Prepared for:

Utah Department of Environmental Quality
Science for Solutions Research Grant – FY 2021

Prepared by:

Ramboll US Consulting, Inc.
50 West Broadway, Suite 300
Salt Lake City, UT 84101

Utah State University
Bingham Research Center
320 N Aggie Blvd
Vernal, UT 84078

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Assessing Wintertime Ozone Prediction Sensitivity to Photochemical Mechanism

A Proposal Submitted to the Utah Division of Air Quality Science for Solutions Research Grant Program – FY 2022

RAMBOLL Bright ideas. Sustainable change.

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1.1 Project Title

Assessing Wintertime Ozone Prediction Sensitivity to Photochemical Mechanism

1.2 Applicant Information

Organization:	Ramboll US Consulting, Inc.
Address:	50 West Broadway, Suite 300 Salt Lake City, UT 84101
Co-Principal Investigator:	Greg Yarwood, Principal
Phone number:	(415) 899-0704
Email address:	gyarwood@ramboll.com

Organization:	Utah State University
Address:	Bingham Research Center 320 N Aggie Blvd Vernal, UT 84078
Co-Principal Investigator:	Huy Tran, Senior Research Scientist
Phone number:	(435) 722-1773
Email address:	huy.tran@usu.edu

1.3 USU Sponsored Programs Office Information

Maren Redd
Utah State University
1415 Old Main Hill
Logan, UT 84322
(435) 797-9089
maren.redd@usu.edu

1.4 Funding Requested

Total Project Budget:	$109,048
UDAQ Funding:	$98,048
USU co-funding:	$11,000

1.5 Project Period

July 1, 2021 – June 30, 2022

2.0 Scope of Work

2.1 Abstract

Ramboll and the Bingham Research Center (BRC) of Utah State University (USU) are pleased to present this proposal in response to the Request for Proposals, "Science for Solutions Research Grant - FY 2022." This project will be conducted as a collaboration among Ramboll, BRC, and Dr. William Stockwell of the University of Texas at El Paso as an independent sub-contractor. The objective of the study is to thoroughly investigate wintertime ozone prediction sensitivity in the Uinta Basin (UB) among two current photochemical mechanisms using a consistent modeling platform. Recent modeling conducted by BRC using different modeling systems indicates that the Regional Atmospheric Chemistry Mechanism (RACM) produces much higher ozone concentrations than Carbon Bond (CB) mechanisms. Our proposed scope of work will: (1) implement RACM version 2 (RACM2) into the Comprehensive Air quality Model with extensions (CAMx); (2) develop RACM2 photolysis rates for CAMx and emission speciation profiles for the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system; and (3) comprehensively test and understand RACM2 performance in simulating wintertime ozone in the UB relative to the CB version 6 (CB6) mechanism currently implemented in CAMx.

Our proposed project will address one of the goals and priorities defined in the RFP: (VI) Air Quality and Meteorological Model Improvements. Ramboll is the developer of CAMx, which is used throughout the State of Utah to address air quality issues and to provide the technical underpinnings of State Implementation Plans in both UB and the Wasatch Front ozone nonattainment areas. Our proposed project leverages the modeling datasets, insights and experience from BRC's photochemical modeling research projects addressing wintertime ozone in the UB. Dr. Stockwell is the author of the RACM photochemical mechanism and will serve as technical advisor on implementing RACM2 in CAMx and developing photolysis rates and emission speciation profiles.

2.2 Basis and Rationale

Background and Previous Work

Under specific wintertime stagnation conditions, ozone concentrations in the UB can exceed the health-based National Ambient Air Quality Standard (NAAQS). The US Environmental Protection Agency (EPA) designated the UB below an elevation of 6,250 feet as a Marginal Nonattainment Area for the 2015 ozone NAAQS (EPA, 2018a). With continued ozone exceedances in February and March 2019, EPA is certain to re-designate the area to Moderate in 2021. This designation will require agencies who have jurisdictions over the UB, including the Utah Division of Air Quality (UDAQ) and the Ute Tribe, to develop Implementation Plans that demonstrate how emission reduction strategies will attain the standard by 2024. In a manner consistent with EPA guidance (EPA, 2018b), the demonstration must employ photochemical modeling that accurately replicates conditions during historical winter ozone episodes and appropriately simulates effects of emission strategies.

Photochemical modeling studies of the UB winter ozone phenomenon began in 2013. These studies have employed a variety of models, including the Community Multiscale Air Quality (CMAQ) modeling system (e.g., AECOM and STI, 2014;, Tran et al., 2015, Matichuk et al., 2017), the Comprehensive Air quality Model with extensions (CAMx; e.g., Emery et al., 2015, Lyman et al., 2019, Mansfield, Tran and Tran, 2017) and the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem; e.g., Ahmadov et al., 2015, Lyman et al., 2020). Further, these studies utilized several photochemical mechanisms including

Carbon Bond 2005 (CB05; Yarwood et al., 2005), Carbon Bond version 6 (CB6; Emery et al., 2015), the California Statewide Air Pollution Research Center 2007 mechanism (SAPRC07; Carter, 2010), and the Regional Atmospheric Chemistry Mechanism version 1 (RACM1; Stockwell, 1997). In spite of recent improvements to meteorological simulations and ozone precursor emissions estimates, most photochemical models strongly underestimate winter ozone.

Modeling studies documented by Ahmadov et al. (2015) and Lyman et al. (2020) indicate that much higher ozone can be achieved using WRF-Chem with RACM1. Recently, Lyman et al. (2020) tested two emission inventories: the standard "bottom-up" (BU) 2014 National Emissions Inventory, and a "top-down" (TD) emission inventory estimated from ambient aircraft and surface sampling conducted during a 2013 episode (Ahmadov et al., 2015). In both cases, WRF-Chem/RACM1 generated significantly more ozone than WRF-Chem/CB05 or CAMx/CB6 (Figure 1). RACM1 contains several aldehyde-forming reactions that are omitted from the CB mechanisms, which could be at least part of the reason for the difference.

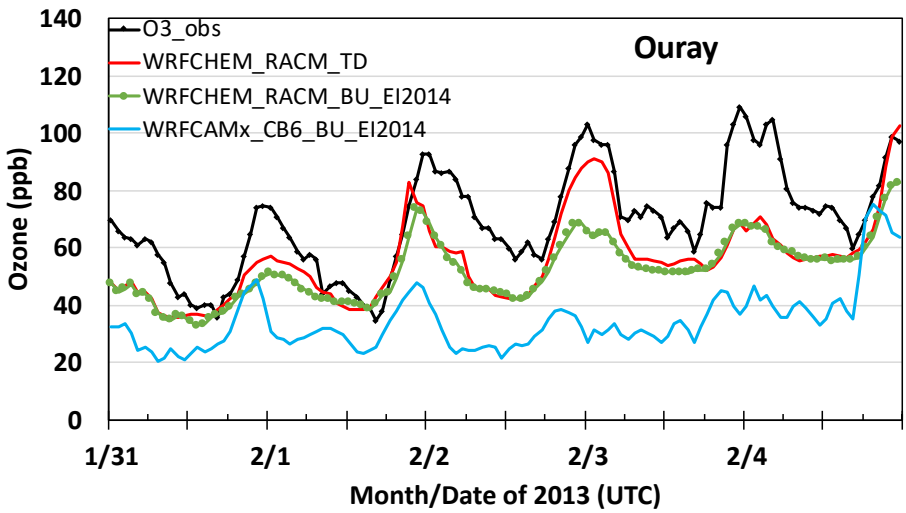

Figure 1. Simulated ozone concentrations at Ouray using WRF-CHEM/RACM1 with the 2013 top-down (TD) emission inventory (red), WRF-Chem/RACM1 with the 2014 bottom-up (BU) emission inventory (green), and CAMx/CB6 with the 2014 BU inventory (blue). Observed ozone is shown in black. Taken from Figure 5-11 in Lyman et al. (2020).

Lyman et al. (2020) consider their results preliminary. The consensus among photochemical modelers is that RACM and CB mechanisms are not likely to result in significant differences in ozone concentrations, so this finding is surprising and merits further scrutiny. Research published in peer-reviewed literature (Knote et al., 2015; Sarwar et al., 2013) comparing RACM and CB mechanisms for both summer and winter conditions show only a small difference between that two, but no comparison has been made for winter conditions with high ozone. It remains necessary to verify these findings, carefully investigate reaction mechanisms, and compare simulated concentrations of many different chemicals to measurements to determine which mechanism best approximates winter conditions unique to the UB.

The RACM1 mechanism was developed two decades ago and is now considered obsolete relative to contemporary mechanisms such as RACM2 (Stockwell and Goliff, 2013) and CB6, which reflect significant science updates. Therefore, it is necessary to determine if the

ozone sensitivity reported by Lyman et al. (2020) carries over to RACM2. Currently, the RACM1 mechanism is only available in WRF-Chem. However, as a coupled meteorology-chemistry model, WRF-Chem demands much larger computational resources than its decoupled counterparts like CAMx or CMAQ because WRF-Chem must simulate meteorology in tandem with chemistry in every run. BRC reports nearly a 20-fold increase in run time between WRF-Chem/RACM1 and CAMx/CB6. Therefore, it will be most useful to perform new tests comparing RACM2 and CB6 in the photochemical model platform that UDAQ intends to use for the UB ozone State Implementation Plan (SIP).

Objectives

Our objectives for the proposed project include:

1) Implement RACM2 into CAMx and its Probing Tools such as source apportionment, process analysis and the Decoupled Direct Method (DDM) of sensitivity analysis;

2) Prepare UB emission inputs, photolysis rates, and initial/boundary conditions specific to RACM2 speciation;

3) Apply CAMx for a historical episode that aligns with UDAQ's UB SIP modeling platform, and comprehensively evaluate ozone predictions from RACM2 and CB6 to understand underlying causes of differences.

This project will leverage the expertise of the CAMx model developers at Ramboll, the RACM mechanism developer, Dr. Stockwell, and air quality modelers at USU/BRC in the application and evaluation of photochemical models for winter ozone in the UB. The CAMx/RACM2 model will include the wintertime improvements that UDAQ previously funded (Emery et al., 2015). The project will also leverage BRC's computational resources, extensive ozone and VOC measurements database, and UDAQ's latest comprehensive UB oil and gas emission inventory.

Alignment with FY 2022 Science for Solutions Goals and Priorities

Our proposed project will address one of the goals and priorities defined in the RFP: (VI) Air Quality and Meteorological Model Improvements, with a focus on "improving the chemical mechanism and physical processes associated with wintertime air pollution".

Measurable Benefits Utah DAQ Can Report to the Legislature

This project will offer new insights and provide definitive, quantified conclusions on the sensitivity of simulated wintertime ozone in the UB to the choice of photochemical mechanism based on a consistent modeling system. The updated model will be publicly available to support future research into the UB winter ozone phenomenon, and directly applicable to UDAQ's development of the UB ozone SIP.

Leveraging of Other Resources

USU will provide matching funds for this project from the Uintah Basin Air Quality Research Project, which is funded by the Utah legislature. See Section 3 for specific information.

2.3 Technical Approach

Task 1: Implement RACM2 in CAMx

Ramboll will lead and conduct the scope of work under Task 1. At the start of the project, we will coordinate with Dr. Stockwell, the RACM2 mechanism developer, to obtain an accurate and current mechanism listing in electronic format, including the chemical species

list, reactions, rate constants, and photolysis data. We will format these data for use in Ramboll's Chemical Mechanism Compiler (CMC), which automates the development of Fortran code for CAMx that efficiently solves the matrix of gas-phase reaction equations. Additionally, the CMC produces code that meters chemical reactions to support CAMx Probing Tools, such as Source Apportionment, Decoupled Direct Method (DDM) of sensitivity analysis, and Process Analysis. We will then incorporate the resulting RACM2-specific Fortran code into the latest CAMx model (currently v7.1, released in January 2021) such that RACM2 can be invoked as an option among several available gas-phase chemical mechanisms. Note that while the CAMx aerosol chemistry routines will not be modified, we will interface the RACM2 mechanism with the CAMx aerosol chemistry algorithms.

Additionally, we will implement RACM2 photolysis data, including species-dependent quantum yields and cross-sections, into the CAMx photolysis rate preprocessor. This processor is built upon the Tropospheric Ultraviolet and Visible (TUV) radiative transfer model developed by the National Center of Atmospheric Research (NCAR, 2021). TUV uses information such as solar zenith angle, altitude, ozone column and other atmospheric constituents to calculate mechanism-specific photolysis rate inputs for CAMx.

We will test and quality assure CAMx and TUV updates by applying our standard model development testing protocol suite. The first step includes process-level testing and benchmarking to ensure code changes are correct and error-free. Then we test the entire CAMx system using our standard 2-day test case to check for reasonableness and to quantify concentration differences for all species resulting from the updated model relative to the unmodified model (i.e., in this case, RACM2 vs. CB6). These tests are applied for the core model and all Probing Tools. Any differences outside our reasonable expectations are flagged for more in-depth diagnostic evaluation and testing until causes are identified and fixed or are otherwise confirmed to be correct.

