THE UCLA CENTER FOR HEALTH POLICY RESEARCH

Impacts of Short-term Particulate Matter 2.5 Exposure on Work Loss Days

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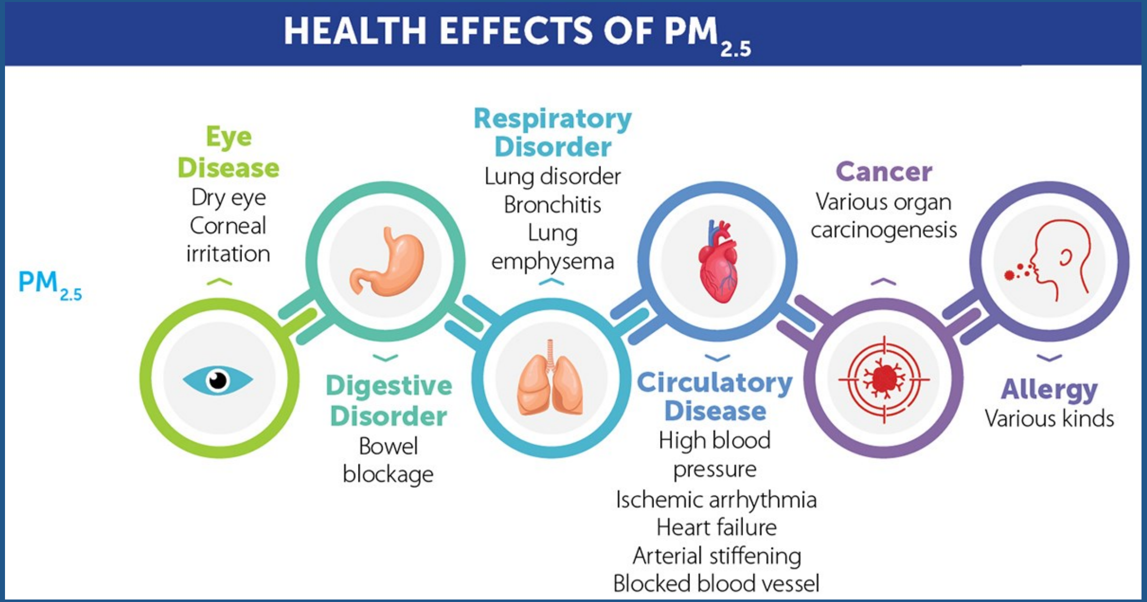
- Data provision and assistance from the CHIS Group
- California Air Resources Board and California EPA
- Feng-Chiao Su, Barbara Weller, Bonnie Holmes-Gen from CARB

Contents

Reference:
https://stillstandingmag.com/2015/02/19/returning-worklife-loss/
https://www.open.edu/openlearn/health-sports-psychology/mental-health/grief-during-covid-19-supporting-our-colleagues-return-work-and-thrive-following-loss

Air Pollution

- One of the global scourges, has been raised as a public health concern due to its impacts on increasing morbidity and mortality
- **$PM_{2.5}$** is among the most damaging pollutants
  - can penetrate into the deepest parts of the lung and bloodstream
  - linked to a variety of adverse health effects including cardio-pulmonary disorders, diabetes, and central nervous system dysfunctions

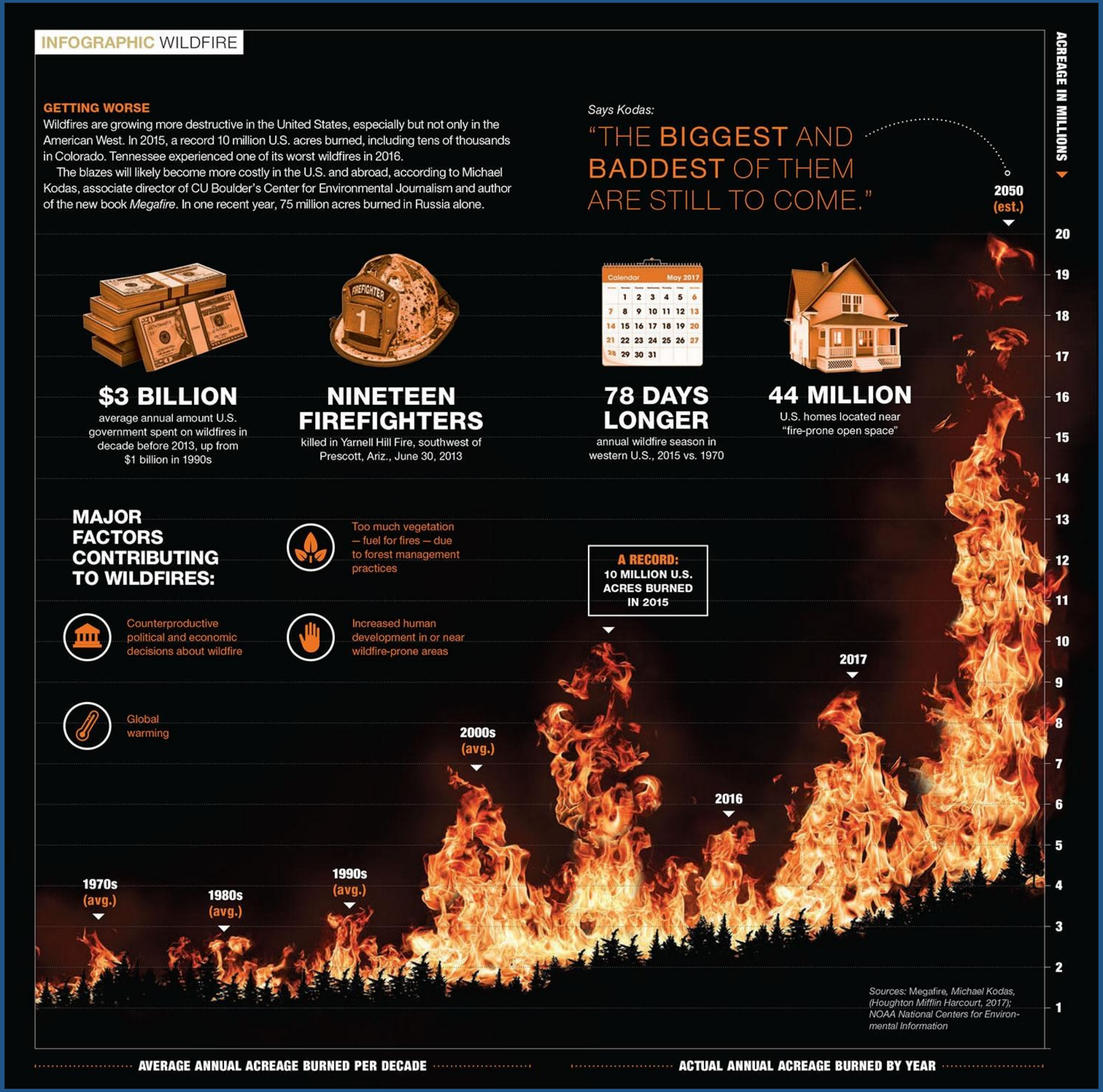


Reference:

https://www.teriin.org/project/assessing-health-effects-exposure-air-pollution-through-survey-based-study

Wildfire

- A frequent and dreadful threat across the U.S. in the recent years
- Total area burned in the western U.S. has been doubled 1984 – 2015
- Usually have a high proportion of smoldering fuel, a form of incomplete combustion, producing high levels of toxins



Reference: https://www.colorado.edu/coloradan/2017/12/01/infographic-wildfire

Research Gap

- Extensive studies investigating short-term air pollution exposure on health outcomes
  - measured via the endpoints such as hospitalization and ED visits
  - fail to capture more subtle health impacts such as work loss
- Two papers on work loss published in the 1980s (Ostro 1987; Ostro and Rothschild 1989)
  - limited PM exposure information from airport visibility rather than actual measurements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Acute health impact of wildfire-related and conventional $PM_{2.5}$ in the United States: A narrative review

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ABSTRACT

The impacts of air pollution on public health have become great concerns worldwide. Particulate matter with an aerodynamic diameter small than 2.5μm ($PM_{2.5}$), either from conventional sources such as traffic emissions or wildfire smoke, is among the most damaging air pollutants. Owing to increasing economic activities, consumption of natural gasses, and wildfires, the concentration of $PM_{2.5}$ in the United States climbed back again. Compared with a large body of research summarizing $PM_{2.5}$ chronic effects on health, fewer studies focused on its acute health impacts, especially from both wildfire-related and conventional sources. To fully capture the acute health impact of short-term $PM_{2.5}$ exposure and estimate the associated economic cost in the United States, we conducted a narrative review of the available epidemiology studies on both sources and found a large body of evidence indicating the acute health impact of $PM_{2.5}$ exposure, not only limited to cardio-respiratory diseases but also including depression, metabolic dysfunction, reproductive health effects such as placental abruption and gestational thyroid dysfunction. Although rare, some studies also indicated the acute impacts on work loss due to some symptom exacerbations that are not perceived as severe enough to search for medical assistance. More studies focusing on the acute impacts of $PM_{2.5}$, especially from wildfire sources, on various outcomes such as neuropsychological, metabolic disorders, and sick leave and/or work productivity are needed to fully understand the extent of the acute health impact of $PM_{2.5}$ exposure from both sources to inform the public health interventions.

1. Introduction

Ambient air pollution is one of the global scourges, not only because of its associations with climate change but also its impacts on public health with increased morbidity and mortality (Manisalidis et al., 2020; Paul et al., 2019). Among the various types of air pollutants, fine particle – a mixture of solid and liquid particles with an aerodynamic diameter small than 2.5 μm ($PM_{2.5}$) – is among the most damaging (Wei et al., 2019). Owing to its large surface area to volume ratio, $PM_{2.5}$ can carry many toxic chemicals and penetrate the respiratory system more deeply and enter into the bloodstream (Brook et al., 2004; Feng et al., 2016), causing both acute and chronic diseases (Du et al., 2016; Lim et al., 2012; Manisalidis et al., 2020; Stieb et al., 2012).

