Impacts of Multiple Climate Change Stressors on Health in California

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EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

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

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Project Title: Impacts of Multiple Climate Change Stressors on Health in California

Project Summary/Abstract

Although often examined individually, populations in California are increasingly exposed to multiple climate stressors at the same place and time. This includes, for example, wildfires or air pollution co-occurring with extreme heat. Exposure to multiple climate stressors may exacerbate certain health conditions and disproportionately affect vulnerable populations, but there is a lack of a comprehensive evaluation of these effects. The overarching objective of this project is to understand the joint effect of multiple climate-related stressors and the heterogeneity across potentially vulnerable communities in different regions of California. In this project, the Contractor will produce a literature review of the individual and combined impact of multiple climate stressors on health outcomes with a focus in the United States (U.S.) and California. The Contractor (University of California, Los Angeles [UCLA]) will map regional variations in climate stressor exposure across California over the past fifteen years, with a particular focus on heat, air pollution, wildfires, and precipitation extremes, while also exploring the modulating effect of droughts. These exposures will be linked to multiple health outcomes to quantify health impacts and associated costs across the life course of different populations. The Contractor will also evaluate how social determinants of health and long-term patterns of climate stressors modify the health risks analyzed. This work will support the California Air Resources Board (CARB) in quantifying comprehensive health co-benefits potentially associated with actions to reduce California's greenhouse gas emissions and identify pathways to protect vulnerable populations throughout the State.

Statement of Significance

The frequency and intensity of climate hazard exposures in California have increased over the past several decades, a trend that is expected to continue under future climate change scenarios. Multiple climate-related stressors, also referred to as compound climate events, consider exposure to two or more co-occurring climate hazards at the same place and time (Zscheischler *et al* 2020). Understanding the potential joint effect of multiple climate-related stressors and the heterogeneity across potentially vulnerable communities is increasingly important to protect public health.

Over the course of this project, the Contractor will address the following objectives:

- Evaluate acute and chronic exposures to individual and multiple climate stressors in different regions of California, focusing on exposures to wildfires, air pollution (from wildfires and other sources), extreme heat, and precipitation extremes (stratified by drought conditions).

- Assess the total and interactive health outcomes and economic burden associated with individual and multiple climate stressor exposures in different regions of California.

- Consider the modification of health outcomes associated with individual and multiple climate stressors exposures by environmental justice metrics, racial equity, and/or social vulnerability metrics.

CARB's 2022 Climate Change Scoping Plan outlines the pathway for California to achieve carbon neutrality by 2045 or earlier, along with an assessment of potential health co-benefits (CARB 2022b). The results from this project will be beneficial to CARB in several ways. First, the Contractor will quantify the comprehensive health and economic co-benefits that could potentially accrue from actions to reduce greenhouse gas emissions, including the synergistic effects among multiple climate stressor exposures. Health outcomes associated with climate exposures will not be distributed equally. The full extent of these benefits will depend on the spatial and temporal patterns in future climate-related exposures as well as variation among community members with respect to closer proximity to additional environmental exposures, underlying vulnerabilities, and adaptive capacity (CARB 2022a, Carleton *et al* 2022). The Contractor will analyze health data at the ZIP code level, but statistical power may be an issue for some relationships, and will necessitate larger spatial scales like counties whenever it is necessary.

Second, the Contractor will deliver to CARB a statewide geospatial database of exposures, health outcomes, and vulnerability indicators at the ZIP code scale for the past fifteen years, with regional summaries by climate zone and air basin. This will complement existing statewide tools, such as the Climate Change & Health Vulnerability Indicators for California (CCHVIs), CalEnviroScreen, and the Climate Vulnerability Metric (CVM) (CDPH 2023, Carleton *et al* 2022, August *et al* 2021) by providing a comprehensive mapping of individual and co-occurring climate stressors exposures at acute and chronic scales that accounts for regional variability in exposures and outcomes.

Third, the Contractor will identify pathways to protect vulnerable populations in the State from adverse effects of climate change. Taken together, the results from this project will support CARB's ability to estimate and monetize health outcomes associated with climate change policies, and to communicate the risks and benefits of CARB's climate programs (CARB 2021).

Introduction

Populations in California are exposed to multiple climate-related stressors, such as wildfires, heat, air pollution, and extreme precipitation (Rosenthal *et al* 2022, Kalashnikov *et al* 2022). When these exposures overlap in space and time, there is potential for synergistic effects that could exacerbate exposures and adversely affect health (Anenberg *et al* 2020, Schwarz *et al* 2021, Rahman *et al* 2022). Further, individual communities across California may respond differently to the same climate exposure based on the burden of additional environmental

exposures, community characteristics, or both (CARB 2022a, Carleton *et al* 2022). Existing statewide tools like the CVM (Carleton *et al* 2022) and CalEnviroScreen (August *et al* 2021), for example, show regional disparities in exposures, population vulnerabilities, or outcomes. Recent research, including by the Contractor (Rosenthal *et al* 2022), has identified regional variability in recent exposure patterns to combined climate stressors, but a long-term inventory of the implications for health and equity is lacking.

To quantify health co-benefits associated with California's pathway to achieve carbon neutrality by 2045 or earlier (CARB 2022b), it is critical to move beyond individual and often static health assessments of climate stressors towards a comprehensive mapping of multiple, interacting climate exposures on health impacts in different regions of California. The multidisciplinary team of investigators at UCLA and University of California, San Diego (UCSD) will leverage expertise with climate exposure assessments and climate epidemiology to complete the project. The Contractor will address the following research questions: (Task 1) What is the current state of knowledge and research needs with respect to the individual and combined influence of climate stressors on population health in California? (Task 2) What is the burden of multiple climate stressors in different locations in California over the past fifteen years? (Task 3) What are the region-specific health and economic impacts of combined climate stressors over this period, and (Task 4) How do community characteristics modify climate-health impacts?

Project Tasks

Task 1: Assess Current Knowledge and Identify Research Needs in Climate-Health Studies.

Populations in California are increasingly exposed to climate-related stressors (Bedsworth *et al* 2018). Although often examined individually, these exposures also include multiple, overlapping stressors that co-occur in space or time (AghaKouchak *et al* 2020, Zscheischler *et al* 2020). Recent research in California and the western U.S. has examined the distribution of co-occurring climate-related hazards such as wildfires, air pollution, extreme heat, and drought (Rosenthal *et al* 2022, Kalashnikov *et al* 2022). Gaps remain in understanding the cumulative health burden and how this varies regionally and across community characteristics. Current evidence supports the potential synergistic effects of extreme heat and air pollution co-exposures on adverse health outcomes (Anenberg *et al* 2020, Rahman *et al* 2022, Schwarz *et al* 2021), including wildfire-specific pollution (Shaposhnikov *et al* 2014, Austin *et al* 2020). Less is understood, however, regarding the interactions among other climate-related hazards such as drought or other precipitation regimes and which populations are most vulnerable. The objective of this task is to review the current literature and identify research needs in climate-health studies, with a particular focus on studies conducted in California, the western U.S., or similar climate zones. Results from the literature review will be used in subsequent tasks to: (1) characterize dominant climate stressor exposures in different regions of California in Task 2, (2) identify the most important health outcomes to be included in Task 3, and (3) examine community vulnerability characteristics that could modify the health and economic outcomes in Task 4.

Task 1.1: Develop Search Criteria for Literature Review of Climate-Health Studies.

The Contractor will conduct a two-stage literature review. A preliminary scoping review will identify climate stressors in California and the extent of available research evidence to inform a subsequent systematic review. In the second stage, the Contractor will follow Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page *et al* 2021). The Contractor will search for articles in online databases, such as PubMed, Elsevier, and Web of Science after selecting keywords, in consultation with a UCLA data librarian. Preliminary inclusion criteria include scientific studies published within the last ten years, in a peer-reviewed journal, written in English, and considering climate-health impacts in any age group, gender, or population sub-group.

In summary, the planned search criteria for the literature review is as follows:

1. Databases

    a. PubMed,
    b. Elsevier,
    c. Web of Science,
    d. Embase,
    e. PsycInfo, and
    f. 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,
    d. Population, and
        i. All age groups
        ii. All genders
        iii. Domestic populations or similar climate zones
        iv. Any population subgroup
    e. Climate exposures include air pollution, wildfire, heat, and/or precipitation extremes.

Task 1.2: Identify Dominant Climate Stressors in California.

The literature review will include health outcomes associated with individual and combined exposures. The preliminary list of climate stressors includes heat, wildfire, air pollution, and precipitation extremes (drought and intense precipitation). Exposure studies must include California in the study region; population health studies may also consider populations in other domestic locations or similar climate zones. The Contractor will prioritize direct, quantifiable impacts of climate exposures on health to identify dominant stressors, but will also include qualitative studies to inform additional research needs and potential sources of bias in existing research. The review will assess considerations of population vulnerability and adaptive capacity (resilience) for Tasks 2-4.

Task 1.3: Categorize Climate Stressors in Key Focus Regions in California.

The Contractor will summarize the literature review results according to nine regional climate zones and 15 air basins (Figure 1). For each regional climate zone and air basin, the Contractor will provide the number and type of climate stressor exposures, definitions or thresholds of extreme exposures used in previous studies, the nature of overlap among climate stressors (i.e., whether the overlap occurs at acute or chronic scales), health outcomes, and strength of evidence.

Task 1. Deliverables.

The Contractor will provide CARB with an Endnote database and summary table that includes article information, study design, location, community characteristics, climate stressor(s), health outcomes, results, strengths, and/or limitations. A description of the literature review and discussion of research gaps will be included in a publication in a peer-reviewed open access journal.

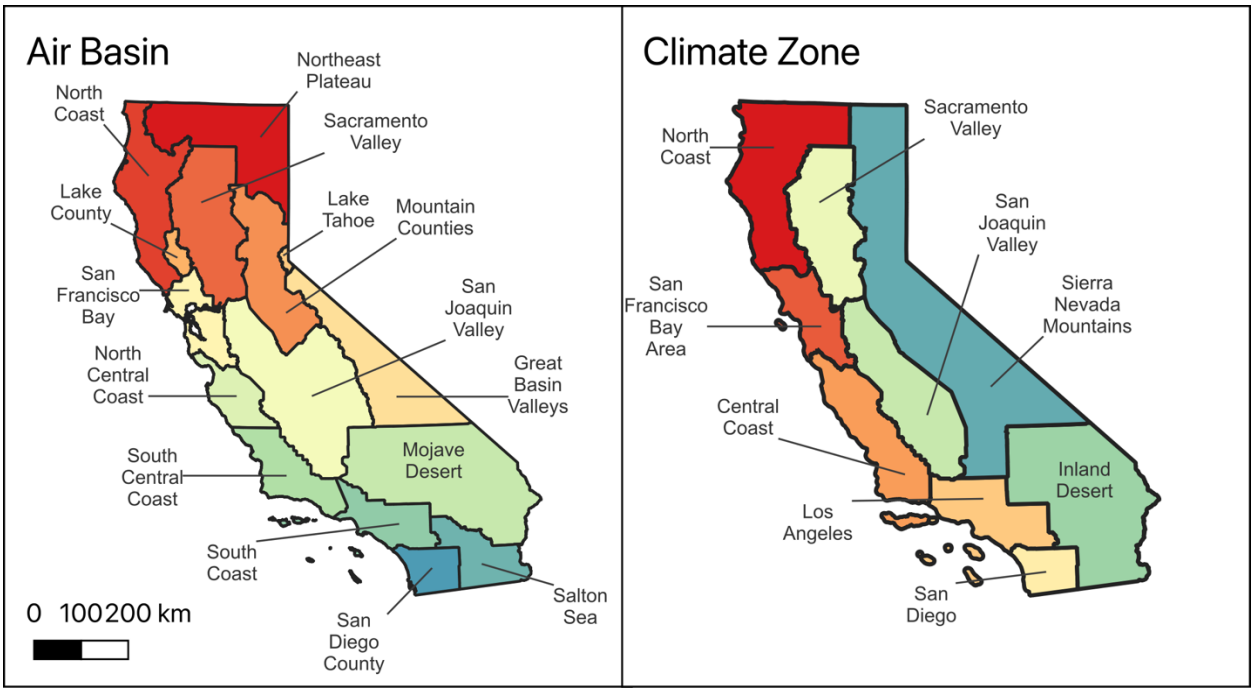

Figure 1. CARB air basin and regional climate zone from California's Fourth Climate Assessment (CARB 2004, California Natural Resources Agency 2022).

There are a few limitations in Task 1. First, the Contractor will focus on direct health impacts from multiple climate stressor exposures, although there are likely additional health impacts due indirect climate exposures (e.g., changes in water quality or vector-borne disease). These exposures could be significant, but are not included due to differences in the timing of acute exposures for direct and indirect exposures and data availability. Time permitting, the Contractor will discuss these indirect effects in the literature review. Second, certain regions in California, types of direct climate stressor pathways, and/or health impacts may be underrepresented in the published literature.

Task 2: Assess Combined Climate Stressor Exposure.

Californians are exposed to a range of climate stressors, including extreme heat, wildfires, air pollution, and extreme precipitation (Bedsworth *et al* 2018). These exposures vary across several different dimensions, including regional differences in the intensity and timing of the dominant climate stressors, combinations of co-exposure patterns, and underlying population characteristics. Several exposure and vulnerability screening tools are available for California (or broader regions), including: (1) CalEnviroScreen, which maps communities disproportionately affected by various environmental hazards at the census tract level (August *et al* 2021), (2) the CVM, which quantifies the economic impact of climate change at the community scale under future climate change scenarios (Carleton *et al* 2022), (3) the CCHVIs, which identifies exposure, sensitivity, and adaptive capacity to climate-related exposures at the county or census tract level (CDPH 2023), and (4) vulnerability assessments for specific climate-related exposures, such as the Community Health-Vulnerability Index (CHVI) for wildfire smoke (Rappold *et al* 2017). These tools provide critical insights into exposure, vulnerability, and impacts of climate-related exposures, but we currently lack a comprehensive map of individual and interacting climate-related hazards at high spatial and temporal resolutions across the State. The objective of this task is to map regional variations in exposure to individual and combined climate stressors across different community characteristics at acute and chronic scales.

Task 2.1: Develop Individual Climate Exposure Indices for California.

The Contractor has already produced or analyzed daily climate datasets for fifteen years (~2006-2020) in California using ground monitors, satellite observations, and atmospheric models, including dataset validation (Aguilera *et al* 2023, Rosenthal *et al* 2022, Wilkins *et al* 2018). For each climate stressor (surface air pollution concentrations, extreme heat, precipitation extremes, and meteorological extremes), described below, the Contractor will map individual exposures at the census tract and ZIP code level using three indicators: (1) *frequency*: number of daily or multi-day exceedances over varying thresholds such as 95th or 99th percentile (to be informed by the literature review in Task 1), (2) *duration*: length of consecutive daily exceedances, and (3) *intensity*: magnitude of exceedances over daily and annual thresholds. For each stressor, the Contractor will first rank census tracts and ZIP codes by quintile from one (low) to five (high) across the state for each indicator and then sum to compute an individual climate exposure index. The individual climate exposure index will be estimated at daily (acute) and annual (chronic) scales and summarized for each year, either from 2006-2020 or 2008-2018, depending on the availability of individual datasets. The input datasets of the climate stressors are available at different spatial resolutions (two-kilometers [km], four-km, 12-km, or ZIP code). In the calculation of each individual climate exposure index, each dataset will be spatially averaged to the census tract, as well as the ZIP code scale (to facilitate comparison with the health outcome datasets described in Task 3).

- Surface air pollution concentrations: The Contractor will include all-source (industry, transportation, wildfires, dust, etc.) and smoke-specific (fires only) daily fine particulate matter ($PM_{2.5}$) and ozone (O_3), from statistical approaches (ZIP code scale; 2006-2020) and atmospheric chemical transport models (12-km scale; 2008-2018). Both datasets have already been produced and/or analyzed in the Contractor's previous work (Wilkins *et al* 2018, Aguilera *et al* 2023). The Contractor will use the two air pollution datasets (statistical or modeling-based approach) for all-source and wildfire-specific $PM_{2.5}$ as a measure of uncertainty in the air pollution exposure estimates. The all-source and wildfire-specific O_3 estimates are available from the modeling dataset only. Time-permitting, the Contractor will

also include ~one-km spatial resolution satellite-derived nitrogen dioxide (NO_2) as an additional air pollution exposure (Cooper *et al* 2022).

- Extreme heat: The Contractor has previously calculated statewide daily extreme heat metrics, based on temperature and relative humidity, at four-km spatial resolution from the GridMET blended monitoring and reanalysis surface meteorology product (Rosenthal *et al* 2022, Abatzoglou 2011). The Contractor will calculate extreme heat metrics from 2006-2020 to match the temporal availability of air pollution data. As in this prior work, the definition of extreme heat will be calculated separately for each four-km grid cell to capture location-specific differences in behavioral or physical adaptations to heat. For example, previous work by the Contractor defined extreme heat exceedance as days exceeding the 85th percentile of historic July and August heat index values, with absolute minimum and maximum cutoffs (Rosenthal *et al* 2022). As a result, areas of the state (e.g., the coast) that experience milder temperatures will have a lower extreme heat threshold than areas (e.g., the desert) that experience warmer temperatures. Time permitting, the Contractor will explore alternative definitions of extreme heat, such as the National Weather Service HeatRisk approach, which defines extreme heat as the warmest five percent of temperatures for a given date and location based on maximum and minimum daily temperatures.

- Precipitation extremes: The Contractor will produce a statewide record of relative dryness based on the Palmer Drought Severity Index (or comparable index) and intense precipitation, using four-km statewide estimates derived from GridMET for 2006-2020 (Abatzoglou 2011).

- Meteorological extremes. Additional meteorological conditions may modify exposures and health outcomes (Cayan *et al* 2022). The Contractor will develop indices of Santa Ana and Diablo winds for Southern and Northern California, respectively, based on the new high-resolution (2-km) downscaling of a global (ERA-5) reanalysis (Guzman-Morales *et al* 2016).

Task 2.2: Develop Cumulative Exposure Indices to Characterize Interactions Among Multiple Climate Stressors.

Cumulative exposures at the annual scale will be calculated by summing individual exposure rankings described in Task 2.1. The Contractor will also capture acute (daily) climate exposures that occur at the same place and time (instead of in the same location, but at different times in the year). This will follow an approach recently developed in the Contractor's previous work to characterize overlapping smoke and extreme heat exposures at the daily scale (Rosenthal *et al* 2022). The Contractor will adapt this framework for all exposures listed in Task 2.1 to compute a combined climate exposure index.

First, the Contractor will calculate joint exposures for each combination of two or more stressors according to three indicators, as before. For example, for heat and air pollution: (1) *frequency*: number of days when both heat and air pollution exceed varying thresholds, (2) *duration*: length of combined exceedance events, and (3) *intensity*: relative magnitude of heat and air pollution over baseline during exceedance events. For each combination of climate stressors, the Contractor will rank each of the three indicators from one to five across the state at the census tract and ZIP code level and then sum to compute a combined climate exposure index. When merged with results from Task 2.1, the Contractor will have ranked exposures to individual and different combinations of multiple climate stressors for all census tracts and ZIP codes across California. This will include:

1. Individual (daily and annual)

    a. Heat
    b. Wildfire smoke
    c. Ambient air pollution
    d. Drought
    e. Extreme precipitation

2. Combined (daily and annual)

    a. Heat + ambient air pollution
    b. Heat + wildfire smoke
    c. Heat + all air pollution (ambient + wildfire smoke pollution)

The individual drought and extreme precipitation exposure indices will be used to stratify results from other combined exposures in subsequent tasks.

Task 2.3: Examine Differences in Exposure Across Community Characteristics.

