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ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
UNIVERSITY of WASHINGTON | SCHOOL OF PUBLIC HEALTH

Assessing Exposures to Source-specific Air Pollution through a Multi-pollutant Mobile Monitoring Campaign in Seattle, WA

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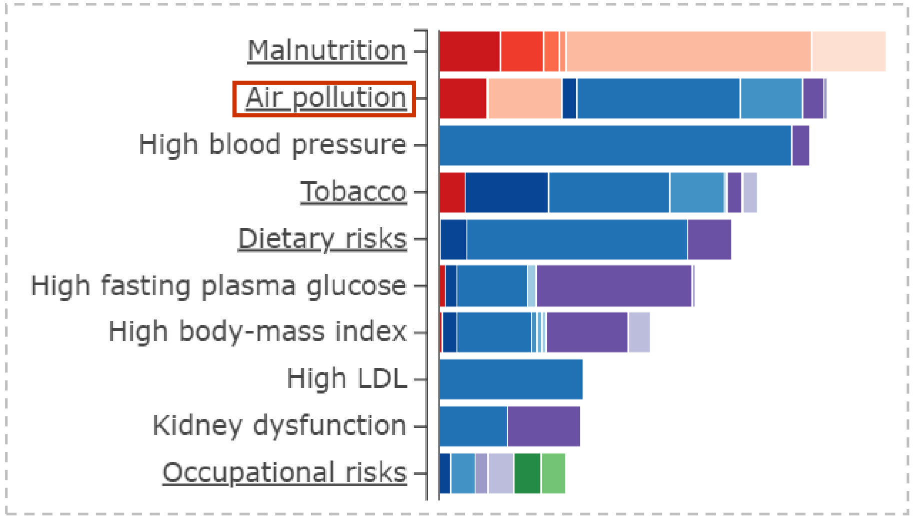
Introduction

Health issues of air pollution

- Adverse health outcomes: cardiovascular diseases, respiratory diseases, lung cancer, etc.
- Global Burden of Disease 2021: Air pollution is the second leading risk factor, accounting for 8.2% of total DALYs.

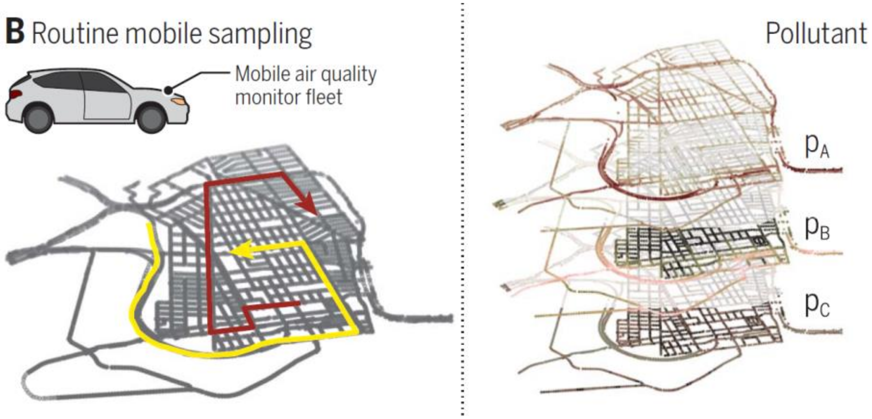


Mobile monitoring (MM) studies

- Drive vehicles with high-quality instruments through fixed routes
- Have higher spatial resolution than regulatory monitoring

RESEARCH GAP OF MM

- More focus on $PM_{2.5}$ than ultrafine particles (UFPs), while health impacts depend on size distribution and chemical composition
- Multi-pollutant spatiotemporal data from MM have not been fully used in health studies.

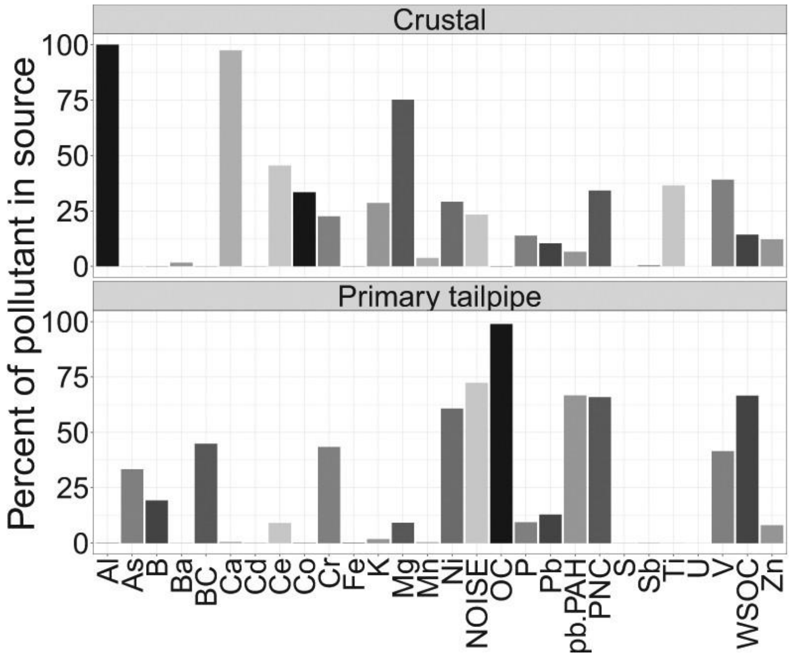


GBD2021, *Lancet*, 2024, 403: 2162–2203. Apte et al., *Science*, 2024, 385: 380–385.

Introduction

■ Source apportionment (SA) studies

- Use multi-pollutant data to derive the sources
- Approach: positive matrix factorization (PMF), PCA, et al.
- Many relied on regulatory monitoring data, and few on MM



RESEARCH GAP OF SA-MM

- Few considered particle size distribution
- Few classified traffic-related source into different vehicle types
- Limited time frames (days to weeks)

■ Research aims: PMF + MM

1. **Characterize emission sources** more accurately
2. Assess **source-specific** air pollution exposures
3. Estimate the **annual average emission factors** for different vehicle types

Hopke et al., *Sci. Total Environ.*, 2020, 740: 140091. Hopke et al., *Sci. Total Environ.*, 2022, 819: 153104. Larson et al., *Atmos. Environ.*, 2017, 152: 201-211.