Task 2: Implement RACM2 for SMOKE Emissions Processing

Ramboll will lead and conduct the scope of work under Task 2, with assistance from BRC. We will coordinate with Dr. Stockwell to obtain information needed to map individual VOC compounds to the RACM2 model species. The mapping information will serve as the basis for creating emission speciation profiles for SMOKE (CMAS, 2021) specific for the CAMx RACM2 mechanism. We will develop RACM2 speciation profiles for SMOKE from SPECIATE 5.1 that specifically support the BRC's UB modeling database and can also support EPA national CAMx modeling platforms.

Task 3: Testing and Analysis in Uinta Basin

BRC will lead and conduct the scope of work under Task 3. Modelers at BRC will apply the modified CAMx/RACM2 model developed under Task 1 to simulate the winter ozone episodes that occurred within the UB from January 31 to February 10, 2013 (Figure 2). This episode has been extensively analyzed and modeled by many groups. Based on recent communications with UDAQ, we understand that the agency will continue to apply CAMx for this same period to support their UB ozone SIP. Therefore, this project will leverage the most recent input datasets that have already been developed. For example, new WRF meteorological modeling will not be needed for this project as we will employ the WRF simulations that BRC has conducted specifically for UDAQ's ozone SIP model (Tran and Tran, 2021).

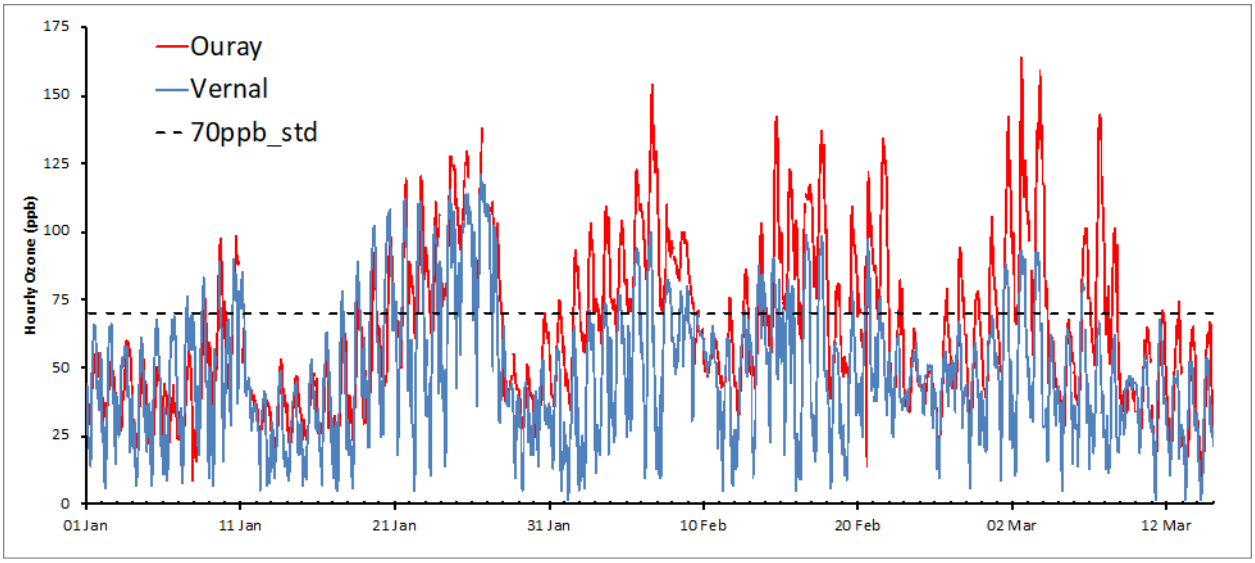

Figure 2. Observed ozone concentrations at Ouray and Vernal during January – March 2013. Time in MST.

We will configure CAMx identically to the 2017 Air Resource Management Strategy (ARMS) modeling study (Mansfield, Tran and Tran, 2017) as detailed in Table 1. BRC will perform CAMx simulations on domain "d03" in Figure 3, which comprises a high-resolution grid with 1.33 km spacing. Boundary and initial conditions will be taken from existing datasets developed for CB6, with necessary updates to accommodate different RACM2 speciation. BRC will run CAMx using both RACM2 and CB6 and with two different UB emission inventories, 2013 and 2017, to assess mechanism sensitivity to emission levels from the oil and gas sector.

Estimates of NOx and VOC emissions are vastly different in UDAQ's Uintah Basin Emission Inventory for oil and gas productions for base years 2014 (UDAQ, 2014) and 2017 (UDAQ, 2017), referred to as UBEI2014 and UBEI2017, respectively. For example, VOC emissions in Duchesne and Uintah counties total 90,383 tons/yr in UBEI2014 but increase to 155,651 tons/yr in UBEI2017. Such a VOC increase will likely have a significant impact on modeled ozone using either chemistry mechanism. Therefore, we will separately employ UBEI2014 and UBEI2017 in the analyses of both CAMx/RACM2 and CAMx/CB6.

BRC will use the SMOKE emission processing system (CMAS, 2021) to process the UBEI2014 and UBEI2017 without applying any emission projections to the 2013 base year. Other anthropogenic emissions will be taken from the NEI2017 database. We will use the RACM2 speciation profiles from Task 2.

BRC will evaluate the performance of CAMx/RAMC2 and CAMx/CB6, as well as prior modeling conducted by BRC, against the available ozone and precursor measurement data. CAMx model performance will be evaluated following EPA (2018b) guidelines. Observation data available for the model performance evaluation include ozone, NOx, NOy, total VOC, formaldehyde, benzene, toluene, xylene, groups of alkanes and alkenes that were measured by BRC and other research entities in 2013 (Stoeckenius and McNally, 2014).

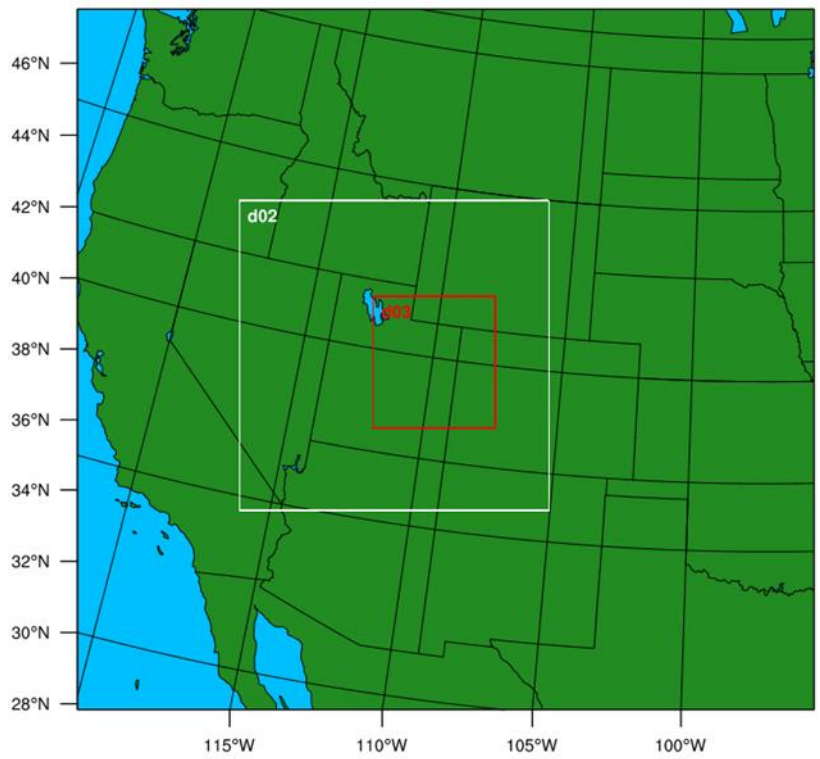

Figure 3. Spatial coverage of WRF model domain as configured in Tran and Tran (2021). CAMx simulations will be performed for domain d03.

Table 1. CAMx model configuration.

Science Options	Configuration
Model Code Version	CAMx v7.1 (updated with RACM2)
Horizontal Grid	1.33 km (298x322)
Vertical Grid	25 vertical layers
Initial and Boundary conditions	Existing ARMS datasets (updated for RACM2)
Landuse Data	Land-use fields from meteorological model
Photolysis Rate Preprocessor	TUV V4.8 (Clear-sky photolysis rates based on TOMS data)
Gas-phase chemistry	CB6 and RAMC2
Aerosol phase	CF (coarse and fine mode aerosols)
Plume-in-Grid sub-model	Not invoked
Surface Chemistry sub-model	Not invoked
Diffusion Scheme	
Horizontal grid	Explicit horizontal diffusion
Vertical grid	K-theory 1st-order closure without ACM2 convection
Deposition Scheme	
Dry deposition	ZHANG03
Wet deposition	CAMx formulation
Numerical Solvers	
Gas-phase chemistry	Euler Backward Iterative (EBI) solver
Horizontal advection	Piecewise Parabolic Method (PPM)
Vertical advection	CAMx formulation

We will also perform CAMx simulations invoking the in-line Chemical Process Analysis (CPA) tool for both RACM2 and CB6 to develop chemical explanations of differences between model results. Detailed comparisons of CPA outputs (e.g., photolysis rates, radical concentrations, ozone production and loss rates, formaldehyde production, etc.) of the two mechanisms will be performed and analyzed to isolate key differences.

Task 4: Project Management and Reporting

This task will comprise project management activities during the execution of the contract. Activities include: (1) day-to-day staff and resource management; (2) internal team meetings and external conference calls with UDAQ, including a project kickoff meeting; (3) monthly invoicing and progress reporting to UDAQ; (4) preparation of quarterly progress reports; (5) assembly of the draft and final project report; (6) preparation for, and attendance at the Science for Solutions technical conference; and (7) sharing of data and modeling system with UDAQ.

2.4 Expected Outputs and Outcomes

Based on the technical approach described above, the Ramboll/BRC team expects to gain new insights, and to draw definitive, quantified conclusions on the sensitivity of simulated wintertime ozone in the UB to the choice of photochemical mechanism based on a consistent modeling system. The team will provide UDAQ with the modeling programs, datasets and evaluation products from our proposed study.

2.5 Deliverables

Monthly and Quarterly Progress Reports

Ramboll is proposing to conduct our portion of the study on a time and materials basis. As such, we will submit monthly invoices for labor and other direct costs around the 15th of the following month. Each invoice will be accompanied by a brief monthly progress report that summarizes activities performed during the month, anticipated activities for the following month, and a budget summary.

As required by the RFP, the team will prepare quarterly progress reports over the course of the contract. Based on information in the RFP, and assuming a start date of July 1, 2021, quarterly reports will be submitted in October of 2021, and in January and April of 2022. Each report will follow the example template provided by the UDAQ.

Final Report

A draft final project report is required within 90 days of project completion. The team will develop a draft report and submit it to UDAQ for review at the close of all technical work. The team will then address comments and suggestions received on the draft, compile the final report and submit it to UDAQ by the specified deadline. The final report will contain all of the components required by UDAQ and listed in the RFP.

Conference Presentation

As required by the RFP, the team will prepare and deliver an oral or poster presentation at a Science for Solutions conference. The presentation will include study objectives, approach, results, and recommendations for any additional investigation. The specific conference that we attend will be decided in coordination with UDAQ; based on information in the RFP and our proposed schedule, we expect to attend the conference in Spring 2022. We understand that the conference may be held virtually.

Data Sharing

The team will share with UDAQ all datasets and models developed during the course of the proposed project. We will arrange with UDAQ the most appropriate way to provide the data. Following the specifications of the RFP, all data to be shared will be made available within 8 months of project completion. We anticipate the following data will be generated and shared from this project:

- All CAMx modeling codes, scripts and files specifically developed in this work (all other general CAMx updates are periodically made available to the public at Ramboll's website www.camx.com);
- All CAMx, SMOKE, and pre-processor inputs;
- All CAMx and post-processor output files, or a subset of key files selected in coordination with UDAQ.

2.6 Schedule

Our proposed project schedule with key deliverable dates is shown in Figure 4. We anticipate a start date of July 1, 2021 and expect to complete all tasks of the project by June 30, 2022, including the submission of our final report and presentation at the Spring 2022 Science for Solutions conference. We expect to complete all data transfer by June 30, 2022.

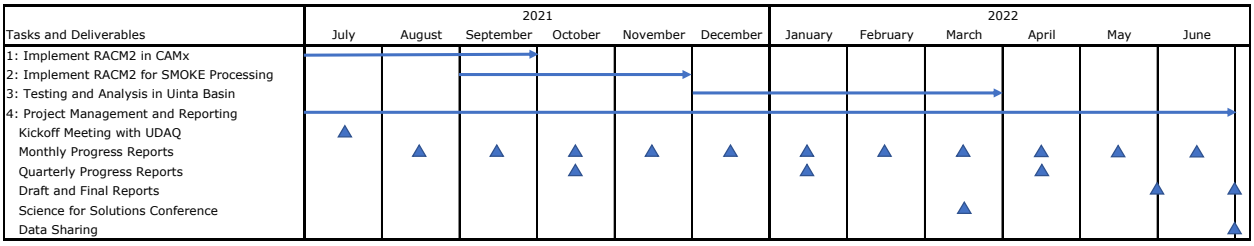

Figure 4. Proposed project schedule by task, including deliverable dates.

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3.0 Budget

This project will be completed as a collaboration among Ramboll, BRC, and Dr. William Stockwell. Dr. Stockwell will serve under subcontract to Ramboll. We request that Utah DAQ contract with USU and Ramboll separately. USU charges indirect costs for subcontracts, so if Utah DAQ contracts with Ramboll and USU separately we will be able to avoid those indirect costs. Ramboll and BRC will submit invoices separately to UDAQ.

