EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

Does this project include Research (as defined in the UTC)? ☒ Yes ☐ No

PI Name: Alex Guenther

Project Title: Closing the soil NOx gap: Agronomic drivers, canopy processes and long-term flux measurements

Project Summary/Abstract

This research aims to quantify soil NOx emissions from representative Californian agricultural landscapes to improve emission estimates used in air quality modeling. The results will be used to develop the modules for soil NOx emissions and canopy NOx reduction within the MEGAN3 emissions modeling framework. They will also be used in a regional air quality model to determine if differences between SJV “bottom-up” emission model estimates and “top-down” aircraft and satellite observations can be reconciled. First, NOx eddy covariance (EC) fluxes will be measured over San Joaquin Valley (SJV) crops, and the site-specific driving variables (e.g., meteorological, soil characteristics and agronomic management) required to model NOx emissions from these landscapes will be monitored. These measurements include long-term continuous NO and NO2 fluxes for up to six site-years across representative agricultural landscapes. Simultaneously, in at least one site, a vertical gradient profile of NOx and dynamics (turbulence and transport) spanning from soil to below the crop canopy, within canopy and above the canopy will be characterized. This profile will be combined with a corresponding short-term intensive study of canopy chemistry (HONO, HNO3, VOCs) to quantify the soil NOx Canopy Reduction Factor (CRF) and the contribution of HONO to total reactive nitrogen emissions. Finally, the results of this project are expected to inform air quality management efforts by evaluating uncertainties associated with modeled soil NOx emission estimates per the recommendations from 2024-2025 Subject Matter Expert Review Panel (SMERP) on soil NOx.

If Third-Party Confidential Information is to be provided by the State:

☐ Performance of the Scope of Work is anticipated to involve use of third-party Confidential Information and is subject to the terms of this Agreement; ***OR***

☐ A separate CNDA between the University and third-party is required by the third-party and is incorporated in this Agreement as Exhibit A7.

Scope of Work

1.0 Overview

Biogenic emissions of reactive nitrogen (e.g., NO, NO_2, and HONO) compounds are important inputs to the models CARB uses to support air quality planning and management. A recent report by the Subject Matter Expert Review Panel (SMERP) on nitrogenous emissions from soils (Horwath et al. 2025) identifies significant uncertainties in soil NO and NO_2 emission estimates at both global and regional scales. Together, NO and NO_2 are referred to as NO_x. In the San Joaquin Valley (SJV), the SMERP noted that published estimates differ by an order of magnitude. This project will address these uncertainties in estimates by collecting field observations to better characterize agricultural soil NO_x emissions and improve their representation in version 3 of the Model of Emissions of Gases and Aerosols from Nature (MEGAN3) emissions model. The research will focus on dominant agricultural systems in the SJV. By quantifying soil NO_x emissions, understanding the governing processes, and assessing associated uncertainties, the project will address key knowledge gaps identified by the SMERP and strengthen the scientific basis for air quality modeling (Horwath et al. 2025).

This project will generate long-term NO_x flux measurements and collect the site-specific observations needed to develop, evaluate, and refine soil NO_x emission parameterizations. These observations, including measurements from an intensive field campaign (IFC) to investigate canopy nitrogen (N) uptake processes and nitrous acid (HONO) emissions, will be incorporated into the MEGAN3 framework to better represent soil NO_x emissions in air quality model simulations for California. The enhanced framework will inform a range of modeling approaches from simplified methods that rely on commonly available meteorological inputs to more detailed parameterizations incorporating information on atmospheric N deposition and fertilizer application.

2.0 Guiding Research Framework

2.1 Framework Summary

The Research Framework illustrated in Figure 1 is designed to work as an integrated measurement-to-model effort. First, three flux towers at three respective sites will provide the core observations, capturing how soil NO_x emissions vary across the SJV's dominant crop and fertilizer combinations for major cropland types (FT-SLURRY, FT-ORCHARD, FT-ROW). The HONO and canopy-uptake activities measure what the long-term above-canopy flux towers are missing: additional reactive nitrogen gases beyond NO_x, and the portion of emitted NO_x reabsorbed by the plant canopy before it reaches the above-canopy atmosphere (IFC-HONO, IFC-CRF). The reconciliation activity connects these ground-based measurements to the aircraft and satellite observations that operate at regional scale, testing whether the two approaches can be brought into agreement (RECONCILE). The results from each of these activities will feed directly into the modeling objective. The aim is to advance a better-constrained, better-validated soil NO_x emission model for California agriculture (MODEL). Each section below conveys how each activity (i.e. objective) in this Research Framework addresses priorities identified by the SMERP soil NOx report and describes the respective experimental approaches to accomplish an integrated measurement-to-model effort.

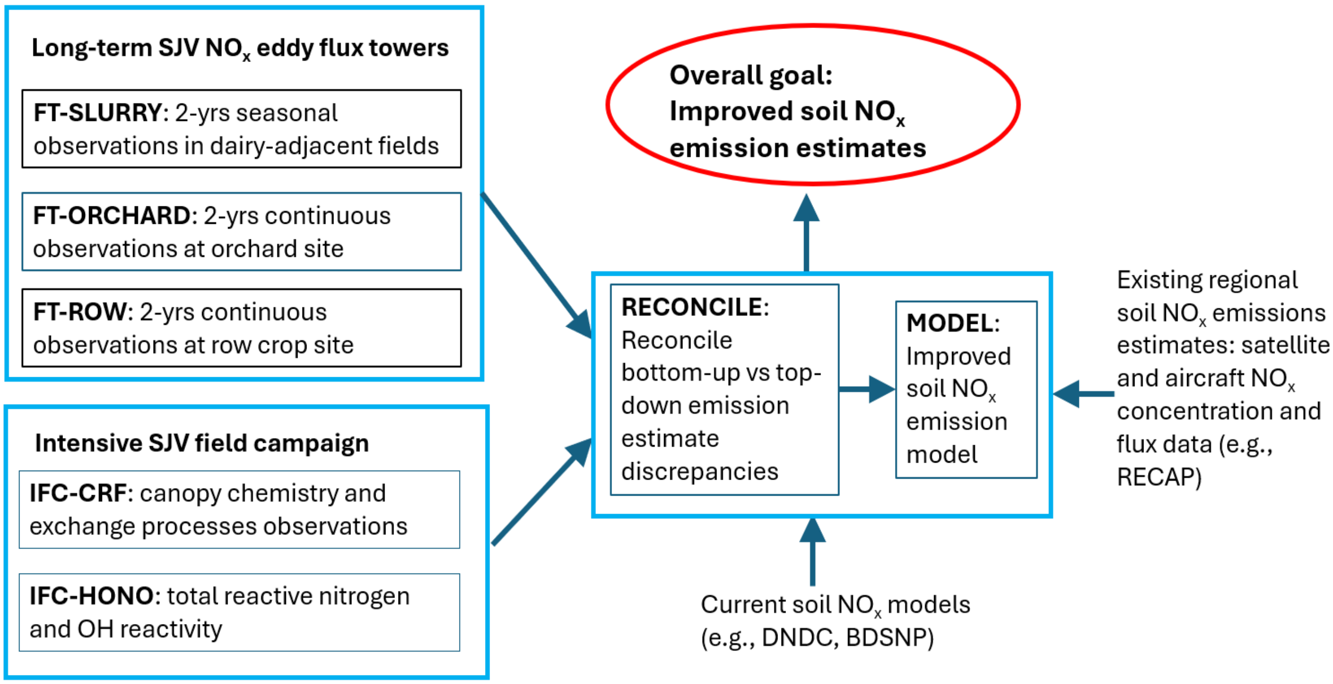

Figure 1. *Schematic of project objectives and overall goal.*

2.2 All year NO_x flux tower measurements

The SMERP report identifies the need for continuous, year-round measurements of soil NOx flux to improve understanding of soil NOx emissions from croplands, such as those receiving manure in liquid and solid form, furrow-irrigated field crops, and sprinkler- or surface drip-irrigated orchard crops (Horwath et al. 2025). This need can be addressed by deploying and operating three NO_x flux tower systems over a two-year period for up to a total of six site-years of observations. The specific scientific questions addressed by each of the three flux tower systems are:

- What are the magnitudes and spatiotemporal variability of NO_x emissions from agricultural systems?
- How do management practices, and crop and soil characteristics influence SJV cropland seasonal NO_x fluxes?

Croplands under consideration for three sites include SJV croplands (e.g., cornfields) receiving dairy waste slurry (FT-SLURRY; Figure 1), annual row crops (e.g., cotton, tomatoes, garlic or onions) fertilized by synthetics and/or compost (FT-ROW), and orchards (e.g., almonds, pistachios or citrus) fertilized by synthetics and/or compost (FT-ORCHARD). The NO_x flux measurements will be accompanied by characterization of the edaphic drivers of soil NO_x emissions that are critical for model development and reducing uncertainties in model outputs (Table 1). These driving variables control soil carbon (C) and N dynamics and soil-N availability, which determines gaseous-N emissions, including soil NO_x.

Approach. The following offers an overview of the proposed methodological approach to address objectives and scientific questions pertaining to year-long NO_x flux tower measurements. Fast response NO/NO_2 measurements for NO_x eddy covariance (EC) flux estimates have primarily utilized chemiluminescence analyzers that directly measure NO and indirectly measure NO_2 by converting it to NO. In this project, standard chemiluminescence NO_x analyzers will be deployed at all three flux tower sites. A dual channel cavity ring-down spectrometer (CRDS) NO_x analyzer will also be deployed at the orchard and row crop sites. The CRDS analyzer directly measures NO_2 and indirectly measures NO by converting it to NO_2.

In tandem with the flux measurements, a long-term vertical gradient profile will be measured in at least one site. The long-term vertical gradient profile measurements will include NO_x, O_3, CO_2, H_2O, sensible heat and turbulence. The profile will span from soil to below the crop's canopy, within the canopy and just above the canopy. To identify any systematic issues in the EC system that could affect the continuity of high-quality data, the performance of the multi-modal NO_x EC flux systems will first be compared against the University of Innsbruck's long-term NO_x EC system, which utilizes a traditional Ecophysics 899Y chemiluminescence analyzer. During the post-processing steps for EC flux data, small gaps in data (<3 days) will be filled with linear interpolation. Larger gaps in data (>3 days) will be filled based on a set of empirical models, an artificial neural network, and a random-forest model to determine which will work best in these environments.

Table 1. *DNDC and MEGAN3-BDSNP soil NOx model inputs and model sensitivity to the input variables (High: highly sensitive, Moderate: moderately sensitive, Low: low sensitivity, --: not an input). † = indirect (enters through another variable) based on Li et al. (2000) for DNDC and Rasool et al. (2016) for BDSNP. Data sources include online continuous flux tower measurement systems (FTMS), one-time site characterization (site char.), annual site characterization (Ann. Site Char.), time series (up to biweekly and event) sampling (TSS), satellite data (Satellite) and reported by cropland managers (Management).*

Category	**Input variable**	**DNDC**	**BDSNP**	**Data Source**
Environmental conditions	Air temperature	Moderate–High	High	FTMS
	Soil temperature	Model calculated	High	FTMS
	Precipitation	High	Moderate †	FTMS
	Solar radiation / PAR	Low–Mod	—	FTMS
	Soil moisture (WFPS)	Model calculated	Very High	FTMS
Soil physical	Bulk density (by depth)	High	Low–Moderate †	Site Char.
	Clay content / texture (by depth)	High	—	Site Char.
	Field capacity / wilting point	Moderate	—	Site Char.
	Porosity	† (via BD)	Moderate	Site Char.
	Saturated hydraulic conductivity	Moderate	—	Site Char,
Soil chemistry / state	Initial SOC	High	—	Ann. Site Char.
	Soil EC	Moderate	—	FTMS
	Soil pH	High	—	FTMS
	Extractable NO_3^- / NH_4^+	Moderate–High	† (used to assess N_avail)	TSS
	Total C, Total N, C/N ratio	Moderate	Indirect through N availability	Ann. Site Char.
Nitrogen inputs / management	Fertilizer rate	High	High	Management
	Fertilizer timing / type / depth	High	Low–Moderate	Management

Category	Input variable	DNDC	BDSNP	Data Source
	Manure / slurry / organic amendment rate and composition	High	—	Management
	Irrigation/fertigation timing, amount and method	Moderate-High	Moderate†	
	Irrigation/fertigation water inorganic-N	High†	Moderate†	
	N deposition	Moderate	Moderate	Model
	Crop residue incorporation	High	—	Management
	Tillage / irrigation / rotation	Mod–High	—	Management
	Planting / harvest, crop type	Moderate	—	Management
Land surface / state variables	Latitude (daylength)	Low	—	Site Char.
	Biome / land-cover type	Moderate	High	Site Char.
	LAI / canopy	Model calculated	Moderate	Satellite
	Aridity class	—	Moderate	Site Char.
	N-cycling functional-gene abundance by qPCR	† (via Biome)	† (via Biome)	Seasonal site char.

The soil characterization described above (Table 1) targets the state variables that directly force the DeNitrification and DeComposition (DNDC) and Berkeley-Dalhousie Soil Nitric Oxide (NO) Parameterization (BDSNP) process representations [e.g., inorganic nitrogen pools (NO_3^-, NH_4^+), soil moisture (gravimetric and volumetric water content, and water filled pore-space), temperature, pH, and organic carbon]. Together, these determine the substrate availability and physical conditions governing soil NO_x production. These state variables constrain the drivers of nitrification and denitrification but do not directly control the microbial process rates and pathways that partition nitrogen transformations into NO, nitrous oxide, and nitrogen gas. Direct process-level measurements such as potential nitrification and denitrification assays, isotopic analyses, and characterization of microbial community composition and functional-gene abundance, would strengthen the mechanistic interpretation of the observed flux variability and may reduce uncertainty in the emission parameterizations. These experimental approaches will be considered during development of the Work Plan (Task 1) and prioritized against their expected reduction in model uncertainty. Because they entail additional laboratory and analytical effort beyond the core measurement program, their inclusion may require additional funding. At a minimum, soil edaphic characteristics and C and N pool turnover will be assessed at regular intervals and more frequently during events when higher gaseous N emissions are anticipated, including irrigation and fertilization events (Table 1).

In closing, the three flux tower systems are not intended as a statistically representative sample of the full diversity of SJV agriculture; they are positioned to constrain soil NO_x emission processes across three dominant management archetypes that span the primary controls on soil NO_x. The approach is process-based rather than sample-based: the tower measurements will be used to develop and constrain the mechanistic response functions driven by the variables in the soil NO_x emission models (Table 1). Within-type heterogeneity, such as differences in irrigation, fertilization, canopy density, and soil texture, is represented through variation in these driving variables rather than requiring a dedicated tower for each combination. This design addresses the order-of-magnitude spread in reported SJV estimates, which the SMERP report attributes largely to inadequately constrained process representation rather than to unsampled site types alone.

2.3 HONO measurements & quantifying canopy NO_x uptake (IFC-HONO and IFC-CRF)

The SMERP report indicates that field measurements of HONO emissions from California's agricultural systems are lacking, and relatively little is known about the magnitude and relevance of HONO emissions from soil to California air quality. Soil-emitted HONO is rapidly photolyzed during the day into hydroxyl radical (OH) and NO, with each of these two molecules impacting air quality through independent pathways. As a source of OH, the primary driver of atmospheric photochemistry, HONO amplifies ozone (O_3) and fine particulate matter production. As a photolytic source of NO, HONO constitutes an additional soil NO_x source that is missing from most emission inventories. Here, the goal is to estimate the contribution of HONO to total reactive N soil emissions from a representative SJV cropland (IFC-HONO, Figure 1). The SMERP report also highlights the need to better characterize uncertainty ranges in soil NO_x modeling results. This will be addressed in the intensive field campaign (IFC) to characterize the canopy reduction factor (CRF), which accounts for the fraction of soil NO_x emissions that does not reach the above-canopy atmosphere because it is taken up by the plant canopy (IFC-CRF, Figure 1). The soil NO_x emission model is sensitive to CRF estimates, but a relatively large uncertainty associated with CRF values currently exists.

Approach. The following describes the proposed methodological approach to address the objectives pertaining to HONO measurements and quantification of canopy NO_x uptake. An IFC will measure HONO, other reactive trace gases [NO, NO_2, O_3, ammonia (NH_3), gaseous nitric acid (HNO_3), volatile organic compounds (VOC)] and total OH reactivity. A long-term vertical gradient profile, measuring NO, NO_2, O_3, CO_2, H_2O, sensible heat and turbulence will also occur in at least one of the fixed tower sites where the IFC will be conducted. This vertical gradient profile will span from the soil to below the crop canopy, within the canopy, and above the canopy zones. The reactive gas concentrations will be measured sequentially at a minimum of five heights, each using the same type of analyzers. Canopy structure and conditions will be quantified using optical canopy LAI meters (LAI 2000) and thermal/multispectral/LiDAR imagery. The measurements from the IFC, in combination with the long-term vertical gradient profile, will be used to estimate NO_x fluxes from the soil to within the canopy to above the canopy (whole ecosystem) using an inverse modeling approach such as the Inverse Lagrangian Transport (ILT) with Localized Near Field (ILT-LNF) scheme shown in Figures 2 and 3. Location(s) and times for the IFC and long-term vertical gradient profiling will be selected in consultation with CARB based on environmental conditions and management practices.

In the objective for IFC-CRF, the goal is to assess the average soil NO_x uptake by a representative SJV cropland canopy and whether the CRF can be treated as a constant value. The accuracy of model CRF estimates used to simulate soil NO_x fluxes into the above canopy atmosphere will be evaluated (Figure 1). If the CRF varies significantly and cannot be treated as a constant value, then this variance will be represented in soil NO_x models. To accomplish this, the average CRF will be quantified through the use of long-term vertical gradient profiles of turbulence, NO, NO_2, and O_3, (as described in 2.2 and Figure 2) and a short-term intensive observation of canopy chemistry and turbulent processes. In turn, the NO, NO_2, O_3 and VOC source and sink distribution of each canopy layer will be calculated using an inverse model (e.g., Karl et al. 2004). While classical Eulerian (K-theory) flux measurement approaches are not suitable for within and below canopy flux measurements, inverse techniques can be used to estimate fluxes even for nonhomogeneous diffusion in a dense canopy. For example, Figure 3 shows that the ILT-LNF model, driven by measured profiles of turbulence and trace gases, can be used to quantify trace gas sources and sinks at the soil surface and within the canopy. The integrated sum of all layers can be constrained by comparison to the measured above-canopy EC NO_x flux.

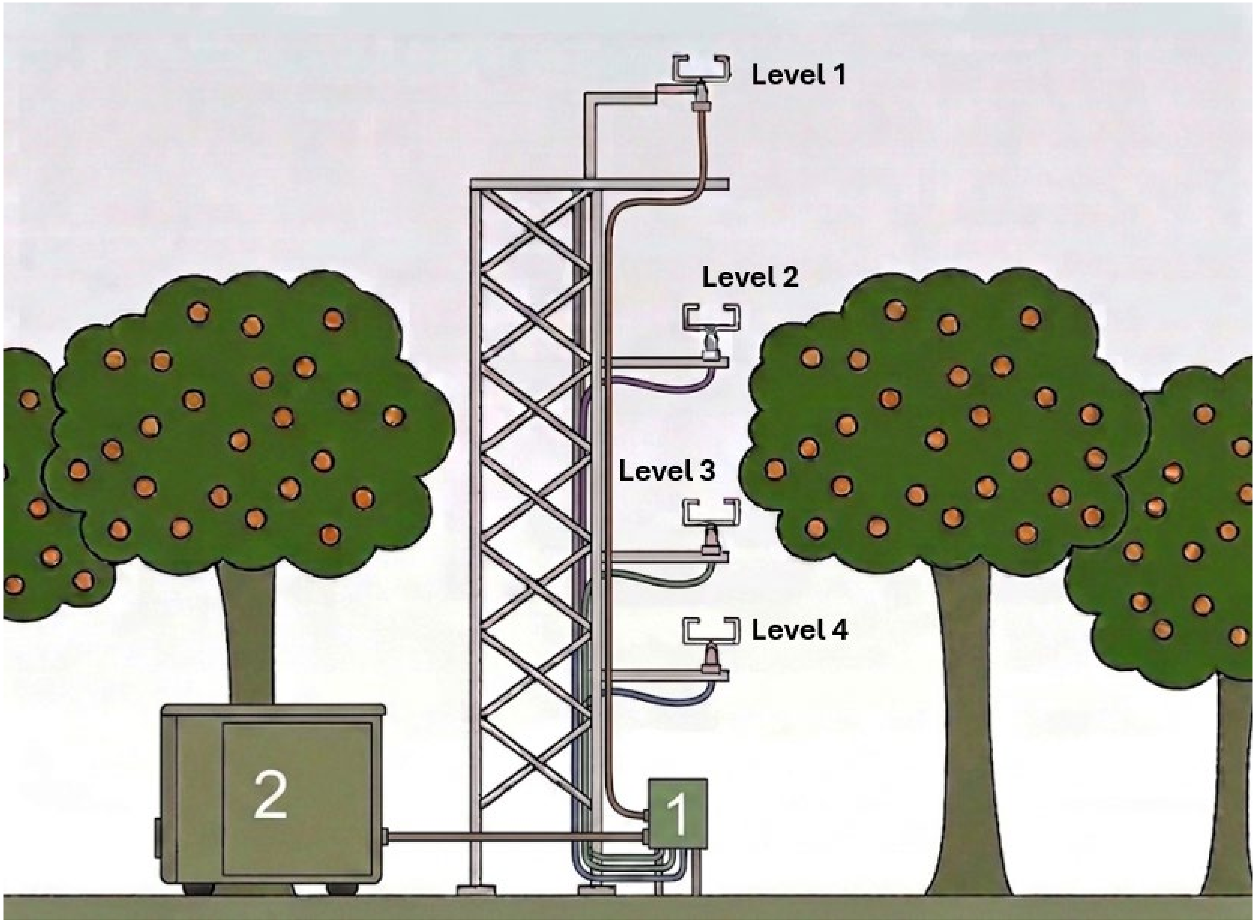

Figure 2. *Schematic of a flux tower intensive sampling layout with a sonic anemometer and Teflon tubing sampling line inlet at each level. Long-term measurements conducted by trace gas analyzers in shelter #1 will include 1) a* NO_x *analyzer for continuous above canopy eddy covariance measurements at level 1 height (FT-SLURRY, FT-ORCHARD, FT-ROW) and 2)* NO_x, O_3, H_2O *and* CO_2 *analyzers for continuous vertical gradient profile measurements by sequential sampling (e.g., five minutes at each height for a 20-minute cycle over four levels). Intensive field campaign (IFC) measurements conducted by trace gas instruments in shelter #2 include HONO,* NH_3, *speciated VOC, and total OH reactivity analyzers (IFC-HONO). The IFC measurements from equipment in "2" will also be used to characterize the canopy reduction factor (IFC-CRF).*

Further, two or more inverse model approaches for estimating soil and within canopy flux measurements will be evaluated. One approach will be selected based on an uncertainty analysis and agreement with whole ecosystem (net above-canopy) flux measurements according to metrics described in the Work Plan. For example, Wu et al. (2023) estimated soil emissions and canopy uptake of NH_3 and other trace gases using the ILT-LNF and two other inverse models. Rummel et al. (2002) used a different inverse approach to estimate soil NO emissions and canopy NO_2 uptake in an Amazon tropical forest. The ILT analysis will be extended with the Framework for O-D Atmospheric Modeling Master Chemical Mechanism (FOAM–MCM) box model using detailed chemistry (Wolfe et al. 2016). The box model will be used to estimate the emissions required to sustain the observed HONO concentrations. The model will also provide estimates of unmeasured reaction products which will be combined with observed values of reactive C and N. The sum of the OH reactivity associated with all observed compounds will be compared with the measured total OH reactivity, and the difference will be used to determine if there are any missing reactive compounds. In the nitrogen-rich environment of a fertilized agricultural field, this is expected to provide insights on the total reactive-N emissions.

