EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

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

PI Name: **Zhu, Yifang**

Project Title: **Enhancing Health Impact Assessment in California: Integrating High-Resolution Air Quality Modeling and Community Characteristics**

Project Summary/Abstract

To better quantify the health risks faced by overburdened communities in California, the Contractor proposes a refined health impact assessment (HIA) model to enhance the methodologies currently employed by the California Air Resources Board (CARB). The overarching goal is to assess the health impacts of air pollution at a fine spatial resolution, specifically targeting communities most burdened by air pollution and other stressors. The approach involves: (1) developing a high-resolution exposure assessment framework using advanced air quality models to estimate $PM_{2.5}$ and ozone levels across California; (2) ground-truthing model outputs through established air quality monitoring networks and community-based data collection; (3) generating fine-scale spatial baseline health data that account for social, racial-ethnic, and other susceptibility factors; (4) integrating these refined baseline health data with exposure assessments to develop adjustment factors for community-specific characteristics that influence health outcomes; and (5) constructing mobile source policy scenarios to project future health impacts and disparities. This project will provide CARB with much needed data to guide mobile source policy interventions, establish adjustment factors, and refine strategies for enhanced HIA. These efforts will help mitigate the adverse health impacts from air pollution, particularly for California's most vulnerable populations.

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

Statement of Significance

Overburdened communities including but not limited to those defined by California Senate Bill 535[1] are more likely to be located near air pollution sources and at higher health risk given the cumulative effects of other chronic stressors they experience[2]. This pattern is rooted in historical discriminatory practices contributing to environmental health disparities, which highlights the need to prioritize equitable health benefits in the design and evaluation of air quality policies[3]. To support equitable policy design, it is important yet challenging to accurately assess health impacts of regulations on a finer scale in overburdened communities.

To address this challenge, the Contractor has assembled a multidisciplinary team of experts in transportation policy, chemical transport modeling, air quality measurements, health impact assessment, epidemiology, geographic information science, biostatistics, and environmental justice (see Figure 1). Building on their previous and ongoing research projects, the Contractor will establish an advanced high-resolution health impact assessment (HIA) modeling framework, as well as collect and create high-resolution, local-scale input data for California. Specifically, the Contractor will pursue the following aims: (1) conduct air quality modeling using WRF-CMAQ or WRF-Chem (of CARB's choice) to estimate $PM_{2.5}$ and ozone concentrations at a high-spatial resolution in California; (2) validate air quality modeling results using data from the existing monitoring network, research-grade measurements the Contractor has taken as part of earlier CARB-funded research from portable monitoring equipment, and low-cost air sensors in selected communities; (3) compile and estimate fine-scale spatial baseline health data and quantify community adjustment factors accounting for social, racial-ethnic and other factors where possible to be integrated into the HIA framework; and (4) develop modeling scenarios for predicting health impacts and health disparities into the future.

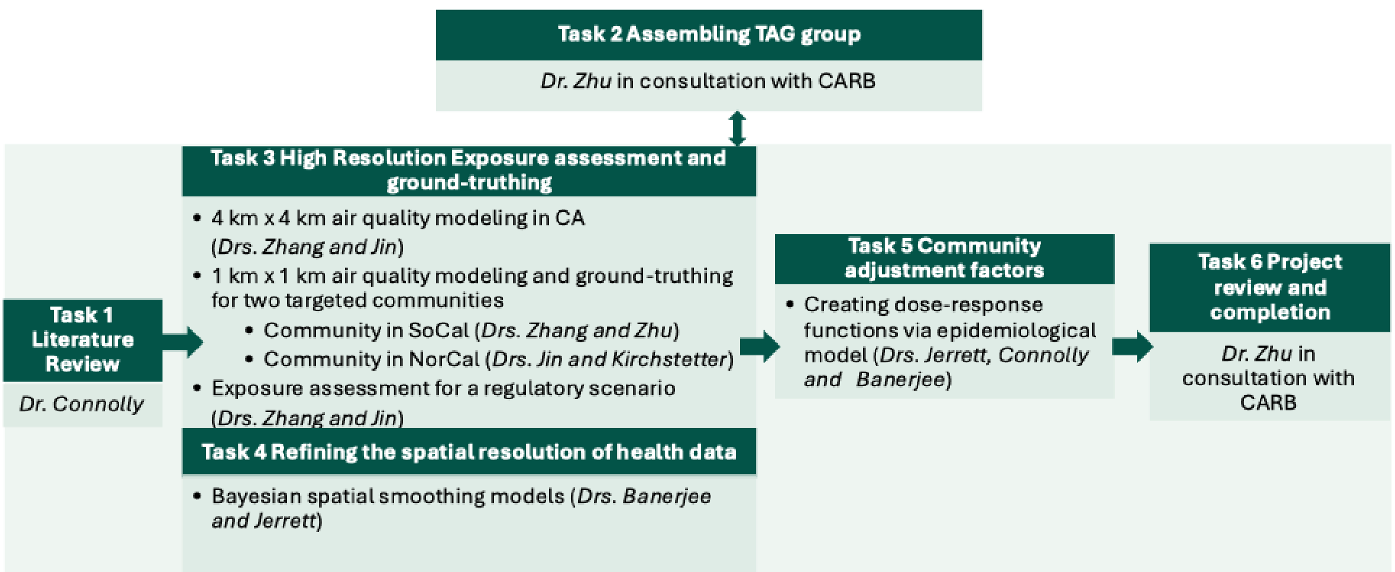

Figure 1. Overview of study design and task responsibilities assigned to each investigator.

The findings from this study will enable CARB to more accurately estimate the health impacts of its air pollution reduction programs, particularly within communities that are disproportionately affected. This improved understanding will also help the agency to better inform the public about the effectiveness of these initiatives in mitigating health risks in overburdened communities.

Project Tasks

Overview: Figure 1 presents a comprehensive overview of the study design and outlines the responsibilities of each investigator for each of the six proposed tasks. Briefly, Task 1, led by Dr. Connolly, will involve conducting a comprehensive literature review. In Task 2, Dr. Zhu, in consultation with CARB, will assemble a Technical Advisory Group (TAG) including community experts. Task 3, led by Drs. Zhang and Jin, will focus on exposure assessment and ground-truthing, including 4 km × 4 km air quality modeling in California, and more detailed 1 km × 1 km modeling for targeted communities in southern California (led by Dr. Zhang) and northern California (led by Drs. Jin and Kirchstetter), along with exposure assessment for a regulatory scenario in consultation with CARB. Task 4, led by Drs. Banerjee and Jerrett, will refine the spatial resolution of health data using Bayesian spatial smoothing models. Task 5, led by Drs. Jerrett, Connolly, and Banerjee, will involve creating dose-response functions through statistical models. The information from Tasks 3, 4, and 5 will be integrated to allow the Contractor to estimate the health effects of pollution sources on each community (census tract or ZIP code) compared to the average population. Finally, Task 6, led by Dr. Zhu in consultation with CARB, will oversee the project's review and completion. Below, the Contractor provides detailed descriptions of each task, demonstrating how they integrate with the overall objectives and methodologies of the project.

