Characterizing Ultrafine Particulate Matter and Black Carbon Exposure Levels for a Seattle-Based Cohort From a Mobile Monitoring Campaign

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Funding: ACT – Air Pollution Study (National Institute of Environmental Health Sciences; National Institute on Aging, R01ES026187)

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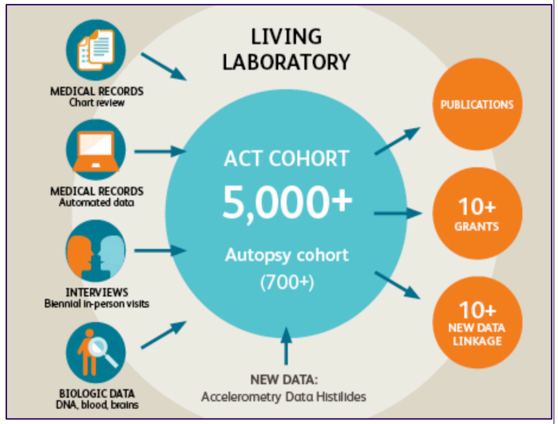
-Work was conducted as part of my dissertation
-funded: NIEHS; NIA
-I'll cover some background before describing the work we conducted

Adult Changes in Thought (ACT) Study

- Seattle-based prospective cohort study investigating aging and the brain
  - Started in 1994
- Participants
  - Elderly individuals (65+ yr)
  - Dementia-free at baseline
- Participants are followed until they are diagnosed with dementia

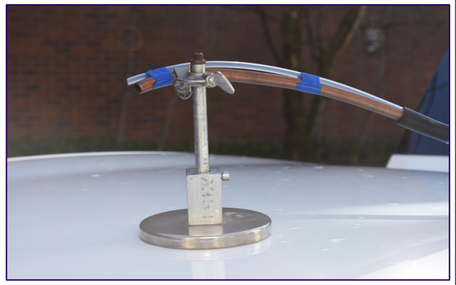


Top: Huges 2018. **Bottom**: Bowles 2019. ACT study visit – grip strength test.

- An ideal cohort to study long-term air pollution exposure & dementia incidence

Mobile Monitoring

- Collect repeated short-term samples used to estimate long-term averages
  - Time- and cost- efficient
    - Site sampling duration can be very short
    - Increased spatial coverage
    - One platform
  - Convenience sampling
    - Short time periods (e.g., Mon-Fri)
    - Non-residential areas (e.g., highways, industry)
    - Mobile, on-road samples (vs. stationary samples near residences)



Top to bottom: 1) Instrumentation in the mobile monitoring vehicle. 2) Sampling inlet on vehicle rooftop. Photograph by Sarah Fish, fischs@uw.edu. 3) Mobile monitoring vehicle.

* We were interested in using mobile monitoring to assess air pollution exposure

References
• Mobile monitoring campaigns to characterize average air pollution levels (Apte et al. 2017; Hatzopoulou et al. 2017; Kerckhoffs et al. 2016; Messier et al. 2018; Xie et al. 2017)