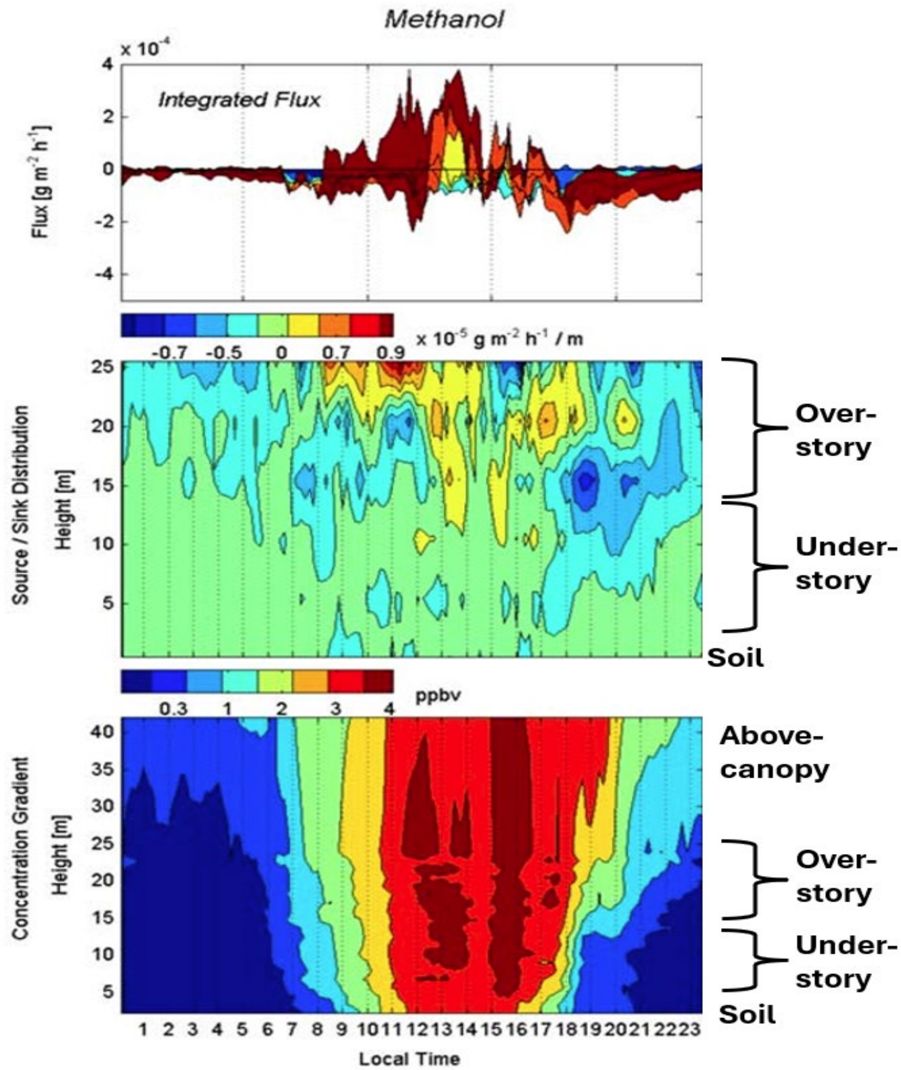

Figure 3. *Average contour plots of within and above canopy methanol mixing ratios (bottom), calculated methanol source/sink distributions (middle) as a function of local time (x axis) and height (y axis), total methanol fluxes integrated over individual source/sink layers (top) where the color-coding indicates the relative difference between subsequent source/sink layers and the dark red color represents the top layer (from Karl et al. 2004)*

2.4 Reconciling top-down and bottom-up approaches & improving soil NO_x emission model accuracy (RECONCILE and MODEL)

The SMERP report identifies differences in findings from the scientific literature and CARB inventory (CEPAM). Thus, the objective is to understand the sources of these differences by reconciling “top-down” (aircraft and satellite observations) and “bottom-up" (emission model) approaches. Specifically, the work will examine differences between current CARB SJV soil NO_x inventories and existing satellite and aircraft observations. It will also characterize the uncertainties and assumptions used to relate satellite and aircraft observations to soil emission estimates (RECONCILE, Figure 1). The SMERP report also indicates the need for continuous, year-round NO_x flux datasets for the purpose of calibrating and validating process-based and partially mechanistic models of NO_x emissions. Pairing with the RECONCILE objective, the project will identify the major uncertainties, sensitivities and biases of soil NO_x emission models for SJV agricultural landscapes, such as orchards, annual crops, and dairy waste fertilized fields. It also will identify how existing models can be improved (MODEL, Figure 1). The aim is to integrate observations to improve NO_x emission model inputs and algorithms.

Approach. Reconciling the “bottom-up” soil NO_x emission model estimates and “top-down” aircraft and satellite NO_x observation emission estimates require a better understanding of the uncertainties and assumptions associated with these estimates (RECONCILE, Figure 1). A comprehensive review of the contributing factors to any discrepancies and associated model sensitivity will be conducted. Examples of contributing factors include uncertainties in the flux divergence of “top-down” aircraft flux measurements and uncertainties in the canopy reduction factor of “bottom-up” emission estimates. The implications of assumptions will also be assessed, including “top-down” estimates that attribute all NO_x emissions in an agricultural region to soil NO_x sources. Thereafter, the long-term flux tower measurements and IFC observations will be integrated into a model testbed that will be used to test soil NO_x emissions models with CMAQ or similar air quality models. The model testbed will be available to CARB for future model testing. It will also include existing SJV NO_x concentration and flux data from near-surface air quality monitors, soil enclosure NO_x studies (reviewed in the SMERP report), aircraft data (e.g., the CARB sponsored RECAP study), and satellite datasets (e.g., TROPOMI and TEMPO NO_2 distributions). The model testbed will be developed in collaboration with consultant Dien Wu (Colorado State University), who is leading a NASA funded program to investigate NOx soil emissions using satellite and other observations.

A revised soil NO_x emissions model will be developed within the MEGAN3 model framework with updated emission factors, response functions and canopy reduction factor estimation (see Figure 1, MODEL). The revised model components will be based on this project’s observations by using traditional statistical assessments (e.g., normalized mean bias, root mean square error (RMSE), mean fractional bias) and additional analyses that will be described in the Work Plan. It will be further refined using a hybrid mechanistic and machine learning (ML) framework in which the existing mechanistic model acts as the backbone and the ML component targets only the structured residuals rather than independently predicting the flux itself. The ML model will be trained to predict the residual between the model and the six site-years of observed EC NO_x fluxes and IFC results. This will reveal the variability that existing soil emission and canopy reduction parameterizations fail to capture, and any skill the mechanistic model already has will be retained rather than relearned. This approach will also identify missing driving variables that will be incorporated into the model as additional algorithms. The NO_x and HONO emissions estimated by the new soil NO_x model will be compared to estimates from the CARB CEPAM emissions inventory and the MEGAN3 emission model predictions using current options such as BDSNP. The current and new emissions predictions will be input to an air quality model to calculate SJV regional concentration and flux distributions that will be assessed by statistical comparisons to the observations within the SJV NO_x model testbed. The Work Plan will include explicit criteria for determining whether reconciliation between “top-down” and “bottom-up” estimates has been achieved, including quantitative performance targets.

2.5 Uncertainty and error evaluation

To summarize, the Contractor will develop and use models of 1) soil NOx emission, 2) canopy reduction/deposition and transformation, and 3) background NO_x deposition associated with NO_x sources outside of the tower measurement flux footprint (Figure 1). The Contractor will construct an error budget that propagates measurement and model-component uncertainties through to the inferred soil NO_x emission.

Above-canopy EC uncertainty will be partitioned into different sources: 1) sensor precision, calibration accuracy and measurement frequency, 2) data processing such as gap-filling, 3) external parameters including meteorology, background deposition and 4) the CRF. The CRF uncertainty will be bound empirically using the ILT-derived layer fluxes and their temporal variability rather than treated as a fixed value. The within-canopy chemical-conversion term will be constrained by the FOAM–MCM box-model. These terms will be combined to yield confidence bounds on the derived soil emission and on the residual attributed to each process. Model–observation comparisons (normalized mean bias, RMSE, mean fractional bias) will then be evaluated against these propagated bounds.

Correlation and regression analysis will test how well each model reproduces the observed diel and seasonal cycles and quantify sensitivity of the residuals to the environmental drivers. Specifically, model-observation error will be regressed against soil moisture, temperature, and other variables. In-field measurements from fertilizer application, precipitation pulse-response, and other events will permit evaluation of the timing and magnitude of the modeled emission spikes. The attribution of the resulting error to these components will indicate which parameters or process representations require improvement. Potential drivers of any differences in nitrogen availability of soil core samples will also be evaluated. While six site-years is modest for data-driven modeling with a purely empirical model, and would risk overfitting and poor generalization, the residual-learning design mitigates this. The ML component does not predict the flux, but only the structured residual between the mechanistic model and observations. Thus, the mechanistic backbone of the model supplies the physical form, and the ML term fits a much smaller, bounded signal. This substantially lowers the effective data requirement and constrains extrapolation to physically plausible ranges. Cases in which the ML term fails to generalize will be interpreted as evidence of missing driving variables or process representation, feeding back into mechanistic model development rather than being absorbed as unexplained fit.

3.0 Project Tasks

3.1. Task 1: Develop a detailed Field Study, Data Management, and Modeling Plan (*alias* Work Plan)

The finalized Field Study, Data Management, and Modeling Plan (Work Plan) will include a detailed strategy to accomplish each objective delineated in Figure 1: FT-SLURRY, FT-ORCHARD, FT-ROW, IFC-CRF, IFC-HONO, RECONCILE, and MODEL. All components of the Work Plan will be developed in consultation with CARB. The Contractors will finalize the development of the detailed Work Plan, which will at minimum include the following elements and information. The Contractor will delineate metrics for success for these objectives and deliverables, including data management and archiving, data quality and completeness, and improved model predictive capacity and measurement capacity. Any changes to the finalized Work Plan during the project will require CARB approval.

3.1.1 Long-term NO_x eddy flux measurements (FT-SLURRY, FT-ORCHARD and FT-ROW)

The Work Plan developed by the Contractor will define the timeline, sampling and deployment strategy and how this strategy addresses the objectives of the research. Ongoing partnerships with industry groups and commercial SJV farm operations will be used to locate and establish EC flux sites for this research project. These partnerships will build on agricultural contacts that have been used to facilitate the successful deployment of EC flux towers in California farmland for past and ongoing research studies. Throughout the development and refinement of the Work Plan, the Contractors will identify and pursue opportunities to collaborate with CARB partners and stakeholders engaged in complementary research on NO_x emissions in the region.

The measurements at each flux tower site will include the observations required to drive, develop and assess soil NO_x emission models (Table 1). The Contractor will select agricultural field sites in the SJV (within Fresno, Tulare or Kern Counties) and design field observations to measure above-canopy NO_x fluxes up to a two-year period using three EC flux tower systems focused on the FT-SLURRY, FT-ORCHARD and FT-ROW objectives (Figure 1). Data gathered in this trial will be used to validate and refine emissions models for soil NO_x. The field sites will represent the most common SJV agricultural types and agronomic practices for irrigation, nutrient management, tillage and other floor management. In addition to covering representative systems, site selection will consider accessibility, logistics and suitability for long-term flux measurements.

The field measurement strategy will ensure site safety, accessibility, and minimal impact on agricultural activities on the host farms.

For each EC flux tower system, a detailed description will be compiled of instrumentation required for each of the variables listed in Table 1. The Work Plan will include a rationale for sensor selection and a quality assurance plan for each sensor.

- *Eddy Covariance NO_x Flux Tower Sampling Strategies:* The Contractor will operate EC flux towers to obtain long-term, continuous observations with the location and number of sites to be determined based on access, results of initial measurements and CARB data needs.
- *Tower Installation:* An appropriate tower height for the site will be selected, and all instrumentation will be installed securely at the site.
- *Sensor Selection:* The Contractor will collaborate with CARB to select instruments and tools that will be used during the field campaign and will also demonstrate the efficacy of both the instruments and the methods prior to the field campaign to optimize deployment and sampling strategies. This includes building and powering a secure tower, suitable sensors, and supporting instrumentation for measuring:
    - Data logging and recording system: A datalogger with appropriate sampling frequency to capture rapid fluctuations in gas concentrations and wind velocity,
    - Meteorological Conditions: Sensors will include air temperature, relative humidity, incoming PAR, incoming total radiation, net radiation, soil temperature, soil moisture, precipitation.
    - Wind speed and direction: A sonic anemometer suitable for EC measurements
    - Gas concentration: NO_x analyzers suitable for EC or disjunct EC measurements
    - Networking Devices: A cell modem or other networking device that will provide constant internet access for any tower left in place for a year or longer. This access will allow CARB or the Contractor to assess the status of the tower's sensors.
    - Power Systems: Power will be available at the EC flux tower site of sufficient capacity to support the installation, given typical site conditions and power requirements.
- *Safety:* The Contractor will develop a plan to optimize the security and stability of the tower and sensors to both natural and human threats. The plan will include responses if the tower and/or sensors are lost.
- *Deployment and Maintenance*: The Contractor will conduct pre-deployment checks of all sensors/instruments to ensure proper functioning, regularly calibrate gas analyzers and other sensors according to manufacturer guidelines, and record high frequency NO and NO_2 concentrations and vertical wind speed.

3.1.2 Soil sampling protocols and agronomic management information (FT-SLURRY, FT-ORCHARD and FT-ROW)

The continuous observations from the flux towers will be supplemented by periodic measurements to characterize soils, fertilizer and irrigation inputs, crop type and density, and agronomic management practices as shown in Table 1. During development of the Work Plan, the approach for obtaining and assessing management information and the soil sampling protocols will be developed in consultation with CARB. This will include field collection and sample processing methodology, as well as determination of analytical methods to best address the goal in the solicitation to advance parameterization of the MEGAN3 and DNDC models for soil NO_x emissions. Sampling protocols will include a description of the frequency and location of sample collection to capture site heterogeneity and the area encompassing the fetch. During field collection for soils that will be analyzed for gravimetric water content, dissolved organic carbon and dissolved organic-N (DON), ammonium-N (NH_4-N), nitrate-N (NO_3-N), and any other labile pools that change rapidly over hours to days, soil samples will be placed on ice in coolers or extracted in the field and placed in coolers. Samples will be transported to the laboratory and stored at 4 °C until extraction the following day. If extraction with standard protocols (i.e. 0.5 M potassium sulfate solution) is not possible on the day of collection, samples will be processed within 24 hours of field collection. Extracted samples will be aliquoted for the respective analysis into freezer-safe tubes to minimize freeze-thaw cycles, which can affect concentrations of NH_4-N and DON. The extracts will be stored in a temperature stable -20 °C freezer (i.e. without a defrost cycle). The

Work Plan will develop a soil sampling approach to characterize the upper 30 cm of soil, focused on input parameters required to drive soil NO_x emission models.

3.1.3 Canopy Processes Sampling Strategy (IFC-CRF and IFC-HONO objectives)

The Contractor will install and operate additional instruments for at least one of the fixed EC flux towers, including long-term measurements of vertical gradient profiles of NO, NO_2, O_3 and turbulence and conduct a short-term campaign to investigate canopy chemistry, dynamics, and uptake processes that control the soil NO_x CRF.

Briefly, a custom-built Chemical Ionization Mass Spectrometer with SF6 ion chemistry (CIMS, 1 Hz sampling frequency, 15 ppt detection limit) will measure HONO and HNO_3 concentrations at a single height using a no-inlet configuration to prevent inlet artifacts. NH_3 will be measured with a chemiluminescence detector by converting NH_3 to NO. A comprehensive range of reactive VOC, including the dominant VOC emitted from crops and fertilizers, will be measured using EC with a Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOFMS, IONICON: > 5 Hz sampling frequency, < 10 ppt detection limit) and VOC vertical gradients collected on sorbent tube samplers and analyzed by Thermal Desorption Gas Chromatography with Mass Spectrometer and Flame Ionization Detector (TD-GC-MS/FID, Markes: < 10 ppt detection limit) analysis. Total OH reactivity will be measured using a comparative reactivity method and used to constrain the total reactive nitrogen and carbon gases and identify any important missing reactive compounds. PTR-TOFMS, total OH reactivity and the CIMS are leveraged resources available for the project.

3.1.4 Data Collection, Management, and Analysis Plan

As part of the Work Plan, the Contractor will develop a Data Collection, Management, and Analysis plan for all model input data and other measurements. It will include a data management plan for remotely accessing, offloading, processing, cleaning, and storing data. It will also include automation of approaches for downloading and managing data. Measurement data will be processed, offloaded and provided to CARB at regular intervals agreed upon by the Contractor and CARB and within 6 months for the IFC data. Data products will be cleaned using standardized practices established in the literature. Ancillary variables (e.g., soil moisture, solar radiation, precipitation, and temperature) will be measured continuously at a 5-minute frequency. The Work Plan will explain methodological validation and gap-filling. The Contractors will also describe the formats that will be used for metadata, notes, and data products, which will be determined in consultation with CARB. The Work Plan will additionally describe the statistical comparisons that will be used to assess soil NOx model skill using the observations from the above-canopy EC flux measurements. The Work Plan will also describe the analysis approaches that will be used to investigate the chemical, physical, and biological processes that control canopy NOx uptake and HONO emissions from an SJV orchard using the IFC observations. Additional data analysis will be described in detail in the Work Plan.

3.1.5 Contingency Planning

The Contractor will develop a contingency plan for field operations, data preservation, and data collection. Contingency plans will be developed to maximize data collection, especially during active fertilizer management periods. Alternative sites will be identified in advance, and the security and stability of tower and sensors will be assessed for natural and human threats. The Contractor will minimize data collection interruptions through a combination of redundancy in instrumentation, remote monitoring, hardened site infrastructure, and pre-arranged alternatives, so that no single equipment, power, access, or safety disruption results in a major loss of the flux record. The FT-ORCHARD, FT-ROW, IFC-CRF, and IFC-HONO objective measurement systems will be tested in a cropland setting at the UC South Coast Research and Extension Center (SCREC) in Irvine prior to deployment. The FT-SLURRY system will be tested at UC Davis. All analyzers, sonic anemometers, and meteorological sensors will log to local dataloggers with onboard storage sized to retain several weeks of high-frequency data, ensuring that a loss of network connectivity or a delayed site visit does not result in data loss; continuous cell-modem telemetry will stream instrument health, shelter conditions, and power status to enable early fault detection and remote diagnosis before a field visit is required. The Work Plan will include the role of mobile NO_x platforms in the contingency plan.

- *Equipment failure:* The dual-analyzer configuration at the orchard and row-crop sites (co-located chemiluminescence and CRDS NO_x analyzers) provides mutual backup so that a single analyzer fault does not interrupt the flux time series. The third site will only have one NOx sensor to measure emissions, but this scenario will be developed in the Work Plan in consultation with CARB. The Contractor will maintain a standing calibration schedule and an inventory of critical spare parts and consumables. If any leveraged instrument (e.g., PTR-TOFMS, CIMS, OH reactivity) is unavailable due to equipment failure or other reasons, the IFC campaign will be rescheduled within the two-year long-term flux measurement period.

- *Long-term measurements in slurry fertilized crop:* The farm management practices at dairy-adjacent croplands fertilized with dairy waste slurry may preclude the establishment of a long-term flux tower. The Work Plan will include a contingency plan to address how to accomplish the project if fixed towers are not feasible for this or any other long-term flux tower objective. Alternative approaches described in the Work Plan will include the use of a mobile flux tower platform for repeated seasonal measurements.
- *Orchard and row crop long-term measurements:* Instruments will be housed in an insulated, climate-controlled enclosure with active cooling sized for peak SJV summer conditions, since analyzer stability degrades outside the manufacturer operating range. Redundant internal temperature sensors will be logged and alarmed via telemetry, and a spare portable cooling unit will be held on hand for rapid replacement. Primary power will use a utility/grid connection where a service drop is available at or near the field site (e.g., adjacent to irrigation infrastructure). At sites lacking reliable grid access, the Contractor will deploy a solar system explicitly sized to carry the combined analyzer and shelter air conditioning load with battery autonomy sufficient to bridge cloudy periods and short outages. Power source, battery state of charge, and load status will be monitored remotely, with automated low-power and fault alerts.
- *Safety concerns and site inaccessibility:* During grower activities that restrict field entry—pesticide/fertilizer application and associated restricted-entry intervals, fumigation, harvest operations, or irrigation-related flooding, and impassable access roads—telemetry and onboard logging will allow instruments to continue collecting data without personnel on site, and maintenance will be deferred to the next safe access window. Field crews will follow wildlife protocols and required UC Environmental Health and Safety guidelines for field work in agricultural systems and remote locations, heat-illness and wildfire-smoke, including the UC-required plan for medical emergencies. Site visits will be scheduled around known agronomic operations. Each tower will have a defined equipment loss-response procedure covering theft, vandalism, and severe-weather damage, including insurance/replacement pathways.