Task 1: Literature review of community health impact assessments

The Contractor will conduct a scoping literature review to evaluate the state of the science on modifiers of the air pollution-mortality relationship and methods to incorporate sociodemographic datasets in health burden analysis. The Contractor will prioritize studies based in California[4–6] but extend geographically as needed[7–11], including systematic review and meta-analysis articles[12]. The Contractor will prioritize $PM_{2.5}$ but include other pollutants as time and resources permit.

The Contractor will select keywords in consultation with a UCLA data librarian who specializes in systematic reviews for health sciences disciplines. The Contractor will include two online databases (PubMed and Web of Science) in the literature review. This review will ultimately be structured based on advisement from the data librarian, though the Contractor will use the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) as guidance[13].

The literature review will explore the impact of community characteristics on air pollution-health dose-response relationships and their integration into health burden analysis. Outcomes from the literature review will inform the model in Task 5 through the identification of specific factors that modify the effects of $PM_{2.5}$ on mortality, which will then be incorporated in the model to the extent relevant data are available.

The search will be structured to extract research articles (1) quantifying the concentration-response relationship for $PM_{2.5}$ and mortality for population subgroups within California, including effect modification by factors such as race and ethnicity, education status, income levels, and neighborhood greenness (to inform variable choice for the model in Task 5); and (2) presenting or utilizing methodologies for incorporating community characteristics and adjustment factors into health burden analyses (to support CARB in developing a framework for incorporating such factors). The search will focus on California but expand to North America and beyond depending on the number of studies available. Preliminary inclusion criteria for the review include peer-reviewed scientific studies published within the last ten years.

In summary, the planned search criteria for the literature review will follow:

1. Databases
    a. PubMed
    b. Web of Science
    c. Snowballing (using reference list to identify additional papers)
2. Keywords to be developed in consultation with UCLA data librarians
3. Inclusion Criteria
    a. Published in peer-reviewed journal
    b. Published in last ten years
    c. Written in English
4. Population
    a. All age groups
    b. All genders
    c. Any population subgroup
5. Geography
    a. California (to expand beyond as needed)
6. Topic areas
    a. Socioeconomic, demographic, and environmental factors impacting the relationship between air pollution and mortality (to incorporate in Task 5 modeling)
    b. Existing methodologies for incorporating community characteristics into health burden analyses (to support CARB in improving its health impact assessment framework)

Deliverables: The Contractor will provide CARB with (1) a Zotero library with citations, and (2) the literature review findings in the final report.

<u>Task 2: Technical advisory group (TAG) including community experts</u>

In consultation with CARB staff, the Contractor will establish a technical advisory group (TAG) consisting of at least five experts from universities, research institutes, national laboratories, community-based organizations, or government agencies who have extensive and expert knowledge related to air quality and health effects. The Contractor has already collaborated and are currently collaborating with many colleagues with complementary expertise related to this project, including Rob McConnell and Jill Johnston from USC, John Levy from Boston University, Tarik Benmarhnia from UC San Diego, Bryan Hubbel from US EPA, Scott Epstein from SCAQMD, Veronica Padilla from Pacoima Beautiful, and David Reichmuth from Union of Concerned Scientists, to name a few. In consultation with CARB staff, the Contractor will reach out to potential TAG members and invite them to serve on the TAG. The TAG will initially meet to review the study design and then convene semiannually to discuss progress, validate exposure data, and review ground-truthing methods, including community selection. Additionally, they will provide suggestions for refining disease rate estimation methods and developing community adjustment factors. They will also provide written feedback on the final report.

Deliverables: The Contractor will provide CARB with a list of TAG members by month 3.

Task 3: Exposure assessment and ground-truthing of air quality data

3.1: High spatial resolution air quality modeling throughout California

Using a chemical transport model (CTM, either WRF-Chem or WRF-CMAQ), the Contractor will simulate $PM_{2.5}$ and ozone concentrations at a horizontal resolution of 4 km x 4 km covering the entire California over a one-year period. Furthermore, the Contractor will set up the model with more detailed nested domains, specifically for the Bay Area (building on Dr. Jin's ongoing projects) and the South Coast Air Basin (building on Dr. Zhang's previous and ongoing projects), each at an enhanced horizontal resolution of 1 km x 1 km and varying vertical resolution depending on the boundary layer meteorology of respective subregions. The Contractor has extensive experience with setting up and running these state-of-the-art models (see Table 1 and CVs). The Contractor will determine the choice of the model based on CARB's suggestions. Should additional budget be provided, the Contractor may consider nested model runs with enhanced resolution at additional sub-domains such as San Joaquin Valley (SJV) using a hybrid approach: (1) conduct AERMOD modeling to capture the sub-grid variations (i.e. within the 4 km by 4 km grids) of inert species such as primary $PM_{2.5}$ around important emission sources (such as roadways, ports, area sources); (2) integrate the primary $PM_{2.5}$ dispersion at enhanced resolution (1 km or less) from AERMOD with the 4 km by 4 km secondary pollutant outputs from CMAQ/WRF-Chem (such as secondary $PM_{2.5}$ and ozone). This hybrid approach is used in an ongoing project of Dr. Jin, funded by the Health Effect Institute (HEI) for the San Francisco Bay Area. The SJV subdomain[14] is about ten times larger than the other two subdomains with much reduced coverage of low cost sensors (such as PurpleAir) for ground-truthing. As a result, including this subdomain to the modeling and ground-truthing effort at enhanced resolution will be more costly. Additional budget will be needed to cover the efforts for refining spatial resolution in this subdomain for emission input preparation and simulations for the base year and scenario years, as well as for ground-truthing. With the original budget, 4 km resolution air quality data will be provided for the SJV as part of the model runs for the California domain and ground-truthed primarily by the EPA's Air Quality System that integrates data from CARB and local air districts.

