Harriet Tubman Middle School Air Quality Monitoring Phase II

Phase II, Presentation to ETAC

10/29/2018

Green Building Research Laboratory

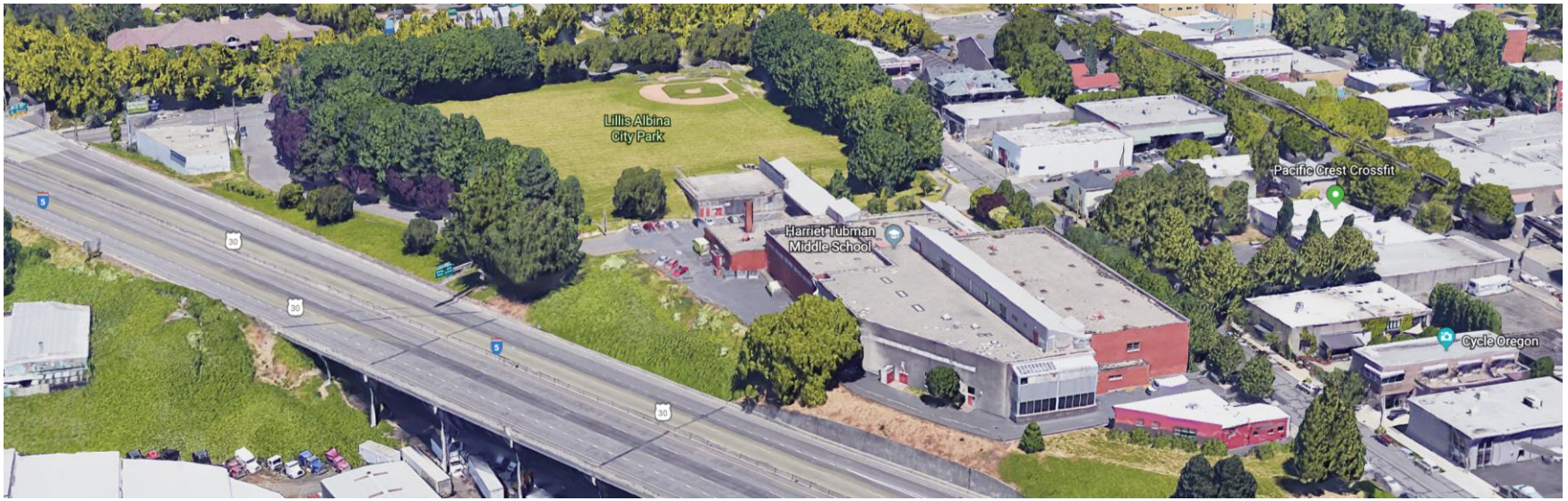
STAR Lab

Portland State University

Air quality at Harriet Tubman Middle

Harriet Tubman Middle School:

- Located 60-350 feet (20 – 125 m) from I-5
- 7 lane highway
- >120,000 vehicles/day



In January 2018, PPS selected PSU to lead an evaluation of air quality issue at site

- Phase I: Outdoor air quality monitoring (March – April 2018)
- Phase II: Indoor/outdoor air quality monitoring, wind tunnel (Aug – Oct 2018)
- Phase III (planned): IAQ/OAQ monitoring after 1 school year (April 2019)

Phase I outcomes: Air quality

Finding #1: There is a gradient of traffic related pollutants….reaching background levels about 200-300 feet from the freeway.

Finding #2: Air sampled on the SW side (freeway side) of Tubman Middle School is heavily impacted by freeway emissions.

Finding #3: Many air pollutants measured at Tubman are elevated compared to Portland urban background site (DEQ SE Lafayette).

Finding #4: Air pollutants of concern in HVAC outdoor ventilation air can be reduced ... below urban background and levels of health concern.

Paraphrased from Phase I report

Renovation post phase I

Major renovation of school included:

- HVAC system with MERV16 particle filtration
- Gas-phase air cleaning w/ broad spectrum activated carbon filtration
- Improvements to building shell

Goals of Phase II air quality campaign

Goals of HTMS Phase II:

1. Characterize indoor and air quality at HTMS following renovation
   a. Outdoor air pollution levels in Fall season
   b. Exposure levels to air pollution inside school

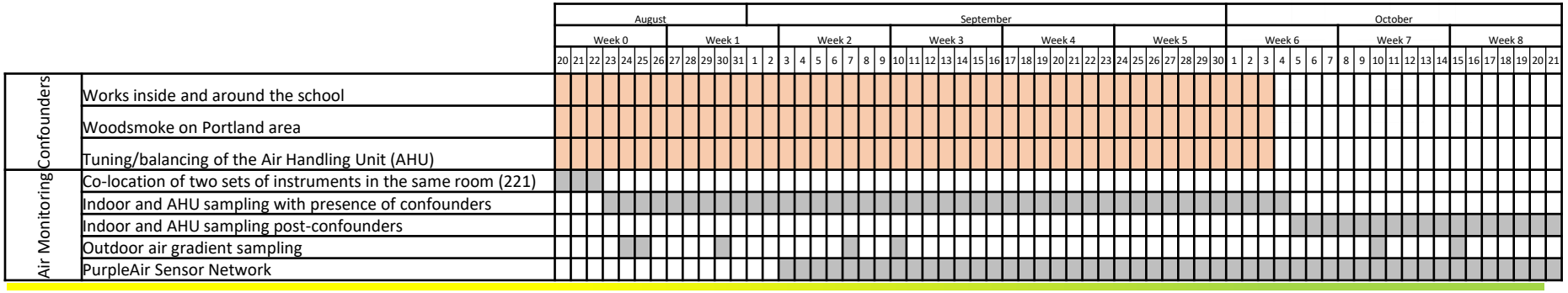
2. Is the HVAC air cleaning system performing as designed?
   a. Particle-phase air pollutants (MERV 8 + MERV 16 filter)
   b. Gas-phase air pollutants (Carbon filtration)

3. To what extent is there infiltration of outdoor pollutants through the building envelope?

4. How do air pollution levels vary spatially near vicinity of HTMS?

Timeline of events

1. Co-location of two sets of instruments in the same room (221)
   ➔ from the 08/20 to 08/22
2. Indoor and AHU sampling with presence of confounders
   ➔ from 08/22 to 10/04
3. Indoor and AHU sampling post-confounders
   ➔ from 10/05 to 10/19
4. Outdoor air gradient sampling
   ➔ 08/24, 08/25, 08/30, 09/07, 09/10, 10/10 and 10/15
5. PurpleAir Sensor Network
   ➔ in classroom : from 08/24 to present
   ➔ outdoor : from 09/10 to present



Goals of Phase II air quality campaign

Aug 20th, 2018

Aug 20th, 2018

Oct 1st, 2018

Issues resulted in delay of ETAC (currently scheduled for Oct 29):

- Wildfire smoke events - **abated mid Sept**
- Ongoing presence and usage of diesel construction equipment - **fully abated as of Oct 3**
- Construction/renovation/cleanup inside and outside of building – **fully abated as of Oct 6**
- HVAC system not fully operational – **tuning/balancing completed mid to late Sept**

Overview of AQ sampling

Sampling completed in AHU (RA, OA, SA):