3.1.6. Communications and Training

The Contractor will describe an approach for communications in the Work Plan, including publications and reports as well as stakeholder engagement. The Contractor will engage with relevant parties to provide updates on the work, per consultation with CARB. The Contractor will consult with CARB prior to any external communications about the findings from this project, including university-sponsored press releases, abstracts, manuscripts and updates with stakeholders. Collaboration will be facilitated by frequent email discussions, monthly virtual meetings, and annual project meetings, including CARB. All researchers will take anti-bias training and farm competency training within 30 days of contract start. The farm competency training materials will be developed in consultation with CARB and, if needed, with stakeholders. The Work Plan will also include data, communication, and documentation standards. Specifically, all data products will include a validation and/or uncertainty analysis. Field protocols will be documented for non-scientific technicians. Both raw data and a full processing workflow (including QA/QC, gap-filling, partitioning, and plotting) will be delivered to CARB. All code and analyses will be documented for independent use and re-analysis by CARB without Contractor support. Reports will be public-ready, clearly presenting methods, results, and conclusions. Workflows will be in R or Python unless agreed to by CARB. All methods and dependencies will be open source, with GPL v.3-equivalent licensing. Remote sensing workflows will process raw data with publicly accessible tools.

3.1.7. Task 1 Deliverables

The Task 1 deliverables include:

- Within the first month of contract execution, the Contractor will provide a draft Work Plan. This will include a more developed data collection strategy. The Work Plan will seek to include collaborations with CARB partners and stakeholders engaged in complementary research, especially in the SJV region.
- Within two months of contract execution, the Contractor will submit a finalized and CARB-approved Work Plan to CARB staff that satisfies the requirements outlined in Task 1 and addresses CARB comments. The plan will include a detailed description of the sampling methodology, protocols, and sensors used for each of the three NO_x EC flux towers (FT-SLURRY, FT-ORCHARD and FT-ROW objectives), as well as the canopy processing and HONO intensive field campaign (IFC-CRF and IFC-HONO objectives). In addition, the report will include a data collection and management plan, along with a detailed description of the planned synthesis and comparison with existing data (RECONCILE objective) and the model development and assessment approach (MODEL objective). The interim report will include information about choosing appropriate data collection tools. The Work Plan will incorporate any updates to the research design before fully launching the data collection and data analysis phase.

3.2. Task 2. Initiate and perform field measurements

Measurements will be initiated after CARB approval of field sites and sampling approaches. The Contractor will follow the strategies and approaches detailed in the finalized Work Plan. The Contractor will obtain CARB approval before making any changes to the Work Plan. A thorough review of the following criteria will be conducted prior to installation and reported in an Interim Report as an addendum to the approved Work Plan:

- **Site Safety:** Site selection will define the risks experienced by researchers and by deployed equipment.
- **Agronomic management types**: Based on research objectives and current knowledge gaps, identify the appropriate farmland types for sampling.
- **Management practices**: Characterize previous land-use history and document nutrient management methods/timing/rates, nitrogen content of irrigation sources, irrigation type and timing, tillage practices, harvest timing and yield, cover crop types, and other field management activities to the maximum practical degree possible contingent upon establishing partnerships with host farmers.
- **Site accessibility**: Ensure the sites are accessible for installation, maintenance, and data collection. This assessment should also factor in challenges associated with sampling locations and the availability of supporting infrastructure.
- **Meteorological conditions**: Assess prevailing wind patterns, stability conditions, and potential disturbances that could affect the EC flux tower measurements. This assessment should include the anticipated tower footprint based on prevailing meteorological conditions.
- **Cropland characteristics**: Document crop type and age, canopy structure, and phenology in the flux tower footprint.
- **Minimize disruptions to agriculture**: Field site measurement programs will be designed to minimize disruptions to agricultural activities, and to compensate farmers for any disruptions that cannot be avoided.
- **Partnerships and Stakeholders**: The Task 2 interim report will include updates on collaborations, partnerships, and stakeholder engagement efforts.

3.2.1 Task 2 Deliverables

The task 2 deliverables include:

- At the start of Task 2 and at least once every two weeks following, the Contractors will provide CARB with a status update of the field site, tower installation process, and any relevant agreed upon actions and products from the Work Plan.
- Monthly updates on the status of the field operations. This includes any updates to the sampling protocol and standard operating procedures. In consultation with CARB, significant changes in these

components or any necessary changes in approaches will be incorporated into the Work Plan from Task 1.
- A monthly summary of the measured variables and an archived full dataset including raw and processed data.
- High-quality pictures of the field site (with permissions where appropriate) and instrumentation that CARB can publish for this project's research website.

3.3. Task 3: Data collection, QA/QC, dataset constructions, and archiving

Data collection for each objective will follow the procedures developed for Task 1, including any modifications identified in Task 2. Any changes to data collection, QA/QC, dataset construction and archiving will be conducted in consultation with CARB. Data collected during this research trial is intended for soil NO_x model evaluation and improvement and is specific to farms in the SJV. The Contractor will screen and assess data quality using standardized QA/QC protocols that adhere to established standards. No data will be permanently removed between collection and handoff to CARB.

In addition to the database of field observations, all raw data will be archived, and a variety of post-processing approaches will be used including temporal averaging, calibration, and filtering. These additional processes will generate reduced datasets. Metadata and notes will be included to provide complete information for the interpretation of each sample. The plain text metadata will include descriptions of any hardware and software used (including make, model, and version where applicable). Additional data products that will be made available include emission factors and parameterizations of NO_x emission algorithms. Any potential changes to the format of metadata, notes and data products described in the Work Plan from Task 1 will be determined in consultation with CARB. The postdoctoral researcher or other staff hired for this project will oversee all data management aspects of this project including responsibility for maintaining data storage and backup systems. They will be trained by the PIs who have extensive experience in archiving similar data sets. All research computers will be backed up on a regular basis.

3.3.1. Task 3 Deliverables

Task 3 deliverables include:

- If further modifications to the data collection, QA/QC, dataset construction, and archiving are required (beyond what procedures agreed upon in Tasks 1 and 2), the Contractors will provide CARB with an update within 2 weeks of the identified need.
- An interim report using CARB-approved templates describing the implementation of QA/QC process for both raw data and post-processed fluxes.
- The Contractor will process, offload, clean, and deliver all long-term measurement data to CARB at regular intervals agreed upon by the Contractor and CARB, and all IFC data within 6 months. Data products will be cleaned using standardized practices established in the literature.
- A detailed description of how to access and use the archived data and a training session for CARB staff on how to utilize the data.
- Tools for QA/QC workflows, including R or python code, will be provided to CARB

3.4. Task 4: Data analysis and model development

Task 4 will be described in Task 1. Any adjustments to the approach in Task 4 will require approval from CARB. Any adjustments will be described in the interim report (see Deliverables for Task 4).

3.4.1 Above canopy eddy covariance flux measurements (FT-SLURRY, FT-ROW and FT-ORCHARD)

The Contractor will use hourly, daily, monthly, and interannual dynamics and budgets of above-canopy NO and NO_2 fluxes to investigate primary sources and drivers of NO_x fluxes into the above-canopy atmosphere and to identify existing model components that do not accurately represent observations. The Contractor will use these observations to assess soil NO_x model skill through statistical comparisons that will be described in the Work Plan. This will test how well each soil NO_x model reproduces the observed diel and seasonal cycles and quantify sensitivity of the residuals to the environmental drivers including soil moisture, temperature, and other variables. The Contractor will also investigate how fertilizer application, precipitation pulse-response, and other events relate to the timing and magnitude of the NO_x emission spikes. The Contractor will then determine the resulting error attribution to identify which parameters or process representations require improvement. The assessment will also consider differences in nitrogen availability of soil core samples and assess the potential drivers of these differences, especially agronomic management practices. All analyses will be provided to CARB as a written report or presentation.

3.4.2 Canopy chemistry, dynamics and fluxes (IFC-CRF and IFC-HONO)

The Contractor will collaborate with CARB to design an IFC to characterize the NO_x CRF impact and HONO contributions to total soil reactive nitrogen emissions (see IFC-CRF and IFC-HONO objectives in Figure 1). The IFC will include at least 20 site-days of observations at one or more sites. The IFC observations will be analyzed to investigate the chemical, physical and biological processes that control canopy NO_x uptake and HONO emissions from an SJV orchard using the approaches described in the Work Plan. Any updates to the IFC will be added to the Work Plan in Task 1. The observations will be integrated into a model testbed and used to assess model estimates of soil NO_x canopy uptake and soil HONO emission.

The long-term vertical gradient profile measurements of NO, NO_2 and O_3 will be analyzed using an inverse model to quantify NO, NO_2 and O_3 interactions and source and sink terms at the soil surface and within the canopy. The sum of the NO_x flux estimated for each level will be compared with the measured above canopy NO_x flux. The long-term measurement record will be used to investigate seasonal to interannual variations in the canopy reduction factor and determine how the controlling processes can be represented in soil NO_x models.

3.4.3. Model development and comparison to existing observations (MODEL and RECONCILE)

The Contractor will use statistical and ML approaches to assess and reconcile differences between soil NO_x emission model estimates, including BDSNP and DNDC, and above canopy aircraft and satellite observations. A regional air quality model will be used to account for the background NO_x deposition flux at each SJV site so that the observed EC NO_x net fluxes can be compared with modeled values. The residuals between observed and predicted NO_x fluxes will reveal the variability that existing soil emission and canopy reduction parameterizations (among others) fail to capture. The observations and predictions analysis will form the basis for improving emission factors and analytical response functions for the soil NO_x emission and canopy reduction formulations within MEGAN3.

An updated soil NO_x emission model and updated CRF model will be added to the MEGAN3 model framework and used to estimate NO_x and HONO emissions throughout the SJV region. The NO_x and HONO emission results for the new model will be compared to estimates for existing MEGAN3 options, such as BDSNP, and CARB's estimates using the DNDC model. The above canopy and within canopy NO_x and HONO observations obtained for this study will be combined with existing surface, aircraft, satellite, and other relevant NO_x observations for SJV agricultural landscapes to create a model testbed that will be used to assess the model predictions. In addition to comparing with direct flux observations, the model emission estimates will be used as inputs for a series of air quality model simulations that will extend to previous aircraft observations, such as the RECAP study, and span periods with both TROPOMI and TEMPO satellite data. Model comparisons with aircraft and satellite observations will be investigated using insights from the EC and canopy process measurements conducted for this study.

3.4.4. Task 4 Deliverables

Task 4 deliverables include:

- An interim report describing a preliminary evaluation of the first year of EC measurements and the IFC. The evaluation will follow the approaches described in the Work Plan, including any CARB-approved revisions to MODEL and RECONCILE objectives. The evaluation will include a statistical analysis of the relationship between environmental conditions, management practices, canopy processes, background deposition fluxes, and above canopy net fluxes. The report will summarize any CARB-approved adjustments to the Work Plan, in which documentation should have been

provided as stated in Tasks 2 and 3. It will document equipment maintenance and calibration and a description of management practices at each flux tower site. The report will also include the following:
  - An uncertainty analysis for all observations including error sources described in section 2.5.
  - A description of the approaches used for gap-filling the long-term flux datasets, estimating background deposition fluxes, and uncertainties associated with variability in the physical environment and chemical and biological processes.
  - A model sensitivity study including key assumptions, known factors, and unknown factors controlling variability, and implications of uncertainties for interpreting the results.
  - A detailed data analysis including statistical analysis of NO_x emission responses to environmental conditions and nitrogen management practices. This will include time series plots of emission trends and correlations of emissions with driving variables.
  - An interpretation of the preliminary observational findings and model assessment and improvements.
- Input datasets suitable for driving DNDC and models with the MEGAN3 framework, including BDSNP.
- A model testbed suitable for testing emission, chemistry and transport models.
- Tools to reproduce workflows, tables and figures using R or python code.
- Tutorial session(s) to guide CARB staff through the data workflows, tables, and figures, where questions can be answered and further data insight can be provided. The training may be conducted as a webcast.

3.5 Task 5: Final Data, Data Publication, Tower Removal, Draft and Final Report

The Contractor will provide CARB with all data developed through this project. In consultation with CARB, the Contractor will publish the data generated through this project. The Contractor will submit the draft report in a format compliant with the Exhibit A1 Section 2 – Research Final Report Format. The Contractor will submit a draft final report to CARB six (6) months prior to the agreement end date. The results of the project will be presented to CARB staff. The primary deliverable will be a final report describing the background, experimental and analytical methods, and results. The final report will be amended based on CARB comments and submitted to CARB before the end date of the agreement. In the final report, the Contractor will also include a one-page Public Outreach Document that will use clear and accessible language to communicate this work to the public. The Public Outreach Document should contain a graphic that aids public's understanding of the project goals and/or outcomes.

All data developed through this project will be provided to CARB with appropriate meta-data and documentation. The Contractor will provide a tutorial for running the workflows that generated this data to ensure that CARB staff will have the ability to replicate the deliverables. The Contractor will ensure that all methods execute tasks correctly and will work with CARB staff to ensure that workflows can be reproduced using the computational resources available to CARB staff. Data will be provided in a clean, easily understandable state with sufficient documentation for understandability and transferability.

In consultation with CARB, the Contractor will remove the EC tower installation and all related infrastructure. The site will be restored to a state comparable to the condition prior to installation. All equipment borrowed or purchased by this contract will be delivered to an address in Sacramento, CA provided by CARB unless other arrangements are agreed to by CARB. The Contractor will ensure the instrumentation is not damaged in transport.

A draft version of the Final Report detailing the purpose and scope of the work undertaken, the work performed, the results obtained, and conclusions, and a Public Outreach Document and an Equity Implications Section will be copy-edited and reviewed for 2.0 ADA compliance before being sent to CARB for review. The Principal Investigator shall attest that the Final Report has been reviewed and approved by co-PIs, consultants and subcontractors.

3.5.1 Task 5 Deliverable

The Contractor will submit a Draft version of the Final Report using CARB-approved templates, along with a Final Report to CARB. The final report will include a one-page Public Outreach Document which uses clear and accessible language. Both the Draft Final Report, and Final Report must be submitted in accordance with the requirements outlined in Exhibit A1, Section 2 – Research Final Report Format.

Project Schedule

Task 1: Develop a Detailed Work Plan

Task 2: Initiate field measurements

Task 3: Data collection, QA/QC, dataset constructions, and archiving

Task 4: Data Analysis and model development

Task 5: Final Data, Data Publication, Tower Removal, Draft and Final Report

Table 2

	Year 1				Year 2				Year 3			
T1												
T2												
T3												
T4												
T5												
	m.p	p	m.p	p	m.p	p	m.p	p	m,p	p	m.p.d	f

m = meeting with CARB staff
p= quarterly progress report
d= deliver final draft report
f= deliver final report

Meetings

A. Initial meeting. Before work on the contract begins, the Principal Investigator and key personnel will meet with the CARB Contract Project Manager and other staff to discuss the overall plan, details of performing the tasks, the project schedule, items related to personnel or changes in personnel, and any issues that may need to be resolved before work can begin.

B. Progress review meetings. The Principal Investigator and appropriate members of his or her staff will meet with CARB's Contract Project Manager at quarterly intervals to discuss the progress of the project. These meetings may be conducted by phone.

   Community Engagement. For community engagement efforts, the Contractor must co-create meeting materials, including presentation slides, flyers, and speaking notes with CARB staff. The Contractor will work with CARB to understand policies and agree to accurately represent those policies or defer for follow-up.

C. Technical Seminar. The Contractor will present the results of the project to CARB staff and a possible webcast at a seminar at CARB facilities in Sacramento or El Monte.

UCI instruments and facilities available for this project

The Guenther, Kim, Banerjee and Carlton research groups each have a laboratory in adjacent buildings on the UC Irvine campus and office space for students and postdoctoral scientists adjacent to the labs that include computers outfitted with ARCGIS, various data analysis software (Python, R, IGOR), and the latest version of Microsoft Office. In addition, the labs have software for data acquisition and analysis, which facilitates instrument operation and maintenance. Equipment in the labs available for this project includes the following:

Offline GCs for VOC analysis: thermal-desorption (Markes Ultra/Unity) gas chromatograph (Agilent 7890b) equipped with time-of-flight mass spectrometer (Markes BenchTOF-SeV) and flame ionization detector (TD-GC-FID/TOFMS). The ToF-MS, compared to the quadrupole MS used for most previous BVOC studies, has better sensitivity (< 1 ppt detection limit), chromatographic separation, and deconvolution of co-eluting compounds due to higher scan rates, mass resolution, and accuracy. The system is highly inert with a heated transfer line and suitable for analyzing SVOCs. The unique select-eV technology provides simultaneous measurements with conventional electron ionization (-70 eV) and much softer ionization, down to -10 eV, without loss of sensitivity to aid in detecting molecular ions. In addition, the labs have a portable GC system fitted with a vacuum UV detector (VUV analytics VGA 100) and another GC system configured with a chiral column for analyzing monoterpene enantiomers. Three other portable GC-QMS systems (Inficon HAPSITE ER) and two portable GC-PIDs are also available. In addition, we have access to an offline liquid chromatograph high-resolution orbitrap mass spectrometer (LC-OMS, Q Extractive Plus, ThermoScientific) for measuring semi-volatile BVOC.

Continuous trace gas measurement systems: An on-line proton transfer reaction time-of-flight mass spectrometer (PTR-TOFMS, Ionicon 1000 Ultra) with fast response (10 Hz) suitable for BVOC eddy covariance measurements and stress studies. LICOR-7000 high precision CO_2 and H_2O infrared gas analyzers (IRGAs) suitable for eddy covariance measurements. RM Young model 81000 and Campbell Scientific CSAT3 3D ultrasonic anemometers. Ozone (Thermo 49i) and NO_x analyzers with a molybdenum converter to measure NO and NOy (Thermo 42i-TL). A custom-built, on-line OH reactivity comparative reactivity method system for total OH-reactivity measurements. A custom-built, Chemical Ionization Mass Spectrometer with SF6 ion chemistry (CIMS, 1 Hz sampling frequency, 15 ppt detection limit) for measuring HONO and HNO_3.

Other UCI facilities

In addition, a 1000 sq ft high bay storage area next to Croul Hall is available for storing shipping containers and field equipment. Expertise in instrumentation in the UCI Instrumental Development Facility, within the UCI ESS department, is available for developing and repairing electronics, communications, plumbing, and other components. This facility has extensive experience supporting trace gas flux and concentration measurements. In addition, the UCI School of Physical Sciences has outstanding professional mechanical and electrical facilities.

Project Management Plan

This project combines the knowledge and capabilities of eleven internationally recognized experts at five universities (UC Irvine, UC Davis, Colorado State University, U. of Innsbruck, U. Maryland) and two research institutes (NCAR, USDA-ARS). Alex Guenther, a UCI professor, lead developer of the MEGAN model, and a leader of more than 30 integrated regional emissions, chemistry and transport studies on six continents, will serve as Principal Investigator and have overall responsibility for coordinating this project including submitting deliverables. He will supervise two postdoctoral scientists, including one who will serve as project manager for the FT-ORCHARD, FT-ROW, IFC-HONO components and another for the IFC-CRF field study observational components. He will also supervise postdoctoral scientist Yingnan Zhang and graduate student researcher Lixuan Wang who will focus on the MODEL and RECONCILE activities. Communication will include monthly virtual meetings for observational and modeling working groups and annual project meetings (In Irvine, Davis or SJV or timed adjacent to conferences such as AGU).

UCI Professor Saewung Kim will be responsible for the HONO and OH reactivity measurements and will supervise a graduate student, Jared Novelly, who will support the construction and maintenance of the long-term flux towers for the FT-ORCHARD and FT-ROW objectives. UCI Professors Ann Marie Carlton will co-supervise a postdoctoral scientist conducting the soil sampling and analysis activities and will provide guidance for the regional air quality modeling efforts. Tirtha Banerjee will guide a graduate student and postdoctoral scientist on eddy flux measurement assessment and canopy turbulence measurements.

UCD Professor Mike Kleeman will lead the FT-SLURRY objective and will supervise a UCD postdoctoral scientist. UCD professor Holly Oldroyd will provide NO_x eddy covariance expertise for the FT-SLURRY eddy flux systems.

Subcontractor Dr. Ray Anderson (USDA-ARS) will provide contacts for orchard field site access and guidance on orchard management practices and flux tower setup and operation. Collaborators bringing additional expertise to project include Professor Dien Wu (Colorado State University) for reconciling “top-down” satellite data with “bottom-up” emission models, Professor Thomas Karl (U. Innsbrook) for long-term NO_x eddy covariance measurements and canopy chemistry, dynamics and fluxes, NCAR scientist Ned Patton for canopy chemistry and transport field studies and modeling, and U. Maryland Professor Stephanie Yarwood for characterizing soil microbial communities and their functioning.

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EXHIBIT A1

DELIVERABLES

List all items that will be delivered to the State under the proposed Scope of Work. Include all reports, including draft reports for State review, and any other Deliverables, if requested by the State and agreed to by the Parties.

If use of any Deliverable is restricted or is anticipated to contain preexisting Intellectual Property with any restricted use, it will be clearly identified in Exhibit A4, Use of Preexisting Intellectual Property & Data.

Unless otherwise directed by the State, the University Principal Investigator shall submit all deliverables to State Contract Project Manager, identified in Exhibit A3, Authorized Representatives.

