis, D. Swensen, and S. Munson, and W. Cox, “Fire-Side Corrosion of Heat Transfer Surface Materials for Air- and Oxy-coal Combustion,” The 36th International Technical Conference on Clean Coal & Fuel Systems, Paper #118, Clearwater, Florida June 5 - 9, 2011.

A. Fry, B. Van Otten, **B. Adams**, L. Bool, “Mercury Speciation and Emission from Pilot-Scale PC Furnaces under Air- and Oxy-fired Conditions,” The 36th International Technical Conference on Clean Coal & Fuel Systems, Paper #119, Clearwater, Florida June 5 - 9, 2011.

B. Adams, A. Fry, “CFD Modeling of Pilot-scale Oxycombustion Experiments,” The 36th International Technical Conference on Clean Coal & Fuel Systems, Paper #122, Clearwater, Florida June 5 - 9, 2011.

Fry, A., **B. Adams**, K. Davis, D. Swensen, and W. Cox, “Potential Impacts of Oxy-Combustion Retrofit on Boiler Tube Corrosion Rate,” AIChE 2010 Annual Meeting, Paper 419d, Salt Lake City, UT, Nov. 10, 2010.

B. Adams, A. Fry, K. Davis, M. Cremer, D. Swensen, S. Munson, P. Kazalski, W. Cox, “Oxy-Coal Retrofit of Utility Boilers – Burner Principles and Fire-Side Corrosion,” AFRC 2010 Pacific Rim Combustion Symposium, Maui, Hawaii, September 26-30, 2010.

A. Fry, **B. Adams**, K. Davis, M. Cremer, D. Swensen, S. Munson, P. Kazalski, W. Cox, “Topics in Oxy-Coal Retrofit of Utility Boilers – Burner Principles and Fire-Side Corrosion,” Paper # 125, DOE-EPRI-EPA-A&WMA Power Plant Air Pollutant Control "Mega" Symposium, Baltimore, MD, Aug. 30 – Sept. 2, 2010.

B. Adams, A. Fry, J. Shan, “Oxy-Burner Retrofit Principles for Existing Coal-Fired Utility Boilers,” The 35th International Technical Conference on Clean Coal & Fuel Systems, Clearwater, FL, June 6 - 10, 2010.

A. Fry, **B. Adams**, “Characterization and Prediction of Oxy-combustion Impacts in Existing Coal-fired Boilers,” 34th International Technical Conference on Clean Coal and Fuel Systems, Clearwater, Florida, May 31 - June 4, 2009.

C. Senior, A. Fry, **B. Adams**, “Modeling Mercury Behavior in Coal-Fired Boilers with Halogen Addition,” Paper #150, DOE-EPRI-EPA-A&WMA Power Plant Air Pollutant Control "Mega" Symposium, Baltimore, MD, August 25-28, 2008.

B. Adams and Q. Tang, “Modeling Flame Behavior and Low NOx Emissions in Cracking Furnaces,” 15th International Flame Research Foundation Member’s Conference, Pisa, Italy, June 13-15, 2007.

M. Cremer, **B. Adams**, C. Giesmann, K. Stuckmeyer, R. Himes, J. Boyle, “ALTA Achieves Sub 0.15 lb/MBtu NOx Emissions On A 500 MW Cyclone Fired Boiler,” EPRI-EPA-DOE-A&WMA Power Plant Air Pollutant Control "Mega" Symposium, Washington, DC, August 28, 2006.

S.R. Wu, H.S. Shim, **B.R. Adams**, S.L. Chen, “Study of Fuel Staging for NOx Control in an Oil-fired Furnace,” 5th Asia-Pacific Conference on Combustion, The University of Adelaide, Adelaide, Australia, 17-20 July 2005.

Q. Tang, **B. Adams**, M. Bockelie, M. Cremer, M. Denison, C. Montgomery, A. Sarofim, "Towards Comprehensive Modeling of Process Heaters with Ultra-low NOx Burners using Transport PDF Method", The Fourth Joint Meeting of the U.S. Sections of the Combustion Institute, Philadelphia, PA, March 20-23, 2005.

Senior, C. and **Adams, B.**, "Measurement and Control of Mercury Emissions in Utility Boilers," presented at the 8th Annual Electric Utilities Environmental Conference, Tucson, AZ, January 24-26, 2005.

Tang Q., **Adams B.**, Bockelie M., Cremer M., Denison M., and Sarofim A., "Advanced CFD Tools for Modeling Finite Rate Chemistry in Reacting Flows", 2005 Design, Service and Manufacturing Research and Grantees Conference, Scottsdale, AZ, Jan. 3-6, 2005.

Cremer, M.A., Wang, D. H., **Adams, B.R.**, Boll, D.E., and Stuckmeyer, K.B., "Evaluation of Cost Effective Non-SCR Options for NOx Control in PRB Fired Cyclone Boilers." Paper presented at 19th International Conference on Lignite, Brown, and Subbituminous Coals, Billings, MT, October, 2004.

S. Conn, K. Frizzell, G. Dusatko, M. Vacek, **B. Adams**, “Combustion Optimization at OMU’s Elmer Smith Unit 1: Meeting SCR Specifications and Maintaining Plant Heat Rate,” Paper #6, Combined Power Plant Air Pollutant Control Mega Symposium, Washington DC, Aug 30 – Sept 2, 2004.

Wang, D.H., Cremer, M.A., and **Adams, B.R.**, Santangeli, R., "CFD Modeling of Combustion-Generated NOx in a Utility Furnace Firing Heavy Residual Fuel Oil", PVP-VOL. 491-2, Computational Technologies for Fluid/Thermal/Structural/Chemical Systems with Industrial Applications, Vol.2, San Diego, California UAS, July 25-29, Edited by V. Kudriavtsev, C.R. Kleijn, and S. Kawano, PP131-138, 2004.