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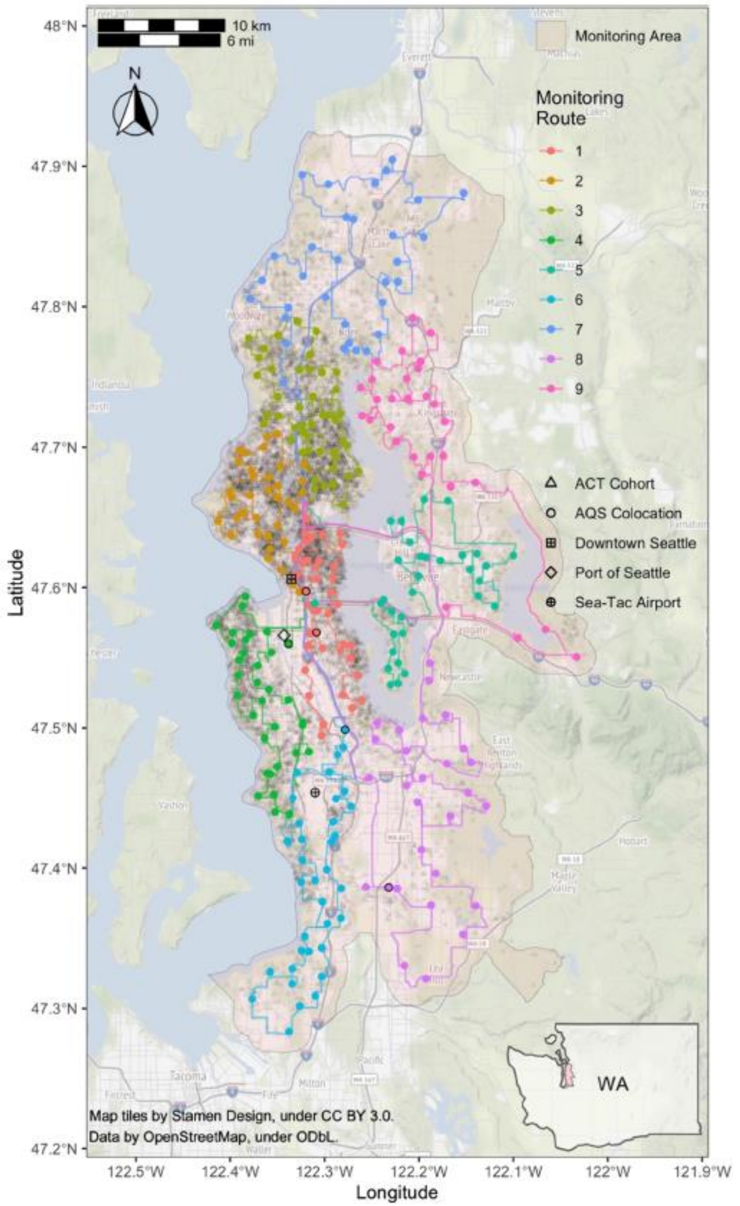
Methods

■ Mobile monitoring campaign in ACT-AP study

***A**dult **C**hange in **T**hought*
***A**ir **P**ollution*

- **Purpose:** Provide high-spatial-resolution air pollution exposure estimates for epidemiological analysis about dementia
- **Pollutants:** Size-resolved ultrafine particle number concentration (PNC), $PM_{2.5}$, black carbon (BC), total carbon (TC), NO_2, and CO_2
- **Location:** 309 sites in Seattle, WA
- **Time:** ~29 repeated measures of air pollutants with a **time-balanced design** from 2019 to 2020
- A total of 8152 visit-level data were obtained.



Mobile monitoring routes of ACT study

Blanco et al., *ES&T*, 2022, 56 (16): 11460-11472.

Methods

■ Positive matrix factorization (PMF) analysis

- **PMF model:** EPA PMF 5.0 used for calculations

$$x_{ij} = \sum_{k=1}^{K} g_{ik} f_{kj} + e_{ij}$$

i=1,2,…,I; j=1,2,…,J
I = 8125 visits, J = 18 species

✓ x_{ij} means the concentration of species j in sample i (i=1,2,…,I; j=1,2,…,J)
✓ g_{ik} means the **contribution** of source/factor k in sample i (k=1,2,…,K)
✓ f_{kj} means the species **profile** of source/factor k, i.e., the concentration of species j in factor k

- **Robustness of PMF results:** Similar factor profiles were obtained from randomly selected subset of sites (50% of 309 sites).

- **Source-specific air pollution exposure** (attributable to source k)

$$x_{ij,k} = g_{ik} f_{kj}$$

Methods

External validation & Factor interpretation

- **Particle size distribution:** Comparison with known sources in the literature
- **Mapping annual average site-specific factor contribution with various external variables**: Seasons, rush hours, wind directions, and ambient temperatures
- **Land use regression (LUR) model:** Using a comprehensive dataset of geospatial covariates, with Elastic Net and partial least squares (PLS) for variable selection
- **Ratios between different pollutants:** BC/CO_2, BrC/CO_2, NO_2/CO_2, PNC/CO_2, and $PM_{2.5}/BC$

  * Brown carbon (BrC) = TC – BC in the post-PMF analysis.

Traffic-related emission factors (EFs)

$$EF_{j,k} = \frac{\Delta C_{j,k}}{\Delta CO_{2,k}} \times \omega \times 10^3 = Ratio \times \frac{44}{12} \times \omega \times 10^3$$

✓ $EF_{j,k}$ is the fuel-based EF of pollutant *j* for source *k*, g/kg fuel
✓ $\triangle C_{j,k}$ is the concentration of pollutant *j* in the profile of source *k*, g/m³ (#/m³ for PNC)
✓ $\triangle CO_{2,k}$ is the **background subtracted CO_2 concentration** in the profile of source *k*, g carbon/m³
✓ ω is the carbon mass fraction in the fuel, set as 0.85 in this study

Background CO_2 is defined as the minimum CO_2 among all sites that day.

Austin et al., *ES&T*, 2021, 55 (5): 2847-2858. Shirmohammadi et al., *Atmos. Environ.*, 2017, 151: 82-93.