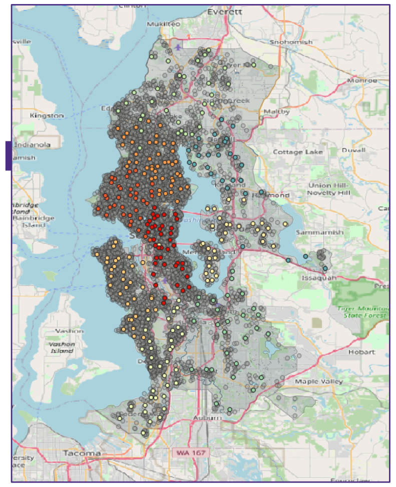
Study Overview

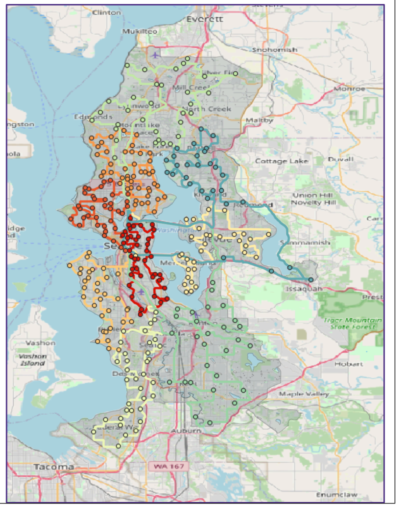
- Conducted a mobile monitoring campaign to measure annual-average traffic-related air pollution levels for the ACT cohort
- Built UFP and BC prediction models
- Characterized exposure for the ACT cohort and the greater Seattle area

Photograph by Sarah Fish, fischs@uw.edu.

Our Mobile Monitoring Campaign

- Purpose: Address past monitoring limitations
- 309 stop locations representative of ACT cohort (large, geographically diverse area)
- 9 fixed driving routes
- 2-min samples per stop
- Measured UFPs, BC, $PM_{2.5}$, CO, CO_2, NO_2
- A driving schedule ensured temporally balanced sampling

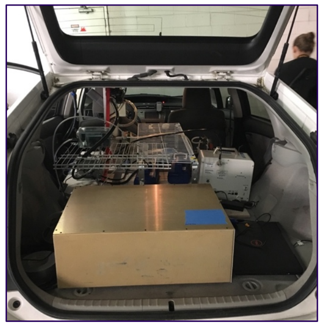




Top: Jittered ACT locations and monitoring stops. **Bottom:** Mobile monitoring routes and stops

Final Samples

> Collected ~27 samples per site
  - 5 AM – 12 AM
  - March 2019 – March 2020
  - >270 drive days



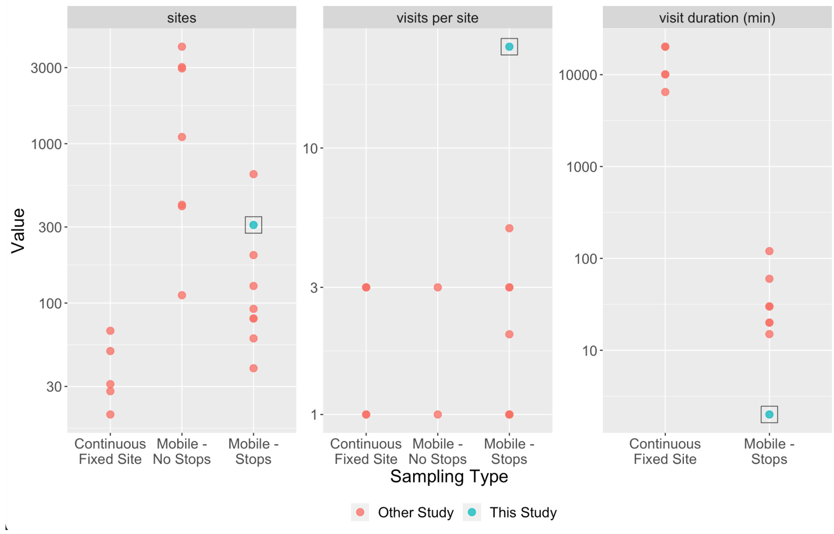
Left: Instruments inside the vehicle. **Right**: Monitoring laptop. Photograph by Sarah Fish, fischs@uw.edu.

- This was a fairly extensive campaign

Sampling Approaches Across Other UFP Studies

> **Compared to other similar studies, we had:**
> - **More sites**
> - **more repeat visits**
> - **Shorter visits**