According to Environmental Protection Agency (EPA), the annual average concentration of $PM_{2.5}$ increased 5.5% between 2016 and 2018 in the United States (US) after decreasing by around 24% over the previous seven years, which could be explained by increases in economic activities, consumption of natural gasses, decreased efforts in the enforcement of the Clean Air Act, as well as the increasing wildfire episodes, especially in the vulnerable western US (Clay and Muller, 2019). It has been reported that the total area burned by wildfires in the western US has been doubled between 1984 and 2015 (Abatzoglou and Williams, 2016). The wildfire smoke contains high concentrations of $PM_{2.5}$ and can disperse across many miles, causing serious impacts on human health (James et al., 2018).

Compared to a large body of studies investigating the association between various health outcomes from long-term exposure to $PM_{2.5}$ (Fu et al., 2019; Hahn et al., 2022; Haikerwal et al., 2021; Holm et al., 2020; Katoto et al., 2021; Kizer, 2021; Niu et al., 2020; Reid et al., 2016a; Trushna et al., 2020; Turner et al., 2020; Yang et al., 2021; Yee et al., 2021; Young and Kindzierski, 2020), fewer studies focused on impacts of short-term $PM_{2.5}$ exposure, and few review articles intentionally summarized the acute health impacts from both wildfire-related and conventional $PM_{2.5}$ exposures in the US. Thus, the objective of this review

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To investigate the impact of short-term $PM_{2.5}$ exposure on work loss due to sickness among adults living in California

To investigate the health and economic impacts of work loss due to sickness related to daily total $PM_{2.5}$ and wildfire smoke exposures

Specific Aims

(1) **Data linking** – California Health Interview Survey (CHIS) respondents' geocoded residential addresses to exposure data;

(2) **Characterizing** air pollution exposure distributions

(3) **Logistic regression analyses** –

- Association between short-term PM2.5 exposure and work loss due to sickness
- How wildfire smoke exposure influence the association

(4) **Investigating** health and economic impacts of work loss associated with daily total PM2.5 and wildfire-specific PM2.5 exposures on the BenMAP-CE platform.

California Health Interview Survey (CHIS)

- Continuous telephone survey with an annual target of 20,000 households
- A geographically stratified sample design, random-digit-dial (RDD) sampling method
- Covers dozens of health-related topics
- Multi-language interview: English, Spanish, Cantonese, Mandarin, Korean, Tagalog, or Vietnamese
- Adult population aged 18 and older, 2015-2018

Study Method – Related Survey Questions

CHIS adult respondents were asked

Q1: Which of the following were you doing last week?

- (1) With a job or business but not at work
- (2) Working at a job or business
- (3) Looking for work
- (4) Not working at a job or business

Q2: What is the main reason you did not work last week?

(1) taking care of house or family,
(2) on planned vacation,
(3) couldn't find a job,
(4) going to school/student,
(5) retired,
(6) disabled,
(7) unable to work temporarily,
(8) on layoff or strike,
(9) on family or maternity leave,
(10) offseason,
(11) sick, and
(12) other.

Q1: Which of the following were you doing last week?

Q2: What is the main reason you did not work last week?

CHIS respondents who were in the workforce

With a job or business but not at work

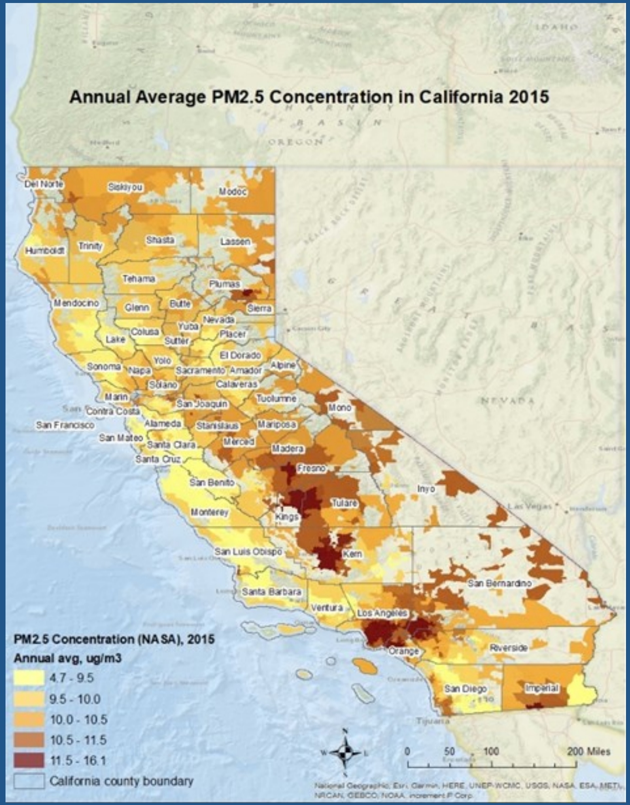
Sick

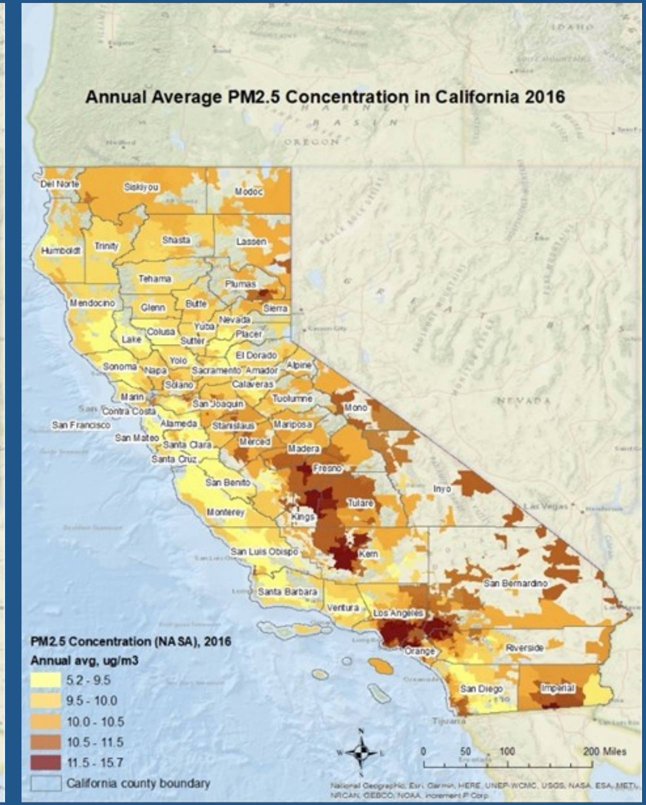
Daily total PM2.5 Concentration

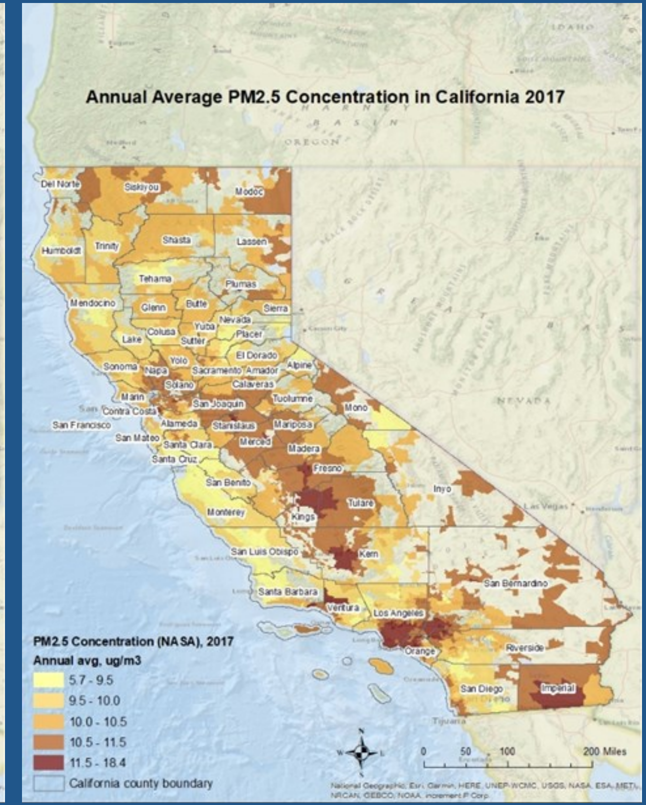
- Funded by the National Aeronautics and Space Administration (NASA) Health and Air Quality Applied Sciences (HAQAST) Program
- Spatial resolution at 3-kilometers
- Environmental data from
  - USEPA ground observation Air Quality System (AQS) database
  - NASA Moderate Resolution Imaging Spectroradiometer (MODIS)
- Geostatistical surfacing algorithm
  - Including linear regression models, B-spline and Inverse Distance Weighted (IDW) smoothing models
  - A quality control procedure for the EPA AQS data,
  - A bias adjustment procedure for MODIS/Aerosol Optical Depth-derived $PM_{2.5}$ data

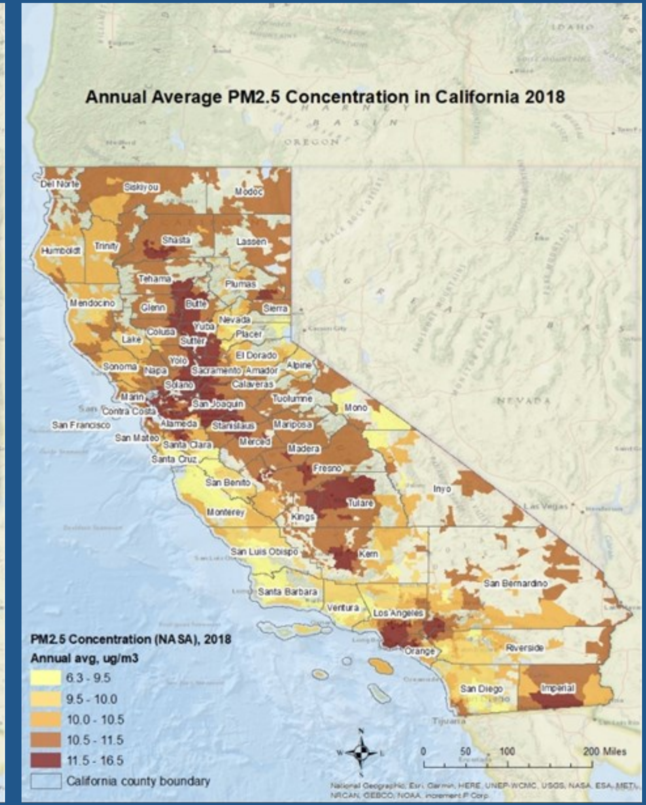
Reference:
1. Al-Hamdan et al. 2019. Development and validation of improved pm2. 5 models for public health applications using remotely sensed aerosol and meteorological data. Environmental monitoring and assessment 191(2):1-16.
2. Al-Hamdan et al. 2009. Methods for characterizing fine particulate matter using ground observations and remotely sensed data: Potential use for environmental public health surveillance. J Air Waste Manag Assoc 59(7):865-881.
3. Al-Hamdan et al. 2014. Environmental public health applications using remotely sensed data. Geocarto international 29(1):85-98.
4. Diao et al. Satellite applications for analysis of surface pm 2.5 concentrations in California and contiguous US. In: Proceedings of the AGU Fall Meeting Abstracts, 2019a, Vol. 2019, GH21B-1212

Estimated annual average daily total $PM_{2.5}$ concentration in California, 2015-2018.