Particle-phase compounds:

- Black Carbon (BC)
- Size resolved particles (PM2.5, PM10)
- Ultrafine particles* (UFP)

Gas-phase compounds:

- Nitric oxide (NO)
- Nitrogen dioxide (NO2)
- Volatile organic compounds via GC-MS
- Carbon monoxide
- Carbon dioxide (proxy for occupancy)

Indoor/outdoor sampling:

- Network of purple air sensors
- Walking transects for UFP
- Passive NO2 sensors

Site meteorology

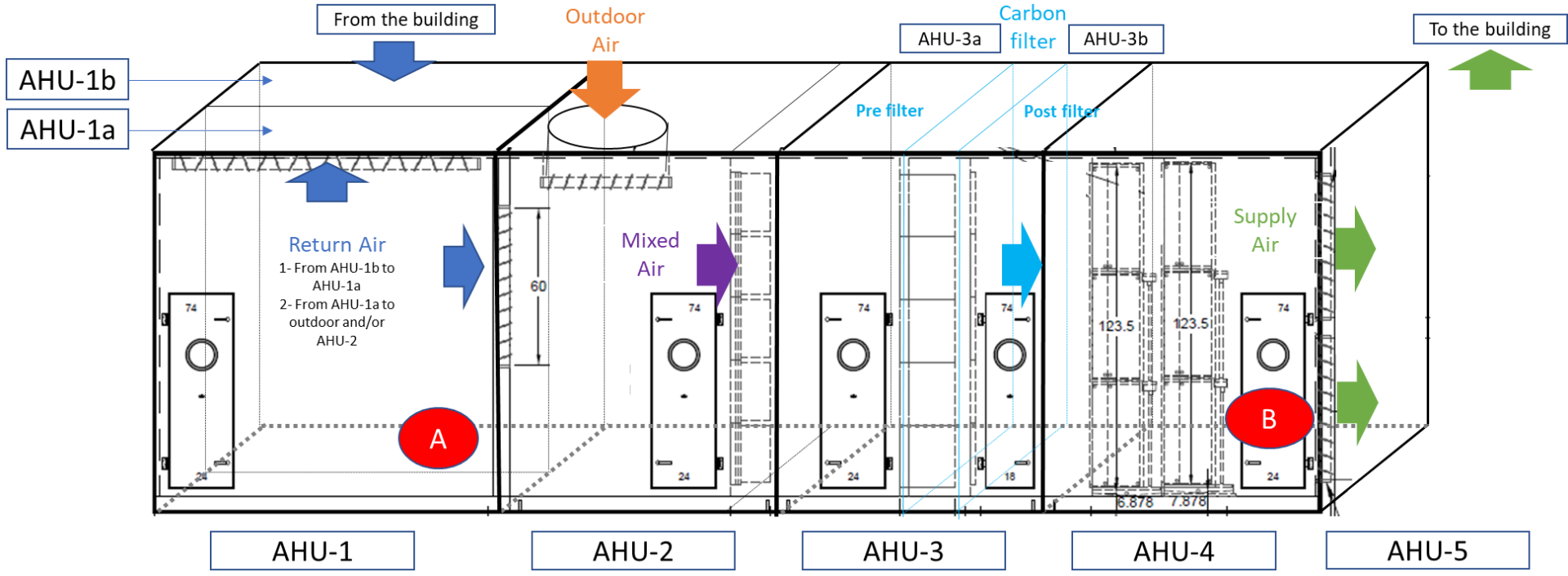
- Weather station
  - Wind direction
  - Wind speed
  - Temperature
  - Humidity

*damage to monitor from high RH in AHU prevented long-term monitoring

Goal 1: Indoor and outdoor air pollution

1. Characterize indoor and outdoor air quality at HTMS following renovation
   a. Outdoor air pollution levels in Fall season
   b. Exposure levels to air pollution inside school

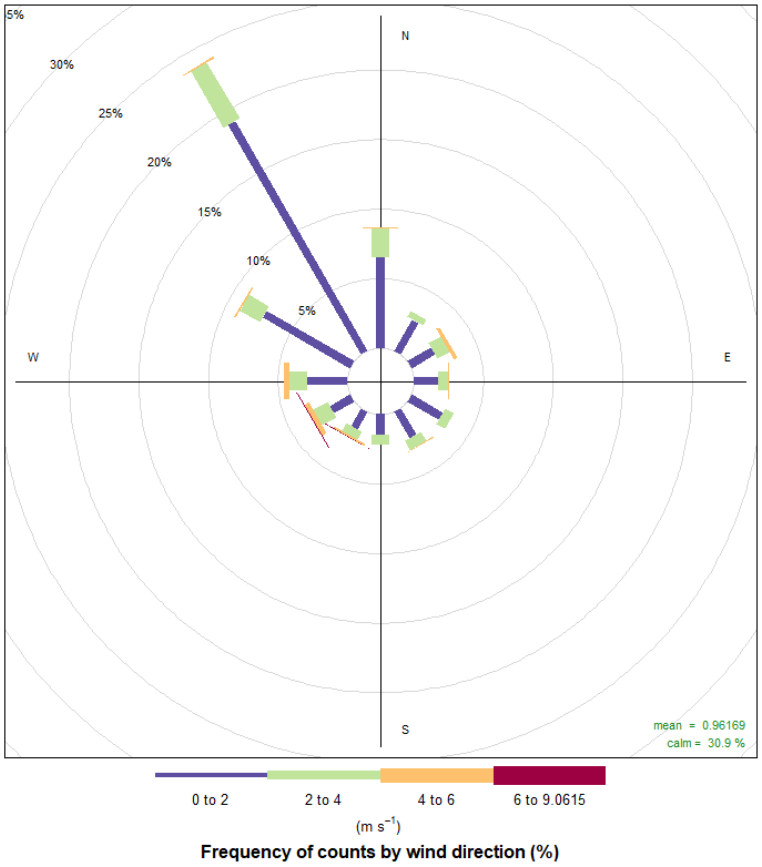
Overview of sampling



A = set 1 (blue cart)
B = set 2 (red cart)