> **Similar for BC**

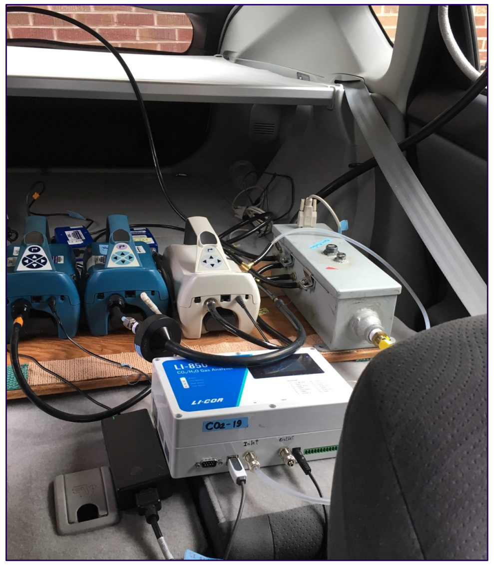


- To put this into perspective, we can compare some of the features of our study design to other studies. On the x-axis you have studies stratified by the type of sampling type that was conducted…3 types…Our study is in teal. We can see that overall, we generally sampled more study sites, visited each site more times even though we were there for shorter periods of time

Instrumentation

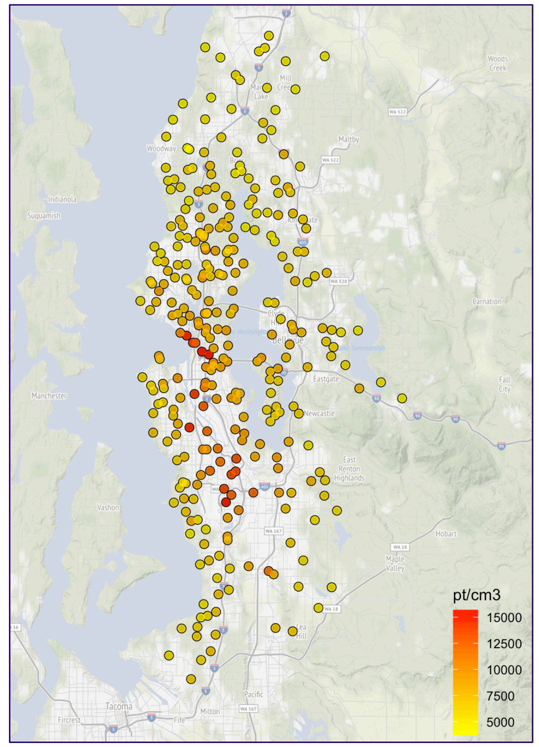
> **UFPs: P-TRAK 8525 (TSI)**
  - **Time resolution: 1 sec**
  - **Particle size range: 20-1,000 nm diameter**

> **BC: MicroAeth, MA200 (AethLabs)**
  - **Time resolution: 10 sec**
  - **Wavelength: 880 nm (IR)**



Top: P-TRAKs in the monitoring vehicle.
Bottom: MicroAethalometers (AethLabs, 2018).

Annual Averages



> Calculated site annual averages using linear regression to address unbalances in data

Annual average UFP estimates from mobile monitoring observations.

The first step of this analysis involves data reduction.