Tang, Q., **Adams, B**., Bockelie, M., Cremer, M., Denison, M., Montgomery, C., Sarofim, A., and Brown, D.J., “Advanced CFD Tools for Modeling Lean Premixed Combustion in Ultra-Low NOx Burners in Process Heaters,” *2004 AFRC-JFRC Joint International Symposium*, Maui, Hawaii, October 2004.

B. Adams, H.S. Shim, S.R. Wu, W.C. Chang, H.W. Chiao, S.L. Chen, “CFD Evaluation Of NO_X Reduction Strategies In An Oil-Fired Furnace,” The Fourth Asia-Pacific Conference on Combustion, Nanjing, P.R. China, November 24-26, 2003.

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Biographical Sketch – Hosein Foroutan

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(a) Professional Preparation

Iran University of Science and Technology	Iran	Mechanical Engineering	B.Sc.	2006
Iran University of Science and Technology	Iran	Mechanical Engineering	M.Sc.	2009
Pennsylvania State University	PA	Mechanical Engineering	Ph.D.	2015
U.S. Environmental Protection Agency	NC	Atmospheric Modeling	Postdoc	2015-2017

(b) Appointments

August 2017 – Present	Assistant Professor, Virginia Tech, Blacksburg VA
2015 – 2017	Postdoctoral Fellow, U.S. Environmental Protection Agency, Durham NC

(c) Publications

(i) Five publications most related to the proposed project

1. **Foroutan, H.**, Young, J., Napelenok, S., Ran, L., Appel, K., Gilliam, R., and Pleim, J., 2017, "Development and evaluation of a physics-based windblown dust emission scheme implemented in the CMAQ modeling system," *Journal of Advances in Modeling Earth Systems*, Vol. 9(1), pp. 585-608 (selected for the cover page).
2. **Foroutan, H.** and Pleim, J., 2017, "Improving the simulation of convective dust storms in regional-to-global models," *Journal of Advances in Modeling Earth Systems*, Vol. 9(5), pp. 2046-2060.
3. Appel, K., Napelenok, S., Foley, K., Pye, H., Hogrefe, C., Luecken, D., Bash, J., Roselle, S., Pleim, J., **Foroutan, H.**, Hutzell, W., Pouliot, G., Sarwar, G., Fahey, K., Gantt, B., Gilliam, R., Kang, D., Mathur, R., Schwede, D., Spero, T., Wong, D., and Young, J., 2017, "Description and evaluation of the Community Multiscale Air Quality (CMAQ) model version 5.1," *Geosci. Model Dev.*, Vol. 10, pp. 1703-1732.
4. **Foroutan, H.**, Tang, W., Heist, D., Perry, S., Brouwer, L., Monbureau, E., 2018, "Numerical analysis of pollutant dispersion around elongated buildings: an embedded large eddy simulation approach," *Atmospheric Environment*, Vol. 187, pp. 117-130.
5. Pye, H.O.T., Zuend, A., Fry, J.L., Isaacman-VanWertz, G., Capps, S.L., Appel, K.W., **Foroutan, H.**, Xu, L., Ng, N.L., and Goldstein A.H., 2018, "Coupling of organic and inorganic aerosol systems and the effect on gas-particle partitioning in the southeastern US," *Atmos. Chem. Phys.*, Vol. 18, pp. 357-370.

(ii) Five other publications

1. Nolan, P., Pinto, J., González-Rocha, J., Jensen, A., Vezzi, C., Bailey, S., de Boer, G., Diehl, C., Laurence, R., Powers, C., **Foroutan, H.**, Ross, S., and Schmale, D., 2018, "Coordinated unmanned aircraft system (UAS) and ground-based weather measurements to predict Lagrangian coherent structures (LCSs)," *Sensors*, Vol. 18(2), p. 4448.
2. Monbureau, E., Heist, D., Perry, S., Brouwer, L., **Foroutan, H.**, and Tang, W., 2018, "Enhancements to AERMOD's building downwash algorithms based on wind-tunnel and embedded-LES modeling," *Atmospheric Environment*, Vol. 179, pp. 321-330.
3. **Foroutan, H.** and Yavuzkurt, S., 2015, "Numerical simulations of the near-field region of film cooling jets under high free stream turbulence: Application of RANS and hybrid URANS/LES models," *ASME J. Heat Transfer*, Vol. 137(1), p. 011701.

4. **Foroutan, H.** and Yavuzkurt, S., 2014, "A partially-averaged Navier-Stokes model for the simulation of turbulent swirling flow with vortex breakdown," *International Journal of Heat and Fluid Flow*, Vol. 50, pp. 402-416.
5. Mehdizadeh, A., **Foroutan, H.**, Vijayakumar, G., and Sadiki, A., 2014, "A new formulation of scale adaptive simulation approach to predict complex wall bounded shear flows," *Journal of Turbulence*, Vol. 15(10), pp. 629-649.

(d) Synergistic Activities

- Development of a windblown dust emission module implemented (and publically available as the default option) in the Community Multiscale Air Quality (CMAQ v5.2) modeling system of the U.S. EPA (2017).

- Journal Technical Reviewer (2014 – Present): *Atmosphere - Atmospheric Chemistry and Physics - Atmospheric Environment - Canadian Journal of Chemical Engineering - Flow, Turbulence, and Combustion - International Journal of Environmental Research - International Journal of Heat and Fluid Flow - International Journal of Heat and Mass Transfer - International Journal of Multiphase Flow - Journal of Applied Water Engineering and Research - Journal of Power and Energy - Journal of the Energy Institute - Progress in Computational Fluid Dynamics - Scientific Reports - Sustainable Cities and Society*