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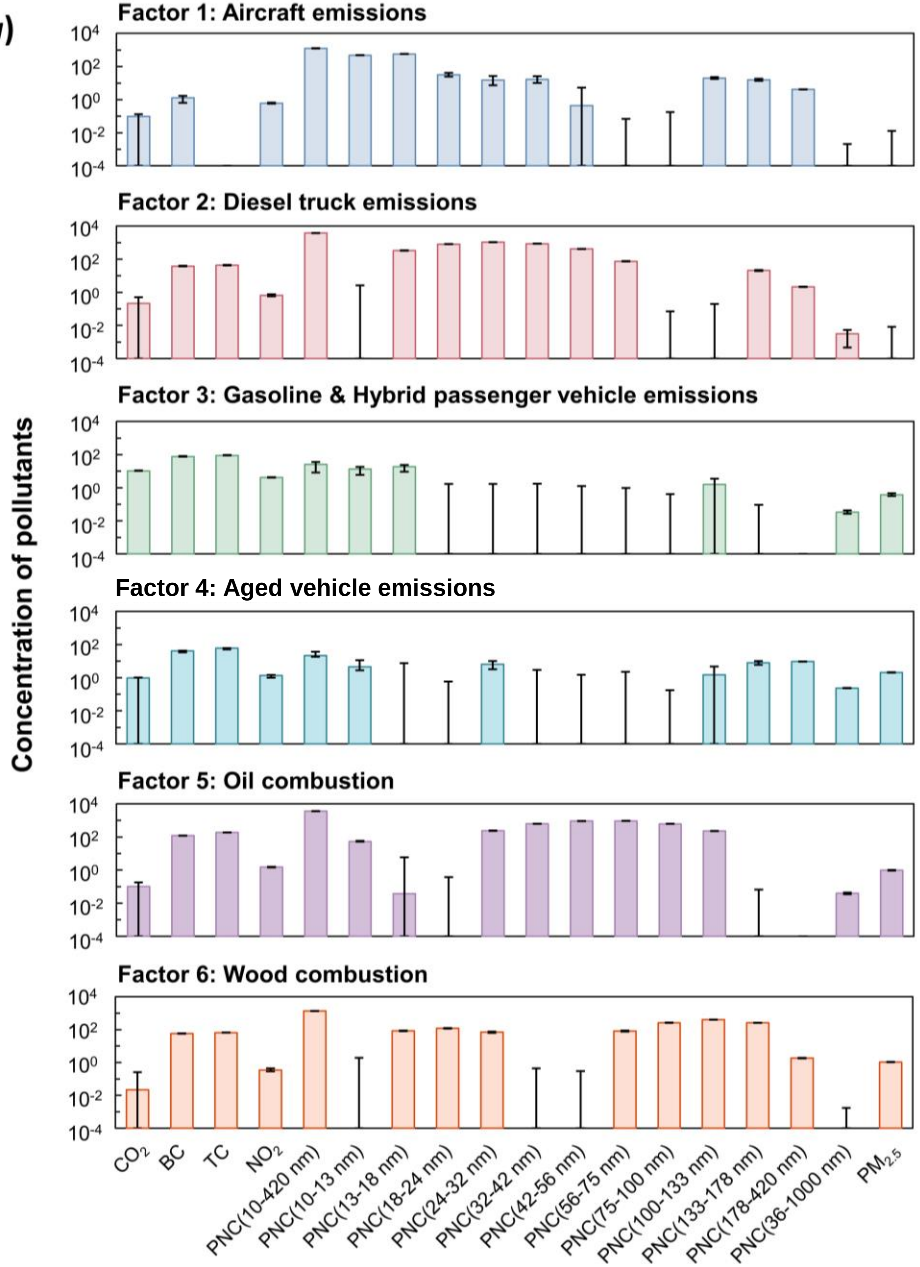
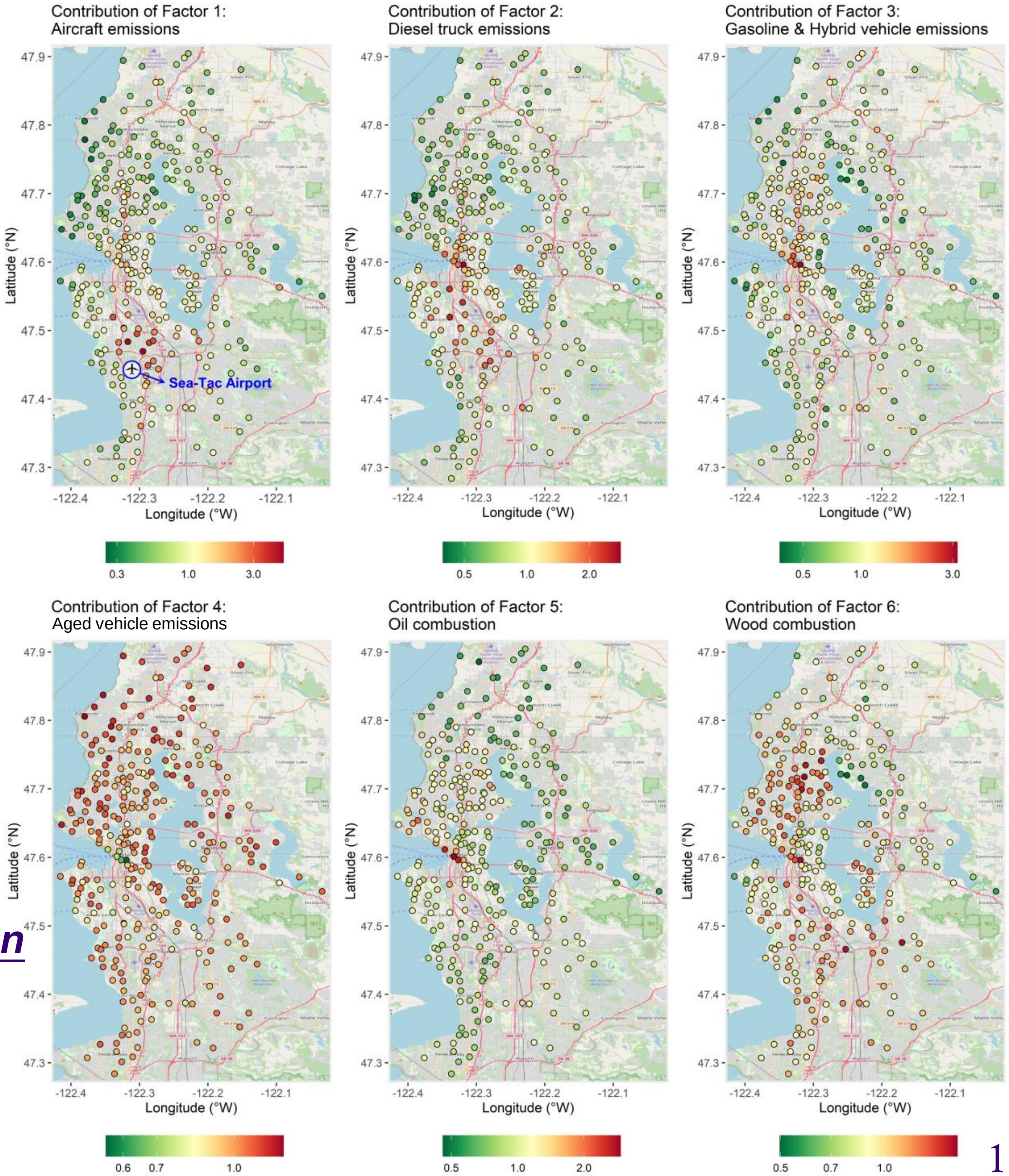
Results: Overview of PMF