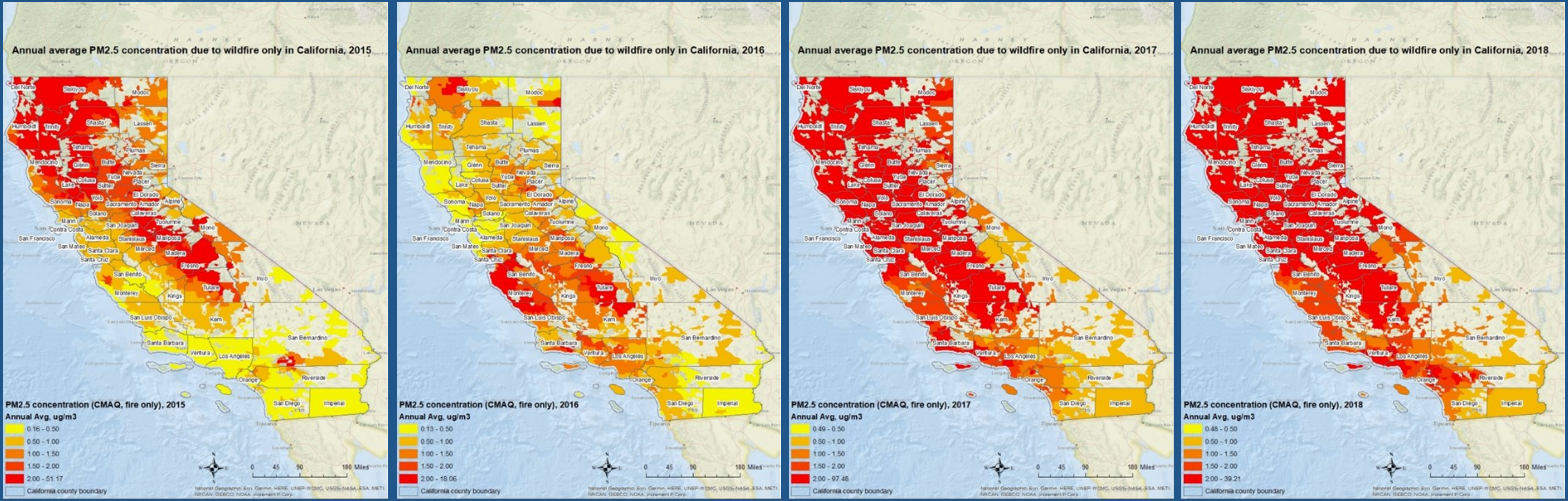


Wildfire Smoke Exposure

- Community Multiscale Air Quality (CMAQ) modeling system (version 5.0 - 5.3)
- Spatial resolution at 12-kilometers
- Using SMARTFIRE emission to simulate the changes in air pollution concentration with and again without fires
- Incorporate multiple sources of fire activity such as Earth observations, federal, state, local, and tribal databases
- Emission factors were taken from the Fire Emission Production Simulator (FEPS) model
- Non-fire emissions sources are from the National Emissions Inventory (NEI).
- The difference between the two simulations isolates the wildfire-specific $PM_{2.5}$ contribution

Reference:
1. Rappold et al. 2017. Community vulnerability to health impacts of wildland fire smoke exposure. Environ Sci Technol 51(12):6674-6682.
2. Sullivan et al. 2008. A method for smoke marker measurements and its potential application for determining the contribution of biomass burning from wildfires and prescribed fires to ambient pm2.5organic carbon. Journal of Geophysical Research 113(D22).
3. Wilkins et al. 2018. The impact of us wildland fires on ozone and particulate matter: A comparison of measurements and CMAQ model predictions from 2008 to 2012. Int J Wildland Fire 27(10).
4. Ottmar RD, Sandberg DV, Riccardi CL, Prichard SJ. 2007. An overview of the fuel characteristic classification system—quantifying, classifying, and creating fuelbeds for resource planning. Canadian Journal of Forest Research 37(12):2383-2393

Estimated annual average wildfire-specific $PM_{2.5}$ concentration in California, 2015-2018.



Part I:

Investigate the Association between Short-term $PM_{2.5}$ Exposure on Work Loss

Reference: Meng et al. 2023. Short-term total and wildfire fine particulate matter exposure and work loss in California. Environment International 178, https://doi.org/10.1016/j.envint.2023.108045.

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Full length article

Short-Term total and wildfire fine particulate matter exposure and work loss in California

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ABSTRACT

Background: Few studies investigated the impact of particulate matter ($PM_{2.5}$) on some symptom exacerbations that are not perceived as severe enough to search for medical assistance. We aimed to study the association of short-term daily total $PM_{2.5}$ exposure with work loss due to sickness among adults living in California.
Methods: We included 44,544 adult respondents in the workforce from 2015 to 2018 California Health Interview Survey data. Daily total $PM_{2.5}$ concentrations were linked to respondents' home addresses from continuous spatial surfaces of $PM_{2.5}$ generated by a geostatistical surfacing algorithm. We estimated the effect of a 2-week average of daily total $PM_{2.5}$ exposure on work loss using logistic regression models.
Results: About 1.69% (weighted percentage) of adult respondents reported work loss in the week before the survey interview. The odds ratio of work loss was 1.45 (odds ratio [OR] = 1.45, 95% confidence interval [CI]: 1.03, 2.03) when a 2-week average of daily total $PM_{2.5}$ exposure was higher than 12 μg/m^3. The OR for work loss was 1.05 (95% CI: 0.98, 1.13) for each 2.56ug/m^3 increase in the 2-week average of daily total $PM_{2.5}$ exposure, and became stronger among those who were highly exposed to wildfire smoke (OR = 1.06, 95% CI: 1.00, 1.13), compared to those with lower wildfire smoke exposure (OR = 1.04, 95% CI: 0.79, 1.39).
Conclusions: Our findings suggest that short-term ambient $PM_{2.5}$ exposure is positively associated with work loss due to sickness and the association was stronger among those with higher wildfire smoke exposure. It also indicated that the current federal and state $PM_{2.5}$ standards (annual average of 12 μg/m^3) could be further strengthened to protect the health of the citizens of California.

1. Introduction

Ambient air pollution is the leading environmental cause of death, globally accounting for million deaths annually (Burnett et al., 2018). Fine particles with an aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$), which can carry many toxic chemicals and penetrate the respiratory system more deeply and may enter into the bloodstream (Feng et al., 2016). have been associated with multiple adverse health outcomes, including cardio-pulmonary diseases, metabolic, central nervous system dysfunctions, and premature mortality (Yu et al., 2022).

Although numerous studies have examined both the acute and chronic effects of $PM_{2.5}$ on health outcomes using medical and death records, few studies investigated the relationship between short-term $PM_{2.5}$ exposure and some acute condition exacerbations, such as coughs. These conditions may not be perceived as serious enough to necessitate medical assistance but may lead to a loss of productivity or work loss days (Zivin and Neidell, 2012). Exposure to $PM_{2.5}$ may induce direct physical disorders or psychological discomforts such as headaches, which possibly alter the marginal return to an additional hour of labor supplied or an increment of effort exerted within any given hour.

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Study Method – Statistical Analyses

Study Endpoint

Work loss due to sickness
- Categorical, Yes vs. No

Exposure

2-week average daily total $PM_{2.5}$ concentration
- Continuous, standardized by IQR (= 2.56 μg/m³)
- Categorical, ≥ 12 μg/m³ vs. <12 μg/m³

Wildfire exposure level
- Categorical, Higher vs. Lower

Week 3:	Week 2:	Week 1:	Week 0:
$PM_{2.5}$ exposure	$PM_{2.5}$ exposure	Work loss	Interview

Wildfire Exposure Level

(1) Higher Wildfire Smoke Exposed Day

Daily wildfire-specific $PM_{2.5}$ ≥ 85th percentile value of the estimated daily wildfire-specific $PM_{2.5}$ concentrations across the state in each specific year

(2) Highly Wildfire Smoke Exposed Status

Any day during the 2-week period (Week 2 and Week 3) before interview date is defined as Higher Wildfire Exposed Day

Covariate

- Age, gender, race/ethnicity, poverty, smoking, comorbidity, interview year
- Interview season, insurance coverage, residential location, occupation, full-time/part-time position, length of current address residence
- Wildfire exposure
- Temperature, precipitation, relative humidity, dew point, wind direction