The emission data that will be used in the air quality model (WRF-Chem or WRF-CMAQ) are based on CARB emission inventory developed for a recent year without the COVID impact. The Contractor is flexible with the choice of base year and will work with CARB to make final selection based on project needs and data availability. The emission inventory will contain multiple anthropogenic sources including mobile (e.g., passenger cars), stationary point (e.g., oil refineries), off-road (e.g., ocean going vessels), and areawide (e.g., unpaved roads) sources. For on-road mobile sources, subarea (county-level) light-duty and heavy-duty vehicles emission rates will be based on the EMFAC2021 model. The Contractor will then use the Emissions Spatial and Temporal Allocator (ESTA) model to apply available spatial and temporal surrogates to EMFAC emissions. Specifically, the spatial surrogates provided by CARB at 1 km and 4 km resolutions will be used to grid the EMFAC emissions into two distinct domains matching the air quality model grids: 4 km × 4 km over California and 1 km × 1 km over the South Coast Air Basin. For areawide and off-road sources, the raw reported emissions at the local air districts level (provided by CARB) will be processed by the Sparse Matrix Operator Kernel Emissions (SMOKE) model to apply spatial and temporal surrogates. Furthermore, the Contractor will use the California Emissions Projection Analysis Model (CEPAM), to backcast the 2020 emission data to the base year (e.g. 2018) and also project the emission data for a future year (2045) based on available emissions for year 2020 as well as growth and control data.

For the Bay area modeling domain in northern California, CMAQ-ready emissions at 1 km by 1 km grid resolution have been developed by the Bay Area Air Quality Management District (BAAQMD) for the 2018 emission year. SMOKE was used to process annualized county- or facility-level emissions data and perform several processing steps to convert the data to the spatial, temporal, and chemical resolution required by CMAQ. The anthropogenic emissions data used in SMOKE cover four main source sectors (point, area, on-road mobile, and off-road mobile) and were assembled from a variety of data sources as detailed below.

Depending on the choice of base year (if not 2018), the Contractor will use the CEPAM projection to extrapolate the 2018 emissions to the chosen base year. Furthermore, the Contractor will consult with CARB staff to determine the adequacy of source categories (listed below) available in the model ready inputs, update the sources to the latest version, and conduct further refinement if needed.

- **Point (permitted stationary sources)** – emissions data from the District's California Emission Inventory Development and Reporting System (CEIDARS), which is updated annually and submitted to the California Air Resources Board (CARB).
- **Area (non-permitted stationary sources)** – emissions data from CARB's California Emission Projection and Analysis Model (CEPAM). Specifically, county-level emissions for 2018 were downloaded from the CEPAM 2016 State Implementation Plan (SIP) Inventory, version 1.05. In the area source sector, emissions for residential wood combustion in Bay Area counties were updated with the new 2018 inventory.
- **On-road mobile sources** – emissions data by county and month were developed using outputs from CARB's Emission FACtor 2021 (EMFAC2021) model, which reports emissions by vehicle type and emissions process (e.g., idling, running exhaust, brake wear, tire wear).
- **Off-road mobile sources** – county-level emissions data from the CEPAM 2016 SIP Inventory, version 1.05 (same as area sources).
- **Residential wood combustion emissions** – data were processed through SMOKE and input to CMAQ separately from emissions from other area source categories.

In addition to anthropogenic sources, the Contractor will generate emissions from biogenic sources using the Model of Emissions of Gases and Aerosols from Nature (MEGAN) at 1 km x 1 km resolution for the South Coast Air Basin and Bay Area as well as 4 km x 4 km resolution for the state. It should be noted that meteorological data are required to generate emission inventory for some specific sources. This input meteorology data will be the base year model results from the WRF model.

The Contractor will use the meteorology of the base year for all calendar years to isolate the air quality and subsequent impact of emission changes. To manage the computational burden while obtaining a temporally valid annual estimate of air pollutant concentrations, the Contractor will model one week per month in each modeling year and average these outputs into annual estimates for use in subsequent health and equity analyses.

The Contractor will perform air quality simulations for a selected base year, for example 2018, which has the recent emission inventory available before the pandemic. This will allow the Contractor to (1) validate the model setup against observations, and (2) provide baseline air quality data for exposure assessments. Furthermore, the Contractor will simulate a future year scenario, such as the impact of mobile source regulations in 2045, when CARB aims for achieving carbon neutrality. The Contractor has extensive experience with similar scenarios, as detailed in the CVs and shown in Table 1, which could inform the initial selection. The final choice of base and future scenarios will be determined in consultation with CARB staff. Based on the ground truthing results from task 3.2, the Contractor may consider further refinement of the model, such as observational nudging and sub-grid level dispersion modeling, to improve the accuracy of exposure assessment. The modeling output will provide high-resolution $PM_{2.5}$ and ozone concentrations data suitable for exposure and health impact assessment at community levels.

Table 1. Past and ongoing projects with relevant emission control scenarios

Project Name	Description	Spatial Coverage	Emission resolution	Time span	Funding Source	Point of Contact
California's Deep Decarbonization Pathways: A Holistic Multi-Layer Assessment	To quantify the air quality impacts of vehicle electrification in California through the coupling of transportation, electric grid and reduced-complexity air quality models.	California	HDV emissions at $1km^2$ - $48km^2$ varying resolution	2018-2050	University of California Office of President	Dr. Jin
BILD-AQ	To assess the air quality benefits of electric vehicle charging infrastructure deployment plans, and at what rate those benefits accrue to disadvantaged communities in the context of Justice40	Western Interconnection regions	LDV emissions at 1 - 48 km^2 varying resolution	2018, 2040	DOE-DOT Joint Office	Dr. Jin
BREATHE	An agent-based model for evaluating long-term impacts of traffic related air pollution on disadvantaged communities under multiple scenarios of clean transportation (electrification, telecommunity, and community-based scenarios).	San Francisco Bay Area	LDV, MDV, HDV emissions at varying resolutions (50~100 meter in AERMOD to 1 - 48 km^2 for InMAP)	2018-2050	Health Effect Institute	Dr. Jin
ZET Impacts	Assess the impact of recently adopted zero-emission truck regulations (Advanced Clean Trucks and Advanced Clean Fleets) on health risks in historically marginalized Southern California communities along freight movement corridors	South Coast Air Basin	Truck emissions at 1 km^2 resolution	2019, 2025, 2037, 2045	Health Effect Institute	Dr. Zhang
LA100	Assess the air quality co-benefits of adopting renewable energy and electrification in the City of Los Angeles	Southern California	Emissions at 2 km^2 resolution	2012, 2045	Los Angeles Department of Water and Power	Dr. Zhang, Dr. Zhu

3.2: Validation of air quality modeling data through ground-truthing in disadvantaged communities

Historical pollution levels and their spatial gradients observed both within and across communities will be used to validate the chemical transport model (CTMs) simulations from WRF-Chem or WRF-CMAQ for the base year. This ensures an accurate representation of the magnitude and spatial variations of $PM_{2.5}$ and ozone exposure, highlighting differences between overburdened communities and others. In particular, the Contractor will identify at least two overburdened communities within the two subdomains in northern and southern California, for ground-truthing, which will ensure the scalability of results within different regions. Several potential communities the Contractor has previously engaged include South Los Angeles, an AB 617 community (community partner: Redeemer Community Partnership), and Pacoima (community partner: Pacoima Beautiful), a community consistently nominated for the AB 617 program. In northern California, the Contractor will consider West Oakland, an AB 617 community where extensive modeling and monitoring activities[16–18] have been conducted under the West Oakland Community Action Plan. The Contractor will consult with TAG members to identify final communities for ground-truthing.