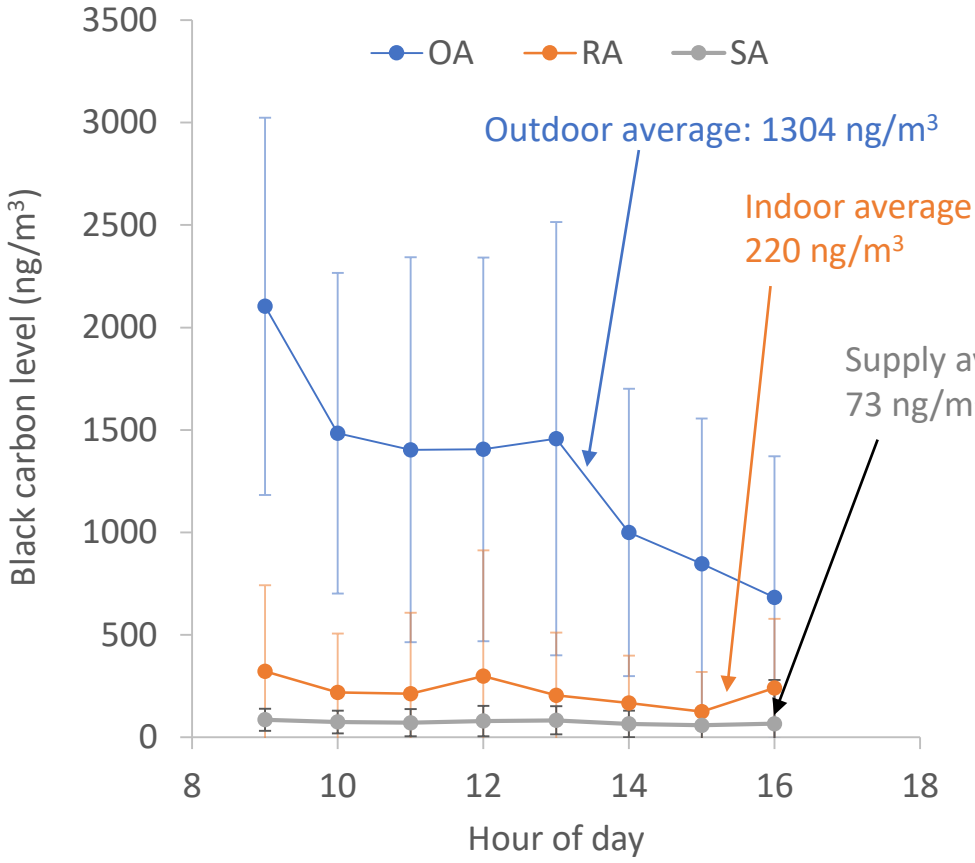
Weather Station

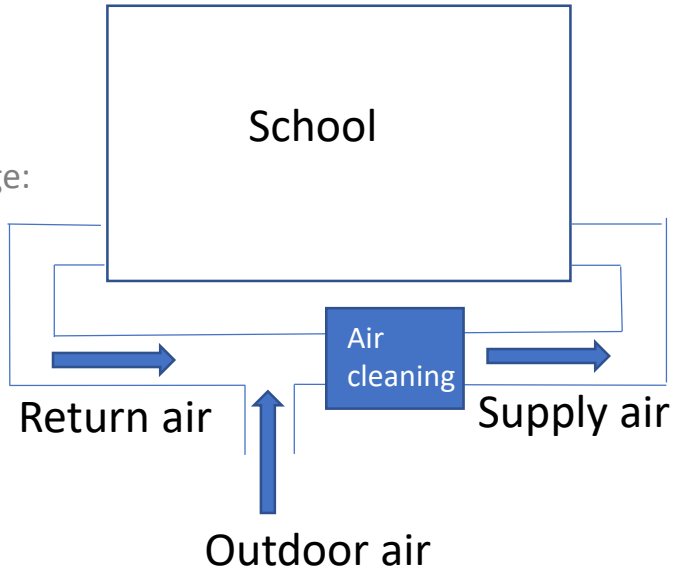
N



Air pollutant trend example: BC

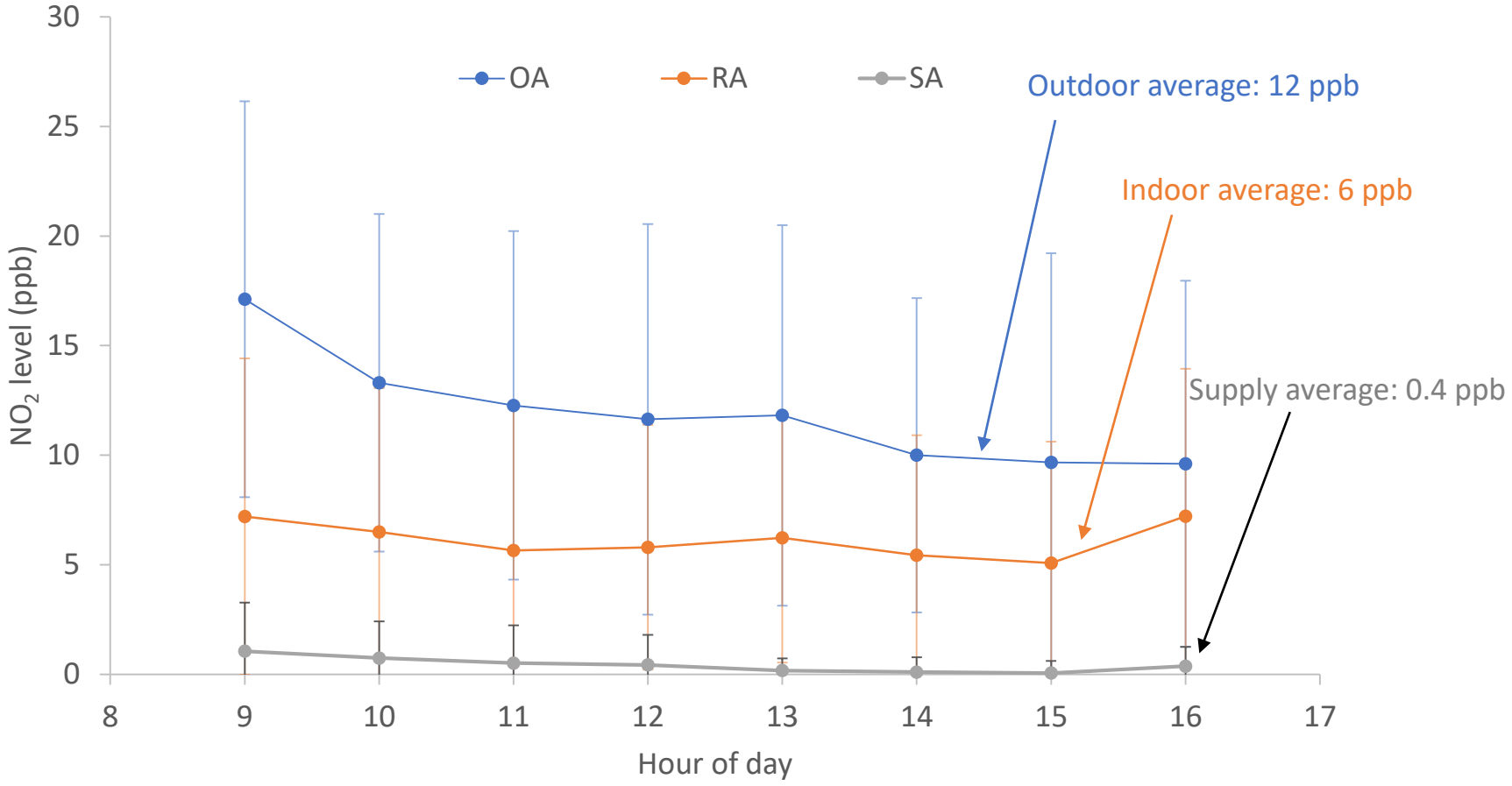
Hourly averages from 10/6 – 10/19, 9 AM – 4 PM only





