UNIVERSITY OF ALBERTA
SCHOOL OF PUBLIC HEALTH

# Characterization of indoor and outdoor sub-micron particles ($PM_1$) in Edmonton homes

AWMA CPANS Edmonton Luncheon
University of Alberta Faculty Club, Edmonton, AB
April 1, 2016

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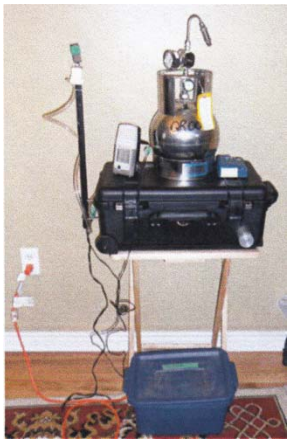
**School of Public Health, University of Alberta**
**Edmonton, AB**

# Levels of air pollution *exposure* measurement

Decreasing uncertainty in representing exposure

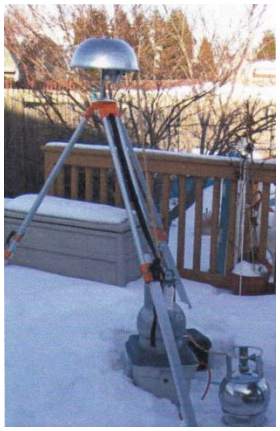
**(Personal)**

**(Indoor)**



**(Near-field outdoor)**


**Street Level**



**Backyard**

**(Ambient)**

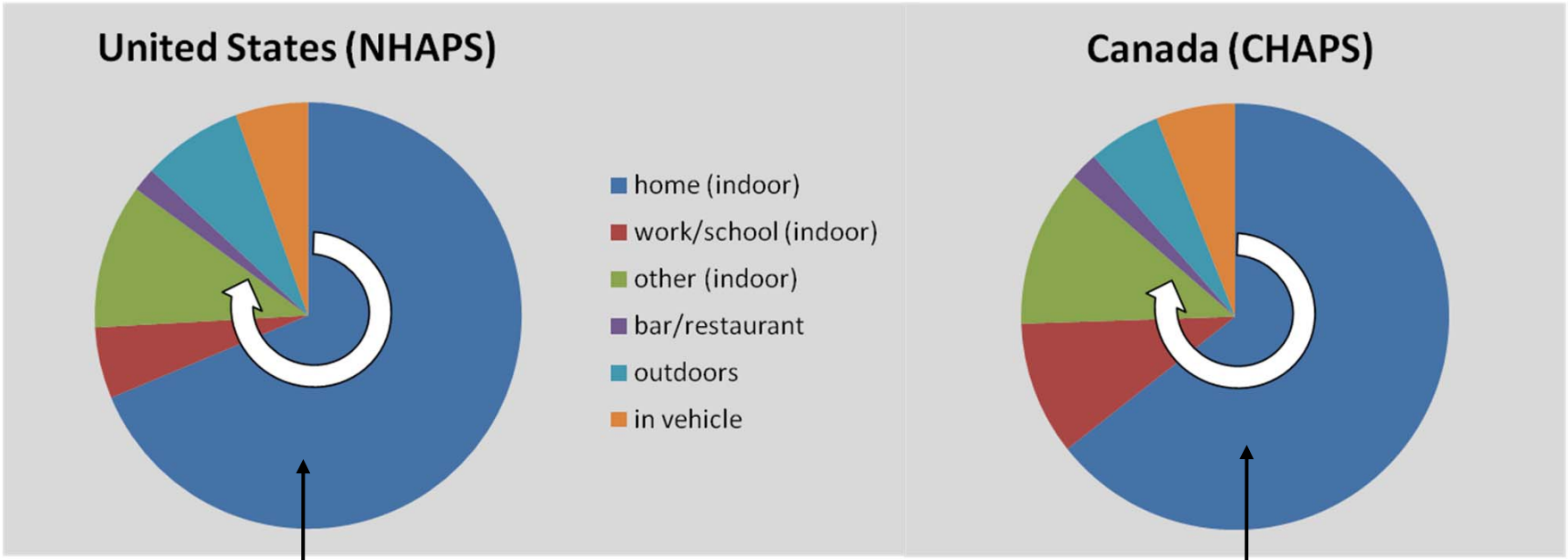
**IV** **III** **II** **I**

# Background



- Indoor air quality is an important determinant of health.
- Several studies have been conducted across Canada (e.g., Quebec City, Windsor, Regina, Halifax etc.) in order to compare baseline data and upgrade Health Canada's Indoor Air Quality Guidelines.
- Most epidemiological studies assume outdoor air as a risk factor and are not free from bias because they ignore exposure from indoor air quality.

# Indoor Environment and Time-Activity – Mean Amounts of Time Spent in Various Microenvironments for North American Adults




87% total time indoors
69% time at home

88% total time indoors
64% time at home

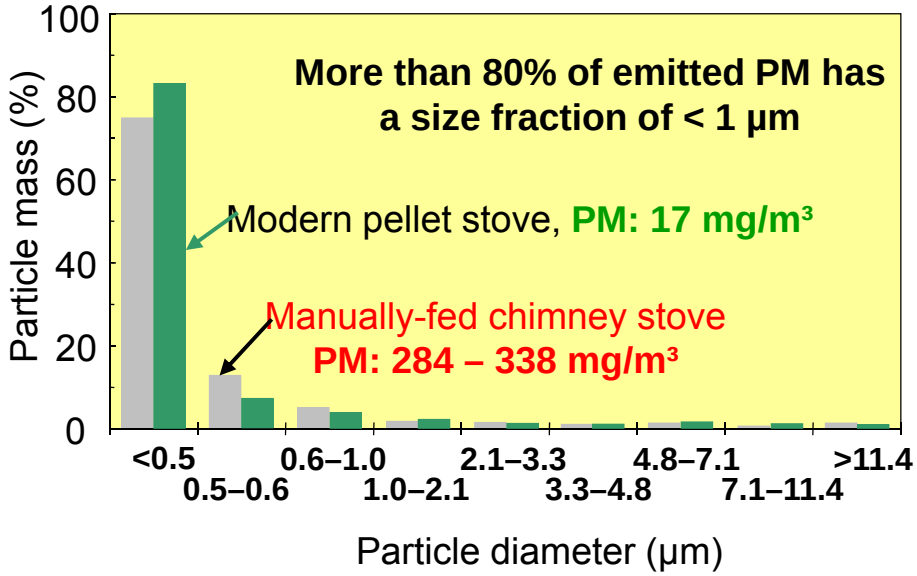
*Leech et al. 2002. J. Exp. Anal. Environ. Epidemiol., 12, 427-432*

# Emission sources of sub-micron particles



Vehicle emissions

Biomass burning (wood stoves/fireplaces)




*Bari et al., 2011. Atmospheric Environment 45, 7627-7634*

# Objective

- **Characterize indoor and outdoor levels and sources of sub-micron particles ($PM_1$) at Edmonton homes.**

Environmental Science & Technology

Article

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# Indoor and Outdoor Levels and Sources of Submicron Particles ($PM_1$) at Homes in Edmonton, Canada

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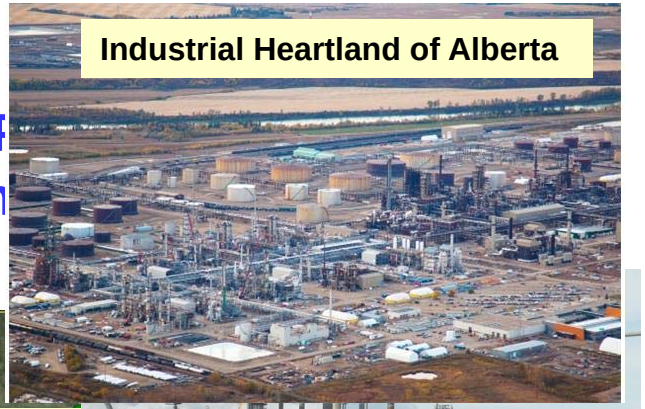
*Bari et al., 2015. Environmental Science & Technology 49, 6419–6429*

# Industrial sources reporting to Environment
# nventory (NP
# ding Region

Generating Plants

ement plant



Industrial Heartland of Alberta


Fort Saskatchewan

Wabamun Lake

Edmonton


SUNCOR

**Coal combustion sources related to power generation**




Google Earth (Image IBCAO © 2013 Google)

National Pollutant Release Inventory, 2015 (http://www.ec.gc.ca/inrp-npri/)