Using publicly available data from CalEnviroScreen (August *et al* 2021), Healthy Places Index (Delaney *et al* 2018), and census data from the American Community Survey (U.S. Census Bureau 2023), the Contractor will map the climate exposure indices to community characteristics, such as the proportion of racial/ethnic subgroups, or the cumulative CalEnviroScreen score, which incorporates sensitive populations, socioeconomic factors, and the burden of other environmental exposures. The community characteristics datasets are not typically available annually, but rather are representative of multi-year averages. The Contractor will use the most recent datasets available from CalEnviroScreen, Healthy Places Index, and American Community Survey. The Contractor will also map multiple adaptive capacity metrics such as green space, impervious surface coverage, and air conditioning access, as informed by the Task 1 literature review and to the extent that these metrics are available at the needed spatial and temporal resolution. For the individual and cumulative climate exposure indices, the Contractor will calculate the ratio at which different subgroups are affected relative to their share of the general population (Rosenthal *et al* 2022). This information will be viewable in the online database alongside the exposure indices and summarized within climate zones and air basins. Relationships between health outcomes and community characteristics will be analyzed in Task 4.

Task 2. Deliverables.

The index calculations will be conducted with cloud computing resources available through Google Earth Engine (GEE) (Gorelick *et al* 2017). The GEE platform is freely available for academic researchers. In addition to relevant climate exposure datasets that are already hosted in the GEE platform, researchers can upload their own datasets for analysis. As with past work by PI Marlier (Marlier *et al* 2019) that used GEE to conduct analyses and share results online, the Contractor will provide CARB with a link to the online geospatial GEE database of climate exposures and derived indices across all census tracts and ZIP codes in California. Datasets can then be analyzed directly in GEE or downloaded (Geotiff or comma-separated values format (CSV)). The Contractor will also produce summary tables to identify regional patterns, by air basin and climate zone for dominant individual and multiple climate stressors, according to

community characteristics. The Contractor will publish results from Task 2 in a peer-reviewed open access journal.

There are a few limitations in Task 2. First, different definitions of extreme thresholds of individual climate stressors could alter the exposure distribution, which the Contractor will test through multiple extreme threshold definitions in sensitivity analyses. Second, the exposure datasets are available at different spatial resolutions and may not be able to resolve exposure gradients in some urban settings or with strong topographical variation. Third, some community characteristics, such as air conditioning prevalence, may capture the availability, but not the actual usage, by communities due to resource constraints. The Contractor will use the literature review results from Task 1 to consider alternative supplemental datasets, such as household energy expenditures to infer potential air conditioning use (Carleton *et al* 2022).

Task 3: Estimate Health Impacts of Combined Climate Stressors and Associated Economic Burdens.

Aside from increases in co-occurrence, acute exposure to climate-related stressors might act synergistically to further aggravate health effects due to their similar physiological impacts on human health. Recent research in California found synergistic effects on adverse health outcomes from acute exposure to concurrent climate-related stressors, such as extreme heat and O_3 (Schwarz *et al* 2021), extreme heat and $PM_{2.5}$ (Rahman *et al* 2022), and extreme heat and wildfire smoke (Chen *et al* 2023). Gaps remain in understanding compound exposures to other pairs of climate-related stressors (e.g., drought and extreme heat) or multiple (>two) exposures to combined climate stressors (including definitions requiring more than two consecutive days of exposure to the climate stressors). The literature review in Task 1 will further provide the Contractor with insights on important health endpoints and timings for lag effects. The objective of this task focuses on estimating acute health impacts of climate stressors (health impacts from exposure days to weeks before) and will evaluate effect modification by long-term patterns of climate stressors coupled with heterogeneity tests. Specifically, the Contractor will (1) evaluate the interactions of other important climate-related stressors identified in Task 1 to estimate spatially varying (at the ZIP-code level) synergistic effects between pairs of climate stressors while considering lagged effects; (2) estimate state-level and region-level joint and synergistic effects between pairs of stressors while considering lagged effects; (3) estimate the total health impacts from multiple (>two) climate stressors using the combined climate exposure indices developed in Task 2; and (4) evaluate the previous three sets of estimates across the life course of different populations and stratified by long-term patterns of climate stressors.

Task 3.1: Obtain Datasets for Health Outcomes and Covariates in California Population Across the Life Course.

The Contractor have access to two main health outcome datasets covering the California population from birth outcomes to aging outcomes:

(1) An administrative birth cohort of all births and fetal deaths in California linked to hospital discharge summaries, covering one year before birth (mother) and one year after birth (mother and child) from 2005 to 2021 (Study of Outcomes in Mothers and Infants: SOMI) (Bandoli *et al* 2021). The Contractor will focus on two sets of outcomes: i) birth outcomes including preterm birth and small for gestational age and ii) unscheduled hospital admissions and emergency departments visits (referred to as unscheduled hospital visits for the rest of this document) for

children under the age of 1 stratified by preterm status. The Contractor will also obtain gender and race/ethnicity information for the health outcomes for further analysis in Task 4.

(2) Age and cause-specific unscheduled hospitalization and emergency department visit (referred to as unscheduled hospital visit for the rest of this document) data for all visits in California from the Patient Discharge Data and the Emergency Department Data collected by the California Department of Health Care Access and Information from 2006 to 2019 (HCAI 2023). The Contractor will focus on unscheduled hospital visits for various International Classification of Diseases (ICD) codes. The following primary diagnoses will be evaluated, as listed in the International Classification of Disease codes, 9th Revision, Clinical Modification (ICD-9): acute myocardial infarction (MI) (410), acute renal failure (584), cardiac dysrhythmias (427), cardiovascular diseases (CVDs) (390–459), dehydration/volume depletion (276.5), essential hypertension (401), heat illness (992), ischemic heart disease (410–414), ischemic stroke (433–436), all respiratory diseases (460–519). Furthermore, the Contractor will focus on unscheduled hospital visits related to mental health issues. Specifically, the Contractor will use unscheduled hospital visits of ICD-9 and ICD-10 codes for climate-related mental health endpoints identified in task 1, such as self-inflicted injury, suicide, intentionally inflicted injury, anxiety, mood disorder, eating disorder, and homicide. The Contractor will also obtain gender and race/ethnicity information for the health outcomes for further analysis in Task 4.

Furthermore, as exploratory analyses, the Contractor will use daily non-accidental mortality for similar ICD codes as for unscheduled hospital visit as an outcome of interest stratified by age groups, race/ethnicity, and gender. Data will be obtained from the California Department of Health Services, Health Data and Statistics Branch for the 2006-2019 period.

Task 3.2: Estimate Region-Specific Health Impacts of Combined Climate Stressors in California.

The Contractor will estimate three sets of health impact estimates for dominant climate stressors identified in Task 1 for all combinations of health endpoint and population: birth outcomes in the birth cohort, unscheduled all-cause hospital visit in the birth cohort, and unscheduled cardiovascular hospital visit, respiratory hospital visit, heat-related hospital visit, and hospital visit related to mental health issues in the general population (VanderWeele and Knol 2014). Below includes the detailed methods for estimating the three sets of health impacts: the spatially-varying (at the ZIP-code level) synergistic effects between two climate stressors, the state and region-specific (stratifying by climate zones and air basins) joint and synergistic effects between two climate stressors, and state and region-specific (at the climate zone level) total health impacts of multiple (>two) climate stressors. The first and second sets of estimates will provide the Contractor the opportunity to further explore etiological mechanisms and interactions among the climate stressors and spatial heterogeneity, while the third set of estimates will provide the total effect of all dominant climate stressors.

Since interaction at additive scale is the more relevant public health measure, first, the Contractor will quantify the synergistic effect at additive scale using the relative excess risk due to interaction (RERI; see Equation 1) in the first and second set of estimates, which quantifies the relative difference between the joint effect of two co-occurring hazards and the sum of individual effects of the two hazards. As a sensitivity analysis, the Contractor will quantify the interaction at multiplicative scale using the ratio of odd ratio for the second set of estimates.

1. *The spatially-varying (at the ZIP-code level) synergistic effects between two climate stressors (multiple pairs if more than two dominant stressors were identified in Task 1):*

The Contractor will modify and apply the existing method developed by the Contractor to incorporate consideration of lagged effects (Chen *et al* 2023, Schwarz *et al* 2021). Specifically, the Contractor will estimate at the ZIP-code level spatially-varying joint and synergistic effects using the modified within community matched design coupled with spatial Bayesian hierarchical model. In the within community matched design, the Contractor will first categorize ZIP-code days into unexposed days and three types of exposed days: exposed to stressor one alone, exposed to stressor two alone, and exposed to both stressors.

Second, the Contractor will identify matched control days for each exposed day as unexposed days in the same ZIP-code, within 30 days before and after the exposed day, and at least three days away from any exposed day.

Third, the Contractor will calculate the rate ratio for each exposed days as the event counts in the exposed day divided by weighted average of event counts in matched control days, with weight equal to the inverse distance from the control day to the exposed day. The ZIP-code specific rate ratio for each type of exposed day is equal to the average rate ratios of all exposed day for the type in each ZIP-code.

Fourth, the Contractor will calculate the RERI for each ZIP-code following Equation 1, where RR stands for rate ratio. Since areas closer together are more likely to experience similar synergistic effect (spatial autocorrelation), the Contractor will apply the spatial Bayesian hierarchical model to improve precision of the ZIP-code level RERIs and obtain the post-pooling ZIP-code level RERIs and confidence intervals. Based on knowledge from Task 1, the Contractor will also redefine the criteria for exposure and control in the within-community matched design to allow lagged effect estimations for spatially varying joint and synergistic effects and multiple sensitivity analyses will be conducted.

$$RERI = RR_{both} - RR_{stressor\ one\ alone} - RR_{stressor\ two\ alone} + 1 \qquad \text{Equation 1}$$

2. *The state and region-specific (stratifying by climate zones and air basins) joint (i.e., total effect of both stressors) and synergistic effects between two climate stressors*:

   The Contractor will use the case-crossover design to calculate the state and region-specific synergistic and joint effects by including an interaction term between the two climate stressors in the conditional logistic regression model using data from the corresponding region. The joint effect is the exponentiated sum of three coefficients for the exposure terms while the synergistic effect will be summarized using RERI and calculated based on Equation 1, where RR will be replaced by corresponding odds ratio. Confidence intervals will be estimated using the delta method. The Contractor will also incorporate consideration of lagged effects by including exposures of different lags separately (effect of individual lags) and by including multiple lagged exposures simultaneously while restricting the effect to follow the natural cubic spline function across the lags. The number of lags and degree of freedom for the natural cubic spline function will vary depending on the literature review from Task 1. As a sensitivity analysis, the Contractor will also estimate the interaction at multiplicative scale as the coefficient for the interaction term between the two climate stressors in the conditional logistic regression model.

3. *The state and region-specific (at the climate zone level) total health impacts of multiple (>two) climate stressors*:

The Contractor will utilize the combined climate exposure indices from Task 2 and case-crossover design to capture the total health impacts from multiple climate stressors. Besides, the Contractor will also adapt and apply existing state-of-the-art mixtures methods [including quantile g-computation (Keil *et al* 2020), weighted quantile sum regressions (Carrico *et al* 2015) and Bayesian Kernel Machine Regression (Bobb *et al* 2015) to estimate the joint health impacts of multiple climate stressors as well as their individual contributions to the change in health risks. In these mixture method analyses, the Contractor will use individual climate stressors instead of the climate exposure indices from Task 2. Depending on computational time and distribution of the climate stressors, the Contractor might choose to apply only one of the mixture methods (quantile g-computation, weighted quantile sum regression, and Bayesian Kernel Machine Regression).

Task 3.3: Monetize the Health Impacts of Combined Climate Stressors.

Based on the previous work of the Contractor on excess health burden (Moreno *et al* 2022) and validated economic cost estimates for the U.S. context (Wei *et al* 2019), the Contractor will use health and economic impact assessments to obtain the number of unscheduled hospital visits attributable to climate stressors and the associated economic burden. As shown in Equation 2, B_i represents the number of unscheduled hospital visit attributable to climate stressor or the associated burden of unscheduled hospital visit cost in region *i*; *C* is 1 if estimating the attributable number of unscheduled hospital visit and represents the average cost of care for one unscheduled hospital visit in region *i* if estimating the burden of unscheduled hospital visit cost; d_i represents the number of days during the period when health impacts were estimated; n_i represents the average daily number of unscheduled hospital visit in region *I* among days without the climate stressors (i.e., unexposed) during the period when health impacts were estimated; β_i represents the coefficient associated with the combined climate stressors, as estimated in Task 3.2.

$$B_i = C \times d_i \times n_i \times (1 - e^{\beta_i}) \qquad \text{Equation 2}$$

Task 3.4: Evaluate How Long-Term Patterns of Climate Stressors, including Droughts, Might Modify the Region-Specific Health Impacts.

Some long-term patterns of climate stressors (e.g., annual patterns of drought and precipitation regimes identified in Task 2) also affect human health and climate-sensitive exposure profiles via modifying the health impacts of acute exposure to other climate stressors like extreme heat and wildfire. The Contractor will evaluate how these long-term patterns, including seasonal effects, might modify climate-heath inequity by stratifying all analyses in Tasks 3.2 and 3.3 by drought and precipitation regime characteristics and evaluating potential heterogeneity in effect estimates (similar to the method described in Task 4.1).

There are a few limitations in Task 3. First, although the Contractor plans to evaluate multiple health endpoints, the Contractor could not evaluate all potential adverse health outcomes related to the compound climate hazards due to the limitation of data access. Similarly, the Contractor could only estimate the economic burden related to unscheduled hospital visit cost, while the total economic burden of compound climate hazards includes many aspects not considered (e.g., loss of productivity). Second, the Contractor plans to focus on acute effects of climate hazards while such hazards could have long-term impacts. Third, the Contractor could not rule out the possibility of residual confounding because the Contractor are studying a set of relatively new hazards and their synergistic effects and previous evidence is limited.

Task 3. Deliverables.

The Contractor will provide maps of ZIP-code specific synergistic effects between pairs of dominant climate stressors, with an example shown in Figure 2. The Contractor will also provide CARB with maps and tables that summarize at the state, air basin, and climate zone levels, total health and economic impacts for multiple health endpoints of the dominant climate stressors, stratified by long-term patterns of climate stressors. Region-specific health and economic impacts will be available in the GEE database for analysis and download. Results will be published in a peer-reviewed open access journal. The analytic code will be made available through GitHub. To facility access to above results, the Contractor will also publish an online platform via R shiny, which will provide intuitive visualization and easy data access to planners and government agencies (see for example this platform the Contractor created to visualize the results from a paper comparing various heat waves definitions for each zip code across all counties in California: https://kristenhansen.shinyapps.io/HeatCA/).

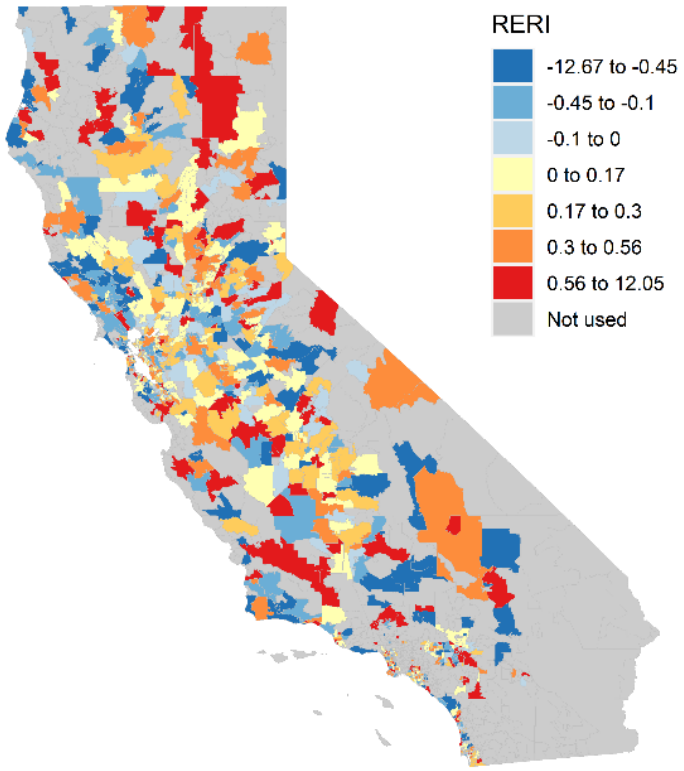

Figure 2. Spatial distribution of ZIP code-level pooled additive synergistic effect of wildfire smoke and extreme heat summarized (RERI) estimated using monthly weighting method under the main definition for climate hazards. A positive RERI value indicates an increase in risk of cardiorespiratory unscheduled hospital visits due to interaction between the two hazards. Strong spatial heterogeneity in ZIP code-specific RERIs is observed, with positive synergistic effects in the northern mountain, central valley, and large coastal metropolitan areas, such as Los Angeles and the Bay Area, and antagonistic effects in the northern coast. Adopted from Chen et al. (2023).

Task 4: Investigate Social Determinants of Climate-Health Equity.

Community factors, as well as individual-level characteristics could modulate the synergistic effect of co-occurring climate-related stressors. This task will explore what individual-level (see Task 4.1) and community-level (see Task 4.2) characteristics are important effect modifiers for the synergistic effects estimated in Task 3.

Task 4.1: Explore How Individual Characteristics Modify Climate-Health Relationships at Region and State Level.

The Contractor will use stratified analysis and Wald test to evaluate whether the effects are homogeneous across individual characteristics (e.g., age group, gender and race/ethnicity) (Kaufman and MacLehose 2013). The Contractor will stratify the state-level and region-level analyses (the second and third set of analyses described in Task 3.2) by age groups (i.e., early

life pediatric population and the general population from adolescence to late aging) and compare the effect estimates across age groups. Similarly, the Contractor will evaluate effect modification by gender and race/ethnicity via stratification and test for homogeneity across the strata. These analyses will allow the Contractor to explore the impacts of combined climate stressors on the diverse populations across California for different health endpoints across the life course of different populations. Due to limitations in statistical power, the Contractor will not conduct stratified analysis for ZIP code specific estimates.

Task 4.2: Identify Social Determinants of Climate-Health Relationships and Evaluate How they Might Modify Region-Specific Health Impacts.

The Contractor will utilize publicly available data on community characteristics obtained in Task 2.3 to quantify how community characteristics (e.g., per capita income and the proportion of race/ethnicity groups from the Healthy Places Index) contribute to the potential heterogeneity in ZIP code-specific health impact estimates obtained in Task 3.2 (the first set of estimates). The Contractor will conduct a meta-regression as done in previous work (Schwarz *et al* 2021). Specifically, for each community characteristic, the Contractor will run a random effect model using post-pooling ZIP code-specific RERI as the response variable and the community characteristics as the independent variable. The corresponding coefficient in this model will quantify how does the synergistic effect vary across the level of the community characteristics.

Task 4. Deliverables.

The Contractor will provide CARB with figures and tables that (1) summarize sub-population (i.e., age group and race/ethnicity) specific health impacts from combined climate stressors; and (2) identify populations vulnerable to combined climate stressors based on region-specific health impacts based on community-level characteristics. The Contractor will also publish an online platform via R shiny for visualization and data access purposes. Results will be published in a peer-reviewed open access journal. The analytic code will be made available through GitHub.

There are a few limitations in Task 4. First, due to the limitation in statistical power, the Contractor can only evaluate effect modification by individual characteristics in relatively big spatial areas (e.g, state-level). Second, the Contractor could not disentangle underlying causes of the disparity observed across community characteristics. For example, if the Contractor observed higher synergistic effects in communities with higher percentage of racial/ethnical minority residents, it is unclear whether it is caused by the lack of capacity to self-protection, the lack of awareness of the hazards, or a higher prevalence of existing health conditions, which makes it hard to provide direct suggestions on specific interventions.

Task 5: Project Reporting, Trainings, Outreach, and Other Deliverables.

5.1. UCLA will meet with CARB staff quarterly and submit quarterly progress reports using the CARB-designated template, and in invoice for the same period will accompany each progress report.