Statistical Model

- Logistic Regression Model

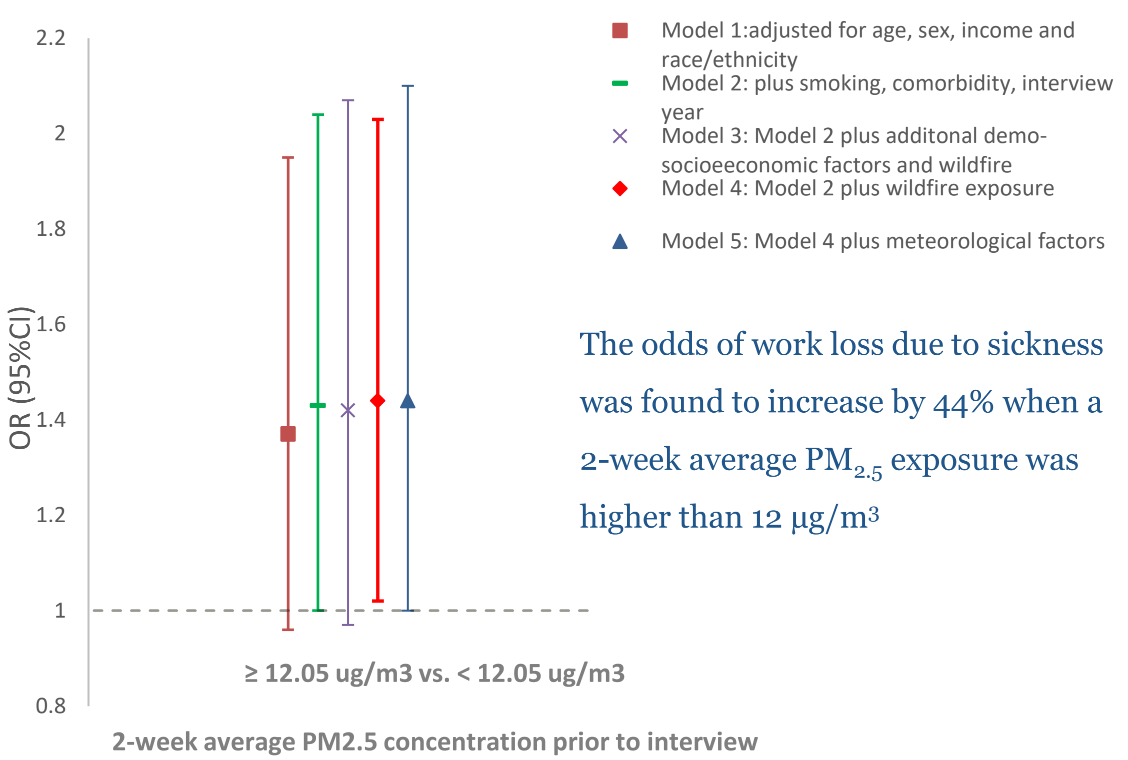
$$\text{Logit}(\Pr(A=1 \mid PM_{2.5})) = \beta_{intercept} + \beta_{PM_{2.5}} + \beta_{covariates}$$

- Stratified analyses and 2-way joint effect analyses
- Sensitivity analyses: Firth model, Poisson model with 1000 bootstrapped samples, Propensity score weighting method

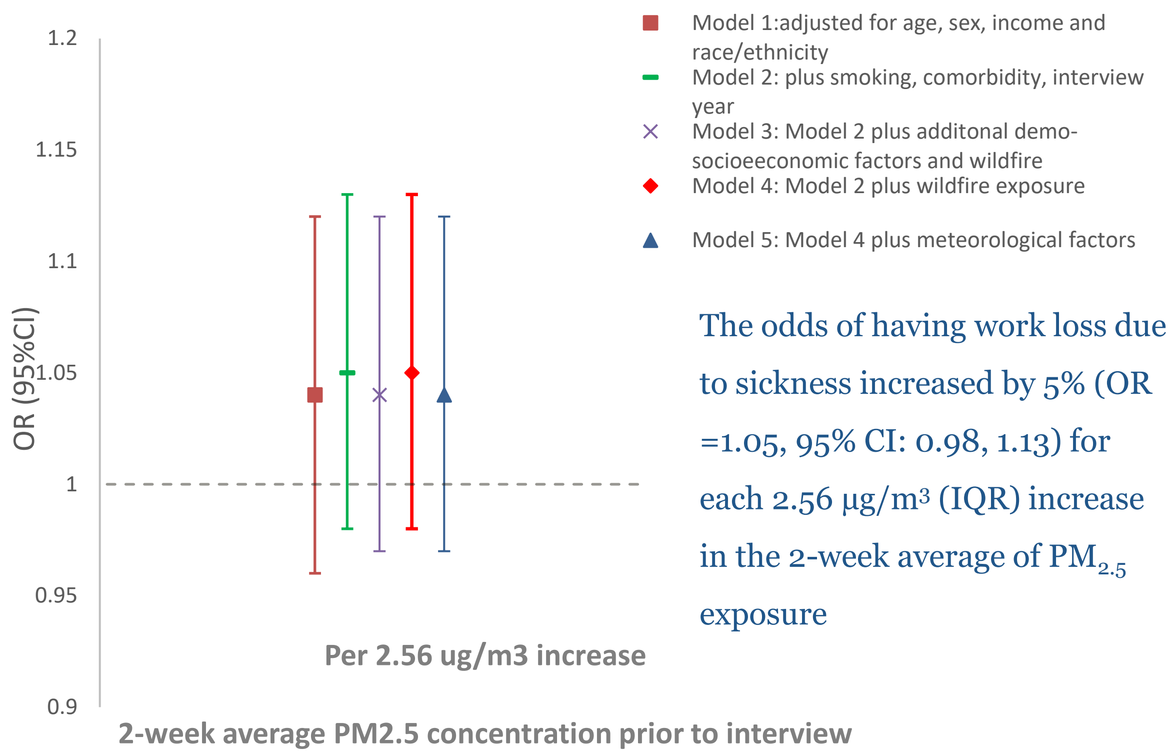
Summary of characteristics among the CHIS respondents in workforce, 2015-2018.

- 905 (weighted%= 1.69%) reported to have work loss due to sickness
- Comparing those who had work loss vs. no work loss, they were:
    - More 40 years old and above (78.2% vs. 52.6%)
    - More Hispanics (54.3% vs. 37.7%)
    - More living at 0-99% FPL (39.5% vs. 13.2%)
    - More had two or more comorbidities (35.3% vs. 8.3%)
    - Fewer covered by private insurance (20.5% vs. 62.8%)

The odds of work loss due to sickness was found to increase along with higher 2-week average $PM_{2.5}$ exposure



The odds of work loss due to sickness was found to increase by 44% when a 2-week average $PM_{2.5}$ exposure was higher than 12 μg/m³



The odds of having work loss due to sickness increased by 5% (OR =1.05, 95% CI: 0.98, 1.13) for each 2.56 μg/m³ (IQR) increase in the 2-week average of $PM_{2.5}$ exposure

When stratified by sociodemographic risk factors

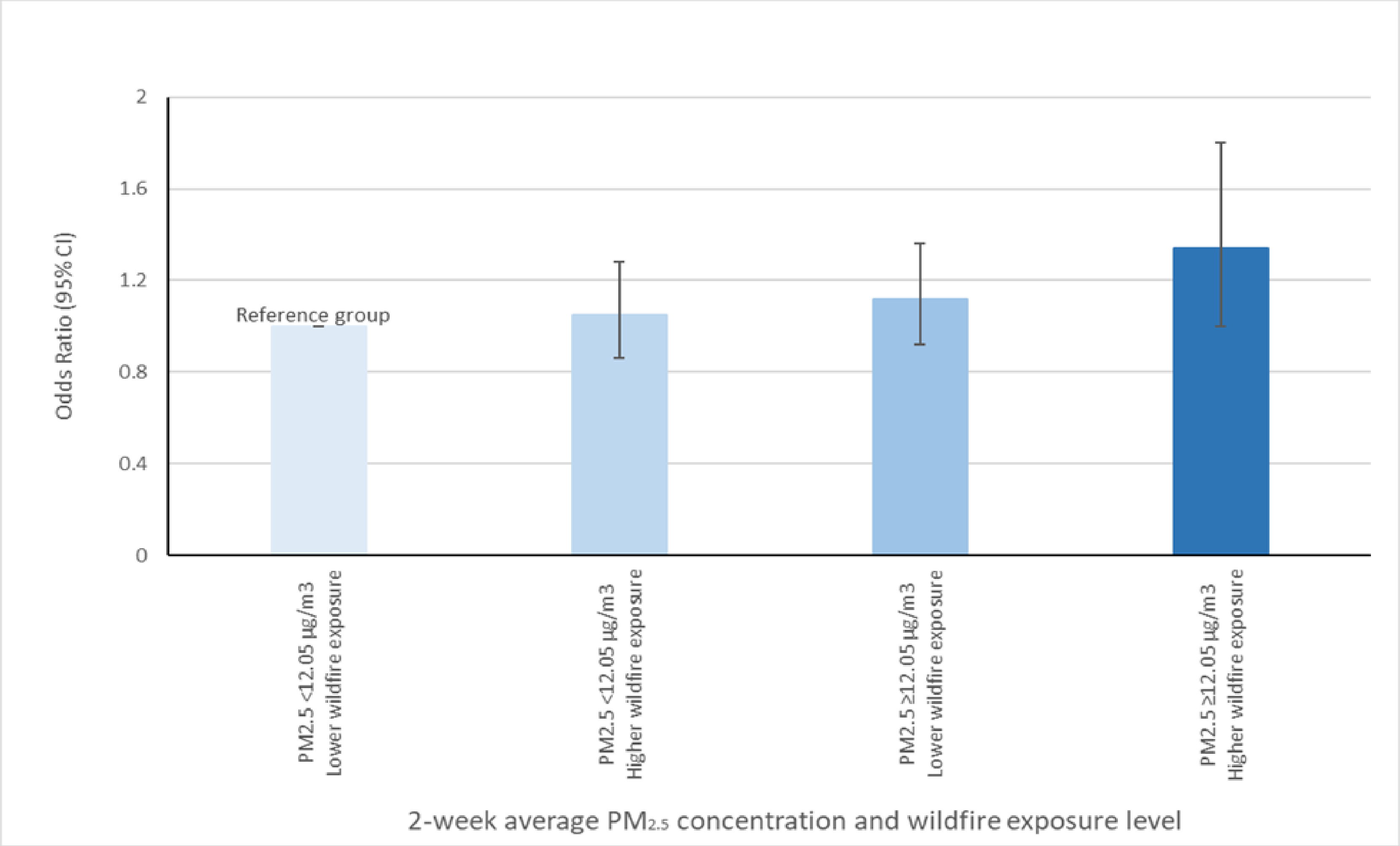
- Higher 2-week average PM2.5 exposure was consistently and positively associated with work loss in almost all categories
- High ORs of work loss were found among those
  - Whose income level of 0-99% FPL (OR= 1.20, 95% CI: 1.02, 1.42)
  - Who lived in a duplex, building with 3 or more units, or mobile homes (OR= 1.08, 95% CI: 1.01, 1.17)
  - Who had chronic conditions (OR= 1.09, 95% CI: 1.00, 1.18)