Deliverable	**Description**	**Due Date**
Bias training	The Principal Investigator and key personnel must demonstrate that they have taken, or will take, implicit bias training. Training certificates or certificates of completion completed within one (1) year prior to the agreement start date will be accepted. If the training has not been completed within one (1) year prior to the agreement start date, then the Principal Investigator and key personnel must demonstrate that they have scheduled the training within 30 days of the agreement start date and shall complete the training within 90 days of the agreement start date.	Within 90 days of the agreement start date.
Farm competency training	The project team will work with the agricultural industry representatives to identify or develop farm competency training materials that shall require no more than one hour to complete (e.g., https://gpcah.public-health.uiowa.edu/core-course-online-modules/). All project team members will complete farm competency training within 90 days of the agreement start date.	Within 90 days of the agreement start date.
Initial Meeting	Principal Investigator and key personnel will meet with CARB Contract Project Manager and other staff to discuss the overall plan, details of performing the tasks, project schedule, items related to personnel or changes in personnel, and any issues that may need to be resolved before work can begin.	Month 1
Task 1: Field Study, Data Management, and Modeling Plan (alias Work Plan)	The Contractor shall submit to CARB an interim report (Work Plan) that includes a detailed description of the research design, results from the literature review, refined research questions, finalized methodology, and the finalized research plan. The report will document the sampling protocol for field experiments, including measures to minimize researcher bias and subjective interpretation, and ensure consistent training and systematic data recording. The interim report shall be submitted to CARB in a mutually agreed upon format.	Month 6

Task 2: Initiate field measurements	The Contractor will submit to CARB an interim report that describe any updates to the sampling protocol and standard operating procedures. In consultation with CARB, significant changes in these components or any necessary changes in approaches will be incorporated into the Field Plan from Task 1.	Month 9
Task 3: Data collection, QA/QC, dataset constructions, and archiving	The Contractor will provide a written progress report and an up-to-date log of maintenance, calibration, and any other changes to the flux tower since installation. The Contractor will submit eddy covariance tower data progress report and maintenance log, including all collected meteorological and flux tower data values. The Contractor will provide a progress report and all data related to the collection and analysis of soil samples in Month 27.	Month 27
Task 4: Data Analysis and model development	The Contractor will provide either a written report or a presentation to CARB staff detailing data analysis of all observations.	Month 32
Task 5: Final Data, Data Publication, Tower Removal, Draft and Final Report	The Contractor will demonstrate the final products with an uncertainty analysis, appropriate meta-data and documentation. The Contractor will publish all generated eddy covariance tower data and all dated soil core data to the public. The Contractor will Provide CARB with data compilations produced in the performance of this Agreement.	Month 34
Progress Reports & Meetings	Quarterly progress reports and meetings throughout the agreement term, to coincide with work completed in quarterly invoices.	Quarterly
Draft Final Report	Draft version of the Final Report detailing the purpose and scope of the work undertaken, the work performed, the results obtained and conclusions, and a Public Outreach Document and an Equity Implications Section. The Draft Final Report shall be copy-edited before being sent to CARB for review and the Principal Investigator shall attest that the Final Report has been reviewed and approved. The Draft Final Report must be submitted in accordance with the requirements outlined in Exhibit A1, Section 2 – Research Final Report Format.	Six (6) months prior to the agreement end date.
Data	Data compilations first produced in the performance of this Agreement by the Principal investigator or the University's project personnel.	Two (2) weeks prior to agreement end date.
Technical Seminar	Presentation of the results of the project to CARB staff and a possible webcast at a seminar at CARB facilities in Sacramento or El Monte. The Technical Seminar slides shall be submitted in an ADA compliant format. CARB's standard for ADA compliance requires that the submitted document adhere to WCAG 2.1 AA (https://www.w3.org/TR/WCAG21/) and Federal Section 508 (https://www.section508.gov/).	On or before agreement end date.

Tutorial(s)	Tutorial(s) for running the workflows that generated this data to ensure that CARB staff will have the ability to replicate the deliverables. The tutorial may be conducted as a webcast.	On or before agreement end date.
The following Deliverables are subject to paragraph 19. Copyrights, paragraph B of Exhibit C		
Final Report	Written record of the project and its results. The Final Report must be submitted in accordance with the requirements outlined in Exhibit A1, Section 2 – Research Final Report Format.	Two (2) weeks prior to agreement end date.

1. Reports and Data Compilations

A. With respect to each invoice period University shall submit, to the CARB Contract Project Manager, one (1) electronic copy of the progress report. When emailing the progress report, the “subject line” should state the contract number and the billing period. Each progress report must accompany a related invoice covering the same billing period. Each progress report will begin with the following disclaimer:

> *The statements and conclusions in this report are those of the University and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products*.

B. Each progress report will also include:

1. A brief summary of the status of the project, including whether the project is on schedule. If the project is behind schedule, the progress report must contain an explanation of reasons and how the University plans to resume the schedule.

2. A brief narrative account of project tasks completed or partially completed since the last progress report.

3. A brief discussion of problems encountered during the reporting period and how they were or are proposed to be resolved.

4. A brief discussion of work planned, by project task, before the next progress report. and

5. A graph or table showing percent of work completion for each task.

C. Six (6) months prior to Agreement expiration date, University will deliver to CARB an electronic copy of the draft final report in both PDF and Microsoft Word formats. The draft final report will conform to Exhibit A1, Section 2 – Research Final Report Format.

D. Within forty-five (45) days of receipt of CARB’s comments, University will deliver to CARB’s Contract Project Manager an electronic copy of the final report incorporating all reasonable alterations and additions. Within two (2) weeks of receipt of the revised report, CARB will verify that all CARB comments have been addressed. Upon acceptance of the amended final report approved by CARB in accordance to Exhibit A1, Section 2 – Research Final Report Format, University will within two (2) weeks, deliver to CARB an electronic copy of the final report in both PDF and Microsoft Word formats.

E. As specified in Exhibit A1, Section 2, Final Report will be submitted in an Americans with Disabilities Act compliant Format.

F. Together with the final report, University will deliver a set of all data compilations as specified in Exhibit A1 – Schedule of Deliverables.

G. University's obligation under this Agreement shall be deemed discharged only upon submittal to CARB of an acceptable final report in accordance to Exhibit A1, Section 2 – Research Final Report Format, all required data compilations, and any other project deliverables.

2. Research Final Report Format

The research contract Final Report (Report) is as important to the contract as the research itself. The Report is a record of the project and its results and is used in several ways. Therefore, the Report must be well organized and contain certain specific information. The CARB's Research Screening Committee (RSC) reviews all draft final reports, paying special attention to the Abstract and Executive Summary. If the RSC finds that the Report does not fulfill the requirements stated in this Exhibit, the RSC may not recommend release, and final payment for the work completed may be withheld. This Exhibit outlines the requirements that must be met when producing the Report.

Note: In partial fulfillment of the Final Report requirements, the Contractor shall submit a copy of the Report in PDF format <u>and</u> in a word-processing format, preferably in Word – Version 6.0 or later. The electronic copy file name shall contain the CARB contract number, the words "Final Report", and the date the report was submitted.

Accessibility. Contractor must ensure that the Final Report complies with Web Content Accessibility Guidelines 2.0, levels A and AA, and otherwise meets the accessibility requirements set forth in California Government Code Sections 7405 and 11135, Section 202 of the federal Americans with Disabilities Act (42 U.S.C. § 12132), and Section 508 of the federal Rehabilitation Act (29 U.S.C. § 794d) and the regulations promulgated thereunder (36 C.F.R. Parts 1193 and 1194) (collectively, the "Accessibility Requirements"). For any report provided in PDF format, Contractor shall also provide an electronic version in the original electronic format (for example, Microsoft Word or Adobe InDesign). CARB may request documentation from the Contractor of compliance with the Accessibility Requirements and may perform testing to verify compliance. Contractor must bring into compliance, at no cost to CARB, any report by Contractor or its subcontractors not meeting the Accessibility Requirements. If Contractor fails to bring its or its subcontractors' report into compliance with the Accessibility Requirements within five (5) business days of written notice from CARB, or within the time frame specified by CARB in its notice, Contractor will be responsible for all costs incurred by CARB in bringing Contractor's or its subcontractors' report into compliance with the Accessibility Requirements. Contractor agrees to respond to and resolve any complaint brought to its attention regarding accessibility of deliverables provided under this Contract for a period of one year following delivery of the final deliverable under this Contract.

Deviations from the Accessibility Requirements are permitted only by written consent by CARB.

Watermark. Each page of the draft Report must include a watermark stating "DRAFT." The revised report should not include any watermarks.

Title. The title of the Report should exactly duplicate the title of the contract. However, minor changes to the title may be approved provided the new title does not deviate from the old title. These minor changes must be approved in writing by the contract manager. Significant changes to the title would require a formal amendment.

Page size. All pages should be of standard size (8 ½" x 11") to allow for photo-reproduction.

Corporate identification. Do not include corporate identification on any page of the Final Report, except the title page.

Unit notation. Measurements in the Reports should be expressed in metric units. However, for the convenience of engineers and other scientists accustomed to using the British system, values may be given in British units as well in parentheses after the value in metric units. The expression of measurements in both systems is especially encouraged for engineering reports.

Section order. The Report should contain the following sections, in the order listed below:

Title page
Disclaimer
Acknowledgment (1)
Acknowledgment (2)
Table of Contents
List of Figures
List of Tables
Abstract
Public Outreach Document
Executive Summary
Equity Implications Section
Body of Report
References
List of inventions reported and copyrighted materials produced
Glossary of Terms, Abbreviations, and Symbols
Appendices

Page numbering. Beginning with the body of the Report, pages shall be numbered consecutively beginning with "1", including all appendices and attachments. Pages preceding the body of the Report shall be numbered consecutively, in ascending order, with small Roman numerals.

Title page. The title page should include, at a minimum, the contract number, contract title, name of the principal investigator, contractor organization, date, and this statement:
"Prepared for the California Air Resources Board and the California Environmental Protection Agency"

Disclaimer. A page dedicated to this statement must follow the Title Page:

> The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

Acknowledgment (1). Only this section should contain acknowledgments of key personnel and organizations who were associated with the project. The last paragraph of the acknowledgments must read as follows:

> This Report was submitted in fulfillment of [CARB contract number and project title] by [contractor organization] under the [partial] sponsorship of the California Air Resources Board. Work was completed as of [date].

Acknowledgment (2). Health reports should include an acknowledgment to the late Dr. Friedman. Reports should include the following paragraph:

> This project is funded under the CARB's Dr. William F. Friedman Health Research Program. During Dr. Friedman's tenure on the Board, he played a major role in guiding CARB's health research program. His commitment to the citizens of California was evident through his personal and professional interest in the Board's health research, especially in studies related to children's health. The Board is sincerely grateful for all of Dr. Friedman's personal and professional contributions to the State of California.

Attestation. A page dedicated to this attestation statement must follow the Acknowledgement(s). The Principal Investigator (PI) must digitally sign below the following statement:

> The Final Report for CARB Agreement No. [contract number] titled "[Enter project title]" has been copy-edited for grammar, style, and format and is reviewed and approved by the Principal Investigator (PI), [title and name of PI] of [Contractor Name]. The signature below attests that the PI has completed a thorough review of this Final Report and approves it for submission to the California Air Resources Board.
>
> PI Signature
> Date

Table of Contents. This should list all the sections, chapters, and appendices, together with their page numbers. Check for completeness and correct reference to pages in the Report.

List of Figures. This list is optional if there are fewer than five illustrations.

List of Tables. This list is optional if there are fewer than five tables.

Abstract. The abstract should tell the reader, in nontechnical terms, the purpose and scope of the work undertaken, describe the work performed, and present the results obtained and conclusions. The purpose of the abstract is to provide the reader with useful information and a means of determining whether the complete document should be obtained for study. The length of the abstract should be no more than about 200 words. Only those concepts that are addressed in the executive summary should be included in the abstract.

Example of an abstract:

A recently developed ground-based instrument, employing light detecting and ranging (lidar) technology, was evaluated, and found to accurately measure ozone concentrations at altitudes of up to 3,000 meters. The novel approach used in this study provides true vertical distributions of ozone concentrations aloft and better temporal coverage of these distributions than other, more common methods, such as those using aircraft and ozonesonde (balloon) techniques. The ozone and aerosol measurements from this study, in conjunction with temperature and wind measurements, will provide a better characterization of atmospheric conditions aloft and the processes involved in the formation of unhealthful ozone concentrations than can be achieved with traditional ground-based monitors.

Public Outreach Document. The public outreach document is a one-page document that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. CARB will be translating the document into other languages. This document must adhere to the following guidelines:

- Single space, limited to one-page or about 500 words.
- Use narrative form and active voice.
- Incorporate a graphic that it is easy to interpret and captures the results' central message.
- Avoid jargon and technical terms. Use a style and vocabulary level comparable to that of sixth grade reading level.
- The document should contain a title and the following five sections: Issue/s, Main Question, Key Research Findings, Conclusion/s, and More Information. Guidance on how to write these sections is described below.

  TITLE: Adopt a short, non-technical title to make the topic clear and concise. The title will likely differ from the original title of the contract.

  ISSUE/S: In one to two paragraphs, describe why the project was needed. In this section, identify the problem leading to this study and what the study was set to accomplish to help address the problem. Reference any history that is relevant such as a regulation, legislation, program, law, or other. Without going into detail and disclosing the research findings, mention the methods used in the study and how it informed the results.

  MAIN QUESTION: Present a concise central research question driving this project.

  KEY RESEARCH FINDING/S: This section covers the key research findings. List key points and or findings.

  CONCLUSION/S: In one to two paragraphs, discuss how the results could be used. Mention its relevance to policies, rules, regulations, legislations, or CARB programs. Include suggestions for next steps, additional research, or other actions.

  MORE INFORMATION: In two to three short sentences provide specifics about the study. This section should include the full title of the study, sponsor, authors, and where the full report can be found (the final report will be posted on the CARB website). In addition to a direct contact to gain more information (author and CARB contract manager).

Executive Summary. The function of the executive summary is to inform the reader about the important aspects of the work that was done, permitting the reader to understand the research without reading the entire Report. It should state the objectives of the research and briefly describe the experimental methodology[ies] used, results, conclusions, and recommendations for further study. All of the concepts brought out in the abstract should be expanded upon in the Executive Summary. Conversely, the Executive Summary should not contain concepts that are not expanded upon in the body of the Report.

The Executive Summary will be used in several applications as written; therefore, please observe the style considerations discussed below.

Limit the Executive Summary to two pages, single spaced.

Use narrative form. Use a style and vocabulary level accessible to the general audience. Assume the audience is being exposed the subject for the first time.

Do not list contract tasks in lieu of discussing the methodology. Discuss the results rather than listing them.

Avoid jargon.

Define technical terms.

Use passive voice if active voice is awkward.

Avoid the temptation to lump separate topics together in one sentence to cut down on length.

The Executive Summary should contain four sections: Background, Objectives and Methods, Results, and Conclusions, described below.

THE BACKGROUND SECTION. For the Background, provide a one-paragraph discussion of the reasons the research was needed. Relate the research to the Board's regulatory functions, such as establishing ambient air quality standards for the protection of human health, crops, and ecosystems; the improvement and updating of emissions inventories; and the development of air pollution control strategies.

THE OBJECTIVES AND METHODS SECTION. At the beginning of the Objectives and Methods section, state the research objectives as described in the contract. Include a short, one or two sentences, overview of what was done in general for this research.

The methodology should be described in general, nontechnical terms, unless the purpose of the research was to develop a new methodology or demonstrate a new apparatus or technique. Even in those cases, technical aspects of the methodology should be kept to the minimum necessary for understanding the project. Use terminology with which the reader is likely to be familiar. If it is necessary to use technical terms, define them. Details, such as names of manufacturers and statistical analysis techniques, should be omitted.

Specify when and where the study was performed if it is important in interpreting the results. The findings should not be mentioned in the Objectives and Methods section.

THE RESULTS SECTION. The Results section should be a single paragraph in which the main findings are cited, and their significance briefly discussed. The results should be presented as a narrative, not a list. This section must include a discussion of the implications of the work for the Board's relevant regulatory programs.

THE CONCLUSIONS SECTION. The Conclusions section should be a single short paragraph in which the results are related to the background, objectives, and methods. Again, this should be presented as a narrative rather than a list. Include a short discussion of recommendations for further study, adhering to the guidelines for the Recommendations section in the body of the Report.

Body of Report. The body of the Report should contain the details of the research, divided into the following sections:[5]

INTRODUCTION. Clearly identify the scope and purpose of the project. Provide a general background of the project. Explicitly state the assumptions of the study.

[5] Note that if the research employs multiple distinct methods, analyses, etc., the final report can include separate materials/methods, results, and discussion sections to allow for coherent discussion of each set of analyses and findings. However, the executive summary and conclusions sections should synthesize the collective findings of the entire study.

Clearly describe the hypothesis or problem the research was designed to address. Discuss previous related work and provide a brief review of the relevant literature on the topic.

MATERIALS AND METHODS. Describe the various phases of the project, the theoretical approach to the solution of the problem being addressed, and limitations to the work. Describe the design and construction phases of the project, materials, equipment, instrumentation, and methodology.

Describe quality assurance and quality control procedures used. Describe the experimental or evaluation phase of the project.

RESULTS. Present the results in an orderly and coherent sequence. Describe statistical procedures used and their assumptions. Discuss information presented in tables, figures, and graphs. The titles and heading of tables, graphs, and figures, should be understandable without reference to the text. Include all necessary explanatory footnotes. Clearly indicate the measurement units used.

DISCUSSION. Interpret the data in the context of the original hypothesis or problem. Does the data support the hypothesis or provide solutions to the research problem? If appropriate, discuss how the results compare to data from similar or related studies. What are the implications of the findings?

Identify innovations or development of new techniques or processes. If appropriate, discuss cost projections and economic analyses.

SUMMARY AND CONCLUSIONS. This is the most important part of the Report because it is the section that will probably be read most frequently. This section should begin with a clear, concise statement of what, why, and how the project was done. Major results and conclusions of the study should then be presented, using clear, concise statements. Make sure the conclusions reached are fully supported by the results of the study. Do not overstate or overinterpret the results. It may be useful to itemize primary results and conclusions. A simple table or graph may be used to illustrate.

RECOMMENDATIONS. Use clear, concise statements to recommend (if appropriate) future research that is a reasonable progression of the study and can be supported by the results and discussion.

References. Use a consistent style to fully cite work referenced throughout the Report and references to closely related work, background material, and publications that offer additional information on aspects of the work. Please list these together in a separate section, following the body of the Report. If the Report is lengthy, you may list the references at the end of each chapter.

List of inventions reported and publications produced. If any inventions have been reported, or publications or pending publications have been produced as a result of the project, the titles, authors, journals or magazines, and identifying numbers that will assist in locating such information should be included in this section.

Glossary of terms, abbreviations, and symbols. When more than five of these items are used in the text of the Report, prepare a complete listing with explanations and definitions. It is expected that every abbreviation and symbol will be written out at its first appearance in the Report, with the abbreviation or symbol following in parentheses [i.e., carbon dioxide (CO_2)]. Symbols listed in table and figure legends need not be listed in the Glossary.

Appendices. Related or additional material that is too bulky or detailed to include within the discussion portion of the Report shall be placed in appendices. If a Report has only one appendix, it should be entitled "APPENDIX". If a Report has more than one appendix, each should be designated with a capital letter (APPENDIX A, APPENDIX B). If the appendices are too large for inclusion in the Report, they should be collated, following the binding requirements for the Report, as a separate document.

The contract manager will determine whether appendices are to be included in the Report or treated separately. Page numbers of appendices included in the Report should continue the page numbering of the Report body. Pages of separated appendices should be numbered consecutively, beginning at “1”.

3. Other Deliverables

A. Contractor must ensure that all products and services submitted, uploaded, or otherwise provided by the Contractor and/or its subcontractors under this Agreement, including but not limited to data, software, plans, drawings, specifications, reports, operating manuals, notes, and other written or graphic work prepared in the course of performance of this Contract (collectively, the “Work”), comply with Web Content Accessibility Guidelines 2.0, levels A and AA, and otherwise meet the accessibility requirements set forth in California Government Code Sections 7405 and 11135, Section 202 of the federal Americans with Disabilities Act (42 U.S.C. § 12132), and Section 508 of the federal Rehabilitation Act (29 U.S.C. § 794d) and the regulations promulgated thereunder (36 C.F.R. Parts 1193 and 1194) (collectively, the “Accessibility Requirements”). For any Work provided in PDF format, Contractor shall also provide an electronic version in the original electronic format (for example, Microsoft Word or Adobe InDesign). CARB may request documentation from the Contractor of compliance with the Accessibility Requirements and may perform testing to verify compliance. Contractor must bring into compliance, at no cost to CARB, any Work by Contractor or its subcontractors not meeting the Accessibility Requirements. If Contractor fails to bring its or its subcontractors’ Work into compliance with the Accessibility Requirements within five (5) business days of written notice from CARB, or within the time frame specified by CARB in its notice, Contractor will be responsible for all costs incurred by CARB in bringing Contractor’s or its subcontractors’ Work into compliance with the Accessibility Requirements. Contractor agrees to respond to and resolve any complaint brought to its attention regarding accessibility of deliverables provided under this Contract for a period of one year following delivery of the final deliverable under this Contract.

   Deviations from the Accessibility Requirements are permitted only by written consent by CARB.

EXHIBIT A2

KEY PERSONNEL

List Key Personnel as defined in the Agreement starting with the PI, by last name, first name followed by Co-PIs. Then list all other Key Personnel in alphabetical order by last name. For each individual listed include his/her name, institutional affiliation, and role on the proposed project. Use additional consecutively numbered pages as necessary.

Last Name, First Name	**Institutional Affiliation**	**Role on Project**
Principal Investigator (PI):		
Guenther, Alex	UCI	PI
Co-PI(s) – if applicable:		
Michael Kleeman	UCD	Co-PI
Other Key Personnel:		
Kim, Saewung	UCI	Co-I
Carlton, Ann Marie	UCI	Co-I
Banerjee, Tirtha	UCI	Co-I
Oldroyd, Holly	UCD	Co-I
Anderson, Ray	USDA-ARS	Subcontractor
Karl, Thomas	University of Innsbruck	Consultant
Yarwood, Stephanie	University of Maryland	Consultant
Patton, Edward (Ned)	NCAR	Consultant
Wu, Dien	Colorado State University	Consultant

EXHIBIT A3

AUTHORIZED REPRESENTATIVES

The following individuals are the authorized representatives for the State and the University under this Agreement. Any official Notices issued under the terms of this Agreement shall be addressed to the Authorized Official identified below, unless otherwise identified in the Agreement.