5.2. Six months prior to the end of the study, UCLA will submit a draft final report (DFR), which will include the results of the study and the additional deliverables identified in Exhibit A1, Schedule of Deliverables. The DFR will be submitted in accordance with the Final Report format and will be reviewed by CARB staff. CARB's comments will be sent

to UCLA and after receiving the reviewer's comments, UCLA shall modify and resubmit the modified DFR to the CARB Project Manager. The modified DFR will be subject to formal review by the Research Screening Committee (RSC). Once accepted by the RSC, UCLA will revise the modified draft final report addressing the RSC comments and any remaining concerns from CARB staff and will submit the revised final report to CARB. If CARB has additional comments on the report, the UCB will be notified so appropriate changes can be made; otherwise, CARB will accept the revised final report as the final. The UCB will submit the final report in an Americans with Disabilities compliant format. A notation in the Final Report task should denote that the University will incorporate a one-page Public Outreach Document into the Final Report, that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. The format for the Public Outreach Document is outlined in Exhibit A1 Public Outreach, Section 2.

5.3. Trainings. The Contractor will complete or schedule cultural competency training within 30 days of contract execution.

5.4. Public Outreach. At the contract start, the Contractor will develop a 1-page plain-language project summary in consultation with CARB staff. The Contractor will hold a seminar for the general public at the contract close to communicate project results. The Contractor will provide research summaries and fact sheets of the scientific journal articles, in English and Spanish, targeted towards a broad audience and those communities identified as most vulnerable to synergistic climate exposures.

5.5. Publications. The Contractor will submit a minimum of two manuscripts to open-access peer-reviewed journals describing results of the literature review and regional climate exposure assessments (Tasks 1 and 2) and health impacts and equity assessment (Tasks 3 and 4). Manuscripts will be sent to CARB for review before submission to the scientific journals for peer review.

Summary of Input Datasets and Generated Data Products

	Task	Description	Spatial		Temporal		Source/Format
			Range	Data Resolution	Range	Data Resolution	
Input	1	Climate-health studies	California, domestic populations, or similar climate zones	N/A	Publication in last ten years	N/A	Peer-reviewed literature
	2	All-source and wildfire-specific $PM_{2.5}$	California	Zip-code	2006-2020	Daily	Aguilera et al. (2023)
	2	All-source and wildfire-specific $PM_{2.5}$ and O_3	California	12-km	2008-2018	Daily	Wilkins et al. (2018)
	2	Extreme heat	California	4-km	2006-2020	Daily	Abatzoglou (2011)
	2	Drought	California	4-km	2006-2020	Daily	Abatzoglou (2011)
	2	Precipitation	California	4-km	2006-2020	Daily	Abatzoglou (2011)
	2	Santa Ana Winds regional index (SAWRI)	Southern California	Zip-code	2000-2020	Daily	Guzman-Morales et al. (2016)
	2; 4	Community characteristics	California	Varies	Varies	Varies	CalEnviroScreen, American Community Survey, Healthy Places Index (August *et al* 2021, U.S. Census Bureau 2023, Delaney *et al* 2018)
	3	Birth Cohort	California	Individual	2005-2021	Daily	Study of Outcomes in Mothers and Infants (Bandoli *et al* 2021)
	3	Age and cause-specific, unscheduled hospital visits	California	Zip-code	2006-2019	Daily	Patient Discharge Data and Emergency Department Data collected by the California Department of Health Care Access and Information (HCAI 2023)
Output	1	Literature review of climate-health studies	California	Summarized by climate zone and air basin	Varies	Varies	Peer-reviewed literature
	2	Individual and cumulative exposure indices	California	Zip-code, census tract, summarize	Varies (2006-2020 or 2008-2018)	Daily or annual	Google Earth Engine (GEE) database

				d by climate zone and air basin			
	3	Region-specific synergistic and total health and economic impacts for multiple health endpoints of the dominant climate stressors stratified by age group, race/ethnicity and long-term patterns of climate stressors	California	Statewide, climate zone, and air basin	2006-2019	Across the study period	GEE database for analysis and download; online platform via R shiny to visualize and access health outcome data
	3	ZIP code-specific synergistic effects for multiple health endpoints of the dominant climate stressors	California	ZIP-code	2006-2019	Across the study period	GEE database for analysis and download; online platform via R shiny to visualize and access health outcome data
	3	Region-specific total effects for multiple health endpoints of all dominant climate stressors	California	Statewide, climate zone, and air basin	2006-2019	Across the study period	GEE database for analysis and download; online platform via R shiny to visualize and access health outcome data
	4	Associations between community characteristics and synergistic effects for multiple health endpoints of pairs of dominant climate stressors	California	Statewide, climate zone, and air basin	2006-2019	Across the study period	Online platform via R shiny to visualize and access data

Several input datasets and methods have already been assembled or developed by the Contractor and Institutional Review Board (IRB) for Health Care Access and Information (HCAI) and SOMI are already in place. Air pollution concentrations (wildfire-specific and all-source) and extreme heat metrics are available from previous work by the Contractor (Aguilera *et al* 2023, Rosenthal *et al* 2022, Chen *et al* 2023) for integration with Task 2. The Contractor also previously developed and published a framework to track exceedances over multiple climate stressor exposures at acute scales (Rosenthal *et al* 2022), which is being further developed in a grant led by the UCLA Principal Investigator. The approach for the health and equity analysis will be adapted for this project (Schwarz *et al* 2021). Co-PI is co-leading a grant to examine which pre-existing medical conditions, social and environmental characteristics lead to higher susceptibility to extreme heat, including how concurrent environmental extremes occurring jointly with extreme heat events may amplify the health impacts in the elderly across the entire U.S. This grant is relevant to this project as it will be possible to leverage the literature review and methodological developments to address compounded impacts.

Conclusion

This project will quantify health outcomes associated with the dominant individual and interacting climate stressors for different regions (climate zones and air basins) in California. The multi-disciplinary team, co-led by PI Marlier (UCLA) and Co-PI Benmarhnia (UCSD), has a track record of climate-health research collaboration and access to existing datasets to successfully complete the project in 24 months. The Contractor will first complete a literature review to identify key climate stressors in different regions (climate zones and air basins) in California and pathways that affect health through individual and combined exposures. This will guide the inclusion of stressors in the statewide exposure assessment that will leverage existing geospatial climate exposure datasets that the Contractor has already produced or analyzed based on satellites, atmospheric modeling, and ground stations. The Contractor will produce a user-friendly geospatial database of multiple climate stressors and their interactions from 2006-2020 and summarize for different regions (climate zones and air basins). To evaluate the health impact of multiple climate stressors during different life stages and explore potential effect modifiers, the Contractor will utilize multiple health outcome datasets which the Contractor already has access to and expand methods the Contractor previously developed. Since communities in California may respond to multiple climate stressors in different ways, the Contractor will examine exposures and health outcomes according to various population characteristics. The Contractor will produce datasets, open access publications, research briefs and seminars to quantify and communicate the benefits of CARB's climate programs. The datasets and analysis produced by this study will help CARB to estimate and monetize health co-benefits associated with strategies to reduce greenhouse gas emissions, especially in vulnerable communities.

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Data Management Plan

Data Collection.

The Contractor will use open access climate exposure datasets to quantify individual and combined climate stressor exposures for the State. The wildfire smoke pollution ($PM_{2.5}$ and O_3) are available from the Contractor's recent projects (Aguilera *et al* 2023, Wilkins *et al* 2018). Population-level characteristics are publicly available through CalEnviroScreen, the California Healthy Places Index, and the American Community Survey (August *et al* 2021, Delaney *et al* 2018, U.S. Census Bureau 2023). The Contractor already has access to both the administrative birth cohort and cause-specific unscheduled hospitalization and emergency department visit data.

Computational Approach.

The Contractor will leverage cloud computing resources available through GEE for academic researchers (Gorelick *et al* 2017). This will enable processing of large geospatial climate datasets for computation of the single and combined climate exposure indices. This data will be provided to CARB through a link to the GEE repository for navigation or download (in CSV or Geotiff format). The health analysis will be conducted in an encrypted computer server housed in University of California San Diego. All IRB have been already obtained.

Statistical Methods and Quality Assurance.

The Contractor will modify and apply previously developed analytical frameworks for compound exposures (case-crossover analysis, within community matched design with spatial Bayesian hierarchical model) and exiting mixture methods that team members applied in previous studies (Sun *et al* 2022, Letellier *et al* 2022, Bista *et al* 2023).

Project Schedule

	QUARTER							
TASK	1	2	3	4	5	6	7	8
1: Assess Current Knowledge and Identify Research Needs in Climate-Health Studies.								
1.1: Develop search criteria for literature review of climate-health studies.								
1.2: Identify dominant climate stressors in California.								
1.3: Categorize climate stressors in key focus regions in California.								
2: Assess Combined Climate Stressor Exposure.								
2.1: Develop individual climate exposure indices for California.								
2.2: Develop cumulative exposure indices to characterize interactions among multiple climate stressors.								
2.3: Examine differences in exposure across community characteristics.								
3: Estimate Health Impacts of Combined Climate Stressors and Associated Economic Burdens.								
3.1: Obtain datasets for health outcomes and covariates in California population across the life course.								
3.2: Estimate health impacts of combined climate stressors in California.								
3.3: Monetize the health impacts of combined climate stressors.								
3.4: Evaluate how long-term patterns of climate stressors, including droughts, might modify the region-specific health impacts								
4: Investigate Social Determinants of Climate-Health Equity.								
4.1: Explore how individual characteristics modify climate-health relationships.								
4.2: Identify social determinants of climate-health relationships and evaluate how they might modify region-specific health impacts.								
5: Project Reporting, Trainings, Outreach, and Other Deliverables.								
5.1: Quarterly Reports.								
5.2: Draft and Final Report								
5.3 Trainings								
5.4 Public Outreach								
5.5 Publications								
	pm	pm	pm	pm	pm	pm	dm	mf

p = Quarterly progress report (to be delivered at the end of each quarter).
d = Deliver draft final report (to be submitted 6 months prior to contract expiration).
f = Deliver final report.
m = Meeting with CARB staff.

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. Public Research 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.

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.

CONFIDENTIAL HEALTH DATA AND PERSONAL INFORMATION

CARB will 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 regulations regarding access to and the use of confidential data, including the Health Insurance Portability and Accountability Act (HIPAA) and requirements related to the IRB process. CARB will not be a listed entity with authorized access to confidential information pursuant to the IRB process for this contract.

Project Management Plan

Project Management Approach.
This project will be co-led by PI Marlier (UCLA) and Co-PI Benmarhnia (UCSD). PI Marlier will be responsible for the overall management of the project. UCLA will lead the comprehensive literature review (Task 1) and compound climate hazard exposure assessment (Task 2). UCSD will lead the health assessment (Task 3) and equity analysis (Task 4). The Contractor will hold weekly task-specific meetings and monthly full-team meetings by conference call throughout the duration of the project.

The project team includes experts in multiple climate exposure assessment with novel remote sensing and modeling techniques (PI Marlier, Co-PI Benmarhnia, Co-Is Gershunov and Aguilera), spatially varying health effects and economic outcomes (Co-PI Benmarhnia, Co-Is Aguilera, Bandoli, and Jerrett), and climate equity analysis (PI Marlier, Co-PI Benmarhnia, Co-Is Chen, Jerrett, and Connolly).

A. Marlier, Miriam, PI (UCLA): Dr. Marlier will provide overall leadership for the project, coordinate meetings with the project team and CARB, assist with the literature review, lead development of the geospatial database of multiple climate exposures, lead contributions to draft and final reports, and will disseminate project results through open-access journal publications.

B. Benmarhnia, Tarik, Co-PI (UCSD): Dr. Benmarhnia will provide leadership for the UCSD team, attend regular project meetings, lead modification and adaptation of analytical frameworks for health impacts of compound exposure, contribute to writing papers and drafting final reports.

C. Aguilera, Rosana, Co-I (UCSD): Dr. Aguilera will help with the modelling and interpolation of various climate-sensitive exposures in Task 2 and will help with the statistical analyses in task 3.

D. Bandoli, Gretchen, Co-I (UCSD): Dr. Bandoli will provide expertise in maternal and child health and be responsible for analyses involving the SOMI cohort.

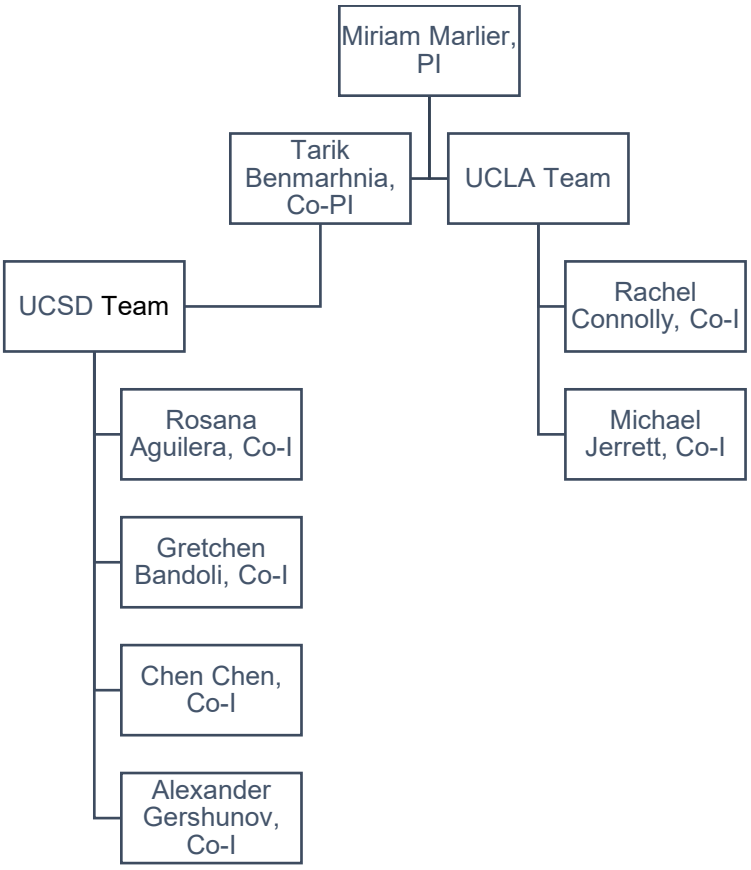
E. Chen, Chen, Co-I (UCSD): Dr. Chen will lead the estimation of synergistic, joint and total health impacts from compound climate stressors and evaluation of effect modification, attend regular project meetings, contribute to writing papers, and drafting final reports.

F. Connolly, Rachel, Co-I (UCLA): Dr. Connolly will lead the literature review, contribute to development of the geospatial database of multiple climate exposures, attend regular project meetings, contribute to draft and final reports, and contribute to writing papers that result from the research.

G. Gershunov, Alexander, Co-I (UCSD): Dr. Gershunov will contribute to the modelling of weather extremes (extreme heat, precipitation) in Task 2 and provide expertise in climate modelling for task 1 and of other tasks in the project.

H. Jerrett, Michael, Co-I (UCLA): Dr. Jerrett will assist with selection of papers to be included in the literature review, assist with selection of statistical models for exposure and health analyses, attend regular project meetings, and contribute to writing papers and reports.

Organizational Chart



Facilities

UCLA

Scientific Environment

UCLA was founded in 1919, and is rated as the top public university in the U.S., and one of the world's great research universities, according to the U.S. News rankings (2022). UCLA, with a student body of about 46,000 students, is the largest university in the state of California. The UCLA faculty includes Nobel Laureates, Pulitzer Prize winners, multiple MacArthur fellows and scores of national academy members. Interdisciplinary teaching and research is a particular strength, with initiatives in the arts, stem cells and other biosciences, nanoscience, international studies and the environment. The Western Association of Schools and Colleges is the regional organization that provides umbrella accreditation for UCLA as a whole, through its Accrediting Commission for Senior Colleges and Universities.

Fielding School of Public Health

For 60 years, UCLA Fielding School of Public Health has played an instrumental role in advancing the field of public health in the areas of research, training and service. UCLA's Fielding School of Public Health world class faculty in collaboration with students have made research discoveries that have improved the health of communities large and small around the world; the talented students come from all over the globe to receive training and mentoring from the faculty, then take their knowledge to become leaders in communities as far as the Congo and as near as East LA; through the field study programs, faculty and students bring information and education to underserved communities, that have changed behaviors and saved lives. Departments include biostatistics, community health services, environmental health sciences, epidemiology, and health policy and management, 247 faculty (70 full time), and 690 students from across 25 countries.

Center for Healthy Climate Solutions

The UCLA Center for Healthy Climate Solutions (C-Solutions) at the UCLA Fielding School of Public Health identifies, tests, evaluates, and disseminates information on public health solutions that increase human resilience, strengthen adaptation, and enhance the mitigation of greenhouse gases. UCLA's C-Solutions has been generously supported by the donation of an anonymous funder which supports the center's staff and operations. C-Solutions has approximately 20 core researchers, staff, and faculty, as well as numerous faculty associates and affiliates. The Center for Health Policy Research is one of the nation's leading health policy research centers and the premier source of health policy information for California, and is our core institutional partner, thus, increasing our administrative and research capacities.

All members of the research team have access to Zoom telecommunication software. The research team also have automatic access to a free enterprise Box account with unlimited storage. This is a university approved, secure method to store and share multiple file types online. Box facilitates collaboration across the research team and other research partners and permits different levels of access to files, as appropriate for project purposes. UCLA Digital Information Technology (DGIT) serves the Information Technology needs of the UCLA Health Sciences schools and other UCLA Health Science units. These computing resources will facilitate data storage and collaboration at UCLA and UCSD.

Marlier Laboratory, Office and Computers

UCLA will use high performance computing resources at UCLA to analyze the satellite and climate model output required for the project. The Hoffman2 Cluster is UCLA's centralized compute resource for UCLA researchers. The Hoffman2 Cluster provides UCLA researchers with 21,000 cores across 1,300 high-performance compute nodes with an aggregate of over 76TB of memory and 2.5PB of high-performance network storage. The cluster includes both a general campus-use section that is freely available to all interested researchers, and a condo-style section where researchers with significant computing needs can purchase and contribute nodes for their own priority use. In addition, Dr. Marlier has a high-performance MacBook Air laptop and external monitor to conduct preliminary analyses, connect to high performance computing resources, prepare manuscripts, and use during project travel.

Jerrett Laboratory, Office and Computers

Dr. Jerrett has a 2,000 square foot lab facility that includes secure-storage. Computing facilities include seven multi-processor personal computer workstations and a secure data server. These computers are installed with mathematical and statistical software that includes ArcGIS with Arc Info, Arc Business Analyst, and a full complement of extensions, R, SPSS, Stata, and MatLab.

UCSD Facilities and Resources

Academic: The UCSD campus was established in 1959 and has become in the ensuing 50+ years one of the nation's leading research universities. The UCSD School of Medicine has over 900 faculty physicians, pharmacists and scientists, and the highly regarded teaching program accepts 125 new students per year. Additionally, over 670 residents and fellows receive postdoctoral training in research laboratories and the patient care setting.

At Scripps Institution of Oceanography, the Climate Change Epidemiology lab, led by Tarik Benmarhnia has access to a virtual secure server that is accessible via VPN where data can be encrypted and with high memory capacities. All models will be conducted in this server and any syntax/code will be posted on the lab GitHub account for reproducibility purposes.

Computer: The California Institute for Telecommunications and Information Technology (Calit2) offers researchers access to one of the most advanced computing environments in the nation. The building is the hub of several national networks for data communications. Researchers will have access to campus (OptIPuter), regional (CENIC), national (NLR) and international (STAR TAP) wireless and optical networking test beds.

The core of Calit2 UCSD Division's computer resources is the OptIPuter. The OptIPuter is a NSF-funded test bed for multi-gigabit cluster computing. This network extends nationally via dedicated optical fiber (National Lamba Rail) and regionally. The network links campus visualization and computing resources, including computer clusters in the School of Engineering, School of Medicine, Scripps Institution of Oceanography, San Diego Supercomputer Center, and Calit2.

