

UFPs and Population Health

Historical Perspective and Recent Progress in Canada

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UFPs and Me: A Completely Unplanned Journey



2005-2008

“People are exposed to UFPs but we don’t know much about potential population health impacts ”

20 years!



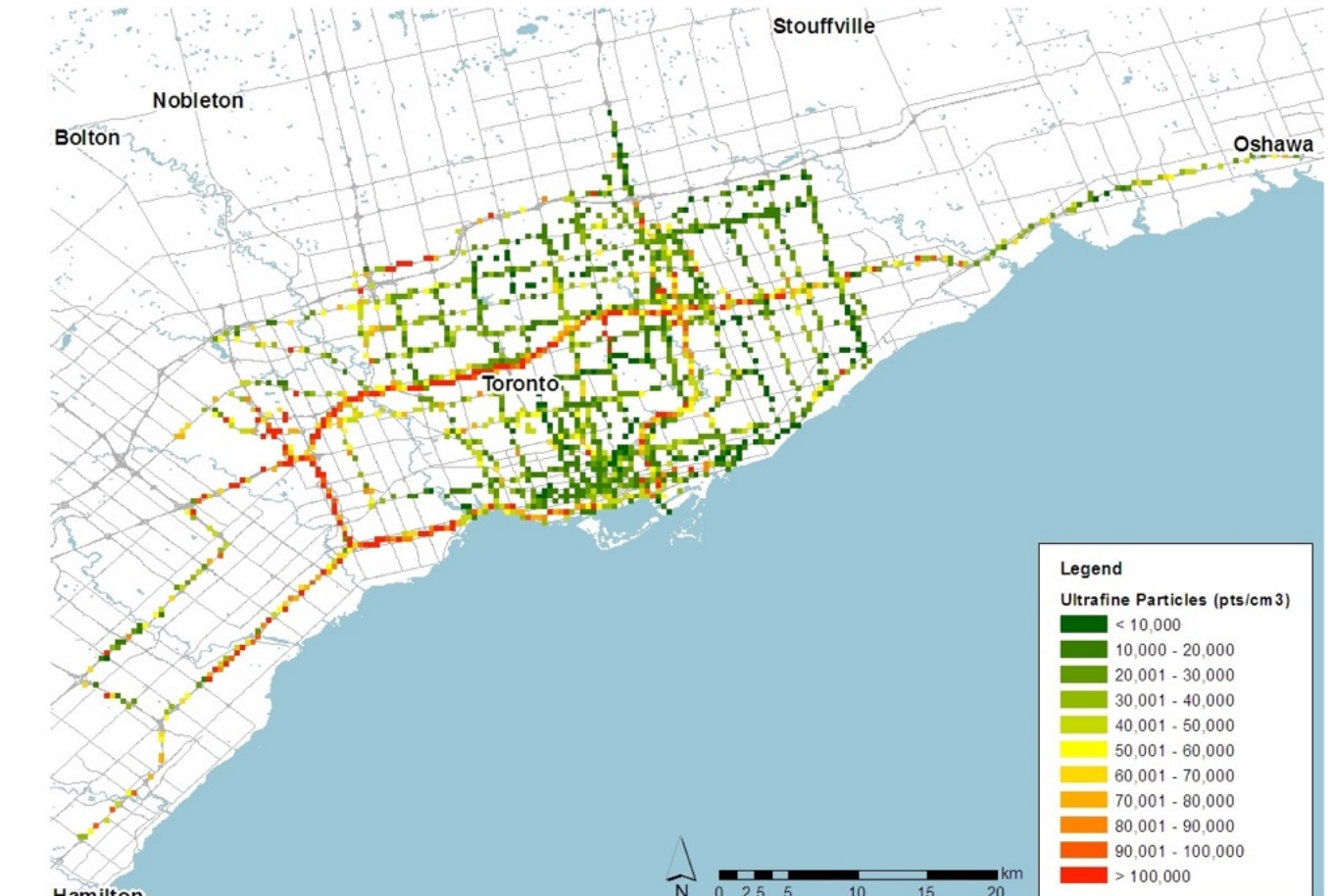
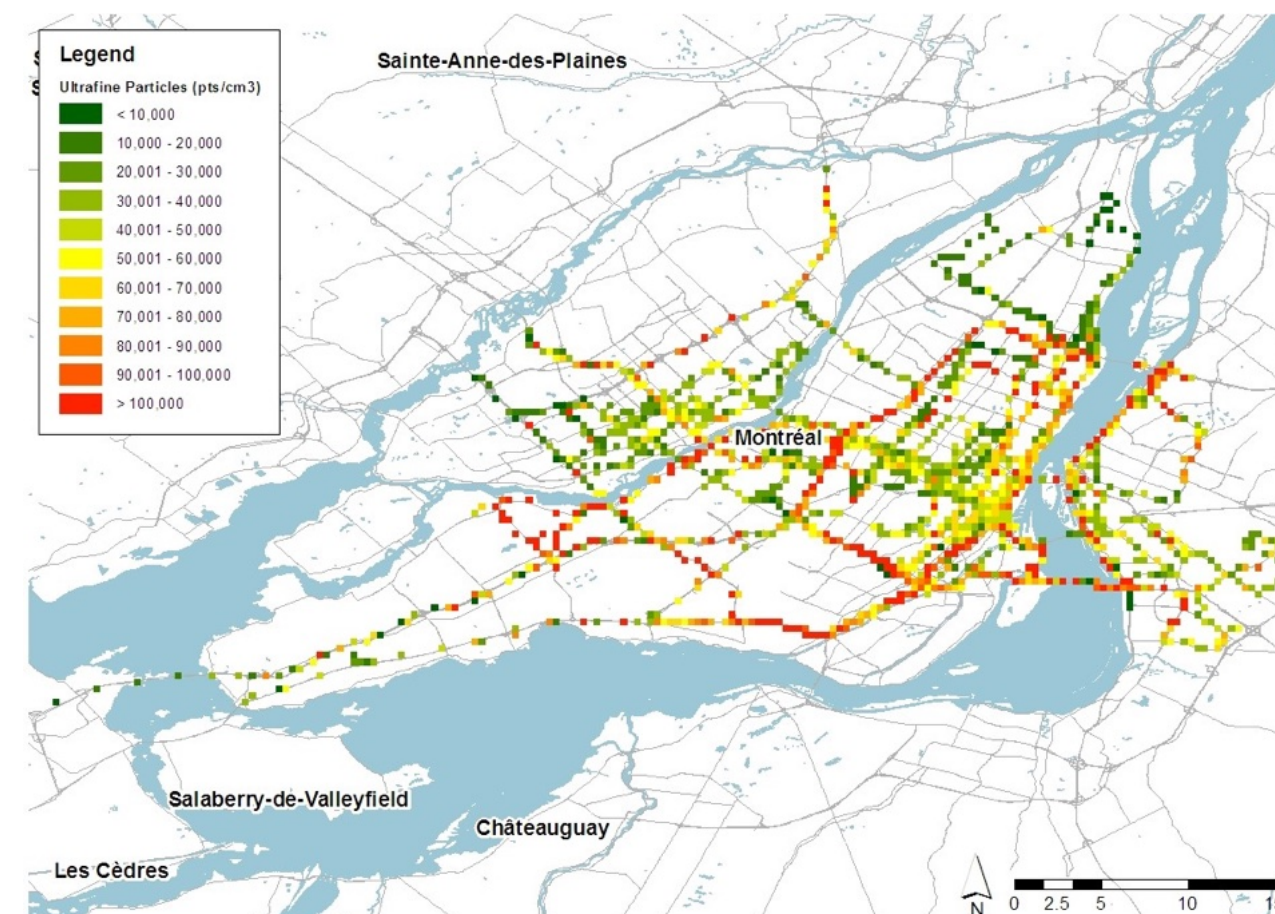
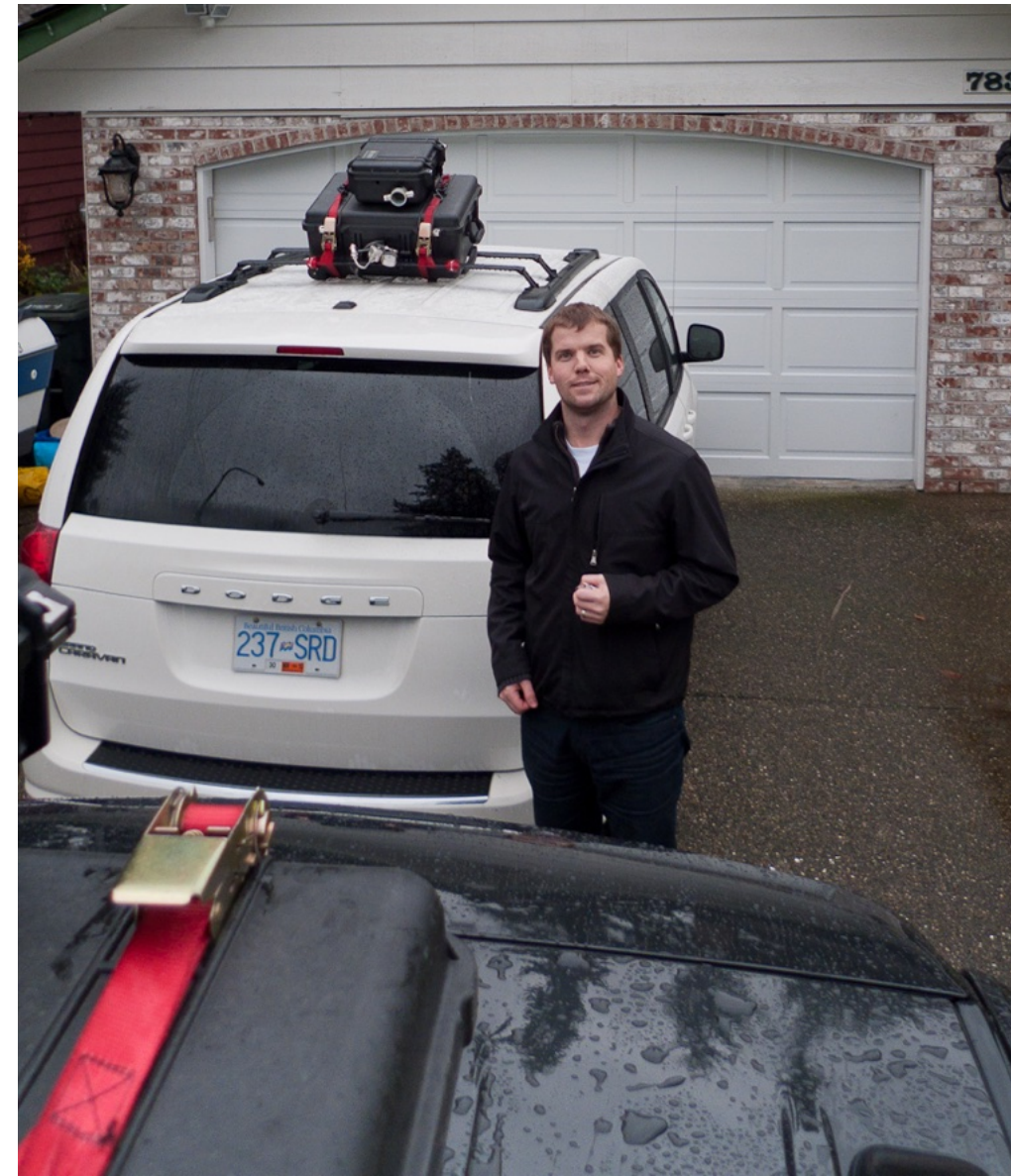
2025

“People are exposed to UFPs, we know where exposures are greatest in cities, and numerous studies now indicate important health impacts including premature mortality and cancer.”