- Median site visit concentrations
- Trimmed extreme observations at each site

Prediction Models

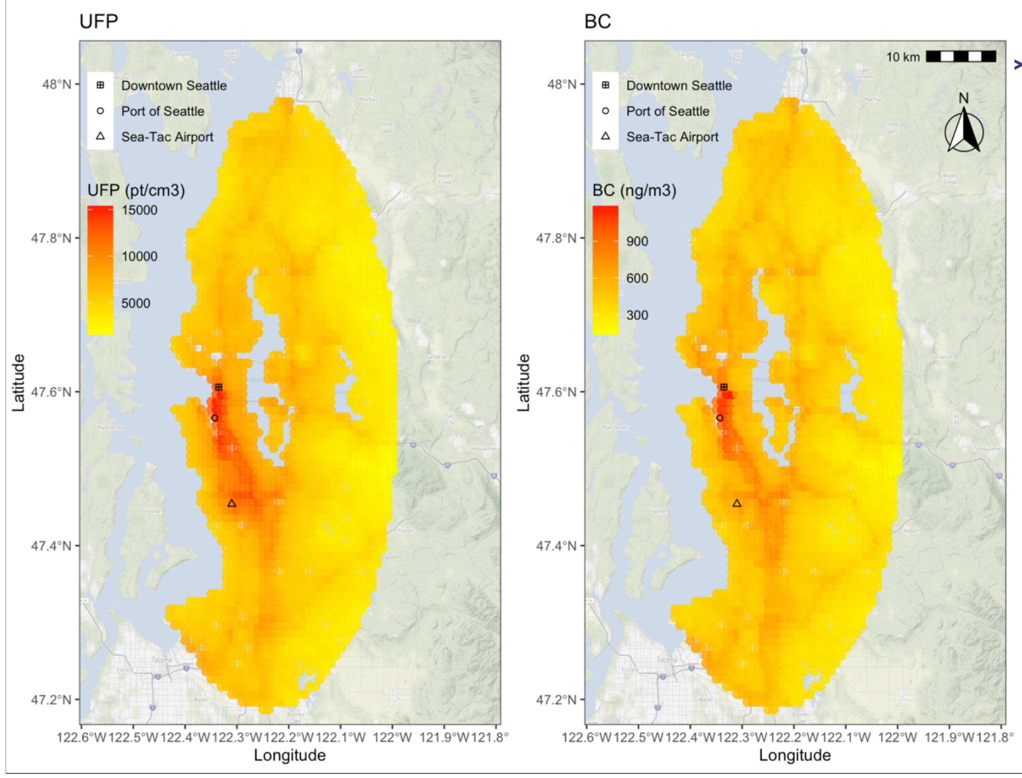
> **Built universal kriging (UK) models using partial least squares (PLS) and geostatistical smoothing (kriging):**

$$\log(Conc) = \alpha + \sum_{m=1}^{M} \theta_{m,s} Z_{m,s} + \varepsilon$$

where $Z_{m,s}$ are the PLS component scores; α and $\theta_{m,s}$ are estimated model coefficients; ε is the residual term with mean zero and a geostatistical structure modeled as an exponential function with range ϕ_i, partial sill σ_i, and nugget τ_i

- PLS summarized hundreds of geographic covariates into a smaller number of new features
- Kriging allows for spatial correlation in the data…Models part of the structure that resides in error term not otherwise captured by regression

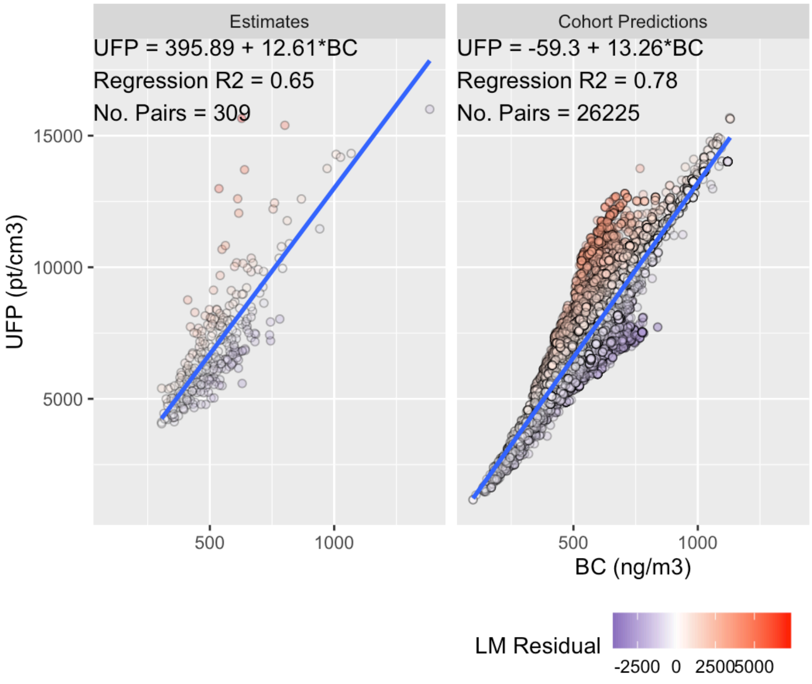
Predicted UFP and BC Exposure Surfaces



- **Higher predicted concentrations between downtown and the airport, on highways**