State Agency Contacts Agency Name: **CARB**	**University Contacts** University Name: UCI
Contract Project Manager (Technical) Name: Address: Research Division 1001 I Street, 5th Floor Sacramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Principal Investigator (PI)*** Name: Alex Guenther Address: University of Calfornia, Irvine Earth System Science 3325 Croul Hall Irvine, CA 92697 Telephone: (949) 824-7320 Email: alex.guenther@uci.edu Designees to certify invoices under Section 14 of Exhibit C on behalf of PI: 1. <Name>, <Title>, <EmailAddress> 2. <Name>, <Title>, <EmailAddress> 3. <Name>, <Title>, <EmailAddress>
Authorized Official (contract officer) Name: Alice Kindarara, Branch Chief Address: Acquisitions Branch Fiscal Services Division 1001 I Street, 20th Floor Sacramento, CA 95814 Telephone: (279) 216-0406 Email: alice.kindarara@arb.ca.gov ***Send notices to (if different):*** Name: Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Authorized Official*** Name: Erika Blossom Senior Contract & Grant Officer Address: Sponsored Projects Administration 324 Aldrich Hall Irvine, CA 92697 ***Send notices to (if different):*** Telephone: (949) 824-2237 Fax: (949) 824-2094 Email: Erika.Blossom@uci.edu

Administrative Contact Name: Address: Research Division 1001 I Street, 7th Floor S acramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Administrative Contact*** Name: Julissa Terriquez Sr. Contracts & Grants Analyst Address: UCI Physical Sciences, Dean's Office 162 Rowland Hall Irvine, CA 92697 Telephone: (949) 824-1068 Email: jterriqu@uci.edu
Financial Contact/Accounting Name: Accounts Payable Address: P.O. Box 1436 Sacramento, CA 95814 Email: AccountsPayable@arb.ca.gov **Send courtesy copy to:** rd.invoices@arb.ca.gov	***Authorized Financial Contact/Invoicing*** Name: Griselda Duran Accounting & Operations Manager Address: Contracts & Grants Accounting 228 Aldrich Hall Irvine, CA 92697 Telephone: (949) 824-6828 Email: griseld@uci.edu Designees for invoice certification in accordance with Exhibit C – University Terms and Conditions, Section 14 on behalf of the Financial Contact: 1. 2. 3.

EXHIBIT A4

USE OF INTELLECTUAL PROPERTY & DATA

If either Party will be using any third-party or pre-existing intellectual property (including, but not limited to copyrighted works, known patents, trademarks, service marks and trade secrets) "IP" and/or Data with restrictions on use, then list all such IP/Data and the nature of the restriction below. If no third-party or pre-existing IP/Data will be used, check "none" in this section.

A. State: Preexisting Intellectual Property (IP)/Data to be provided to the University from the State or a third party for use in the performance in the Scope of Work.

☒ None or ☐ List:

Owner (State Agency or 3rd Party)	Description	Nature of restriction:

B. University: Restrictions in Preexisting IP/Data included in Deliverables identified in Exhibit A1, Deliverables.

☒ None or ☐ List:

Owner (University or 3rd Party)	Description	Nature of restriction:

C. Anticipated restrictions on use of Project Data.
If the University PI anticipates that any of the Project Data generated during the performance of the Scope of Work will have a restriction on use (such as subject identifying information in a data set), then list all such anticipated restrictions below. If there are no restrictions anticipated in the Project Data, then check "none" in this section.

☒ None or ☐ List:

Owner (State Agency or 3rd Party)	Description	Nature of restriction:

EXHIBIT A5

Résumé / Biosketch

Previous experience quantifying biogenic fluxes and compiling observations for biogenic emission model development and evaluation.

The research team has extensive experience relevant to addressing the research gaps identified by the SMERP report (Horwath et al. 2025). This includes specific areas of expertise as well as managing complex field studies, long term NO_x measurements, reconciling top-down and bottom-up measurement discrepancies and integrating diverse observations into emission models. PI Guenther has measured biogenic fluxes across multiple scales (e.g., Guenther et al. 1996) and integrated the results into biogenic emission models for NO_x and VOC (e.g., Williams et al. 1992, Guenther et al. 1995, Guenther et al. 2012). He is the lead developer of the MEGAN biogenic emission model framework which includes recent soil NO_x emission updates including high resolution (10 m) agricultural landcover, BDSNP soil NO_x emission algorithms and the Wang et al. (2025) soil HONO emission scheme. Co-PI Kleeman has worked extensively with agricultural partners on past successful CARB funded projects including ozone formation potential of dairy waste (Howard et al., 2008, Howard et al., 2010) and identifying the composition of dairy digester biogas (Li et al., 2019, Chin et al., 2020). His CARB supported work also includes modeling the effects of soil NO_x emissions in California (Kleeman et al., 2019).

Co-I Kim has developed a custom-built CIMS for measuring HONO and has used cavity ring-down laser spectroscopy techniques for measuring NO_2. He was also responsible for improving the airborne mesoscale mass balance measurements approach for estimating whole facility emissions that we will use for this project (Wong et al 2024). Co-I Carlton has analyzed soil core physical and biological traits at USDA Long-Term Agricultural Research stations that are being used to develop scalable, data-informed tools to improve prediction of nitrogen emissions. In collaboration with USDA, co-I Carlton is using Julia-based modeling frameworks to analyze satellite and field scale observational data to improve prediction of soil nitrogen emissions to support air quality management in agricultural regions. As a developer for the CMAQ modeling system, co-I Carlton also brings experience in model development and application to policy-relevant questions. Her collaboration with the Central California Environmental Justice Network supports identifying key emission sources in the SJV by translating complex science into actionable insights that support community-informed and equitable decision-making. Subcontractor Anderson (USDA) has deployed and operated a network of multi-year EC flux sites (CO_2, H_2O, energy) in SJV orchards including almonds (Kandhway et al. 2025) and citrus (Dhungel et al. 2024). Co-Is Banerjee and Oldroyd have deployed and operated EC flux systems and characterized canopy dynamics and fluxes in various California ecosystems (Desai et al. 2024). Consultant Thomas Karl (U. Innsbruck) has deployed and operated a multi-year eddy covariance NOx flux site (Karl et al. 2017). Consultant Ned Patton has led field experiments and model development of canopy chemistry and transport of reactive trace gases. Consultant Dien Wu (Colorado State) has expertise comparing biogenic VOC and NOx with aircraft and satellite data and will leverage her ongoing NASA funded research to use TEMPO observations to constrain soil NOx emissions estimates for this project. Consultant Stephanie Yarwood is expert on soil microbial communities and their functioning including nitrogen dynamics.

Alex B. Guenther
Distinguished Professor, Department of Earth System Science

3200 Croul Hall, University of California, Irvine, CA 92697-3100, USA
alex.guenther@uci.edu; phone:1-949-824-7320

Education:

1989 Ph.D., Engineering Science, Washington State University, Pullman WA
1986 M.S., Environmental Engineering, Washington State University, Pullman WA
1984 B.S., Biology with minor in Computer Science, University of Puget Sound, Tacoma WA

Appointments:

2015-present Professor, Dept. of Earth System Science, U. of California, Irvine, CA 92697
2013-2015 Laboratory Fellow, Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland WA 99352

2004-2013 Senior Scientist and Section Head, Atmospheric Chemistry Division, National Center for Atmospheric Research (NCAR), Boulder, Colorado

1990-2004 Scientist I, II, III, Atmos. Chemistry Division, NCAR, Boulder, Colorado
1989-1990 Visiting Fellow (post-doctoral), Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

Selected Awards:

- 2023 Research.com Environmental Sciences Leader Award
- 2022 Fellow of the American Association for the Advancement of Science (AAAS)
- 2015 Fellow of the American Geophysical Union (AGU)
- 2014 Essential Science Indicators Highly Cited Researcher (Thomson Reuters)
- 2012 UCAR Outstanding Publication Award
- 2011 Yoram J. Kaufman Award for Unselfish Cooperation in Research (AGU)

Significant Activities:

- Lead developer of the Model of Emissions of Gases and Aerosols from Nature (MEGAN) community model: 2000-present.
- Principal Investigator or Co-PI for NSF, NASA, NOAA, EPA, DOE, TCEQ (Texas), CARB, BAAQMD, and SCAQMD (California) funded projects
- Editorial Board member: Elementa (2013 – present), Frontiers in Forests and Global Change (2018-present), PeerJ (2017-present), Atmos. Chem. and Physics (2001-21), Geo. Model Dev. (2014-19), Atmos. Envir. (2000-12), J. Geophys. Res. (1998-2000), Tree Phys. (1997-2000)
- Contributing author: IPCC assessment; IGBP-IGAC integration and synthesis
- Int. Geosphere Biosphere Program (IGBP): Co-chair of integrated Land Ecosystem Atmosphere Processes Study (iLEAPS), 2010-2015; Co-chair of Global Emissions Inventory Activity (GEIA), 2003-2010, Science Steering Committee member: 2011-2015.

Ten relevant publications (out of >400 publications, H index = 124; Total Citations > 70000)

- Opacka, B., Stavrakou, T., Müller, J.-F., De Smedt, I., van Geffen, J., Marais, E. A., Horner, R. P., Millet, D. B., Wells, K. C., and Guenther, A. B.: Natural emissions of VOC and NO_x over Africa constrained by TROPOMI HCHO and NO2 data using the MAGRITTEv1.1 model, Atmos. Chem. Phys., 25, 2863–2894, https://doi.org/10.5194/acp-25-2863-2025, 2025.

- Huang, M., Carmichael, G. R., Bowman, K. W., De Smedt, I., Colliander, A., Cosh, M. H., Kumar, S. V., Guenther, A. B., Janz, S. J., Stauffer, R. M., Thompson, A. M., Fedkin, N. M., Swap, R. J., Bolten, J. D., and Joseph, A. T.: Reactive nitrogen in and around the northeastern and mid-Atlantic US: sources, sinks, and connections with ozone, Atmos. Chem. Phys., 25, 1449–1476, https://doi.org/10.5194/acp-25-1449-2025, 2025.

- Wang, H., Welch, A.M., Nagalingam, S., Leong, C., Czimczik, C.I., Tang, J., Seco, R., Rinnan, R., Vettikkat, L., Schobesberger, S., Holst, T., Brijesh, S., Sheesley, R.J., Barsanti, K.C., & Guenther, A.B. High temperature sensitivity of Arctic isoprene emissions explained by

sedges. Nature Communications, 15, 6144, doi:10.1038/s41467-024-49960-0, 2024.

- Chen, Weihua, Alex B. Guenther, Shiguo Jia, Jingying Mao, Fenghua Yan, X. Wang and Min Shao. “Synergistic effects of biogenic volatile organic compounds and soil nitric oxide emissions on summertime ozone formation in China.” The Science of the Total Environment, 828, 154218, 10.1016/j.scitotenv.2022.154218, 2022.
- Ye, C., X. Zhou, D. Pu, J. Stutz, J. Festa, M. Spolaor, C. Tsai, C. Cantrell, R. L. Mauldin, T. Campos, A. Weinheimer, R. S. Hornbrook, E. C. Apel, A. Guenther, L. Kaser, B. Yuan, T. Karl, J. Haggerty, S. Hall, K. Ullmann, J. N. Smith, J. Ortega & C. Knote (2016) Rapid cycling of reactive nitrogen in the marine boundary layer. Nature, 532, 489-491.
- Guenther, A., X. Jiang, C. Heald, T. Sakulyanontvittaya, T. Duhl, L. Emmons & X. Wang. The Model of Emissions of Gases and Aerosols from Nature version 2.1 (MEGAN2.1): an extended and updated framework for modeling biogenic emissions, Geophysical Model Development, 5, 1471-1492, 2012.
- Karl, T., Guenther, A., Turnipseed, A., Patton, E. G., and Jardine, K.: Chemical sensing of plant stress at the ecosystem scale, Biogeosciences, 5, 1287–1294, https://doi.org/10.5194/bg-5-1287-2008, 2008.
- Turnipseed, A., G. Huey, E. Nemitz, R. Stickel, J. Higgs, D. Tanner, D. Slusher, J. Sparks, F. Flocke, and A. Guenther, Eddy covariance fluxes of peroxyacyl nitrates (PANs) and NOy to a coniferous forest, J. Geophys. Res., 111, D09304, doi:1029/2005JD006631, 2006.
- Guenther, A., C. Geron, T. Pierce, B. Lamb, P. Harley, and R. Fall, Natural emissions of non-methane volatile organic compounds, carbon moide, and oxides of nitrogen from North America, Atmos. Environ, 34, 2205-2230, 2000.
- Williams, E., A. Guenther, and F. Fehsenfeld, An inventory of nitric oxide emissions from soils in the United States, J. Geophys. Res., 97: 7511-7520, 1992.

ANN MARIE GROVER CARLTON
Professor and Vice Chair

Department of Chemistry, University of California, Irvine, CA agcarlto@uci.edu

ACADEMIC APPOINTMENTS

Professor of Chemistry, University of California, Irvine 2020-pres.

Vice-Chair, Dept. of Chemistry, University of California, Irvine 2020-2021; 2023-pres.
Associate Professor, Dept. of Chemistry, University of California, Irvine, CA 2016-2020
Assistant Professor (promoted with tenure), Dept. of Environmental Sciences

Rutgers University, New Brunswick, NJ 2010-2016

PROFESSIONAL POSITIONS

Fellow & Special Govt. Employee, White House Office of Science & Tech. Policy 2021-2023
Physical Scientist, U.S. EPA, Office of Research and Development, RTP, NC 2008-2010
Research Physical Scientist, NOAA, Air Resources Lab., Research Triangle Park, NC 2006-2008
Environmental Engineer, U.S. EPA–Region 2, New York, NY 1996-2002

EDUCATION

Ph.D., Environmental Science, Rutgers University, New Brunswick, NJ Oct. 2006

M.S., Bioenvironmental Engineering, Rutgers University, New Brunswick, NJ October 1999
B.S., Bioresource Eng., Rutgers University-College of Engineering, Piscataway, NJ May 1995

SELECTED HONORS AND AWARDS

Fellow of the American Geophysical Union 2024

American Association for Aerosol Research Susanne V. Hering Award 2023
AAAS Revelle Fellow in Global Stewardship 2021-2022

AEESP Plenary Lecture at American Association for Aerosol Research 2020
ASCENT Award, Atmospheric Sciences of the American Geophysical Union 2017
Dennis M. Fenton Distinguished Graduate Alumni Award 2017

Rutgers University Board of Trustees Research Fellowship for Scholarly Excellence 2016
U.S.EPA –Science Advisory Board: Level II Science and Technology Achievement Award 2012
U.S.EPA National Honor Award (Gold Medal) for Air Quality Forecasting 2009

COMMUNITY FIELD CAMPAIGN LEADERSHIP

- Greater New York Oxidant Trace Gas Halogen & Aerosol Airborne Mission (GOTHAAM): Co-PI for NSF/NCAR supported field study in the NYC metropolitan area. +LINK
- Southern Oxidant And Aerosol Study (SOAS): Lead investigator for NSF/NOAA/EPA/EPRI supported field study in the southeast U.S. +LINK to short documentary, *Skycatcher*.

SELECTED PEER-REVIEWED PUBLICATIONS

1. R.-J. Huang† … **A.G. Carlton** … M. Glasius (2025) Secondary organic aerosol in urban China: A distinct chemical regime for air pollution studies, *Science*, 389, 6763.
2. K. Fahey† ; N. Sareen*; **A.G. Carlton**; W. Hutzell (2025) Updated in-cloud secondary aerosol production in the Northern Hemisphere predicted by the Community Multiscale Air Quality modeling system, *ACS Earth & Space Chem*, *2025,* 9:1043–1059.

3. D.L. Goldberg†, …, **A.G. Carlton**, et al., (2025) NO2 concentration differences under clear versus cloudy skies and implications for applications of satellite measurements, *Atmospheric Chemistry & Physics,* 25, 16287–16302.
4. A.M. Burns*, G.J. Chandler, K. Dunham, **A.G. Carlton**† (2023) The Data Gap: Air Quality Networks Miss Air Pollution from Concentrated Animal Feeding Operations, *Environmental Science & Technology,* 57(49):20718–20725
5. Y.-T. Chiu*; A. M. Burns*; S. Rosanka*; T. Hu**; C.J. Hennigan; **A.G. Carlton** (2024) Chloride Interferences in Wet Chemical Oxidation Measurements: Plausible Mechanisms and Implications, *Environ Sci Technol - Water,* 4(12): 5399-5407.
6. A. Epps; … **A.G. Carlton**; S. Pusede† (**2025**) Satellite observations of atmospheric ammonia inequalities associated with industrialized swine facilities in Eastern North Carolina, *Environ Sci Technol,* 59(5):2651-2664.
7. **A.G. Carlton**, et al. (2020) Multiphase Atmospheric Chemistry in Liquid Water: Impacts and Controllability of Organic Aerosol, *Accts of Chem Res* 53:1714-1723.
8. **A.G. Carlton**† et al. (2018), Additional benefits of federal air quality rules: model estimates of controllable biogenic secondary organic aerosol, *Environ Sci Technol*, 52(16): 9254-5011.
9. K.M. Fahey†, **A.G. Carlton,** et al. (2017), A framework for expanding aqueous chemistry in the Community Multiscale Air Quality (CMAQ) model version 5.1, *Geosci Mod Dev,* 10, 1587-1605, doi:10.5194/gmd-10-1587-2017.
10. **A.G. Carlton**†, et al. (2010) Model Representation of Secondary Organic Aerosol in CMAQv4.7, E*nviron Sci Technol,* 44:8553-8560.

SELECTED PROFESSIONAL ACTIVITIES

Executive Editor, Environmental Science & Technology effective Apr. 2026

Elected Co-Chair Advisory Council, Bay Area Air Quality Management District 2024- present
Elected Co- Chair, Gordon Conference on Atmospheric Chemistry 2019-2023

Board of Reviewing Editors: *Science* 2018-present
Editor: *Reviews of Geophysics* 2016-2025
Member: National Academy of Sciences Committee,

"The Future of Atmospheric Chemistry Research" 2015-2016
Co-editor: *Atmospheric Chemistry and Physics* 2013-2018

SELECTED INIVITED, PLENARY AND KEYNOTE TALKS

Consulate General of Finland, Panelist for "Women in Science" Los Angeles, CA Feb 2025

AAAR Plenary, The Clear Sky Bias Oct 2020

University of Toronto Centre for Global Change Science, Distinguished Lecture in Climate Change, Aerosol Water: Now you see it, now you don't! Toronto, Ontario Jan 2016 International Global Atmospheric Chemistry, *keynote*: Atmosphere-biosphere interactions during SOAS through multiphase chemistry" Natal, Brazil Sep. 2014

Saewung Kim
Associate Professor

Department of Earth System Science University of
California, Irvine

Appointments and Positions

2018 - present Associate Professor, University of California, Irvine, United States

2012 - 2018 Assistant Professor, University of California, Irvine, Irvine, California, United States
2011 - 2012 Project Scientist, National Center for Atmospheric Research, Boulder, Colorado, United States

2010 - 2011 Scientific Visitor, National Center for Atmospheric Research, Boulder, Colorado, United States

2008 - 2010 ASP Postdoctoral Fellow, National Center for Atmospheric Research, Boulder, Colorado, United States

Education

PhD, Atmospheric Chemistry, Georgia Inst. of Tech. Atlanta, Georgia, 12/2007

Selected Publications

1. Kim S, Seco R, Gu D, Sanchez D, Jeong D, Guenther AB, Lee Y, Mak JE, Su L, Kim DB, Lee Y, Ahn JY, Mcgee T, Sullivan J, Long R, Brune WH, Thames A, Wisthaler A, Müller M, Mikoviny T, Weinheimer A, Yang M, Woo JH, Kim S, Park H. The role of a suburban forest in controlling vertical trace gas and OH reactivity distributions - a case study for the Seoul metropolitan area. Faraday Discuss. 2021 Mar 1;226:537-550.

2. Shrivastava M, Andreae MO, Artaxo P, Barbosa HMJ, Berg LK, Brito J, Ching J, Easter RC, Fan J, Fast JD, Feng Z, Fuentes JD, Glasius M, Goldstein AH, Alves EG, Gomes H, Gu D, Guenther A, Jathar SH, Kim S, Liu Y, Lou S, Martin ST, McNeill VF, Medeiros A, de Sá SS, Shilling JE, Springston SR, Souza RAF, Thornton JA, Isaacman-VanWertz G, Yee LD, Ynoue R, Zaveri RA, Zelenyuk A, Zhao C. Urban pollution greatly enhances formation of natural aerosols over the Amazon rainforest. Nat Commun. 2019 Mar 5;10(1):1046.

3. Jiang X, Guenther A, Potosnak M, Geron C, Seco R, Karl T, Kim S, Gu L, Pallardy S. Isoprene Emission Response to Drought and the Impact on Global Atmospheric Chemistry. Atmos Environ (1994). 2018 Jun;183:69-83.

4. Gu D, Guenther AB, Shilling JE, Yu H, Huang M, Zhao C, Yang Q, Martin ST, Artaxo P, Kim S, Seco R, Stavrakou T, Longo KM, Tóta J, de Souza RAF, Vega O, Liu Y, Shrivastava M, Alves EG, Santos FC, Leng G, Hu Z. Airborne observations reveal elevational gradient in tropical forest isoprene emissions. Nat Commun. 2017 May 23;8:15541.

5. Kim S, Sanchez D, Wang M, Seco R, Jeong D, Hughes S, Barletta B, Blake DR, Jung J, Kim D, Lee G, Lee M, Ahn J, Lee SD, Cho G, Sung MY, Lee YH, Kim DB, Kim Y, Woo JH, Jo D,Park R, Park JH, Hong YD, Hong JH. OH reactivity in urban and suburban regions in Seoul, South Korea - an East Asian megacity in a rapid transition. Faraday Discuss. 2016 Jul 18;189:231-51.

6. Crawford JH, Ahn JY, Al-Saadi J, Chang L, Emmons LK, Kim J, Lee G, Park JH, Park RJ, Woo JH, Song CK, Hong JH, Hong YD, Lefer BL, Lee M, Lee T, Kim S, Min KE, Yum SS, Shin HJ, Kim YW, Choi JS, Park JS, Szykman JJ, Long RW, Jordan CE, Simpson IJ, Fried A, Dibb JE, Cho S, Kim YP. The Korea-United States Air Quality (KORUS-AQ) field study. Elementa (Wash D C). 2021 May 12;9(1):1-27.

7. Sullivan JT, McGee TJ, Stauffer RM, Thompson AM, Weinheimer A, Knote C, Janz S, Wisthaler A, Long R, Szykman J, Park J, Lee Y, Kim S, Jeong D, Sanchez D, Twigg L, Sumnicht G, Knepp T, Schroeder JR. Taehwa Research Forest: A receptor site for severe domestic pollution events in Korea during 2016. Atmos Chem Phys. 2019;19(7):5051-5067.