Contributions from Canada

2010-2020s

- **Ottawa Bike Study**
 - *Heart Rate Variability*
- **Montreal Women's Health Study**
 - *Endothelial function*
- **Urban Transportation Exposure Study**
 - *Wide-spread population exposures in Canadian cities*
- **Early LUR models: Montreal and Toronto**
 - *Derived from UTES data above*
- **Numerous Epidemiological Studies**
 - *Nonaccidental /cause-specific mortality*
 - *Multiple cancers: Brain, lung, prostate*
 - *Disease incidence (hypertension, myocardial infraction)*



RESEARCH REPORT

Long-Term Exposure to Outdoor Ultrafine Particles and Black Carbon and Effects on Mortality in Montreal and Toronto, Canada

Scott Weichenthal, Marshall Lloyd, Arman Ganji, Leora Simon,
Junshi Xu, Alessya Venuta, Alexandra Schmidt, Joshua Apte,
Hong Chen, Eric Lavigne, Paul Villeneuve, Toyib Olaniyan,
Michael Tjepkema, Richard T. Burnett, and Marianne
Hatzopoulou

Objectives

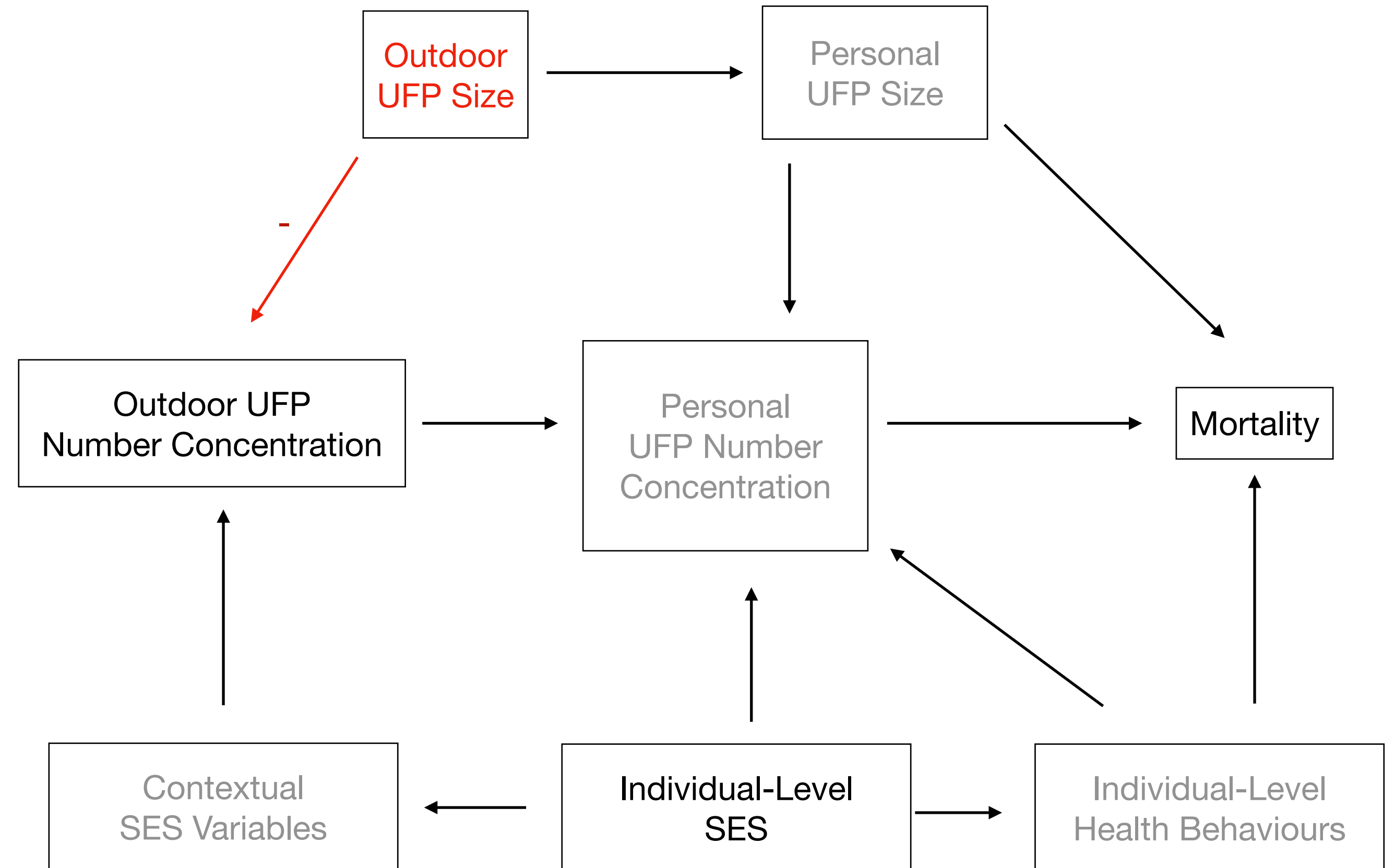
Exposure Modelling

- Address limitations of past models
- Develop new **land use regression models** and **machine learning models including satellite images** for *UFP number concentrations* and *UFP size* in Montreal and Toronto, Canada
- **1-year mobile monitoring campaign**
 - **All days of the week**
 - **Most times of the day**
 - Back-casted exposure estimates

Objectives

Epidemiology

- **Apply new models** in a *cohort study* of long-term exposure to UFPs and mortality in CanCHEC (2001-2016)
 - **Examine and adjust for UFP size** (relates to confounding and version-of-treatment, Weichenthal et al. 2023 AJE)
- Examine concentration-response relationships