# Methodology: Indoor/outdoor sampling

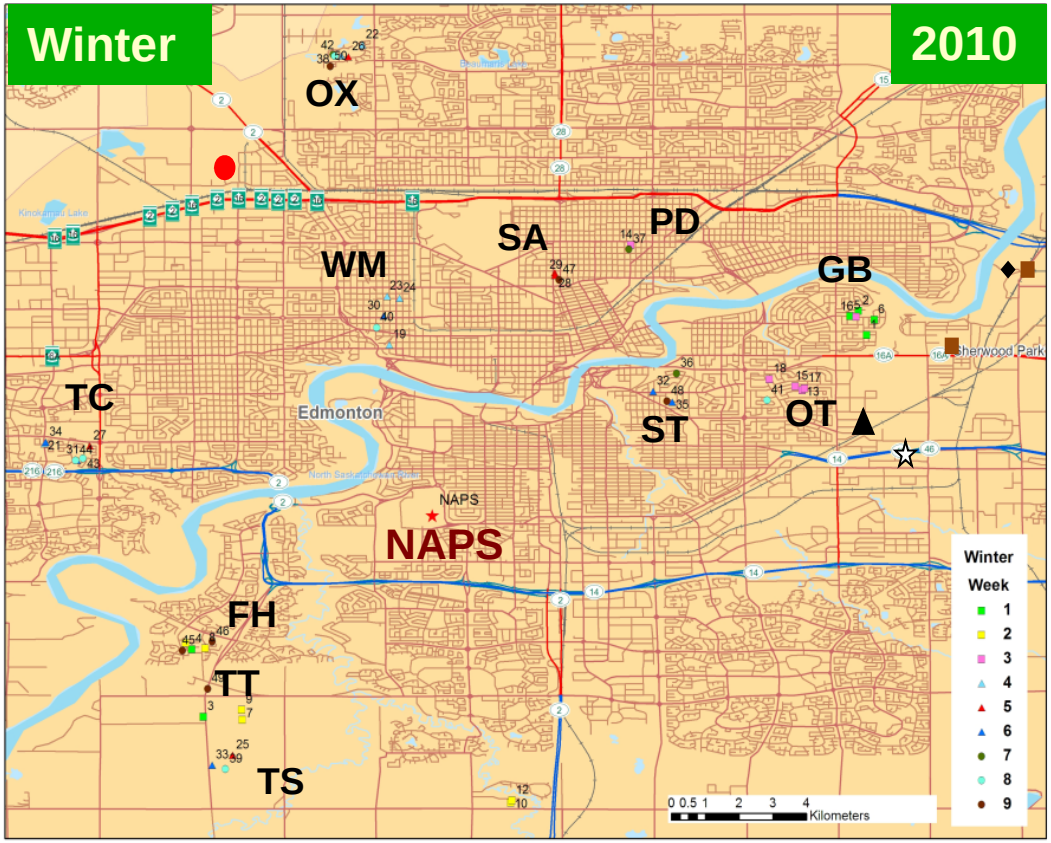


- Winter: Jan–Apr (n =50)
- Summer: Jul – Aug (n = 50)
- 74 non-smoking homes

- Nine consecutive 7-day sampling period per season (5-6 homes per period).

- Homes sampled were stratified by age – residences grouped into five construction year strata.
  - ≤ 1946
  - 1946 – 1960
  - 1961 – 1980
  - 1981 – 2000
  - ≥ 2001

**NAPS: National Air Pollution Surveillance**




OX- Oxford
WM-Westmount
SA-Spruce Avenue
PD-Parkdale
TC-Thorncliff
GB-Gold Bar
OT-Ottewell
ST-Strathearn
FH-Falconer Heights
TT-Terwillegar Towne
TS-Terwillegar South

# Methodology – Questionnaires



**Baseline Questionnaire data:**

- Year of construction.
- Heating and cooking systems.
- Attached or detached garage.
- Supplemental heating-wood stoves/fireplace.
- Carpets in bed rooms and living rooms.
- Nearby outdoor sources.

**Daily Diary Questionnaire data:**

- Environmental Tobacco Smoke (ETS); burning of candles, incense.
- Window opening and air conditioner use
- Any cleaning activities e.g., vacuuming, dusting, sweeping.
- Car idling in the garage.
- Cooking (type, duration) and use of exhaust fan.
- Barbeque use.
- Use of stoves to fry, grill, burn foods.

# Methodology – $PM_1$ sampling and analysis



## Indoor/outdoor sampling

- Seven consecutive 24 h PM sampling (**$PM_1$**, $PM_{1\text{-}2.5}$, $M_{10\text{-}2.5}$) using Harvard coarse mode impactor (HCI)

**Harvard coarse impactor**

## Chemical analysis

- 34 heavy and trace metals
- Energy dispersive X-ray fluorescence (ED-XRF)
- Inductively coupled plasma mass spectrometry (ICP-MS)

# Results: Data quality



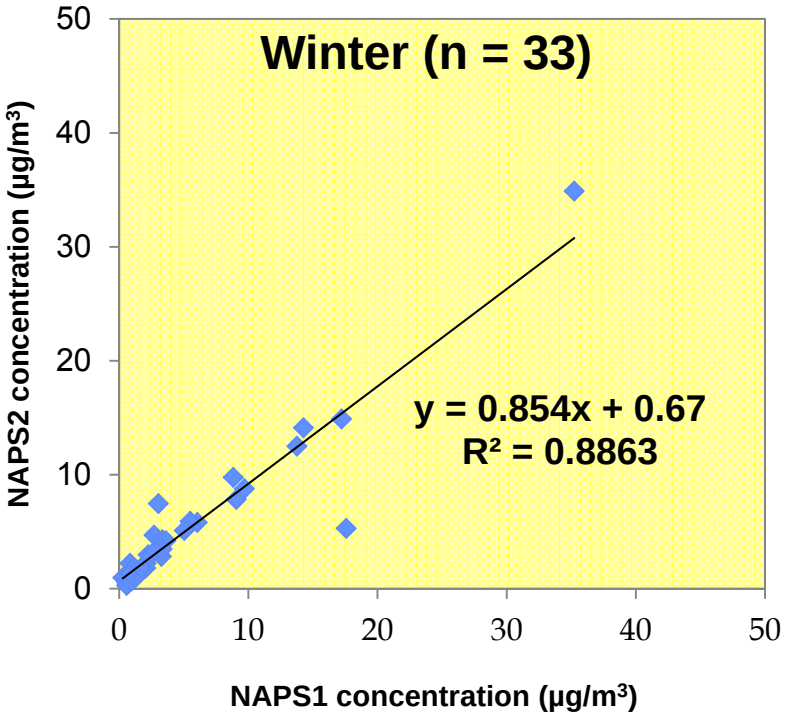
- No blank correction (>50% of blanks are below detection limit (BDL).
- First four 7-day sampling periods in winter were invalid and excluded.

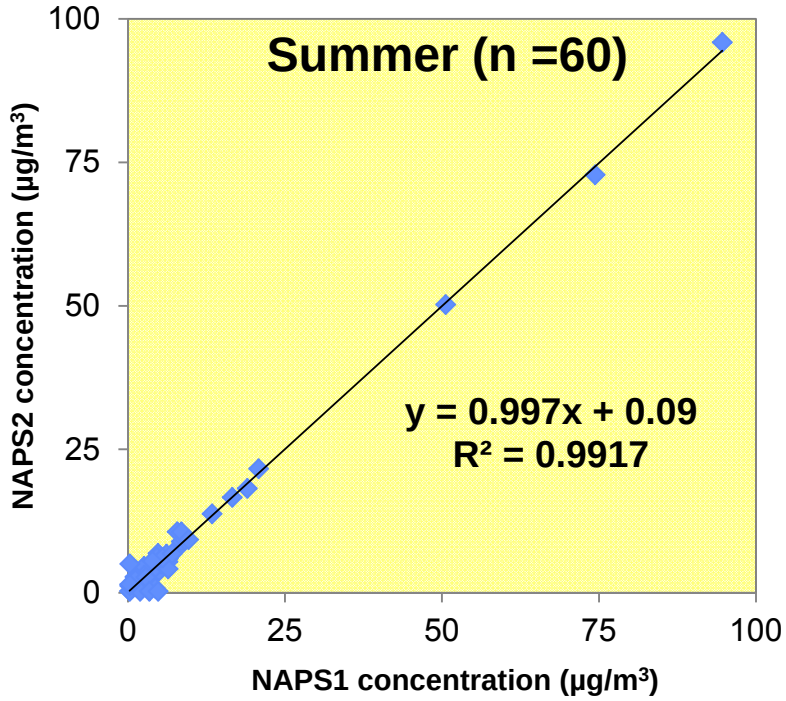
| | Winter | | Summer | |
|---|---|---|---|---|
| N = 27 | Indoor BDL (%) | Outdoor BDL (%) | Indoor BDL (%) | Outdoor BDL (%) |
| $PM_1$ | 8 | 4 | 20 | 10 |
| Silver (Ag) | 0 | 12 | 5 | 24 |
| Aluminum (Al) | 19 | 17 | 13 | 11 |
| Arsenic (As) | 3 | 1 | 0 | 0 |
| Boron (B) | 27 | 19 | 0 | 0 |
| Barium (Ba) | 11 | 7 | 14 | 8 |
| Bismuth (Bi) | 17 | 8 | 27 | 27 |
| Calcium (Ca) | 5 | 4 | 19 | 27 |
| Cadmium (Cd) | 39 | 34 | 19 | 12 |
| Chlorine (Cl) | 36 | 26 | 29 | 18 |
| Cobalt (Co) | 19 | 11 | 41 | 40 |
| Chromium (Cr) | 47 | 66 | 41 | 47 |
| Copper (Cu) | 40 | 50 | 18 | 19 |
| Iron (Fe) | 0 | 0 | 6 | 4 |
| Potassium (K) | 7 | 1 | 7 | 4 |
| Magnesium (Mg) | 2 | 1 | 22 | 24 |
| Manganese (Mn) | 0 | 0 | 0 | 0 |
| Molybdenum (Mo) | 19 | 7 | 5 | 3 |
| Sodium (Na) | 12 | 17 | 46 | 50 |
| Nickel (Ni) | 60 | 70 | 48 | 46 |
| Lead (Pb) | 24 | 4 | 14 | 8 |
| Sulfur (S) | 0 | 0 | 0 | 0 |
| Antimony (Sb) | 1 | 1 | 0 | 0 |
| Silicon (Si) | 9 | 2 | 14 | 29 |
| Tin (Sn) | 22 | 61 | 2 | 58 |
| Thallium (Tl) | 23 | 6 | 24 | 16 |
| Vanadium (V) | 7 | 1 | 3 | 1 |
| Zinc (Zn) | 7 | 2 | 16 | 8 |

# Results – Data quality (precision)



- Duplicate sampling (~10% of total sampling) at NAPS station.