8. Liu Y, Seco R, Kim S, Guenther AB, Goldstein AH, Keutsch FN, Springston SR, Watson TB, Artaxo P, Souza RAF, McKinney KA, Martin ST. Isoprene photo-oxidation products quantify the effect of pollution on hydroxyl radicals over Amazonia. Sci Adv. 2018 Apr;4(4):eaar2547.

9. Liu Y, Brito J, Dorris MR, Rivera-Rios JC, Seco R, Bates KH, Artaxo P, Duvoisin S Jr, Keutsch FN, Kim S, Goldstein AH, Guenther AB, Manzi AO, Souza RA, Springston SR, Watson TB, McKinney KA, Martin ST. Isoprene photochemistry over the Amazon rainforest. Proc Natl Acad Sci U S A. 2016 May 31;113(22):6125-30.

10. Seco R, Karl T, Guenther A, Hosman KP, Pallardy SG, Gu L, Geron C, Harley P, Kim S. Ecosystem-scale volatile organic compound fluxes during an extreme drought in a broadleaf temperate forest of the Missouri Ozarks (central USA). Glob Chang Biol. 2015 Oct;21(10):3657-74.

Banerjee, Tirtha
ORCID: 0000-0002-5153-9474

POSITION TITLE & INSTITUTION: Associate Professor, University of California, Irvine

PROFESSIONAL PREPARATION

PHD Environmental Science. Duke University. Durham, NC, 2015 BS

Civil Engineering Jadavpur University Kolkata, India, 2011

APPOINTMENTS

2023 - Present. Associate Professor (Tenured), University of California, Irvine, Department of Civil & Environmental Engineering, Irvine, CA

2019 – 2023. Assistant Professor, University of California, Irvine, Department of Civil & Environmental Engineering, Irvine, CA

2017 – 2019. Postdoctoral Fellow, Los Alamos National Laboratory, Division of Earth & Environmental Sciences (EES-16), Los Alamos, NM

2015 – 2017. Postdoctoral Research Associate, Karlsruhe Institute of Technology (KIT),

Institute of Meteorology and Climate Research (IMK-IFU), Garmisch-Partenkirchen

SELECTED PUBLICATIONS

1. Banerjee, T., 2026. The Role of Canopy Turbulence in Wildland Fire Behavior. Annual Review of Fluid Mechanics, 58(1), pp.473-502.
2. Banerjee, T., Katul, G.G., Zahn, E., Dias, N.L. and Bou-Zeid, E., 2024. A single compartment relaxed eddy accumulation method. Journal of Geophysical Research: Atmospheres, 129(19), p.e2024JD040811.
3. Chowdhuri, S., Ghannam, K. and Banerjee, T., 2022. A scale-wise analysis of intermittent momentum transport in dense canopy flows. Journal of Fluid Mechanics, 942, p.A51.
4. Raghav, P., Wagle, P., Kumar, M., Banerjee, T. and Neel, J.P., 2022. Vegetation index-based partitioning of evapotranspiration is deficient in grazed systems. Water Resources Research, 58(8), p.e2022WR032067.
5. Helbig, M., Gerken, T., Beamesderfer, E.R., Baldocchi, D.D., Banerjee, T., Biraud, S.C., Brown, W.O., Brunsell, N.A., Burakowski, E.A., Burns, S.P. and Butterworth, B.J., 2021. Integrating continuous atmospheric boundary layer and tower-based flux measurements to advance understanding of land-atmosphere interactions. Agricultural and Forest Meteorology,
6. Banerjee, T., Brugger, P., De Roo, F., Kröniger, K., Yakir, D., Rotenberg, E. and Mauder, M., 2018. Turbulent transport of energy across a forest and a semiarid shrubland. Atmospheric Chemistry and Physics, 18(13), pp.10025-10038.
7. Banerjee, T., De Roo, F. and Mauder, M., 2017. Connecting the failure of K theory inside and above vegetation canopies and ejection–sweep cycles by a large-eddy simulation. Journal of Applied Meteorology and Climatology, 56(12), pp.3119-3131.
8. Banerjee, T., De Roo, F. and Mauder, M., 2017. Explaining the convector effect in canopy turbulence by means of large-eddy simulation. Hydrology and Earth System Sciences, 21(6), pp.2987-3000.

9. Banerjee, T., Katul, G., Fontan, S., Poggi, D. and Kumar, M., 2013. Mean flow near edges and within cavities situated inside dense canopies. Boundary-layer meteorology, 149(1), pp.19-41.
10. Kröniger, K., De Roo, F., Brugger, P., Huq, S., Banerjee, T., Zinsser, J., Rotenberg, E., Yakir, D., Rohatyn, S. and Mauder, M., 2018. Effect of secondary circulations on the surface–atmosphere exchange of energy at an isolated semi-arid forest. Boundary-Layer Meteorology, 169(2), pp.209-232.

SYNERGISTIC ACTIVITIES

1. Awards: AGU Global Environmental Change Early Career Award, AMS Boundary layers and Turbulence STAC Early career award, NSF CAREER Award, Director's Fellowship, LANL; Chick Keller Postdoctoral fellowship, LANL; LANL Spot Award; DAAD Fellowship; Certificate in Nonlinear and Complex Systems Science, Duke University; Outstanding contribution in reviewing, Elsevier; Top peer review recognition, Publons.
2. Membership: AMS STAC Committee on Agricultural and Forest Meteorology, 2020-2023. Member, Science Advisory Panel, Fire and Forest Resilience Task Force, State of California, 2021-present.
3. Journal Editorship: Editor: Agricultural and Forest Meteorology Associate Editor: Earth systems and Environment, Springer;, Elsevier, Nature Scientific Reports.
4. Reviewer: 100+ peer-reviewed journals including Bulletin of the American Meteorological Society, Journal of Fluid Mechanics, Physics of Fluids, Geophysical Research Letters, Water Resources Research, etc. Participated in several NSF proposal review panels.
5. Convener of AGU session: 'Advances in wildland fire-atmosphere interaction', American Geophysical Union Fall Meeting, 2020, 2021, 2022, 2023, 2024

BIOGRAPHICAL SKETCH

NAME Kleeman, Michael J	POSITION TITLE Professor
eRA COMMONS USER NAME MJKLEEMAN	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
University of Waterloo, Canada	B.A.Sc.	1993	Mechanical Engineering
California Institute of Technology, Pasadena	M.S.	1994	Env. Eng. Science
California Institute of Technology, Pasadena	Ph.D.	1998	Env. Eng. Science

A. Personal Statement

Dr. Kleeman is a recognized expert in urban / regional air pollution problems with experience acting as Principal Investigator for more than $20M of externally-funded research and co-Investigator for another +$60M of externally-funded research during his 27 year career at UC Davis. Dr. Kleeman has pioneered measurement methods for ultrafine particles and developed source apportionment techniques to quantify the ambient ultrafine contributions from different source types. He has also pioneered the development of source apportionment techniques for primary and secondary particulate matter within regional chemical transport models. Measurement programs carried out by Dr. Kleeman have studied ozone formation potential from agricultural emissions and trace contaminants in biogas produced from dairy digesters. Dr. Kleeman has published more than 180 manuscripts in leading scientific journals that have been cited more than 19,000 times.

For this project, Dr. Kleeman will act as PI. He will coordinate project activities and serve as the primary contact point with the funding agency. Dr. Kleeman will also contribute to the measurement objectives by assembling an advisory panel, establishing contracts with agricultural partners, and coordinating field studies. Dr. Kleeman will contribute to the interpretation of exposure results and write reports and peer-reviewed papers documenting the project results.

Selected major contributions:

a. 2024 J. Jiang, Y. Li, and M.J. Kleeman. Air Quality and Public Health Effects of Dairy Digesters in California. Atmospheric Environment, 331, 120588. *https://doi.org/10.1016/j.atmosenv.2024.120588*.
b. 2022 S. Wu, H.J. Lee, A. Rohrbacher, S. Liu, T. Kuwayama, J.H. Seinfeld, and M.J. Kleeman. Direct Measurements of Ozone Response to Emissions Perturbations in California. Atmospheric Chemistry and Physics, 22, pp4929-4949, *https://doi.org/10.5194/acp-22-4929-2022*.

c. 2020 K.F. Chin, C. Wan, Y. Li, C.P. Alaimo, P.G. Green, T.M. Young, and M.J. Kleeman. Statistical Analysis of Trace Contaminants Measured in Biogas. Science of the Total Environment, 729 Article No. 138702.
d. 2019 J. Peppers, Y. Li, J. Xue, X. Chen, C. Alaimo, L. Wong, T. Young, P.G. Green, B. Jenkins, R. Zhang, M.J. Kleeman. Performance analysis of membrane separation for upgrading biogas to biomethane at small scale production sites. Biomass and Bioenergy, 128, Article No. UNSP 105314.
e. 2010 Howard, C., A. Kumar, F. Mitloehner, K. Stackhouse, P. Green, R. Flocchini, M.J. Kleeman. Direct Measurements of the Ozone Formation Potential from Livestock and Poultry Waste Emissions. Environmental Science and Technology, 44, 2292-2298.

B. Positions and Honors

Positions

1999–2003 Assistant Professor, Department of Civil and Environmental Engineering, UC Davis, Davis CA.

2003–2006 Associate Professor, Department of Civil and Environmental Engineering, UC Davis, Davis CA.

2006–pres. Professor, Department of Civil and Environmental Engineering, UC Davis, Davis CA.

Honors

1993-1994 *California Institute of Technology Knapp Fellowship*

2007 *California Air Resources Board Silver Superior Accomplishment Award*

2008 *United States Environmental Protection Agency Scientific and Technological Achievement Award Level III*

C. Contributions to Science

1. Dr. Kleeman has carried out a series of emissions characterization experiments to measure the size and composition distribution of airborne particles immediately after release from dominant sources. These measurements provide vital input data for chemical transport models and they also provide the basis for chemical fingerprints that can be recognized in the downwind atmosphere. The source profile measurements that he has made are used by the California Air Resources Board for atmospheric simulations and planning in the heavily polluted San Joaquin Valley and the South Coast Air Basin surrounding Los Angeles. Collectively, these regions account for 7 of the top 10 polluted cities in the US. The source profile measurements have contributed to our improved understanding of the air pollution problem and the design of effective control strategies.

References:

1999 Kleeman, M.J., J.J. Schauer, and G.R. Cass. Size and Composition Distribution of Fine Particulate Matter Emitted from Wood Burning, Meat Charbroiling and Cigarettes. Environmental Science, and Technology, Environmental Science, and Technology, 33:3516-3523.

2000 Kleeman, M.J., J.J. Schauer, and G.R. Cass. Size and Composition Distribution of Fine Particulate Matter Emitted from Motor Vehicles. Environmental Science, and Technology, 34:1132-1142.

2007 Robert, M.A., C.A. Jakober, and M.J. Kleeman. Size and Composition Distribution of Particulate Matter 2. Heavy -duty Diesel Vehicles. Journal of the Air and Waste Management Association, 57, pp1429-1438.

2007 Robert, M.A., C.A. Jakober, S. VanBergen, and M.J. Kleeman, Size and Composition Distribution of Particulate Matter 1. Light-duty Gasoline Vehicles. Journal of the Air and Waste Management Association, 57, pp1414-1428.
2008 Kleeman, M.J., M.A. Robert, S.G. Riddle, P.M. Fine, M.D. Hays, J.J. Schauer, and M.P. Hannigan. Size Distribution of Trace Organic Species Emitted From Biomass Combustion and Meat Charbroiling. Atmospheric Environment, 42 pp3059-3075.

2. Dr. Kleeman has developed and applied receptor-based source apportionment calculations for ultrafine particles (Dp<0.1μm) through a series of source profile measurements and community monitoring. By developing new methods to chemically analyze particles in the ultrafine size range, he was able to extend the source apportionment tools traditionally used for PM2.5 into the PM0.1 size fraction. This included the development of molecular marker libraries used in Chemical Mass Balance (CMB) models and the development of efficient elemental analysis techniques for Inductively Coupled Plasma Mass Spectrometry (ICPMS) that can be used to support Positive Matrix Factorization (PMF) models. These source apportionment methods for ultrafine particles have been demonstrated in roadside and community receptor environments throughout California.

References:
2007 Riddle SG, M.A. Robert, C.A. Jakober, M.P. Hannigan, M.J. Kleeman. Size distribution of trace organic species emitted from light duty gasoline vehicles. Environmental Science and Technology, 41, pp7464-7471.
2008 Kleeman, M.J., S.G. Riddle, and C.A. Jakober. Size Distribution of Particle-Phase Molecular Markers During a Severe Winter Pollution Episode. Environmental Science and Technology, 42, pp4697-4703.
2008 Kleeman, M.J., Riddle, S.G., Robert, M.A., Jakober, C.A., Fine, P.M., Hays, M.D., Schauer, J.J. and Hannigan, M.P. Source Apportionment of Fine (PM1.8) and Ultrafine (PM0.1) Airborne Particulate Matter During a Severe Winter Pollution Episode. Environmental Science and Technology, DOI: 10.1021/es800400.
2013 T. Kuwayama, C.R. Ruehl, and M.J. Kleeman. Daily Trends and Source Apportionment of Ultrafine Particulate Mass (PM0.1) over and Annual Cycle in a Typical California City. Environmental Science and Technology, dx.doi.org/10.1021/es403235c.

Complete List of Published Work in MyBibliography:
http://faculty.engineering.ucdavis.edu/kleeman/publications/

D. Research Support – Ongoing

1. "Intercomparison of New Methods for the Quantification of Metals in Biomethane"
   PI for a project funded by CARB, July 2025 – June 2027
   Total Funding $400,000
2. "O3 Exposure and Respiratory Effects – School absenteeism, Asthma-related symptoms, and Asthma-related ED visits and hospitalization"
   Co-I for a project funded by CARB, Jan 2024 – Dec 2026
   UC Davis Portion of Funding $100,000
3. "Evaluation of Air Toxics, Metals, and VOCs Found in Biogas, Biomethane, and their Combustion Products"
   PI for a project funded by CARB, July 2023 – June 2026
   Total Funding $499,884

4. “Smoke Taint Risk from Vineyards exposed to Wildfire Smoke: Assignment and Management Strategies.”
   Co-PI for a project funded by the USDA, Jan 2022 – Dec 2026.
   Total UCD Funding $906,356; Total Project Funding $6,743,644
5. “Childhood Autism Risks from Genetics and the Environment.”
   Co-I for a project funded by the NIEHS, Jan 2020 – Jun 2026.
   Total Funding for Kleeman lab: $200,000
6. “Extreme weather, air pollution, and stroke among an aging female population”
   Co-PI for a project funded by the NIEHS, Jan 2022 – Dec 2026.
   Total UCD Funding $51,553
7. “Updated welding toxic emissions estimates in California”
   PI for a project funded by the California Air Resources Board 5/1/2022-6/30/2024
   Total UCD Funding $198,358
8. “Extreme weather-related events and environmental exposures in the risk for Alzheimer's disease and related dementias”
   Co-PI for a project funded by NIH Total
   UCD Funding $2,200,000
9. “Do atmospheric ultrafine particles lodge in the brain and cause cognitive decline leading to Alzheimer's Disease Related Dementias?”
   Co-PI for a project funded by NIH Total
   UCD Funding $3,864,725
10. “Early Life Vulnerability to Climate-driven Wildfire Events on Pregnancy and Child Development Health Outcomes in Underserved Populations”
    Co-PI for a project funded by EPA
    Total UCD Funding $1,350,000
11. “Aliso Canyon Community Exposure and Health Study”
    Co-PI for a project funded by the LA Department of Public Health
    Total UCD Funding $540,805, total Project Funding $19,500,000
12. “Air Quality Impacts of bio-synthetic natural gas”
    PI for a project funded by the California Office of Environmental Health Hazard Assessment.
    Total UCD Funding $500,000
13. “Using Integrated Observations and Modeling to Better Understand Current and Future Air Quality Impacts of Wildfires and Prescribed Burns”
    PI for a project funded by the California Air Resources Board
    Total UCD Funding $805,000

Recently completed:

1. "Biogenic vs. Anthropogenic VOC Analysis During Peak Ozone Events in the SoCAB." PI for a project funded by the Coordinating Research Council, Mar 2021 – Dec 2021.
   Total UCD Funding $100,000
2. "Modeling the Air Quality Impacts of Oregon's Proposed Clean Fuels Program Amendments."
   Co-PI for a project funded by the Oregon Department of Environmental Quality, Jan 2021 – Dec 2021.
   Total UCD Funding $100,000
3. "Direct Measurements of Ozone Sensitivity to Oxides of Nitrogen and Volatile Organic Compounds in the South Coast Air Basin"
   PI for a project funded by the California Air Resources Board August 2019-July 2022
   Total UCD Funding: $263,861
4. "Ambient Air Pollution and COVID-19 in California."
   PI for a project funded by the Health Effects Institute, Apr 2021 – Mar, 2023.
   Total UCD Funding $495,122
5. "Alternative Jet Fuel in California – Modeling LCFS Policy Scenarios and Air Quality Impact Considerations in the 2030 Timeframe"
   Co-PI for a project funded by Climateworks
   Total UCD Funding $280,287
6. "Sources of Primary and Secondary Formaldehyde in Houston"
   PI for a project funded by Earthjustice
   Total UCD Funding $30,000
7. "Updating California Temporal Profiles"
   PI for a project funded by CARB July 2022 – June 2025
   Total Funding $234,162

BIOGRAPHICAL SKETCH

NAME Oldroyd, Holly J.	POSITION TITLE Associate Professor
eRA COMMONS USER NAME HJOLDROYD	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
University of Utah, Salt Lake City, UT	B.S.	2006	Mechanical Engineering
University of Utah, Salt Lake City, UT	M.S.	2010	Mechanical Engineering
École Polytechnique Fédérale de Lausanne, Switzerland	Ph.D.	2015	Civil & Env Engineering

A. Personal Statement

Dr. Oldroyd is an expert in land-atmosphere interactions and turbulent surface fluxes. She has been Principal Investigator for over $1.2M of externally-funded research and co-Investigator for another +$4M of externally-funded research. Her overarching research aims are to improve our understanding of fundamental transport physics and to drive model developments from observed phenomena such that knowledge gained locally can be applied globally. She uses numerical modeling, and principally, field observations as investigative tools. She has been using the Eddy covariance (EC) method since 2010 to measure surface fluxes of heat, moisture, momentum, and trace gases in a wide range of environments with and complexities in flow conditions, and has developed methods for calculating EC fluxes for non-idealized cases. Her research has produced 25 peer-reviewed journals, one book chapter, and 60+ research presentations at international conferences. She is an active member of the American Geophysical Union (AGU) and the American Metrological Society (AMS) and contributes to the Ameriflux and Fluxnet communities.

For this project, Dr. Oldroyd will act as co-I. She will help coordinate project activities and oversee eddy-covariance fieldwork and data processing. Dr. Oldroyd will contribute to the interpretation of flux data and write reports and peer-reviewed papers documenting project results.

Selected major contributions:

a. 2016 **Oldroyd HJ**, Pardyjak ER, Huwald H, and Parlange MB. Adapting Tilt Corrections and the Governing Flow Equations for Steep, Fully Three-Dimensional, Mountainous Terrain. Boundary-Layer Meteorology 159:539–565. DOI: 10.1007/s10546-015-0066-0
b. 2019 Higgins CW, Drake SA, Kelley J, **Oldroyd HJ**, Jensen DD, and Wharton S. Ensemble-Averaging Resolves Rapid Atmospheric Response to the 2017 Total Solar Eclipse. Front Earth Sci 7:198. DOI: 10.3389/feart.2019.00198

c. 2020 Kelley J, McCauley D, Alexander GA, Gray WF, Siegfried R, and **Oldroyd HJ**. Using Machine Learning to Integrate On-Farm Sensors and Agro-Meteorology Networks into Site-Specific Decision Support. Transactions of the ASABE 63:1427–1439. DOI: 10.13031/trans.13917
d. 2022 Alexander GA, Holmes HA, Sun X, Caputi D, Faloona IC, and **Oldroyd HJ**. Simulating land-atmosphere coupling in the Central Valley, California: Investigating soil moisture impacts on boundary layer properties. Agricultural and Forest Meteorology 317:108898. DOI: 10.1016/j.agrformet.2022.108898
e. 2024 Thirkill RH, Ramón CL, **Oldroyd HJ**, Seelos M, Rueda F, and Forrest AL. Navigating Greenhouse Gas Emission Unknowns: A Hydroacoustic Examination of Mediterranean Climate Reservoirs. Journal of Geophysical Research: Biogeosciences 129:e2024JG008080. DOI: 10.1029/2024JG008080

B. Positions and Honors

Positions

2016–2022	Assistant Professor, Department of Civil and Environmental Engineering, UC Davis, Davis CA.
2022–pres.	Associate Professor, Department of Civil and Environmental Engineering, UC Davis, Davis CA.

Honors

2018	*National Science Foundation CAREER Award*
2021	*National Academies Frontiers of Engineering Selection*
2023	*UC Davis Lab Safety Award*

C. Contributions to Science

1. Dr. Oldroyd has several past and ongoing field experiments focused on fundamental turbulent flow physics and scalar transport in varied montane ecosystems such as California's costal redwood forests, the Sierra-Nevada mountains, and the Swiss Alps. Studying these environments pose numerous challenges because the complex terrain violates several assumptions for modeling and measuring turbulent surface fluxes. Addressing these issues, Dr. Oldroyd developed approaches to process EC data for sloped terrain. She used these data to elucidate how fluxes are fundamentally different in buoyantly-driven slope flows than over horizontal terrain. Her research showed that the empirical flux-gradient parameterizations that are used in almost all numerical weather prediction models—derived in the Monin-Obukhov similarity theory (MOST) framework—do not hold for slope flows and require revision. She has proposed a new flux gradient model for downslope katabatic flows that holds for momentum fluxes over gentle and steep slopes. This work represents real progress toward new methods to improve numerical simulations of slope flows.