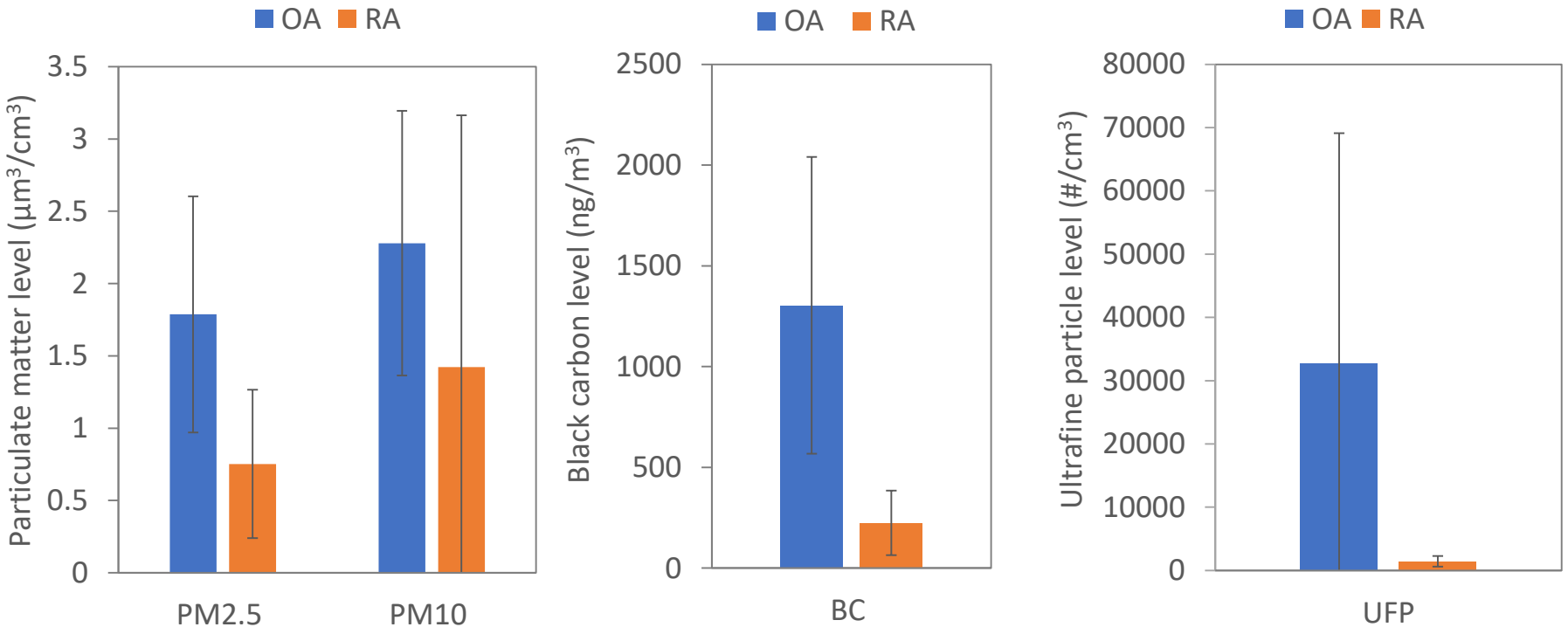
Air pollutant trend example: NO_2

Hourly averages from 10/6 – 10/19, 9 AM – 4 PM only



Indoor/outdoor levels: particles

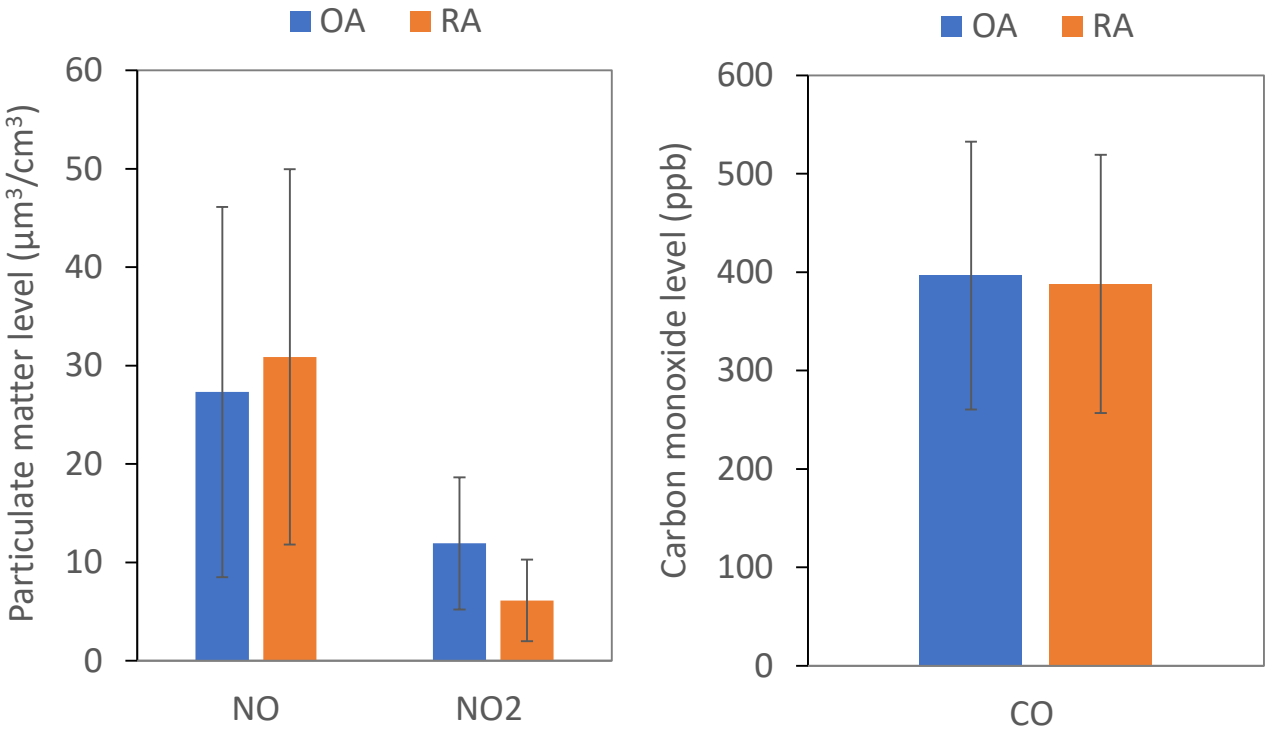
Averages from 10/6 – 10/19, 9 AM – 4 PM only*



- HVAC system addresses all particle-phase constituents
  - However, indoor activities are strong sources of PM_{10}, $PM_{2.5}$
- Low indoor/outdoor ratio of BC and UFP, implies HVAC and building protective
  - UFP is based on two days of monitoring only