The total estimated cost for the scope of work described in Section 2 is $109,048, which is split among Ramboll with Dr. Stockwell ($53,564) and USU ($55,484). USU will provide $11,000 (10%) in matching funds for this project from the Uintah Basin Air Quality Research Project, which is funded by the Utah legislature. Therefore, the total requested funding from UDAQ is $98,048.

3.1 Ramboll Budget

Table 2 presents a detailed budget workup, which includes costs by task, personnel (fully loaded labor rates, hours and cost), and other direct costs. Ramboll's loaded labor rates are developed by applying our indirect rates (Fringe, Overhead, G&A and Fee) to bare salaries. We base our indirect costs on the preceding fiscal year's actual expenditures for benefits and fringes, overhead, and G&A expenses. At the end of each fiscal year, actual expenses are compared to the previous year's and any significant variances in indirect rates are applied back through rate adjustments.

We add 3% to direct labor costs for telephones, copier services, and facsimile charges, and 3% of our personnel direct labor costs for computers and printers (6% total). These indirect rates are not applied to sub-contractor costs. Additionally, we are waiving our customary 10% fee on Dr. Stockwell's subcontractor labor cost.

Table 2. Ramboll proposed project budget, including breakdown by task, personnel (rates, hours and cost), and other direct costs.

	Hourly Labor Rate	Task 1 Implement RACM2 in CAMx		Task 2 Implement RACM2 in SMOKE		Task 3 Testing & Analysis		Task 4 Management & Reporting		Total All Tasks	
Lbr Category/Name		**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**
Principal											
Greg Yarwood	235.00	24	5,640	8	1,880	8	1,880	14	3,290	54	12,690
Sr. Managing Consultant											
Chris Emery	204.75	8	1,638	4	819	16	3,276	59	12,080	87	17,813
Managing Consultant											
Tejas Shah	169.37		0	8	1,355	4	677	12	2,032	24	4,065
Gary Wilson	178.40	8	1,427		0		0		0	8	1,427
Ross Beardsley	149.04	2	298	2	298		0		0	4	596
Consultant 2											
Yuge Shi	103.88	40	4,155	8	831		0	4	416	52	5,402
Sai Sredhar Varada	103.88		0	24	2,493		0	4	416	28	2,909
Sr. Support	105.00		0		0		0	4	420	4	420
Support	98.61		0		0		0	16	1,578	16	1,578
Ramboll Labor Subtotal		82	13,158	54	7,676	28	5,833	113	20,231	277	46,900
Subcontractor											
Dr. William Stockwell	150.00	12	1,800	4	600		0	4	600	20	3,000
G&A on Subcontractors	0.00%		0		0		0		0		0
Labor Subtotal		94	14,958	58	8,276	28	5,833	117	20,831	297	49,900
Other Direct Costs											
Communications (1)	3%		395		230		175		607		1,407
Computing (2)	3%		395		230		175		607		1,407
Travel			0		0		0		750		750
Misc.									100		100
ODCs Subtotal			790		461		350		2,064		3,664
GRAND TOTAL		94	15,748	58	8,737	28	6,183	117	22,895	297	53,564

Other direct costs include a high-volume data disk drive to transfer project-generated modeling datasets, programs and scripts to UDAQ at the close of the project. To account for the possibility that the 2022 Science for Solutions conference is held in-person rather than virtually, other direct costs include travel for a single-person 1-day trip by air with meals and hotel accommodations. No other costs related to equipment, materials/supplies, or travel is anticipated during the project.

We propose to conduct this study on a time and materials basis. As such, we will submit monthly invoices for labor and other direct costs around the 15th of the following month. We request payment terms on a net 30-day basis.

3.2 USU Budget

Table 3 presents the project budget for activities to be carried out by BRC. Total budget estimated for BRC is $55,484, which includes:

- Personnel costs ($48,140): 620 person-hours for Huy Tran at $41/hour and 120 person-hours for Seth Lyman at $62/hour, fringe benefits calculated as 46.5% of salaries.
- Supplies ($1,800): Data storage for model inputs and outputs on Utah CHPC system, estimated for 12 TB at $150/TB.
- Travel costs ($500): Travel costs for 1 person to the Utah Science for Solution conference during Spring 2022; costs assume one automobile round-trip from Vernal to Salt Lake City, with per-diem but without lodging.
- Indirect costs ($5,044): Facilities and administration costs are calculated as 10% of direct costs as allowed by the RFP.

Table 3. Budget Summary for USU/BRC.

	Total Funded by Utah DAQ	Matching Funds	Grand Total
PERSONNEL			
Huy Tran 620h@$41/h	**$25,420**		**$25,420**
Seth Lyman 120h@$62/h	**$614**	**$6,826**	**$7,440**
BENEFITS @ 46.5%	**$12,106**	**$3,174**	**$15,280**
SUPPLIES			
Computer Storage	**$1,800**		**$1,800**
TRAVEL			
Travel for 1, Sci. for Solns.	**$500**		**$500**
TOTAL DIRECT COSTS	**$40,440**	**$10,000**	**$50,440**
TOTAL INDIRECT @10%	**$4,044**	**$1,000**	**$5,044**
TOTAL PROJECT COST	**$44,484**	**$11,000**	**$55,484**

4.0 Personnel Roles and Responsibilities

Below we list the key personnel that will conduct the proposed scope of work, noting their titles and describing their main roles and responsibilities. We also provide a summary paragraph for each describing relevant qualifications and experience. Full resumes for each are presented in Appendix A. Additional Ramboll and BRC staff, not listed here for page restrictions, will be utilized in this project to support our key personnel.

Dr. Greg Yarwood (Ramboll) will serve as the project co-principal investigator. Dr. Yarwood will lead the implementation of the RACM2 photochemical mechanism in CAMx, oversee emissions speciation, and contribute to progress and final reporting.

Dr. Yarwood is an internationally recognized expert with 30 years of experience in atmospheric chemistry, air quality modeling, photochemical model development, interpreting ambient air quality data, and emissions inventory development. He directs air quality, meteorological and emissions modeling studies for clients in government and industry with emphasis on photochemical air pollution issues, such as ozone, secondary particulate matter (PM), visibility and air toxics. Greg designs and directs complex photochemical modeling studies using models such as CAMx, CMAQ, GEOS-Chem, SCICHEM and WRF-Chem. He oversees development of Ramboll's Comprehensive Air quality Model with extensions (CAMx: http://www.camx.com) and he implemented the CAMx methods for source attribution (OSAT and PSAT), sensitivity analysis (DDM and HDDM) and process analysis. He is an expert atmospheric chemist and leads development of the Carbon Bond chemical mechanisms (including CB05 and CB6) that are used to model ozone and PM in both CAMx and US EPA's CMAQ model. He has specialized expertise in characterizing air emissions from biogenic sources, engines and industrial flares. He has performed international air quality studies in Europe, the Middle East, China, Australia and Africa. In the US, Greg advises regional, state and local planning agencies as they develop and implement plans to address air quality (non-attainment) issues. He is experienced in communicating on air quality matters in settings that range from international scientific conferences to local meetings with diverse audiences. His publication record has an H-index

of 39. Greg was appointed to USEPA's Board of Scientific Counselors for the Clean Air Research Program.

Dr. Huy Tran (BRC) will serve as the project co-principal investigator. Dr. Tran will lead the processing of Uinta Basin emission inventories for CAMx, lead the application, testing and evaluation of CAMx using BRC's Uinta Basin CAMx modeling platform, and contribute to progress and final reporting.

Dr. Tran has more than 10 years performing research as an air quality modeler and has experience with various modeling system including meteorology models (WRF, MM5), dispersion models (AERMOD, CALPUFF), receptor models (CMB, PMF) and photochemical models (CAMx, CMAQ). He carried out researches involving modifying source codes of WRF and CAMx model and so gained extensive understanding on the models' structure. He participated in performing WRF simulations for UDAQ's ozone SIP model based on which is this project, Dr. is elevated

Mr. Chris Emery (Ramboll), will serve as overall project manager while assisting and guiding photochemical modeling applications and evaluation. In this capacity, Mr. Emery will manage Ramboll's day-to-day project activities including ensuring the project remains on schedule and budget, managing personnel assignments, and communicating progress, technical issues, and results to UDAQ. He will also lead the development of the project report.

Mr. Emery has 30 years of experience in numerical modeling and analysis of multi-scale air pollution and meteorology. His expertise includes design, development and application of air quality modeling systems. Chris co-authors the Comprehensive Air Quality Model with extensions (CAMx). He has applied a variety of models for private and public clients, in both local and regional regulatory arenas, throughout the US and abroad. His projects have included ozone, particulate matter and carbon monoxide modeling to support regulatory planning; analyzing source contributions and emission sensitivity; modeling fate of toxic air pollutants; determining effects of alternative and innovative air quality management strategies including urban heat island mitigation; studying prospective and retrospective air quality trends; and estimating North American background ozone. Chris has applied and evaluated meteorological models and global chemical transport models to develop inputs needed by regional photochemical modeling applications. He has served as a member of the American Meteorological Society's Board of the Urban Environment.

Mr. Tejas Shah (Ramboll) will lead the development of RACM2 emission speciation profiles for use in the SMOKE emission processing system.

Mr. Shah has over 17 years of experience with air pollution analyses. His expertise includes emission inventory development, emission modeling, air quality modeling, spatial analysis with GIS, database tool development, control-measure evaluation and economic impact analysis. Tejas manages EPA work to maintain the Speciation Tool ancillary processor that creates speciation profiles for SMOKE using SPECIATE data. He has managed a review of available emission inventories for Mexico that are used in photochemical modeling studies of North America, which used satellite-derived data products for sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and natural gas flaring to evaluate spatial characterization and magnitude of the emissions inventories. Tejas has managed photochemical modeling studies for the US and area around the world and has supported developing oil and gas emission inventories in the western US. Additionally, he has extensive experience emissions inventories developed by Regional Planning Organizations, the US EPA national emissions inventory (NEI), and the Environment Canada national inventory. Tejas' work at Ramboll includes Sparse Matrix

Operator Kernel Emissions (SMOKE) processing of regional and project-level emission inventories for various oil and gas EIS projects in the Intermountain West; preparing gridding surrogates and speciation profiles for the SMOKE model input; augmenting SPECIATE—a repository of speciation profiles; spatial analyses and preparing landuse/landcover files for the Comprehensive Air Quality Model with extensions (CAMx) and MEGAN models using GIS; and developing database tools.

Dr. Seth Lyman (BRC) will serve as a technical advisor on the project, prepare measurement data for comparison with model results, and will aid in overall study execution, analysis, and report writing.

Dr. Lyman has successfully completed a wide array of air quality research projects during his career, including emissions measurements from oil and gas sources and ambient air quality measurement campaigns. He has more than nine years of experience researching the wintertime ozone issue in the Uinta Basin.

Dr. William Stockwell (UTEP/Consultant) will serve as technical advisor on implementing RACM2 in CAMx and developing photolysis rates and emission speciation profiles.

Dr. Stockwell is a research professor at the University of Texas at El Paso. He has authored or co-authored 250 scientific publications on atmospheric chemistry and physics. His research interests include the development of atmospheric chemistry mechanisms, air quality modeling, field measurements for model evaluation and research on the effects of toxic environmental agents on biologically important molecules. He developed the Regional Acid Deposition Model/Regional Atmospheric Chemistry Mechanism series that is widely used for air quality modeling. Dr. Stockwell has performed air quality modeling to evaluate ozone and particulate matter photochemical formation pathways for cities such as Los Angeles, California and El Paso, Texas. Dr. Stockwell is the editor for atmospheric chemistry of the Bulletin of the American Meteorological Society. His honors include the American Meteorological Society Editor's Award (2009), a fellowship from the Oak Ridge Institute for Science and Education (2008 – 2009) and the Alfred P. Sloan Foundation recognized him for advancing the education of underrepresented minority students in mathematics, science and engineering (2008).

APPENDIX A

Resumes of Key Personnel

GREGORY YARWOOD, PhD

Principal

Dr. Greg Yarwood is an internationally recognized expert with 30 years of experience in atmospheric chemistry, air quality modeling, photochemical model development, interpreting ambient air quality data, and emissions inventory development. He directs air quality, meteorological and emissions modeling studies for clients in government and industry with emphasis on photochemical air pollution issues, such as ozone, secondary particulate matter (PM), visibility and air toxics. Greg designs and directs complex photochemical modeling studies using models such as CAMx, CMAQ, GEOS-Chem, SCICHEM and WRF-Chem. He oversees development of Ramboll's Comprehensive Air quality Model with extensions (CAMx: http://www.camx.com) and he implemented the CAMx methods for source attribution (OSAT and PSAT), sensitivity analysis (DDM and HDDM) and process analysis. He is an expert atmospheric chemist and leads development of the Carbon Bond chemical mechanisms (including CB05 and CB6) that are used to model ozone and PM in both CAMx and US EPA's CMAQ model. He has specialized expertise in characterizing air emissions from biogenic sources, engines and industrial flares. He has performed international air quality studies in Europe, the Middle East, China, Australia and Africa. In the US, Greg advises regional, state and local planning agencies as they develop and implement plans to address air quality (non-attainment) issues. He is experienced in communicating on air quality matters in settings that range from international scientific conferences to local meetings with diverse audiences. His publication record has an H-index of 39. Greg was appointed to USEPA's Board of Scientific Counselors for the Clean Air Research Program.