For larger computational and data storage projects, the project team has access to supercomputing equipment at the San Diego Supercomputer Center (SDSC). This includes the ability to archive large amounts of data on the SDSC High Performance Storage System. Computationally intensive jobs can be scheduled on a variety of supercomputers at The Triton

Resource at the San Diego Supercomputer Center. Triton Resource is a high performance computing system supporting researchers at the University of California. It consists of two subsystems: The Triton Compute Cluster (TCC) and the Petascale Data Analysis Facility (PDAF). The TCC is a 256-node Appro *HyperGreen* cluster. Each node contains dual quad-core Intel Xeon 5500 (formerly code- named Nehalem) processors running at 2.4 gigaHertz, and 24 gigabytes of main memory. The nodes are interconnected with a 10 gigabit-per-second Myrinet fabric. The TCC has a peak theoretical performance of 20 teraflops and six terabytes of memory. The PDAF is a unique data-intensive computing resource with one of the largest main memory capacities of any publicly available system. The PDAF comprises 28 Sun x4600M2 symmetric multiprocessing (SMP) nodes. Each node contains eight quad-core AMD 8380 processors running at 2.5 gigaHertz. Twenty of the nodes have 256 gigabytes of main memory per node and eight of the nodes have 512 gigabytes of main memory. The PDAF nodes are interconnected with a 10 gigabit-per-second Myrinet fabric. The PDAF has a peak theoretical performance of nine teraflops, and nine terabytes of memory. Both TCC and PDAF are supported by a high performance parallel file system and have connectivity to high bandwidth research networks.

The Computer Science and Engineering Department at UCSD provides extensive computing resources for research and education. This includes more than 200 high-performance UNIX/Linux and Windows-based workstations, a large number of laptop systems, and several hundred wireless personal digital assistants. In addition to general purpose file, e-mail, Web, and compute servers, the department maintains two network- attached terabyte disk arrays and four separate high-performance compute clusters supported by two recent NSF infrastructure grants.

Other: UCSD is part of the University of California Digital Library project and maintains subscriptions to all major medical, public health, social science and statistical journals. In addition, the university participates in an interlibrary loan program that encompasses all University of California campuses and other universities in the greater San Diego area.

The Altman Clinical and Translational Research Institute (ACTRI) helps researchers obtain the education, resources, and collaborations necessary to translate discoveries into practice. The Institute is a partnership among the University of California, San Diego, and other local institutions dedicated to improving human health. To achieve this goal requires collaboration between many groups: academia, industry, non-profit agencies, government, and most importantly, the community. Any researcher or individual interested in translational research is invited to become a member of the ACTRI. The ACTRI is part of a national consortium, the Clinical and Translational Science Awards (CTSA), and is partially funded under grants from the National Center for Advancing Translational Science (NCATS).

EXHIBIT A1

SCHEDULE OF DELIVERABLES

Deliverable	Description	Due Date
Trainings	The Contractor will complete or schedule cultural competency training within 30 days of contract execution.	Month 0
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. At the contract start, the Contractor will develop a 1-page plain-language project summary in consultation with CARB staff.	Month 1
Progress Reports & Meetings	Quarterly progress reports and meetings throughout the agreement term, to coincide with work completed in quarterly invoices.	Quarterly
Draft Final Report	The Contractor will submit a draft version of the Final Report detailing the purpose and scope of the work undertaken, the work performed, and the results obtained and conclusions. The draft report will include detailed information on the results and a section on equity implications and a plain language summary. The draft report will be formatted in accordance with Exhibit A- Research Final Report Format to be reviewed by CARB staff and the Research Screening Committee (RSC).	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.
Literature Review	Endnote database and regional summary tables.	Two (2) weeks prior to agreement end date.
Geospatial Database of Climate Stressors	Online database and summary tables of acute and chronic climate stressor exposures and derived indices.	Two (2) weeks prior to agreement end date.
Health and Economic Impacts	Maps and tables that summarize health and economic impacts.	Two (2) weeks prior to agreement end date.
Social determinants of climate-health equity	Figures and tables that identify vulnerable groups.	Two (2) weeks prior to agreement end date.
Public Research 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.	On or before agreement end date.

	The Contractor will provide research summaries and fact sheets of the scientific journal articles, in English and Spanish, targeted towards a broad audience and those communities identified as most vulnerable to synergistic climate exposures.	
Publications	The Contractor will submit a minimum of two manuscripts to open-access peer-reviewed journals describing results of the literature review and regional climate exposure assessments (Tasks 1 and 2) and health impacts and equity assessment (Tasks 3 and 4). Manuscripts will be sent to CARB for review before submission to the scientific journals for peer review.	On or before agreement end date.
The following Deliverables are subject to paragraph 19. Copyrights, paragraph B of Exhibit C		
Final Report	The Contractor will deliver a written record of the project and its results. The Contractor will deliver a final report by project end date in response to comments by CARB staff and RSC comments. The Contractor will incorporate a one-page Public Outreach Document into the Final Report, that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. The Final Report shall be submitted in an Americans with Disabilities Act compliant format. The Public Outreach Document, as described in Exhibit A1, Section 2, shall be incorporated into the Final Report.	Two (2) weeks prior to agreement end date.

EXHIBIT A2

KEY PERSONNEL

Last Name, First Name	Institutional Affiliation	Role on Project
Principal Investigator (PI):		
Marlier, Miriam	UCLA	● Provide overall leadership for the project. ● Ensure completion of deliverables to CARB. ● Coordinate meetings with project team. ● Assist with the literature review (Task 1). ● Lead development of geospatial database of multiple climate exposures (Task 2). ● Lead contribution to draft and final reports.
Co-PI:		
Benmarhnia, Tarik	UCSD	● Provide leadership for the UCSD team. ● Attend regular project meetings. ● Lead modification and adaptation of analytical frameworks for health impacts of compound exposure (Task 3 and 4). ● Contribute to writing papers and drafting final reports.
Other Key Personnel:		
Aguilera, Rosana	UCSD	● Contribute to exposure modelling (Task 2) ● Help with statistical analyses (Tasks 2 and 3)
Bandoli, Gretchen	UCSD	● Provide expertise on maternal and child health ● Supervise the analyses with the SOMI cohort
Chen, Chen	UCSD	● Lead the estimation of synergistic, joint and total health impacts from compound climate stressors and evaluation of effect modification (Tasks 3 and 4). ● Attend regular project meetings. ● Contribute to writing papers and drafting final reports.
Connolly, Rachel	UCLA	● Lead the literature review (Task 1). ● Contribute to development of geospatial database of multiple climate exposures (Task 2). ● Attend regular project meetings.

		● Contribute to writing papers and reports.
Gershunov, Alexander	UCSD	● Provide expertise in weather extreme modelling (Task 2) ● Contribute to the climate index creation (Task 2) ● Help with analyses considering droughts and precipitation regimes (Task 4)
Jerrett, Michael	UCLA	● Assist with selection of papers to be included in literature review (Task 1). ● Assist with statistical models for exposure and health analyses (Tasks 2 and 3). ● Attend regular project meetings. ● Contribute to writing papers and reports.

EXHIBIT A3

AUTHORIZED REPRESENTATIVES & NOTICES

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: **The Regents of the University of California, Los Angeles**
Contract Project Manager (Technical) Name: Feng-Chiao Su Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (916) 720-2988 Email: feng-chiao@arb.ca.gov	***Principal Investigator (PI)*** Name: Miriam Marlier, Assistant Professor Address: Environmental Health Sciences 650 Charles E. Young Dr. S 71-259 CHS Los Angeles, CA 90095 Telephone: (310) 825-2927 Email: mmarlier@ucla.edu Designees to certify invoices under Section 14 of Exhibit C on behalf of PI: none
Authorized Official (contract officer) Name: Alice Kindarara, Chief Address: Acquisitions Branch 1001 I Street, 19th Floor Sacramento, CA 95814 ***Send notices to (if different):*** Name: Renee Carnes Address: Research Division	***Authorized Official*** Name: Yessenia Sarmiento Contract & Grant Officer Address: UCLA Office of Contract and Grant Administration 10889 Wilshire Boulevard, Suite700 Los Angeles, CA 90095-1406 Telephone: (310) 794-0393 Email: yessenia.sarmiento@ucla.edu ***Send notices to (if different):*** Email: awards@research.ucla.edu

1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (279) 208-7754 Email: renee.carnes@arb.ca.gov	
Administrative Contact Name: Renee Carnes Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (279) 208-7754 Email: renee.carnes@arb.ca.gov	***Administrative Contact*** Name: Yessenia Sarmiento Contract & Grant Officer Address: UCLA Office of Contract and Grant Administration 10889 Wilshire Boulevard, Suite 700 Los Angeles, CA 90095-1406 Telephone: (310) 794-0393 Email: yessenia.sarmiento@research.ucla.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: Yoon Lee Senior Director Address: UCLA Extramural Fund Management 10889 Wilshire Blvd., Suite 600 Los Angeles, CA 90095 Telephone: 310-206-3204 Email: efmoperations@research.ucla.edu Designees for invoice certification in accordance with Exhibit C – University Terms and Conditions, Section 14 on behalf of the Financial Contact: 1. Christian Diaz, Accountant, cdiaz@research.ucla.edu

EXHIBIT A4

USE OF PREEXISTING 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 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

MIRIAM E. MARLIER, PhD

Department of Environmental Health Sciences
University of California, Los Angeles
Email: mmarlier@ucla.edu

650 Charles Young Dr. S.
71-259 CHS
Los Angeles, CA 90095

Qualifications for Proposed Work

My research examines the intersection of climate change and human health outcomes. I use satellite remote sensing data and atmospheric modeling techniques to map linkages between human-caused environmental changes and health outcomes in various locations around the world. In California, I examine the exposure of vulnerable populations to multiple climate-related hazards, including wildfires, drought, and extreme heat, to support policy measures that protect public health.

Academic Appointments

Assistant Professor, Environmental Health Sciences, UCLA	2020-Present
Adjunct Physical Scientist, The RAND Corporation	2019-Present
Associate Physical Scientist, The RAND Corporation	2017-2019
Adjunct Assistant Professor, UCLA Institute of Environment & Sustainability	2017-2019

Education

University of California, Los Angeles, CA	2015-2017
Postdoctoral Research Scientist, Geography	
Columbia University, New York, NY	2014-2017
Postdoctoral Research Scientist, Ecology, Evolution, and Environmental Biology	
Columbia University, New York, NY	2008-2014
Ph.D., Earth & Environmental Sciences, *NSF Graduate Research Fellow*	
University of California, Los Angeles, CA	2003-2007
B.S., Atmospheric, Oceanic, & Environmental Sciences, *summa cum laude with honors*	
Minor, Environmental Systems & Society	

Relevant Peer-Reviewed Publications

Citations: 3830, h-index: 23; i10-index: 29 (Google Scholar, 5-10-23)

Publications with * denotes my role as lead or senior author and are listed first, by year, followed by co-authored publications in alphabetical order. Students who I have mentored are underlined.

1. **Marlier, M.E.*,** Brenner, K.I., Raby, S., Liu, J.C., Mickley, L.J., James, E., Ahmadov, R., and H. Riden. "Exposure of agricultural workers in California to wildfire smoke under past and future climate conditions." *Environmental Research Letters*. 17: 094045. 2022.
2. **Marlier, M.E.*,** Crnosija, N., and T. Benmarhnia. "Wildfire smoke exposures and adult health outcomes." *Fire, Smoke, and Health*, edited by R. Puett et al. American Geophysical Union, In Press.
3. **Marlier, M.E.***, Resetar, S., Lachman, B., Anania, K., and K. Adams. "Remote sensing for natural disaster recovery: Lessons learned from Hurricanes Irma and Maria in Puerto Rico." *Environmental Science and Policy*. 132: 153-159. 2022.
4. Rosenthal, N., Benmarhnia, T., Ahmadov, R., James, E., and **M.E. Marlier.*** "Population co-exposure to extreme heat and wildfire smoke pollution in California during 2020." *Environmental Research: Climate.* 1: 025004. 2022.
5. D'Evelyn, S.M., Jung, J., Alvarado, E., Baumgartner, J., Caligiuri, P., Hagmann, R.K., Henderson, S.B., Hessburg, P.F., Hopkins, S., Kasner, E.J., Krawchuk, M.A., Krenz, J.E., Lydersen, J.M., **Marlier, M.E.**, et al. and J.T. Spector. "Wildfire, smoke exposure, human health, and environmental justice need to be integrated into forest restoration and management." *Current Environmental Health Reports*. 20 pp. 2022.

6. Heaney, A., Stowell, J.D., Liu, J.C., Basu, R., **Marlier, M.E.,** and P. Kinney. "Impacts of fine particulate matter from wildfire smoke on respiratory and cardiovascular health in California." *GeoHealth*, 6: e2021GH000578. 2022.
7. Jerrett, M., Jina, A.S., and **Marlier, M.E.** "Up in smoke: California's greenhouse gas reductions could be wiped out by 2020 wildfires." *Environmental Pollution*. 310: 119888. 2022.
8. Xu, Q., Westerling, A.L., Notohamiprodjo, A., Wiedinmyer, C., Picotte, J.J., Parks, S.A., Hurteau, M.D., **Marlier, M.E.**, Kolden, C.A., Sam, J., Baldwin, J., and C. Ade. "Wildfire Burn Severity and Emissions Inventory: An example implementation over California." *Environmental Research Letters*. 17: 085008. 2022.
9. **Marlier, M.E.***, Madrigano, J., Huttinger, A., and N. Burger. "Indonesian fires and haze: Measuring the health consequences of smoke exposure." Santa Monica, CA: RAND Corporation. 2021.
10. **Marlier, M.E.***, Bonilla, E.X., and L.J. Mickley. "How do Brazilian fires affect air pollution and public health?" *GeoHealth*. 4: e2020GH000331. 2020.
11. **Marlier, M.E.*,** Xing, J., Zhu, Y., and S. Wang. "Impacts of COVID-19 response actions on air quality in China." *Environmental Research Communications*. 2: 075003. 2020.
12. Liu, T., Mickley, L.J., **Marlier, M.E.,** DeFries, R.S., Khan, M.F., Latif, M.T, and A. Karambelas. "Diagnosing spatial biases and uncertainties in global fire emissions inventories: Indonesia as a regional case study." *Remote Sensing of Environment*. 237: 111557. 2020.
13. **Marlier, M.E**.*, Liu, T., Yu, K., Buonocore, J.J., Koplitz, S.N., DeFries, R.S., Mickley, L.J., Jacob, D.J., Schwartz, J., Wardhana, B.S., and S.S. Myers. "Fires, smoke exposure, and public health: An integrative framework to maximize health benefits from peatland restoration." *GeoHealth.* 3: 178-189. 2019. ***One of the most downloaded articles in GeoHealth in the first 12 months of publication.***
14. Engel, R., **Marlier, M.E.**, and D.P. Lettenmaier. "On the causes of the summer 2015 Eastern Washington wildfires." *Environmental Research Communications*. 1: 011009. 2019.
15. Miro, M.E., **Marlier**, **M.E.,** and R.S. Girven. "Transboundary environmental stressors on India-Pakistan relations: An analysis of shared air and water resources." Santa Monica, CA: RAND Corporation. 2019.
16. Liu, T., **Marlier**, **M.E.*,** DeFries, R.S., Westervelt, D.M., Xia, K.R., Fiore, A.M., Mickley, L.J., Cusworth, D.C., and G. Milly. "Seasonal impact of regional outdoor biomass burning on air pollution in three Indian cities: Delhi, Bengaluru, and Pune." *Atmospheric Environment*. 172: 83-92. 2018.
17. **Marlier, M.E.***, Xiao, M., Engel, R., Livneh, B., Abatzoglou, J.T., and D.P. Lettenmaier. "The 2015 drought in Washington State: A harbinger of things to come?" *Environmental Research* Letters. 12: 114008. 2017.
18. Khandelwal, A.*, Karpatne, A.,* **Marlier, M.E.*** Kim, J., Lettenmaier, D.P., and V. Kumar. "An approach for global monitoring of surface water extent variations using MODIS data." *Remote Sensing of Environment*. 202: 113-128. 2017. **Shared first authorship*
19. **Marlier, M.E.***, Jina, A.S., Kinney, P.L., and R.S. DeFries. "Extreme Air Pollution in Global Megacities." *Current Climate Change Reports*. 2(1): 15–27. 2016.
20. **Marlier, M.E.***, DeFries, R.S., Kim, P.S., Koplitz, S.N., Jacob, D.J., Mickley, L.J., and S.S. Meyers. "Fire emissions and regional air quality impacts from fires in oil palm, timber, and logging concessions in Indonesia." *Environmental Research Letters.* 10(8): 085005. 2015.

Selected as best early career article for 2015 by ERL Editorial Board

21. **Marlier, M.E.***, DeFries, R.S., Kim, P.S., Gaveau, D.L.A., Koplitz, S.N., Jacob, D.J., Mickley, L.J., Margono, B.A., and S.S. Myers. "Regional air quality impacts of future fire emissions in Sumatra and Kalimantan." *Environmental Research Letters*. 10(5): 054010. 2015.
22. **Marlier, M.E.***, DeFries, R., Pennington, D., Nelson, E., Ordway, E.M., Lewis, J., Koplitz, S.N., and L.J. Mickley. "Future fire emissions associated with projected land use change in Sumatra." *Global Change Biology*. 21(1): 345–62. 2015.

23. **Marlier, M.E.***, Voulgarakis, A., Shindell, D.T., Faluvegi, G., Henry, C.L., and J.T. Randerson. "The role of temporal evolution in modeling atmospheric emissions from tropical fires." *Atmospheric Environment.* 89: 158-68. 2014.
24. **Marlier, M.E.***, DeFries, R.S., Voulgarakis, A., Kinney, P.L., Randerson, J.T., Shindell, D.T., Chen, Y., and G. Faluvegi. "El Niño and health risks from landscape fire emissions in Southeast Asia." *Nature Climate Change*. 3: 131-36. 2013.
25. Johnston, F.H., Henderson, S.B., Chen, Y., Randerson, J.T., **Marlier**, **M.,** DeFries, R.S., Kinney, P., Bowman, D.M.J.S., and M. Brauer. "Estimated global mortality attributable to smoke from landscape fires." *Environmental Health Perspectives*. 120(5): 695-701. 2012.

Relevant Research Funding

Current

- **NASA** ($250,000). Mapping Vulnerable Populations in California to Climate-Related Hazards. 2023-2024. **PI: M. Marlier.** Co-Is: J. Wilkins, M. Jerrett, P. English.
- **NASA** ($25,000 to M. Marlier). Assessment of Wildland Fire-Related Environmental Exposure Issues Impacting Vulnerable Populations in California. 2022-2023. PI: J. Wilkins. **Co-I: M. Marlier.** Collaborator: M. Jerrett.
- **University of California,** Center for Climate, Health, and Equity ($10,000). Community Vulnerability to Health Risks Associated with Compound Climate Hazards in California. 2022-2023. **PI: M. Marlier.** Co-PI: C. Chen.
- **Google,** Research Scholar Program ($60,000). Mapping California's Compound Climate Hazards in Google Earth Engine. 2021-2023. **PI: M. Marlier.**

Completed

- **UCLA Society of Hellman Fellows** ($23,000). Evaluating the Use of Prescribed Burning to Reduce Wildfire Pollution in California. 2021-2022. **PI: M. Marlier**
- **Western Center for Agricultural Health & Safety** ($14,783). Agricultural Worker Exposure to Wildfire Smoke Pollution in California During the 2020 Fire Season. 2021. **PI: M. Marlier**
- **Southern California NIOSH Education and Research Center** ($10,000). Exposure of Agricultural Workers in California to Wildfire Smoke. 2020-2021. **PI: M. Marlier**
- **UCLA Faculty Research Grant Program** ($7,875). Remote Sensing of Severe Air Pollution from California's Wildfires. 2020-2021. **PI: M. Marlier**
- **University of California,** Multicampus Research Programs & Initiatives ($48,495 to M. Marlier). Drought and Public Health in a Warming California. 2017-2020. PI: D. Lettenmaier.