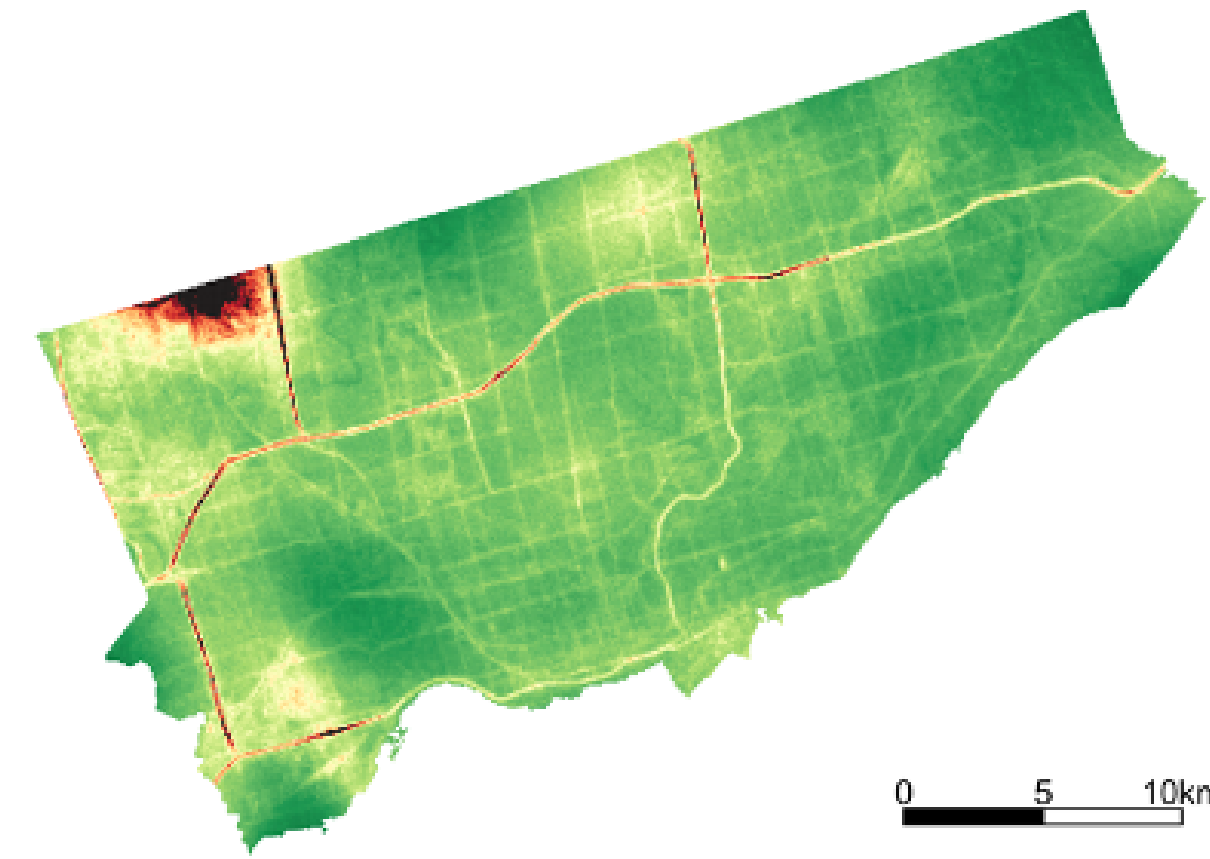


Results

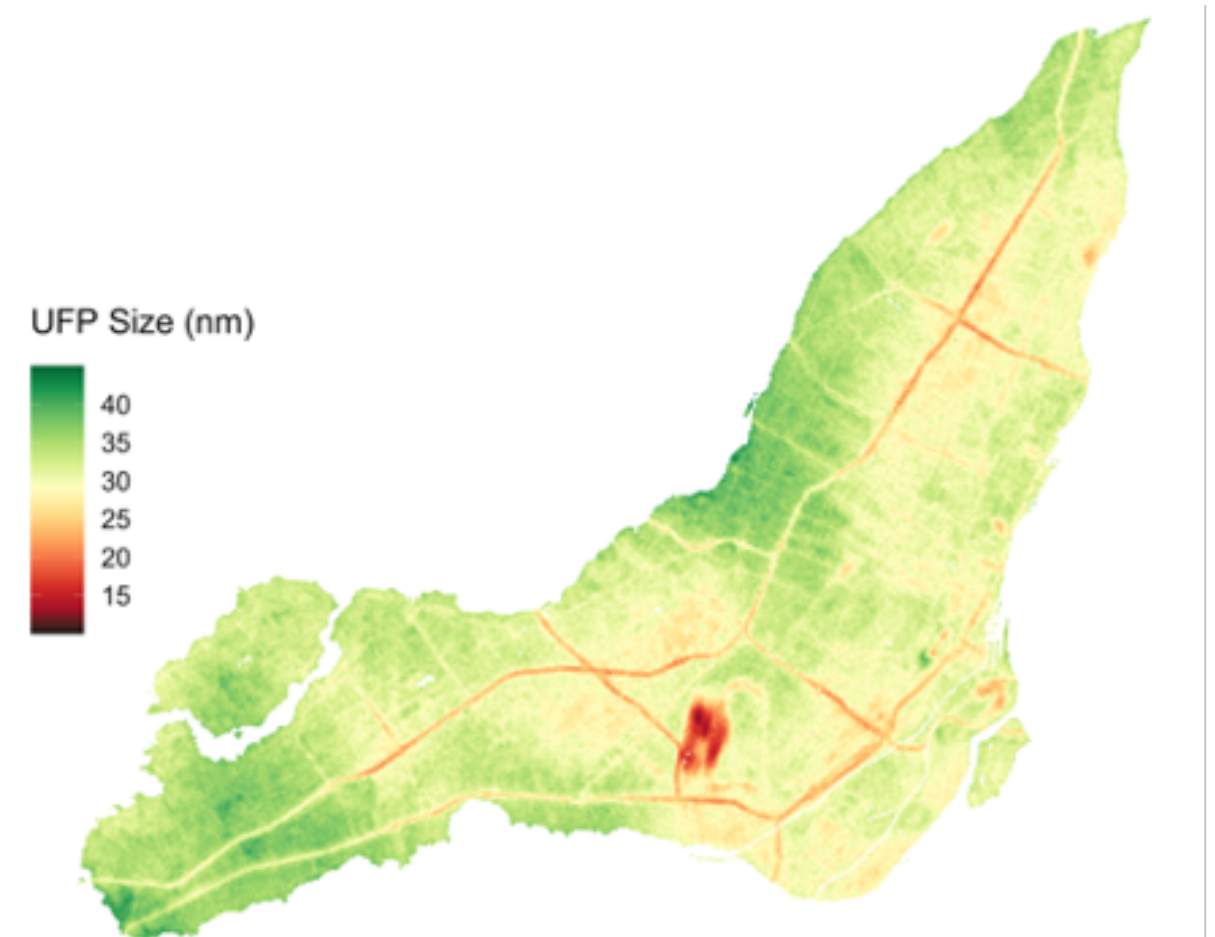
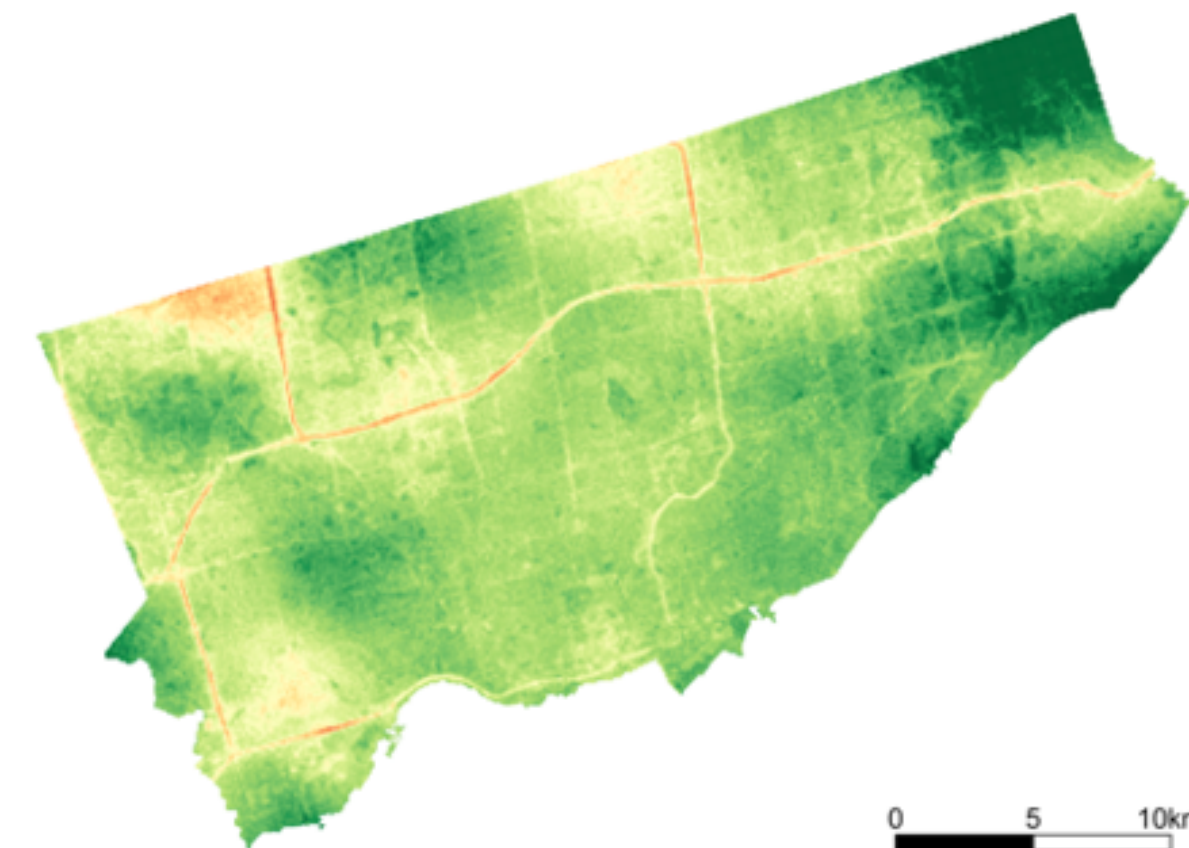
Exposure Modelling

City	Pollutant	R ² in Test Set		
		LUR	CNN	Combined
Montreal	UFP (pt/cm ³)	0.59	0.49	0.60
	UFP Size (nm)	0.48	0.41	0.49
Toronto	UFP (pt/cm ³)	0.71	0.66	0.73
	UFP Size (nm)	0.56	0.43	0.55

Toronto



Montreal



Results

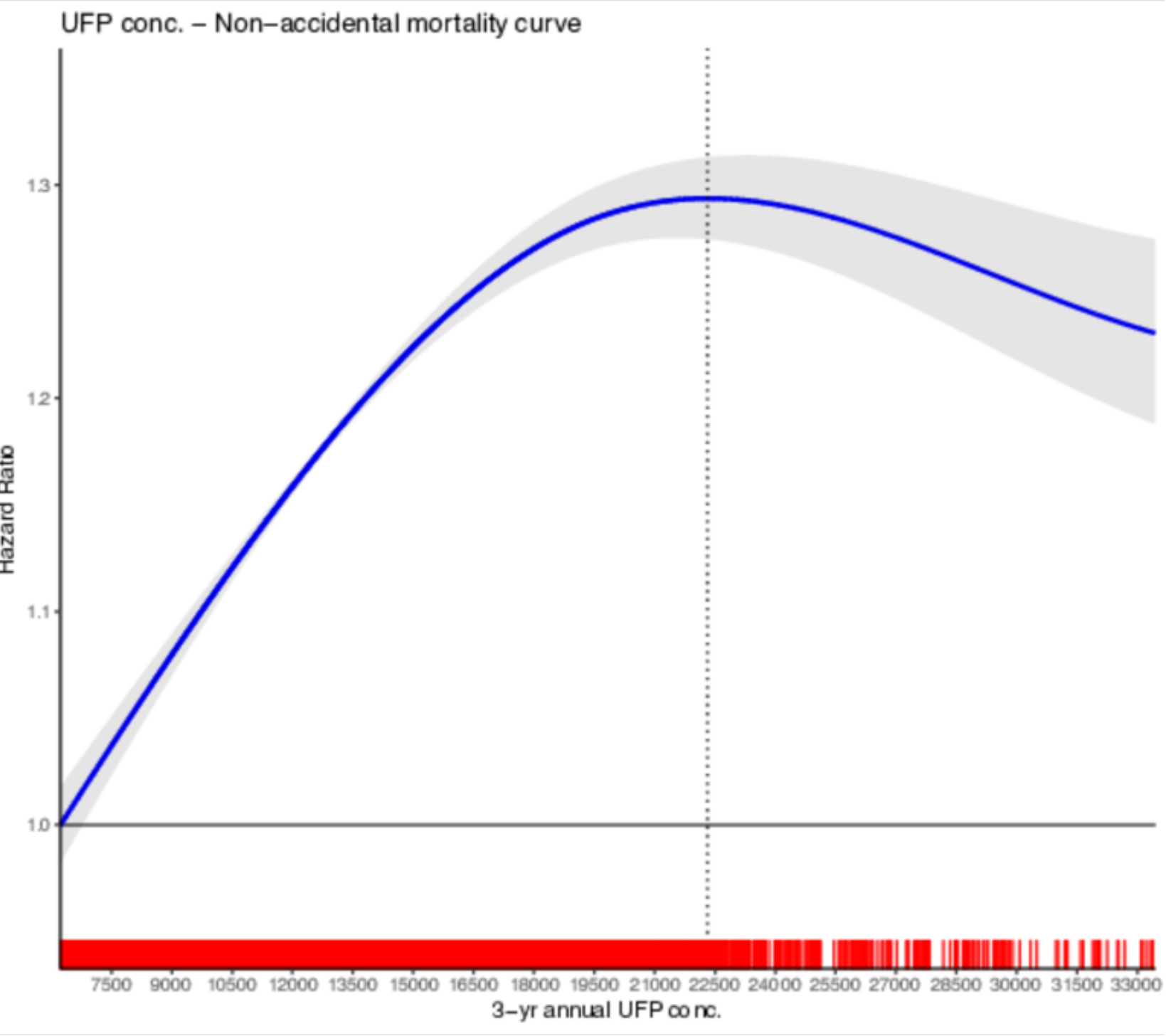
Epidemiology: Excluding UFP Size Underestimates Health Risks

UFP HRs (per ~5000 pt/cm³) with Various Forms of Size in Model (Combined Residential Model with Back-Casting)

Mortality Outcome	UFP Size Not in Model	Continuous term for UFP Size	Non-Linear term for UFP Size
Nonaccidental	1.020 (1.014, 1.025)	1.030 (1.023, 1.037)	1.042 (1.035, 1.049)
Cardiovascular	1.010 (1.001, 1.02)	1.032 (1.019, 1.044)	1.040 (1.027, 1.054)
Cerebrovascular	0.992 (0.97, 1.015)	1.024 (0.995, 1.053)	1.035 (1.004, 1.067)
Respiratory	1.053 (1.035, 1.07)	1.081 (1.06, 1.104)	1.098 (1.074, 1.123)
Lung Cancer	1.031 (1.015, 1.048)	1.023 (1.001, 1.045)	1.033 (1.010, 1.056)