CONTACT INFORMATION

Gregory Yarwood

gyarwood@ramboll.com
+1 (415) 899 0704

Ramboll
7250 Redwood Boulevard
Suite 105
Novato, CA 94945
United States of America

CAREER

1995-Present
Principal
Ramboll (formerly Ramboll Environ and ENVIRON)

1991-1995
Senior Scientist
ICF Systems Applications International, San Rafael, California, United States

1988-1991
Post-Doctoral Researcher
Centre for Atmospheric Chemistry, York University, Canada

1987-1988
Post-Doctoral Researcher
Brookhaven National Laboratory, New York, United States

EDUCATION

1987
PhD, Chemistry
University of Cambridge, United Kingdom

1982
BSc, Chemistry
University of Bath, United Kingdom

EXPERIENCE

Regional Air Quality Planning

- Near-real-time (NRT) photochemical modeling for Texas since 2013. The WRF/CAMx-based system models US-wide air quality with fine-scale resolution for Dallas and Houston.
- Global modelling using GEOS-Chem to determine contributions of US and foreign emissions to background ozone in Texas' ozone non-attainment areas.
- Developed ozone control strategies for the Northeast Texas region through a multi-stakeholder process. These measures are included in the Texas State Implementation Plan (SIP) and the region is attaining the National Ambient Air Quality Standards (NAAQS).
- Technical support to the Midwest Regional Planning Organization (MRPO) and member states in conduction regional planning for particulate matter (PM), visibility, ozone and mercury deposition.
- Directed technical studies to support Texas' State Implementation Plan (SIP) for the Houston and Dallas ozone nonattainment areas including air quality, meteorological and emissions modeling and the design and evaluation of emissions reduction strategies.
- Regional air quality planning studies for the Arabian Gulf (confidential client), China (Pearl River Delta) and Southern Africa (Cross-border Air Pollution Impact Assessment).
- Modeling weekday/weekend emissions changes and air quality for the Los Angeles area to demonstrate that lower weekend NOx emissions are the cause of higher weekend ozone.

Photochemical Model Development

- Ramboll's Comprehensive Air quality Model with extensions (CAMx). Greg has primary responsibility for the gas-phase chemistry for ozone and secondary PM, and the advanced "probing tools" for source apportionment (OSAT and PSAT), sensitivity analysis (DDM) and chemical process analysis (CPA).
- Designed a full-chemistry plume-in-grid model for CAMx called IRON-PiG (Incremental Reactions for Organics and NOx) to better represent the evolution of plumes from major point-sources within a grid model simulation.
- Developed the gas-phase chemistry solvers and associated chemical mechanism compiler (CMC) for the CAMx model.

Air Quality Data

- Developed conceptual models describing the reasons for high 1-hour and 8-hour ozone in the Dallas area and Northeast Texas to guide the development of the State Implementation Plan.
- Testified on the PM impacts of re-powering a large utility boiler from oil to gas in a major Northeastern US city.
- Designed aircraft-based and surface monitoring studies for ozone and precursors in Texas.
- Analyzed ozone air quality benefits for reformulated fuels and advanced vehicle programs across all of Canada for the Canadian Council of the Ministers of the Environment.
- Reviewed VOC receptor modeling and ambient ratio (VOC/NOx and CO/NOx) studies for evidence of systematic biases between emission inventories and ambient data.
- Evaluated the air quality impacts of offshore oil drilling near Prudhoe Bay and the Arctic National Wildlife Refuge ANWR) in Alaska.

Atmospheric Chemistry

- Member of the CRC Research Panel on the Atmospheric Chemistry of Hydrocarbons (RPACH) that published reviews of the chemistry of alkenes and aromatic hydrocarbons.
- Developed the 2005 version of the Carbon Bond mechanism (CB05) now used for all EPA regulatory modeling studies of ozone, particulate matter and air toxics.
- Critically evaluated photochemical mechanisms for global tropospheric chemistry for an EPA inter-comparison of models to estimate climate impacts of methane, CO, VOCs and NOx emissions.
- Developed VOC-reactivity scales using 3-D grid photochemical modeling with DDM sensitivity analysis in CAMx.
- Made laboratory measurements of reaction rates for NOx species under high temperature (combustion) and low temperature (stratospheric) conditions.

Emission Inventories

- Directed development of a Northeast Texas emission inventory for SIP modeling and submission to the National Emission Inventory (NEI). Local surveys were conducted to improve the area, off-road and biogenic emission inventories.
- Directed optical remote sensing studies to measure VOC, NOx and SOx emissions from chemical industry facilities in Texas and the Middle East.
- Developed the GloBEIS biogenic emission inventory system as an ACCESS database application. Directed software development, GIS analysis of landcover and satellite data, and tree surveys.
- Developed procedures for analyzing point-specific data to develop VOC speciation profiles for photochemical modeling of the Houston and Dallas areas.
- Analyzed the effects of reformulated/alternative fuels and advanced vehicles on mobile source emissions for the joint Auto/Oil Air Quality Improvement Research Program (AQIRP).

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MEMBERSHIPS

Air and Waste Management Association (AWMA)
American Association for Aerosol Research (AAAR)
American Chemical Society (ACS)
American Geophysical Union (AGU)

Huy Tran, Ph.D.

Sr. Research Scientist, Bingham Research Center
Utah State University
320 N. Aggie Blvd.,Vernal, UT 84078
435.722.1773 (office) 435.219.6818 (cell)
huy.tran@usu.edu

Education

INSTITUTION AND LOCATION	DEGREE	YEAR CONFERRED	FIELD OF STUDY
Ho Chi Minh City University of Technology, Vietnam	B.Eng.	2004	Environmental Engineering and Management
Asian Institute of Technology, Thailand	M.Eng.	2008	Environmental Engineering and Management
University of Alaska Fairbanks, Alaska, U.S.	Ph.D.	2013	Atmospheric Sciences
Utah State University, Utah, U.S.	Post-doc	2014	Air Quality Modeling

PERSONAL STATEMENT

Dr. Tran is a researcher who has great enthusiasm in utilize the power of computers to solve challenges in atmospheric sciences. As such, he has more than 10 years doing research as an air quality modeler who has experience with various modeling system including meteorology models (WRF, MM5), dispersion models (AERMOD, CALPUFF), receptor models (CMB, PMF) as well as 3d-photochemical models (CAMx, CMAQ). Dr. Tran is fluent with various programing langue and is comfortable with modifying model source codes to suit them better for specific studying areas. Working together with colleagues and the USU's Bingham Research Center, he has carried out and participated in projects to develop and improve air quality models for studying winter ozone pollution in the Uintah Basin. Dr. Tran's research aim at providing regulatory agency with effective tools for controlling pollutions, and to promote the public awareness on air quality issues.

POSITIONS AND HONORS: *Concluding with present position, list in chronological order previous employment, experience, and honors.*

2004-2008: Environmental Engineer, Power Engineering Consulting Joint Stock Company 3, Vietnam.
2008: A&WMA Graduate Student Paper Award
2009-2012: Graduate Student Research Assistant, University of Alaska Fairbanks, Alaska
2013: Project Scientist, SLR Consulting, Anchorage, Alaska
2014: Postdoctoral, Bingham Research Center, Utah State University, Vernal, Utah
2014 – present: Sr. Research Scientist, Bingham Research Center, Utah State University, Vernal, Utah
2019: Most appreciated team member, awarded by Bingham Research Center team.

CONTRIBUTIONS TO SCIENCE

Dr. Tran's work has broad impacts on the scientific and regulatory worlds, but also makes a positive contribution in his local community:

1. Dr. Tran has developed software that are utilized by several research groups for ambient air quality monitoring. For example, in collaboration with research group from Bringham Young University in developing instrument for measuring fine particulate maters, Dr. Tran developed a new software that processes the collected data more than ten times faster than the existing software.

2. Dr. Tran work in air quality modeling has contributed widely to other research groups and regulatory agencies, and has significant positive impacts on the local economy. In a particular case, Dr. Tran utilized a global chemistry model to demonstrate a stratospheric ozone intrusion event to the Uintah Basin in 2015. This work ultimately contributed to lowering of Uintah Basin ozone nonattainment status from moderate to marginal which requires less stringent requirements on emissions controls and less strain and the economy.
3. Dr. Tran, together with his colleagues in the Bingham Research Center, operates ozone forecast and alert service for the Uintah Basin during winter season. This service provides the local community with timely warning of upcoming high ozone events and by that appropriate planning on emission control of ozone-generating pollutants and avoidant of could be made.
4. Dr. Tran has authored or coauthored 16 publications with 123 citations. His work in air quality modelling has led to additional study by other research groups.
5. Dr. Tran is actively working with researchers in developing countries such as the South East Asian region to promote air quality research and exchanging expertise in such region.

SELECTED PUBLICATIONS:

1. **Tran, H.N.Q.,** Leelasakultum, K., Mölders, N., **2012**. A Tool for Public $PM_{2.5}$-concentration Advisory based on Mobile Measurements. *Journal of Environmental Protection*, p. 1671-1688, doi: 10.4236/jep.2012.312183.
2. **Tran, H.N.Q.**, Mölders, N., **2012**. Wood-burning device changeout: Modeling the impact on $PM_{2.5}$-concentrations in a remote subarctic urban nonattainment area. *Advances in Meteorology*, 2012, p. 12. doi:10.1155/2012/853405.
3. **Tran, H.N.Q.**, Mölders, N., **2012**. Numerical investigations on the contribution of point-source emissions to the $PM_{2.5}$-concentrations in Fairbanks, Alaska. *Atmos. Pol. Res.* 5, 199-210. doi: 10.5094/APR.2012.022.
4. Nguyen, O.T.K., Permadi, D.A., Bao-Ninh, Z., **Tran, H.N.Q.**, Nguyen, L.P., Kanabkaew, T., Iqbal, A., **2013**. Application of Photochemical Smog Models for Assessment of Ozone, Particulate Matter Air Quality, and Acid deposition in Asian city. In Nguyen O.T.K., *Integrated Air Quality Management - Asian case studies* (pp. 151-197). Boca Raton, FL: CRC Press.
5. Mölders, N. , Butwin, M. , Madden, J. , **Tran, H.** , Sassen, K. and Kramm, G., **2015.** Theoretical Investigations on Mapping Mean Distributions of Particulate Matter, Inert, Reactive, and Secondary Pollutants from Wildfires by Unmanned Air Vehicles (UAVs). *Open Journal of Air Pollution*, **4**, 149-174. doi: 10.4236/ojap.2015.43014.
6. Tran, T., **Tran, H.**, Mansfield, M., Lyman, S., Crosman, E., **2018**. Four dimensional data assimilation (FDDA) impacts on WRF performance in simulating inversion layer structure and distributions of CMAQ-simulated winter ozone concentrations in Uintah Basin. Atmospheric Environment 177, 75-92.
7. **Tran, H.N.Q.**, Lyman, S.N., Mansfield, M.L., O'Neil, T., Bowers, R.L., Smith, A.P., Keslar, C., **2018**. Emissions of organic compounds from produced water ponds II: Evaluation of flux chamber measurements with inverse-modeling techniques, Journal of the Air & Waste Management Association, 68:7, 713-724.
8. Lyman S. N., Holmes M. L., **Tran H. N. Q.**, Tran T., O'Neil, T., 2021. High ethylene and propylene in an area dominated by oil production. Atmosphere, 12, 1.

CHRISTOPHER A. EMERY

Senior Managing Consultant

Chris Emery has 30 years of experience in numerical modeling and analysis of multi-scale air pollution and meteorology. His expertise includes design, development and application of air quality modeling systems. Chris co-authors the Comprehensive Air Quality Model with extensions (CAMx—a regional nested grid photochemical model with Probing Tool extensions), prepares the CAMx User's Guide, and manages public distributions of CAMx and support programs. He has delivered training on photochemical modeling for numerous US and international clients including private, governmental, and academic institutions. He has applied a variety of models for private and public clients, in both local and regional regulatory arenas, throughout the US and abroad. His projects have included ozone, particulate matter and carbon monoxide modeling to support regulatory planning; analyzing source contributions and emission sensitivity; modeling fate of toxic air pollutants; determining effects of alternative and innovative air quality management strategies including urban heat island mitigation; studying prospective and retrospective air quality trends; and estimating North American background ozone. Chris has applied and evaluated meteorological models and global chemical transport models to develop inputs needed by regional photochemical modeling applications. He has served as a member of the American Meteorological Society's Board of the Urban Environment.