The Contractor will create a harmonized observational database with sufficient coverage across different communities combining the following observational data sources: (1) The gold standard measurement data from the EPA's Air Quality System (AQS) that integrates data from CARB and local air districts; (2) PurpleAir II data, a widely utilized $PM_{2.5}$ network across California (2722 in CA, 1015 in Bay Area, and 294 in Los Angeles). The Contractor has extensive experience using PurpleAir II data at the community scale[15,16], and their previous work has suggested that PurpleAir II data are spatially correlated with gold standard measurements for $PM_{2.5.}$

Ozone monitoring data are only available from the AQS network and will be used for ground truthing the exposure to maximum daily 8 h average (MDA8) ozone simulated from the CTMs. The Contractor's previous work[17] has demonstrated that CTMs are able to capture the spatial and temporal variations in observed ozone consistently at horizontal spacing of 4 km.

For $PM_{2.5}$, the aforementioned data sources each have their own unique accuracy and coverage in location, time and chemical composition, and therefore a concerted strategy is required for ground-truthing. The AQS dataset uses the Federal Reference Method (FRM) based on the gravimetric method and is the benchmark for PM measurement. Despite its accuracy, the intensive labor and cost requirements prevent its wide deployment within and across communities. On the other hand, low-cost sensors, such as PurpleAir, with more extensive spatial coverage due to their affordability, come with their own set of biases and uncertainties due to factors like sensor aging, environmental conditions, and calibration drifts[18–21]. To bridge the gap between these low-cost sensors and the FRM gold standard, it's crucial to develop calibration protocols that mitigate these biases, ensuring the integration of reliable and accurate air quality data across monitoring networks.

To evaluate the <u>total $PM_{2.5}$</u> predictions from the CTM, the Contractor will first conduct data quality assurance and quality control (QA/QC) followed by a calibration step to harmonize the observations from the AQS and PurpleAir data. The Contractor has previously downloaded hourly-averaged $PM_{2.5}$ data over the 2018-2019 period from PurpleAir network for the entire California domain. Downloaded data contained date and time of measurement, estimated PM mass concentration at 1, 2.5, and 10 microns reported by the two sensors in each device labeled channels A and B, temperature in degree F, and relative humidity. The Contractor will apply the data cleaning methods developed in a previous study in the Los Angeles metropolitan area[22] to QA/QC the state-level data. More specifically, the Contractor will

- Exclude sensors if they have missing temperature measurements or have missing data rate of 10% or higher
- Remove data points per Plantower's factory standards
- Removed records associated with extreme temperature and relative humidity values (RH% ⩽0 or RH% ⩾100; temperature ⩽-200 degree F (-129 degree C) or temperature ⩾1000 degree F (537 degree C))
- Average measurements from the A and B sensors to determine a final measurement of $PM_{2.5}$.

After the data cleaning, the Contractor will develop an environmental adjustment algorithm to calibrate the PurpleAir data against AQS data. No additional deployment of low-cost sensors will be conducted in this project due to budget constraints. Previous studies have shown that PurpleAir sensors can both overestimate and/or underestimate $PM_{2.5}$ to different degrees depending on the local environment (relative humidity, temperature, and dust loadings)[18,21]. These location-dependent environmental factors introduce biases not only in the absolute concentrations but also in the relative spatial gradient in $PM_{2.5}$ measured by PurpleAir sensors. The Contractor will evaluate alternative methods based on regressions (e.g. Barkjohn et al (2021)[23]) and/or machine learning (e.g. Vajs et al. (2021)[24]) to determine the algorithmic approach to calibrate PurpleAir data as a function of raw measurements and environmental factors. More specifically, a subset of PurpleAir data that are collocated with FRM measurements will be used to model the PurpleAir data assuming an underlying process of the ground-truth $PM_{2.5}$ (represented by the FRM measurements) modified by an environmental bias as a function of the concurrent environmental factors (including but not limited to relative humidity, temperature, and dew point temperature). The Contractor will evaluate the prediction accuracy of alternative models with different input features and specifications and determine the final choice to be applied to PurpleAir calibration.

The Contractor will then apply the calibrated PurpleAir and FRM measurements to evaluate the total $PM_{2.5}$ simulated by the CTM at hourly, daily, seasonal and annual scales. The ground-truthing will focus on both the absolute $PM_{2.5}$ levels and their spatial gradients within and across communities. The Contractor will report performance metrics derived from paired comparison between observed and modeled data including but not limited to R^2, mean bias and percentage bias, mean gross error and percentage gross error, and root mean squared errors. The Contractor will report the mean and standard deviation of the performance metrics aggregated by communities and refine the CTMs to ensure consistent and adequate model performance within and across communities.
To evaluate the model's ability to capture the exposure disparity among different communities and racial/ethnic/age groups, the Contractor will additionally compare the population weighted $PM_{2.5}$ concentrations between modeled and observed, with the subpopulations spatially determined by the American Community Survey (ACS) census data at census tract (CT) level. The comparison results will critically inform the ability of CTMs to simulate the differences in population-weighted exposure at the required resolution (i.e., CT level) for the subsequent health analysis.

Lastly, the Contractor will also explore the possibility of utilizing speciated $PM_{2.5}$ data in the benchmarking effort, including (1) Previously collected $PM_{2.5}$ speciation data funded by CARB[25] and from other projects - for example, in 2018-2019, the Contractor collected ambient $PM_{2.5}$ filter samples at 46 sampling sites representing background, desert, community, and traffic locations in the greater Los Angeles area[26]; (2) Previous community monitoring data collected in 2017 at West Oakland, from a fixed-site low cost sensor network of 100 black carbon sensors and mobile monitoring[27–29]; and (3) SCAQMD mobile platform sampling in AB 617 communities[30].

These datasets provide observed chemical components of $PM_{2.5}$ such as black carbon and elemental compositions in various parts of the two selected sub-domains (Bay Area and South Coast Air Basin). These primary species carry unique source signatures such as on-road traffic, port activities, and heavy-duty trucking activities and capture the spatial variation in the primary pollutant concentrations between source and receptors. While these species are not directly simulated by CTMs due to lack of explicit emission inputs, they can be used as spatial proxy to evaluate the relative magnitude in primary $PM_{2.5}$ simulated by CTMs at near source versus downwind locations. If timeline allows, the Contractor will leverage the comparison results to guide further refinement of the emission allocation process.

Deliverables: The Contractor will provide CARB with benchmarked concentration fields for $PM_{2.5}$ and ozone simulated at hourly and aggregated (i.e., annual average, and seasonal average) resolution for the base year and a future scenario year for the entire state and in two subdomains.