Indoor/outdoor levels: non-VOC gases

Averages from 10/6 – 10/19, 9 AM – 4 PM only

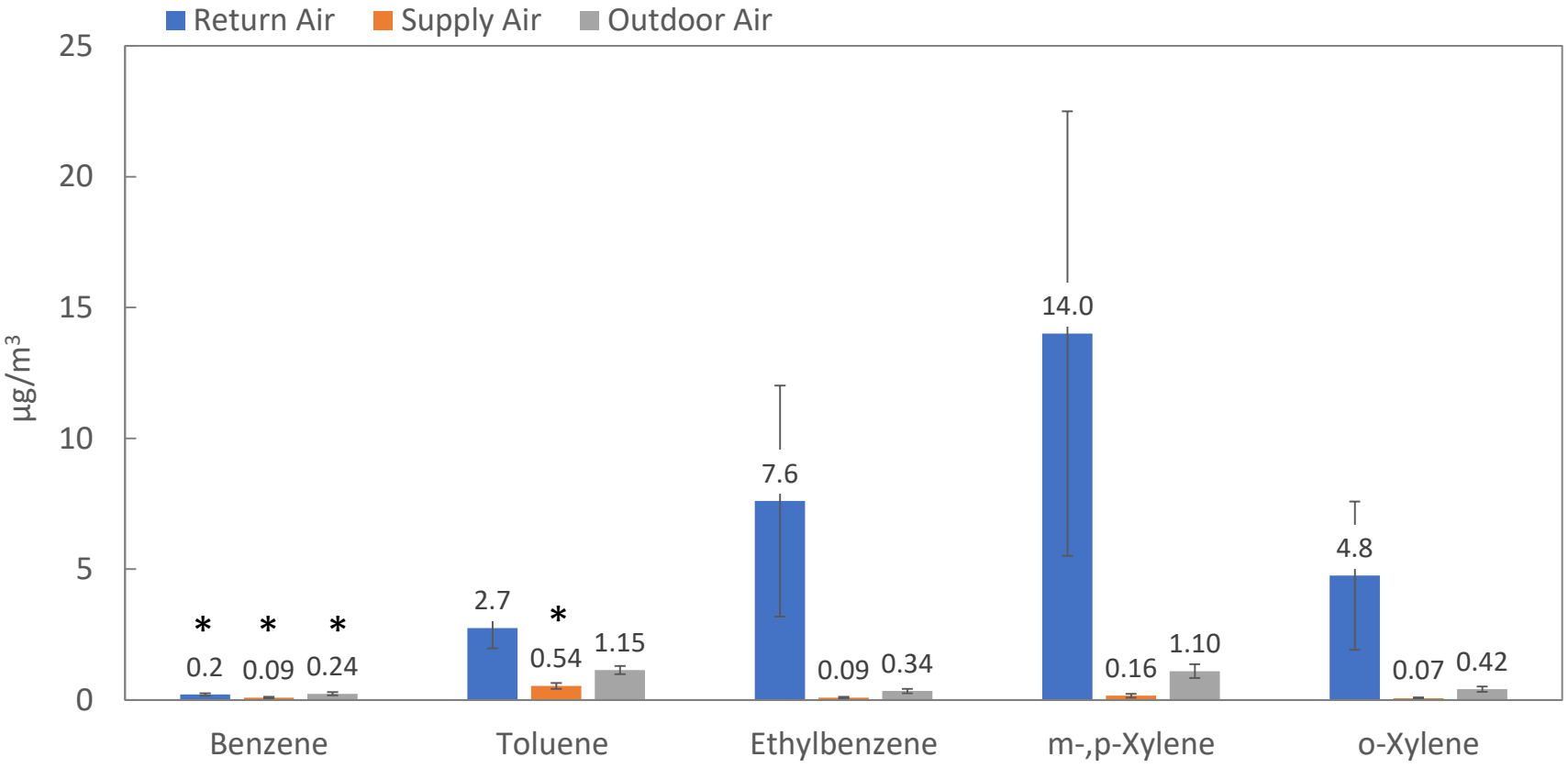


- HVAC system removes NO_2, not NO and CO, results are as expected for NO, CO
- I/O ratio for NO_2 of ~0.5, implies some infiltration along small cracks + gaps

BTEX: VOCs indoors, outdoors, supply air

Averages are shown over three points in time

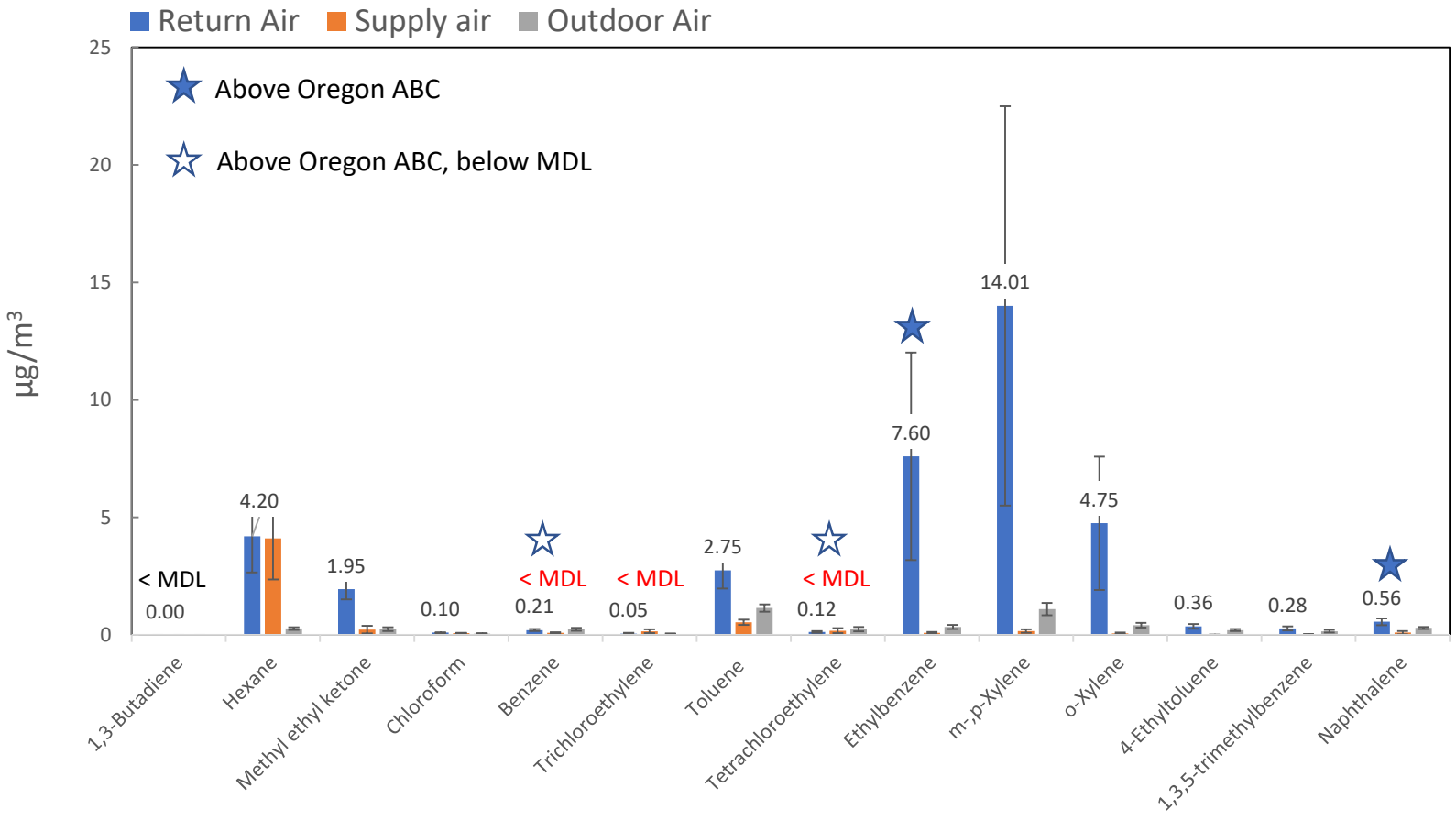
Values for TEX decrease with time e.g., ethylbenzene 23 → 2.8 → 0.3 µg/m^3 across 3 weeks



Average 7 replicates taken on weekdays in the timeframe of 9 AM – 4 PM between 18 Sept. to 10 Oct.