CAREER

1995-Present
Senior Managing Consultant
Ramboll / ENVIRON International Corporation

1990-1995
Staff and Senior Scientist
ICF Systems Applications International, San Rafael, California, United States

EDUCATION

1988-1990
MS, Meteorology
San Jose State University, San Jose, California, United States

1985-1988
BS, Meteorology
San Jose State University, San Jose, California, United States

CONTACT INFORMATION

Christopher A. Emery

cemery@ramboll.com
+1 (415) 8990740

Ramboll
7250 Redwood Boulevard
Suite 105
Novato, 94945
United States of America

MEMBERSHIPS

Air and Waste Management Association (AWMA)
American Meteorological Society (AMS)

EXPERIENCE

Air Quality Model Development

- Co-developer of Ramboll's Comprehensive Air Quality Model with extensions (CAMx); manages updates and distribution of CAMx and associated pre- and postprocessors, and model documentation. Conducted CAMx training for numerous US and international private, governmental, and academic institutions.
- Leading the development of a hemispheric CAMx modeling capability.
- Providing technical support for CAMx applications throughout China.
- Co-developer of emission estimating models for sea salt, wind-blown dust, and lightning NOx.
- Assisting the development and testing of a near-real-time CAMx air quality system for Texas.
- Implemented chemical mechanism updates to address ozone formation in cold conditions in oil and gas development basins of the western US.
- Co-developer of the Mesoscale Model InterFace (MMIF) program that directly translates MM5 and WRF meteorological output to CALPUFF and AERMOD input format.
- Co-developer of METSTAT, a widely used program that facilitates the verification and statistical performance evaluation of meteorological models against surface observation data for winds, temperature and humidity.
- Contributed updates/improvements to numerous urban and regional air quality models, including deposition, vertical diffusion parameterizations, plume rise parameterizations, particulate chemistry, plume-in-grid, and calculations of visibility impairment.

Air Quality Model Applications

- Managing modeling analyses of toxic air pollutants and deposition at the Hanford, Washington Site.
- Assessing international anthropogenic pollutant contributions on Utah air quality.
- Reviewed CAMx modeling of $PM_{2.5}$ for the Salt Lake City, Utah, State Implementation Plan; investigated causes of ammonia emission shortfalls in that modeling system.
- Assessed contributions of California natural gas power plants to Statewide ozone and $PM_{2.5}$ using the CAMx source apportionment tool.
- Developed modeling guidance recommendations for single-source environmental assessments for ozone and $PM_{2.5}$ in the Lower Fraser Valley of British Columbia.
- Managed assistance to the San Francisco Bay Area Air Quality Management District of California with modeling of toxic contaminants in support of analyses related to California AB617 actions.
- Managed assistance to the San Joaquin Valley Air Pollution Control District of California with WRF/CAMx air quality modeling in support of $PM_{2.5}$ State Implementation Plans.
- Managed the development of CAMx ozone modeling systems and databases to support regulatory modeling for Baton Rouge, Louisiana.
- Managed an analysis of and comments on EPA's draft guidance on Modeled Emissions Rates for Precursors (MERP) addressing single-source impacts on ozone and $PM_{2.5}$.
- Evaluated global chemical transport models (GEOS-Chem, MOZART, AM3) to characterize US background sources of ozone and to supply boundary conditions for regional models (CAMx and CMAQ).
- Assisted in the development of international CAMx ozone and PM modeling programs for the Marseille area of France, Rhine area of France/Germany, Po Valley (Milan) area of Italy, Medellin area of Colombia, and several areas of Spain.

- Managed a modeling project to estimate ozone sensitivity to US anthropogenic precursor reductions to help inform the EPA ozone NAAQS review process.
- Managed a North American modeling analysis to estimate spatial and temporal patterns in background ozone over the US, and related source attribution, for input to the EPA ozone NAAQS review process.
- Managed the application of a hybrid CMAQ/AERMOD modeling system supported by MM5 meteorological and SMOKE emissions modeling for the Birmingham, Alabama $PM_{2.5}$ SIP.
- Managed a research project investigating the role of current and future local vs. regional sources on PM and visibility in the Columbia River Gorge.
- Managed the development of a CAMx ozone modeling system and database for the Maricopa Association of Governments in Arizona.
- Managed the development and application of a CAMx ozone modeling system and database for the San Francisco Bay Area and central California region.
- Participated in various projects associated with modeling and analysis of Rapid Ozone Formation Events, and control strategy assessments, in the Houston/Galveston area of Texas.
- Analyzed CAMx model performance and carried out sensitivity scenarios for the Dallas-Fort Worth ozone SIP modeling developed by the Texas Commission on Environmental Quality.
- Managed the development of several CAMx modeling databases for the San Antonio and Austin, Texas ozone nonattainment areas.
- Managed the application of CAMx for two episodes in Boise, Idaho, for the development of a PM10 maintenance SIP; managed a screening analysis of 8-hour ozone in Boise.
- Managed the application of CAMx for the Kansas City/St. Louis area for the purposes of developing an 8-hour ozone SIP for the region.
- Developed an international CAMx ozone and CO modeling program for the El Paso, Texas area.

Meteorological Model Applications and Analysis

- Managed a high-resolution application of WRF to the Upper Green River Basin in southwest Wyoming to support winter photochemical modeling of the area.
- Managed an application of WRF to provide boundary conditions for highly refined computational fluid dynamics (CFD) windflow modeling of a neighborhood in the South Coast air basin in California.
- Managed testing of WRF meteorological model improvements that allow for more detailed treatment of clouds and vertical diffusion in the CAMx photochemical model.
- Managed high resolution applications of MM5 for four cities (Detroit, Atlanta, Philadelphia, Seattle) to support annual CMAQ modeling for hazardous air pollutants (toxics).
- Managed several applications of MM5 for the central/eastern Texas area (San Antonio, Austin, Dallas, East Texas) to support ozone modeling for 8-hour ozone State Implementation Plans.
- Assisted in the evaluation of seasonal/annual MM5 meteorological fields used to drive CMAQ and CAMx applications for several Regional Planning Organizations (RPOs).
- Developed meteorological fields with the MM5 meteorological model to drive several CAMx ozone applications in California's South Coast Air Basin, in the Kansas City/St. Louis areas, in the Boise Idaho area, the San Francisco Bay Area, and the Phoenix Arizona area.

Specialized Analyses

- Managed an analysis of impacts on mobile-source NOx, VOC, and CO emissions from gasoline RVP changes in Baton Rouge, LA.
- Reviewed and developed new recommendations on photochemical model performance evaluation and benchmarks for statistical performance metrics.
- Assisted in an EPA evaluation of various modeling platforms for the purpose of simulating single-source impacts on ozone, PM, visibility, and AQRVs for NEPA, PSD, and NSR assessments.

- Applied and evaluated modeling methodologies that simulate the impacts of Urban Heat Island (Cool Communities) measures involving intensive tree planting and use of light-colored building materials to lower urban temperatures and ambient pollutant concentrations in Los Angeles and Houston.
- Assisted in the development of guidance for performance evaluation of air quality modeling systems for PM2.5 and visibility.
- Oversaw an analysis of PM source attributions for all 147 Class I areas in the United States, and used the results to develop a Class I grouping strategy for use by EPA in their promulgation of regional haze rules.
- Evaluated retrospective and prospective local/regional air quality and visibility impairment in federally protected Class I areas across the nation as impacted by the Clean Air Act and 1990 Amendments.

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Emery, C. A. (with others). 2002. "Development of a Joint CAMx Photochemical Modeling Database for the Four Southern Texas Near Non-Attainment Areas." Prepared for the Alamo Area Council of Governments, City of Corpus Christi, City of Victoria, TX.

Emery, C. A., D. Souten, A. Pollack, R. Morris, G. Mansell, Ph. D., B. Joy, C. Anderson, D. Calkins, G. Hawthorne, R. Sawyer, Ph.D., R. Chi, C. Tan, E. Tai. 2002. "Transportation Effects of the 1997 Changes to the National Ambient Air Quality Standards." Prepared for the National Cooperative Highway Research Program. September.

Emery, C. A. (with others). 2001. "Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes." Prepared for the Texas Natural Resources Conservation Commission, Austin, TX.

Emery, C.A. (with others). 2001. "Development of an Ozone Precursor Emission Reduction Credit Program Based on Urban Heat Island Mitigation Measures." Prepared for Environmental Affairs Dept., City of Los Angeles, Los Angeles, CA.

Emery, C. A. (with others). 2001. "Evaluation of the CAMx Model over the Midwestern US for Two Historical Ozone Episodes." Prepared for the Kansas City Ozone Technical Workgroup through the Kansas Department of Health and Environment, Topeka, KS, and the Missouri Department of Natural Resources, Jefferson City, MO.

Emery, C. A. (with others). 2001. "Evaluation of the MM5 Model over the Midwestern US for Three 8-hr Oxidant Episodes." Prepared for the Kansas City Ozone Technical Workgroup through the Kansas Department of Health and Environment, Topeka, KS, and the Missouri Department of Natural Resources, Jefferson City, MO.

Emery, C. A. (with others). 2001. "Evaluation of Ambient Ozone and Carbon Monoxide Concentrations Resulting from Automotive Fuel Changes in the Paso Del Norte Airshed." Prepared for the US Environmental Protection Agency, Region VI, Dallas, TX.

Emery, C. A. (with others). 1999. "The Las Vegas Valley Carbon Monoxide Urban Airshed Model Update Project – Phase II: Modeling to Demonstrate Attainment of the Carbon Monoxide Standard." Prepared for the Clark County Department of Comprehensive Planning, Las Vegas, NV.

Emery, C.A. (with others). 1999. "Analysis of Meteorological and Air Quality Conditions Associated with 8-Hour Ozone Exceedances in the Las Vegas Valley." Prepared for Clark County Health District, Las Vegas, NV.

Emery, C.A. (with others). 1999. "Ozone Modeling for the Kansas City Nonattainment Area." Prepared for Kansas City Ozone Technical Workgroup, Topeka, KS.

Emery, C. A. (with others). 1998. "Assessment of the Ozone Benefits in the Dallas-Fort Worth, Houston/Galveston, and Beaumont/Port Arthur Nonattainment Areas due to NOx Control on Local Versus Regional and Low-Level Versus Elevated Sources." Prepared for Texas Utilities, Dallas, Texas.

Emery, C. A. (with others). 1998. "The Las Vegas Valley Carbon Monoxide Urban Airshed Model Update Project - Phase II: UAM Base Case and Sensitivity Applications." Prepared for the Clark County Department of Comprehensive Planning, Las Vegas, NV.

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Emery, C. A. (with others). 1998. "Air Quality Modeling Evaluation of the Cool Communities Ozone Control Strategy." Prepared for the South Coast Air Quality Management District, Diamond Bar, California.

TEJAS SHAH

Managing Consultant

Tejas Shah has over 17 years' experience with air pollution analyses. His expertise includes emission inventory development, emission modeling, air quality modeling, spatial analysis with GIS, database tool development, control-measure evaluation and economic impact analysis. Tejas manages EPA work to maintain the Speciation Tool ancillary processor that creates speciation profiles for SMOKE using SPECIATE data. He recently managed a project for BAAQMD to design innovative methods for spatially allocating emissions to support local-scale modeling. He managed a review of available emission inventories for Mexico that are used in photochemical modeling studies of North America in which we used satellite-derived data products for sulfur dioxide (SO2), nitrogen dioxide (NO2) and natural gas flaring to evaluate spatial characterization and magnitude of the emissions inventories. Tejas has managed photochemical modeling studies for the US and other world regions and provided support to developing oil and gas emission inventories in the western US. Additionally, he has extensive experience using the RPOs emissions inventory, the USEPA's national emissions inventory (NEI) and the Environment Canada national inventory. Tejas' work at Ramboll includes Sparse Matrix Operator Kernel Emissions (SMOKE) processing of regional and project-level emission inventories for various oil and gas EIS projects in the Intermountain West; preparing gridding surrogates and speciation profiles for the SMOKE model input; augmenting SPECIATE—a repository of speciation profiles; spatial analyses and preparing landuse/landcover files for the Comprehensive Air Quality Model with extensions (CAMx) and MEGAN models using GIS; and developing database tools.

CONTACT INFORMATION
Tejas Shah

tshah@ramboll.com
+1 (415) 8990735

Ramboll
7250 Redwood Boulevard
Suite 105
Novato, CA 94945

EDUCATION

2000-2003
MS, Chemical Engineering
Lamar University, Beaumont, Texas

1996-2000
BS, Chemical Engineering
Mumbai University, Mumbai, India

SELECTED EXPERIENCE

Air Quality and Emissions Modeling Support to EPA OAQPS

- Manages EPA work to maintain the "Speciation Tool" ancillary processor that creates speciation profiles for SMOKE using SPECIATE data. Recently managed a project to update the Speciation Tool to support VBS schemes in air quality models to enable an improved representation of secondary organic aerosol (SOA) formation and create new mechanism mappings to accommodate recent changes in the gas speciation profiles of the EPA's SPECIATE 5.0 repository and support the revised aerosol modules (AE7 and AE8) of CMAQ.
- Developed ancillary files for processing oil and gas emissions for use in the EPA's national modeling platform. Work included development and assignment of speciation profiles for WRAP Phase III oil and gas source categories, development and assignment of spatial surrogates, and preparation of inventory input files for SMOKE.

BAAQMD Improve Methods for Spatially Allocating Emissions

- Developed methods for characterizing the spatial distribution of emissions in the San Francisco Bay Area at fine resolution to support local scale modeling.

BOEM Air Quality Impacts of Off-Shore Oil and Gas Production

- Recently managed regional emissions modeling for analyzing the on-shore air quality impacts of outer continental shelf oil and gas development in the Arctic Sea near Alaska and the Gulf of Mexico. This multi-year multi-million-dollar study will project future year emissions and air quality impacts and develop emission exception screening thresholds.

Allegheny County PM2.5 State Implementation Plans

- Task Manager for developing emissions input for air quality modeling to demonstrate that Allegheny County (Pittsburgh), Pennsylvania will attain the PM2.5 National Ambient Air Quality Standard (NAAQS).