Task 4: Refining the spatial resolution of health data

Table 2 presents the datasets currently available to the Contractor, or those the Contractor is acquiring. The Contractor is in the process of acquiring daily death data by race, ethnicity, and education at the CT level from the California Department of Public Health (CDPH) (California Comprehensive Death File [CCDF]); this request is in the final stages and the Contractor anticipates it will be available in late 2024. The Contractor has also obtained several other supplemental datasets to be used as time and resources permits. These include statewide census tract (CT) mortality data from the USALEEP project[31] collaborators at the “Industrial Economics” firm, and CT life expectancy data from the same project. Additionally, the Contractor has statewide emergency department and hospitalization data from 2008-2022 at the ZIP code level, provided by the state government and assembled as part of their ongoing project funded by CARB. Lastly, the Contractor has access to publicly available annual ZIP code-level death data from the CDPH.

To estimate age and sex-adjusted mortality rates for each CT, the Contractor will employ Bayesian spatial smoothing models that were developed by Dr. Banerjee and colleagues[35,36]. These models explicitly compensate for small counts in some cells by drawing on neighboring observations to impute likely counts, which will result in complete statewide coverage. In the following section, the Contractor outlines the calculation of the standardized mortality ratios (SMRs) for each CT in the state. An SMR is a ratio that estimates the observed occurrence of an event in a population (e.g. deaths) relative to the expected occurrence of the deaths in a larger comparison population that is often designated as normal, average, or healthy[37]. The dataset supporting this analysis will be the CCDF mortality data (Table 2) for the years 2017, 2018, and 2019. This dataset consists of data collected at the individual level, including some socioeconomic, demographic, and social variables such as age, sex, racial-ethnic status, highest education level, occupation, date of death, decedent’s address at time of death, and primary cause of death. Prior to analysis, the data will be processed and cleaned as needed, including removing duplicates and erroneous entries, and geocoded. The final data will be categorized into age and sex groups. Age will be divided into four categories: 00-19, 20-44, 45-64, and 65+. Sex will be divided into three categories: female (F), male (M), and unknown (U).

Table 2: Summary of health data sets available to the Contractor

Dataset Description	Source	Spatial Resolution/ Geography	Time Frame
Daily deaths by race and ethnicity and education	California Comprehensive Death File (CCDF Static) from CDPH[32]	Census tract (CT)/CA	2005-2021
Mortality rates by age group	United States Small-Area Life Expectancy Estimates Project (USALEEP)[31], Industrial Economics	Census tract (CT)/U.S.	2010-2015[1]
Life expectancy	USALEEP[31]	Census tract (CT)/U.S.	2010-2015[1]
Emergency and hospitalization data	CA Department of Health Care Access and Information[33]	ZIP code/CA	2008-2022
Annual deaths by age group	CA Department of Public Health (CDPH) - CA Vital Data[34]	ZIP code/CA	2014-2024

[1] USALEEP estimates are for the combined years of 2010-2015, rather than individual years.

The goal of the analysis is to obtain estimates for the SMRs for all causes of death minus accidents and injuries. For this study, the reference group is defined as the statewide population, with SMRs showing the relative ratio of deaths for a given CT*i* to the statewide average deaths. To begin, the Contractor will divide the total number of observed deaths in each age/sex category by the total number of individuals belonging to that age/sex category in the population, which will be estimated using the ACS census data. This calculation provides the expected death rate for each age/sex combination in the statewide population. Using these rates, the expected number of cases will be calculated for each CT/age/sex combination. The total number of observed deaths in each CT*i* will then be divided by total number of expected deaths in the same area, and the SMR in the i^{th} CT will be calculated as follows:

$$SMRi = \frac{observed\ deaths\ i}{expected\ deaths\ i} \quad \text{(Eq 1)}$$

where observed deaths_i is the total number of observed deaths in CTi, and expected deaths_i is the expected number of deaths in CT_i calculated based on the assumption that the CT_i has the same age-sex adjusted rate of death as the statewide average.

Because the Contractor proposes to estimate the SMRs over small-areas (i.e., CTs), many of the age/sex groupings will likely have small numbers or zeros[38]. This is a well-known problem in spatial epidemiology, with the solution being to calculate relative risks and SMRs from a hierarchical Bayesian smoothing model as described below.

The underlying idea is to adopt a hierarchical model that will model the counts in the first stage as a Poisson distribution with a CT-specific intensity function. The intensity function will incorporate CT-specific explanatory variables such as age, sex, race-ethnicity, highest education level, and occupation. The Contractor will also adjust for other possible variables using the CT-level estimates from the CDC PLACES data[39] – which includes confounders found to be important in air pollution epidemiology, including smoking and obesity rates – as well as spatially dependent random effects. More specifically, the Contractor will introduce two sets of CT- referenced random effects. The first set of random effects will introduce spatial dependence using the conditional autoregressive (CAR) distribution designed to borrow information from neighbors and capture spatial clustering, while the second set of random effects will model spatial heterogeneity using unstructured random effects. To elucidate further, let Y_i denote the observed number of deaths in CTi for each of n CTs and let $X_{i1}, X_{i2}, \ldots, X_{ip}$ be a set of p explanatory variables to be adjusted for. The Contractor will use the Bayesian hierarchical model,

$$Y_i \sim Poisson(E_i\theta_i);\ log\,(\theta_i) = \beta_0 + X_{i1}\beta_1 + \cdots + X_{ip}\beta_p + u_i + v_i \ \ for\ i = 1,2,\ldots,n. \qquad \text{(Eq 2)}$$

where, E_i is the standardized expected number of deaths under a homogeneous assumption (each individual in the population is equally likely to die) in CTi and θ_i represents relative risk by modeling the adjusted intensity (average) death as a departure from the homogeneity assumption attributable to factors represented by the explanatory variables, the spatial clustering effects u_i and the unstructured heterogeneity effects v_i. The collection of n random effects $\{u_i\}$ are jointly modeled as a CAR distribution using the full conditional specification $u_i \mid u_{\{-i\}} \sim N(\{\bar{u}\}_i, \sigma^2/m_i)$, where $\{\bar{u}\}_i$ denotes the weighted average of the random effects corresponding to census tracts that are neighbors of tract i, m_i is the number of neighbors of tract i and σ^2 is the spatial variance. The unstructured random effects are identically and independently distributed as $v_i \sim N(0, {\sigma^2}_v)$, where ${\sigma^2}_v$ is a variance term designed to explain heterogeneous variation.