**% difference: Median 14.7**
**(IQR: 6.8, 49.0)**

**% difference: Median 15.4**
**(IQR: 4.4, 38.2)**

# Home characteristics

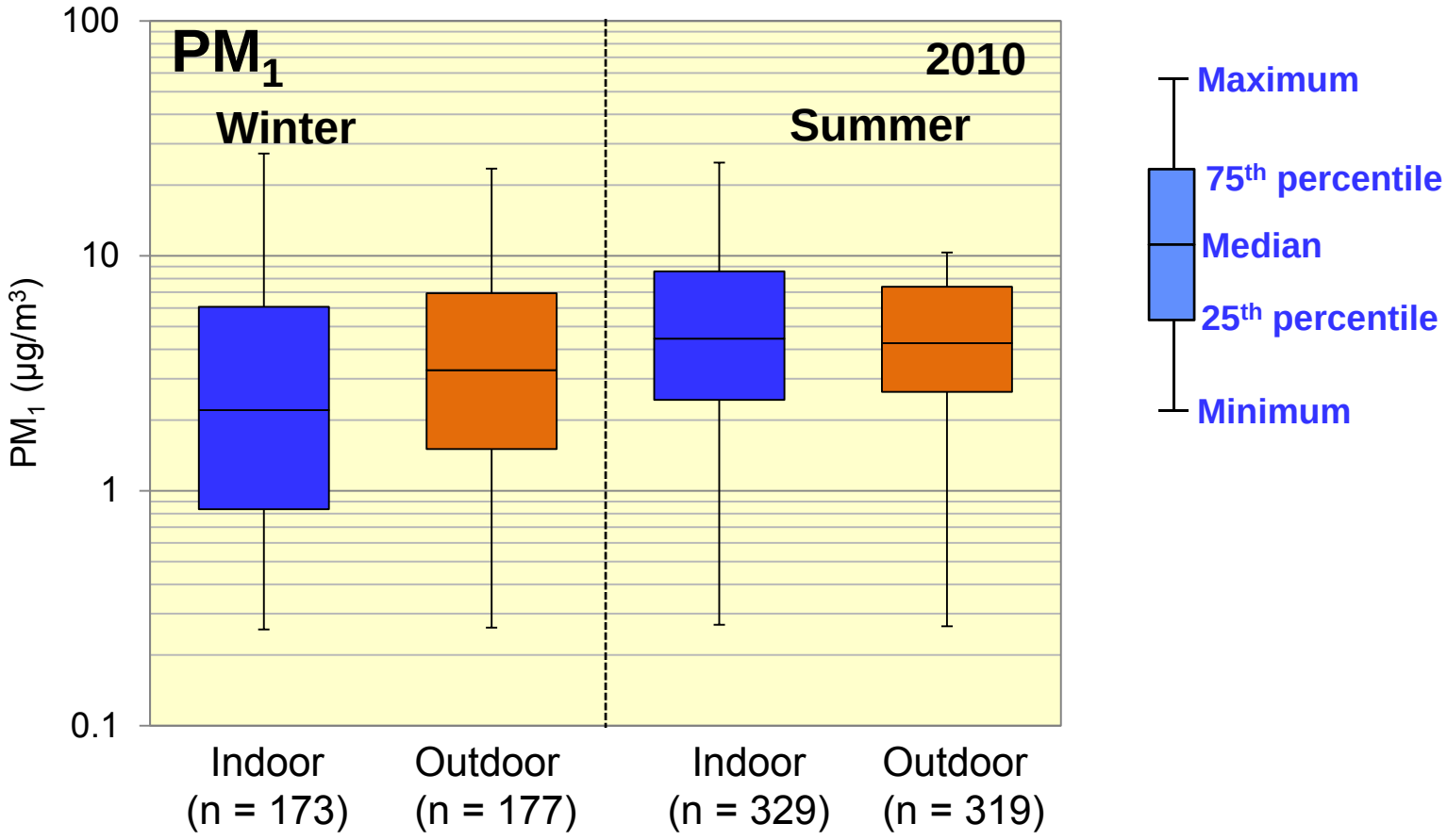


| Characteristics | Winter (n = 26) | Summer (n = 50) |
|---|---|---|
| Attached home | 3 (12%) | 3 (6%) |
| Attached garage with connecting door to home | 8 (32%) | 17 (34%) |
| Detached garage | 17 (65%) | 32 (64%) |
| Air conditioning operation | – | 13 (26%) |
| Carpet in home | 25 (100%) | 46 (98%) |
| Windows open at least one day during monitoring | 23 (88%) | 50 (100%) |
| Visitor smoking at home at least one day during monitoring | 3 (12%) | 1 (2%) |
| Visitor smoking outside home at least one day during monitoring | 8 (32%) | 9 (18%) |
| Barbeque use | – | 31 (62%) |
| Anyone left cars idling at least one day during monitoring | 6 (24%) | 9 (18%) |
| Electric cooking stove use | 22 (88%) | 41 (42%) |
| Anyone used stove to sauté, fry or grill | 23 (88%) | 45 (90%) |
| Anyone burned food at least one day during monitoring | 7 (27%) | 14 (28%) |