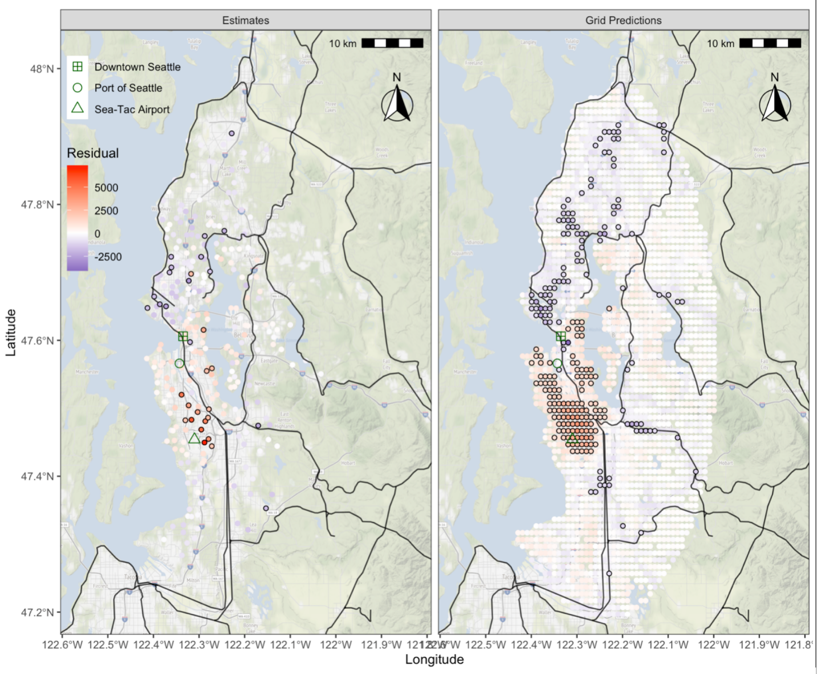
Differences in UFP and BC Surfaces

> Can BC be used as a surrogate for UFP?
> UFP levels at some locations are mischaracterized more when using BC models (large residuals)



Differences in UFP and BC Surfaces

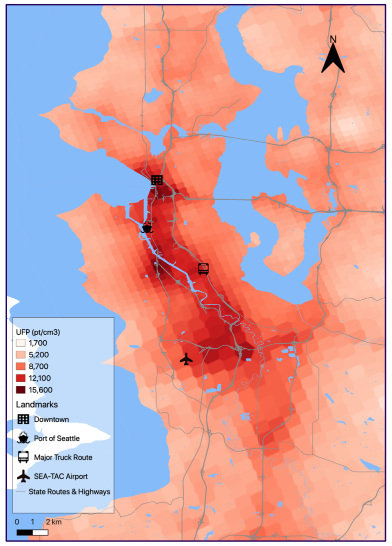
- Plotting the difference between UFP observations and predictions based on BC models (residuals)
- UFP levels were:
- (+): Sea-Tac Airport
- (-): Rail yards, large ports



UFP residuals for UFP-BC linear regressions using estimates (from mobile monitoring observations) and model predictions (at grid locations). Black circles are locations with high residuals (< 5th quantile or > 95th quantile); black lines are railroads. Residual predictors were selected using Lasso regression.

Conclusions

- > **First to characterize the long-term UFP and BC exposure surface with high spatial resolution for the greater Seattle area**
  - – **Innovative mobile monitoring campaign specifically designed for epidemiologic application**
- > **Differentiated UFP and BC surfaces**
- > **Next steps: use of these models in epidemiologic studies**



Top: UFP predictions from the Seattle area. **Bottom**: Our mobile monitoring vehicle. Photograph by Sarah Fish, fischs@uw.edu.