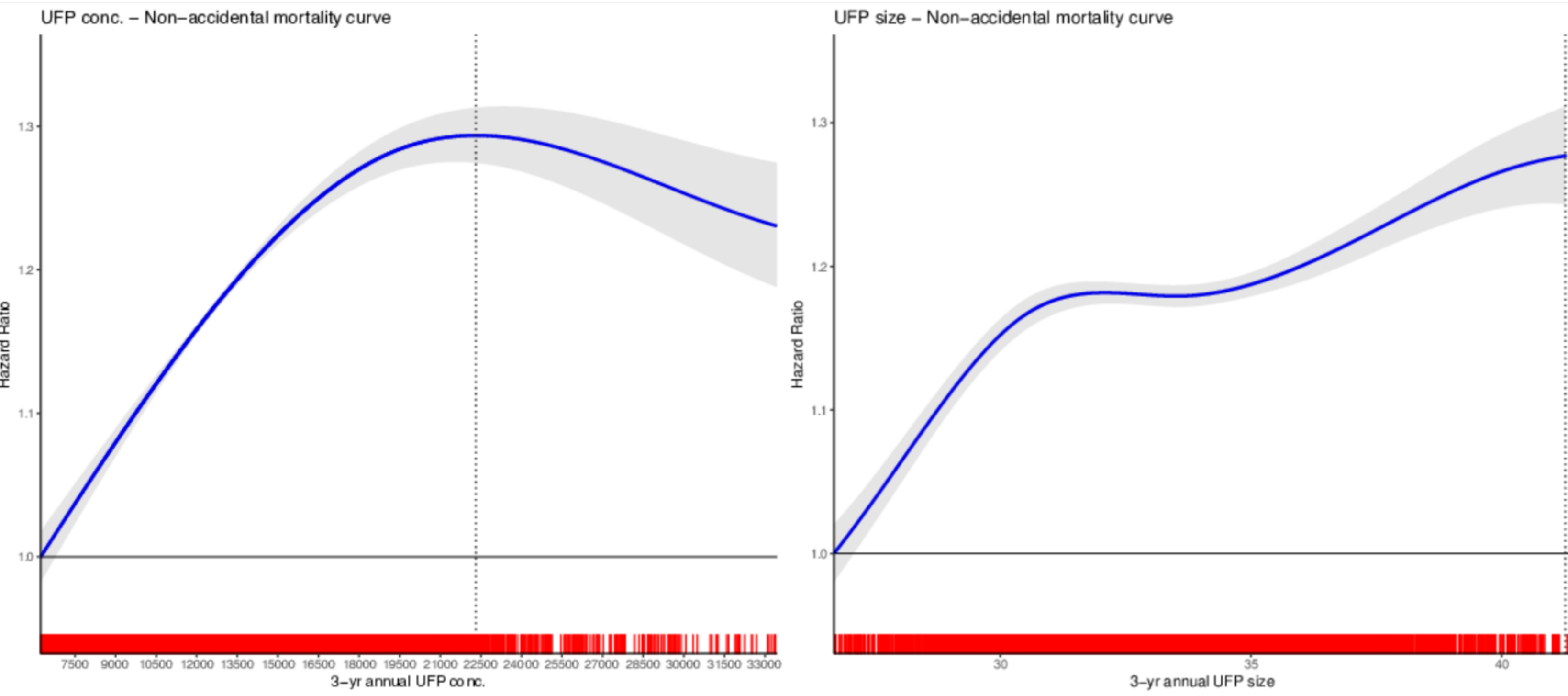
Results

Epidemiology: UFPs and Nonaccidental Mortality



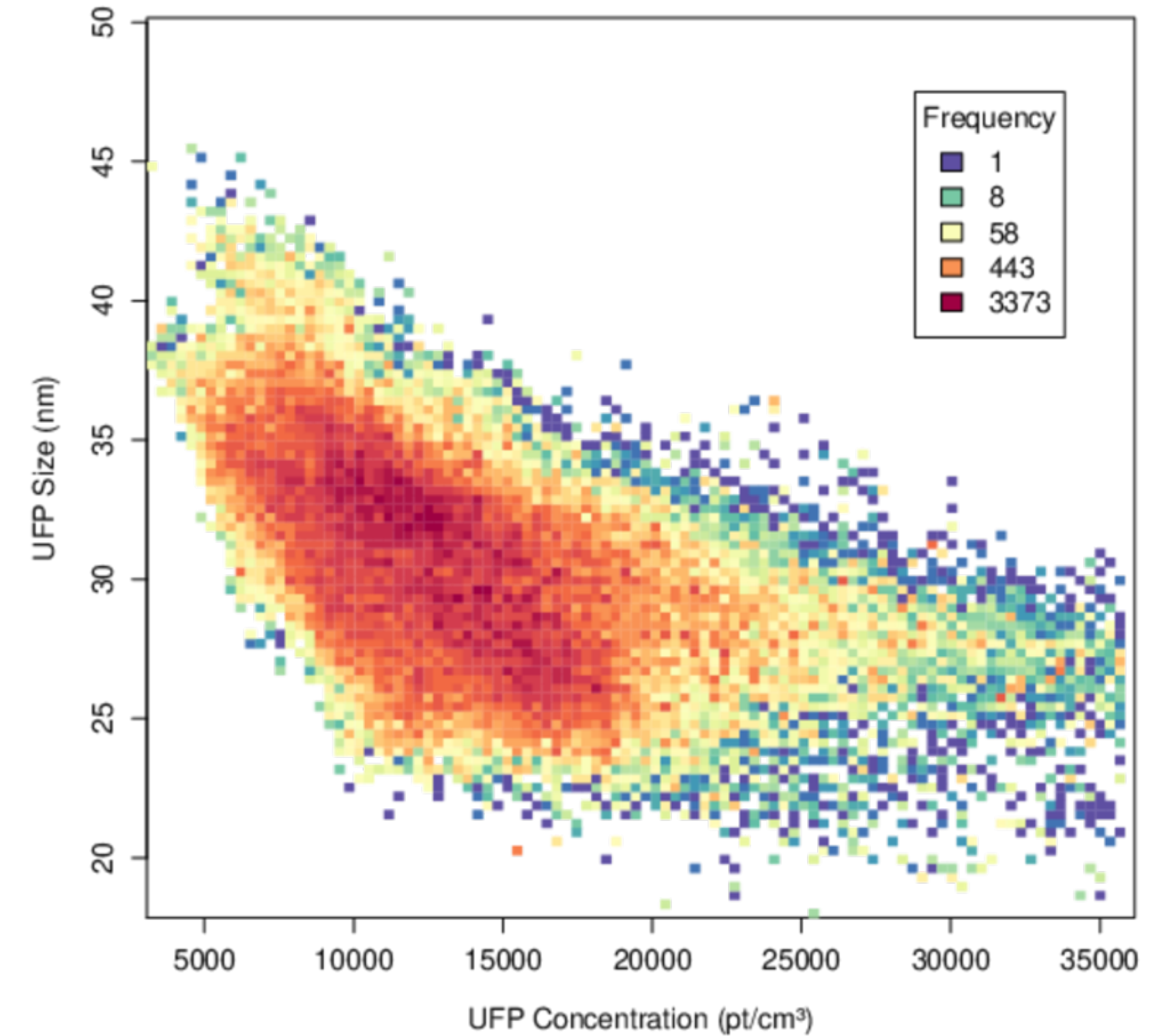
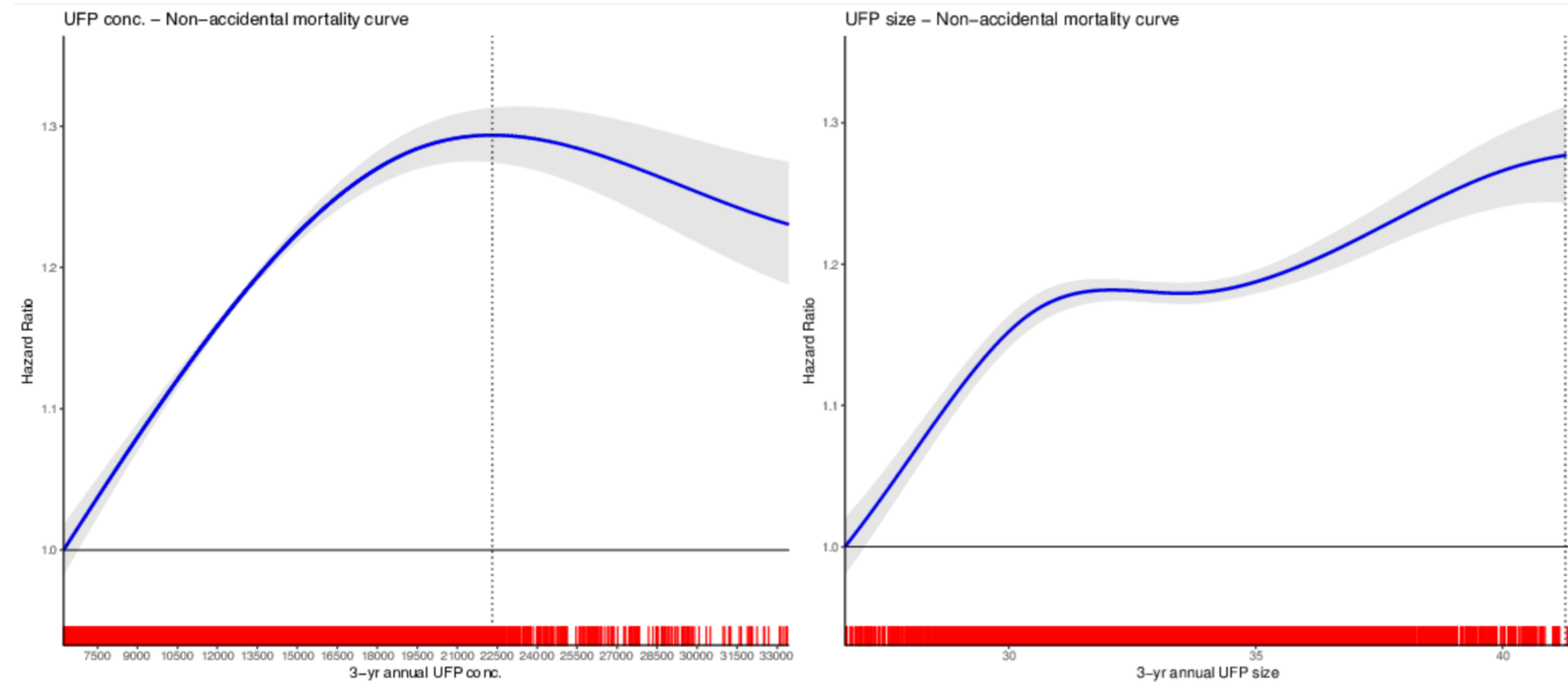
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Epidemiology: UFPs and Nonaccidental Mortality