(*a*)



Traffic related sources

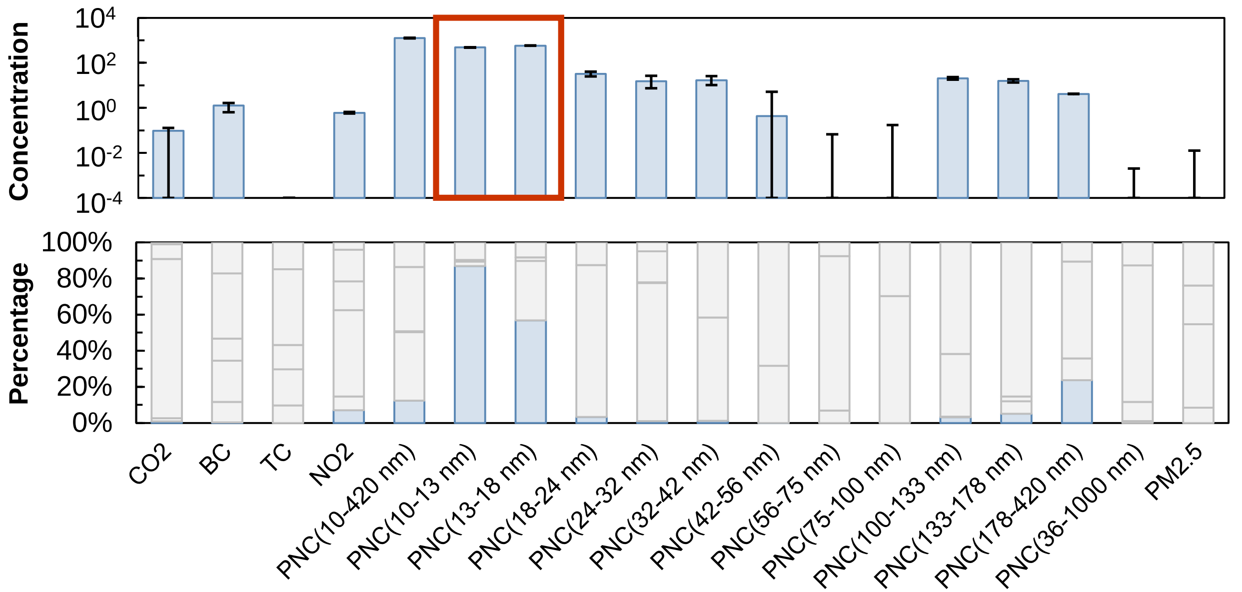
Other combustion sources

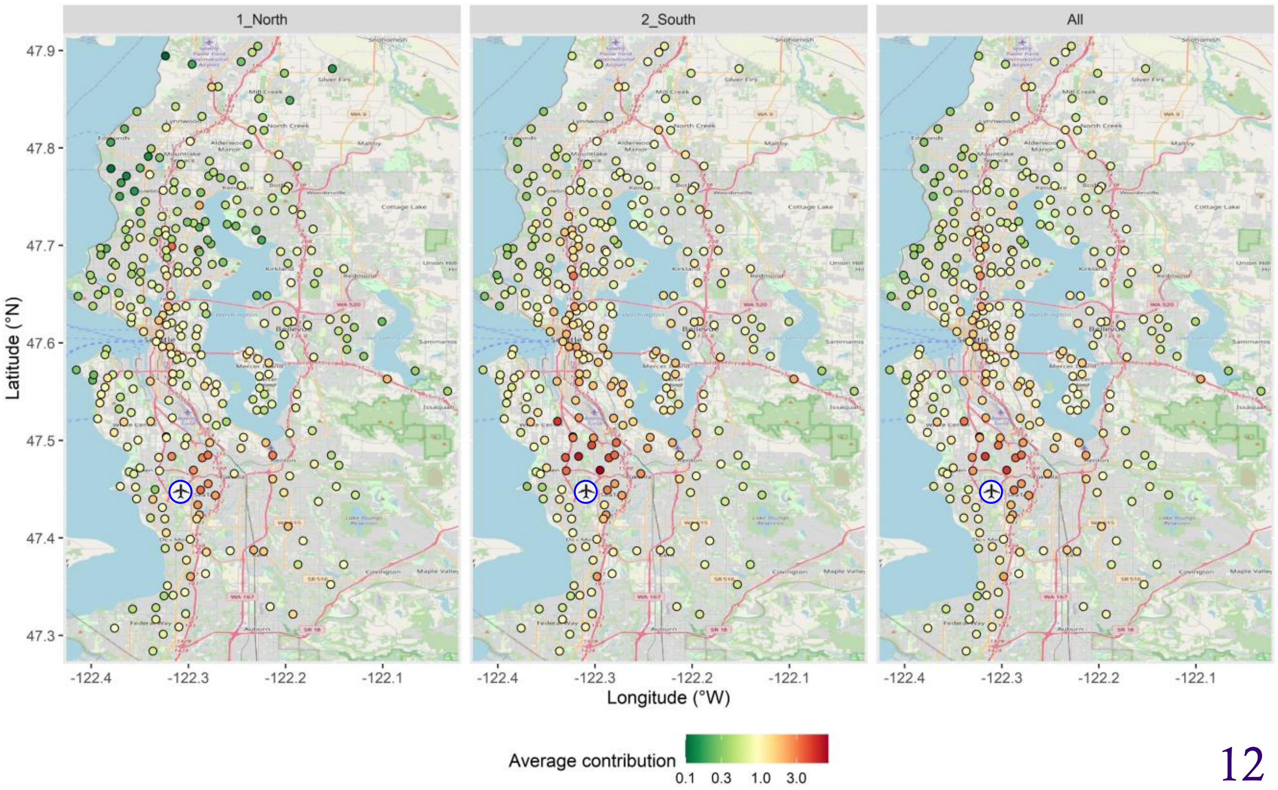


Results: Each source

■ Factor 1: Aircraft

- **Particle size distribution in the literature**
  - Dominated by UFPs (10-20 nm)
  - Sometimes with another peak at 100-150 nm
- **Mapping with external variables**
  - Factor contribution was higher downwind (north) of the SEA/TAC Airport under southerly winds
- **Important covariates from LUR model**
  - Distance to the large airport
  - Distance to the landing/takeoff air routes
- **Ratios**
  - Higher PNC/CO_2 than the other two traffic related sources