Western Regional Air Partnership (WRAP) Region-Wide Emissions Inventory

- Provided GIS support in developing a region-wide O&G emissions inventory for current and future years in the western US for the Western Regional Air Partnership (WRAP). It includes performing spatial analyses using ARC/GIS tools, preparing map displays using ARC/MAP and developing gridding surrogates based on O&G activities using ARC Macro Language (AML) scripts.

Development of Gridded Ocean-Going Vessel Emissions Inventories

- Prepared gridded Commercial Marine Vessel Emissions Inventory for EPA. Detailed US port emission inventory was spatially allocated into a gridded format. The port emissions were then blended with the STEEM data, which together create the merged, gridded commercial marine vessel emissions inventory. ARC/GIS buffer tool was used to define various distance regions (25, 50, 100, and 200 nautical miles) from the US shoreline.

Development of California Emission Estimator Model (CalEEMod)

- Collaborated on the development of CalEEMod, a statewide land use emissions computer model designed to provide a uniform platform to quantify potential criteria pollutant and greenhouse gas (GHG) emissions associated with both construction and operation from a variety of land use projects. Air districts throughout the state are recommending its use for air quality analysis.

BLM Oklahoma-Kansas-Texas (OKT) EIS and Resource Management Plan

- Managed emissions modeling task of the BLM Oklahoma-Kansas-Texas (OKT) modeling study to assess the air quality impacts of oil and gas development and coal mines on federal and non-federal lands and other cumulative regional sources. Emissions of criteria air pollutants from predicted oil and gas development in the three-state area were developed for this study.

BLM Colorado Air Resource Management Modeling Study (CARMMS)

- Emissions Modeling Lead for the BLM CARMMS study that assess the air quality (AQ) and air quality related value (AQRV) impacts of new federal oil and gas and other cumulative sources including non-federal O&G, mining and other regional emissions in each of the BLM Colorado Field Office planning areas, as well as the Mancos Shale area in northwest New Mexico. Air quality modeling emissions inputs were developed for high, medium and low O&G development scenarios for future years 2021 and 2025.

BLM Montana/Dakotas PGM Modeling Study

- Task Manager for developing air quality modeling emissions for the BLM Montana/Dakotas PGM modeling study to assess the AQ and AQRV impacts due to oil and gas development. The Bakken Shale formation in the Montana/Dakotas region is the most rapidly growing oil and gas development area in the U.S. Under this study, Ramboll Environ is developing a comprehensive oil and gas emissions inventory and performing base year 2012/2013 and future year 2032 modeling using the CAMx photochemical grid model.

Navajo Generating Stations (NGS) EIS Assessment

- Task Manager for developing criteria and HAP emission inventory for NGS for lease extension EIS. This was the most comprehensive and complete AQ, ecological and human health assessment ever performed for an EIS.

SMOKE-MOVES Processing for Denver Ozone Modeling

- Developed an approach to use link-based data from TDM models as input to SMOKE-MOVES processing tool. Processed detailed vehicular activity data to prepare model-ready emissions for onroad sources. The pre-gridded activity data was input to the tool for the on-network processing and treated each grid cell and speed class as a pseudo-county. The off-network emissions were spatially allocated using surrogates developed from trip starts (start exhaust) and trip ends (for evaporative processes) by Traffic Analysis Zone (TAZ). This approach takes advantage of detailed link-based spatial and temporal varying activity data available from the TDM model and the robust emissions calculation methodology of SMOKE-MOVES that takes into account temporal and spatial variations in meteorology and has EPA approval and support.

Air Quality Assessments in Alberta, Canada

- Performed emissions modeling of regional emission inventories for North East Alberta modeling studies and North Saskatchewan Region of Alberta.

Continental-Divide Creston O&G EIS

- Performed emission modeling for the BLM Continental Divide-Creston (CD-C) O&G EIS air quality assessment. This was the first BLM O&G EIS that elected to use a PGM for the mid-field and far-field AQ and AQRV impacts. The CD-C O&G EIS proposes to drill almost 9,000 new wells in southwestern Wyoming and represents BP Americas largest on-land natural gas production field. The ROD was released in September 2016.

Hiawatha Energy Development

- Technical Lead for developing mode-ready emissions for the Hiawatha Energy Development O&G EIS located on the border of Wyoming and Colorado. This BLM O&G EIS used the CAMx PGM to estimate the AQ and AQRV impacts.

SELECTED PRESENTATIONS & PUBLICATIONS

Shah, T. 2019. "Improving Mexico Emissions Inventory Using Satellite Data" Presented at the 2019 CMAS Conference. October

Shah, T. 2017. "Composition of Organic Gas Emissions from Flaring Natural Gas" Presented at the EPA's 2017 International Emissions Inventory Conference. August https://www.epa.gov/sites/production/files/2017-11/documents/organic_gas.pdf

Nopmongcol, U., J. Grant, E. Knipping, M. Alexander, R. Schurhoff, D. Young, J. Jung, T. Shah, G. Yarwood. 2017. "Air Quality Impacts of Electrifying Vehicles and Equipment across the United States." Environmental Science & Technology. doi.org/10.1021/acs.est.6b04868

Collet, S., T. Kidokoro, P. Karamchandani, T. Shah, and J. Jung. 2017. "Future year ozone prediction for the United States using updated models and inputs." JAWMA. doi.org/10.1080/10962247.2017.1310149

Shah, T., Y. Alvarez, M. Jimenez, R. Morris, A. Brimmer and K. Lloyd. 2016. "Incorporate Traffic Demand Model Data in SMOKE-MOVES Processing for Denver Ozone Modeling" Presented at the 2016 CMAS Conference. October

Vijayaraghavan, K., C. Lindhjem, B. Koo, A. DenBleyker, E. Tai, T. Shah, Y. Alvarez, G. Yarwood. 2016. "Source Apportionment of Emissions from Light-Duty Gasoline Vehicles and Other Sources in the United States for Ozone and Particulate Matter." Journal of the Air & Waste Management Association, 66, 2, 98-119. doi.org/10.1080/10962247.2015.1112316

Seth Lyman, Ph.D.

Director, Bingham Research Center
Research Associate Professor, Department of Chemistry and Biochemistry
Utah State University
320 N. Aggie Blvd.
Vernal, UT 84078
435.722.1740 (office) 435.630.1433 (cell)
seth.lyman@usu.edu
binghamresearch.usu.edu; ubair.usu.edu

EDUCATION

2009-2010: Postdoctoral training, University of Washington Bothell. Supervisor: Dr. Daniel Jaffe.

2009: Doctor of Philosophy, Graduate Program in Environmental Sciences and Health, University of Nevada, Reno. Dissertation title: Investigation of Atmospheric Mercury Concentrations and Dry Deposition Rates using Established and Novel Methods. Advisor: Dr. Mae S. Gustin.

2004: Bachelor of Science in Conservation Biology, Brigham Young University, Provo, Utah.

EXPERIENCE

2017-present: Research Associate Professor, Department of Chemistry and Biochemistry, Utah State University, Vernal, Utah.

2012-present: Director, Bingham Research Center, Utah State University, Vernal, Utah.

2012: Air Quality Scientist, Energy Dynamics Laboratory, Utah State University Research Foundation, Vernal, Utah.

2011: Research Assistant Professor, University of Washington Bothell.

2009-2010: Postdoctoral Research Associate, University of Washington Bothell.

2004-2009: Graduate Research Assistant, University of Nevada, Reno.

MEMBERSHIPS, TRAINING AND AWARDS

2020: Utah Clean Air Person of the Year, awarded by the Utah Clean Air Partnership.

2017: Completed Managing Projects Effectively training, provided by American Chemical Society Center for Professional Development.

2015: Researcher of the Year, Utah State University Uintah Basin Campus.

2015-present: Member of the Air and Waste Management Association.

2014: Member of National Science Foundation Innovation Corps (I-Corps) cohort.

2009: Graduate Student of the Year, Department of Natural Resources and Environmental Science, University of Nevada, Reno.

2006-present: Member of the American Chemical Society and American Geophysical Union.

PUBLICATIONS

Gustin, M., Dunham-Cheatham, S., Huang, J., Lindberg, S., Lyman, S., 2021. Development of an understanding of reactive mercury in ambient air: a review. Atmosphere, 12, 73.

Mansfield, M. L., Lyman, S. N., 2021. Winter ozone pollution in Utah's Uinta Basin is Attenuating. Atmosphere, 12, 4.

Gustin, M. S., Dunham-Cheatham, S. M., Zhang, L., Lyman, S. N., Choma, N., Castro, M., 2021. Use of membranes and detailed HYSPLIT analyses to understand atmospheric particulate, gaseous oxidized, and reactive mercury chemistry. Environmental Science and Technology, DOI: 10.1021/acs.est.0c07876.

Lyman S. N., Holmes M. L., Tran H. N. Q., Tran T., O'Neil, T., 2021. High ethylene and propylene in an area dominated by oil production. Atmosphere, 12, 1.

Dunham-Cheatham S. M., Lyman S. N., Gustin M. S., 2020. Evaluation of sorption surface materials for reactive mercury compounds. Atmospheric Environment, 242, 117836.

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Gustin M. S., Bank M., Bishop K., Bowman K., Branfireun B., Chetalat J., Hammerschmidt C., Lamborg C., Cortizas A.M., Tsui M., Zhang T., 2020. Mercury biogeochemical cycling: a synthesis of recent scientific advances. Science of the Total Environment, 737, 139619.

Lyman S. N., Cheng I., Gratz L. E., Weiss-Penzias P., Zhang L., 2019. An updated review of atmospheric mercury. Science of the Total Environment, 707, 135575.

Lyman S. N., Tran T., Mansfield M. L., Ravikumar A. P., 2019. Aerial and ground-based optical gas imaging survey of Uinta Basin oil and gas wells. Elementa: Science of the Anthropocene, 7, 43.

Foster C. S., Crosman E. T., Horel J. D., Lyman S. N., Fasoli B., Bares R., Lin J. C., 2019. Quantifying methane emissions in the Uintah Basin during wintertime stagnation episodes. Elementa: Science of the Anthropocene, 7, 24.

Lyman S. N., Mansfield M. L., 2018. Organic compound emissions from a landfarm used for oil and gas solid waste disposal. Journal of the Air & Waste Management Association, 68, 637-642.

Mansfield M. L., Tran H. N., Lyman S. N., Bowers R. L., Smith A. P., Keslar C., 2018. Emissions of organic compounds from produced water ponds III: Mass-transfer coefficients, composition-emission correlations, and contributions to regional emissions. Science of the Total Environment, 627, 860-868.

Tran H. N., Lyman, S. N. Mansfield M. L., O'Neil T., Bowers R. L., Smith A. P., Keslar C., 2018. Emissions of organic compounds from produced water ponds II: Evaluation of flux chamber measurements with inverse-modeling techniques. Journal of the Air & Waste Management Association, 68, 713-724.

Lyman S. N., Mansfield M. L., Tran H. N., Evans J. D., Jones C., O'Neil T., Bowers R., Smith A., Keslar C., 2018. Emissions of organic compounds from produced water ponds I: Characteristics and speciation. Science of the Total Environment, 619, 896-905.

Lyman S. N., Watkins C., Jones C. P., Mansfield M. L., McKinley M., Kenney D., Evans J., 2017. Hydrocarbon and carbon dioxide fluxes from natural gas well pad soils and surrounding soils in eastern Utah. Environmental science & technology, 51, 11625-11633.

Tran T., Tran H., Mansfield M., Lyman S., Crosman E., 2018. Four dimensional data assimilation (FDDA) impacts on WRF performance in simulating inversion layer structure and distributions of CMAQ-simulated winter ozone concentrations in Uintah Basin. Atmospheric Environment, 177, 75-92.

Matichuk R., Tonnesen G., Luecken D., Gilliam R., Napelenok S. L., Baker K. R., Schwede D., Murphy B., Helmig D., Lyman S., Roselle S., 2017. Evaluation of the Community Multiscale Air Quality Model for simulating winter ozone formation in the Uinta Basin. Journal of Geophysical Research: Atmospheres, 122, 13-545.

Zhang L., Lyman S., Mao H., Lin C.-J., Gay D. A., Wang S., Gustin M. S., Feng X., and Wania F., 2017. A synthesis of research needs for improving the understanding of atmospheric mercury cycling. Atmospheric Chemistry and Physics 17, 9133-9144.

Lyman S., Jones C., O'Neil T., Allen T., Miller M., Sexauer Gustin M., Pierce A.M., Luke W., Ren X., Kelley P., 2016. Automated Calibration of Atmospheric Oxidized Mercury Measurements. Environmental Science and Technology 50, 12921-12927.

Jones C.P., Lyman S.N., Jaffe D.A., Allen T., O'Neil T.L., 2016. Detection and quantification of gas-phase oxidized mercury compounds by GC/MS. Atmospheric Measurement Techniques 9, 2195-2205.

Cohen M.D., Draxler R.R., Artz, R.S., Blanchard P., Gustin M.S., Han Y.J., Holsen T.M., Jaffe D.A., Kelley P., Lei H., Loughner C.P., Luke W.T., Lyman S.N., Niemi D., Pacyna J.M., Pilote M., Poissant L., Ratte D., Ren X., Steenhuisen F., Steffen A., Tordon R., Wilson S.J.. Modeling the global atmospheric transport and deposition of mercury to the Great Lakes. Elementa, DOI 10.12952/journal.elementa.000118.