Results

Epidemiology: UFPs and Nonaccidental Mortality

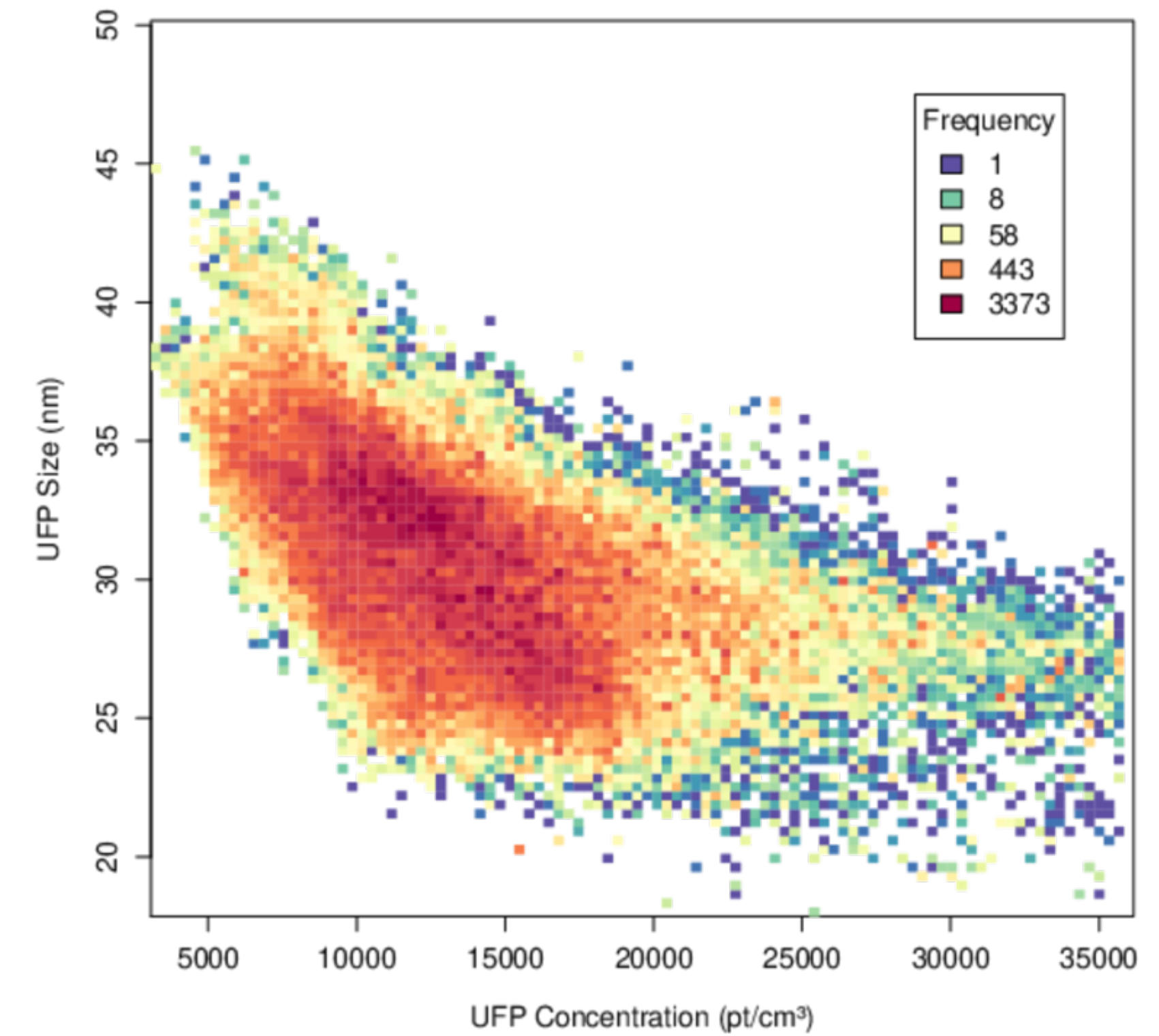
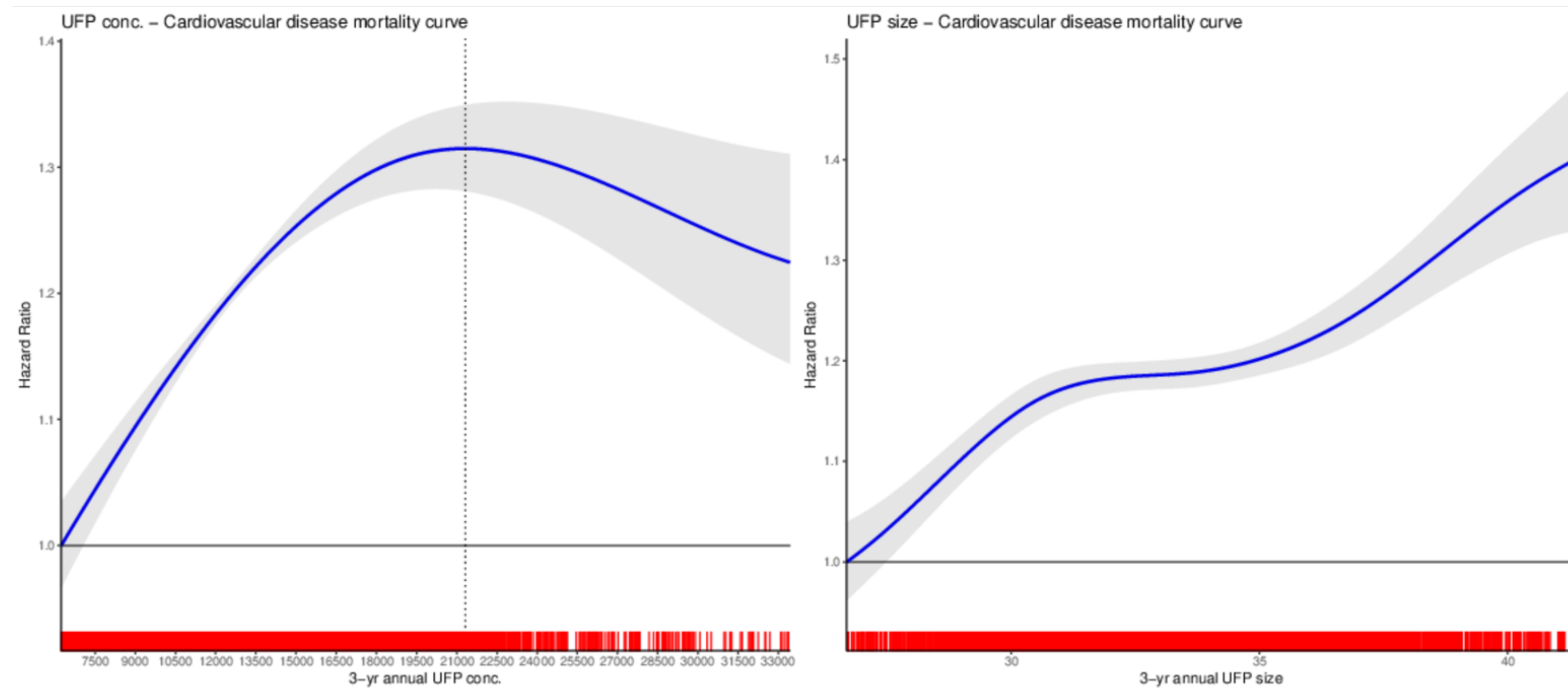


- UFP size distribution is NOT constant across distribution of UFP number concentration
- All UFP number concentrations do not reflect the same type of exposure (i.e., version of treatment)