Selected Presentations

- **2022, Western Center for Agricultural Health and Safety** [Virtual]. Agricultural worker exposure to wildfire smoke in California. Invited.
- **2021, Planetary Health Alliance Annual Meeting** [Virtual]. Air pollution from extreme wildfire events in California.
- **2021, Geo for Good, Google** [Virtual]. Protecting populations from fires and haze: The SMOKE Policy Tool. Invited.
- **2021, Atmospheric & Environmental Chemistry Seminar Series, Harvard University** [Virtual]. Fires, Smoke Exposure, and Public Health: Case Studies from Indonesia and California. Invited.
- **2020, California Fire Science Seminar Series, UC Berkeley** [Virtual]**.** Fires, Air Pollution, and Public Health: A Remote Sensing-Based Perspective. Invited speaker.
- **2020, California Air Resources Board Interdivision Forest Management Working Group** [Virtual]. Land Management, Fires, and Public Health: Developing an Online Decision Support Tool for Indonesia.

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Benmarhnia, Tarik

eRA COMMONS USER NAME (credential, e.g., agency login): TBENMARHNIA

POSITION TITLE: Associate Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Start Date MM/YYYY	Completion Date MM/YYYY	FIELD OF STUDY
Montpellier University, France	BA	09/2003	06/2007	Environmental Sciences
Montpellier University, France	MSc	09/2008	09/2009	Ecotoxicology
EHESP School of Public Health, France	MSc	10/2009	10/2010	Public Health and Environmental Health Sciences
University of Montreal, Canada: School of Public Health (ESPUM) Paris Sud University (ED 420): IRSET INSERM U1085, France	PhD (Joint)	09/2011	02/2015	Epidemiology, Public Health
McGill University, Canada	Postdoctoral training	09/2014	09/2016	Epidemiology, Policy Evaluation

A. Personal Statement

I have a strong background in environmental epidemiology with expertise in epidemiologic methods, geospatial techniques and exposure modelling focusing on climate sensitive exposures. I conducted multiple projects related to the impacts of extreme heat and wildfire smoke on various health outcomes in California and globally. Specifically, I also conducted several projects analyzing synergistic impacts of multiple environmental exposures. Over the course of my career, I have had the opportunity to work with interdisciplinary collaborators (i.e., physicians, urban planners, geographers, meteorologists) which has prepared me well for working with scholars across a wide range of disciplines. Consequently, I am aware of the importance of frequent communication among project members and of constructing a realistic timeline for the research plan.

Four publications related to the proposed project:

1. Schwarz, L., Hansen, K., Alari, A., Ilango, S. D., Bernal, N., Basu, R., ... & **Benmarhnia, T.** (2021). Spatial variation in the joint effect of extreme heat events and ozone on respiratory hospitalizations in California. Proceedings of the National Academy of Sciences, 118(22), e2023078118.
2. Aguilera, R., Corringham, T., Gershunov, A., & **Benmarhnia, T.** (2021). Wildfire smoke impacts respiratory health more than fine particles from other sources: Observational evidence from Southern California. Nature communications, 12(1), 1-8.
3. Aguilera, R., Luo, N., Basu, R., Wu, J., Clemesha, R., Gershunov, A., & **Benmarhnia, T.** (2022). A novel ensemble-based statistical approach to estimate daily wildfire-specific PM2. 5 in California (2006-2020). Environment International, 107719.
4. Rosenthal, N., Benmarhnia, T., Ahmadov, R., James, E., & Marlier, M. E. (2022). Population co-exposure to extreme heat and wildfire smoke pollution in California during 2020. Environmental Research: Climate, 1(2), 025004.

B. Positions, Scientific Appointments and Honors

Positions and Employment

2020-Present	Associate Professor, Scripps Institution of Oceanography, University of California San Diego
2016-2020	Assistant Professor, Family Medicine and Public Health & Scripps Institute of Oceanography, University of California San Diego
2016-Present	Visiting Professor (Concurso Profesores Visitantes Extranjeros Convocatoria en Chile), Universidad de la Católica, Chile
2010-2011	Health Scientist, Coordinator of the national environmental health prevention program, National Institute of Health Education and Prevention, France
2010	Internship, Environmental Health Department, French Ministry of Health, France
2008-2009	Environmental Scientist, Department of Sites and Contaminated Soils, French National Railway Company, France

Other Experience and Professional Memberships

2020- Present	Associate Editor, Environmental Health Perspectives
2022- Present	Associate Editor, Plos Climate
2023	Reviewer for the NASEM RFA on "Understanding the Effects of Climate Change on Environmental Hazards in Overburdened Communities"
2022	Member of the NIH Social Sciences and Population Studies B Study Section
2020	External Reviewer for the Strategic Priorities Fund: UK Natural Environment Research Council
2016-2020	External advisor of the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) Grant Review
2015-Present	Abstract Reviewer for Society of Epidemiologic Research Annual Meeting.
2014-Present	Member of the International Society for Environmental Epidemiology (ISEE) and the Society for Epidemiologic Research

Honors

2014-2016	Postdoctoral Training Award, Montreal Health Equity Research Consortium, Montréal, Canada
2014	Graduate and Postdoctoral studies Fellowship –Montreal University, Canada
2014	Financial Support for Publication, CIHR Team in Gender, Environment and Health
2011-2014	Fellowship for excellence in academic performance during graduate studies, School of Public Health, University of Montreal, Montreal
2013-2014	Public Health Doctoral Network Fellowship, from national Public health Doctoral Network (EHESP), France

C. Contributions to Science

Contribution 1: Health impacts of extreme weather events in California

1. Leibel, S., Nguyen, M., Brick, W., Parker, J., Ilango, S., Aguilera, R., & Benmarhnia, T. (2020). Increase in pediatric respiratory visits associated with Santa Ana wind–driven wildfire smoke and PM2.5 levels in San Diego County. Annals of the American Thoracic Society, 17(3), 313-320.
2. Aguilera, R., Hansen, K., Gershunov, A., Ilango, S. D., Sheridan, P., & Benmarhnia, T. (2020). Respiratory hospitalizations and wildfire smoke: A spatiotemporal analysis of an extreme firestorm in San Diego County, California. Environmental Epidemiology, 4(5).
3. Schwarz, L., Dimitrova, A., Aguilera, R., Basu, R., Gershunov, A., & Benmarhnia, T. (2022). Smoke and COVID-19 case fatality ratios during California wildfires. Environmental Research Letters, 17(1), 014054.
4. Schwarz, L., Castillo, E. M., Chan, T. C., Brennan, J. J., Sbiroli, E. S., Carrasco-Escobar, G., ... & Benmarhnia, T. (2022). Heat Waves and emergency department visits among the homeless, San Diego, 2012–2019. American Journal of Public Health, 112(1), 98-106.

Contribution 2: Methodological developments in epidemiology

1. Benmarhnia, T., Hajat, A., & Kaufman, J. S. (2021). Inferential challenges when assessing racial/ethnic health disparities in environmental research. Environmental Health, 20(1), 1-10.
2. Chen, H., Li, Q., Kaufman, J. S., Wang, J., Copes, R., Su, Y., & Benmarhnia, T. (2018). Effect of air quality alerts on human health: a regression discontinuity analysis in Toronto, Canada. The Lancet Planetary Health, 2(1), e19-e26.
3. Chaix B, Duncan D, Vallée J, Vernez-Moudon A, Benmarhnia T, Kestens Y. The residential effect fallacy in neighborhood and health studies: formal definition, empirical identification, and correction. Epidemiology. 2017 Nov;28(6):789-797. PMID: 28767516.
4. Benmarhnia, T., Huang, J., Basu, R., Wu, J., & Bruckner, T. A. (2017). Decomposition analysis of Black–White disparities in birth outcomes: the relative contribution of air pollution and social factors in California. Environmental health perspectives, 125(10), 107003.

Contribution 3: Geospatial methods for climate and health research

1. Schwarz, L., Hansen, K., Alari, A., Ilango, S. D., Bernal, N., Basu, R., ... & Benmarhnia, T. (2021). Spatial variation in the joint effect of extreme heat events and ozone on respiratory hospitalizations in California. Proceedings of the National Academy of Sciences, 118(22), e2023078118.
2. Carrasco-Escobar, G., Fornace, K., & Benmarhnia, T. (2021). Mapping socioeconomic inequalities in malaria in Sub-Sahara African countries. Scientific reports, 11(1), 1-8.
3. Jankowska, M. M., Yang, J. A., Luo, N., Spoon, C., & Benmarhnia, T. (2021). Accounting for space, time, and behavior using GPS derived dynamic measures of environmental exposure. Health & Place, 102706.
4. Chaix B, Duncan D, Vallée J, Vernez-Moudon A, Benmarhnia T, Kestens Y. The residential effect fallacy in neighborhood and health studies: formal definition, empirical identification, and correction. Epidemiology. 2017 Nov;28(6):789-797. PMID: 28767516.

Complete List of Published Work:
http://www.ncbi.nlm.nih.gov/pubmed/?term=Benmarhnia%20T%5BAuthor%5D&cauthor=true&cauthor_uid=27419005

ROSANA AGUILERA, PhD

Scripps Institution of Oceanography (UCSD) | La Jolla, CA | r1aguilerabecker@ucsd.edu

My research is grounded in my practice, experience and interdisciplinary training in environmental and geographic information sciences, as well as in ecosystem and human health. My recent work involved using statistical methods to estimate wildfire-specific air pollution in California at a fine spatiotemporal resolution, taking advantage of remotely sensed products and air monitoring data collected by environmental agencies.

RECENT PROFESSIONAL EXPERIENCE

2021-Present **Research Data Analyst**
Scripps Institution of Oceanography | University of California San Diego (UCSD)

- Weather Extremes, Climate and Impacts Analytics (WECLIMA), Lab Head: Dr. Alexander Gershunov | Climate Change Epidemiology, Lab Head: Prof. Tarik Benmarhnia

2017-2021 **Postdoctoral Researcher**
Scripps Institution of Oceanography | University of California San Diego (UCSD)

- California's coastal water quality under extreme precipitation events driven by atmospheric rivers. Air quality and wildfire impacts on human respiratory health in a changing world | Co-advisors: Dr. Alexander Gershunov and Prof. Tarik Benmarhnia

2015-2017 **Postdoctoral Researcher**
Marine Science Institute | University of California Santa Barbara (UCSB)

- Statistical analysis and modeling of hydrochemical data in relation to land use, hydroclimate and wildfire effects on nutrient and sediment fluxes from coastal watersheds - Santa Barbara Coastal Long Term Ecological Research Project (SBC LTER) | Advisor: Prof. John Melack

EDUCATION

2010-2015 **Universitat de Girona and Catalan Institute for Water Research | Girona, Spain**
Doctoral Program in Water Science and Technology

- PhD Thesis: "Effects of land use and climate variability on the water quality of Mediterranean rivers: towards a regional vision of global change"
  Co-advisors: Dr. Rafael Marcé and Dr. Sergi Sabater

2007-2009 **Euroaquae Consortium (Europe)**
Hydro-informatics and Water Management | Joint MSc Degree awarded by:

University of Nice – Sophia Antipolis (UNS, France), Brandenburg University of Technology at Cottbus (BTUC, Germany), Budapest University of Technology and

Economics (BME, Hungary), Newcastle University (NU, United Kingdom) and Technical University of Catalonia (UPC, Spain)

- MSc Thesis: "Parameterization and Hysteresis Effects in Distributed Hydrological Modeling" – Co-advisors: Dr. Juha Sarkkula and Dr. János Józsa

2006-2007 **Universidad Nacional de Asunción | Asunción, Paraguay**
Department of Geology, Graduate Specialization in Hydrogeology

2002-2005 **University of the District of Columbia | Washington DC, USA**
ASc in Water Quality and Marine Science
BSc in Environmental Science

PUBLICATIONS

Velásquez EE, Benmarhnia T, Casey JA, **Aguilera R**, Kiang MV. (2023). Quantifying Exposure to Wildfire Smoke Among Schoolchildren in California, 2006 to 2021. JAMA Network Open, 6(4), e235863-e235863.

Aguilera R, Luo N, Basu R, Wu J, Clemesha R, Gershunov A, Benmarhnia T. (2023). A novel ensemble-based statistical approach to estimate daily wildfire-specific $PM_{2.5}$ in California (2006–2020). Environment International, 171, 107719.

Guirguis K, Gershunov A, Hatchett B, Shulgina T, DeFlorio MJ, Subramanian AC, Guzman-Morales J, **Aguilera R**, Clemesha R, Corringham T, Delle Monache L, Reynolds D, Tardy A, Small I, Ralph MF. (2023). Winter wet–dry weather patterns driving atmospheric rivers and Santa Ana winds provide evidence for increasing wildfire hazard in California. Climate Dynamics. 60, 1729–1749

Aguilera R, Leibel S, Corringham T, Bialostozky M, Nguyen MB, Gershunov A, Benmarhnia T. (2022). Mediating Role of Fine Particles Abatement on Pediatric Respiratory Health during COVID-19 Stay-at-Home Order in San Diego County, California. GeoHealth, e2022GH000637.

Schwarz L, Dimitrova A, **Aguilera R**, Basu R, Gershunov A, Benmarhnia T. (2022). Smoke and COVID-19 case fatality ratios during California wildfires. Environmental Research Letters, 17(1), 014054.

Naughten SM, **Aguilera R**, Gershunov A, Benmarhnia T, Leibel S. A Perspective on Pediatric Respiratory Outcomes During California Wildfires Due to Smoke and PM2.5 Exposure. Front Pediatr. 2022 Jul 6;10:891616

Sum KK, Tint MT, **Aguilera R**, Dickens BSL, Choo S, Ang LT, ... & Huang J. (2022). The socioeconomic landscape of the exposome during pregnancy. Environment International, 163, 107205.

Gershunov A, Guzman Morales J, Hatchett B, Guirguis K, **Aguilera R**. et al. (2021) Hot and cold flavors of southern California's Santa Ana winds: their causes, trends, and links with wildfire. Climate Dynamics 57, 2233–2248.

Aguilera R *, Corringham T *, Gershunov A, Benmarhnia T. (2021) Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California. Nature Communications, 12, 1493. * equal contribution

Aguilera R, Corringham T, Gershunov A, Leibel S, Benmarhnia T. (2021) Wildfire smoke particles and wind adversely impact pediatric respiratory health in California. Pediatrics, 147(4).

Casey JA, Kioumourtzoglou M, Elser H, Walker D, Taylor S, Adams S, **Aguilera R**, Benmarhnia T, Catalano R. (2021) Wildfire particulate matter in Shasta County, California and respiratory and circulatory disease-related emergency department visits and mortality, 2013–2018, Environmental Epidemiology, 5 (1).

Aguilera R *, Hansen K *, Gershunov A, Ilango SD, Sheridan P, Benmarhnia T. (2020) Respiratory hospitalizations and wildfire smoke: A spatiotemporal analysis of an extreme firestorm in San Diego County, California. Environmental Epidemiology, 4 (5), p e114. * equal contribution

Aguilera R, Gershunov A, Ilango SD, Guzman-Morales J, Benmarhnia T. (2020) Santa Ana winds of Southern California impact $PM_{2.5}$ with and without smoke from wildfires. GeoHealth, 4.
Research highlighted in Eos - American Geophysical Union (February 2020) and in Frontiers in Ecology and the Environment – News (March 2020)

Leibel S, Nguyen M, Brick W, Parker J, Ilango S, **Aguilera R**, Gershunov A, Benmarhnia T. (2020). Increase in Pediatric Respiratory Visits Associated with Santa Ana Wind-driven Wildfire and $PM_{2.5}$ levels in San Diego County. Annals of the American Thoracic Society, 17(3), 313-320.

Aguilera R, Gershunov A, Benmarhnia T. (2019) Atmospheric rivers impact California's coastal water quality via extreme precipitation. Science of the Total Environment, 671:488-494.

Aguilera R, Melack JM. (2018). Relationships among nutrient and sediment fluxes, hydrological variability, fire, and land cover in coastal California catchments. Journal of Geophysical Research Biogeosciences, 123.

Goodridge BM, Hanan EJ, **Aguilera R**, Wetherley EB, Chen YJ, D'Antonio CM, Melack JM. (2018). Retention of Nitrogen Following Wildfire in a Chaparral Ecosystem. Ecosystems, 1-15.

Marcé R, von Schiller D, **Aguilera R**, Martí E, Bernal S. (2018). Contribution of hydrologic opportunity and biogeochemical reactivity to the variability of nutrient retention in river networks. Global Biogeochemical Cycles, 32.

Aguilera R, Melack JM. (2018). Concentration-discharge responses storm events in coastal California watersheds. Water Resources Research, 54.

Aguilera R, Livingstone DM, Marcé R, Jennings E, Piera J, Adrian R. (2016). Using dynamic factor analysis to show how sampling resolution and data gaps affect the recognition of patterns in limnological time series. Inland Waters, 6(3): 284-294.

Aguilera R, Sabater S, Marcé R. (2016). A methodological framework for characterizing the spatiotemporal variability of river water-quality patterns using dynamic factor analysis. Journal of Environmental Informatics, 31(2), 97-110.

Aguilera R, Marcé R, Sabater S. (2015). Detection and attribution of global change effects on river nutrient dynamics in a large Mediterranean basin. Biogeosciences 12: 4085-4098.

Aguilera R, Marcé R, Sabater S. (2013). Modeling nutrient retention at the watershed scale: does small stream research apply to the whole river network? Journal of Geophysical Research Biogeosciences, 118: 1-13.

Aguilera R, Marcé R, Sabater S. (2012). Linking in-stream nutrient flux to land use and inter-annual Hydrological variability at the watershed scale. Science of the Total Environment, 440: 72-81.

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Bandoli, Gretchen Elizabeth

eRA COMMONS USER NAME (credential, e.g., agency login): GBANDOLI

POSITION TITLE: Assistant Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Xavier University	B.S.	05/2000	Natural Science
Indiana University, Kelley School of Business	M.B.A.	05/2006	Finance
San Diego State University	M.P.H.	05/2011	Epidemiology
University of California, Los Angeles	Ph.D.	06/2015	Epidemiology
University of California, San Diego	Postdoc	06/2018	Epidemiology

A. Personal Statement

I am a perinatal epidemiologist and an Assistant Professor in the Department of Pediatrics, Division of Environmental Sciences and Health, and an Associate Director for the Altman Clinical and Translational Research Institute (ACTRI) Center for Population Research and Scientific Methods (PRSM) at University of California San Diego (UCSD). I have a well-rounded background in pregnancy and early childhood observational research, as well as neuroscience clinical research. My research focuses on perinatal and early childhood determinants of health, with emphasis on maternal chronic disease and environmental determinants of health. In addition, I incorporate novel methodologies into exposure assessment, including supervised and unsupervised machine learning techniques.

The overarching objective of this project is to examine the impact of multiple climate change stressors on health in California. As one approach to this overarching objective, we will use an administrative dataset, The Study of Mothers and Infants (SOMI), to examine how multiple climate stressors independently and jointly affect maternal and infant outcomes. I am a co-investigator of the study (Chambers, PI) and have published extensively from the data, which has 18 years of data consisting of all live births and fetal deaths in California linked to maternal (1 year before and after birth) and infant (birth through 1 year of age) hospital discharge summaries. Dr. Benmarhnia and I have previously collaborated with these data to examine changes in air pollution and infant morbidity, published recently in JAMA Open.