* Our study may be the largest in terms of:

Spatial extent covered
Sampling density
Sampling frequency & duration

Acknowledgements

- PhD Committee
  - Lianne Sheppard
  - Edmund Seto
  - Tim Larson
  - Sara Adar
  - Julian Marshall
- Mobile monitoring team
  - Amanda Gassett
  - Jim Sullivan
  - Dave Hardie
  - Tim Gould
- Additional Support
  - Brian High
  - Elena Austin
  - ACT-AP team
  - Gail Li
  - Paola Filigrana
- Funding
  - ACT – Air Pollution Study (NIEHS, NIA, R01ES026187)
  - BEBTEH: Biostatistics, Epidemiologic & Bioinformatic Training in Environmental Health (NIEHS, T32ES015459)
  - ARCS Foundation Fellowship

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Image Credits

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Appendix

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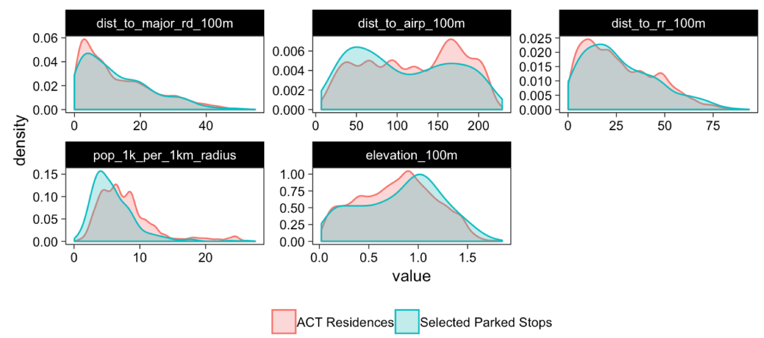
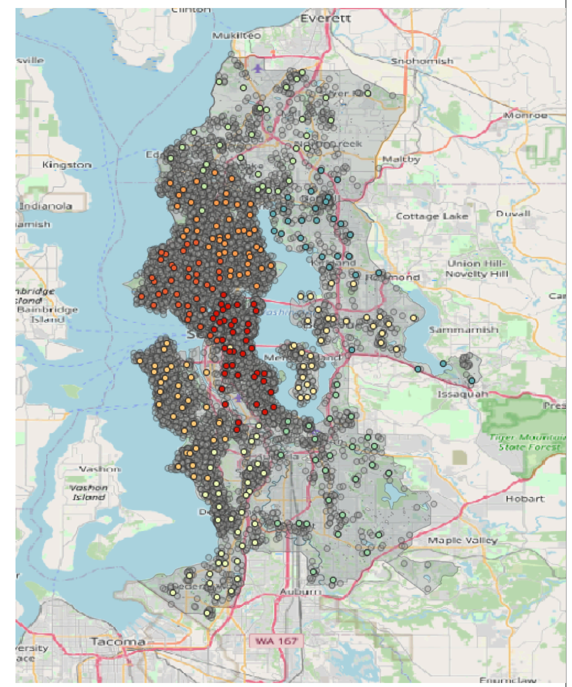
Monitoring Stops & ACT Locations

> Stop locations and ACT residences had similar geocovariate distributions (spatial compatibility)





Left: density plots of geocovariate distributions for monitoring stops and ACT locations. **Right:** Map of jittered ACT locations and monitoring stops.