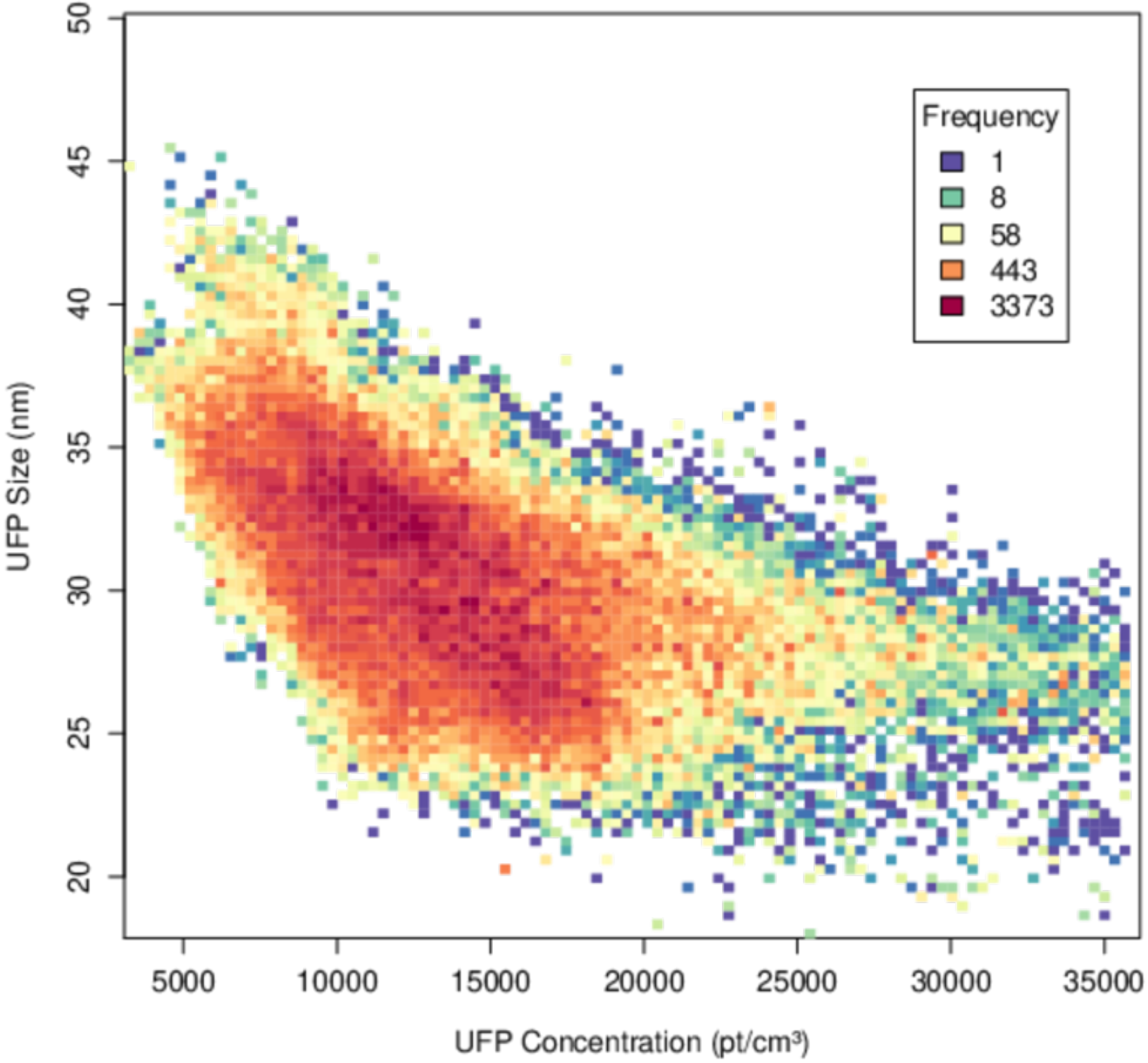
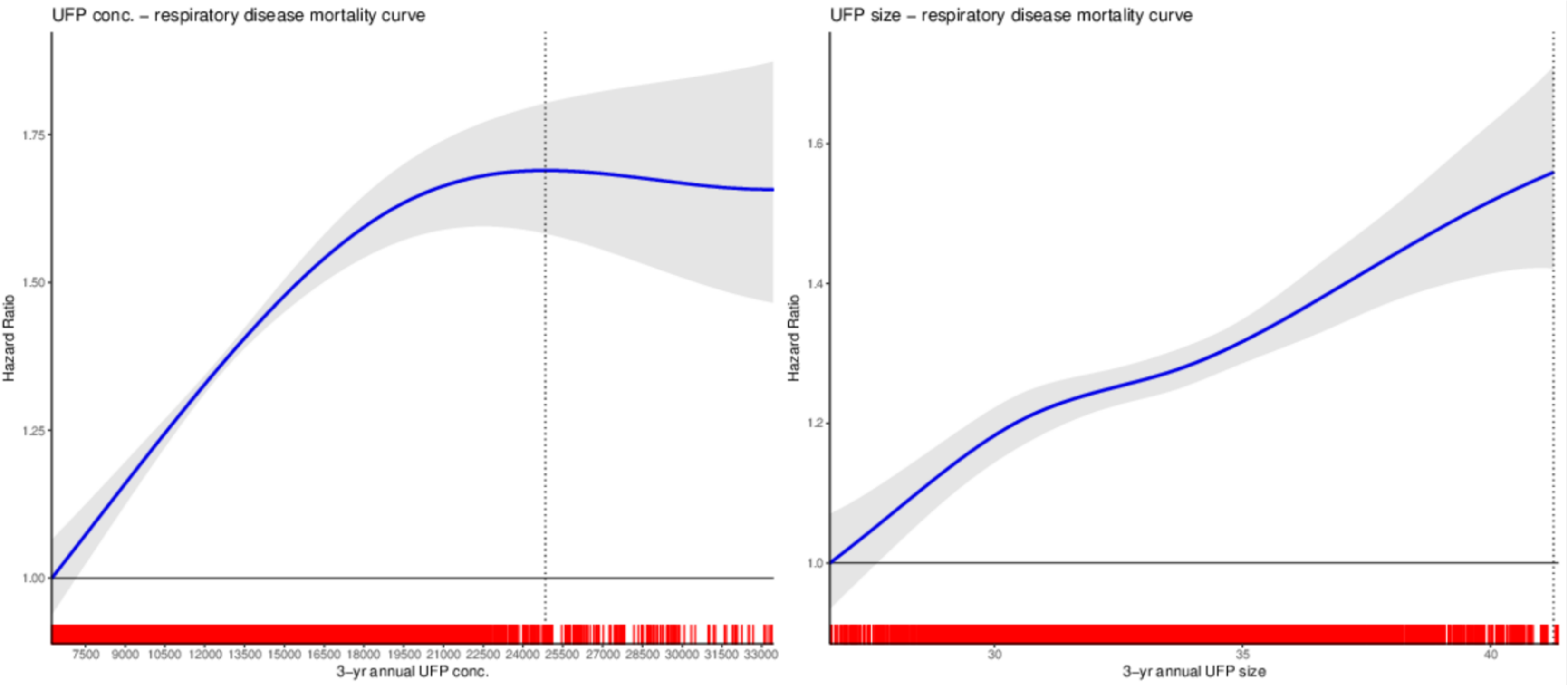
Results

Epidemiology: UFPs and Cardiovascular Mortality



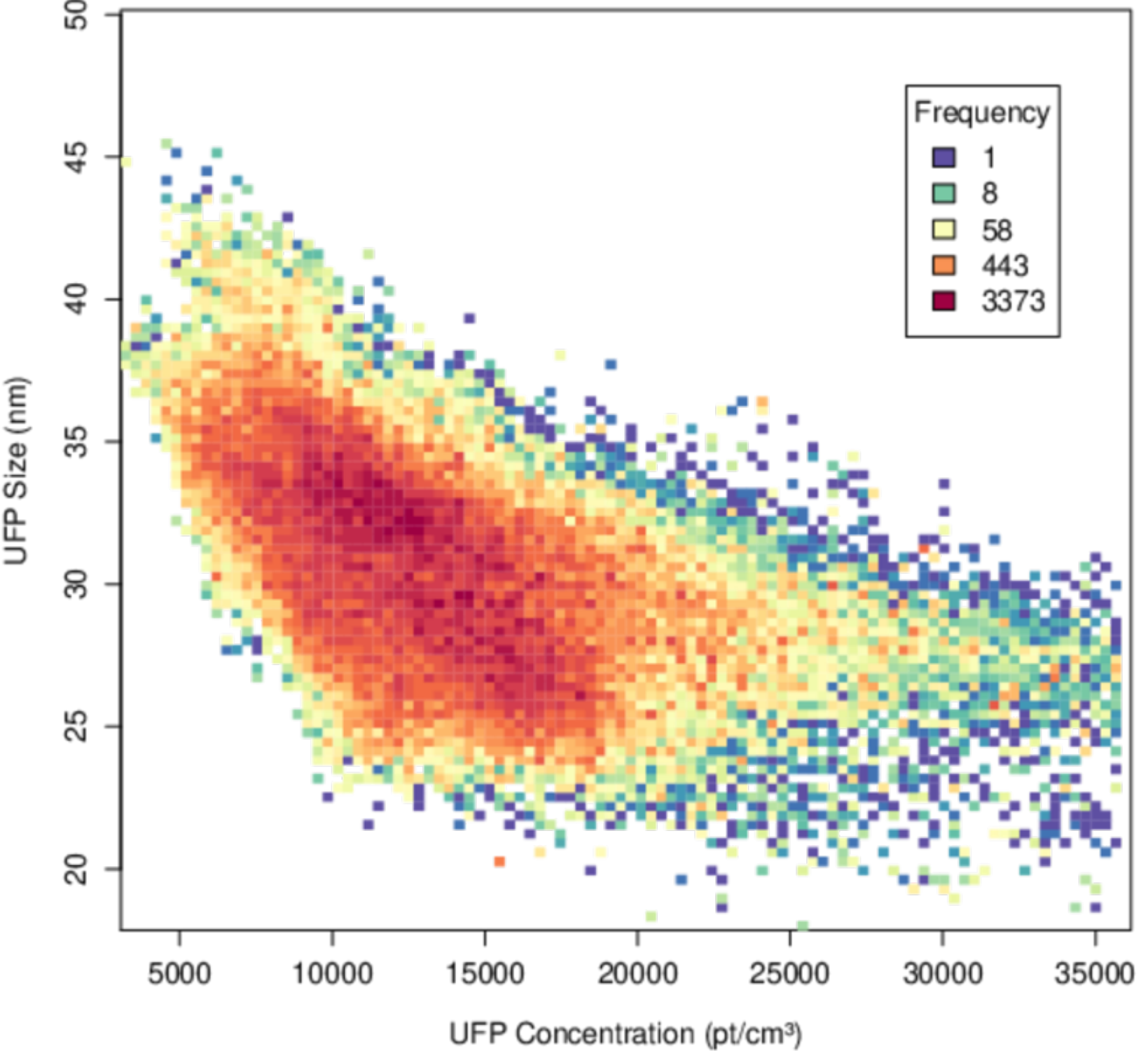
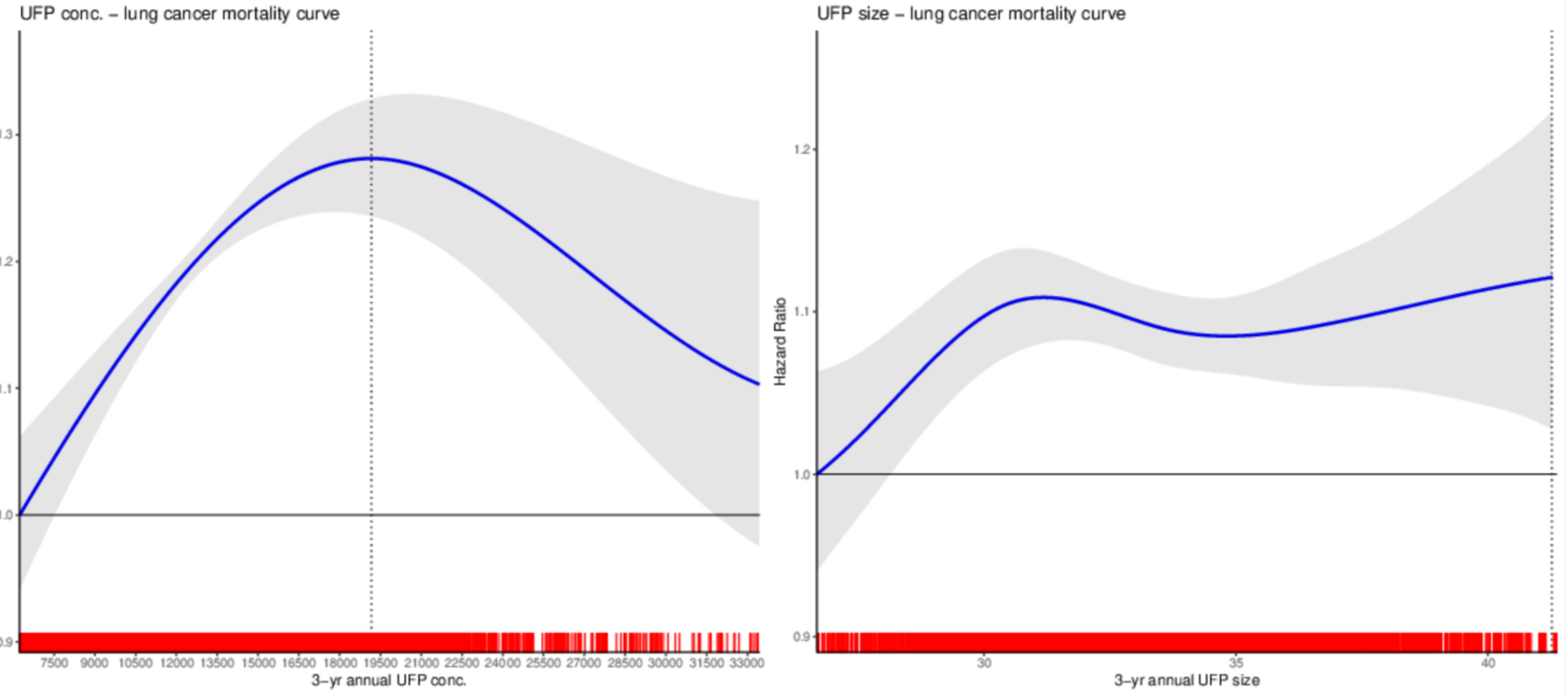
Results