# Characterization of $PM_1$

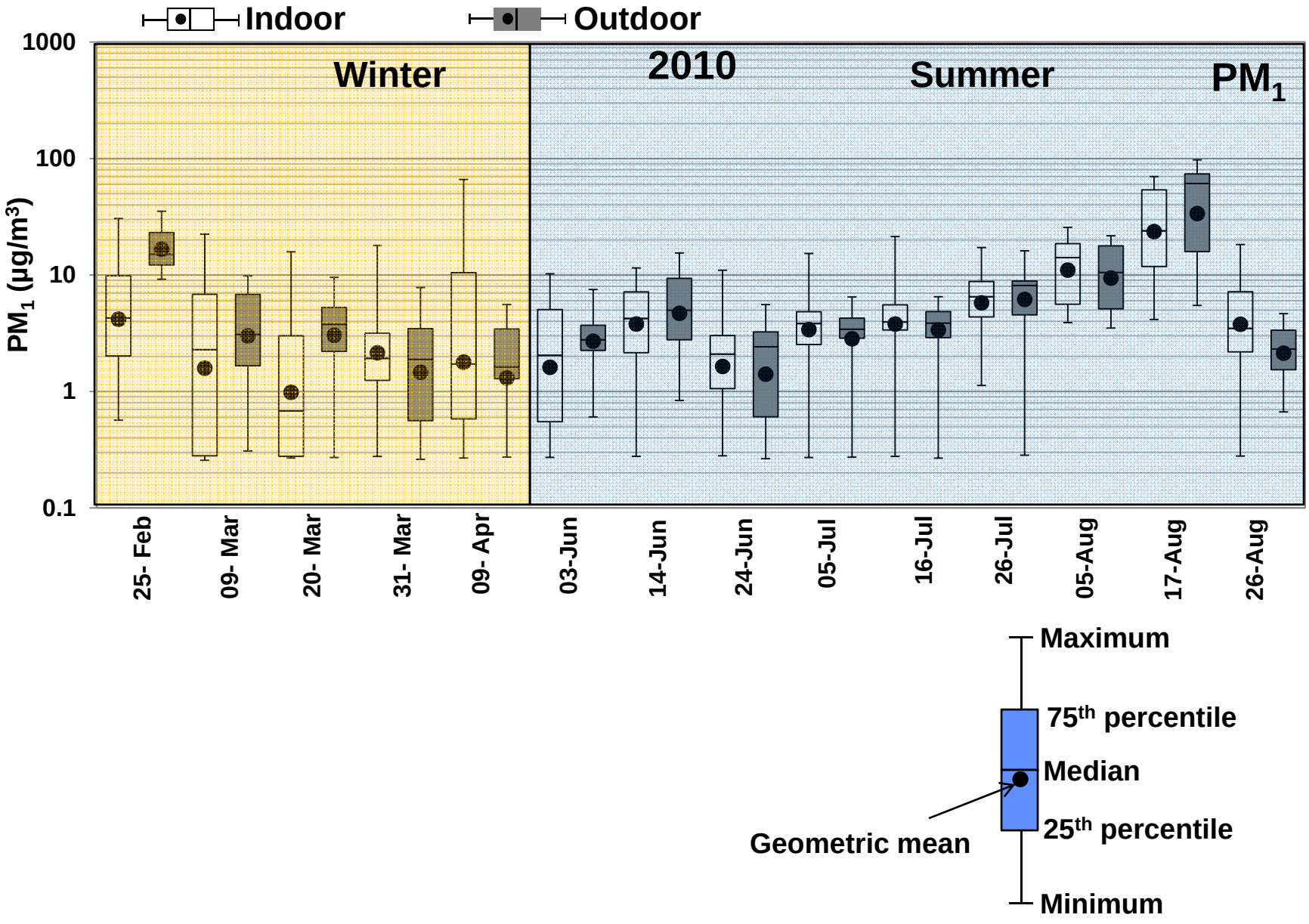
# Results – $PM_1$ levels-Box Plot





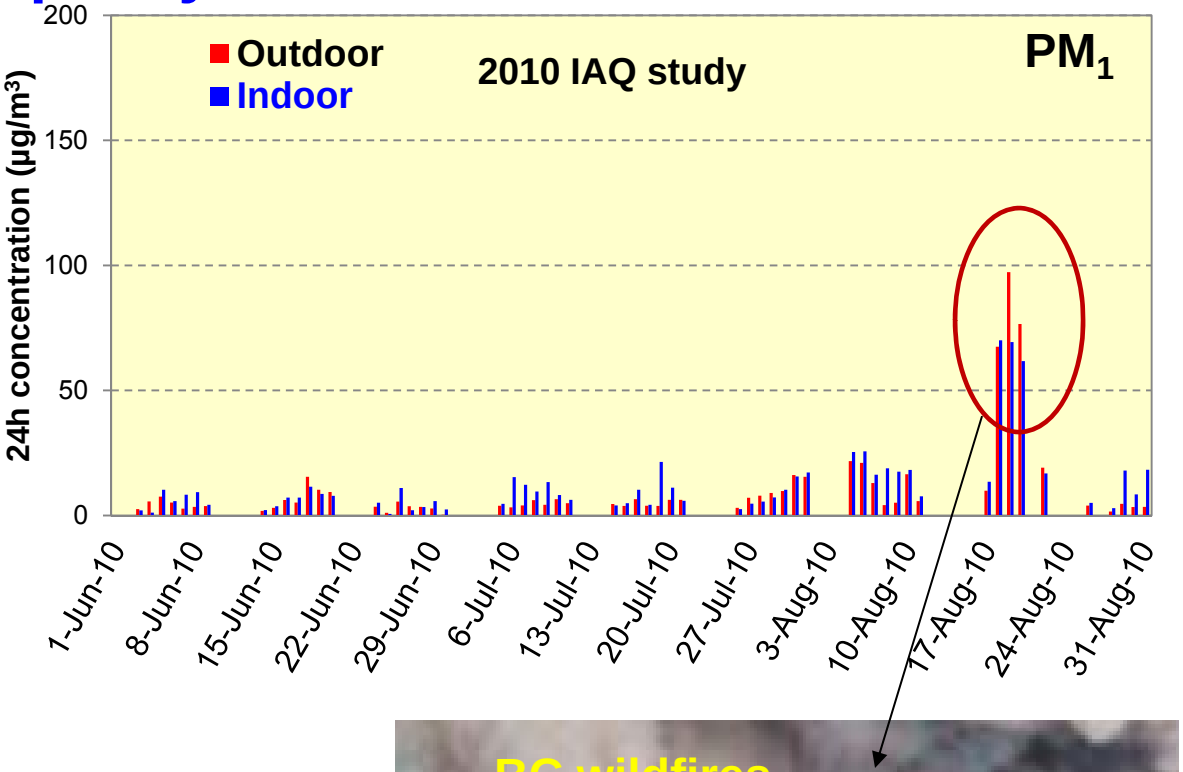
# Temporal profiles of indoor and outdoor $PM_1$