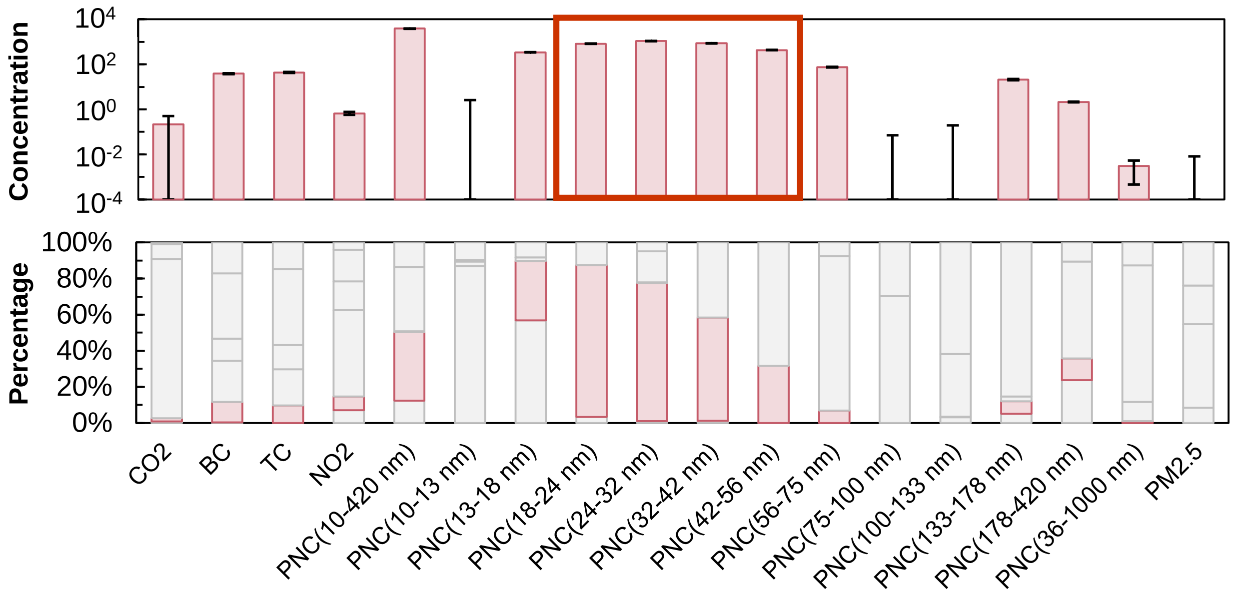


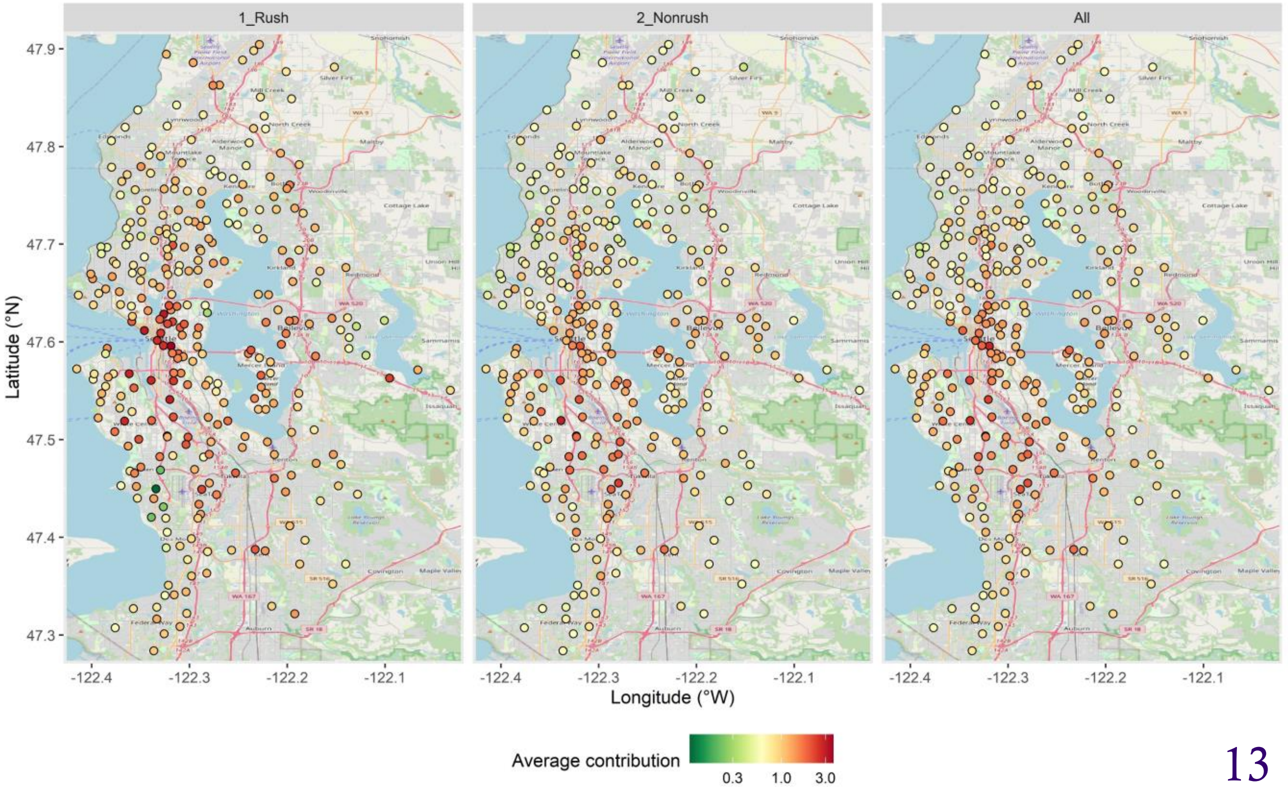


Results: Each source

Factor 2: Diesel truck

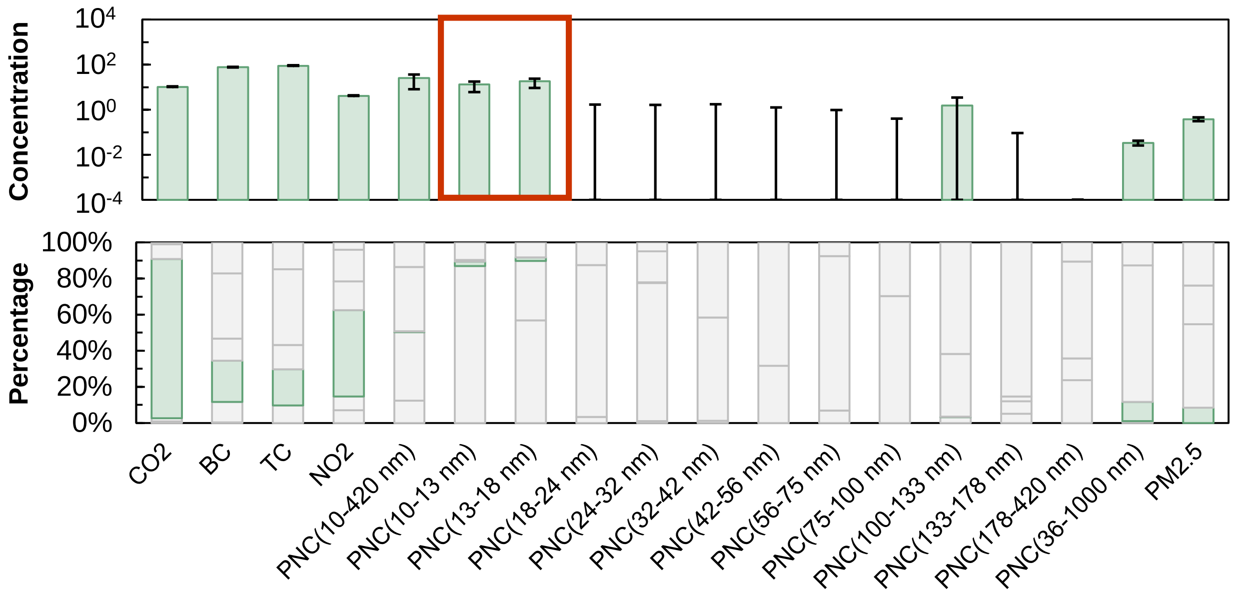
- **Particle size distribution in the literature**
  - Dominated by UFPs (30-50 nm)
  - Vary from 10 and 100 nm according to use of diesel particle filters (DPF), selective catalytic reduction (SCR), and light/heavy-duty
- **Mapping with external variables**
  - Factor contribution was higher around downtown Seattle, industrial district, and the SEA/TAC Airport (freight transport).
- **Important covariates from LUR model**
  - Primary road density
  - Distance to the large airport / air routes
  - Proportion of industrial land use
  - Proportion of developed high-intensity landcover
- **Ratios**
  - Higher BC/CO_2, NO_2/CO_2, and PNC/CO_2 than factor 3 (gasoline)