References:

2016 Oldroyd HJ, Pardyjak ER, Higgins CW, and Parlange MB. Buoyant Turbulent Kinetic Energy Production in Steep-Slope Katabatic Flow. Boundary-Layer Meteorology 161:405–416. DOI: 10.1007/s10546-016-0184-3

2018 Nadeau DF, Oldroyd HJ, Pardyjak ER, Sommer N, Hoch S, and Parlange MB. Field observations of the morning transition over a steep slope in a narrow alpine valley. Environ Fluid Mech 20:1199–1220. DOI: 10.1007/s10652-018-9582-z

2021 Hang C, Oldroyd HJ, Giometto MG, Pardyjak ER, and Parlange MB. A Local Similarity Function for Katabatic Flows Derived from Field Observations Over Steep- and Shallow-

Angled Slopes. Geophysical Research Letters 48:e2021GL095479. DOI: 10.1029/2021GL095479
2022 Drake SA, Rupp DE, Thomas CK, Oldroyd HJ, Schulze M, and Jones JA. Increasing Daytime Stability Enhances Downslope Moisture Transport in the Subcanopy of an Even-Aged Conifer Forest in Western Oregon, USA. Journal of Geophysical Research: Atmospheres 127:e2021JD036042. DOI: 10.1029/2021JD036042
2025 Wang T, Pardyjak ER, Parlange MB, and Oldroyd HJ. The Turbulence Flow Structure of Anabatic Winds over a Steep Alpine Slope. Boundary-Layer Meteorol 191:48. DOI: 10.1007/s10546-025-00943-8

2. Dr. Oldroyd has developed characterization methods for multiscale winds and turbulent coherent structures in the atmosphere. Her Doppler scanning LiDAR work over Lake Geneva validated theories of very large-scale motions and low frequency spectral characteristics. She also used turbulence data from an orchard, an agricultural field of dry grain stubble, and forests to develop Integrated Quadrant Analysis—a new method to track the trajectories of turbulence motion—to characterize turbulent coherent structures over these disparate landscapes. Further, her work has been used to show the importance of multiscale flow processes in California's Central Valley, which has important implications for air quality in the region.

References:
2013 Calaf M, Hultmark M, Oldroyd HJ, Simeonov V, and Parlange MB. Coherent structures and the k^{-1} spectral behaviour. Physics of Fluids 25:125107. DOI: 10.1063/1.4834436
2020 Everard KA, Oldroyd HJ, Christen A. Turbulent Heat and Momentum Exchange in Nocturnal Drainage Flow Through a Sloped Vineyard. Boundary-Layer Meteorol 175:1–23. DOI 10.1007/s10546-019-00491-y
2022 Mangan MR, Oldroyd HJ, Paw U KT, Clay JM, Drake SA, Kelley J, Suvočarev K. Integrated Quadrant Analysis: A New Method for Analyzing Turbulent Coherent Structures. Boundary-Layer Meteorol 184:45–69 DOI:10.1007/s10546-022-00694-w
2023 Caputi DJ, Trousdell J, Mehrotra S, Conley S, Alexander GA, Oldroyd HJ, Faloona I. Entrainment Rates and Their Synoptic Dependence on Wind Speed Aloft in California's Central Valley. Boundary-Layer Meteorol 186:505–532. DOI: 10.1007/s10546-022-00770-1
2024 Mangan MR, Oldroyd HJ, Paw U KT, Clay JM, Suvočarev K. Evaluating the nature of turbulent coherent structures in orchards using integrated quadrant analysis. Agricultural and Forest Meteorology 353:110042. DOI: 10.1016/j.agrformet.2024.110042

Complete List of Published Work in my ORCID:
https://orcid.org/0000-0001-8925-4063

D. Research Support – Ongoing
58-2032-4-085 Oldroyd (PI) USDA-ARS 09/01/2024 - 08/31/2026
Applications of Innovative Sensors to Quantify Atmospheric and Subsurface Fluxes of Water, Energy, and Contaminants
This is a study for using distributed temperature sensing (DTS) in various geophysical sensing applications.
Role: PI

1848019 Oldroyd (PI) NSF 05/06/2019 - 08/31/2026

CAREER:USTAR-ST: Universalizing Similarity Theories coupling the AtmospheRe and Sloping Terrain
This study aims to use observations and theory to better understand and develop new parameterizations for turbulent fluxes over sloping mountainous terrain. This work has a particular focus on turbulent transport below, through, and above a forest canopy.
Role: PI

LADPH Jerrett (PI) 11/1/2022 – 10/31/2025
Aliso Canyon Community Exposure and Health Study
This study will evaluate the acute exposures downwind of the Aliso Canyon natural gas leak and go on to evaluate chronic exposures at this facility.
Role: co-Investigator

2025RELMS01 Oldroyd (PI) Hedgefog Research Inc. 03/17/2025 - 09/09/2025
Remote Lidar Methane Sensor
This contract is to provide eddy-covariance based methane fluxes over a reservoir to be used for testing new instrumentation underdevelopment by Hedgefog Research Inc.
Role: PI

A21-3385 Forrest (PI) Santa Clara Valley Water District 02/01/2020 - 9/30/2025
Greenhouse Gas Monitoring (GHG) Program in Reservoirs of Santa Clara County
This project aims to understand the drivers and estimate the net emissions of methane and carbon dioxide fluxes from Valley Water's reservoirs. We monitor sediments, the water column, and the fluxes into (and out of) the atmosphere via eddy covariance to understand the time and space variability of carbon dioxide and methane fluxes.
Role: Co-PI

A23-3261-002 Suvočarev (PI) CalFire 6/6/2023 - 3/31/2027
Title: An Integrated Observatory for Redwood Forest Health
This project aims to establish an observation network in the coastal redwoods' ecosystem of California, U.S.A. Additional project objectives are to collect preliminary data regarding how the ecosystem uses water and carbon. This network is meant to serve as long-term infrastructure for future research by scientists and engineers worldwide. This project is also a collaboration with Lawrence Berkeley National Laboratory.
Role: Multiple Principal Investigator (MPI) with K.T. Paw U, H. Chu

Contract Forrest (PI) East Bay Municipal Utility District (EBMUD) 3/1/2024 - 2/28/2030
Initial Assessment of Greenhouse Gas Potential in San Pablo Reservoir
This project was developed to use observations to set a baseline of sediment methane gas storage before installation of a Speece cone to increase dissolved oxygen in the sediments.
Role: Co-Investigator

Recently completed:
B658605 Oldroyd (PI) LLNL 06/22/2023 - 07/31/2024
Characterization of the Wind Resource for Wind Turbines Across Regions with Terrain and Land Surface Heterogeneity Master

This contract is to measure winds and turbulence in collaboration with Lawrence Livermore National lab to better understand potential wind resources over complex terrains.
Role: PI

Internal Award Forrest (PI) UC Davis Global affairs 03/01/2019 - 12/31/2023
Methane Flux from Lakes in a Rapidly Warming Arctic
The aim are to validate new techniques for quantifying methane fluxes from reservoir sediments, through the water column and into the atmosphere. This project was designed to create international research collaborations by measuring greenhouse gas fluxes from reservoirs in California and Granada, Spain to better understand these systems for Mediterranean climates.
Role: Co-PI

Pending (excluding present):
Oldroyd (PI) UCMRPI
Microclimates of fog in California's coastal redwoods 12/01/2026- 11/30/2028
This study aims to understand the mechanisms of fog in redwood forests and its roles in the localize ecohydrology. The project also involves high fidelity forest atmospheric modeling.
Role: PI

Ray G. Anderson
Email: ray.anderson@usda.gov

Professional webpage, USDA-ARS

Google Scholar

Education:

PhD. Earth System Science, University of California, Irvine (2010), Michael L. Goulden --advisor. Committee members: James T. Randerson and James S. Famiglietti.

M.S. Earth System Science, University of California, Irvine (2007)

B.S. University of Minnesota (2005) – summa cum laude in Geography/Climatology minor

Employment:

2019-present Adjunct Professor of Environmental Science. University of California-Riverside
2013-present Research Soil Scientist (GS 13 and 14). Supervisor: Dr. Todd H. Skaggs, USDA-ARS, US Salinity Laboratory, Riverside, CA

2011-2013 Research Hydrologist (GS 12). Supervisor: Dr. Dong Wang, USDA-ARS, Water Management Research Unit, Parlier, CA

2010-2011 Postdoctoral researcher. Supervisor: Dr. James S. (Jay) Famiglietti, Center for Hydrologic Modeling, University of California-Irvine

2005-2010 Graduate Student Researcher. Supervisor: Dr. Michael Goulden, University of California-Irvine

Research interests: Fate and transport of fertilizers and associated greenhouse gases. Evapotranspiration and ET partitioning; Precision agriculture, including water and nutrient management; Regional agricultural ecohydrology and productivity (especially under abiotic stress); Soil moisture and salinity and relation to plant stress; Climate Change impacts on agriculture; New observational methods for the above.

Relevant experience/techniques: Eddy covariance, trace gas observations, in-situ observations of soil water balance; satellite remote sensing of ET and soil salinity; regional micrometeorology.

Relevant funding:

2024 – Lead ARS investigator – USDA FAS grant "Fertilize4Life – Group 1 (Precision Agriculture and Big Data) - $90,156 to US Salinity Laboratory (USSL).

2024 – Lead ARS investigator – California Beet Growers Association "Assessing Sugarbeet Water Use using Furrow and Sprinkler Irrigation in the Imperial Valley of California" - $57,569 to USSL. 2020 – Co-investigator (Elia Scudiero – University of California, Riverside, lead investigator) – USDA NIFA AFRI Sustainable Agric. Systems grant, "Artificial Intelligence to Increase Sustainability of Water, Nutrient, Salinity, and Pest management in W. US" - $639,671 to USSL. 2020 – Co-investigator (Francesca Hopkins – University of California, Riverside, lead investigator) – California Energy Commission, "Assessment of Greenhouse Gas and Air Quality Benefits of Dairy Digester Installation in California" - $36,277 to ARS.

Honors and Awards:

2025 - Editor of Distinction Awards– Irrigation Science
2022 – Research featured USDA Radio News

2021 – Research featured on ARS Office of Communications blog 2020
– Best Performing Associate Editor's Award – Irrigation Science

2019 – Outstanding Associate Editor Award – Journal of Environmental Quality

Relevant Publications:

1. Anderson, R. G., Yates, S. R., Ashworth, D. J., Jenkins, D. L., & Zhang, Q. (2019). Reducing the discrepancies between the Aerodynamic Gradient Method and other micro-meteorological approaches for measuring fumigant emissions. Science of The Total Environment, 687, 392–400. https://doi.org/10.1016/j.scitotenv.2019.06.132
2. Ashworth, D. J., Yates, S. R., Anderson, R. G., van Wesenbeeck, I. J., Sangster, J., & Ma, L. (2018). Replicated flux measurements of 1,3-dichloropropene emissions from a bare soil under field conditions. Atmospheric Environment, 191, 19–26. https://doi.org/10.1016/j.atmosenv.2018.07.049
3. Kandhway, A., Scarpare, F., Liu, M., Nelson, R., Adam, J. C., Anderson, R. G., et al. (2025). Water use dynamics of almond and pistachio crops in the Mediterranean region amid climate change. Agricultural Water Management, 307, 109219. https://doi.org/10.1016/j.agwat.2024.109219
4. Pachepsky, Y., Anderson, R., Harter, T., Jacques, D., Jamieson, R., Jeong, J., et al. (2021). Fate and transport in environmental quality. Journal of Environmental Quality, 50(6), 1282–1289. https://doi.org/10.1002/jeq2.20300
5. Rodriguez, M. V., Robles, N. R., Carranza, V., Thiruvenkatachari, R., Reyes, M., Preble, C. V., et al. (2025). Anaerobic Digester Installation Significantly Reduces Liquid Manure Management CH4 Emissions at a California Dairy Farm. GCB Bioenergy, 17(7), e70047. https://doi.org/10.1111/gcbb.70047
6. Wu, F., Davis, K. J., Zhang, L., Anderson, R. G., Horne, J. P., Goslee, S., et al. (2026). Evaluating surface fluxes in WRF using eddy-covariance flux measurements in the Western and Eastern U.S. Agricultural and Forest Meteorology, 379, 111029. https://doi.org/10.1016/j.agrformet.2026.111029
7. Hopkins, F.M.; Carranza, V.; Ajami, H.; Allison, J.E.; Anderson, R.G.; Barrows, C.W.; Barth, M.; Jenerette, G.D.; Porter, W.C.; Rolinski, T.; et al. California's Fourth Climate Assessment: Inland Deserts Region Report; 2018; p. 67;.
8. Anderson, R.G.; French, A.N. Crop Evapotranspiration. Agronomy 2019, 9, 614, doi:10.3390/agronomy9100614.
9. Anderson, R., D. Wang, Energy budget closure observed in paired Eddy Covariance towers with increased and continuous daily turbulence, 2014, Agric. and Forest Meteorology, Vol. 184, Pages 204-209, ISSN 0168-1923, *https://doi.org/10.1016/j.agrformet.2013.09.012*.
10. Dhungel, R., Anderson, R.G., French, A.N., Saber, M.N., Sanchez, C.A., & Scudiero, E. (2022). Assessing evapotranspiration in a lettuce crop with a two-source energy balance model. Irrigation Science, 41, 183-196.

Thomas Karl
Univ. Prof. DI. Dr.

Institute for Atmospheric and Cryospheric Sciences, University of Innsbruck, Innrain 52, 6020 Innsbruck, AUSTRIA

Professional development:

- Research assistant at the University of Innsbruck, Austria, 1999-2000.
- Joint ASP, ACD and CU/CIRES post-doctorial fellowship at the National Center for Atmospheric Research, 2000 –2003.
- Scientist I (tenure track) at the National Center for Atmospheric Research, 2003-2006.
- Scientist II (tenure track) at the National Center for Atmospheric Research, 2006-2009.
- Scientist III (tenure) at the National Center for Atmospheric Research, 2009-2012.
- Full professor in atmospheric physics, Institute for Atmospheric and Cryospheric Sciences, University of Innsbruck, Austria, 2013-present
- Head of the department for Atmospheric and Cryospheric Sciences, University of Innsbruck, Austria, 2024-present

Academic education:

- 1994 Technical University of Graz, Austria, 1. Studienabschnitt: BEng in Physics.
- 1997 Technical University of Graz, Austria, 2. Studienabschnitt: MEng(DiplEng) in Physics.
- 2000 University of Innsbruck, Austria, Ph.D. in Physics, Austria.
- 2012 University of Innsbruck, Austria, Habilitation, PD in Experimental Physics, Austria.

Number of papers published: 162, H-Index: 76
ORCID: http://orcid.org/0000-0003-2869-9426

ResearcherID: *http://www.researcherid.com/rid/D-1891-2009*

Selected publications

1. Peron, A., Graus, M., Striednig, M., Lamprecht, C., Wohlfahrt, G., and Karl, T.: Deciphering anthropogenic and biogenic contributions to selected non-methane volatile organic compound emissions in an urban area, Atmos. Chem. Phys., 24, 7063–7083, https://doi.org/10.5194/acp-24-7063-2024, 2024.
2. Lamprecht, C., Graus, M., Striednig, M., Stichaner, M., Jud, W., Held, A., and Karl, T.: Turbulent enhancement ratios used for characterizing local emission sources in a complex urban environment, Atmos. Meas. Tech., 18, 5003–5016, https://doi.org/10.5194/amt-18-5003-2025, 2025.
3. Thomas Karl et al. , High urban NO_x triggers a substantial chemical downward flux of ozone. Sci. Adv.9 2365 (2023). DOI:10.1126/sciadv.add2365.
4. Fischer, L., Breitenlechner, M., Canaval, E., Scholz, W., Striednig, M., Graus, M., Karl, T. G., Petäjä, T., Kulmala, M., and Hansel, A.: First eddy covariance flux measurements of semi-volatile organic compounds with the PTR3-TOF-MS, Atmos. Meas. Tech., 14, 8019–8039, https://doi.org/10.5194/amt-14-8019-2021, 2021.
5. Striednig, M., Graus, M., Märk, T. D., and Karl, T. G.: InnFLUX – an open-source code for conventional and disjunct eddy covariance analysis of trace gas measurements: an urban test case, Atmos. Meas. Tech., 13, 1447–1465, https://doi.org/10.5194/amt-13-1447-2020, 2020.
6. T. Karl,M. Striednig,M. Graus,A. Hammerle, & G. Wohlfahrt, Urban flux measurements reveal a large pool of oxygenated volatile organic compound emissions, Proc. Natl. Acad. Sci. U.S.A. 115 (6) 1186-1191.

7. Karl, T., Graus, M., Striednig, M. et al. Urban eddy covariance measurements reveal significant missing NO_x emissions in Central Europe. Sci Rep 7, 2536 (2017). https://doi.org/10.1038/s41598-017-02699-9
8. Misztal, P. K., Avise, J. C., Karl, T., Scott, K., Jonsson, H. H., Guenther, A. B., and Goldstein, A. H.: Evaluation of regional isoprene emission factors and modeled fluxes in California, Atmos. Chem. Phys., 16, 9611–9628, https://doi.org/10.5194/acp-16-9611-2016, 2016.
9. Misztal, P. K., Karl, T., Weber, R., Jonsson, H. H., Guenther, A. B., and Goldstein, A. H.: Airborne flux measurements of biogenic isoprene over California, Atmos. Chem. Phys., 14, 10631–10647, https://doi.org/10.5194/acp-14-10631-2014, 2014.
10. Karl, T., Guenther, A., Turnipseed, A., Patton, E. G., and Jardine, K.: Chemical sensing of plant stress at the ecosystem scale, Biogeosciences, 5, 1287–1294, https://doi.org/10.5194/bg-5-1287-2008, 2008.

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Education
University of Utah Ph.D. & M.S. in Atmospheric Sciences
Advisor: Prof. John C. Lin

2014 – 2020 Salt Lake City, US

Florida State University B.S. in Meteorology
Advisor: Prof. Jon E. Ahlquist

2012 – 2014 Tallahassee, US Nanjing
University of Information Science and
Technology

B.S. in Meteorology 2010 – 2012 Nanjing, China

Employment
Assistant Professor Dept. of Atmospheric Science,
Colorado State University

Jan 2025 – present

Staff Scientist & Postdoctoral Scholar

Division of Geological and Planetary Sciences,

Research Associate

California Institute of Technology

Supervisors: Prof. Paul Wennberg and Dr. Junjie Liu July
2020 – Dec 2024

Professional Experience
NASA Tropospheric Emissions: Monitoring of Pollution (TEMPO)
Science Team Member 2025 - present

NASA Orbiting Carbon Observatory (OCO-2/3) Science Team Member 2016 – present Current

Research Grants and Roles

Aug 2025 – July 2028

NASA A.21 TEMPO/ACX Science and Applications Teams: Quantifying NO_x emissions from agricultural lands

PI ($566k/3yrs for CSU) Oct
2024 – Sept 2027

NASA A.6 Carbon Monitoring System: Towards a Multi-scale Near Real-Time Carbon Monitoring System for Vegetation Fires (CMS-Fire) (PI: Dr. Junjie Liu, JPL)

Institutional PI ($1M/3yrs across JPL and CSU ATS)

Selected Publications [Full record from Google Scholar]

Wu, D., Wennberg, P. O., Suselj, K., Crounse, J. D., Baliaka, H., Li, F., Schissel, C., and Liu. J.: Observation-constrained Emissions from a Wildland-Urban Interface Fire: the Eaton Fires. In prep for the Environmental Science & Technology Air, Special Collection on “The 2025 Los Angeles Fires”.

Wu, D., Wennberg, P., Liu, J., Anderson, M., and Cawse-Nicholson, K.: Quantifying Ranch-scale Irrigation over the San Joaquin Valley from Space, in prep.

Wu, D., Liu, J., Laughner, J. L., Hasheminassab, S., Miyazaki, K., and Wennberg, P. O.: Satellite-based multi-tracer inversion in detecting urban emission variability, in prep.

Wu, D., Laughner, J. L., Liu, J., Palmer, P. I., Lin, J. C., and Wennberg, P. O.: A simplified non-linear chemistry transport model for analyzing NO2 column observations: STILT–NO_x, Geosci. Model Dev., 16, 6161–6185, https://doi.org/10.5194/gmd-16-6161-2023, 2023.

Wu, D., Liu, J., Wennberg, P. O., Palmer, P. I., Nelson, R. R., Kiel, M., and Eldering, A.: Towards sector-based attribution using intra-city variations in satellite-based emission ratios between CO_2 and CO, Atmos. Chem. Phys., 22, 14547–14570, https://doi.org/10.5194/acp-22-14547-2022, 2022.

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Wu, D., J.C. Lin, T. Oda, and E.A. Kort: Space-based quantification of per capita CO_2 emissions from cities, Environ. Res. Lett, https://doi.org/10.1088/1748-9326/ab68eb, 2020. (NASA media coverage) April 2026 2.

Wu, D., Lin, J. C., Fasoli, B., Oda, T., Ye, X., Lauvaux, T., Yang, E. G., and Kort, E. A.: A Lagrangian approach towards extracting signals of urban CO_2 emissions from satellite observations of atmospheric column CO_2 (XCO_2): X-Stochastic Time-Inverted Lagrangian Transport model (“X-STILT v1”), Geosci. Model Dev., 11, 4843-4871, https://doi.org/10.5194/gmd-11-4843-2018, 2018.