* < MDL

VOCs indoors, outdoors, supply air

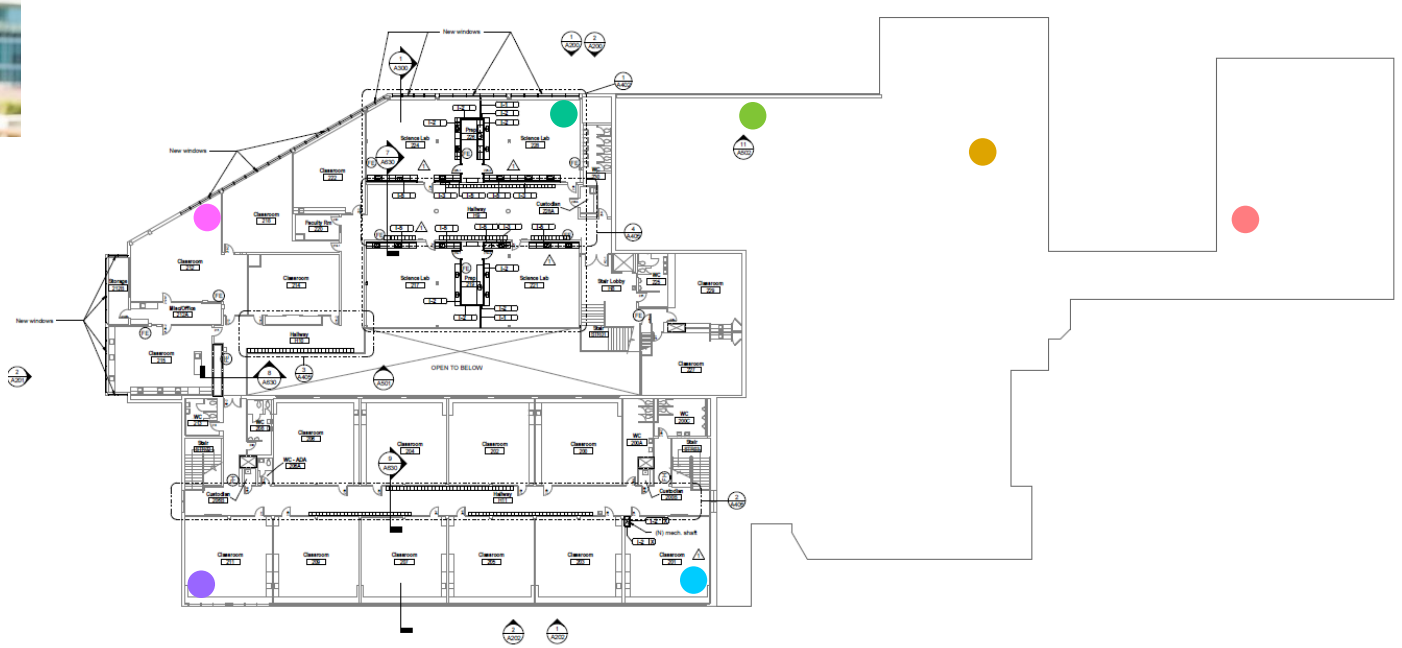


Average 7 replicates taken on weekdays in the timeframe of 9 AM – 4 PM between 18 Sept. to 10 Oct.

Deployment of Purple Air sensors

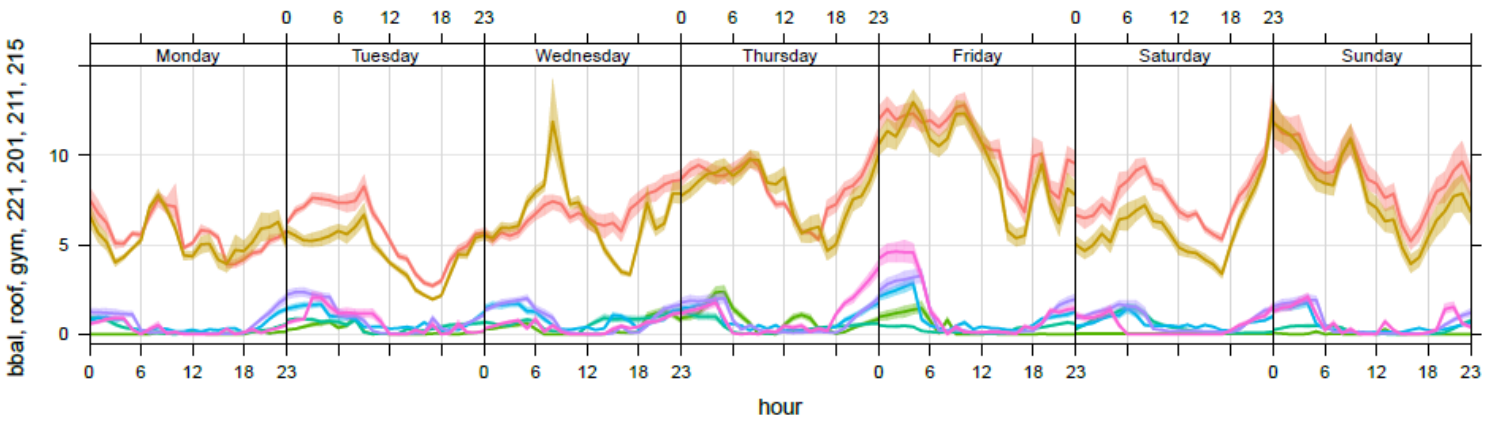
PurpleAir sensors:

- Room 215
- Room 221
- Room 211
- Room 201
- Gymnasium
- Penthouse
- Basketball field



PurpleAir data

PM1.0 in µg/m^3



- Room 215
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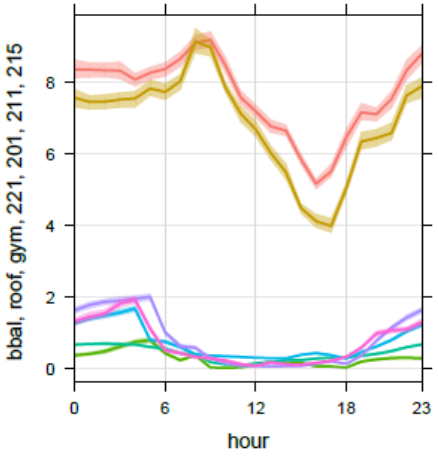
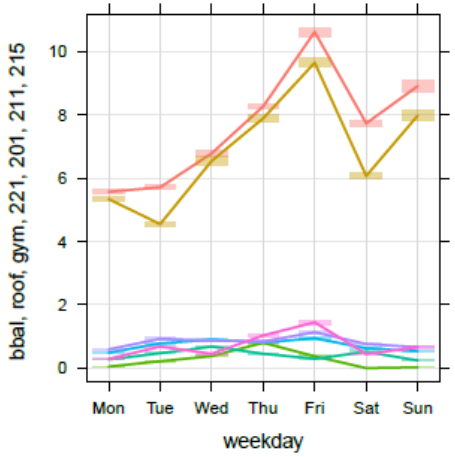