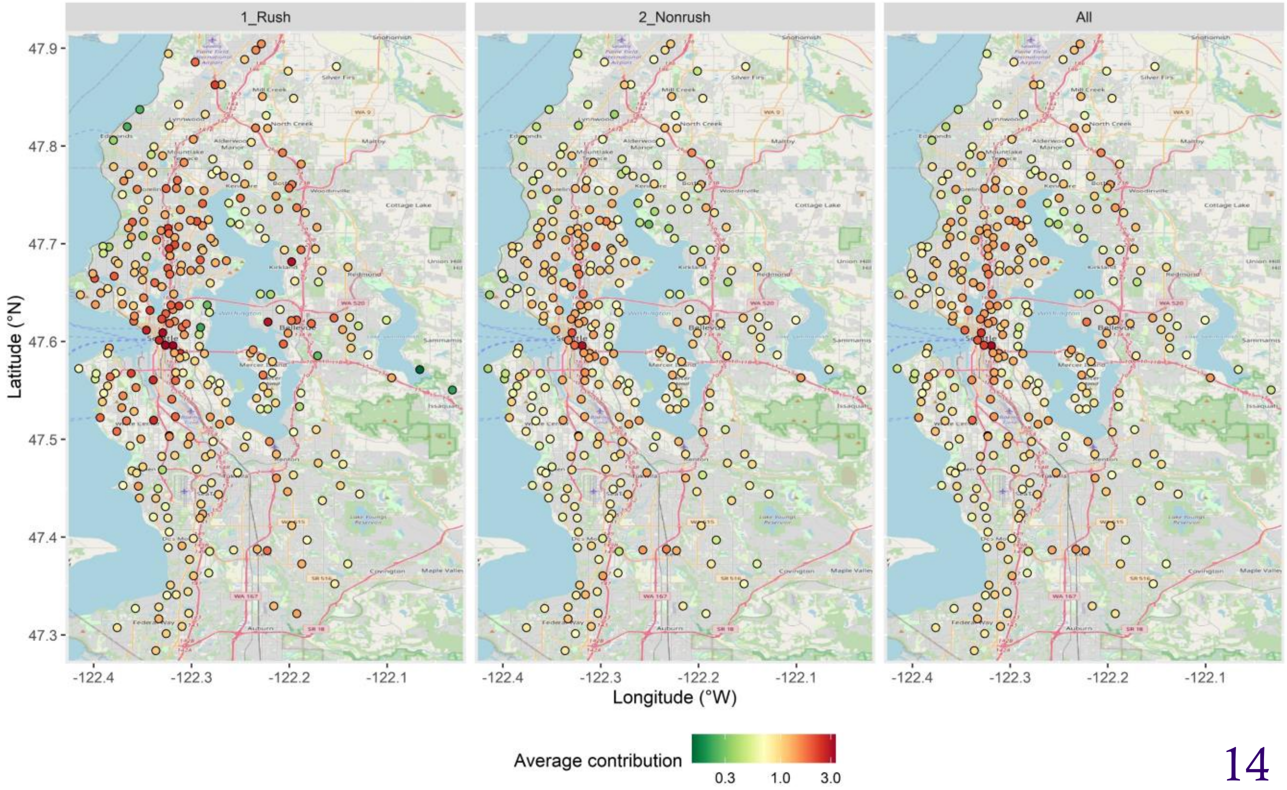




Results: Each source

- **Factor 3: Gasoline & Hybrid passenger vehicle**
  - **Particle size distribution in the literature**
    - UFPs peak at 10-20 nm (nucleation mode)
  - **Mapping with external variables**
    - Factor contribution was higher in downtown Seattle and along I-5 and S-99 Highway.
    - Higher in rush hours
  - **Important covariates from LUR model**
    - Road density
    - Bus route density
  - **Ratios**
    - Lower BC/CO_2, NO_2/CO_2, and PNC/CO_2 than factor 2 (diesel)

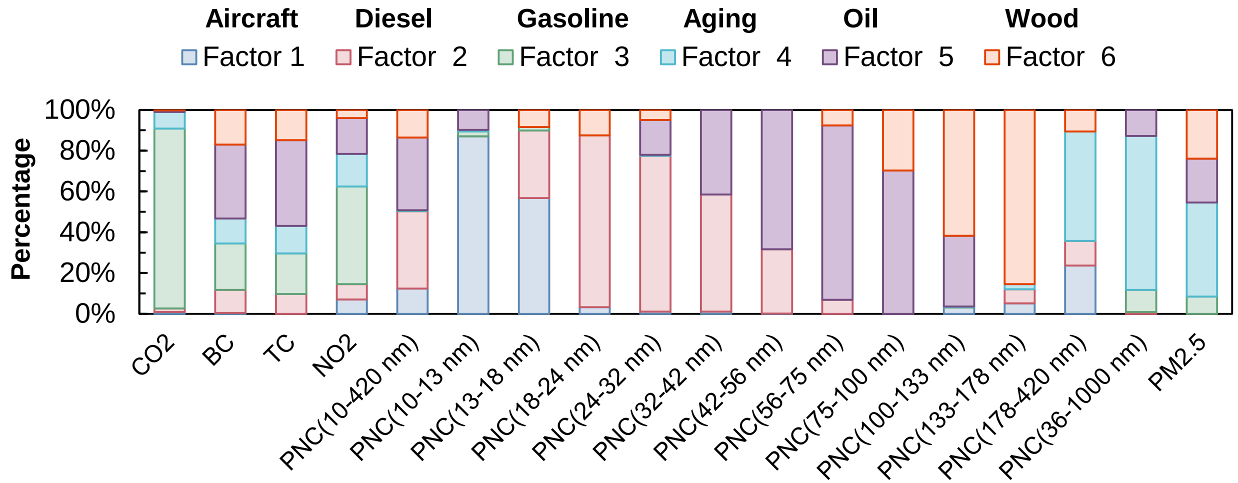