Epidemiology: UFPs and Respiratory Mortality



Results

Epidemiology: UFPs and Lung Cancer Mortality



Study Summary

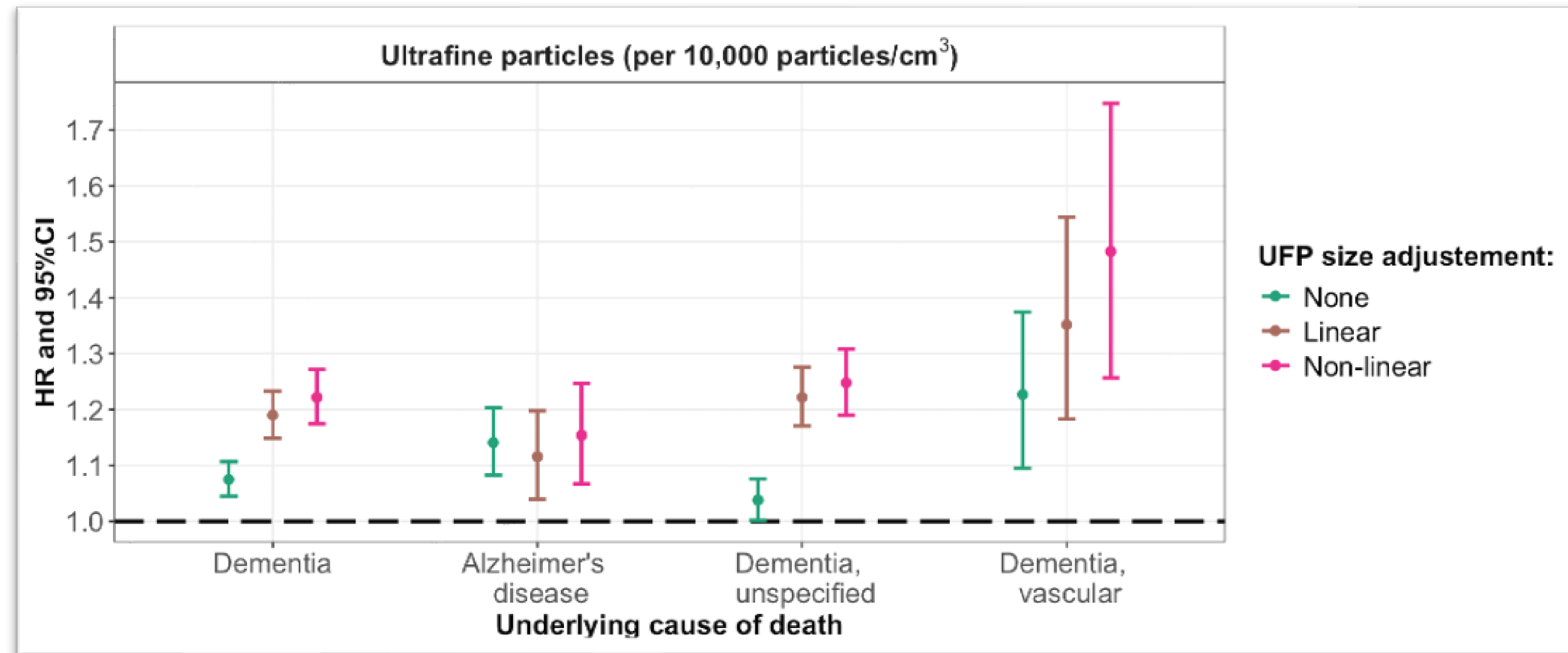
- Consistent associations between long-term exposure to outdoor UFPs and Mortality
 - ✓ Cardiovascular mortality
 - ✓ Respiratory mortality
 - ✓ Cerebrovascular mortality
 - ✓ Lung cancer mortality
- Not explained by $PM_{2.5}$ or other pollutants ($r = 0.10$ for UFP/ $PM_{2.5}$)
- Important to adjust for UFP size (negative confounding otherwise)
 - *Other studies likely underestimate health impacts because of this*

Long-Term Exposure to UFPs and Dementia

Pending publication in *Epidemiology* (PhD Student, Emmanuelle Batisse)

Cohort Study of Dementia Mortality

- CanCHEC: **2.1 million people** followed from 2001-2019
- Adjustment for PM_{2.5}, O_x, and socio-economic factors
- **UFPs associated with increased risk of death from dementia**
- **Strongest for vascular dementia**
- Adjustment for UFP size important!



Daily Spatiotemporal Variations in UFPs

New Daily Models based on HEI data

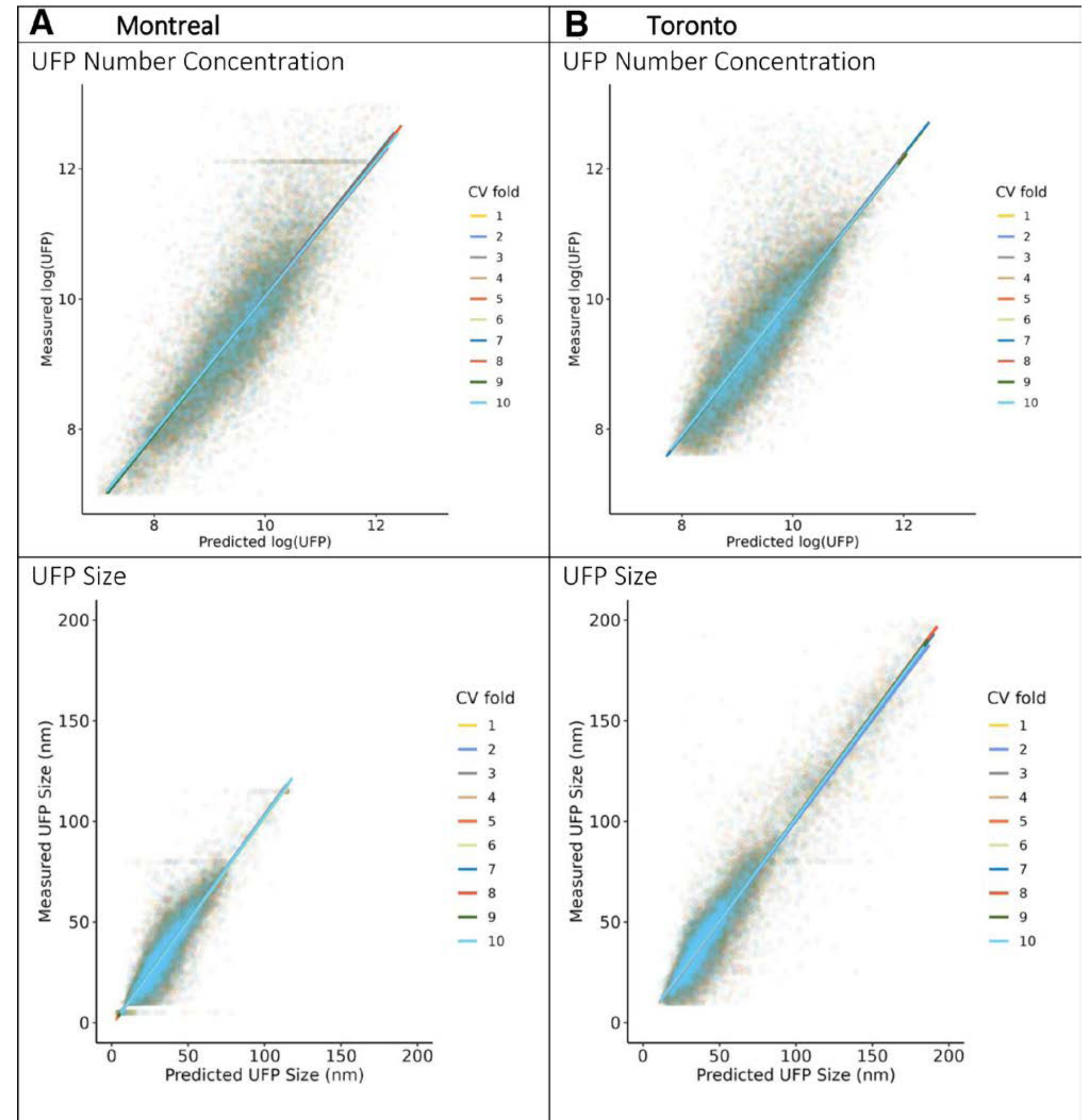
Original Research Article

ISEE ENVIRONMENTAL
EPIDEMIOLOGY

OPEN

Predicting within-city spatiotemporal variations in daily median outdoor ultrafine particle number concentrations and size in Montreal and Toronto, Canada

Alessya Venuta^a, Marshall Lloyd^a, Arman Ganji^b, Junshi Xu^b, Leora Simon^a, Mingqian Zhang^b, Milad Saeedi^b, Shoma Yamanouchi^b, Eric Lavigne^c, Marianne Hatzopoulou^b, Scott Weichenthal^{a,d,*}