Zatko M., Erbland J., Savarino J., Geng L., Easley L., Schauer A., Bates T., Quinn P.K., Light B., Morison D., Osthoff H.D., Lyman S., Neff W., Yuan B., Alexander B., 2016. The magnitude of the snow-sourced reactive nitrogen flux to the boundary layer in the Uintah Basin, Utah, USA. Atmospheric Chemistry and Physics Discussions, doi:10.5194/acp-2016-320.

Lyman S., Tran T., 2015. Inversion Structure and Winter Ozone Distribution in the Uintah Basin, Utah, U.S.A., Atmospheric Environment, 123, 156-165.

Jaffe D.A., Lyman S., Amos H.M., Gustin M.S., et al., 2014. Progress on understanding atmospheric mercury hampered by uncertain measurements, Environmental Science and Technology 48, 7204-7206.

Huang J., Lyman S., Stamenkovic, J., Gustin, M.S., 2014. A review of passive sampling systems for ambient air mercury measurements, Environmental Science: Processes and Impacts 16, 374-392.

Finley B.D., Jaffe D.A., Call K., Lyman S., Gustin M.S., Peterson C., Miller M., Lyman T., 2013. Development, testing, and deployment of an air sampling manifold for spiking elemental and oxidized mercury during the Reno Atmospheric Mercury Intercomparison Experiment (RAMIX). Environmental Science and Technology 47, 7277-7284.

Lyman S., Shorthill H., eds., 2013. Final Report: 2012 Uintah Basin Winter Ozone and Air Quality Study, Commercialization and Regional Development, Utah State University, Document number CRD13-320.32. Available at http://rd.usu.edu/files/uploads/ubos_2011-12_final_report.pdf.

Gustin M.S., Huang J., Miller M.B., Peterson C., Jaffe D.A., Ambrose J., Finley B.D., Lyman S.N., Call K., Talbot R., Feddersen D., Mao H., Lindberg S.E., 2013. Do we understand what the mercury speciation instruments are actually measuring? Results of RAMIX. Environmental Science and Technology 47, 7295-7306.

Ambrose J. L., Lyman S. N., Huang J., Gustin M. S., Jaffe D. A., 2013. Fast time resolution oxidized mercury measurements during the Reno Atmospheric Mercury Intercomparison Experiement (RAMIX). Environmental Science and Technology 47, 7285-7294.

Weiss-Penzias P.S., Gustin M.S., Lyman S.N., 2011. Sources of gaseous oxidized mercury and mercury dry deposition at two southeastern US sites. Atmospheric Environment 45, 4569-4579.

Gustin M.S., Lyman S.N., Kilner P., Prestbo E., 2011. Development of a passive sampler for gaseous mercury. Atmospheric Environment 45, 5805-5812.

Lyman S.N., Jaffe D., 2011. Formation and fate of oxidized mercury in the upper troposphere and lower stratosphere. Nature Geoscience, doi:10.1038/ngeo1353.

Lyman S.N., Jaffe D., Gustin M.S., 2010. Release of mercury halides from KCl denuders in the presence of ozone. Atmospheric Chemistry and Physics 10, 8197-8204.

Lyman S.N., Gustin M.S., Prestbo E.M., 2010. A passive sampler for ambient gaseous oxidized mercury concentrations. Atmospheric Environment 44, 246-252.

Weiss-Penzias P., Gustin M.S., Lyman S.N., 2009. Observations of speciated atmospheric mercury at three sites in Nevada: evidence for a free tropospheric source of reactive gaseous mercury. Journal of Geophysical Research: Atmospheres 114, DOI: 10.1029/2008JD011607.

Lyman S.N., Gustin M.S., Prestbo E.M., Kilner P.I., Edgerton E., Hatsell B., 2009. Testing and application of surrogate surfaces for understanding potential gaseous oxidized mercury dry deposition. Environmental Science and Technology 43, 6235-6241.

Lyman S.N., Gustin M.S., 2009. Determinants of atmospheric mercury concentrations in Reno, Nevada, U.S.A. Science of the Total Environment 408, 431-438.

Peterson C., Gustin M.S., Lyman S., 2009. Atmospheric mercury concentrations and speciation measured from 2004-2007 in Reno, Nevada, USA. Atmospheric Environment 43, 4646-4654.

Lyman S.N., Gustin M.S., 2008. Speciation of atmospheric mercury at two sites in northern Nevada, USA. Atmospheric Environment 42, 927-939.

Lyman S.N., Gustin M.S., Prestbo E.M., Marsik F.J., 2007. Estimation of dry deposition of atmospheric mercury in Nevada by direct and indirect methods. Environmental Science and Technology 41, 1970-1976 (Cover article, March 15 issue).

Stamenkovic J., Lyman S., Gustin M.S., 2007. Seasonal and diel variation of atmospheric mercury concentrations in the Reno (Nevada, USA) airshed. Atmospheric Environment 41, 6662-6672.

Gustin M.S., Engle M.A., Ericksen J., Lyman S., Stamenkovic J., Xin M., 2006. Elemental Hg exchange between the atmosphere and low Hg containing substrates. Applied Geochemistry 21, 1913-1923.

PATENTS

Lyman S.N., 2018. Gaseous mercury detection systems, calibration systems, and related methods. US Patent number 10012622.

Lyman S.N., 2020. Gaseous mercury detection systems, calibration systems, and related methods. US Patent number 10545123.

SELECTED PRESENTATIONS

Lyman S., 2019. Utah's Uinta Basin: a unique laboratory for ozone and mercury Chemistry. Guest lecture at Nanjing University School of the Environment, Nanjing, China.

Lyman S., Mansfield M., Tran H., Tran T., 2018. Wintertime ozone in the Uinta Basin. Invited speaker at the Utah Environmental Health and Safety conference, Vernal, Utah.

Lyman S., Mansfield M., 2016. Measurement of hydrocarbon emissions from uncharacterized area sources. Session chair and invited speaker at Best of RPSEA 10 Years of Research—Ultra-Deepwater and Onshore Technology Conference, Galveston, Texas.

Lyman S., Jones C., Allen T., O'Neil T., 2015. Identifying and quantifying oxidized mercury compounds using GC/MS. Session chair and speaker at the 12th International Conference on Mercury as a Global Pollutant, Jeju, South Korea.

Lyman S., 2015. Filling gaps: improving mercury measurement technology and characterizing neglected oil and gas emission sources. Guest Lecture at Harvard University Department of Earth and Planetary Sciences, Cambridge, Massachusetts.

Lyman S., 2014. Testimony on American Energy Jobs: Opportunities for Education. House Natural Resources Committee, Subcommittee on Energy and Mineral Resources, Washington, D.C.

Lyman S. 2013. Possible impacts of air quality on oil shale development in the Uintah Basin in Utah, U.S.A. Senior advisory board member and speaker at the International Oil Shale Symposium, Tallinn, Estonia.

Lyman S., Mansfield M., 2012 and 2013. Uintah Basin Winter Ozone Study. Invited speaker at the 2012 and 2013 University of Utah Unconventional Fuels Conferences, Salt Lake City, Utah.

Lyman S., 2012. 2012 Uintah Basin Winter Ozone Study. Invited speaker at the Air and Waste Management Association Visibility and Air Pollution Conference, Whitefish, Montana.

Lyman S., Jaffe D., 2011. Aircraft measurements of total and oxidized mercury over North America and Europe. Invited speaker at the 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia, Canada.

December 8, 2020

WILLIAM ROSS STOCKWELL, Ph.D.
Research Professor: University of Texas at El Paso
Affiliated Faculty: Desert Research Institute
Professor Emeritus: Howard University
Email: William.R.Stockwell@gmail.com
Mobile Phone: (949) 307-9286

Mailing Address:
William R. Stockwell
2182 Berkich CT
Reno, NV 89521
USA

EDUCATONAL BACKGROUND:

Post-doc	1982	National Center for Atmospheric Research
Ph.D.	1981	The Ohio State University, Physical Chemistry Research Topic: Gas-Phase Oxidation of Sulfur Dioxide in the Atmosphere
M.S.	1977	The Ohio State University, Physical Chemistry Research Topic: The Gas-Phase Spectrum of Nitrous Acid
B.S.	1975	Bowling Green State University, Chemistry, Minors in Physics and Mathematics

PROFESSIONAL EXPERIENCE

2016 – Present: *Research Professor*, Department of Physics, University of Texas at El Paso
2017 – Present: *Professor Emeritus of Chemistry and Atmospheric Sci*ence, Howard University
2017 – Present: *Graduate Faculty*, Atmospheric Science Program, University of Nevada at Reno
2005 – Present: *Affiliated Faculty*, Desert Research Institute
2006 – 2011: Visiting Scientist, Air Resources Laboratory, NOAA
2006 – 2009: Visiting Professor Department of Environmental Sciences, University of Virginia
2005 – 2017: *Professor of Chemistry and Atmospheric Sci*ence, Howard University
2002 – 2003: *Chief Scientist*, NOAA Air Quality Forecasting Program
1998 – 2005: *Research Professor*, Desert Research Institute
1998 – 2007: *Graduate Faculty*, Atmospheric Science Program, University of Nevada, Reno
1993 – 1998: *Senior Scientist*, Fraunhofer Institute for Atmospheric Research, Germany
1991 – 1993: *Senior Project Scientist*, Woodward-Clyde Consultants
1990: *Senior Visiting Scientist*, Forschungszentrum Jülich, Germany
1987 – 1990: *Senior Research Associate*, Atmospheric Sciences Research Center, State University of New York at Albany
1983 – 1986: *Scientist*, National Center for Atmospheric Research
1982 – 1983: *NCAR Postdoctoral Fellow*, National Center for Atmospheric Research
1976 – 1981: *Graduate Research Associate*, The Ohio State University
1975 – 1976: *Graduate Teaching Associate*, The Ohio State University

Honors and Awards Received

2017: *Graduate Faculty Exemplar Award* – Howard University
2009: *Editor's Award* **–** American Meteorological Society
2008: *Certificate of Appreciation for Advancing Underrepresented Minority Students in Mathematics, Science and Engineering* **–** Alfred P. Sloan Foundation
2003: *Listed: Who's Who in America* – Marquis
1999: *Certificate of Appreciation for Service to the 1998 Scientific Environmental Effects, and the Technological and Economic Assessments under the Montreal Protocol on Substances that Deplete the Ozone Layer* – United Nations Environment Programme
1998: *Editors' Citation for Excellence in Refereeing* – JGR-Atmospheres, American Geophysical Union,
1998: *Listed: Who's Who in Science and Engineering* – Marquis
1996: *Listed: Who's Who in the World* – Marquis
1995: *Research Prize*, Verein der Freunde und Förderer des IFU" (Association of the Friends and Sponsors of the Fraunhofer Institute for Atmospheric Environmental Research)
1993: *Membership* – Sigma Xi

Service to Department, University, Community and Profession:

International Meetings and Organization (Selected):

2020: Organizing Committee, Atmospheric Chemistry Mechanism Conference, University of California Davis

2018: Session Chair, American Association for the Advancement of Science, Pacific Division 99th Annual Meeting, Linking Atmospheric Chemistry, Modeling and Health Effects of Ozone and Particulate Matter with Improved Public Policy for Megacities

2009: Conference Chair, International Aerosol Modeling Algorithms (IAMA) Conference, University of California Davis

2006: Organized and chaired session on "Atmospheric Chemistry at the Interface Between Rural and Urban Regions" for the Fall Meeting of the American Geophysical Union

2002: Plenary Address "Role of Biogenic Hydrocarbons in the Atmosphere", Gordon Research Conference on Biogenic Hydrocarbons in the Atmosphere, Oxford University, UK

1997: Organized and chaired session on "Sensitivity and Uncertainty Analysis" for the Fall Meeting of the American Geophysical Union

International/National Committee Memberships:

2020 – Present: Member Representative for University of Texas at El Paso, University Corporation for University Research (UCAR)

2019 – Present: Member of Atmosphere (journal) Editorial Board

2017 – Present: International Project Team Member, "Development and Evaluation of Databases and Estimation Methods for Predicting Air Quality Impacts of Emitted Organic Compounds", Coordinating Research Council

2009 – Present: Editorial Board, Bulletin of the American Meteorological Society

2013 – 2017: Member Representative for Howard University, University Corporation for University Research (UCAR)

2011: Committee Member, Fourth International Peer Review Panel of the Community Multi-scale Air Quality Model (CMAQ)

2007: Chair, Third International Peer Review Panel of the CMAQ Model

2005: Chair, Second International Peer Review Panel of the CMAQ Model

2003: NOAA Representative, Federal Inter-Agency Air Quality Research Subcommittee of the Committee on Environment and Natural Resources (CENR)

1997 – 2000: Chair, Chemical Mechanism Development Data Evaluation Panel for EUROTRAC-2 project, European Community

1996 – 2002: Leader, Atmospheric Chemistry Modeling, German Tropospheric Research Program (TFS) and Integrator of laboratory and field data from TFS and EUROTRAC-2 program into atmospheric chemistry models

Scientific Leadership in Field Measurement Programs:

2010 – 2015: Supervised graduate and undergraduate students launching ozonesondes in Barbados to better understand tropospheric ozone variability across the Northern Tropical Atlantic