Influence of wildfire exposure on the association between short-term $PM_{2.5}$ exposure and work loss

Wildfire exposure	N	Cases	2-week average $PM_{2.5}$, per 2.56 µg/m^3 increase OR (95% CI)
Higher	26980	522	1.06 (1.00, 1.13)
Lower	17564	383	1.04 (0.79, 1.39)

Among those respondents who were highly exposed to wildfires, the OR of work loss due to sickness was 1.06 for each 2.56 µg/m^3 increase in 2-week average $PM_{2.5}$ exposure relative to those with lower wildfire exposure

Higher wildfire and higher total $PM_{2.5}$ exposures on work loss



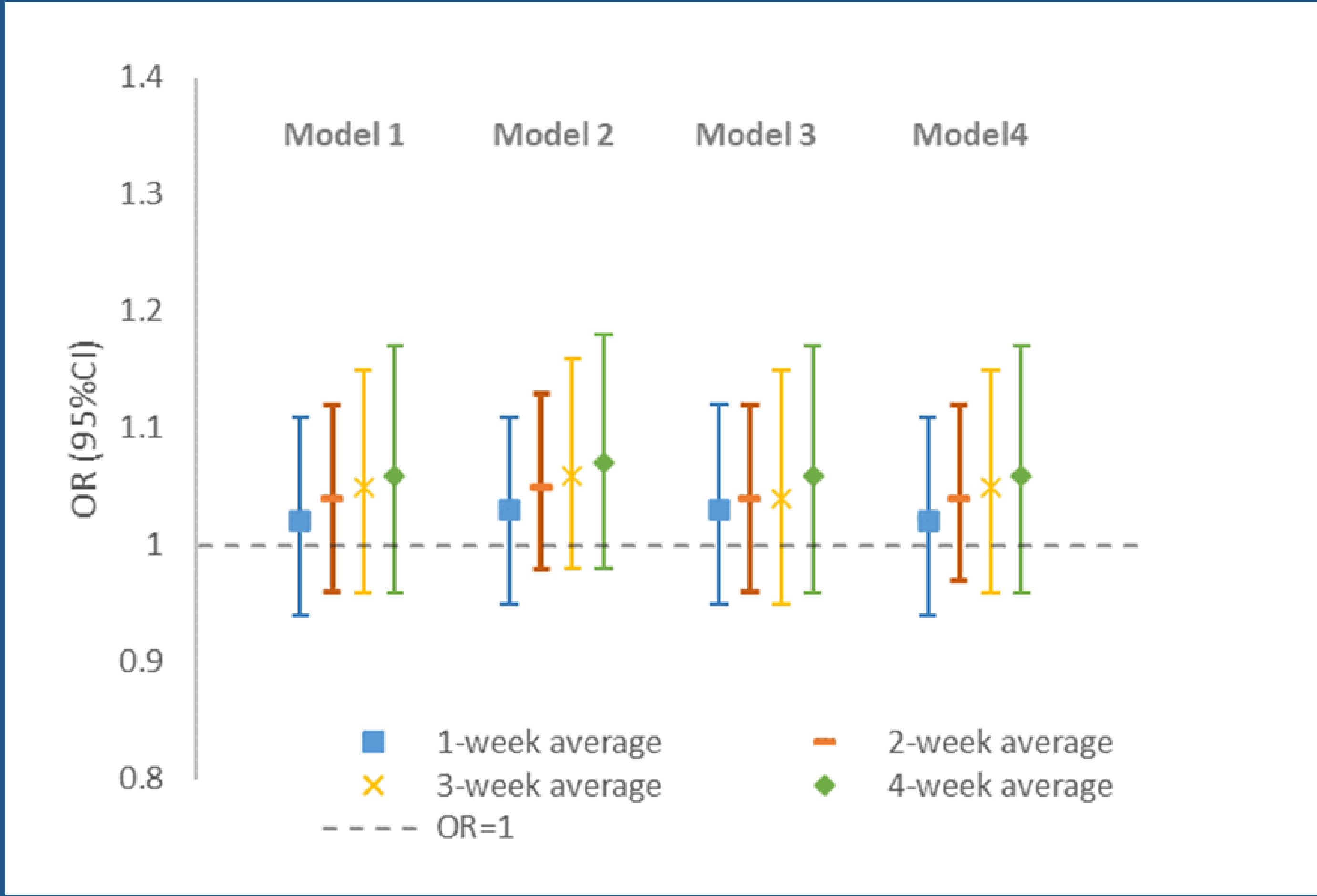
The odds ratio for work loss event among those exposed to a high level of $PM_{2.5}$ (≥ 12.05 µg/m³) who were also exposed to higher-level wildfire was 1.34, compared with those exposed to low level of $PM_{2.5}$ as well as low exposure to wildfire

Effect estimates (and 95%CIs) from other models for short-term PM2.5 exposure on work loss events.

Model comparison	2-week average PM2.5 exposure	
	per 2.56 μg/m³ increase	*≥ 12.05 vs. < 12.05 μg/m³*
	OR (95% CI)	OR (95% CI)
Logistic Model (logit function) (Final weight + Replicate weight)	1.05 (0.98, 1.13)	1.44 (1.00, 2.10)
Firth Model (to address rare event issues with final weight only)	1.048 (1.046, 1.050)	1.447 (1.436, 1.458)
Poisson Model (Final weight +Bootstrap:1000 resample)	1.04 (0.98, 1.10)	1.38 (1.05, 1.74)
Logistic Model (logit function) (Propensity score weighting method)	1.05 (0.99, 1.12)	1.45 (1.01, 2.10)

Note: Models were adjusted for age, sex, income/poverty level, race/ethnicity, smoking status, comorbidity, interview year. Poverty level was assigned using the household incomes and number of persons in the household.
*Other race/ethnicity includes African American only, American Indian/Alaska Native only, Native Hawaiian/Pacific Islander and two or more races
** Other housing type includes duplex, building with 3 or more units and mobile home.

Effect estimates (and 95%CIs) from logistic regression models for short-term (1 to 4-week average) PM2.5 exposure (continuous, per IQRs increase) on work loss events.



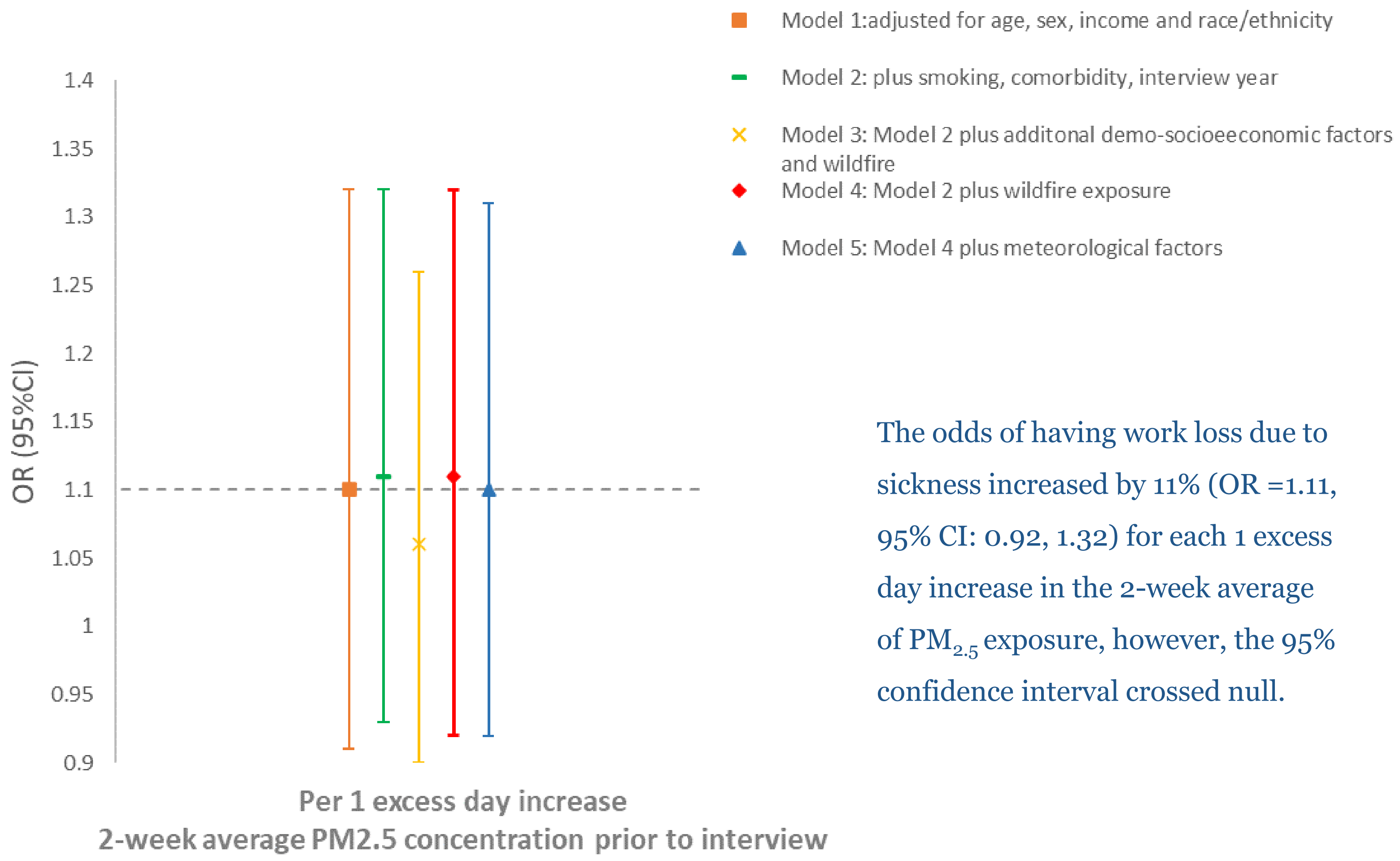
Notes: Model 1 was adjusted for age, sex, income/poverty level and race/ethnicity; Model 2 was additionally adjusted for smoking status, comorbidity, interview year; Model 3 was additionally adjusted for smoking status, comorbidity, interview year, interview season, insurance coverage, occupation, urban/rural, length of living at current address, part/full time job; Model 4 was additionally adjusted for smoking status, comorbidity, interview year, wildfire exposure, temperature, precipitation, relative humidity, dew point, wind run and windspeed.