The SOMI dataset has over 6 million mother-child pairs with residential address, which allows for the investigation of spatially patterned exposures that can be evaluated by any number of effect modifiers, including individual level health or economic factors, neighborhood, or policy level factors. I would like to highlight the following work from SOMI highlighting the range and depth of the dataset:

1. Teyton A, Baer RJ, Benmarhnia T, **Bandoli G**. Exposure to Air Pollution and Emergency Department Visits During the First Year of Life Among Preterm and Full-term Infants. JAMA Netw Open. 2023 Feb 1;6(2):e230262. doi: 10.1001/jamanetworkopen.2023.0262. PubMed PMID: 36811862; PubMed Central PMCID: PMC9947725

2. Cross, R. I. (2022). Gentrification, Residential Mobility, and Preterm Birth among Black Women: A Mixed-Methods Study of Racial Resegregation in Northern California. UCLA. ProQuest ID: Cross_ucla_0031D_20792. Merritt ID: ark:/13030/m5wt5z5f. Retrieved from https://escholarship.org/uc/item/59t0k41w (dissertation; under embargo; Bandoli arranged for use of SOMI data and was a dissertation committee member)
3. **Bandoli G**, Delker E, Schumacher BT, Baer RJ, Kelly AE, Chambers CD. Prenatal cannabis use disorder and infant hospitalization and death in the first year of life. Drug Alcohol Depend. 2023 Jan 1;242:109728. doi: 10.1016/j.drugalcdep.2022.109728. Epub 2022 Dec 9. PMID: 36516553.
4. **Gretchen Bandoli**, Rebecca J. Baer, Mallory Owen, Elizabeth Kiernan, Laura Jelliffe-Pawlowski, Stephen Kingsmore & Christina D. Chambers (2022) Maternal, infant, and environmental risk factors for sudden unexpected infant deaths: results from a large, administrative cohort, The Journal of Maternal-Fetal & Neonatal Medicine, 35:25, 8998-9005, DOI: 10.1080/14767058.2021.2008899

Ongoing and recently completed projects that I would like to highlight include:

U01DA055369 Bandoli (MPI) 7/1/2021-6/30/2026
14/24 The Healthy Brain & Child Development National Consortium
Role: Contact PI

R01AA027785 Bandoli (PI) 7/1/2020-3/31/2024
Reassessing FASD: Novel Approaches for Evaluating Exposure, Diagnosis and Outcomes in Children Prenatally Exposed to Alcohol
Role: PI

R01HD101540 Kingsmore / Chambers (MPI) 4/1/2020-1/31/2025
Genomic and Environmental Determinants of Infant Deaths in San Diego County in 2015-2022
Role: Co-I

K01AA027811 Bandoli (PI) 10/1/2019-9/30/2024
Applying Machine Learning in the Prediction and Identification of Children Affected by Prenatal Alcohol Exposure
Role: PI

B. Positions, Scientific Appointments, and Honors

Positions and Scientific Appointments

2018-present Associate Director, University of California, San Diego, Altman Clinical and Translational Research Institute, Center for Population Research and Scientific Methods
2018-present Assistant Professor, Department of Pediatrics, University of California, San Diego

C. Contributions to Science

I have spent the past 8 years studying and conducting research in perinatal epidemiology. Many of my contributions to the field can best be described as employing methods that best characterize prenatal exposures and outcomes, and assessing how maternal exposures such as medications, alcohol, and cannabis act independently and jointly on a pregnancy or throughout the life course.

1. Alcohol and marijuana in pregnancy

Alcohol and marijuana are commonly consumed by women, and exposure can and often does overlap into gestation. My work has focused on better characterizing these exposures in pregnancy (particularly on using unsupervised machine learning to characterize longitudinal trajectories of prenatal alcohol use), and estimating the effects on the health of the pregnancy and the offspring.

a. **Bandoli G,** Coles CD, Kable JA, et. al. Patterns of Prenatal Alcohol Use That Predict Infant Growth and

Development. Pediatrics. 2019 Feb;143(2):e20182399. doi: 10.1542/peds.2018-2399. PMCID: PMC6361345.

b. **Bandoli G**, Jones K, Wertelecki W, et al. Patterns of Prenatal Alcohol Exposure and Alcohol-Related Dysmorphic Features. *Alcohol Clin Exp Res*. 2020:1-8. doi:10.1111/acer.14430. PMCID: PMC7722075.

c. **Bandoli G**, Coles CD, Kable JA, et al. Assessing the Independent and Joint Effects of Unmedicated Prenatal Depressive Symptoms and Alcohol Consumption in Pregnancy and Infant Neurodevelopmental Outcomes. *Alcohol Clin Exp Res*. 2016;40(6):1304-1311. doi:10.1111/acer.13081. PMCID: PMC4889502.

d. **Bandoli G,** Jelliffe-Pawlowski L, Schumacher B, Baer RJ, Felder JN, Fuchs JD, Oltman SP, Steurer MA, Marienfeld C. Cannabis-related diagnosis in pregnancy and adverse maternal and infant outcomes. Drug Alcohol Depend. 2021 Aug 1;225:108757. doi: 10.1016/j.drugalcdep.2021.108757. PMCID: PMC8282693.

2. Methodology

In addition to disease focused work, my training in causal inference has led to work in perinatal epidemiology methodology. This includes work to demonstrate the use of causal diagrams in perinatal epidemiology, another project where we demonstrated and explained the 'Table 2 Fallacy', and projects performing causal mediation analyses to identify intervention targets on the causal path.

a. **Bandoli G**, Palmsten K, Flores KF, Chambers CD. Constructing Causal Diagrams for Common Perinatal Outcomes: Benefits, Limitations and Motivating Examples with Maternal Antidepressant Use in Pregnancy. *Paediatric Perinat Epidemiol.* 2016; 30(5):521-528. PMCID: PMC4970924.

b. **Bandoli G,** Palmsten K, Chambers CD, Thompson CA, Jelliffe-Pawlowski LL, Baer RJ. Revisiting the Table 2 fallacy : A motivating example examining preeclampsia and preterm birth. Paediatric and Perinatal Epidemiology 2018; 32:390–397. PMCID: PMC6103824.

c. **Bandoli G,** Baer RJ, Gano D, Pawlowski LJ, Chambers C. Migraines During Pregnancy and the Risk of Maternal Stroke. JAMA Neurol. 2020 Sep 1;77(9):1177-1179. doi: 10.1001/jamaneurol.2020.1435. PMCID: PMC7265122.

d. **Bandoli G,** Singh N, Strouse J, Baer RJ, Donovan BM, Feuer SK, Nidey N, Ryckman KK, Jelliffe-Pawlowski LL, Chambers CD. Mediation of Adverse Pregnancy Outcomes in Autoimmune Conditions by Pregnancy Complications: A Mediation Analysis of Autoimmune Conditions and Adverse Pregnancy Outcomes. Arthritis Care Res (Hoboken). 2020 Feb;72(2):256-264. doi: 10.1002/acr.24037. PMCID: PMC7351244.

Complete list of Published Work in MyBibliography:

http://www.ncbi.nlm.nih.gov/sites/myncbi/1z5hNVp4vvdky/bibliography/42987330/public/?sort=date&direction=ascending.

Chen Chen

Postdoctoral Scholar
Scripps Institution of Oceanography
University of California San Diego
Email: chc048@ucsd.edu; Phone: (443)831-9105

Education

Yale University, New Haven, CT
Ph.D in Environment awarded Dec. 2020
Advisor: Professor Michelle L. Bell
Johns Hopkins Bloomberg School of Public Health, Baltimore, MD
M.S.P.H. in Occupational Health and Environmental Hygiene awarded May 2013
Fudan University, Shanghai, China
B.S. in Pharmaceutical Science awarded July 2011

Professional Experience

University of California San Diego, La Jolla, CA
Sept. 2020-Present, *Postdoctoral Scholar*, Climate, Atmospheric Science & Physical Oceanography
Advisor: Professor Tarik Benmarhnia
Johns Hopkins Bloomberg School of Public Health, Baltimore, MD
Dec. 2013-Apr. 2015, *Senior Research Program Coordinator*, Department of International Health
Jan. 2013-Nov. 2013, *Research Assistant*, Department of Environmental Health Sciences
Fudan University, Shanghai, China
Aug. 2009-July 2011, *Research Assistant*, Department of Pharmaceutical science

Selected Fellowships and Awards

2017, Outstanding poster by a student in the ISEE annual conference
2015 to 2020, Yale University School of Forestry and Environmental Studies School Fellowship
2012, American Industrial Hygiene Foundation Scholarship

Funding

2022-2023, *University of California Center for Climate, Health and Equity (competitive)*
Community Vulnerability to Health Risks Associated with Compound Climate Hazards in California
Co-PI: **Chen Chen**, Miriam E. Marlier, $10,000
2018-2019, *Hixon Center for Urban Ecology (competitive)*
Air pollution related health impact under climate change in U.S. urban centers
Co-PI: **Chen Chen**, Michelle L. Bell, $6930
2016-2018, *Yale Institute of Biospheric Studies (competitive)*
Long-term temporal trend in the short-term effect of fine particulate matter concentrations on hospital admissions in the U.S.
Co-PI: **Chen Chen**, Michelle L. Bell, $3000

Peer-reviewed Publications

1. **Chen C**, Chen H, Donkelaar A van, Burnett RT, Martin RV, Chen L, Tjepkema M, Kirby-McGregor M, Li Y, Kaufman JS, Benmarhnia T, 2023. Using parametric g-computation to estimate the effect of long-term exposure to air pollution on mortality risk and simulate the benefits of hypothetical policies: the Canadian Community Health Survey cohort (2005 to 2015). Environmental Health Perspectives 131:037010; doi:10.1289/EHP11095.

2. **Chen C**, Illango S, Casey JA, Henneman LRF, Benmarhnia T, 2023. The local impacts of coal and oil power plants retirements on air pollution and cardiorespiratory health in California: an application of generalized synthetic control method. Environmental Research 226:115626; doi:10.1016/j.envres.2023.115626.

3. Lasky E, **Chen C**, Weiser SD, Benmarhnia T, 2023. Investigating the Links between Climate Injustice and Ableism: A Measurement of Green Space Access Inequalities within Disability Subgroups. Environmental Health Perspectives 131:057702; doi:10.1289/EHP12319.

4. **Chen C**, Kirby-McGregor M, Chen H, Benmarhnia T, Kaufman JS, 2023. Inequities in exposure to ambient fine particulate matter in Canada. Science of the Total Environment 858:159766. https://doi.org/10.1016/j.scitotenv.2022.159766.

5. Alari A, Chaix B, Schwarz LN, **Chen C**, Benmarhnia T, 2023. The role of ozone as a mediator in the relation between heat waves and mortality in 15 French urban agglomerations. American Journal of Epidemiology. doi:10.1093/aje/kwad032.

6. Chen H, Quick M, Kaufman JS, **Chen C**, Kwong JC, Donkelaar A von, Meng J, Martin RV, Kim JH, Lavigne E, Bai L, Li Y, Tjepkema M, Benmarhnia T, Burnett RT, 2022. Impact of lowering fine particulate matter from major emission sources on mortality in Canada: a nationwide causal analysis. Proceedings of the National Academy of Sciences of the United States of America 119:e2209490119. https://doi.org/10.1073/pnas.2209490119.

7. **Chen C**, Wang J, Kwong J, Kim J, Donkelaar A van, Martin RV, Hystad P, Su Y, Lavigne E, Kirby-McGregor M, Kaufman JS, Benmarhnia T, Chen H, 2022. Association between long-term exposure to ambient air pollution and COVID-19 severity: a prospective cohort study. CMAJ 194, E693–E700. https://doi.org/10.1503/cmaj.220068

8. Sheridan P, Thompson C, **Chen C**, Benmarhnia T , 2022. Immortal time bias with time-varying exposures in environmental epidemiology: a case study in lung cancer survival. American Journal of Epidemiology. Accepted.

9. Bai L, Benmarhnia T, **Chen C**, Kwong JC, Burnett RT, Donkelaar A von, Martin RV, Kim JH, Kaufman JS, Chen H, 2022. Chronic Exposure to Fine Particulate Matter Increases Mortality Through Pathways of Metabolic and Cardiovascular Disease: Insights From a Large Mediation Analysis. J Am Heart Assoc e026660. doi:10.1161/JAHA.122.026660.

10. Letellier N, Gutierrez LA, Duchesne J, **Chen C**, Ilango S, Helmer C, Berr C, Mortamais M, Benmarhnia T. 2022. Air quality improvement and incident dementia: Effects of observed and hypothetical reductions in air pollutant using parametric g-computation. Alzheimer's & Dementia 18:2509–2517; doi:10.1002/alz.12606.

11. **Chen C**, Chan A, Dominici F, Peng RD, Sabath B, Di Q, Schwartz J, Bell ML. 2022. Do temporal trends of associations between short-term exposure to fine particulate matter (PM2.5) and risk of hospitalizations differ by sub-populations and urbanicity—a study of 968 U.S. counties and the Medicare population. Environmental Research 206:112271; doi:10.1016/j.envres.2021.112271. **Selected as a finalist of the second annual Office of Health Equity Research Award for Yale Research Excellence in 2022.**

12. Chen H, Kaufman JS, Olaniyan T, Pinault L, Tjepkema M, Chen L, van Donkelaar A, Martin RV, Hystad P, **Chen C**, Kirby-McGregor M, Bai L, Burnett RT, Benmarhnia T. 2021. Changes in exposure to ambient fine particulate matter after relocating and long term survival in Canada: quasi-experimental study. BMJ 375:n2368; doi:10.1136/bmj.n2368.

13. **Chen C**, Warrington JA, Dominici F, Peng RD, Esty DC, Bobb JF, Bell ML. 2021. Temporal variation in association between short-term exposure to fine particulate matter and hospitalisations in older adults in the USA: a long-term time-series analysis of the US Medicare dataset. The Lancet Planetary Health 5:e534–e541; doi:10.1016/S2542-5196(21)00168-6.

14. Choi HM, **Chen C**, Son J-Y, Bell ML. 2021. Temperature-mortality relationship in North Carolina, USA: Regional and urban-rural differences. Science of The Total Environment 787:147672; doi:10.1016/j.scitotenv.2021.147672.

15. Heo S, **Chen C**, Kim H, Sabath B, Dominici F, Warren JL, Di Q, Schwartz J, Bell ML. 2021. Temporal changes in associations between high temperature and hospitalizations by greenspace: Analysis in the Medicare population in 40 U.S. northeast counties. Environment International 156:106737; doi:10.1016/j.envint.2021.106737.

16. Bose S, Romero K, Psoter KJ, Curriero FC, **Chen C**, Johnson CM, Kaji D, Breysse PN, Williams DL, Ramanathan M, Checkley W, Hansel NN. 2018. Association of traffic air pollution and rhinitis quality of life in Peruvian children with asthma. PLoS ONE 13:e0193910; doi:10.1371/journal.pone.0193910.

17. **Chen C**, Zeger S, Breysse P, Katz J, Checkley W, Curriero FC, Tielsch JM. 2016. Estimating Indoor PM2.5 and CO Concentrations in Households in Southern Nepal: The Nepal Cookstove Intervention Trials. PLoS One 11; doi:10.1371/journal.pone.0157984.

18. Soneja S, **Chen C**, Tielsch JM, Katz J, Zeger SL, Checkley W, Curriero FC, Breysse PN. 2014. Humidity and Gravimetric Equivalency Adjustments for Nephelometer-Based Particulate Matter Measurements of Emissions from Solid Biomass Fuel Use in Cookstoves. International Journal of Environmental Research and Public Health 11:6400–6416; doi:10.3390/ijerph110606400.

Manuscripts in Review

1. **Chen C**, Chen H, Kaufman JS, Benmarhnia T, 2023. Differential participation, a potential cause of spurious associations in observational cohorts in environmental epidemiology. Epidemiology. In review.

2. Laouali N, **Chen C**, Shah S, Oulhote Y, Benmarhnia T, 2023. C-reactive protein mediates the association between fruit and vegetable intake, and mortality among US adults. Journal of Clinical Nutrition. In review.

Rachel Connolly, PhD

University of California, Los Angeles
Luskin Center for Innovation
rachelconnolly@g.ucla.edu
Department of Environmental Health Sciences

Los Angeles, California 90095
Email:

QUALIFICATIONS FOR PROPOSED WORK

My research explores the intersection of environmental exposures and environmental justice and involves utilizing geospatial data, predictive modeling, dose-response analysis, and qualitative techniques. I conduct quantitative health impact assessments to characterize public health effects associated with urban green space access and air pollution exposure, including from climate hazards such as wildfire smoke.

EDUCATION

University of California at Los Angeles – Ph.D. in Environmental Health Sciences
2018 - 2023

Dissertation: Green space, wildfires, and access to clean vehicles: Characterizing public health and equity outcomes associated with environmental exposures and policy implementation across California
Advisor: Dr. Yifang Zhu

University of California at Los Angeles – M.S. in Environmental Health Sciences
2016 - 2018

University of California at Berkeley – B.S. in Environmental Science
2009 - 2013

ACADEMIC APPOINTMENTS

Project Director, UCLA Luskin Center for Innovation April 2023 – Present

Staff Researcher, UCLA Department of Environmental Health Sciences
April 2023 – Present

PEER-REVIEWED PUBLICATIONS

Connolly, Rachel, Jonah Lipsitt, Manal Aboelata, Elva Yanez, Jasneet Bains, and Michael Jerrett (2023). “The association of green space, tree canopy and parks with life expectancy in neighborhoods of Los Angeles”. *Environment International* 173: 107785.

Pierce, Gregory and **Rachel Connolly** (2023). “Disparities in the “Who” and “Where” of the Vehicle Purchase Decision-Making Process for Lower-Income Households”. *Travel Behaviour and Society* 31: 363-373.

Kramer, Amber, Jonathan Liu, Liqiao Li, **Rachel Connolly**, Michele Barbato, and Yifang Zhu (2022). “Evaluation of Community $PM_{2.5}$ Exposure from Wildfires using Low-Cost Sensors”. *Science of the Total Environment* 856*:* 159218*.*

Connolly, Rachel, Qiao Yu, Zemin Wang, Yu-Han Chen, Jonathan Z. Liu, Ashley Collier-Oxandale, Vasileios Papapostolou, Andrea Polidori, and Yifang Zhu (2021). “Long-term evaluation of a low-cost air sensor network for monitoring indoor and outdoor air quality at the community scale”. *Science of the Total Environment* 807: 150797.

Connolly, Rachel, Gregory Pierce, Julien Gattaciecca, and Yifang Zhu (2020). "Estimating mortality impacts from vehicle emission reduction efforts: The Tune In and Tune Up program in the San Joaquin Valley." *Transportation Research Part D: Transport and Environment* 78: 102190.

PUBLISHED REPORTS

Pierce, Gregory, **Rachel Connolly**, and Kelly Trumbull (2022). "Supporting Access to Complex Low-Income Energy Assistance Programs: Adapting Outreach and Enrollment Strategies in the San Joaquin Valley" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2022/06/Supporting-Household-Access-to-Complex-Low-Income-Energy-Assistance-Programs.pdf

Pierce, Gregory and **Rachel Connolly** (2021). "Procedural Equity in Implementing California's Clean Cars 4 All Program" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2021/05/Procedural-Equity-in-Implementing-Californias-Clean-Cars-4-All-Program.pdf

Pierce, Gregory and **Rachel Connolly** (2020). "emPOWER: A Scalable Model for Improving Community Access to Environmental Benefit Programs in California" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2020/07/A_Scalable_Model_for_Improving_Community_Access_to_Environmental_Benefit_Programs_in_CA.pdf

Pierce, Gregory and **Rachel Connolly** (2020). "Lessons From San Joaquin Valley's Smog Repair Program: Adapting Outreach Methods to Ensure Household Transportation Benefits. A COVID-19 Response Innovation Case Study" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2020/06/Lessons-From-San-Joaquin-Valleys-Smog-Repair-Program.pdf

Zhu, Yifang, **Rachel Connolly**, Yan Lin, Timothy Mathews, and Zemin Wang (2020). "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California" [Report]. https://coeh.ph.ucla.edu/effects-residential-gas-appliances-indoor-and-outdoor-air-quality-and-public-health-california

Pierce, Gregory and **Rachel Connolly** (2019). "Initial Assessment of Valley Clean Air Now's Clean Car Community Clinic Initiative" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2019/10/Valley_Clean_Air_Nows_Clean_Car_Community_Clinic_Initiative.pdf

Pierce, Gregory and **Rachel Connolly** (2018). "Can Smog Repairs Create Social Justice? The Tune In & Tune Up Smog Repair Program in the San Joaquin Valley" [Report]. https://innovation.luskin.ucla.edu/wp-content/uploads/2019/03/Can_Smog_Repairs_Create_Social_Justice.pdf

PRESENTATIONS

International Association of Wildland Fire: Fire and Climate Conference. "Mortality and Morbidity Attributable to Wildfire Smoke in California from 2008-2018" [Oral Presentation, Co-Author]. Panel Title: Firefighter Health and Public Safety. 26 May 2022.