2001 – 2005: Led Air Quality Modeling for Sacramento Air Quality Management at Desert Research Institute for Central California Ozone Study-2000 (CCOS-2000)

2000 – 2001: Led team to perform solar radiation measurements and analysis for CCOS-2000

1999: Planning Team Member, CCOS-2000

1994 – 1998: Leader, Atmospheric Chemistry Modeling for AERONOX, a project funded by the European Community and the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR German Space Agency) on the atmospheric effects of nitrogen oxide emissions from aircraft in the Northeast Atlantic flight corridor

Scientific Leadership in Atmospheric Chemistry and Modeling Programs:

2015: Author, "The Mechanisms of Reactions Influencing Atmospheric Ozone" by Jack Calvert John Orlando William Stockwell and Timothy Wallington, Oxford University Press

2005 – 2016: Air Quality Modeling Leader for Howard University's NOAA Center for Atmospheric Science – Meteorology NCAS-M. NCAS-M is a Howard University led consortium that includes Penn-State, the University of Maryland, Jackson State University, the University at Albany - SUNY and the University of Texas at El Paso

2008 – 2009: Fellowship, New Atmospheric Chemistry for the Community Muliti-Scale Air Quality Model (CMAQ). Oak Ridge Institute for Science and Education Research Precipitation Program and the National Exposure Research Laboratory, U.S. Environmental Protection Agency (EPA)

2009: International Committee Member, Peer Review Panel for the SAPRC-07 Chemical Mechanism of Dr. William Carter

2003: Scientific Lead. Press and public communications preparation for signing of memorandum of understanding (MOU) and a memorandum of agreement (MOA) between NOAA and the EPA on Air Quality Forecasting. Documents signed by the Undersecretary of the Department of Commerce, Admiral Conrad Lautenbacher and the U.S. EPA Administrator Christie Whitman at a public event held on the Capital Mall

2002 – 2003: Chief Scientist for the Development of the National Oceanic and Atmospheric Administration's (NOAA) Air Quality Forecasting Program

2001 – 2006: Team Leader NASA Project, "Modeling the Effect of Mountainous Terrain on Regional Climate, Natural Hazards and Air and Water Quality"

1993 – 1998: Director, Atmospheric Chemistry Modeling Group at the Fraunhofer Institute for Atmospheric Research, Germany

1983 –1990: Led development of atmospheric chemistry for the Acid Deposition Modeling Project (ADMP) that created the Regional Acid Deposition Model (RADM)

Scientific Leadership in Programs / Grantee:

Partial List: National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the U.S. Department of Energy, the U.S. Environmental Protection Agency, the University of Houston/HARC, California Air Resources Board, Coordinating Research Council, German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie and the Forschungszentrum, Jülich, Germany. The funds total over $25,000,000 in research grants and contracts

Scientific Leadership in Programs / Diversity:

2020 – Present Working Group to develop culturally relevant general chemistry curricula with faculty from Sacramento City College and the University of San Diego

2013: Howard University Lead: National Center for Atmospheric Research Diversity Project for scientific exchanges

2009 – 2012: Howard University Lead: NSF Project, "Track 1: Geoscience Research at Storm Peak with Diversity"

Editorships:

2020: Guest Editor, Atmosphere Special Issue, Title: "Atmospheric Aerosols in North America"

2019 – Present: Member of Atmosphere (journal) Editorial Board

2017: Guest Editor, Atmosphere Special Issue, Title: "Regional Scale Air Quality Modeling"

2009 – Present: Editor for Atmospheric Chemistry, Bulletin of the American Meteorological Society

2012: Guest Editor, "Earthzine", Atmospheric Chemistry, Institute of Electrical and Electronics Engineers (IEEE)

2010 – 2012: Guest Editor, Atmosphere Special Issue, Title: "Air Pollution Modeling: Reviews of Science Process Algorithms"

1997 – 2000: Associate Editor, JGR-Atmospheres, American Geophysical Union

Service as a Reviewer (Partial List):
Peer Reviewer Journals: Atmosphere-MDPI, Atmospheric Chemistry and Physics Discussions, Atmospheric Environment, Atmospheric Pollution Research, Bulletin of the American Meteorological Society, Chemical Reviews, Environmental Pollution, Environmental Science and Technology, EOS Transactions, Journal of Atmospheric Chemistry, Physical Chemistry - Chemical Physics (Royal Society of Chemistry) and Journal of Geophysical Research
Research Proposals: National Aeronautics and Space Administration (NASA), National Science Foundation (NSF)

Society Memberships:
American Association for the Advancement of Science, American Chemical Society, American Geophysical Union, American Meteorological Society, Association for the Rhetoric of Science Technology and Medicine, Institute of Electrical and Electronics Engineers, Sigma Xi

Mentorship, Student Advisement and Outreach:
Served on numerous Ph.D. dissertation (28) and M.S. thesis (7) committees at Howard University, the University of Nevada, Reno / Desert Research Institute and internationally.
Mentored research of six Ph.D. graduates in atmospheric chemistry and atmospheric science at Howard University and the University of Nevada, Reno / Desert Research Institute
Mentored research of three M.S. graduates in atmospheric chemistry and atmospheric science at Howard University at the University of Nevada, Reno / Desert Research Institute
Research advisor and co-advisor for doctoral students at the University of Copenhagen (1), the ETH Zürich (1) and the University of Connecticut (2)
Supervised the research in atmospheric chemistry for numerous undergraduate (26) student researchers at Howard University and the National Center for Atmospheric Research
Summer lecturer at the "Integrated Modeling of Meteorological and Chemical Transport Processes / Impact of Chemical Weather on Numerical Weather Prediction and Climate Modeling", that was held 14-15 July 2008 in Zelenogorsk (near St. Petersburg), Russia (2008)
Taught courses on sensitivity and uncertainty analysis in atmospheric chemistry at the Bergische Universität Wuppertal, Germany (1995)

College/Service to Department – Partial List:

2013 – 2016:	Executive Committee, Department of Chemistry, Howard University
2013 – 2016:	Director of Graduate Studies, Department of Chemistry, Howard University
2013 – 2016:	Chair of the Physical Chemistry Division, Howard University
2010 – 2015:	Chair PhD Comprehensive Examinations, Atmospheric Science Program, Howard University
2008 – 2016:	Member Appointment, Promotion and Tenure Committee, Department of Chemistry, Howard University
2006:	Chair, Wheeler Lecture at Howard University, Invited and hosted Ralph Cicerone, President of the National Academy of Science, Lecture Title: “Atmospheric Chemical Composition and Climate Change”
2004 – 2005:	Served on Promotion Committee for the Division of Atmospheric Sciences, Desert Research Institute
2000 – 2003:	Faculty Senator, Desert Research Institute
2000 – 2002:	Leader for initiatives that established a Desert Research Institute Super-Computing Center

EXTERNAL FUNDING WITHIN THE PAST FIVE YEARS

Agency: **National Science Foundation**
Workshop in Measurements, Modeling and Data Analysis of the Planetary Boundary Layer: Summer, 2020
Total Award Amount: $83,841 Award Period: Oct. 2019 – Sept. 2020

Agency: **National Oceanic and Atmospheric Administration**
Project: NCAS NOAA Center for Atmospheric Sciences
Total Award Amount: $777,505 Award Period: Sept. 2017 – August 2021

Project: NOAA Atmospheric Sciences Cooperative Center, Cycle 3
Total Award: $186,129 Award Period: Sept. 2015 – Sept. 2016

Agency: **Coordinating Research Council**
A-101 Air Quality Modeling of the Relationship Between Projected Ozone and PM Trends and Changes in Precursor Relationships in the South Coast Air Basin in Response to Varying Reductions of Precursor Emissions
Total Award: $119,999 Award Period: Dec. 2015 – Dec 2016

Agency: **Truck and Engine Manufacturers Association**
A-101 Air Quality Modeling of the Relationship Between Projected Ozone and PM Trends and Changes in Precursor Relationships in the South Coast Air Basin in Response to Varying Reductions of Precursor Emissions/Health Effects. Total Award: $29,999 Award Period: Dec. 2015 – Dec 2016

Publications:
216 total publications with 10,329 citations, an h-index of 43 and an h-10 index of 88 (Google Scholar as of December 8, 2020). Published: 88 peer-reviewed journal articles; 3 peer-reviewed journal commentaries; 5 general and popular articles; 1 book; 6 book chapters; and 113 reports, conference papers or other publications.

Book:
Calvert, J.G., J.J. Orlando, **W.R. Stockwell** and T.J. Wallington, *The Mechanisms of Reactions Influencing Atmospheric Ozone*, Oxford University Press, Oxford, May 2015.

Peer Reviewed Publications Since 2016:
Mahmud, S., N.N Karle, R.M. Fitzgerald, D. Lu, N.R. Nalli and **W.R. Stockwell**, Inter-comparison of Sonde, WRF/CAMx and Satellite Sounder Profile Data for the Paso Del Norte Region, *Aerosol Science and Engineering*, *September,* 2020. doi:10.1007/s41810-020-00075-1
Polanco J., M. Ramos, R.M. Fitzgerald and **W.R. Stockwell**, An Improved Method for Optical Characterization of Mineral Dust and Soot Particles at the El Paso-Juárez Airshed, *Atmosphere, 11*, 866, 2020. https://doi.org/10.3390/atmos11080866
Karle, N.N., S. Mahmud, R.K. Sakai, R.M. Fitzgerald, V.R. Morris and **W.R. Stockwell**, Investigation of the Successive Ozone Episodes in the El Paso–Juarez Region in the Summer of 2017, *Atmosphere*, 532, 2020. https://doi.org/10.3390/atmos11050532
Karandana G.T.D., M. Green and **W.R. Stockwell**, Pillars of Solution for the Problem of Winter PM2.5 Variability in Fresno – Effects of Local Meteorology and Emissions, *Atmosphere, 11*, 312, 2020. https://www.mdpi.com/2073-4433/11/3/312/htm and https://doi.org/10.3390/atmos11030312
Stockwell, W.R., E. Saunders, W.S. Goliff, and R.M. Fitzgerald, A Perspective on the Development of Gas-phase Chemical Mechanisms for Eulerian Air Quality Models, *J. Air Waste Manage. Assoc., 70*, 44–70, 2020. doi: 10.1080/10962247.2019.1694605
Samburova, V., M. McDaniel, D. Campbell, M. Wolf, **W.R. Stockwell**, and A. Khlystov, Dominant Volatile Organic Compounds (VOCs) Measured at Four Cannabis Growing Facilities Pilot Study Results, *J. Air Waste Manage. Assoc.*, Published online: *69*, 1267-1276. 2019. doi: 10.1080/10962247.2019.1654038.
Stewart, D.R., E. Saunders, R. Perea, R. Fitzgerald, D.E. Campbell, **W.R. Stockwell**, Projected Changes in Particulate Matter Concentrations in the South Coast Air Basin Due to Basin-Wide Reductions in Nitrogen Oxides, Volatile Organic Compounds and Ammonia Emissions, *J. Air Waste Manage. Assoc., 69*, 192–208*,* 2019. *DOI: 10.1080/10962247.2018.1531795*
Vereecken, L., B. Aumont, I. Barnes, J.W. Bozzelli, M.J. Goldman, W.H. Green, S. Madronich, M.R. McGillen, A. Mellouki, J.J. Orlando, B. Picquet-Varrault, A.R. Rickard, **W.R. Stockwell**, T.J. Wallington and W.P.L. Carter, Perspective on Mechanism Development and Structure-Activity Relationships for Gas-phase Atmospheric Chemistry, *Int. J. Chem. Kinet., 50,* 435–469, 2018 *DOI 10.1002/kin.21172*.
Medina, R., **W. Stockwell** and R.M. Fitzgerald, Optical Characterization of Aerosol Particles in the El Paso-Juarez Airshed, *Aerosol Science and Engineerin*g, *February,* 2018. DOI: 10.1007/s41810-017-0019-8
Stewart, D.R., E. Saunders, R.A. Perea, R. Fitzgerald, D.E. Campbell and **W.R. Stockwell**, Linking Air Quality and Human Health Effects Models: An Application to the Los Angeles Air Basin, *Environmental Health Insights, 11,* 1–13*,* 2017. DOI: 10.1177/1178630217737551
Kim D., M. Chin, T. Diehl, H. Bian, L.A. Remer, H. Yu, M.E. Brown and **W.R. Stockwell**. The Role of Surface Wind and Vegetation Cover in Multi-Decadal Variations of Dust Emission in the Sahara and Sahel, *Atmos. Environ., 148*, 282–296, 2017. DOI: 10.1016/j.atmosenv.2016.10.051

Sangwan, M., **W.R. Stockwell**, D. Stewart and L. Zhu, Absorption of Near UV Light by HNO3/NO_3^- on Sapphire Surfaces, *J. Phys. Chem. A*, *120,* 2877–2884, 2016. doi: 10.1021/acs.jpca.6b01648

Fujita, E.M., D.E. Campbell, **W.R. Stockwell** and E. Saunders, R. Fitzgerald and R. Perea, Projected Ozone Trends and Changes in the Ozone-Precursor Relationship in the South Coast Air Basin in Response to Varying Reductions of Precursor Emissions, *J. Air Waste Manage. Assoc., 66,* 201–214, 2016. doi:10.1080/10962247.2015.1106991