The Bayesian hierarchical model will provide posterior estimates of all the model parameters (coefficients of explanatory variables, random effects and variance components) and will, therefore, yield posterior distributions for each θ_i based upon the observations. This, in turn, will yield the posterior distribution of the expected mortality $E_i\theta_i$ and provide the posterior estimates of the standard mortality ratio:

$$SMR = Y_i/E_i \times 100 \qquad \text{(Eq 3)}$$

The SMRs are effectively point estimates of the relative risks, but when calculated directly they lack advanced modeling constructs such as spatial smoothing to compensate for small counts in some cells, and they give no measures of uncertainty. Application of the Poisson model can indirectly derive SMRs with smoothing for small counts and providing estimates of uncertainty. In fact, the SMR can be estimated for the given model by using the model-fitted values of *Y* for each CT. Once computed, these age- and sex-adjusted rates can be utilized to estimate future health impacts of changes in ambient concentrations of air pollution derived from the CTM (WRF-Chem or WRF-CMAQ).

This model, often referred to as the Besag-York-Mollie (BYM) model, can be implemented in a number of different statistical programming languages including R packages such as NIMBLE, CarBayes, RSTAN, R-INLA and R2BUGS (that offer interfaces to Bayesian modeling languages including scaling up analysis for large datasets). It is worth noting that each of these statistical programming environments will deliver model fitted estimates of Y_i in Eq.3. More specifically, the Contractor will collect simulated draws from the posterior distribution of all the regression slopes and the random effects in Eq.2 to compute posterior samples of θ_i.

For each value of θ_i computed as such, the Contractor will draw a model replicated value of the dependent variable Y_i from the Poisson distribution $Poisson(E_i\theta_i)$. The resulting samples provide the full posterior distribution for the model fitted dependent variable Y_i adjusted for all variables used as covariates. Plugging each of these values of the model fitted dependent variable Y_i into Eq.3 produces the posterior samples of adjusted SMRs. Taking the mean or median of these samples gives point estimates of the adjusted SMR, while the standard deviation and quantiles of these samples help quantify the uncertainty of the estimated SMR. This procedure will generate CT-specific standard errors for the SMRs. The probabilistic underpinnings of Bayesian inference and, more specifically, the generation of posterior samples as drawn above is described in detail in the text by Gelman et al., 2015[40].

Deliverables: The Contractor will provide CARB with statewide CT-level SMRs adjusted for age and sex.

Task 5: Developing community adjustment factors

To develop community adjustment factors, the Contractor will combine findings from the literature review on relevant factors modifying the air pollution-health relationship (Task 1), small-area health data estimates (Task 4), and high-resolution exposure models (Task 3) to assess how neighborhood conditions modify the association between air pollution and mortality. It will allow the Contractor to identify which areas, particularly low-income and ethnically-diverse groups, will benefit most from specific interventions, similar to their previous green space analysis in Los Angeles[41].

Specifically, as described in Task 1, the Contractor will conduct a scoping literature review to identify factors that have been shown to modify the association between $PM_{2.5}$ and mortality. Table 3 includes individual, compositional, and contextual factors that the Contractor will consider incorporating into the models[42]. Some potential variables include green space and parks, poverty, and the percentage of racially-ethnically minoritized people. Once these variables are identified, the Contractor will integrate them into two different but complementary epidemiological models.

Here we briefly summarize the two models and distinctions before describing the approaches in more detail. The first approach will involve developing epidemiological models to directly quantify the dose-response relationship between $PM_{2.5}$ and mortality, following the model form described in Task 4, but introducing interaction effects in the model structure. It is a global (or statewide) model, and can produce estimates of the effect of individuals, grouped, or interacting factors on mortality. The second approach is an extension of these models to explore estimation of spatially varying dose-response functions that will provide specific dose-response values for each CT in California. The model structure remains similar but adds an index to enable space-varying coefficients for both the main effects and interaction effects. Additionally, a spatial meta-regression will provide insights on which factors are driving the CT-level differences in the air pollution effect.

Table 3. Examples of variables to consider for statistical models

Variable	**Individual**	**Compositional**	**Contextual**	**Use in Model**	**Source**
Education	X	NA	X (possible)	**Confounder**/*Effect Modifier*	CCDF deaths data
Age	X	NA	NA	**Confounder**/*Effect Modifier*	CCDF deaths data

Obesity	NA	X	NA	**Confounder**	CDC PLACES
Physical Inactivity	NA	X	NA	**Confounder**	CDC PLACES
Smoking	NA	X	NA	**Confounder**	CDC PLACES
Green space (normalized difference vegetation index (NDVI), tree canopy)	NA	NA	X	**Confounder**/Effect Modifier	National Agriculture Imagery Project (NAIP)[43], National Land Cover Database (NLCD)[44]
Noise	NA	NA	X	**Confounder**/Effect Modifier	U.S. Department of Transportation[45]
Linguistic isolation – percent of limited English-speaking households	NA	NA	X	**Confounder**/Effect Modifier	U.S. American Community Survey
Median household income	NA	NA	X	**Confounder**/Effect Modifier	U.S. American Community Survey
Race and ethnicity	X	NA	NA	**Confounder**/Effect Modifier	CCDF deaths data
CalEnviroScreen	NA	NA	X	Effect Modifier	California Office of Environmental Health Hazard Assessment[46]
Air pollution – Ozone and Nitrogen Dioxide (NO_2)	NA	NA	X	**Confounder**	Various options, including Meng et al. 2021[47] and the Center for Air, Climate, & Energy Solutions[48]

The first approach will involve developing epidemiological models to directly quantify the dose-response relationship between $PM_{2.5}$ and mortality for susceptible populations (ozone and other health outcomes will be considered as time and resources permit). The Contractor will estimate health effects using the deaths data available to them (CCDF from CDPH) as the response variable and the exposure estimates from the CTM as a predictor, while controlling for potential confounders. Models will follow a similar form to those specified in Task 4. These CAR regression models, described in Task 4, will also allow for direct tests of effect modification by sociodemographic characteristics such as neighborhood poverty, race, and ethnicity. This will involve including multiplicative interaction terms (e.g., air pollution * percent green space in CTs). To be specific, we will begin with an extension of Eq (2) by introducing the interaction effects in the mean structure. Let Y_i be the response variable from CT_i and let X_{ij} be the measured value of the j-th covariate in CT_i. If Y_i is distributed as Poisson, as in Eq (2), then we will add interaction terms to the relative risk:

$$Y_i \sim Poisson(\theta_i);\ log(\theta_i) = \beta_0 + X_{i1}\beta_1 + X_{i2}\beta_2 + \cdots + X_{ip}\beta_p + \sum_{\{j,k \in \{1,\ldots,p\}\}} X_{ij} * X_{ik}\beta_{\{jk\}} + u_i + v_i, \quad \text{(Eq 4)}$$

where $\sum_{\{j,k \in \{1,\ldots,p\}\}} X_{ij} * X_{ik}\beta_{\{jk\}}$ denotes the interaction terms we desire to test in the model. If the specific response variable is Gaussian or binary, then we will follow the same modeling structure except to replace the logarithmic relative risk either with the mean (in Gaussian regression) or with a logit function of probabilities (in logistic regression). The spatial and heterogeneous clustering effects u_i+v_i can still be included to reckon with spatial dependence and borrow strength from neighboring CTs but can also be excluded should the analysis seek fixed slope and interaction effects only. In addition to the parameters described in Eq (2), the Contractor will now obtain full posterior inference on the interaction coefficients $\beta_{\{jk\}}$ to ascertain the impact of potential confounders (i.e., to see how the relationship of a variable with the response is impacted by a potential confounder) and effect modifiers using sociodemographic characteristics described earlier (see Table 3). Incorporating appropriate covariates designed for a specific investigation will reveal insights that motivate further modeling and analysis. Similar to Task 4, the Bayesian approach supplies full posterior inference with complete uncertainty quantification using posterior samples.