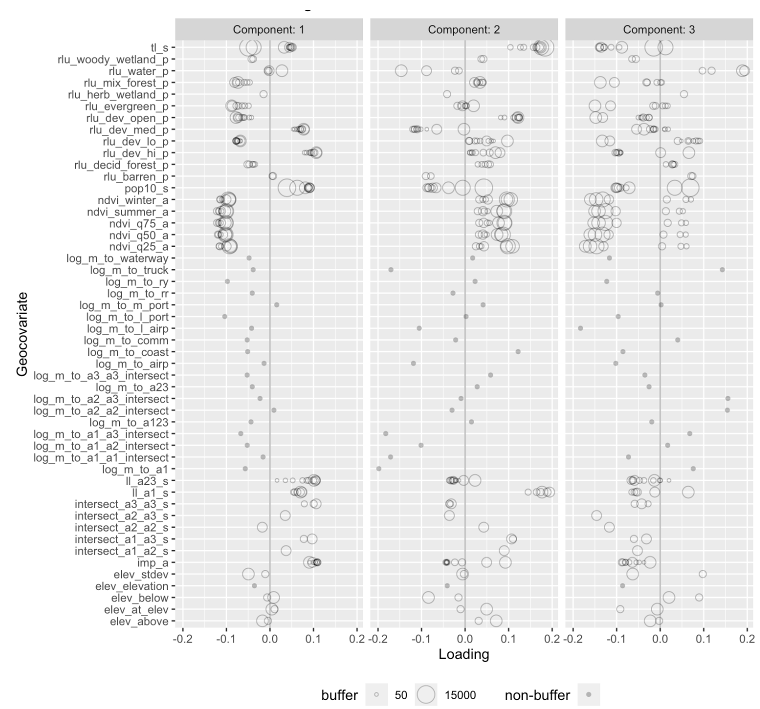
Instrument Specifications

Parameter	Instrument	Manufacturer	Measurement Range	Limit of Quantification	Time Resolution
Particles					
UFP					
10-420 nm (and 13-bin PSD)	NanoScan 3910	TSI	10^2-10^6 pt/cm^3	10 pt/ cm^3	60 sec
10-700 nm	DiSCmini	Testo	10^3-10^6 pt/cm^3	500-2,000 pt/cm^3 [b]	1 sec
20-1,000 nm	PTRAK 8525	TSI	0 - 5 x 10^5 pt/cm^3	1 pt/cm^3	1 sec
50-1,000 nm	PTRAK 8525, with diffusion screen	TSI	0 - 5 x 10^5 pt/cm^3	1 pt/cm^3	1 sec
BC & UV PM (5 wavelength abs analysis)	microAeth MA200	AethLabs	0-1 mg BC/m^3	30 ng BC/m^3 [c]	10 sec
Light scattering extinction coef ($PM_{2.5}$)	M903	Radiance Research	0 - >1 km^{-1}	10^{-6} m^{-1}	10 sec
Gases					
NO_2	CAPS NO_2	Aerodyne Research, Inc.	0-2,000 ppb	2 ppbv	1 sec
CO_2	SenseAir CO2 K-30-FS sensor	CO2Meter.com	0-5,000 ppm (vol)	100 ppmv	1 sec
CO	CO Monitor T15N	Langan, Inc.	0-200 ppm	0.1 ppm	1 sec
Other					
Temperature	Onset UX100-011	HOBO	-4-158°F		1 sec
Relative humidity	Onset UX100-011	HOBO	0-95%		1 sec
Positioning & real-time tracking	DG-500	US GlobalSat	0-515 m/sec speed	2.5 m	1 sec

Strong UFP and BC Predictors

- Length of major roads
- Population density
- Land development, imperviousness
- NDVI, green space
- Distance to large port, rail yard