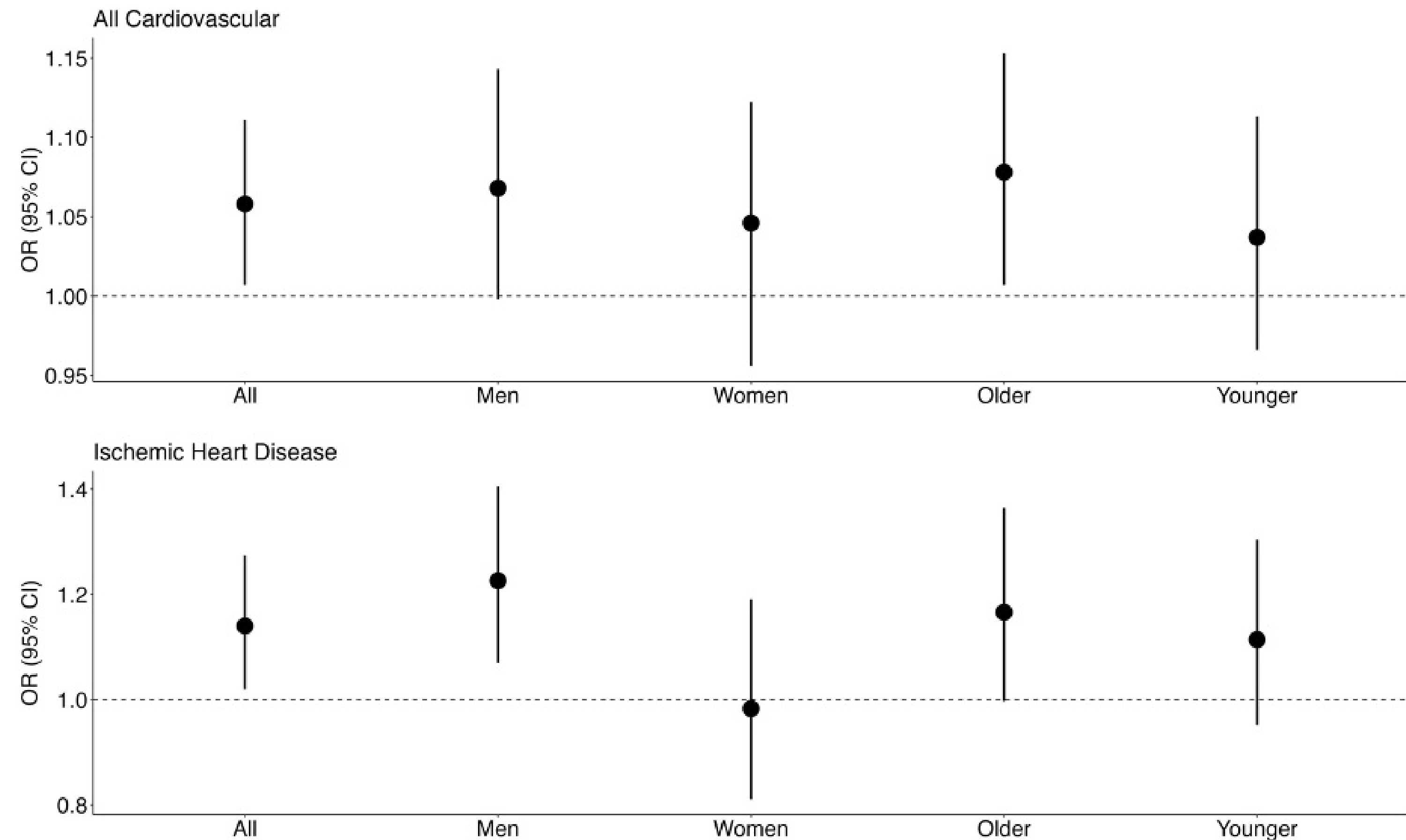
Predicting Daily Spatiotemporal UFPs

New Case-Crossover Study Evidence (Published in *Environmental Epidemiology*)

Case-crossover study in Toronto

- **89,694 cases of acute cardiovascular events**
- Focused on 2019-2020 to overlap closely with monitoring period
- Models adjusted for UFP size, temperature/RH, PM_{2.5}, NO₂, O₃
- **7-day mean UFPs most strongly associated with acute CVD outcomes**

Figure 1. Relationship between 7-day mean outdoor UFP concentrations (per 10,000/cm³) and emergency room visits for all cardiovascular outcomes and ischemic heart disease.



Early Evidence for PM_{2.5} vs Current Evidence for UFPs

Critical Epidemiological Evidence Cited in First Health Canada PM _{2.5} Assessment Document (1998)	PM _{2.5}	UFPs
Impacts on “pre-clinical” outcomes (e.g., lung function)	✓	
<i>Short-term</i> increases in <i>Mortality</i> due to Cardio-respiratory outcomes	✓	
<i>Short-term</i> increases in <i>Hospitalizations</i> due to Cardio-respiratory outcomes	✓	
<i>Long-term</i> exposure and mortality	✓ One Study: Six Cities Study (8111 people) (No Canadian Studies)	
<i>Long-term</i> exposure and <i>disease incidence</i> (e.g., cancer, cardiovascular outcomes)	✗	

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<i>Short-term</i> increases in <i>Hospitalizations</i> due to Cardio-respiratory outcomes	✓	✓
<i>Long-term</i> exposure and mortality	✓ One Study: Six Cities Study (8111 people) (No Canadian Studies)	✓ Canadian studies + International studies (Millions of people)
<i>Long-term</i> exposure and <i>disease incidence</i> (e.g., cancer, cardiovascular outcomes)	✗	✓ Canadian studies + International studies (Millions of people)

What are the *potential health benefits* of future regulatory interventions for UFPs?

Estimating Benefits of Hypothetical Interventions

Emissions Reductions Simulations, in progress

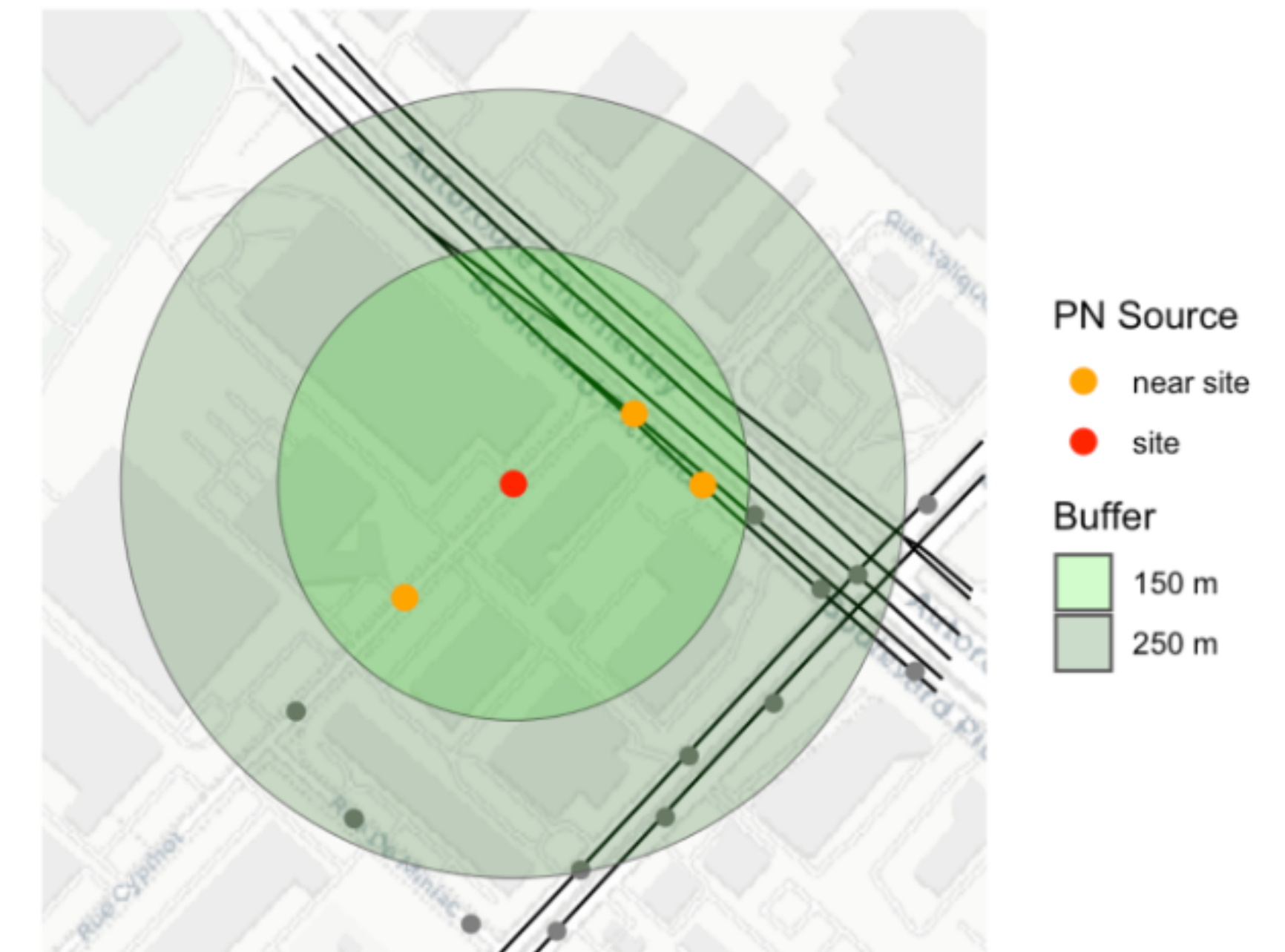
- **Future inventions will likely be emissions-based**
 - We are in the process of *estimating health benefits of **different vehicle emissions reductions scenarios***
 1. *Develop a model relating measured outdoor UFP concentrations to road-segment level UFP emissions (using literature values for emissions factors)*
 2. *Change emission values to estimate how outdoor UFP concentrations change with different interventions*
 3. *Apply mortality risk estimates from our cohort study to estimate reductions in premature deaths*

Estimating Benefits of Hypothetical Interventions

Emissions Reductions Scenarios, in progress

$$\log(UFP_{\text{monitoring}}) = s(PN_{\text{site}}, \text{by} = \text{Cluster}) + s(PN_{\text{nearby}}, \text{by} = \text{Cluster}) + \text{Cluster} + s(Wind_{\text{monitoring}}) + s(Temp_{\text{monitoring}})$$

- $UFP_{\text{monitoring}}$: annual average UFP concentration measured during monitoring
- PN_{site} : total vehicle PN emissions at a given site
- Cluster: land use cluster (5 categories)
- PN_{nearby} : total vehicle PN emissions at within a buffer of a given site
- $Wind_{\text{monitoring}}/Temp_{\text{monitoring}}$: average windspeed/temperature during monitoring (account for chance temporal imbalances during monitoring)



Estimating Benefits of Hypothetical Interventions

Emissions Reductions Scenarios, in progress

City	Scenario	Reductions in Annual Premature Deaths (95% CI)
Toronto	50% of heavy-duty vehicles replaced with EVs	106 (89 – 123)
	50% of all vehicles replaced with EVs	146 (122 - 169)
	100% of all vehicles replaced with EVs	306 (256 – 355)

*Assumes that EFs stay the same over time, we are working on scenarios that capture future trends in emissions as well.

Summary

- Existing evidence indicates that outdoor UFPs have adverse health effects including:
 - Acute Effects
 - Chronic Effects (nonaccidental and cause-specific mortality)
 - Carcinogenic effects
- The health effects of outdoor UFPs appear to be independent of PM_{2.5} mass
- We currently know much more about UFPs than we did about PM_{2.5} when the first health guidelines were released
- Regulatory interventions reducing UFPs emissions will likely reduce premature mortality