Nature and Health Virtual Conference. "The impact of green space, tree canopy and parks on life expectancy in neighborhoods of Los Angeles" [Oral Presentation]. Panel Title: The big picture: Comprehensive urban greening and health. 13 October 2021.

Center for Advancing Research in Transportation Emissions, Energy, and Health: Transportation, Air Quality, and Health Symposium (invited; rescheduled due to COVID-19 pandemic and unable to present on rescheduled dates). "Estimating mortality impacts from vehicle emission reduction efforts: The Tune In and Tune Up program in the San Joaquin Valley" [Invited Oral Presentation]. May 2020; rescheduled to May 2021.

American Public Health Association Annual Meeting. "Estimating mortality impacts from vehicle emission reduction efforts: The Tune In and Tune Up program in the San Joaquin Valley" [Poster Presentation]. Environmental Health Student Achievement Poster Award Track. 13 November 2018.

RESEARCH FUNDING (Student)

- UCLA Dissertation Year Fellowship 2022-2023
- UCLA Graduate Research Mentorship Program
  2019-2020
- Urban Institute: Powering Healthy Lives Grant
  2019-2020
  - *Principal Investigator:* Dr. Michael Jerrett
- UCLA Institute of Transportation Studies 2017-2018 Applied Research Project
  2017-2018
  - *Principal Investigators:* Dr. Gregory Pierce and Dr. Yifang Zhu

RECENT PROFESSIONAL EXPERIENCE

Health Sciences Consultant, Ramboll U.S. Consulting
2018 – Present
Senior Consultant 1 | February 2021 – Present
Consultant 3 | September 2018 – February 2021
Health Sciences Consulting Intern | July 2018 – September 2018

- Provide consulting services on a wide variety of environmental health projects, including human health risk assessments, California Proposition 65 evaluations, and environmental justice analyses.
- Manage and analyze environmental media sampling data and compare to established screening levels, quantify health risks for exposed populations, conduct geospatial and statistical analysis, review compliance documentation, and write reports for clients.
- Collaborate cross-functionally with Ramboll's Engineering and Air Quality teams to increase project efficiency.
- Assist Managing Consultants with project management, including supervision of staff and budget allocations for a long-term project with a multi-million-dollar budget.

Graduate Student Researcher, UCLA Dept. of Environmental Health Sciences
2019 –2023

- Conducted research on environmental health topics, including evaluating the utility of low-cost air sensors for community monitoring, assessing the relationships between park access, green space, and life expectancy, and quantifying mortality impacts associated with exposure to wildfire-specific air pollution.
- Used Geographic Information Systems and R for quantitative data analysis, including geospatial statistics, health impact assessment, predictive model optimization, and map development.
- Co-developed wildfire and green space decision support tool on Google Earth Engine platform.

Graduate Student Researcher, UCLA Luskin Center for Innovation
2017 –2023

- Conducted quantitative and qualitative research on current environment, energy, and sustainability topics, with a focus on transportation and environmental equity.
- Used R, Stata, and Microsoft Excel for quantitative data analysis, including regression analysis and data visualization.
- Applied for research grants, involving the development of proposal text, budgeting and other administrative tasks, and cross-departmental collaboration.

CURRICULUM VITAE

ALEXANDER GERSHUNOV

Climate, Atmospheric Science and Physical Oceanography (CASPO) Division
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0224 **T: 858-534-8418; E: sasha@ucsd.edu; W: https://weclima.ucsd.edu**

RESEARCH INTERESTS

Weather and climate extremes; global and regional weather and climate variability on hourly to multi-century time scales; water cycle, hydro-meteorology and hydro-climate; coupled ocean-land-atmosphere dynamics; teleconnections; long-range seasonal and subseasonal (S2S) predictability and prediction of extreme weather and associated risks; climate model validation, applications of weather and climate forecasts; extreme precipitation, atmospheric rivers and drought; climate and wildfire; fire weather; coastal low clouds; heat waves and cold snaps; climate impacts on public health, water resources, energy and agriculture; climatic history and future change; climate-society interactions

EDUCATION

Ph.D. (1996) University of California, Santa Barbara (UCSB), Geography Department (Climatology)

M. S. (1989) UCSB, Statistics and Applied Probability Department

B. S. (1986) University of California, Irvine, Math Department

RESEARCH EXPERIENCE

Research Meteorologist. 2013 – Present. CASPO, Scripps Institution of Oceanography (SIO)

Associate Research Meteorologist. 2007 – 2013. CASPO, SIO.

Associate Project Scientist. 2006 – 2007. Climate Research Division, SIO.

Assistant Project Scientist. 2000 – 2006. Climate Research Division, SIO.

Visiting Researcher. June - August 2004. Centre National de Recherches Météorologiques (CNRM), Meteo-France.

Visiting Researcher. October 2002 – January 2003 and December 2001 – March 2002. Laboratoire de Météorologie Dynamique (LMD) du CNRS, École Polytechnique, Palaiseau, France.

Postgraduate Research Meteorologist. 1996 – 2000. Climate Research Division, SIO.

NASA Global Change Research Fellow. 1992 – 1995. Geography Department, UCSB.

PARTICIPATION IN ACTIONABLE RESEARCH PROGRAMS

- California Nevada Climate Applications Program (https://scripps.ucsd.edu/programs/cnap/), NOAA, Co-I
- Southwest Climate Adaptation Science Center (https://www.swcasc.arizona.edu), USGS, DOI, Co-PI
- Climate Education Partners (http://www.sandiego.edu/climate/), NSF, Co-PI

AWARDS

- NASA Global Change Research Fellow, 1992–1995
- Rotary Foundation International Teaching Grant, 2004
- UCSD's John Muir Environmental Fellow, 2017

LANGUAGES

- English (fluent) • Russian (native) • French (fluent) • Spanish (workable)

MOST RECENT SELECTED REFEREED PUBLICATIONS

Hatchett, BJ, AL Koshkin, K Guirguis, K Rittger, AW Nolin, A Heggli, AM Rhoades, A East, ER Siirila-Woodburn, WT Brandt, A Gershunov, K Haleakala, 2023: Midwinter dry spells amplify post-fire snowpack decline. *Geophysical Research Letters*. https://doi.org/10.1029/2022GL101235

Cayan, D.R., L. DeHaan, A. Gershunov, J. Guzman Morales, J.E. Keeley, J Mumford and A.D. Syphard, 2022: Autumn precipitation – the competition with Santa Ana winds in determining fire outcomes in Southern California. *International Journal of Wildland Fire*. **31**(11), 1056–1067. https://doi.org/10.1071/WF22065

Corringham, T., J. McCarthy, T. Shulgina, A. Gershunov, D.R. Cayan, F.M. Ralph., 2022: Climate change contributions to future atmospheric river flood damages in the western United States. *Nature Scientific Reports*. **12**, 13747. https://doi.org/10.1038/s41598-022-15474-2

Guirguis, K., A. Gershunov, B. Hatchett, T. Shulgina, M.J. DeFlorio, A.C. Subramanian, J. Guzman Morales, R. Aguilera, R. Clemesha, T.W. Corringham, L. Delle Monache, D. Reynolds, A. Tardy, I. Small and F.M. Ralph, 2022: Winter wet–dry weather patterns driving atmospheric rivers and Santa Ana winds provide evidence for increasing wildfire hazard in California. *Climate Dynamics*. https://doi.org/10.1007/s00382-022-06361-7

Dimitrova, A., S. McElroy, M. Levy, A. Gershunov and T. Benmarhnia, 2022: Precipitation variability and risk of infectious disease in young children: A global analysis. *Lancet Planetary Health*. 6: e147–55.

Michaelis, A., A. Gershunov, A. Weyant, M. Fish, T. Shulgina and F. M. Ralph, 2022: Atmospheric river precipitation enhanced by climate change: A case study of the storm that contributed to California's Oroville Dam crisis. *Earth's Future*, 10, e2021EF002537. https://doi.org/10.1029/2021EF002537

Douville, H., K. Raghavan, J. Renwick, et al., 2021, Water Cycle Changes. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. *Cambridge University Press*.

McElroy, S, S Ilango, A Dimitrova, A Gershunov and T Benmarhnia, 2022: Extreme heat, preterm birth, and stillbirth: A global analysis across 14 lower-middle income countries. *Environment International*, Accepted

Schwarz L, EM Castillo, TC Chan, JJ Brennan, ES Sbiroli, G Carrasco-Escobar, A Nguyen, RES Clemesha, A Gershunov and T Benmarhnia, 2022: Heat waves and emergency department visits among the homeless, San Diego, 2012–2019. *American Journal of Public Health*.112(1):98–106. DOI: https://doi.org/10.2105/AJPH.2021.306557

Schwarz, L., A. Dimitrova, R. Aguilera, R. Basu, A. Gershunov and T. Benmarhnia. 2021: Smoke and COVID-19 case fatality ratios during California wildfires. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ac4538.

Clemesha et al. 2021: A High-Resolution Record of Coastal Clouds and Fog and their Role in Plant Distributions over San Clemente Island, California. *Environmental Research Communications*. *3*(10), 16. doi: 10.1088/2515-7620/ac2894

Corringham, T. W., D. Spokoyny, E. Xiao, C. Cha, C. Lemarchand, M. Syal, E. Olson, E., A. Gershunov, 2021: BERT Classification of Paris Agreement Climate Action Plans, ICML Workshop on Tackling Climate Change with Machine Learning. (Peer reviewed conference paper)

Hatchett, B. J., T. Benmarhnia, K. Guirguis, K. VanderMolen, A. Gershunov, H. Kerwin, A. Khlystov, K.M. Lambrecht and V. Samburova, 2021: Mobility data to aid assessment of human responses to extreme environmental conditions. *Lancet Planetary Health*. *5*(10), E665-E667.

Keeley, J.E., J. Guzman Morales, A. Gershunov, A.D. Syphard, D.R. Cayan, D.W. Pierce, M. Flannigan and T. Brown, 2021: Ignitions explain more than temperature or precipitation in driving Santa Ana Wind fires. *Science Advances. Vol. 7, no. 30, eabh2262. DOI: 10.1126/sciadv.abh2262*

Gershunov, A., J. Guzman Morales, B. Hatchett, R. Aguilera, T. Shulgina, K. Guirguis, J. Abatzoglou, D. Cayan, D. Pierce, P. Williams, I. Small, R. Clemesha, L. Schwarz, T. Benmarhnia, A. Tardy, 2021: Hot and cold flavors of southern California's Santa Ana winds: Their causes, trends, and links with wildfire. *Climate Dynamics*. DOI: 10.1007/s00382-021-05802-z.

Aguilera, R., T. Corringham, A. Gershunov, S. Leibel and T. Benmarhnia, 2021: Fine Particles in Wildfire Smoke and Pediatric Respiratory Health in California. *Pediatrics*. 147(4):e2020027128.

Mehta, S., D. Vashistha, L. Schwarz, I. Corcos, A. Gershunov, K. Guirguis, R. Basu, T. Benmarhnia, 2021: Racial/ethnic disparities in the association between fine particles and respiratory hospital admissions in San Diego County, CA. *Environmental Science and Health*. Part A, DOI: 10.1080/10934529.2021.1887686.

Aguilera, R., T. Corringham, A. Gershunov and T. Benmarhnia, 2021: Wildfire smoke impacts respiratory health much more than fine particles from other sources: observational evidence from Southern California. *Nature Communications*. 12:1493, https://doi.org/10.1038/s41467-021-21708.

Abatzoglou, J.T., B.J. Hatchett, P. Fox-Hughes, A. Gershunov, and N.J. Nauslar, 2020: Global climatology of synoptically-forced downslope winds. *International Journal of Climatology*. DOI: 10.1002/joc.6607.

Aguilera, R., K. Hansen, A. Gershunov, S. Ilango, P. Sheridan, and T. Benmarhnia, 2020: Respiratory Hospitalizations and Wildfire Smoke: A spatio-temporal analysis of an extreme firestorm in San Diego County, California. *Environmental Epidemiology*, 4, doi: 10.1097/EE9.0000000000000114.

Skaff, N.K., Q. Cheng, R.E.S. Clemesha, P.A. Collender, A. Gershunov, J.R. Head, C.M. Hoover, D.P. Lettenmaier, J.R. Rohr, R.E. Snyder, and J.V. Remais, 2020: Thermal thresholds heighten sensitivity of West Nile virus transmission to changing temperatures in coastal California. *Proc. R. Soc. B*. 287: 20201065. http://doi.org/10.1098/rspb.2020.1065

Cao, Q., A. Gershunov, T. Shulgina, F.M. Ralph, N. Sun and D.P. Lettenmaier, 2020: Floods due to atmospheric rivers along the U.S. West Coast: The role of antecedent soil moisture in a warming climate. *Journal of Hydrometeorology*, 21, 1827–1845, DOI:10.1175/JHM-D-19-0242.1.

Goddard, L. and A. Gershunov, 2020: Impact of El Niño on weather and climate extremes. In *El Niño Southern Oscillation in a Changing Climate* (eds M. J. McPhaden, A. Santoso, W. Cai). *American Geophysical Union*. https://doi.org/10.1002/9781119548164.ch16.

Rutz J.J., B. Guan, D. Bozkurt, I. Gorodetskaya, A. Gershunov, D.A. Lavers, K.M. Mahoney, B.J. Moore, W.Neff, P.J. Neiman, F.M. Ralph, A.M. Ramos, H.C. Steen–Larsen, M. Tsukernik, R. Valenzuela, M. Viale, H. Wernli, 2020: Global and Regional Perspectives. Chapter 4 in *Atmospheric Rivers*. Springer, pp 89-140.

Guirguis, K., A. Gershunov, M.J. DeFlorio, T. Shulgina, L. Delle Monache, A.C. Subramanian, T.W. Corringham, and F. M. Ralph, 2020: Four atmospheric circulation regimes over the North Pacific and their relationship to California precipitation on daily to seasonal timescales. *GRL*. https://doi.org/10.1029/2020GL087609.

Schwarz L., B.J. Malig, J. Guzman-Morales, K. Guirguis, S.D. Ilango, P. Sheridan, A. Gershunov, R. Basu and T. Benmarhnia, 2020: The health burden of fall, winter and spring heat waves in Southern California and contribution of Santa Ana Winds. *Environmental Research Letters*. 15, 054017.

McElroy, S., L. Schwarz, H. Green, I. Corcos, K. Guirguis, A. Gershunov and T. Benmarhnia, 2020: Defining heat waves and extreme heat events using sub-regional meteorological data to maximize benefits of early warning systems to population health. *Science of the Total Environment*, 721. DOI: 10.1016/j.scitotenv.2020.137678

Ilango, S.D., M. Weaver, P. Sheridan, L. Schwarz, T. Bruckner, R. Basu, A. Gershunov and T. Benmarhnia, 2020: Extreme heat episodes and risk of preterm birth in California, 2005-2013. *Environment International*, 137. DOI: 10.1016/j.envint.2020.105541

Leibel S., M. Nguyen, W. Brick, J. Parker, S. Ilango, R. Aguilera, A. Gershunov, T. Benmarhnia, 2020: Increase in Pediatric Respiratory Visits Associated With Santa Ana Wind-driven Wildfire and PM 2.5 levels in San Diego County. *Annals of the American Thoracic Society*, doi: 10.1513/AnnalsATS.201902-150OC.

Aguilera, R., A. Gershunov, S.D. Ilango, J. Guzman Morales and T. Benmarhnia, 2020: Santa Ana winds of Southern California impact PM2.5 with and without [illegible] *GeoHealth*, 4, e2019GH000225. https://doi.org/10.1029/2019GH000225.

Barlow, M., W.J. Gutowski Jr., J.R. Gyakum, R.W. Katz, Y.-K. Lim, R.S. Schumacher, M.F. Wehner, L. Agel, M. Bosilovich, A. Collow, A. Gershunov, R. Grotjahn, R. Leung, S. Milrad, S.-K. Min, 2019: North American extreme precipitation events and related large scale meteorological patterns: a review of statistical methods, dynamics, modeling, and trends. *Climate Dynamics*, DOI: 10.1007/s00382-019-04958-z

Corringham, T.W., F.M. Ralph, A. Gershunov, D.R. Cayan and C.A. Talbot, 2019: Atmospheric rivers drive flood damages in the western United States. *Science Advances*, 5, 12, eaax4631, DOI: 10.1126/sciadv.aax4631

Williams A.P., J.T. Abatzoglou, A. Gershunov, J. Guzman Morales, D.A. Bishop and D.P. Lettenmaier, 2019: The link between anthropogenic climate change and wildfire in California. *Earth's Future*, 7. https://doi.org/10.1029/2019EF00121.

Gershunov, A., T.M. Shulgina, R.E.S. Clemesha, K. Guirguis, D.W. Pierce, M.D. Dettinger, D.A. Lavers, D.R. Cayan, S.D. Polade, J. Kalansky and F.M. Ralph, 2019: Precipitation regime change in Western North America: The role of Atmospheric Rivers. *Nature Scientific Reports*, 9:9944, DOI: 10.1038/s41598-019-46169-w. https://rdcu.be/bJPK0

Aguilera, R., A. Gershunov and T. Benmarhnia, 2019: Atmospheric rivers impact California's coastal water quality via extreme precipitation. *Science of the Total Environment*, 671, 488-494.

Guzman Morales, J. and A. Gershunov, 2019: Climate change suppresses Santa Ana Winds of Southern California and sharpens their seasonality. *Geophysical Research Letters*, 46, 2772-2780, DOI: 10.1029/2018GL080261.

Ralph, F.M., A.M. Wilson, T. Shulgina, B. Kawzenuk, S. Sellars, J.J. Rutz, M.A. Lamjiri, E.A. Barnes, A. Gershunov, B. Guan, K.M. Nardi, T. Osborne, and G.A. Wick, 2018: ARTMIP-early start comparison of atmospheric river detection tools: how many atmospheric rivers hit northern Calif[illegible] *Climate Dynamics*, 52, 4973-4994, https://doi.org/10.1007/s00382-018-4427-5

Guirguis, K, A. Gershunov, T. Shulgina, A. Subramanian, R.E.S. Clemesha, F.M. Ralph, 2018: Circulation drivers of Atmospheric Rivers along the North American West Coast. *GRL*, 45. *https://doi.org/10.1029/2018GL079249*

Syphard, A.D., A. Gershunov, D.M. Lawson, H. Rivera Huerta, J. Guzman-Morales, and M.K. Jennings, 2018: San Diego Wildfires: Drivers of Change and Future Outlook. Pages 49 - 69 *in:* Jennings, M.K., D. Cayan, J. Kalansky, A.D. Pairis et al. *San Diego County ecosystems: ecological impacts of climate change on a biodiversity hotspot*[illegible] Fourth Climate Change Assessment, California Energy Commission. Publication number: EXT-CCC4A- 2018-010

Lawson, D.M., R.E.S. Clemesha, S. Vanderplank, A. Gershunov, and D. Cayan. 2018. Impacts and Influences of Coastal Low Clouds and Fog on Biodiversity in San Diego. Pages 69-89 *in:* Jennings, M.K., D. Cayan, J. Kalansky, A.D. Pairis et al. *San Diego County Ecosystems: Ecological Impacts Of Climate Change On A Biodiversity Hotspot*. [illegible] Fourth Climate Change Assessment, California Energy Commission. Publication number: EXT-CCC4A- 2018-010

Guirguis, K., A. Gershunov, T.M. Shulgina, R.E.S. Clemesha, F.M. Ralph, 2018: Atmospheric Rivers impacting Northern California and their modulation by a variable climate. *Climate Dynamics*. https://doi.org/10.1007/s00382-018-4532-5

Guirguis, K., R. Basu, W. Al-Delaimy, T. Benmarhnia, R.E.S. Clemesha, I. Corcos, J. Guzman-Morales, B. Hailey, I. Small, A. Tardy, D. Vashishtha, J.G. Zivin, and A. Gershunov, 2018: Heat, disparities, and health outcomes in San [illegible] *GeoHealth*, 2, https:/doi.org/10.1029/2017GH000127.