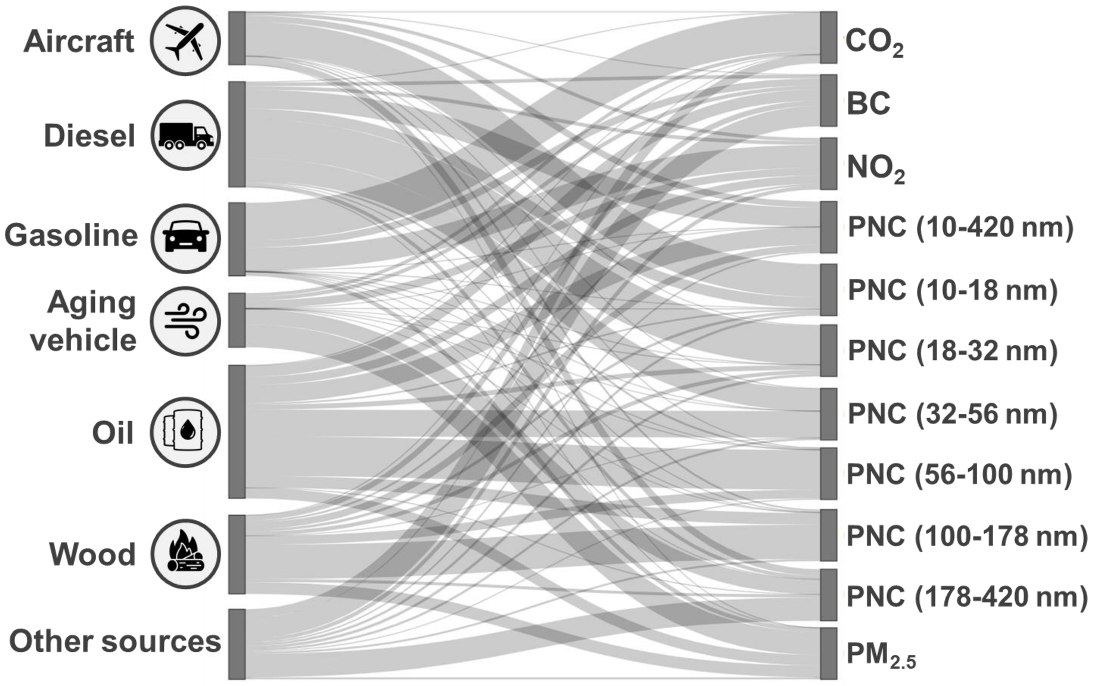


Results: Source-specific exposure

- **Dominant sources for different air pollutants**

Pollutant	1st source	2nd source
CO_2	Gasoline (75%)	Aged (8%)
BC	Oil (22%)	Gasoline (14%)
TC	Oil (29%)	Gasoline (14%)
NO_2	Gasoline (44%)	Oil (16%)
PNC		
Total (10-420 nm)	Diesel (37%)	Oil (35%)
10-18 nm	Aircraft (64%)	Diesel (20%)
18-32 nm	Diesel (76%)	Oil (10%)
32-56 nm	Oil (52%)	Diesel (43%)
56-100 nm	Oil (77%)	Wood (17%)
100-178 nm	Wood (67%)	Oil (23%)
178-420 nm	Aged (38%)	Aircraft (15%)
$PM_{2.5}$	Aged (45%)	Wood (23%)