# Influence of wildfires smoke on indoor and outdoor air quality in Edmonton

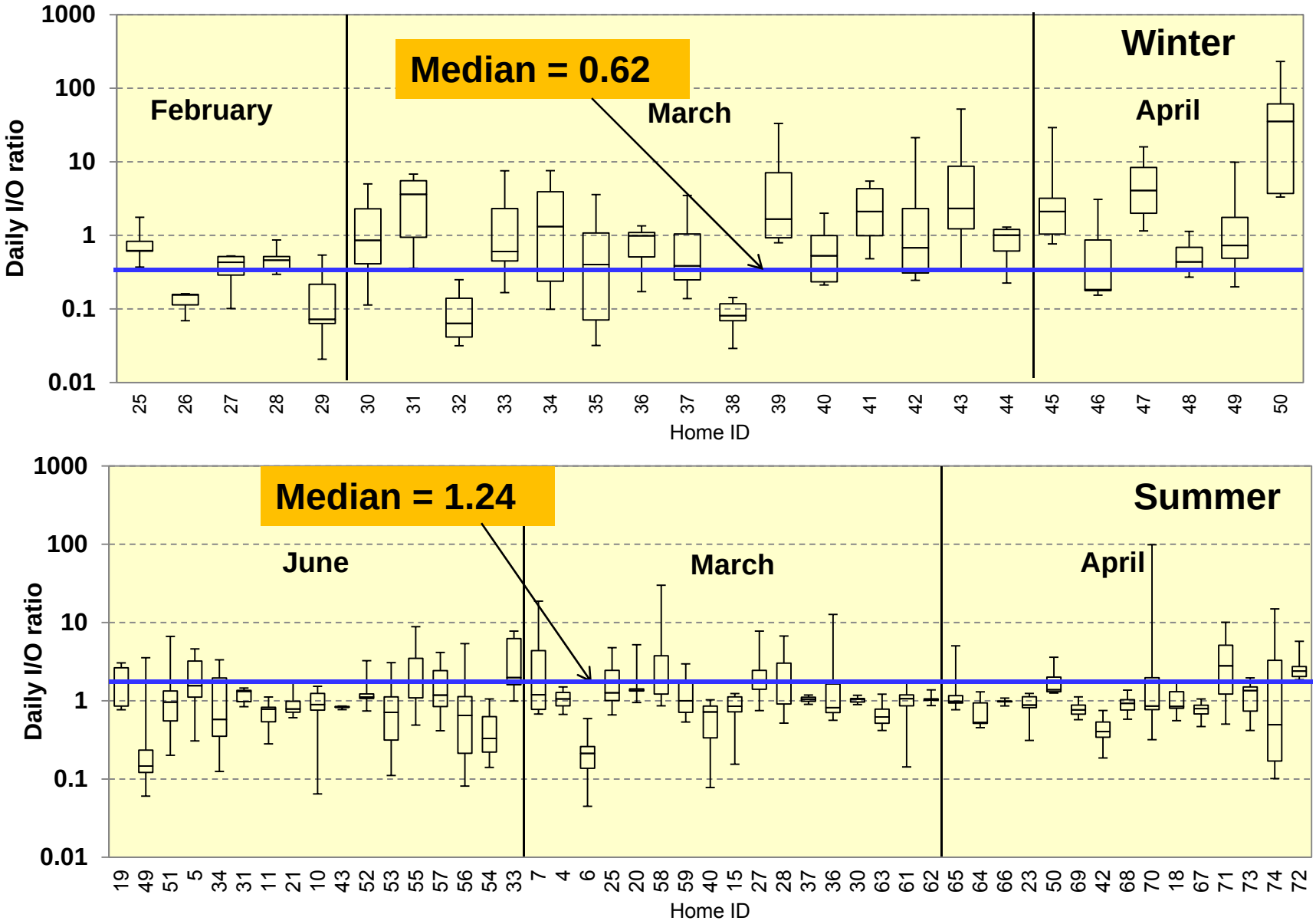




# Variability in indoor/outdoor (I/O) ratios by home





# Influence of particle infiltration



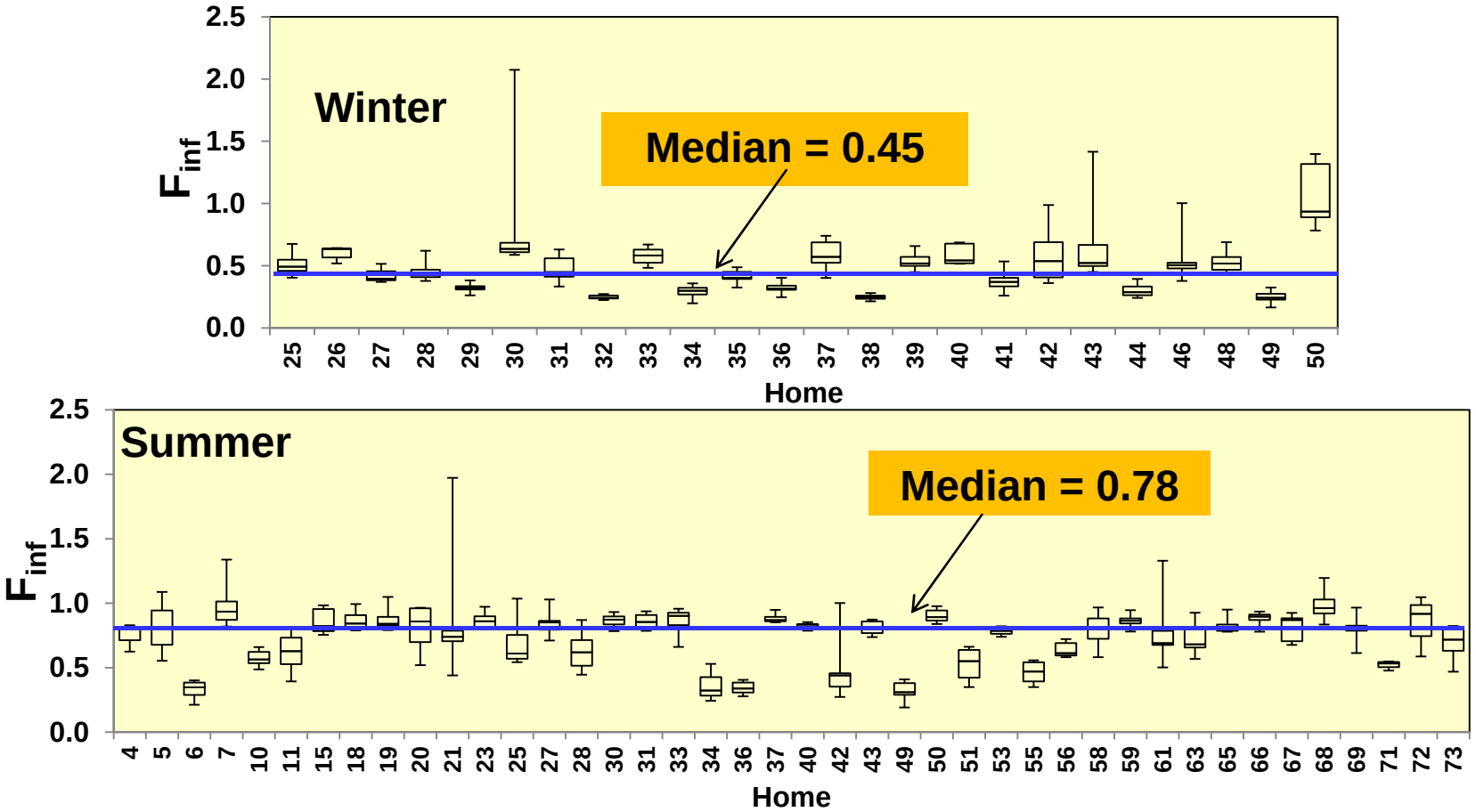
**Infiltration factor, $F_{inf}$**

$$F_{inf} = \frac{Pa}{a+k}$$

*P* = particle penetration coefficient
*a* = air exchange rate (per hour)
*k* = particle loss rate (per hour)

**Estimates of $F_{inf}$**

- Tracer-based method (e.g., using sulfur ratio)



# Source apportionment of $PM_1$ elements

# Analytical Approach for $PM_1$ Source Identification/Verification



**Source Identification:** multivariate analysis…
US EPA positive matrix factorization (PMF)

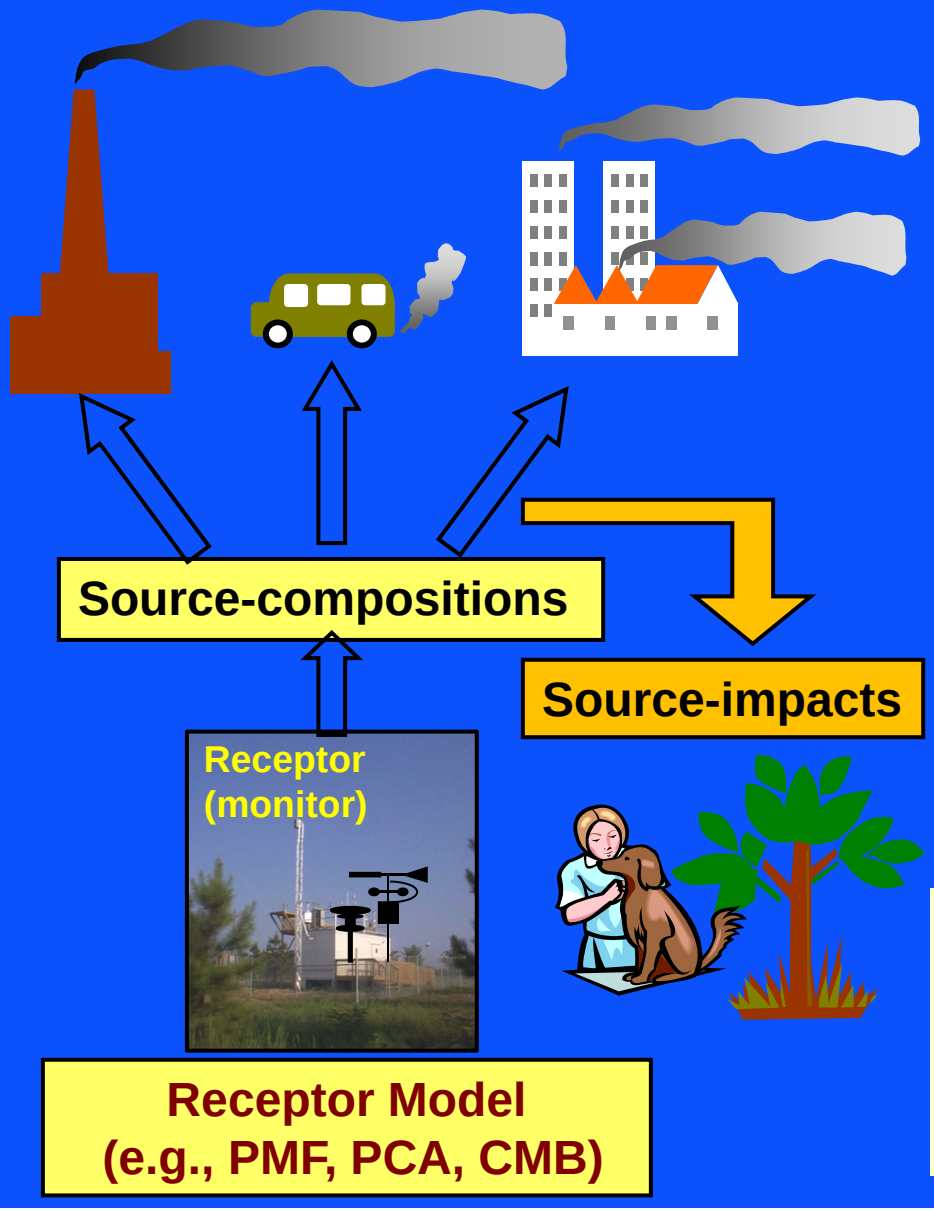
**Source Verification:** ‘local’ source influence…
conditional probability function (CPF) plots

‘regional’ source influence…
air parcel backward trajectories w/NOAA HYSPLIT
[potential source contribution function (PSCF) plots]

statistical correlation w/measured air pollutants…
*Pearson* correlations

# Multivariate analysis: Receptor modeling






- U.S. EPA Positive matrix factorization (EPA PMF3.0).
- based on analysis on correlation between measured chemical species in a number of samples (n >100).

**Edmonton IAQ study:**

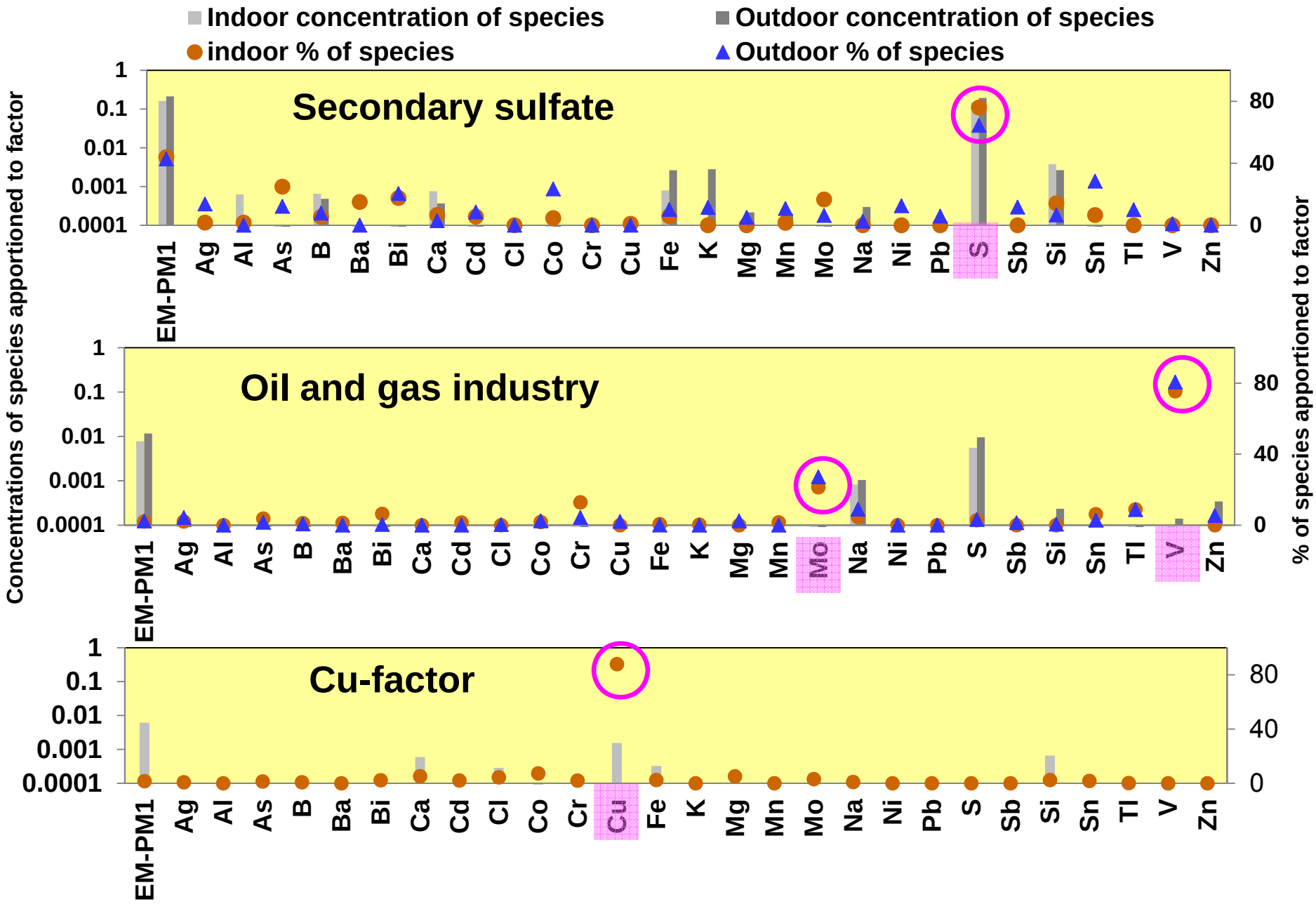
- Indoors (n = 254)
- Outdoors (n = 275)
- Pooled (n = 529)
- No. of elements: 27