Exceedance days (PM2.5 ≥ 35 μg/m3, per 1 day increase) and work loss events

Table. Frequency distribution of exceedance days during the 2-week period (week 2 and week 3 before the interview date) among CHIS respondents 2015-2018.

	Total (n=44544)		With Work Loss Events (n=905)		With No-Work Loss Events (n=43639)	
Frequency of exceedance days	N	% (Weighted)	N	% (Weighted)	N	% (Weighted)
Zero	43115	96.63%	871	93.5%	42244	96.8%
1-3	1193	2.85%	29	5.7%	1164	2.8%
4 - 6	1338	0.29%	5	0.8%	133	0.3%
7 - 9	64	0.17%	0	0.0%	64	0.2%
10 - 12	34	0.06%	0	0.0%	34	0.1%

Effect estimates (and 95%CIs) from logistic regression models for exceedance days ($PM2.5 \geq 35$ μg/m3, per 1 day increase) on work loss events.



The odds of having work loss due to sickness increased by 11% (OR =1.11, 95% CI: 0.92, 1.32) for each 1 excess day increase in the 2-week average of $PM_{2.5}$ exposure, however, the 95% confidence interval crossed null.

- Positive association was found between short-term daily total PM2.5 exposure and work loss due to sickness
- The association was stronger among those who were highly exposed to wildfire smoke, compared to those with lower wildfire smoke exposure

Part II:

Health and Economic Cost Estimates of Short-term Total and Wildfire $PM_{2.5}$ Exposure on Work Loss

Steps of Health and Economic Impact Calculation for Daily Total PM2.5

1. Repeated the analyses by rescaling the continuous exposure variable to **per 1µg/m3 increase** in 2-week average PM2.5 exposure prior to the interview date
2. Calculate the weekly incidence rate of the work loss days per person each year using CHIS data
3. Calculate the health impacts - increased work loss days due to sickness for each 1-µg/m^3 increase in daily total PM2.5 exposure based on the following equation adopted from BenMAP-CE:

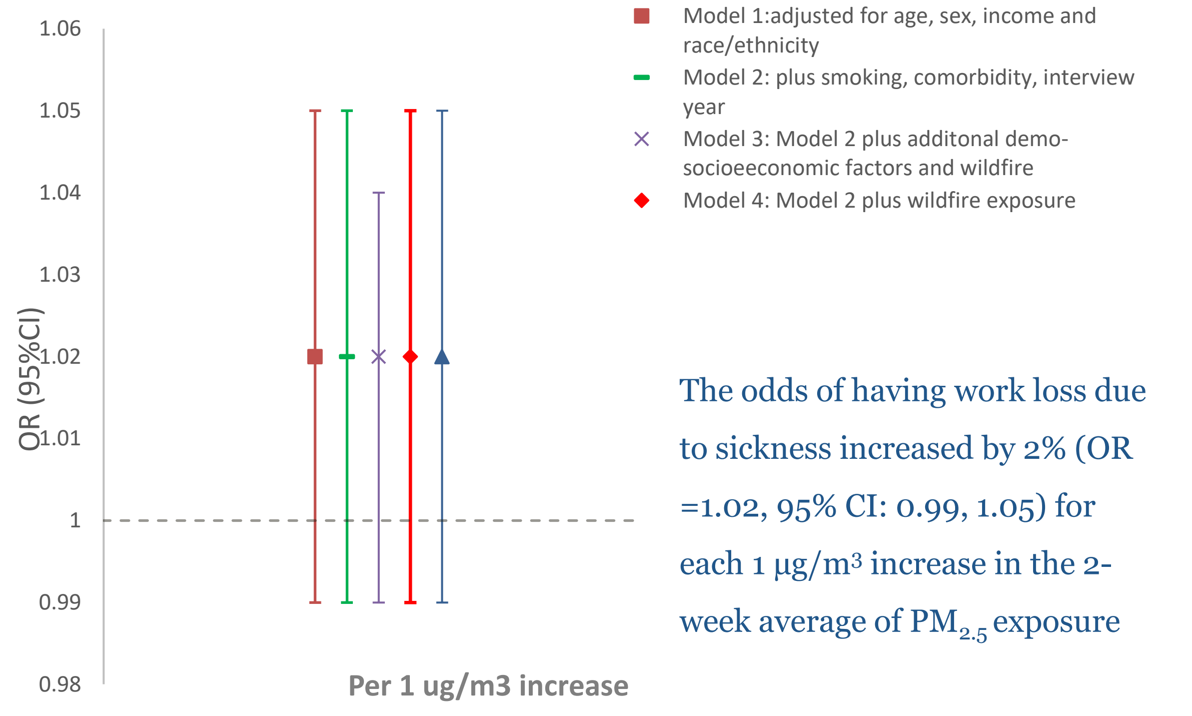
$$\Delta \text{ Incidence} = \Delta\, y \times \text{Population} = (y_1 - y_0) \times \text{Population}$$

$$\Delta\, y = [y_0 \times (e^{\beta \times \Delta PM} - 1)]$$

4. Apply the updated California state-wide average daily salary ($249.04 per day in 2015-2018 from the Bureau of Labor Statistics) to calculate the economic impacts related
5. Additionally, redo the above health and economic impact calculations using the coefficient (Ostro et al 1997), average annual incidence rate of work loss days per person and daily salary from BenMAP for comparison.

Coefficient ($\beta_{PM2.5}$) of the PM2.5 effect estimate = 0.0193 (Std = 0.00143)

where exp ($\beta_{PM2.5}$) represents the odds ratio for work loss corresponding to per 1 µg/m3 increase in 2-week average PM2.5 exposure prior to the interview



The odds of having work loss due to sickness increased by 2% (OR =1.02, 95% CI: 0.99, 1.05) for each 1 µg/m³ increase in the 2-week average of $PM_{2.5}$ exposure

2-week average PM2.5 concentration prior to interview

Models	**2-week average $PM_{2.5}$ exposure,** *per 1 µg/m³ increase* OR (95% CI)
Logistic Model (logit function) (Final weight + Replicate weight)	1.02 (0.99, 1.05)
Firth Model (to address rare event issues with final weight only)	1.020 (1.019, 1.021)
Poisson Model (Final weight +Bootstrap:1000 resample)	1.02 (0.99, 1.04)
Logistic Model (logit function) (Propensity score weighting method)	1.02 (0.99, 1.04)

Health and Economic Impact Estimates of Work Loss Associated with Daily Total PM2.5

Estimated number and cost of work loss days associated with $PM_{2.5}$ exposure (per 1µg/m³ increase) in California, using the incidence rate calculated by CHIS weighted data and updated salary rate, 2015-2018.

Year	*Weekly work-loss-day incidence rate per person (CHIS)*	*Avg work loss days per year in CA (Cawley et al. 2021)*	*Annual incidence rate of work loss days per person*	*β (CHIS)**	*Delta $\Delta PM_{2.5}$ (µg/m³)*	$\Delta y = [y_0 \times (e^{\beta \times \Delta PM} - 1)]$	*Population in CA (BenMAP listed)*	*Work loss days estimate (Δ Incidence = Δ Incidence rate × Population)*	*Median daily wage ($)***	*Economic cost due to work loss per year ($)*
2015-2018	0.017	3.26	**2.863**	0.0193	1	0.0557829	24,932,520	**1,390,808**	249.04	**346,366,706**
2015	0.017	3.26	**2.948**	0.0193	1	0.0574502	24,707,640	**1,419,460**	237.30	**336,837,867**
2016	0.020	3.26	**3.316**	0.0193	1	0.0646245	24,868,644	**1,607,124**	242.17	**389,197,239**
2017	0.016	3.26	**2.777**	0.0193	1	0.0541160	25,013,056	**1,353,606**	253.30	**342,868,331**
2018	0.014	3.26	**2.422**	0.0193	1	0.0471999	25,140,738	**1,186,641**	263.38	**312,537,479**

Note: *According to our study, for each 1 µg/m³ increase in 2-week average $PM_{2.5}$ level, the odds of work loss were 1.02 (95% CI: 0.99, 1.05). Beta = 0.0193, Std = 0.0143.
** The median daily wage rate referred here was from the state-wide average daily salary in California in 2015-2018 from the Bureau of Labor Statistics (https://www.statista.com/statistics/305761/california-annual-pay/).

Estimated number and cost of work loss days associated with $PM_{2.5}$ exposure (per 1µg/m³ increase) in California, using both the coefficient (Ostro 1987) and incidence rate adopted from BenMAP, 2015-2018.

Year	*Weekly work-loss-day incidence rate per person (BenMAP)*	*Annual incidence rate of work loss days per person*	*β (Ostro)**	*Delta $\Delta PM_{2.5}$ (µg/m³)*	$\Delta y = [y_0 \times (e^{\beta \times \Delta PM} - 1)]$	*Population in CA (BenMAP listed)*	*Work loss days estimate (Δ Incidence = Δ Incidence rate × Population)*	*Median daily wage ($)***	*Economic cost due to work loss per year ($)*
2015-2018	0.042	2.17	0.0046	1	0.010005	24,932,520	**249,450**	189.6	**47,283,191**
2015	0.042	2.17	0.0046	1	0.010005	24,707,640	**247,200**	182.7	**45,163,401**
2016	0.042	2.17	0.0046	1	0.010005	24,868,644	**248,811**	186.6	**46,428,064**
2017	0.042	2.17	0.0046	1	0.010005	25,013,056	**250,255**	191.2	**47,848,846**
2018	0.042	2.17	0.0046	1	0.010005	25,140,738	**251,533**	197.7	**49,728,060**

Note: *For each 1 µg/m³ increase in 2-week average of fine particles, the Beta = 0.0046, Std = 0.0021.
** The median daily wage rate referred here was from BenMAP calculations for the wildfire-specific $PM_{2.5}$ exposure related economic impact.