The Contractor will test the change in model fit with and without the interaction term and test overall model fit using the log likelihood ratio test evaluated against the chi-square distribution with 1-degree of freedom. If significantly improved, the Contractor will estimate the interaction coefficient to adjust the dose-response function; with this approach the Contractor can also stratify the model based on, for example, the highest quintile of poverty or CalEnviroScreen scores.

The Contractor appreciates that CARB is interested in the overall effects of these factors. The approach proposed by the Contractor will be able to deliver the estimates of the overall effects by first obtaining the posterior samples of the fixed effects and possible interaction effects in the proposed model and then, obtaining the posterior samples of θ_i using the linear combination (either adjusting for the random effects or not, as the case may be). The posterior estimates of each θ_i with full uncertainty quantification will provide the desired inference on the overall effects of the factors. Such inference will be explored for different models including and excluding interaction terms, spatial random effects and heterogeneous clustering effects.

With the second approach, the Contractor will extend these models to explore estimation of spatially varying dose-response functions that will provide specific dose-response units (at CT or ZIP code levels), a method that Dr. Jerrett helped to pioneer[30]. This method essentially yields a specific dose-response function for each CT as described in Coker et al. 2015[49] (see Figure 2, extracted from this paper).

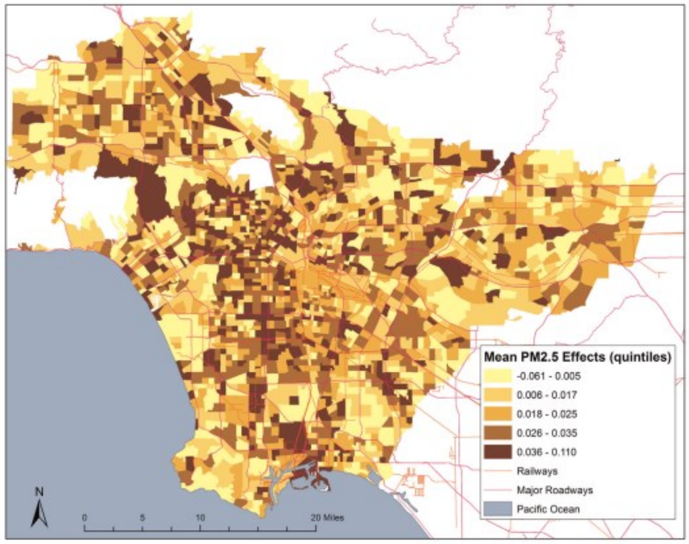

Fig. 2. Census tract $PM_{2.5}$ effects for TLBW (mean) after adjusting for maternal age, race-ethnicity, education, parity, and infant gestation + gestation squared, and infant sex.

Figure 2. Example of census tract-level dose-response estimates for $PM_{2.5}$ and birth outcomes in LA County (extracted from Coker et al., 2015)

Once the effects are estimated, the Contractor can then use a meta-regression to assess which neighborhood variables (e.g., green space, race/ethnicity, etc.) predict the spatially varying effects. This approach has the advantage of generating spatially explicit estimates at the CT-level, which can be used directly to estimate subsequent HIA estimates, while the meta-regression can be used to determine which variables might be driving the difference in the air pollution effect. Although conceptually appealing, these models can suffer from identifiability problems that do not yield stable small-area estimates. The Contractor therefore proposes this second method as a sensitivity analysis because there is no guarantee that the results will be valid until the Contractor begins the empirical modeling process. The Contractor expects to be able to fit the models successfully, but given the possible identifiability issues, the Contractor cannot guarantee this portion of the research as a deliverable.

To offer some additional details on the second approach and help mitigate the aforementioned concerns regarding identifiability, the Contractor will explore opportunities to use spatial-temporal data that afford multiple measurements of the response from each CT. For exemplification purposes using Eq (2) as an example, the Contractor modifies the model as

$$Y_{it} \sim Poisson(\theta_{it});\ log(\theta_{it}) = \beta_0 + X_{it1}\beta_{1i} + X_{it2}\beta_{2i} + \cdots + X_{ip}\beta_{pi} + \sum_{\{j,k \in \{1,\ldots,p\}\}} X_{ijt} * X_{ikt}\beta_{\{jk\}i} + u_{it} + v_{it} \quad \text{(Eq. 5)}$$

Here, the second index, *t*, represents the measurements within a CT. This enables the space-varying coefficients β_{ij} for the main effects and $\beta_{\{jk\}i}$ for the interaction effects, where the suffix *i* denotes the CT index for each coefficient, to be further modeled using a CAR model over the CTs. The multiple measurements will allow these coefficients to be identified from the data, rather than simply from the CAR prior. Importantly, each of the coefficients will be modeled as $\beta_{ij} = \mu_j + z_{ij}$ (for main effects) and $\beta_{\{jk\}i} = \mu_{\{jk\}} + z_{\{jk\}i}$, (for interaction effects). This Bayesian hierarchical model can be looked upon as a spatial meta-regression that allows the Contractor to investigate the main effects as well as the interactions in a space-varying manner, while also offer fully model-based estimates on the meta-regression parameters with full uncertainty quantification. It is worth noting that this approach can be regarded as a regionally aggregated (or CAR model) adaptation of spatially varying coefficient processes used in Gelfand et al.[50] and, more recently, in Schwarz et al.[51] The Contractor notes that μ_{it} and ν_{it} in Eq (5) can now be modeled as spatial-temporal random effects that employ the CAR for spatial dependence and an autoregression for temporal dependence (see Waller et al.[52]). The Contractor will begin with a simpler specification of modeling μ_{it} and ν_{it} as CAR distributions over CTs but independent of time. Based upon the results there, the Contractor will decide on exploring temporal dependence models. The Contractor intends to use the NIMBLE or STAN Bayesian modeling languages, which offer computationally efficient implementations of the CAR model and operate within the R statistical framework, to implement the hierarchical models.