- PCA: Principal component analysis
- PMF: Positive matrix factorization
- CMB: Chemical mass balance

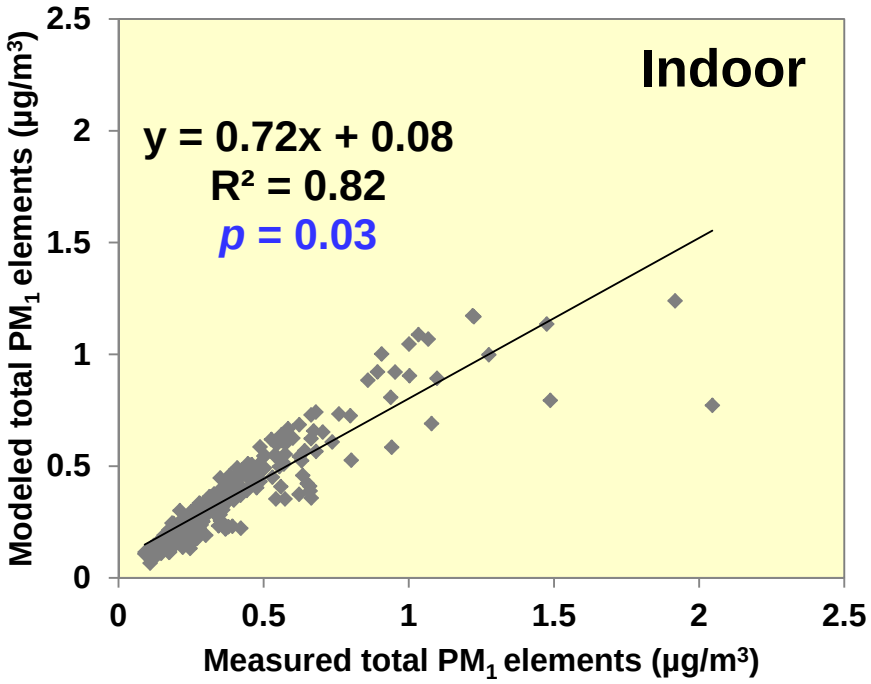
# Sources of elements in $PM_1$ mass in Edmonton homes

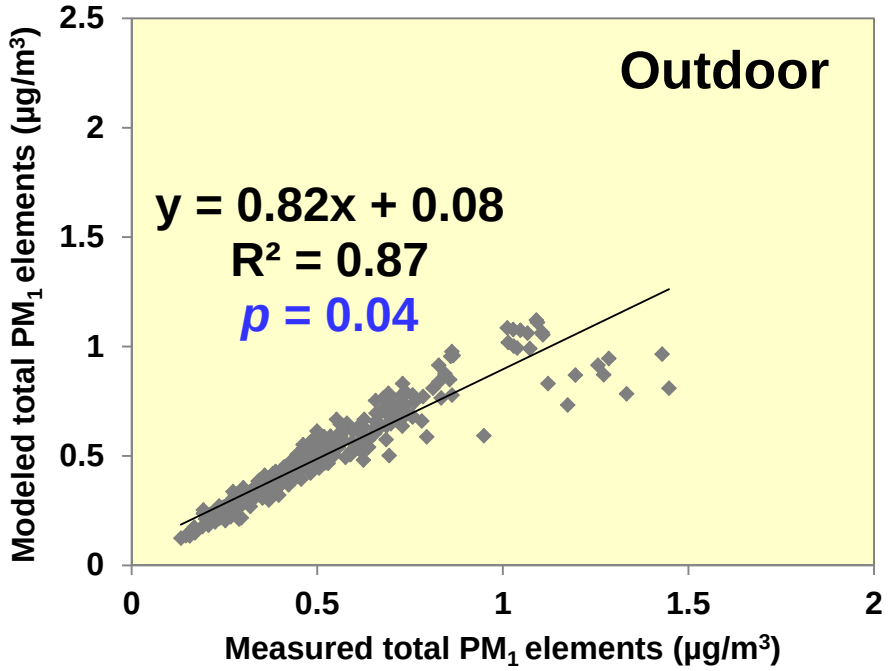
| | | Outdoor model | Pooled indoor/outdoor model |
|---|---|---|---|
| | **Sources** | **Outdoor contributions** | **Indoor contributions** |
| Factor 1 | Secondary sulfate | 42.8% | 43.9% |
| Factor 2 | Soil | 18.7% | 15.8% |
| Factor 3 | Biomass smoke & ETS | 17.1% | 17.8% |
| Factor 4 | Traffic | 4.3% | 2.9% |
| Factor 5 | Settled and mixed dust | 3.7% | 3.9% |
| Factor 6 | Coal combustion | 3.6% | 2.7% |
| Factor 7 | Oil and gas industry | 2.4% | 2.1% |
| Factor 8 | Road salt/ road dust | 2.6% | 1.2% |
| Factor 9 | Urban mixture | 5.0% | 2.0% |
| Factor 10 | Carpet dust | **Indoor** | **4.3%** |
| Factor 11 | Cu-factor | **Indoor** | **1.7%** |
| Factor 12 | Ag-factor | **Indoor** | **1.6%** |

# PMF-derived source profile



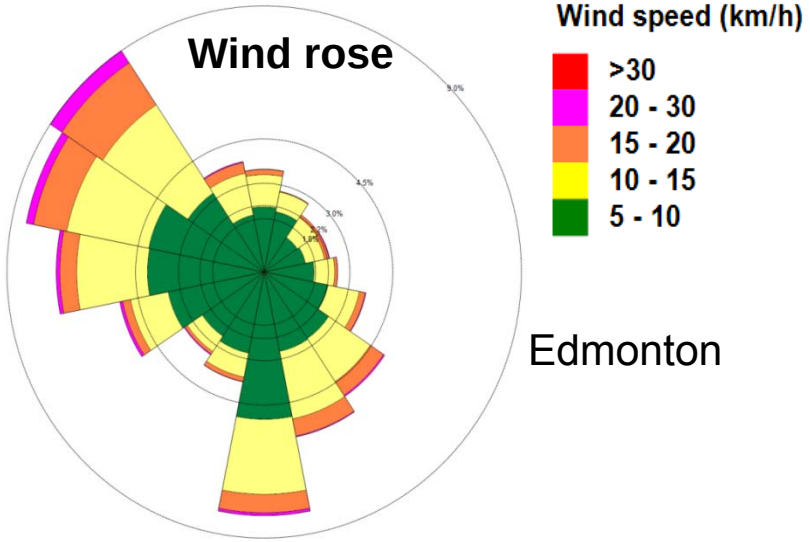
# Performance of PMF model



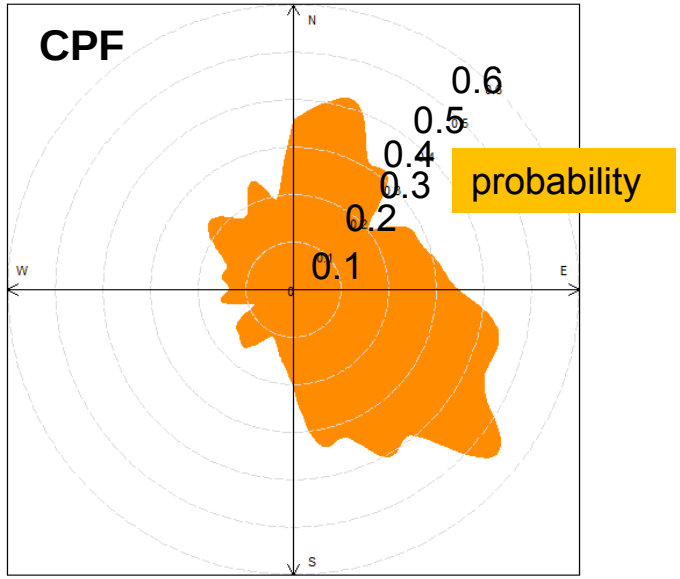



# Local source identification: Conditional probability function (CPF)

- Uses **hourly** wind direction data along with **daily** averaged source contributions to identify the likely sources contributing to a given factor.
- Local sources are likely to be located in the directions that have high conditional probability values.
- Wind directions corresponding to the highest source contributions.
- Threshold criterion: **highest 25%** (i.e, 75$^{th}$ percentile) of the contributions.