Steps of Health and Economic Impact Calculation for Wildfire-Specific PM2.5

1. Repeated the analyses by rescaling the continuous exposure variable to **per 1μg/m3 increase** in 2-week average PM2.5 exposure prior to the interview date
2. Input CMAQ models with fire (all emissions, fire and non-fire sources) and without fire sources (non-fire sources only) emissions run for each year into the BenMAP-CE platform:

   To isolate wildfire-specific PM2.5 concentrations

   by subtracting the daily averages of the control from the daily average baseline CMAQ concentrations
3. Calculate the health and economic impacts - increased work loss days due to wildfire smoke exposure only using same equation and the annual incidence rate and median daily salary incorporated in BenMAP-CE platform

$$\Delta \text{ Incidence} = \Delta y \times \text{Population} = (y_1 - y_0) \times \text{Population}$$

$$\Delta y = [y_0 \times (e^{\beta \times \Delta PM} - 1)]$$

4. Repeat the health and economic impact calculations using the coefficient derived from our study , but with average annual incidence rate of work loss days per person and daily salary of BenMAP.

Health and Economic Impact Estimates of Work Loss Associated with Wildfire-specific PM2.5

Table. BenMAP calculated (Meng 2022) number of work loss days and economic cost associated with wildfire-specific $PM_{2.5}$ exposure in California, 2015-2018.

Year	Endpoint	Author	Delta ($\Delta PM_{2.5}$ Concentration)	Population	Work Loss Days	Economic Cost due to Work Loss
2015	Work Loss Days	Meng	0.71	24,707,640	**708,206**	**129,381,224**
2016	Work Loss Days	Meng	1.02	24,868,644	**1,016,952**	**189,764,176**
2017	Work Loss Days	Meng	2.82	25,013,056	**2,659,312**	**508,400,000**
2018	Work Loss Days	Meng	2.67	25,140,738	**2,652,724**	**521,826,144**

Note: For each 1 µg/m³ increase in 2-week average daily total $PM_{2.5}$ level, the odds of work loss were 1.02 (95% CI: 0.99, 1.05). Beta = 0.0193, Std = 0.0143.

Table. BenMAP calculated (Ostro 1987) number of work loss days and economic cost associated with wildfire-specific $PM_{2.5}$ exposure in California, 2015-2018.

Year	Endpoint	Author	Delta ($\Delta PM_{2.5}$ Concentration)	Population	Work Loss Days	Economic Cost due to Work Loss
2015	Work Loss Days	Ostro	0.71	24,707,640	**170,562**	**31,159,792**
2016	Work Loss Days	Ostro	1.02	24,868,644	**247,405**	**46,166,012**
2017	Work Loss Days	Ostro	2.82	25,013,056	**673,870**	**128,828,672**
2018	Work Loss Days	Ostro	2.67	25,140,738	**651,289**	**128,117,200**

Note: For each 1 µg/m³ increase in 2-week average of fine particles, the Beta = 0.0046, Std = 0.0021. $\Delta PM_{2.5}$ Concentration was automatically calculated and reported by BenMAP.

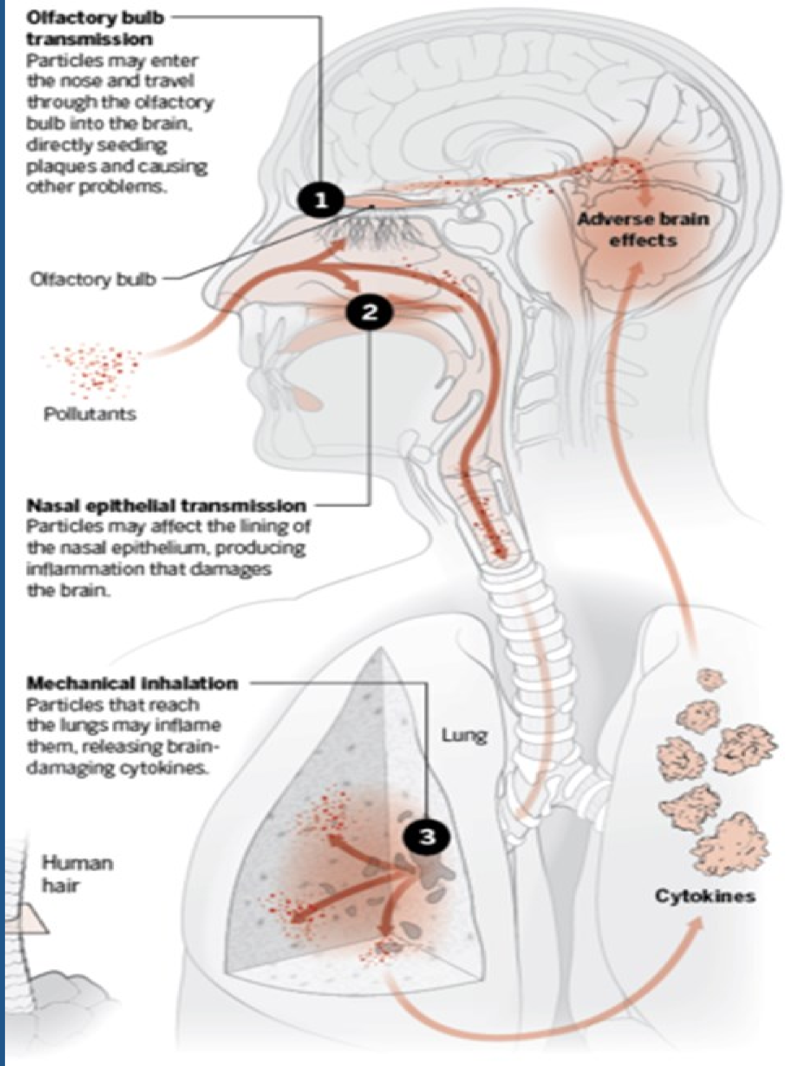
- Each 1-µg/m³ increase in daily total $PM_{2.5}$ exposure will lead to 1.1-million to 1.6-million work loss days, and the related economic loss was 310 to 390 million dollars.
- The wildfire smoke alone could contribute to 0.7-million to 2.6-million work loss days and with a related economic loss of 129 - 521 million dollars per year between 2015-2018.
- Our findings suggest that current standard BenMAP estimates could **underestimate** the related health and economic impact when using Ostro's estimate coefficient, current BenMAP incidence rate and salary rate.

Our study has **improved** estimates in several ways:

- Study sample size
- Exposure assessment methods
- Statistical methods (e.g. sample weights)
- Annual incidence rate of work loss calculated using CHIS data
- Updated median daily salary rates

Total PM2.5 Exposure and Work Loss due to Sickness

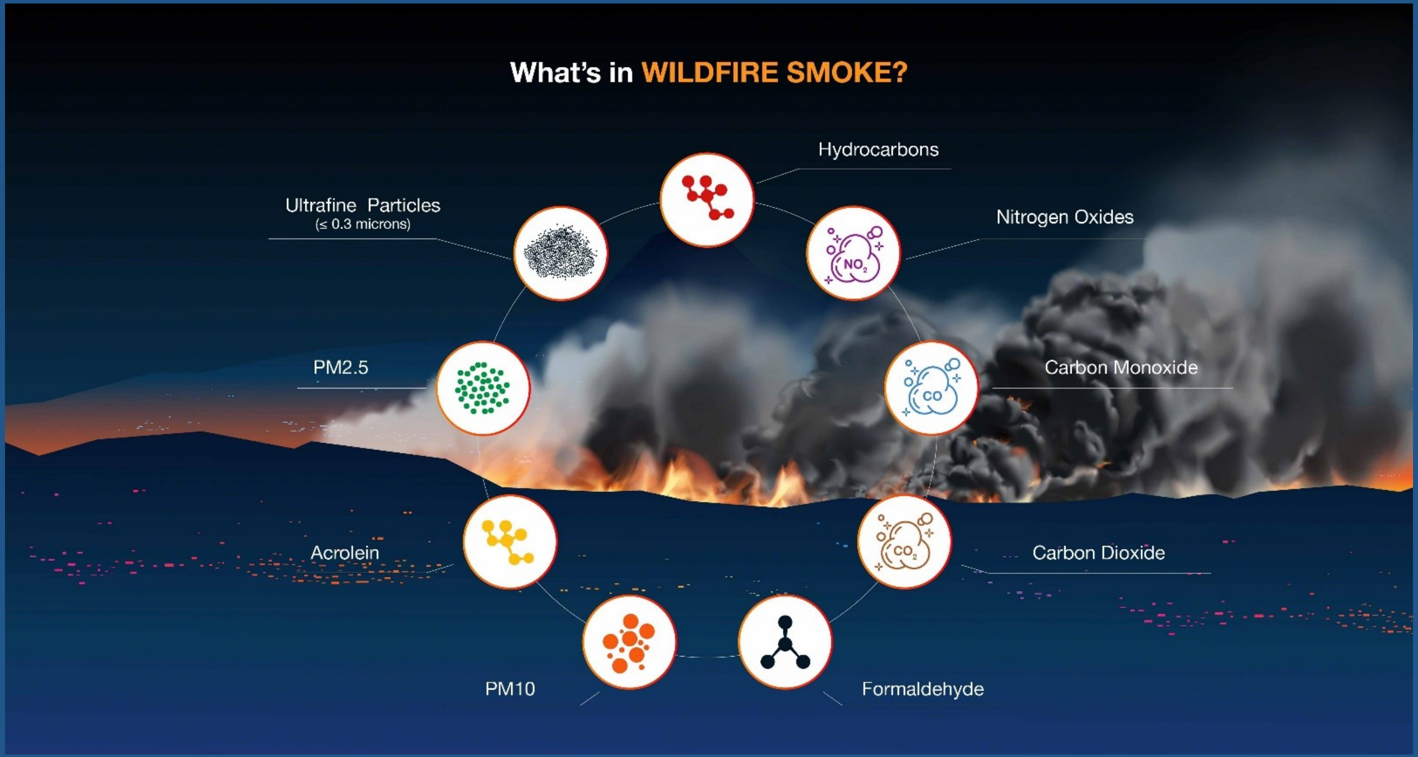
- Air pollution, especially PM2.5, has been evidenced to cause various diseases
- Can carry many toxic chemicals and penetrate the respiratory system more deeply and enter into the bloodstream
- Conventional primary PM2.5 are commonly composed of dust from roads and black or elemental carbon from combustion sources, as well as fossil fuels combustion, which resulted from multiple moderately volatile and potentially toxic elements including the chalcophile elements
- Our study joined a small number of studies and added the empirical evidence that short-term PM2.5 exposure was associated with work loss due to sickness