Mean and 95% confidence interval in mean

Goal 1: Summary

Summary of Goal 1 objectives

Indoor levels of TRAP indicators are substantially below outdoor levels:

- Black carbon averaged 220 ng/m^3 indoors vs. 1300 ng/m^3 outdoors
  - Oregon ABC is 100 ng/m^3 , typical PDX BG: ~1000 ng/m^3
- UFP levels: 1500 #/cm^3 vs. 33,000 #/cm^3 outdoors
  - Typical urban PDX UFP: ~5000-7000 #/cm^3
- NO2 levels: 6.1 ppb vs. 12 ppb outdoors
  - Indoors is below 2016 PDX annual average of 9 ppb

Volatile organic compounds (BTEX)

- Benzene: 0.2 µg/m^3 indoors vs. 0.24 µg/m^3 outdoors
  - Portland background ~0.6 µg/m^3, ABC of 0.13 µg/m^3
- Toluene, xylenes below ABC, but elevated

TEX levels appear to be diminishing with time, likely result from renovation

Goal 2. HVAC + air cleaning effectiveness

Goal 2. Is the HVAC and air cleaning system performing as designed?

a. Particle-phase air pollutants (MERV 8 + MERV 16 filter)
b. Gas-phase air pollutants (Carbon filtration)

AHU air cleaning

Outdoor air penthouse

Effectiveness of air cleaning

Removal: mixed air (calculated) to supply air

Compound	Observed removal eff
Gas-phase compounds	
Carbon monoxide	37% removal
Nitric oxide	15% addition
Nitrogen dioxide	96% removal
Particle-phase compounds	
Black carbon	93% removal
$PM_{2.5}$	90% removal
PM_{10}	80% removal
UFP	98% removal

- Removal of measured compounds generally in-line with expectations
- Bold compounds are those w/ expected removal due to filtration/carbon

Effectiveness of air cleaning

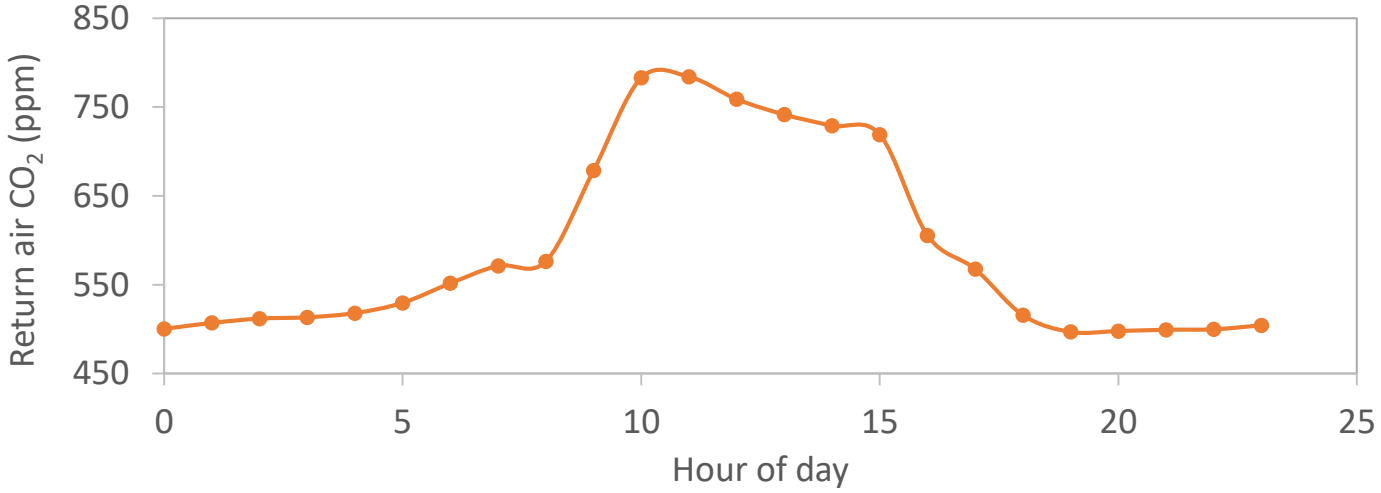
Removal: mixed air (calculated) to supply air

VOC	Observed removal eff	
	Sampling 1 (3 reps)	**Sampling 2 (7 reps)**
Benzene	66% removal	61% removal
Toluene	52% removal	65% removal
Ethylbenzene	94% removal	96% removal
m, p- xylene	94% removal	96% removal
o-xylene	95% removal	95% removal

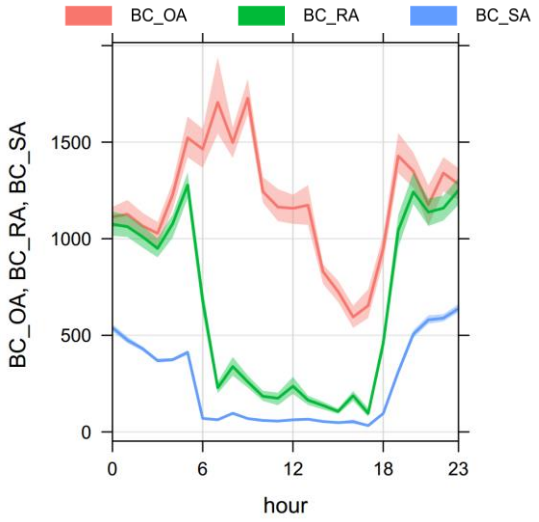
- Removal of measured compounds generally in-line with expectations
  - >90% removal for ethylbenzene and xylenes
- Benzene and toluene substantially lower
  - Confirm residence time through activated carbon filter is > 0.1 s

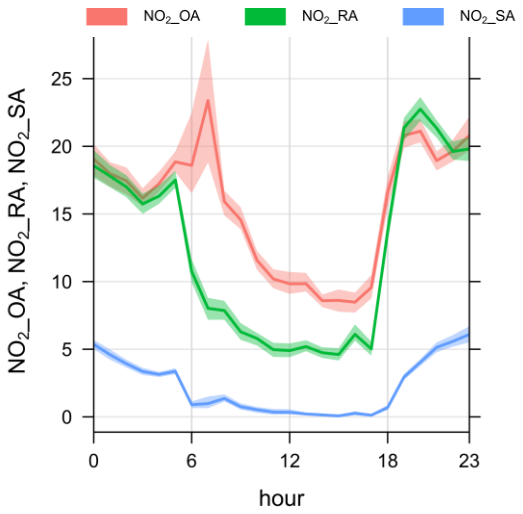
AHU operation

Outdoor air appears to be introduced between 5 – 6 AM, elevated until ~ 6 PM.