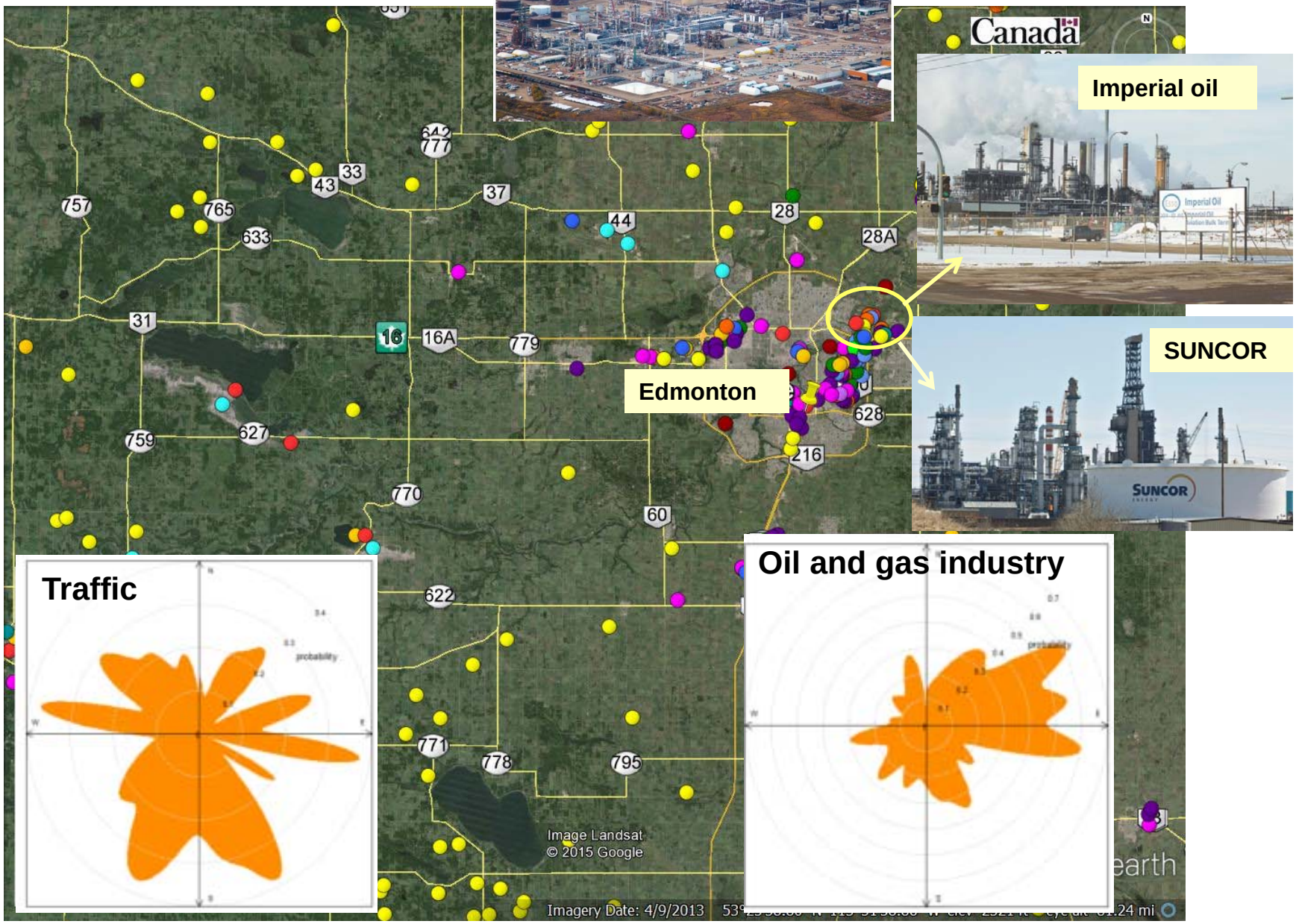

Edmonton



# Conditional probability functio Source Verification

## Example of analysis fo ntification





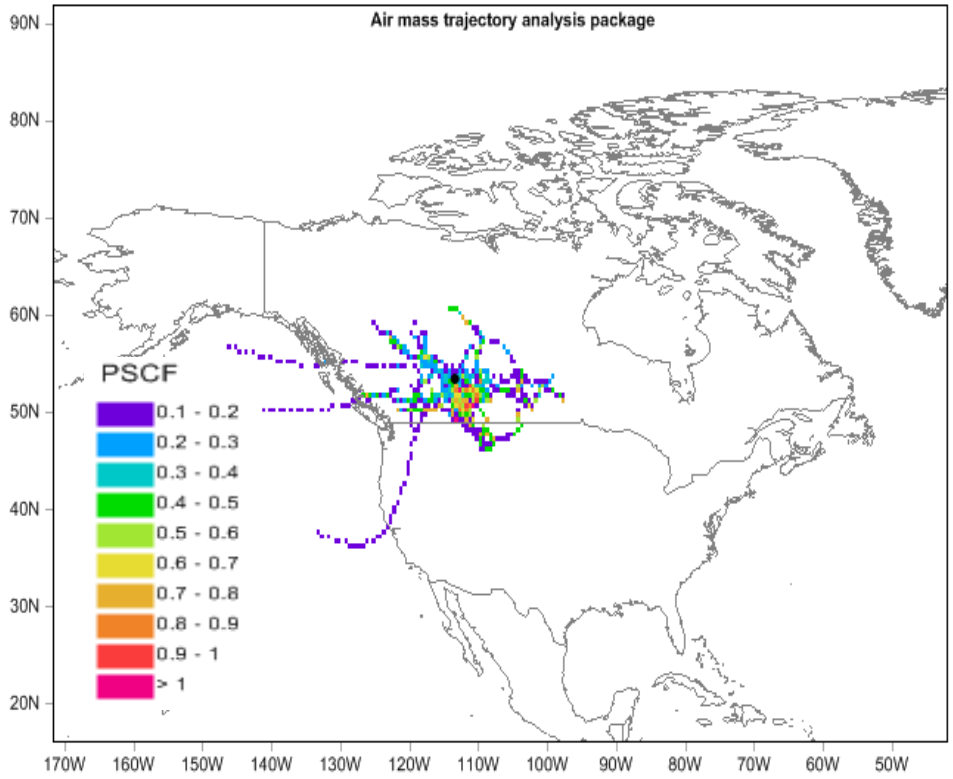
# Example of analysis for potential long-range sources



## Backward trajectory

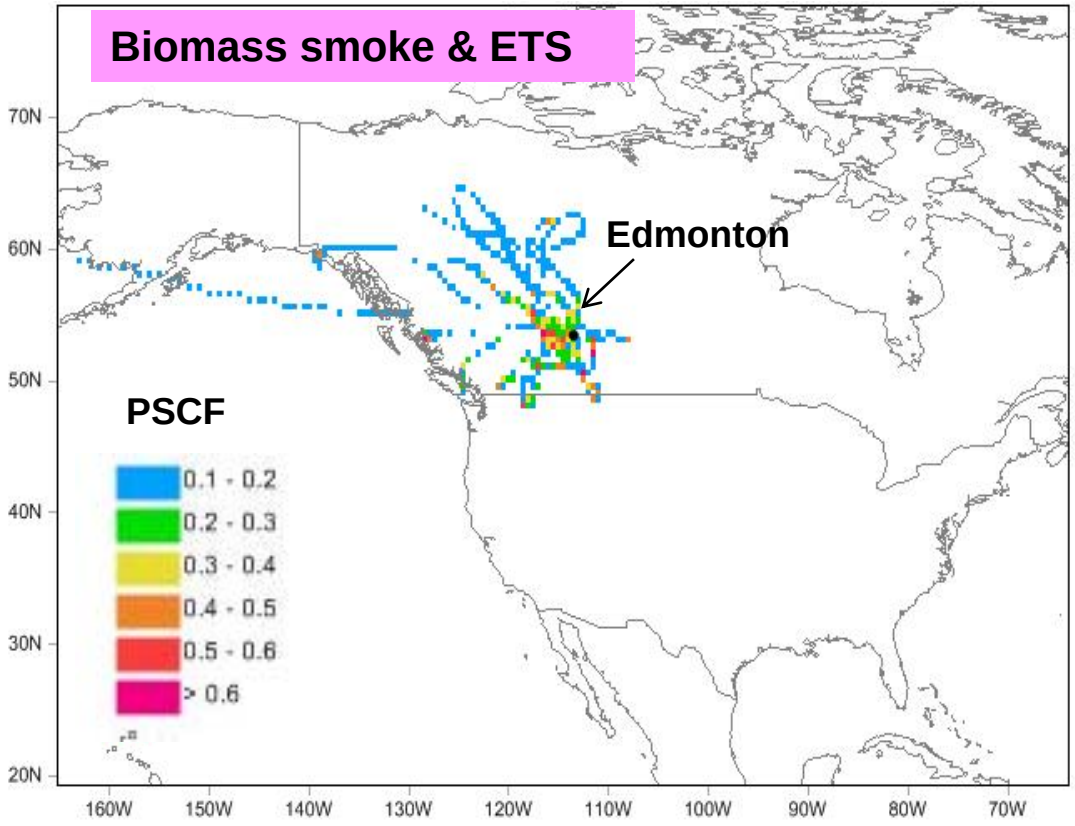
National Oceanic and Atmospheric Administration (NOAA)
Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT)
48 to 96-hr backward trajectories