Different Composition and Higher Toxicity of Wildfire-related $PM_{2.5}$

Previous studies have suggested:

- Wildfire-related PM2.5 is more toxic than PM2.5 from conventional sources
  (Holm et al., 2009; Wegesser et al. 2009)
  - Different composition of $PM_{2.5}$ during smoke waves
  - Influenced by vegetation types, combustion efficiency and weather conditions such as moisture content, fire temperature and wind conditions



Reference:
(1) Holm, S.M., Miller, M.D., Balmes, J.R., 2020. Health effects of wildfire smoke in children and public health tools: a narrative review. J Expo Sci Environ Epidemiol.
(2) Wegesser, T.C., Pinkerton, K.E., Last, J.A., 2009. California wildfires of 2008: coarse and fine particulate matter toxicity. Environ Health Perspect. 117 (6), 893–897.
(3) https://www.iqair.com/us/newsroom/how-to-protect-yourself-from-wildfire-smoke.

Higher Toxicity of Wildfire-related $PM_{2.5}$ (Animal Studies)

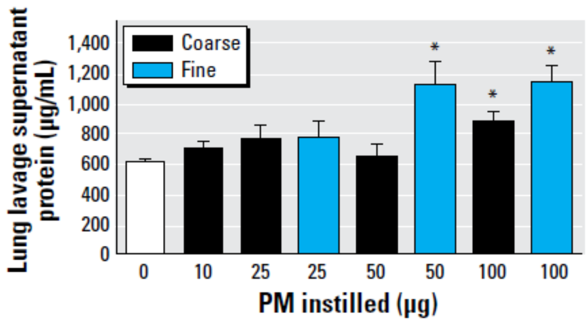


Figure 3. Protein content of lung lavage fluid supernatant of mice instilled with the indicated amounts of wildfire $PM_{10-2.5}$ or $PM_{2.5}$.
*$p < 0.05$ compared with control.

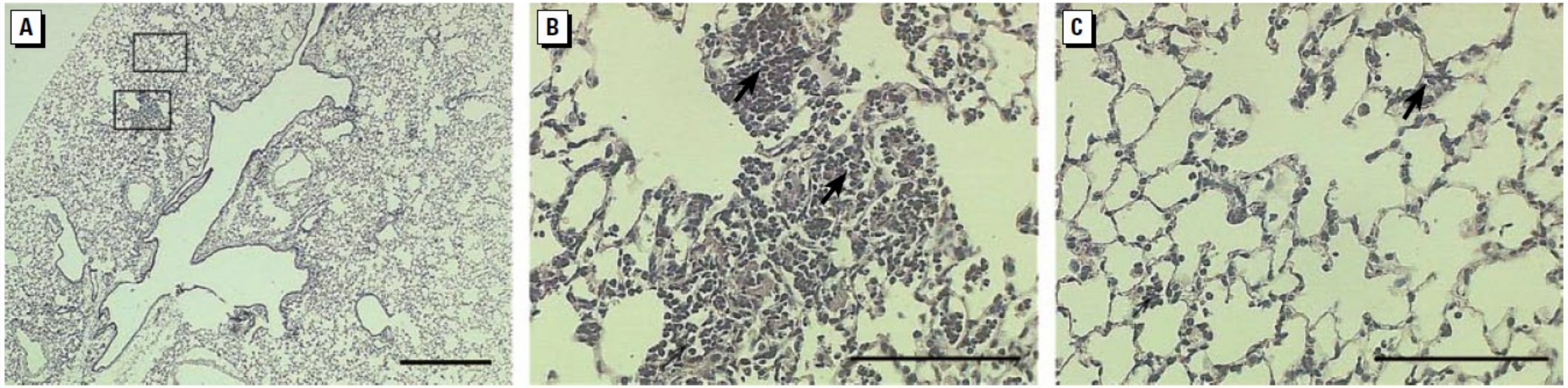


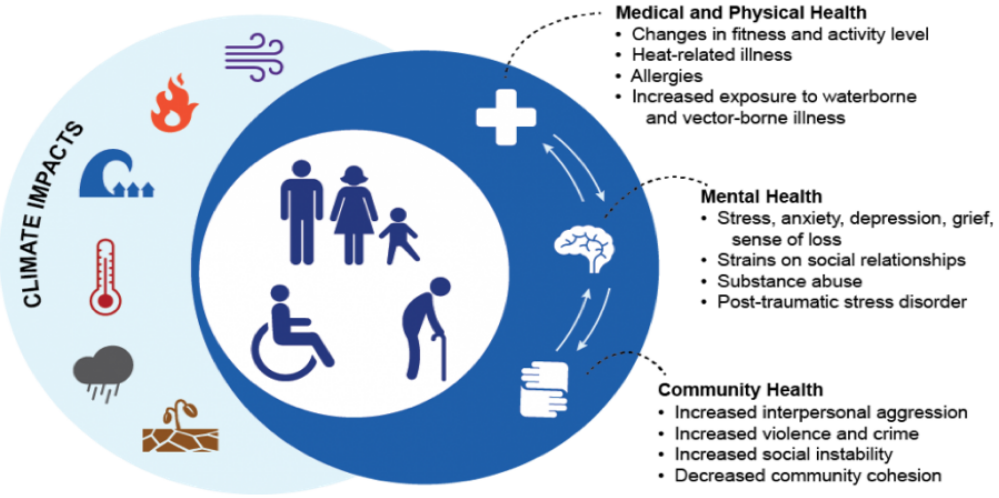
Figure 6. Representative lung sections from mice instilled 24 hr with 100 µg wildfire $PM_{2.5}$. (*A*) Whole lung (low-magnification; bar = 500 µm); boxes indicate areas shown in higher magnification in (*B*) and (*C*). (*B*) Centriacinar lung region showing the prominent accumulation of numerous inflammatory cells within alveolar airspaces. (*C*) Distal alveolar region with a diffuse increase in septal cellularity and occasional inflammatory cells within the alveolar airspaces. Arrows indicate areas of inflammatory cell influx. Bar = 100 µm in (*B*) and (*C*).

Reference: Wegesser TC, Pinkerton KE, Last JA. California wildfires of 2008: coarse and fine particulate matter toxicity. *Environ Health Perspect*. 2009;117(6):893-897.

Other Impacts from Wildfire Smoke

- Wildfire could also exert various impacts and risks on mental health or psychiatric conditions such as depression, sleeping disturbance and anxiety disorders
- Rising evidence has indicated that mental or psychological health disorders can lead to an increased risk of cardiovascular-metabolic diseases both directly via biological pathways and through risky health behaviors

An Illustration on How Climate Change Impacts Physical, Mental, and Community Health



At the center of the diagram are human figures representing adults, children, older adults, and people with disabilities. The left circle depicts climate impacts including air quality, wildfire, sea level rise and storm surge, heat storms, and drought. The right circle shows the three interconnected health domains that will be affected by climate impacts--Medical and Physical Health, Mental Health, and Community Health.

Image source: U.S. Global Change Research Program. 2016. The impacts of Climate Change on Human Health in the United States: A Scientific Assessment.

Reference: https://www.chestfamily.com/

Strengths

- CHIS data
  - A population-based dataset representing Californians
  - Enable to investigate subacute health outcomes that cannot derived from medical records
- High Geo-location quality
- State-of-the-art modeling estimates for both total $PM_{2.5}$ and wildfire exposures
- One of the few recent studies in North America exploring air pollution associated work loss due to sickness

Limitations

- Lack objective measures for work loss event
- Exposure measurement error
  - Not accounting for exposure during commute or at work
  - Lack of information regarding indoor sources
- Selection bias
- Limitations related to exposure models

Conclusion

- Positive association was found between short-term $PM_{2.5}$ exposure and work loss due to sickness.
- The association was stronger among those who were highly exposed to the wildfire smoke, compared to those with lower wildfire smoke exposure.
- The current federal and state $PM_{2.5}$ standards (annual average of 12 μg/m^3) could be further strengthened to protect the health of the citizens of California.
- Current National Ambient Air Quality Standards even do not count for the highly $PM_{2.5}$ exposed days due to the wildfire events, while the wildfire-generated $PM_{2.5}$ might be more toxic due to their different compositions.

Acute Health and Economic Impacts of Particulate Matter 2.5 on Work Loss Days (2015-2018)

Health Impact (the odds of work loss)

Wildfire Impact

Increased by **6%** among those who were highly exposed to wildfire

Short-term Total PM2.5 Exposure

Increased by **5%**

Per each 2.56 µg/m3 increase in 2-week average total PM2.5 increase

Increased by **44%**

When the 2-week average total PM2.5 was higher than 12 µg/m3

Economic Impact

Total PM2.5 related Economic Loss

1.1 - 1.6 million work loss days per year

$ 310 – $390 million per year

Wildfire alone induced Economic Loss

0.7-2.6 million work loss days per year

$ 130 – $520 million per year

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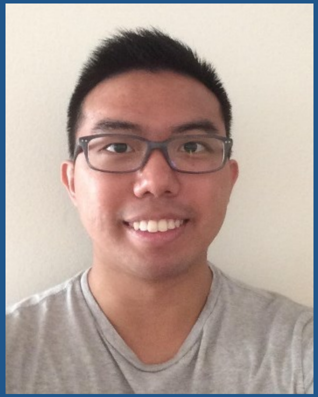
Wei William Zhou, MPH

Thank you!