- In line with literature



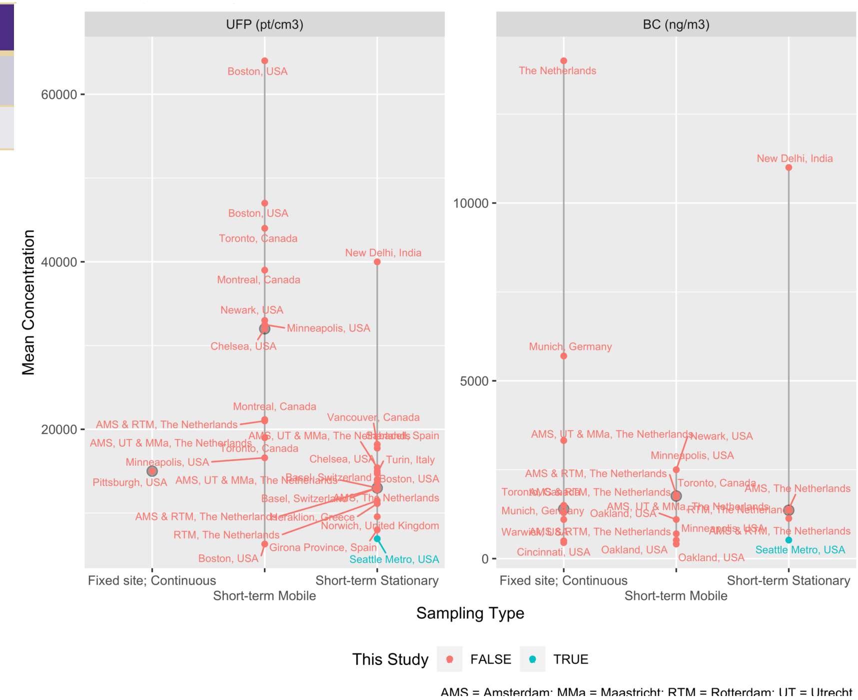
PLS component loadings for UFP model

Exposure Predictions for the ACT Cohort

Pollutant	Median	Range
UFP (pt/cm³)	6,782	2,491-15,682
BC (ng/m³)	525	232-1,130

> A large degree of exposure variation

> Low levels
  - Seattle's air
  - Similar to rural/ suburban locations
  - Wider geographic area & sampling times



Estimated mean/median UFP and BC concentrations from other studies. Gray dots and vertical lines are the median and range.

- Though it is difficult to compare UFP lvls across studies b/c studies use different size ranges, based on instrumentation
  - Though our analyses did not show any clear reason for large coc discrepancies between studies when we compared instruments used and the concentrations reported by those studies
  - EPA has noted this as a limitation in the field

REFS
*BC levels:
Sources: Oakland, CA: Apte et al. 2017; The Netherlands: Kerckhoffs et al. 2016 & 2017, Montagne et al. 2015; Toronto, CA: Minet et al. 2018; New Delhi, India: Saraswat et al. 2013

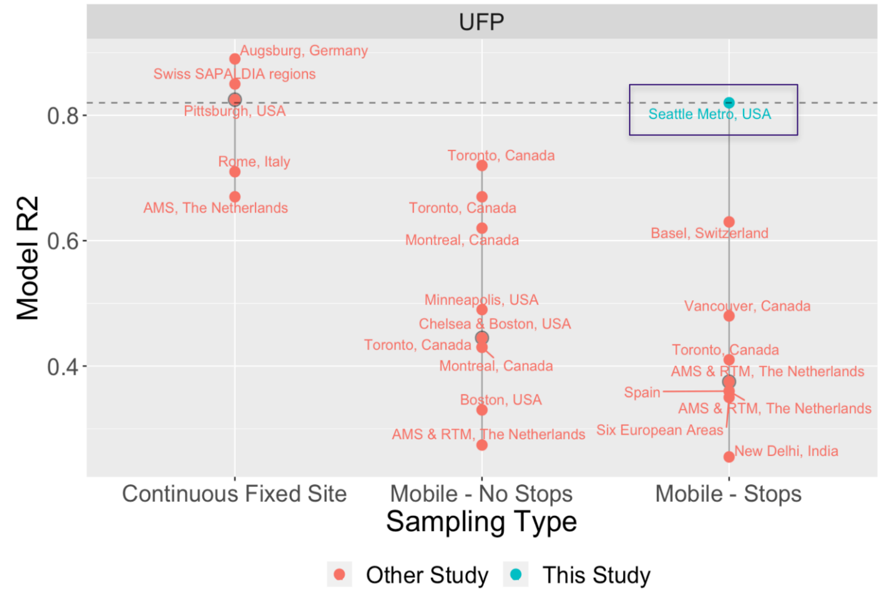
Limitations

- Mobile monitoring stop averages may be noisy (27 two-min samples/site)
  - ≤20% error
- Regression approach for estimating annual averages assumes that sites have similar temporal trends
- Limited built environment covariates that may impact dispersion (e.g., street width)
  - But does include correlated covariates (e.g., population)

Model Performances

> **Higher R^2 model performance than similar studies**

> **Similar for BC**



Model performance from other UFP studies. Gray dot and vertical line are the median and range; this study is in blue; other studies are in red.

- high model performance is an important strength for TRAPs, which have strong decay patterns – models captured exposure surfaces well
- We reported MSE-based CV R2. Others have likely reported an in-sample regression-based R2 (most did not state), which should perform better.