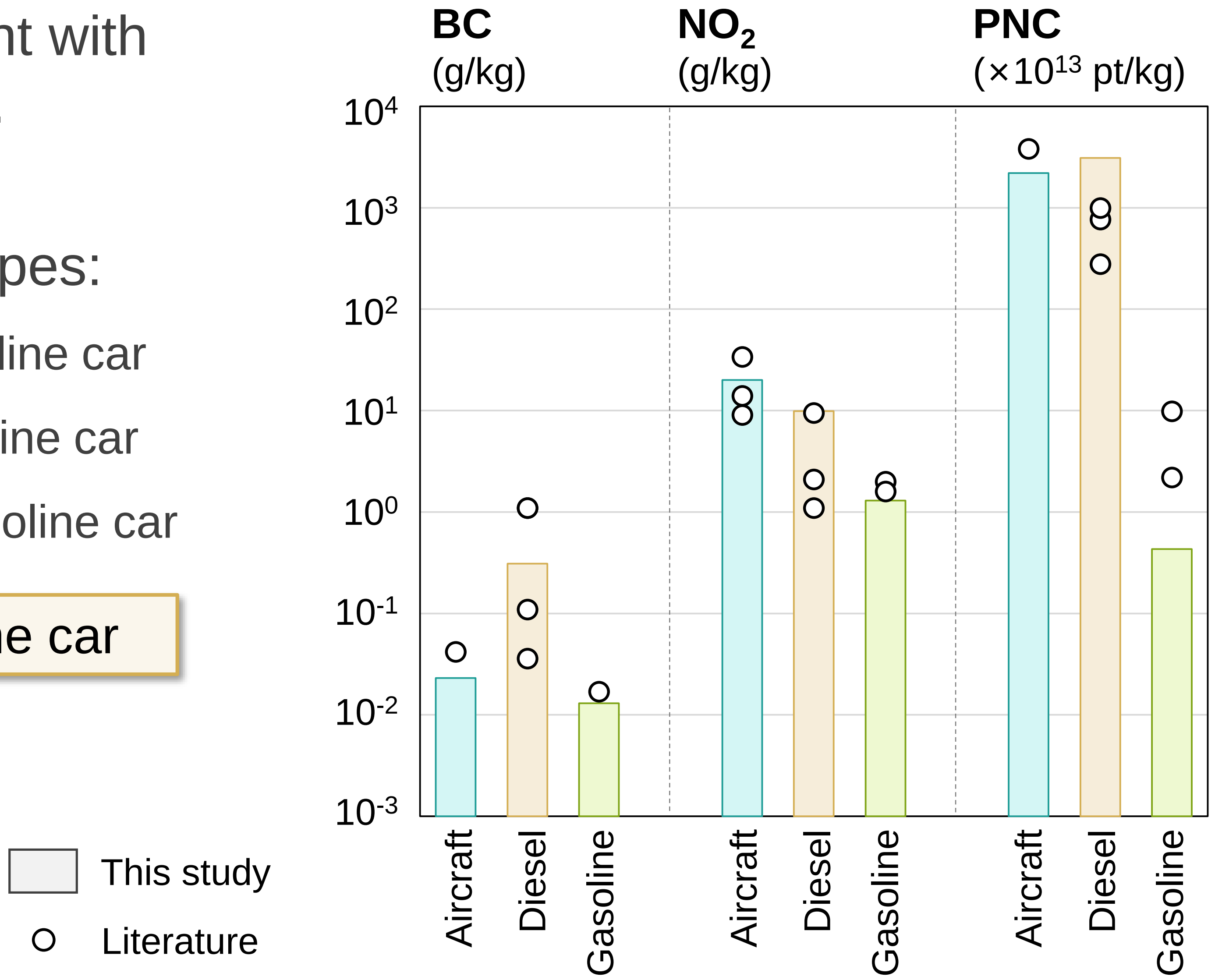


Results: Emission factors (EFs)

- EFs in this study were consistent with reported values in the literature.

- Comparison between vehicle types:
  - **BC**: Diesel truck >> Aircraft > Gasoline car
  - **NO_2**: Aircraft > Diesel truck > Gasoline car
  - **PNC**: Diesel truck > Aircraft >> Gasoline car

Aircraft & Diesel truck > Gasoline car



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Conclusions

- This is the first study to combine a one-year mobile monitoring campaign with PMF analysis to simultaneously estimate source-specific air pollution exposures and emission factors of different vehicle types. → **Can be extended to other metropolitan areas**

- **Aim 1 & 2: Source characterization and source-specific exposure**
  - **Traffic-related sources (aircraft, diesel, gasoline):** Contribute most to CO_2, NO_2, and UFP (10-56 nm)
  - **Aged vehicle emission source:** Contribute most to $PM_{2.5}$ and UFP (178-420 nm)
  - **Other combustion sources (oil, wood):** Contribute most to BC, TC, and UFP (32-178 nm)

- **Aim 3: Traffic-related emission factor**
  - EFs of BC, NO_2, and total PNC were higher for aircraft and diesel trucks, and lower for gasoline vehicles, consistent with previous studies.

- **Limitations**
  - Chemical composition of particles were not considered (e.g., levoglucosan for woodsmoke).
  - PMF was applied in this study, assuming spatiotemporally stable factor profiles.

- **Next step:** use the source-specific air pollution exposure for epidemiological analysis

Thank you for your attention
Questions?

Contact: liunr24@uw.edu (Ningrui Liu)

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