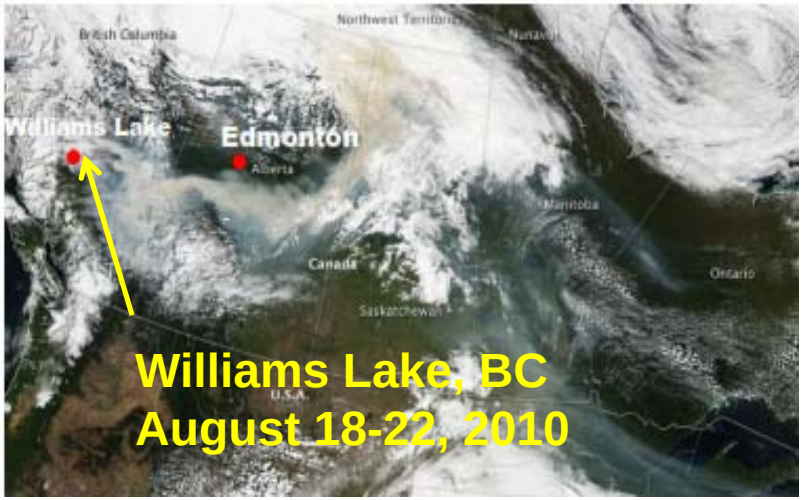
- **Potential Source Contribution Function (PSCF)**
  - 0.5˚ x 0.5˚ latitude and longitude
  - 72-hr backward trajectories
  - Threshold criterion: 75$^{th}$ percentile (highest 25%) of the contributions



# Example of analysis for long-range sources





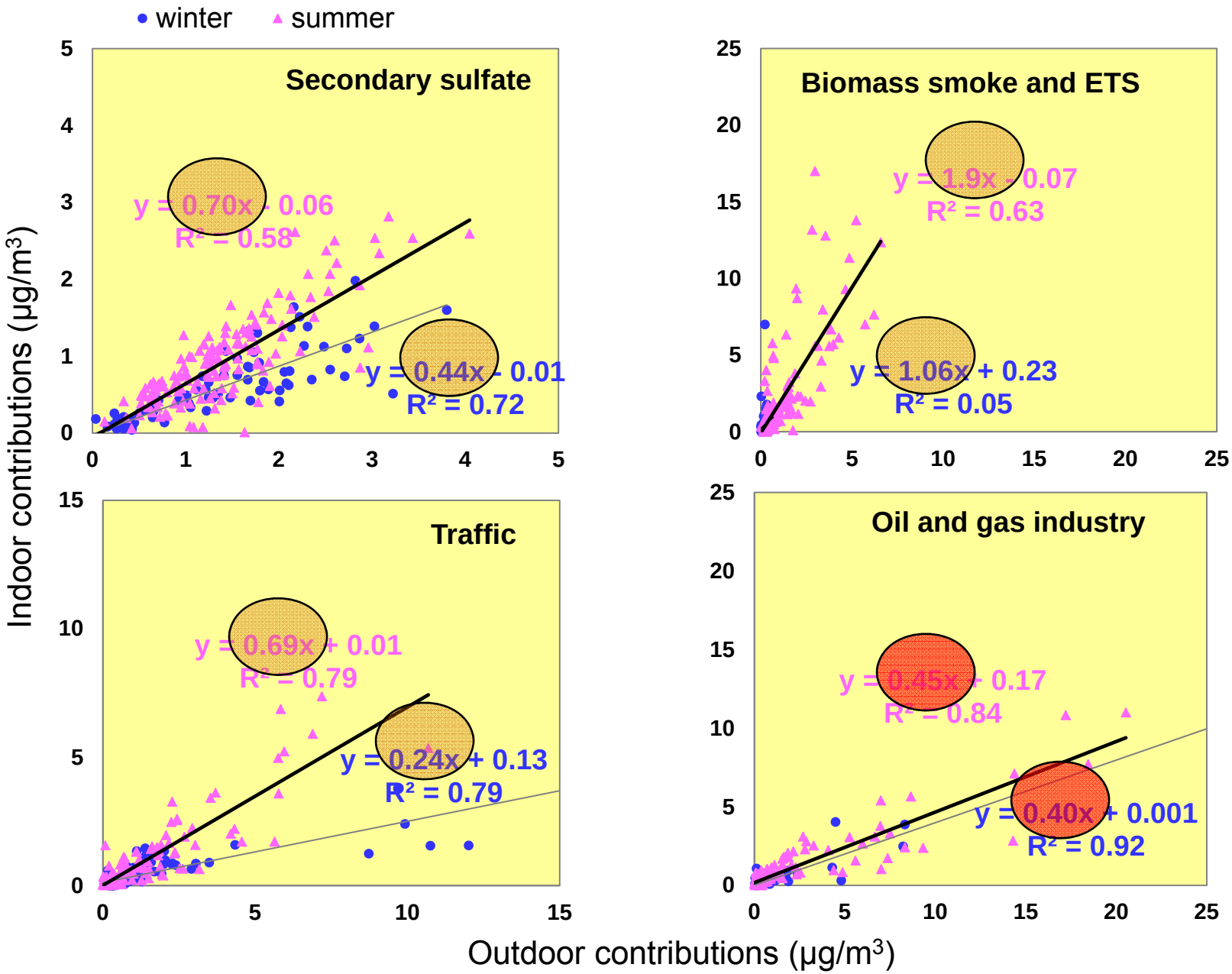

# Correlation (Pearson coefficient) of outdoor sources with other pollutants and meteorological parameters

| Possible sources | OC | EC | $NO_2$ | $SO_2$ | Benzene | Toluene | Acetaldehyde | Temperature |
|---|---|---|---|---|---|---|---|---|
| Secondary sulfate | 0.06 | 0.06 | 0.05 | 0.03 | 0.05 | -0.08 | -0.08 | -0.13* |
| Soil | -0.23* | -0.18** | 0.40** | 0.08 | 0.006 | -0.01 | -0.19** | -0.40** |
| Biomass smoke & ETS | 0.73** | 0.71** | -0.26** | -0.26** | 0.51** | 0.001 | 0.29** | 0.58** |
| Traffic | 0.16* | 0.05 | 0.47** | 0.01 | 0.40** | 0.15* | -0.06 | -0.11 |
| Settled and mixed dust | -0.08 | -0.08 | -0.05 | -0.06 | -0.08 | -0.02 | -0.03 | 0.05 |
| Coal combustion | 0.001 | 0.08 | 0.26** | -0.001 | 0.28** | 0.05 | 0.07 | 0.05 |
| Oil and gas industry | -0.01 | -0.04 | 0.04 | 0.16** | -0.02 | -0.02 | 0.06 | 0.08 |
| Road salt/road dust | -0.1 | -0.10 | 0.79** | 0.08 | 0.34** | 0.08 | -0.16** | -0.40** |
| Urban mixture | 0.76** | 0.79** | 0.28** | -0.18** | 0.74** | 0.07 | -0.09 | -0.15* |

**Correlation significant at $p = 0.01$
*correlation significant at $p = 0.05$

# Influence of particle infiltration (slopes)





# Variability in outdoor sources across different neighborhoods (*p*-values, one-way Wilcoxon score)



**Secondary sulfate**

| | TS' | WM | SA' | ST | GB' | OX |
|---|---|---|---|---|---|---|
| TC | 0.53 | 0.27 | 0.13 | 0.93 | 0.93 | 0.25 |
| TS' | | 0.64 | 0.06 | 0.15 | 0.30 | 0.12 |
| WM | | | 0.03 | 0.84 | 0.15 | 0.08 |
| SA' | | | | 0.02 | 0.36 | 0.70 |
| ST | | | | | 0.73 | 0.25 |
| GB' | | | | | | 0.59 |

**Biomass smoke & ETS**

| | TS' | WM | SA' | ST | GB' | OX |
|---|---|---|---|---|---|---|
| TC | 0.07 | 0.38 | 0.98 | 0.29 | <0.01 | 0.14 |
| TS' | | <0.01 | <0.01 | 0.22 | <0.01 | <0.01 |
| WM | | | 0.69 | 0.07 | 0.04 | 0.20 |
| SA' | | | | 0.27 | 0.01 | 0.03 |
| ST | | | | | <0.01 | 0.06 |
| GB' | | | | | | 0.81 |

**Traffic**

| | TS' | WM | SA' | ST | GB' | OX |
|---|---|---|---|---|---|---|
| TC | 0.84 | | <0.01 | <0.01 | <0.01 | 0.99 |
| TS' | | 0.96 | 0.02 | <0.01 | <0.01 | 0.70 |
| WM | | | <0.01 | <0.01 | <0.01 | 0.35 |
| SA' | | | | 0.34 | 0.42 | <0.01 |
| ST | | | | | 0.70 | <0.01 |
| GB' | | | | | | <0.01 |

**Oil and gas industry**

| | TS' | WM | SA' | ST | GB' | OX |
|---|---|---|---|---|---|---|
| TC | 0.91 | 0.48 | 0.56 | 0.12 | 0.59 | 0.40 |
| TS' | | 0.50 | 0.41 | 0.23 | 0.48 | 0.33 |
| WM | | | 0.77 | 0.13 | 0.21 | 0.14 |
| SA' | | | | 0.20 | 0.59 | 0.85 |
| ST | | | | | 0.30 | 0.35 |
| GB' | | | | | | 0.61 |

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TS-Terwillegar South

**Significant variation, $p < 0.01$**

# Summary

- The major sources of $PM_1$ elements (more than two-third) were made up of secondary sulfate, soil and biomass smoke & ETS.
- Secondary sulfate signal is multi-component.
- Other minor outdoor sources contributed to one-quarter of elemental $PM_1$ mass. These include: traffic, mixed dust, oil and gas industry, coal combustion, road-salt, and urban mixture.
- Indoor-generated sources of $PM_1$ elements: carpet dust, Cu-rich, Ag-rich.
- Larger particle infiltration was observed during summer than winter.

# SPECIAL THANKS

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Dr. Amanda A. J. Wheeler
Morgan MacNeill
Keith Van Ryswyk
Mélissa St-Jean
Tae Maen Shin

**Thank You for your kind attention!**

# Questions?