Shields, C. A., J. J. Rutz, L.-Y. Leung, F. M. Ralph, M. Wehner, B. Kawzenuk, J.M. Lora, E. McClenny, T. Osborne, A. E. Payne, P. Ullrich, A. Gershunov, et al., 2018: Atmospheric River Tracking Method Intercomparison Project (ARTMIP): project goals and experimental design, *Geoscientific Model Development*, 11, 2455-2474, https://doi.org/10.5194/gmd-11-2455-2018.

Clemesha, R.E.S., K. Guirguis, A. Gershunov, I. Small and A.Tardy, 2017: California heat waves: their spatial evolution, variation and coastal modulation by low clouds. *Climate Dynamics*, DOI 10.1007/s00382-017-3875-7.

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Polade, S.D., A. Gershunov, D.R. Cayan, M.D. Dettinger and D.W. Pierce, 2017: Precipitation in a warming world: Assessing projected hydro-climate of California and other Mediterranean climate regions. *Nature Scientific Reports*, 7: *10783*, DOI:10.1038/s41598-017-11285-y.

Gershunov A., T.M. Shulgina, F.M. Ralph, D. Lavers and J.J. Rutz, 2017: Assessing climate-scale variability of Atmospheric Rivers affecting western North America. *Geophysical Research Letters*, 44, doi:10.1002/2017GL074175.

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Jerrett, Michael L.B.

eRA COMMONS USER NAME (credential, e.g., agency login): MJERRETT

POSITION TITLE: Professor and Chair

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Trent University, Peterborough, Canada	B.Sc.	11/1986	Environmental and Resource Science
University of Toronto, Toronto, Canada	M.A.	11/1988	Political Science and Environmental Studies
University of Toronto, Toronto, Canada	Ph.D.	06/1996	Geography
McMaster University, Hamilton, Canada	Postdoc	04/1997	Environmental Health

A. Personal Statement

I am an internationally recognized expert in Geographic Information Science for Exposure Assessment and Spatial Epidemiology. I am a full professor in the Department of Environmental Health Science, School of Public Health, University of California, Los Angeles. I earned my PhD in Geography from the University of Toronto (Canada). For the past 25 years, I have researched how to characterize population exposures to air pollution, meteorology and built environmental variables, the social distribution of these exposures among different groups (e.g., poor vs. wealthy), and how to assess the health effects from environmental exposures. I have published some of the most widely-cited papers in the fields of Exposure Assessment and Environmental Epidemiology in leading journals, including: *The New England Journal of Medicine*, *The Lancet*, *Nature*, and *Proceedings of the National Academy of Science*. Over the 15 years, I have also studied the contribution of the built and natural environment to sedentary lifestyles, obesity, and a numerous health outcomes. In 2009, the U.S. National Academy of Science appointed me to the Committee on "Future of Human and Environmental Exposure Science in the 21st Century." The Committee concluded its task with the publication of a report entitled *Exposure Science in the 21st Century: A Vision and a Strategy*. From 2014 to present, I was named to the Thomson Reuters List of Highly-Cited Researchers, indicating I am in the top 1% of all authors in the fields of Environment/Ecology or the Cross-Field categories in terms of citation by other researchers

B. Positions and Honors

Positions and Employment

1989-1991 Environmental Planner, Land Use Planning Unit, Environmental Planning Section, Approvals Branch, Ontario Ministry of the Environment
1995-1997 Postdoctoral Fellow, Geography and Geology Department, McMaster University
1997-1998 Assistant Professor, Geography Department, San Diego State University
1998-2003 Associate Professor (promoted from Assistant in 2002), School of Geography and Geology, and Health Studies Program, McMaster University
2003-2006 Associate Professor, Preventive Medicine Department, Keck School of Medicine, University of Southern California
2006-2011 Associate Professor, Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley

2011-2012 Full Professor, Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley
2012-2014 Full Professor and Division Head, Division of Environmental Health Science, School of Public Health, University of California, Berkeley
2014-2018 Professor-in-Residence, Division of Environmental Health Science, School of Public Health, University of California, Berkeley
2014-pres. Director, Center for Occupational and Environmental Health
2015-2020 Full Professor and Chair, Department of Environmental Health Science, Fielding School of Public Health, University of California, Los Angeles
2021-pres Full Professor, Department of Environmental Health Science; Co-Director, Center for Healthy Climate Solutions, Fielding School of Public Health, University of California, Los Angeles

Honors

2003 Dangermond Endowed Speaker in Geographic Information Science, Environmental Systems Research Institute, Redlands, CA and University of California, Santa Barbara
2009-2012 U.S. National Academy of Science Member of the Committee on the "Future of Exposure Assessment in the 21st century"
2013-2016 Member, Clean Air Scientific Advisory Panel, Sub-committee on Nitrogen Oxides, Environmental Protection Agency
2014-pres Named to Clarivate Highly Cited Researchers List
2016-2019 U.S. National Academy of Science Standing Committee on Geographical Sciences, Member
2016 Named "Favorite Professor" by the Public Health Students Association
2021 Green Gala UCLA Professor of the Year
2021 International Society of Exposure Science, Excellence in Exposure Science, awarded for making an indelible mark on the field

C. Contribution to Science

1. **Climate Change Research on Exposure to and Health Impacts from Exposure to Heat and other Meteorological Parameters.** I have engaged in climate research focused on the health impacts of heat and other meteorological parameters for more than 10 years. My earlier work focused on developing cumulative indicators of environmental exposures, including heat, air pollution, and social position (1, 2). I have also investigated the impacts of heat exerts on several health outcomes and physical activity (3-5). My most recent work shows how heat and humidity directly the effect the risk death from COVID-19 and how these meteorological factors modify the effects of air pollution on COVID-19 death (6).

1. Su, J., **Jerrett, M.**, Morello-Frosch, R., Jesdale, B., & Kyle, A. 2012. Inequalities in cumulative environmental burdens among three urbanized counties in California. *Environment International*. 40, 79–87. https://doi.org/10.1016/j.envint.2011.11.003
2. English, P., Richardson, M., Morello-Frosh, R., Pastor, M., Sadd, J., King, G., Jesdale W. **Jerrett M**. 2013. Racial and Income Disparities in Relation to a Proposed Climate Change Vulnerability Screening Method for California. International Journal of Climate Change: Impacts and Responses. 4. doi:10.18848/1835-7156/CGP/v04i02/37156
3. Dadvand, P., Ostro, B., Figueras, F., Foraster, M., Basagana, X., Valentin, A., Martinez, D., Beelen, R., Cirach, M., Hoek, G., **Jerrett, M.**, Brunekreef, B., & Nieuwenhuijsen, M. 2014. Residential Proximity to Major Roads and Term Low Birth Weight: the Roles of Air Pollution, Heat, Noise, and Road-Adjacent Trees. *Epidemiology.* 25, 518–525. https://doi.org/10.1097/EDE.0000000000000107
4. Lim, Y., Reid, C., Mann, J., **Jerrett, M.**, & Kim, H. 2015. Diurnal temperature range and short-term mortality in large US communities. International Journal of Biometeorology. 59(9), 1311–1319. https://doi.org/10.1007/s00484-014-0941-2
5. Ho, J., Zijlema, W., Triguero-Mas, M., Donaire-Gonzalez, D., Valentin, A., Ballester, J., Chan, E., Goggins, W., Mo, P., Kruize, H., van den Berg, M., Grazuleviciene, R., Gidlow, C., **Jerrett, M.,** Seto, E., Barrera-Gomez, J., & Nieuwenhuijsen, M. (2021). Does surrounding greenness moderate the relationship between apparent temperature and physical activity? Findings from the PHENOTYPE project. *Environmental Research. 197*. https://doi.org/10.1016/j.envres.2021.110992
6. **Jerrett M**, Nau CL, Young DR, Butler RK, Batteate CM, Su J, Burnett RT, Kleeman MJ. 2022. Air Pollution and Meteorology as Risk Factors for COVID-19 Death in a Cohort from Southern California. Environment International. 171:107675. PMID: 36565571

2. **Advanced Exposure Assessment for Air Pollution Epidemiology.** I have led innovations for exposure assessment in ambient air pollution epidemiology. I was among the first in world to develop a land use regression model for traffic-related air pollution (LUR). I have now implemented LUR models in more than 18 countries. I have expanded on these earlier efforts by introducing machine-learning methods to enhance predictions in California and nationally (1). I have also systematically compared how different exposure modeling approaches influence health effects estimation (2). More recently I have worked to integrate low-cost sensor data with speciated particle measurments to improve exposure assessment (3). Finally, I have employed advanced chemical transport models to estimate the effects of air pollution and meteorology on COVID-19 death risk (4).

1. Beckerman, B.S., **Jerrett, M**., Serre, M., Martin, R.V., Lee, S.J., van Donkelaar, A., Ross, Z., Su, J.G., and Burnett, R.T. 2013. A hybrid approach to estimating national scale spatiotemporal variability of PM2.5 in the contiguous United States. *Environmental Science & Technology* 47(13):7233-41. PMCID: PMC3976544
2. **Jerrett, M.**, Turner, M., Beckerman, B.S., Pope, A., Martin, R.V., Serre, M., Gapstur, S.M., Krewski, D., Diver, R., Thurston, G., and van Donkelaar, A. Comparing remote sensing, atmospheric chemistry and ground-based estimates of fine particulate matter on survival. *Environmental Health Perspectives*. PMCID:PMC5382001
3. Liu, J., Banerjee, S., Oroumiyeh, F., Shen, J., del Rosario, I., Lipsitt, J., Paulson, S., Ritz, B., Su, J., Weichenthal, S., Lakey, P., Shiraiwa, M., Zhu, Y., & **Jerrett, M.** (2022). Cokriging with a low-cost sensor network to estimate spatial variation of brake and tire-wear metals and oxidative stress potential in Southern California. Environment International. 168, 107481. PMID: 36037546
4. **Jerrett M**, Nau CL, Young DR, Butler RK, Batteate CM, Su J, Burnett RT, Kleeman MJ. 2022. Air Pollution and Meteorology as Risk Factors for COVID-19 Death in a Cohort from Southern California. Environment International. 171:107675. PMID: 36565571

2. Spatiotemporal Exposure Modeling and Health Effects Assessment for Wildfires. Over the past 10 years, I have been investigating the health impacts of wildfires. My work in this area focuses on deriving high-resolution exposure, spatiotemporal predictions of air pollutants from the wildfires and on assessing the health effects of those exposures. We have developed highly resolved estimates of exposure to $PM_{2.5}$ using machine learning methods that fuse data from satellites, complete atmospheric emissions models run on supercomputers, and ground data, which have prediction accuracy of 80% (1). We have linked these exposures to hospital admissions, showing adverse effects on respiratory outcomes that were modified by socioeconomic status (SES) such that persons of lower SES experienced greater effects (2). We also completed a major critical review on the exposures and health effects from wildfires that was published in the leading journal *Environmental Health Perspectives* (3). We have extended our estimates to include large fires in Southern California and to estimate ozone that forms from the fire emissions (4, 5). All of our analyses extensively use meteorological variables to develop the exposure assessments and to control for time-varying confounding of air pollution effects by meteorology.

1. Reid, C.E., **Jerrett, M.**, Petersen, M.L., Pfister, G.G., Morefield, P.E., Tager, I.B., Raffuse, S.M., and Balmes, J.R. (2015). Spatiotemporal prediction of fine particulate matter during the 2008 Northern California wildfires using machine learning. *Environmental Science and Technology* 49:3887-3896.
2. Reid, C.E., **Jerrett, M**., Tager, I.B., Petersen, M.L., Mann, J.K., and Balmes, J.R. (2016). Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach. *Environmental Research* 150:227-235.
3. Reid, C.E., Brauer, M., Johnston, F., **Jerrett, M**., Balmes, J.R., and Elliott, C.T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives*. 124: 1344-1343.
4. Watson, G., Telesca, D., Reid, C., Pfister, G., & Jerrett, M. (2019). Machine learning models accurately predict ozone exposure during wildfire events. *Environmental Pollution*. 254: 112792.
5. Reid C.E., Considine E.M., Watson G.L., Telesca D., Pfister G.G., **Jerrett M**. (2019). Associations between respiratory health and ozone and fine particulate matter during a wildfire event. *Environment International*.129: 291-298.

D. Related Ongoing Grants

80NSSC22K1684 PI: Marlier, Jerrett Co-I 07/01/2022 – 06/30/2024 0.5 calendar
National Aeronautics and Space Administration (NASA) $250,000
Mapping Vulnerable Populations in California to Climate-Related Hazards. We will integrate Earth science information of smoke pollution and extreme heat with socioeconomic data to assess climate vulnerability.

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: Miriam Marlier					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Active	80NSSC22K 1684	NASA	Mapping Vulnerable Populations in California to Climate-Related Hazards	1/1/2023	12/31/2024
Active	N/A	Google	Mapping California's Compound Climate Hazards in Google Earth Engine	7/1/2021	9/30/2023
Active	BCR-654305	VW CyPres	Capture excess energy waste for durable, renewable fuels	9/2022	8/2026
Active	GRT000418-100015134	Howard University	Assessment of Wildland Fire-Related Environmental Exposure Issues Impacting Vulnerable Populations in California	1/2023	8/2023
Active	PH-005030	LA Departmen t of Public Health	Aliso Canyon Disaster Health Research Study Services	7/1/2022	6/30/2027
Active	19RD015	CARB	A Scenario Tool For Assessing The Health Benefits Of Conserving, Restoring And Managing Natural Working Lands In California	3/1/2020	2/26/2024
Pending		NSF	S-STEM Workforce Development to Advance Climate Adaptation and Mitigation	10/2023	09/2028
Pending		UC Berkeley	Using massive, multi-regional EHR data to estimate the impacts of climate change of fungal disease epidemiology in the U.S.	04/2023	03/2028

Pending		UC Berkeley	Integrating epidemiologic and environmental approaches to understand and predict Coccidioides exposure and coccidioidomycosis emergence	09/2023	08/2024

Co-PI: Benmarhnia, Tarik					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Current	TBD	CARB	Social Determinants of Health and Climate Change Vulnerability	06/2023	06/2024
Current	TBD	CARB	Health impacts by race/ethnicity in air pollution studies in California	04/2023	04/2024
Current	R01ES031808	NIA	Extreme weather, air pollution, and stroke among an aging female population	10/2021	09/2026
Current	2209058	NSF	Focused CoPe: Heat waves in the Southern California coastal zone: Their oceanic and atmospheric drivers, human health impacts, and sustainable adaptation	09/2022	08/2027
Current	R010S030353	NIEHS	Air Pollution and Pregnancy Complications in Complex Urban Environments: Risks, Heterogeneity, and Mechanisms	07/2019	06/2023
Current	R01CA228147	NCI	Integrating novel GIS and GPS data to assess the impact of built environments on changes in BMI, physical activity and cancer-related biomarkers	04/2019	03/2024
Current	R01AG071024	NIA	Short and long-term consequences of wildfires for Alzheimer's disease and related dementias	04/2021	03/2026
Current	RF1AG080948	NIA	Susceptibility and adverse health outcomes related to climate-sensitive events among older Medicare beneficiaries with Alzheimer and Dementia	12/2022	11/2027

Co-I: Aguilera, Rosana					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Current	RF1AG080948	NIA	Susceptibility and adverse health outcomes related to climate-sensitive events among older Medicare beneficiaries with Alzheimer and Dementia	12/2022	11/2027

Co-I: Bandoli, Gretchen					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Current	K01AA027811	NIAAA	Using machine learning to identify children prenatally exposed to alcohol	9/1/2019	8/31/2024
Current	R01HD101540	NICHD	Determinants of infant deaths in San Diego County	4/1/2020	3/31/2025
Current	R01AA027785	NIAAA	Reassessing FASD: Novel Approaches for Evaluating Exposure, Diagnosis and Outcomes in Children Prenatally Exposed to Alcohol	7/1/2020	3/31/2024
Current	U01DA055369	NIDA	14/24 The Healthy Brain & Child Development National Consortium	9/1/2021	6/30/2026

Co-I: Chen, Chen					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Current	RF1AG080948	NIA	Susceptibility and adverse health outcomes related to climate-sensitive events among older Medicare beneficiaries with Alzheimer and Dementia	12/2022	11/2027

Co-I: Connolly, Rachel					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Active	80NSSC22K1684	NASA	Mapping Vulnerable Populations in California to Climate-Related Hazards	1/1/2023	12/31/2024
Active	GRT00041 8-100015134	Howard University	Assessment of Wildland Fire-Related Environmental Exposure Issues Impacting Vulnerable Populations in California	01/2023	08/2023
Active	N/A	VW Cypres	Zero Emissions Zones in North America	01/2023	12/31/2025
Pending		UC Berkeley	Integrating epidemiologic and environmental approaches to understand and predict Coccidioides exposure and coccidioidomycosis emergence	09/2023	08/2024
Pending		UCOP	Building Nature-based Climate Solutions to CA's Climate Crisis with Innovation and Equity	09/2023	08/2025
Pending		UC ITS	Pathways to achieve procedural equity in environmental benefit policies: a case study of California electric vehicle purchase programs	10/2023	09/2024

Co-I: Gershunov, Alexander					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Current	2209058	NSF	Focused CoPe: Heat waves in the Southern California coastal zone: Their oceanic and atmospheric drivers, human health impacts, and sustainable adaptation	09/2022	08/2027
Current	RF1AG080948	NIA	Susceptibility and adverse health outcomes related to climate-sensitive events among	12/2022	11/2027

			older Medicare beneficiaries with Alzheimer and Dementia		

Co-I: Jerrett, Michael					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
Proposed Project	23RD00x	CARB	Impacts of Multiple Climate Change Stressors on Health in California		
Active	PH-005030	LA Department of Public Health	Aliso Canyon Disaster Health Research Study Services	12/1/2022	10/31/2027
Active	1629802	NASA	Evi-3 Multi-Angle Imager For Aerosols (MAIA)	7/15/2019	6/30/27
Active	7682990	UC Lawrence Berkeley National Laboratory	Cevica: Cooking Electrification And Ventilation Improvements For Children's Asthma	1/30/2023	03/31/2026
Active	80NSSC22K1684	NASA	Mapping Vulnerable Populations in California to Climate-Related Hazards	1/1/2023	12/31/2024
Active	19RD015	CARB	A Scenario Tool For Assessing The Health Benefits Of Conserving, Restoring And Managing Natural Working Lands In California	3/1/2020	2/26/2024
Active	21RD005	CARB	Improved Assessment And Tracking Of Health Impacts For California Communities Most Burdened By Pollution	4/1/2022	3/31/2024
Active	A21-2694-S002	UC Davis	Ambient Air Pollution and COVID-19 in California	4/1/2021	12/31/2023
Active	00011365	UC Berkeley	Impact of Air Pollution Exposure on Metabolic Health Outcomes for California Residents	5/1/2023	4/30/2025
Active	22-E0034	California Environmental Protection Agency	Mapping Neighborhoods Experiencing the Worst Outcomes During Extreme Heat Days: An Interactive Modeling and Mapping Website to Support Public Health Decisions	6/1/2023	3/31/2025
Pending		University of Californi, Berkeley	Impact of Air Pollution Exposure on Metabolic Health Outcomes for California Residents	5/1/2023	4/30/2025

Pending		California Environmental Protection Agency	A Statewide Fire Weather and Smoke Profiling Network to Promote Climate Resilience in California	6/1/2023	3/31/2025
Pending		San Jose State University	A Statewide Fire Weather and Smoke Profiling Network to Promote Climate Resilience in California	9/1/2023	8/30/2025
Pending		UC Office of the President	Co-Creating Cool Outdoor Spaces for California's Hot Cities	9/1/2023	8/31/2025

EXHIBIT A7

THIRD PARTY CONFIDENTIAL INFORMATION REQUIREMENT

CONFIDENTIAL NONDISCLOSURE AGREEMENT

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

Exhibit A7 is not applicable for this Agreement.