Patton, Edward
ORCID iD: https://orcid.org/0000-0001-5431-9541 POSITION
TITLE: Senior Scientist

PRIMARY ORGANIZATION AND LOCATION: National Center for Atmospheric Research, Boulder, Colorado, United States

Professional Preparation:
University of Minnesota, St. Paul, Minnesota, United States
Postdoctoral Fellow 07/1997 - 11/2000

Postdoctoral Scholar and Supercomputing Fellow

University of California, Davis, California, United States PHD 09/1991 -06/1997 Atmospheric Science

University of California, Davis, Colorado, United States BS 09/1986 - 06/1991, Atmospheric Science

Appointments and Positions
2021 - present Senior Scientist, National Center for Atmospheric Research, Boulder, Colorado, United States

2013 - 2021 Project Scientist III, National Center for Atmospheric Research, Boulder, Colorado, United States

2007 - 2013 Project Scientist II, National Center for Atmospheric Research, Boulder, Colorado, United States

2003 - 2007 Project Scientist I, National Center for Atmospheric Research, Boulder, Colorado, United States

2000 - 2003 Long-term Visitor, National Center for Atmospheric Research, Boulder, Colorado, United States

2000 - 2003 Research Associate, Pennsylvania State University, Univ. Park, PA, USA

Selected Publications

1. Clifton O, Patton E, Wang S, Barth M, Orlando J, Schwantes R. Large Eddy Simulation for Investigating Coupled Forest Canopy and Turbulence Influences on Atmospheric Chemistry. Journal of Advances in Modeling Earth Systems. 2022 October 05; 14(10):-. Available from: SCV Biographical Sketch v.2024-1 DOI:10.1029/2022MS003078
2. Patton E, Sullivan P, Shaw R, Finnigan J, Weil J. Atmospheric Stability Influences on Coupled Boundary Layer and Canopy Turbulence. Journal of the Atmospheric Sciences. 2016 April 01; 73(4):1621-1647. Available from: https://journals.ametsoc.org/doi/10.1175/JAS-D-15-0068.1 DOI: 10.1175/JAS-D-15-0068.1
3. Patton E, Horst T, Sullivan P, Lenschow D, Oncley S, Brown W, Burns S, Guenther A, Held A, Karl T, Mayor S, Rizzo L, Spuler S, Sun J, Turnipseed A, Allwine E, Edburg S, Lamb B, Avissar R, Calhoun R, Kleissl J, Massman W, Paw U K, Weil J. The Canopy Horizontal Array Turbulence Study. Bull. Amer. Met. Soc. 2011 92(5):593-611. DOI: 10.1175/2010BAMS2614.1
4. Olivia E. Clifton, Edward G. Patton, Mary Barth, John Orlando, Siyuan Wang, Colleen Baublitz. Influence of Organized Turbulence on OH Reactivity at a Deciduous Forest. Geophysical Research Letters. 2023 April. DOI: 10.1029/2022gl102548
5. Patton E.G., Davis K.J., Barth M.C., Sullivan P.P.. Decaying scalars emitted by a forest canopy: A numerical study. Boundary-Layer Meteorology. 2001; 100(1):91-129. DOI: 10.1023/A:1019223515444
6. Brasseur G, Barth M, Kazil J, Patton E, Wang Y. Segregation of Fast-Reactive Species in

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7. Pedruzo-Bagazgoitia X, Patton E, Moene A, Ouwersloot H, Gerken T, Machado L, Martin S, Sörgel M, Stoy P, Yamasoe M, Vilà-Guerau de Arellano J. Investigating the Diurnal Radiative, Turbulent, and Biophysical Processes in the Amazonian Canopy-Atmosphere Interface by Combining LES Simulations and Observations. Journal of Advances in Modeling Earth Systems. 2023 February 14; 15(2):-. Available from: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022MS003210 DOI: 10.1029/2022MS003210
8. Su L, Patton E, Vilà-Guerau de Arellano J, Guenther A, Kaser L, Yuan B, Xiong F, Shepson P, Zhang L, Miller D, Brune W, Baumann K, Edgerton E, Weinheimer A, Misztal P, Park J, Goldstein A, Skog K, Keutsch F, Mak J. Understanding isoprene photooxidation using observations and modeling over a subtropical forest in the southeastern US. Atmospheric Chemistry and Physics. 2016 June 24; 16(12):7725-7741. Available from: https://acp.copernicus.org/articles/16/7725/2016/ DOI: 10.5194/acp-16-7725-2016
9. Gordon B. Bonan, Sean P. Burns, Edward G. Patton. Beyond surface fluxes: Observational and computational needs of multilayer canopy models – A walnut orchard test case. Agricultural and Forest Meteorology. 2026 March. DOI: 10.1016/j.agrformet.2025.110960
10. Clifton OE, Fiore AM, Massman WJ, Baublitz CB, Coyle M, Emberson L, Fares S, Farmer DK, Gentine P, Gerosa G, Guenther AB, Helmig D, Lombardozzi DL, Munger JW, Patton EG, Pusede SE, Schwede DB, Silva SJ, Sörgel M, Steiner AL, Tai APK. Dry Deposition of Ozone over Land: Processes, Measurement, and Modeling. Rev Geophys. 2020 Mar 1;58(1)

STEPHANIE YARWOOD
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EDUCATION AND TRAINING
Ph.D. 2007 **Oregon State University**, Soil Science
B.A.2001 **Whitman College**, English

RESEARCH AND PROFESSIONAL EXPERIENCE
2024 - present **Professor**, University of Maryland
2017 - 2024 **Associate Professor**, University of Maryland
2011 - 2017 **Assistant Professor**, University of Maryland
2007 - 2011 **Instructor/Advisor**, Oregon State University

PROFESSIONAL ACTIVITIES
• Soil Biology and Biochemistry Division Chair, SSSA, 2022
• Associate Editor FEMS Microbiology Ecology, 2020-present
• Co-director of the UMD Center for Excellence in Microbiome Sciences
• Graduate Director Environmental Science and Technology

HONORS & AWARDS
• United States Department of Agriculture Excellence in College and University Teaching in Food and Agricultural Sciences Award in the "Regional" category, 2023
• Excellence in Teaching—ENST department, 2023
• College of AGNR Paul R. Poffenberger Excellence in Teaching and Advising Award, 2019

GRANTS RECEIVED
1. NASA Inspire, $1,085,310, Carlton, A.M (PI), S. Yarwood, J. Maul. Linking Agricultural Soil Microbiomes to Space-Based Nitrogen Detection, October 2023-September 2026
2. Harry Hughes Center for Agro-ecology, $99,914, Wilmoth, J. (PI), S. Yarwood. Optimizing cover cropping for carbon sequestration under future climate change scenarios. June 2023-June 2025

PUBLICATIONS (last 4 years)
1. Thapa, R., K.L. Tully, *N. Hamovit, **S.A Yarwood**, H.H. Schomberg, M.L. Cabrera, C. Reberg-Horton, S.B. Mirsky. 2022. Microbial processes and community structure as influenced by cover crop residue type and location during repeated dry-wet cycles. *Applied Soil Ecology* 172:10.1016/j.apsoil.2021.104349
2. Scott, B., **S. Yarwood**, A. Baldwin. 2022. Adding organic matter to restore wetland soils may increase methane generation and is not needed for hydric soil development. *Biogeosciences* https://doi.org/10.5194/bg-2021-182
3. Epp Schmidt, D., *G. Dlott, M. Cavigelli, **S. Yarwood**, J. Maul. 2022. Soil microbiomes in three farming systems affected more by depth than farming system. *Applied Soil Ecology* 173:10.1016/j.apsoil.2022.104396
4. Villena, O.C., J. Sullivan, E. Landa, **S.A. Yarwood**, A. Torrents, A. Zhang, P. T. Leisnham. 2022. The role of tire leachate in condition-specific competition and the persistence of a resident mosquito from a competitively superior invader. *Insects* https://doi.org/10.3390/insects13110969
5. Epp Schmidt, D., M. Cavigelli, J. Maul, H. Schomberg, **S.A. Yarwood**. 2023. Components of Nfixation system response to glyphosate are un-coupled in agroecosystems. *Applied Soil Ecology* https://dx.doi.org/10.2139/ssrn.4263504

6. Keshta, A., **S. Yarwood**, A. Baldwin. 2023. Methane emissions are highly variable across wetland habitats in natural and restored tidal freshwater wetlands. *Wetlands* https://doi.org/10.1007/s13157-023-01701-7
7. Bansal, S., I.F. Creed, B.A. Tangen, S.D. Bridgham, A.R. Desai, K.W. Krauss, S.C. Neubauer, G.B. Noe, D.O. Rosenberry, C. Trettin, K.P. Wickland, S.T. Allen, A. Arias-Ortiz, A.R. Armitage, D. Baldocchi, K. Banerjee, D. Bastviken, P. Berg, M. Bogard, A.T. Chow, W.H. Conner, C. Craft, C. Creamer, T. DelSontro, J.A. Duberstein, M. Eagle, M.S. Fennessy, S.A. Finkelstein, M. Göckede, S. Grunwald, M. Halabisky, E. Herbert, M.M.R. Jahangir, O.F. Johnson, M.C. Jones, J.J. Kelleway, S. Knox, K.D. Kroeger, K.A. Kuehn, D. Lobb, A.L. Loder, S. Ma, D.T. Maher, G. McNicol, J. Meier, B.A. Middleton, C. Mills, P. Mistry, A. Mitra, C. Mobilian, A.M. Nahlik, S. Newman, J. L. O'Connell, P. Oikawa, M.P. van der Burg, C.A. Schutte, C. Song, C.L. Stagg, J. Turner, R. Vargas, M.P. Waldrop, M.B. Wallin, Z.A. Wang, E.J. Ward, D.A. Willard, **S. Yarwood**, X. Zhu. 2023. A Practical Guide to Measuring Wetland Carbon Pools and Fluxes. *Wetlands* https://doi.org/10.1007/s13157-023-01722-2
8. Haghnegahdar, M., J. Sun, N. Hultquist, *N.D.Hamovit, N. Kitchen, J. Eiler, S. Ono, **S.A. Yarwood**, A.J. Kaufman, R.R. Dickerson, A. Bouyon, C. Magen, J. Farquhar. 2023. Tracing Sources of Atmospheric Methane Using Clumped Isotopes. *Proceedings of the National Academy of Science* 47 https://doi.org/10.1073/pnas.230557412
9. Epp Schmidt, D., J. Maul, **S.A. Yarwood**. 2024. Quantitative amplicon sequencing is necessary to identify differential taxa and correlated taxa where populations sizes differ. *Microbial Ecology* https://doi.org/10.1007/s00248-023-02273-z
10. Scott, B., A. Baldwin, **S.A. Yarwood**. 2024. Consequences of organic matter amendments for methane emissions and soil and vegetation development in a restored wetland. *Wetland Ecology and Management* 32: 171-190 https://doi.org/10.1007/s11273-023-09967-8
11. Morris, K.A., M. Smith, V.L. Bailey, R. Bittencourt-Peixoto, D.J. Day, *N. Hamovit, A.M. Hopple, J. Lee, K.F. Patel, S. Wilson, **S.A. Yarwood**, P. Megonigal, B. Bond-Lamberty. 2024. Acclimation of net and gross methane fluxes from 4-year-old transplanted coastal forest soil monoliths. *Soil Biology and Biochemistry* https://doi.org/10.1016/j.soilbio.2023.109296
12. Castillo-González, H., Bloomberg, J., Alvarado-Picado, E., **S. Yarwood**, P. Chaverri. 2024. Do agricultural practices influence the foliar endophytic communities in coffee plants of different varieties? *Agrosystems, Geosciences, & Environment* https://doi.org/10.1002/agg2.20476
13. Swain, A., A.J. Kaufman, M. Kalinowski, **S.A. Yarwood**, W.F. Fagan. 2024. Were Neoarchean atmospheric methane hazes and early Paleoproterozoic glaciations driven by the rise of oxygen in surface environments? Earth and Planetary Science Letters
14. Haghnegahdar, M., N. Hultquist, *N. Hamovit, **S. Yarwood**, A. Bouyon, A. Kaufman, J. Sun, C. Megan, J. Farquhar. 2025. A Better Understanding of Atmospheric Methane Sources Using 13CH3D and 12CH2D2 Clumped Isotopes. Journal of Geophysical Research—Biogeosciences 10.1029/2024JG008172
15. *Castillo-González, H., J.C. Slot, **S. Yarwood**, P. Chaverri. 2025. Plant tissue and geographic location shape fungal endophytic communities in wild *Rubiaceae* from tropical forests. PCI Ecology https://doi.org/10.1101/2024.02.13.580172
16. *Hamovit, N., T. Roy Chowdhury, D. M. Akob, X. Zhang, G. McCarty, **S. Yarwood**. 2025. Comparative assessment of a restored and natural wetland using 13C-DNA SIP reveals a higher potential for methane production in the restored wetland. Applied and Environmental Microbiology 10.1128/aem.02161-24
17. *Wood, L., *H. Castillo-González, S. Yarwood. 2025. Urban Forest Quality Corresponds with Soil Microbial Community Composition and Arbuscular Fungi Root Colonization. Urban Sustainability 5, 48 https://doi.org/10.1038/s42949-025-00241-9
18. Stohel, I., Y. Song, A. Turetcaia, A. Wilson, D. Epp Schmidt; S. Yarwood, A. Townsend, E.B. Graham. 2024. Revealing the taxonomy and functional potential of urban soil microbiomes. BioRxiv https://doi.org/10.1101/2024.05.09.592449
19. Holm, J.B., S. Paragkamian, M. Humphreys, A. Chatterjee, **S. Yarwood**, +J. Gaimaro, M. Stavroulaki, D. Tsaparis, M. Plaitis, P. Kasapidis, S. Darivianakis, G. Kotoulas, A. Magoulas, A. Oulas, Z. Kyrpiotakis, P. Pavlidis, P. ten Hoopen, G. Cochrane, W. H.C.F. Kooistra, J.R. Schriml, B.E. Schriml, I.

Lagkouvardos, P. Gkorezis, N. Davies, C. Laney, L. Stanish, G. Sutton, S. Tighe, I. Karsch Mizrachi, D. Park, P. Yilmaz, C. Carey, P. Buttigieg, P. Goldstein, E. Pafilis. L.M. Schriml 2025. First island-wide, single-day soil collection study on Crete reveals environmental drivers of microbial diversity. Environmental Microbiome 20, 94 https://doi.org/10.1186/s40793-025-00752-z

EXHIBIT A6

CURRENT & PENDING SUPPORT

University will provide current & pending support information for Key Personnel identified in Exhibit A2 at time of proposal and upon request from State agency. The "Proposed Project" is this application that is submitted to the State. Add pages as needed.

PI: Alex Guenther					
Status	**Award #**	**Source**	**Project Title**	**Start Date**	**End Date**
Active	25RD001	CARB	Improving estimates of CO_2 and CH4 emissions from southern California coastal wetlands and BVOC emission estimates from all California landscapes	1/1/2026	12/31/2028
Active	AGS-2347370	NSF	Biogenic VOC emissions from managed landscapes and their contribution to atmospheric ozone and aerosol	4/1/2024	3/31/2027

EXHIBIT A7

THIRD PARTY CONFIDENTIAL INFORMATION

CONFIDENTIAL NONDISCLOSURE AGREEMENT

(Identified in Exhibit A, Scope of Work – will be incorporated, if applicable)

Exhibit A7 is not applicable for this Agreement.

EXHIBIT B2

SUBAWARDEE BUDGET(S)

Use Exhibit B2 subawardee budget template for each subrecipient.

EXHIBIT B3

INVOICE ELEMENTS

In accordance with Section 14 of Exhibit C – Payment and Invoicing, the invoice, summary report and/or transaction/payroll ledger shall be certified by the University's Financial Contact and the PI (or their respective designees).

Invoicing frequency

☒ Quarterly ☐ Monthly

Invoicing signature format

☐ Ink ☒ Facsimile/Electronic Approval

Summary Invoice – includes either on the invoice or in a separate summary document – by approved budget category (Exhibit B) – expenditures for the invoice period, approved budget, cumulative expenditures and budget balance available[1]

- Personnel
- Equipment
- Travel
- Subawardee – Consultants
- Subawardee – Subcontract/Subrecipients
- Materials & Supplies
- Other Direct Costs
  - TOTAL DIRECT COSTS (if available from system)
- Indirect Costs
  - TOTAL

Detailed transaction ledger and/or payroll ledger for the invoice period [2]

- University Fund OR Agency Award # (to connect to invoice summary)
- Invoice/Report Period (matching invoice summary)
- GL Account/Object Code
- Doc Type (or subledger reference)
- Transaction Reference#
- Transaction Description, Vendor and/or Employee Name
- Transaction Posting Date
- Time Worked
- Transaction Amount

[1] If this information is not on the invoice or summary attachment, it may be included in a detailed transaction ledger.

[2] For salaries and wages, these elements are anticipated to be included in the detailed transaction ledger. If all elements are not contained in the transaction ledger, then a separate payroll ledger may be provided with the required elements.

EXHIBIT D

ADDITIONAL REQUIREMENTS ASSOCIATED WITH FUNDING SOURCES

If the Agreement is subject to any additional requirements imposed on the funding State agency by applicable law (including, but not limited to, bond, proposition and federal funding), then these additional requirements will be set forth in Exhibit D. If the University is a subrecipient, as defined in 2 CFR 200 (Uniform Guidance on Administrative Requirements, Audit Requirements and Cost Principles for Federal Financial Assistance), and the external funding entity is the federal government, the below table must be completed by the State agency. (Please see sections 10.A and 10.B of the Exhibit C.)

State Agency to Complete (Required for Federal Funding Source):

Federal Agency	
Federal Award Identification Number	
Federal Award Date	
Catalog of Federal Domestic Assistance (CFDA) Number and Name	
Amount Awarded to State Agency	
Effective Dates for State Agency	
Federal Award to State Agency is Research & Development (Yes/No)	

University to Complete:

Research and Development (R&D) means all research activities, both basic and applied, and all development activities that are performed by non-Federal entities. The term research also includes activities involving the training of individuals in research techniques where such activities utilize the same facilities as other R&D activities and where such activities are not included in the instruction function.

This award ☐ does ☐ does not support Research & Development.

EXHIBIT E

SPECIAL CONDITIONS FOR SECURITY OF CONFIDENTIAL INFORMATION

Exhibit E is not applicable for this Agreement.

EXHIBIT F

ACCESS TO STATE FACILITIES OR COMPUTING RESOURCES

Exhibit F is not applicable for this Agreement.

EXHIBIT G

NEGOTIATED ALTERNATE UTC TERMS

I. Exhibit C, UTC – 220 Section 14 – Payment & Invoicing is hereby amended to incorporate the following:

Add Item 6 to Section 14. A. to read as follows:

6) CARB shall withhold payment equal to 10 percent after the Contractor has been compensated for 90 percent of the total agreement amount. The 10 percent shall be withheld until completion of all work and submission to CARB by the University of a final report approved by CARB in accordance with Exhibit A1, Schedule of Deliverables, Section 2. It is the University's responsibility to submit one (1) original and one (1) copy of the final invoice.

Amend Section 14. C.2 – Invoicing to read as follows:

2) Invoices shall be submitted in arrears not more frequently ~~than monthly and not less frequently~~ than quarterly to the State Financial Contact, identified in Exhibit A3. Invoices may be submitted electronically by email. If submitted electronically, invoice must include the following certification for State certification to the State Controller's Office, in compliance with SAM 8422.1

> This bill has been checked against our records and found to be the original one presented for payment and has not been paid. We have recorded this payment so as to prevent later duplicate payment.
>
> Signed:
> State Agency Accounting Officer

Add Item E: to Section 14, to read as follows:

E. Advance Payment

1) Nothing herein contained shall preclude advance payments pursuant to Title 2, Division 3, Part 1, Chapter 3, Article 1 of the Government Code of the State of California.

2) Upon termination or completion of this Agreement, Contractor shall refund any excess funds to the CARB. Contractor will reconcile total Agreement costs to total payments received in advance and any remaining advance will be refunded to the CARB's Accounting Office. In the event the Agreement is terminated, total project costs incurred prior to the effective date of termination (including close-out costs) will be reconciled to total project payments received in advance and any remaining advance will be refunded to the CARB. In either event Contractor shall return any balance due to CARB within sixty (60) days, of expiration or earlier termination.

Amend Section 15.B –Budget Flexibility to read as follows:

B. Budget revisions between identified budget categories in cost reimbursement agreements that are within the total Agreement amount, comply with the Prior Approval Requirements, above and do not change the Scope of Work or substitute Key Personnel, as defined in this Agreement, are allowed as described below:

1) Up to 10% ~~of each annual budget amount or $10,000, whichever is less,~~ is allowed with approval of the State's Contract Project Manager, or as otherwise agreed to by the Parties and documented on Exhibit B.

2) Exceeding 10% ~~or $10,000, whichever is less,~~ of the last approved budget require the State's Contract Project Manager's prior approval and may require a formal amendment to this Agreement. The University will submit a revised budget to the State for approval. Budget transfers that would cause any portion of the funds to be used for purposes other than those consistent with the original intent of this Agreement are not allowed.

II. Add the following sections to the UTC-220 to incorporate additional required provisions:

Add Section 31 to read as follows:

31. GenAI Disclosure Obligations:

A. The following terms are in addition to the defined terms and shall apply to the Contract:

1) "Generative AI (GenAI)" means an artificial intelligence system that can generate derived synthetic content, including text, images, video, and audio that emulates the structure and characteristics of the system's training data. (Gov. Code § 11549.64.)

B. Contractor shall immediately notify the State in writing if it: (1) intends to provide GenAI as a deliverable to the State; or (2), intends to utilize GenAI, including GenAI from third parties, to complete all or a portion of any deliverable that materially impacts: (i) functionality of a State system, (ii) risk to the State, or (iii) Contract performance. For avoidance of doubt, the term "materially impacts" shall have the meaning set forth in State Administrative Manual (SAM) § 4986.2 Definitions for GenAI.

C. Notification shall be provided to the State designee identified in this Contract.

D. At the direction of the State, Contractor shall discontinue the provision to the State of any previously unreported GenAI that results in a material impact to the functionality of the System, risk to the State, or Contract performance, as determined by the State.

E. If the use of previously undisclosed GenAI is approved by the State, then Contractor will update the Deliverable description, and the Parties will amend the Contract accordingly, which may include incorporating the GenAI Special Provisions into the Contract, at no additional cost to the State.

F. The State, at its sole discretion, may consider Contractor's failure to disclose or discontinue the provision or use of GenAI as described above, to constitute a material breach of Contract when such failure results in a material impact to the functionality of the System, risk to the State, or Contract performance. The State is entitled to seek any and all remedies available to it under law as a result of such breach, including but not limited to termination of the contract.

Add Section 32 to read as follows:

32. Health and Safety

Contractors are required to, at their own expense, comply with all applicable health and safety laws and regulations. Upon notice, Contractors are also required to comply with the state agency's specific health and safety requirements and policies.

Contractors agree to include in any subcontract related to performance of this Agreement, a requirement that the subcontractor comply with all applicable health and safety laws and regulations, and upon notice, the state agency's specific health and safety requirements and policies.

Add Section 33 to read as follows:

33. Executive Order N-6-22 – Russia Sanctions

On March 4, 2022, Governor Gavin Newsom issued Executive Order N-6-22 (the EO) regarding Economic Sanctions against Russia and Russian entities and individuals. "Economic Sanctions" refers to sanctions imposed by the U.S. government in response to Russia's actions in Ukraine, as well as any sanctions imposed under state law. The EO directs state agencies to terminate contracts with, and to refrain from entering any new contracts with, individuals or entities that are determined to be a target of Economic Sanctions. Accordingly, should the State determine Contractor is a target of Economic Sanctions or is conducting prohibited transactions with sanctioned individuals or entities, that shall be grounds for termination of this agreement. The State shall provide Contractor advance written notice of such termination, allowing Contractor at least 30 calendar days to provide a written response. Termination shall be at the sole discretion of the State.