In summary, the first approach the Contractor proposed will yield statewide community adjustment factors (effect modifiers of the $PM_{2.5}$-health relationship) that can then be used within CARB's current HIA framework to estimate potential health benefits of new regulations in various populations. The second approach (assuming identifiability problems are avoided, and the models are validated) will result in CT-specific dose-response estimates, which will not be stratified by community characteristics. The Contractor can use the output of both models when projecting exposure changes into the future based on the CTM model outputs for future scenarios. These models will use the same health input data, but they will also employ new estimates of $PM_{2.5}$ to estimate health benefits from exposure changes.

Deliverables: The Contractor will provide CARB with statewide community adjustment factors for the $PM_{2.5}$-mortality relationship, and spatially varying CT-level dose-response estimates (depending on model validity).

<u>Task 6: Project Review and Completion</u>

As part of the final stages of this project, a draft report will be submitted to CARB summarizing the developed methodologies for evaluating health outcomes, including any identified limitations. This report will detail adjustment factors that quantify the differential health impacts on overburdened communities compared to the general population, based on exposure levels, baseline disease rates, and community characteristics. It will also outline a methodology for integrating these factors into CARB's current HIA framework to better reflect the compounded health risks in these communities. The first draft report will be shared with CARB staff and the TAG at least six months before the end of the project. CARB staff and the TAG will provide written comments on the scientific basis for the draft report in about a month. All feedback received will be incorporated into the final report. The PI will give a public seminar based on the final report. Throughout the project, deliverables written in plain language that summarize the key findings from this project will be developed for public dissemination.

Deliverables: The Contractor will provide CARB with the ffinal report.

Conclusion

To support CARB in enhancing its health analysis methods to more effectively account for impacts in overburdened communities, the Contractor proposes a comprehensive approach. This approach utilizes high spatial resolution exposure assessment methods and health estimates (e.g., baseline mortality) for the quantitative analysis of health impacts from mobile source control scenarios focusing on $PM_{2.5}$ and ozone at a more granular spatial scale than CARB's current state and regional regulatory health assessments. The Contractor has extensive experience and expertise in air quality and health effect assessment research. Some of the tasks described in this proposal, including literature review, WRF-Chem or CMAQ modeling, and health data collection, are already in progress. The Contractor will also be supported by a multidisciplinary TAG, including community representatives, to ensure the scientific rigor of the proposed study. The final report will provide much-needed information to inform CARB's and other agencies' efforts to prioritize reducing exposure to air pollutants and protecting public health for the most impacted and vulnerable communities.

Project Schedule

The table below shows the anticipated timeline for this project including tasks and subtasks.

Task		**Project Quarter**							
		Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
1	**Literature review of community health impact assessments**	■	■	■					
2	**Technical Advisory Group (TAG) including community experts**	■		■		■		■	
3	**Exposure assessment and ground-truthing of air quality data**	■	■	■	■	■	■	■	
3.1	High spatial resolution air quality modeling throughout California	■	■	■	■	■	■	■	
3.2	Validation of air quality modeling data through ground-truthing in two overburdened communities			■	■	■			
4	**Refining the spatial resolution of health data**		■	■	■	■			
5	**Developing community adjustment factors**				■	■	■	■	
6	**Project Review and Completion**							■	■

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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. This meeting may be conducted by phone.

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.

CONFIDENTIAL HEALTH DATA AND PERSONAL INFORMATION (OPTIONAL – For projects with Health Data and/or Personal Information)

CARB will not be provided access to and will not receive any confidential health data or other confidential personal information under this contract. Further, CARB will have no ownership of confidential health data or other confidential personal information used in connection with this contract. The entities conducting the research in this contract will follow all applicable rules and regulations regarding access to and the use of confidential health data and personal information, including the Health Insurance Portability and Accountability Act (HIPAA) and requirements related to the Institutional Review Board (IRB) process. CARB will not be a listed entity with authorized access to confidential information pursuant to the IRB process for this contract.

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.

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
Racial equity/implicit bias training certificates	The Principal Investigator and key personnel must demonstrate that they have taken, or will take, cultural competency training, implicit bias training, or racial equity training, whichever is administered at their institution. 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.
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
Progress Reports	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 submitted in an Americans with Disabilities Act compliant format.	Six (6) months prior to 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	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 Americans with Disabilities Act compliant format.	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 shall be submitted in an Americans with Disabilities Act compliant format. The Public Outreach Document and Equity Implications Section, as described in Exhibit A1, Section 2, shall be incorporated into the Final Report.	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 and 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. To maintain compliance with California Government Code Sections 7405 and 11135, and Web Content Accessibility Guidelines, Assembly Bill No. 434, the final Report must be submitted in an Americans with Disabilities Act compliant format. The Final Report will be posted on the CARB website and therefore must be in an accessible format so that all members of the public can access it.

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.

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.

Equity Implication Section. The equity implications section should summarize how the research results inform disparate impacts of policies, regulations, or programs on priority communities. [1] This section should summarize how sociodemographic factors were examined in this research. Given the data used or collected, which populations are excluded or overrepresented? How were relevant communities engaged in the research effort and/or how were existing data gaps identified and ground-truthed during the research project? If ground-truthed data were found to not accurately reflect the lived experiences of community members, what future research projects could address this disconnect. The research results should inform existing or future CARB programs and the equity implications section should discuss how the research results may inform programs to close disparities in health outcomes, pollutant exposure or climate adaptation, etc., for priority communities. This section should be limited to a maximum of two (2) pages, single spaced and shall include the following sections.

HISTORICAL ANALYSIS. Provide an overview of the inequities and disparities observed in the existing data or data gathered during the research and how it ties to historic policies. For example, what is the root-cause of the disparity being experienced by the community or population central to this research?

MATERIALS AND METHODS. Describe how this research project examines racial equity. Some methods can include but are not limited to: examining the potential for existing data to address racial inequalities, ground-truthing existing data, engaging priority communities, assessments for racial and ethnic subgroups in the development of data and approaches, identifying data gaps and filling those gaps.

RESULTS AND DISCUSSION. Describe how the results improve our understanding of the equity issues identified or interventions to address those inequalities .

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[1] Priority communities here encompasses various terms CARB uses such as priority populations[2], communities of concern[3], protected classes[4], or disadvantaged communities[5].

[2] Priority Populations — California Climate Investments

[3] Referenced from the California Public Utilities Commission Environmental and Social Justice Plan an effort resulting from California's Capitol Collaborative on Race & Equity.

[4] Protected Classes | California State Senate

[5] SB-535-Designation-Final.pdf (ca.gov) ; California Climate Investments to Benefit Disadvantaged Communities | CalEPA; CalEnviroScreen 4.0 | OEHHA

Body of Report. The body of the Report should contain the details of the research, divided into the following sections:[1]

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

[1] 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.

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 (CO2)]. 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. Any other deliverables shall be provided in a mutually agreed upon format unless the deliverable format is already specified in Exhibit A.