Coincides with presence of morning rush hour: may save energy, extend filter/carbon life if delayed





Goal 2. HVAC + Air cleaning effectiveness

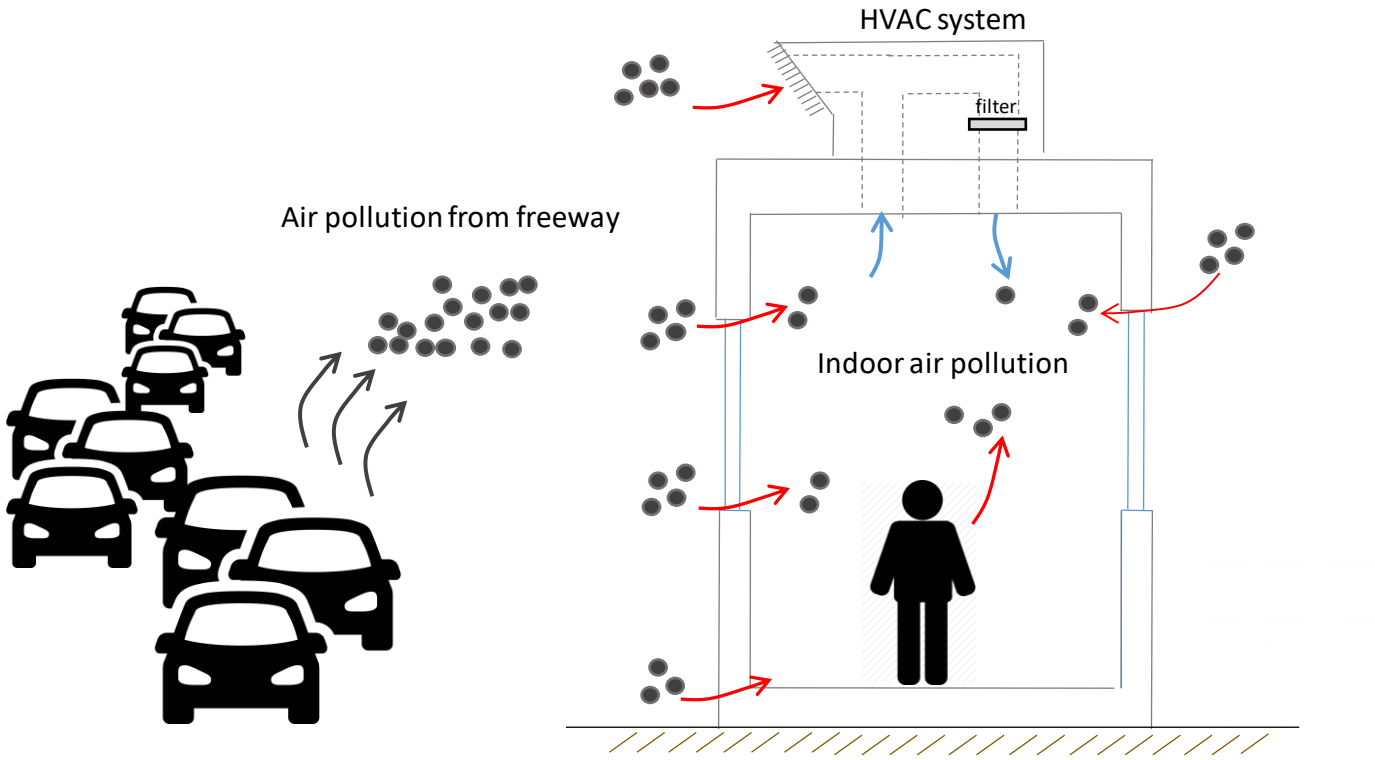
Summary of Goal 2 objectives

Air cleaning systems are operating mostly in line with expectations

- Particle removal generally effective
- Lower PM_{10} removal than expected possibly due to resuspension in newly built AHU
  - Expect this to improve in time
- Gas-phase removal for BTEX
  - Ethlybenzene and xylenes in-line with manufacturer statement
  - **Benzene, toluene lower removal than anticipated**
  - **Confirm flowrates from AHU**
- Timing of outdoor air supply – explore delaying start of outdoor air supply

Goal 3. Assess potential for infiltration

Goal 3. To what extent is there infiltration of outdoor pollutants through the building envelope?

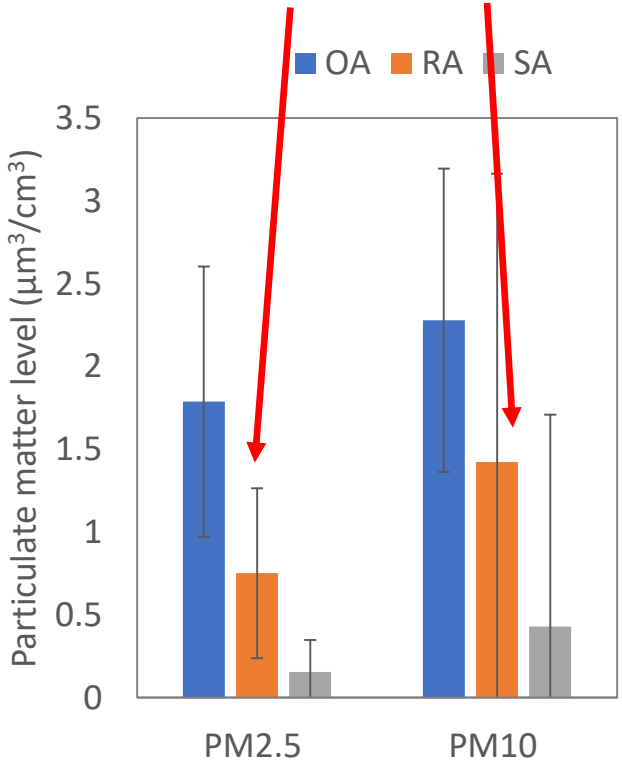


Indoor exposure levels DO NOT equal supply air levels leaving air handling system

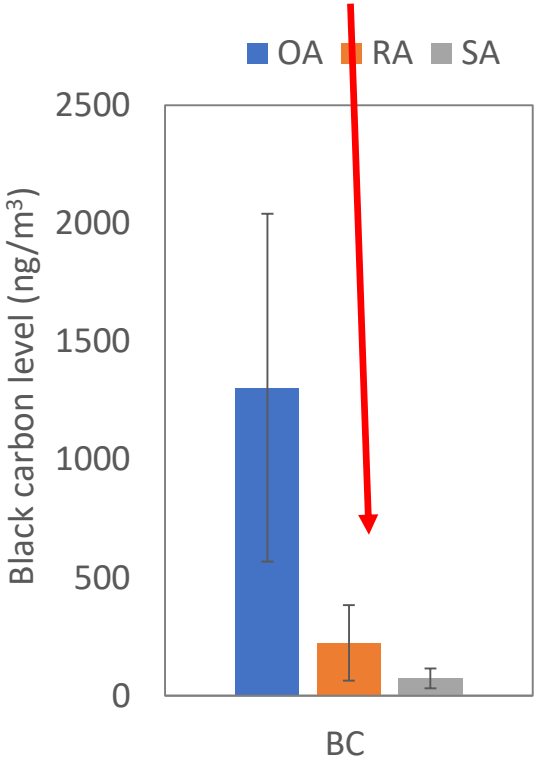
Comparison of supply and return

Infiltration and other indoor sources create differences in supply and return air

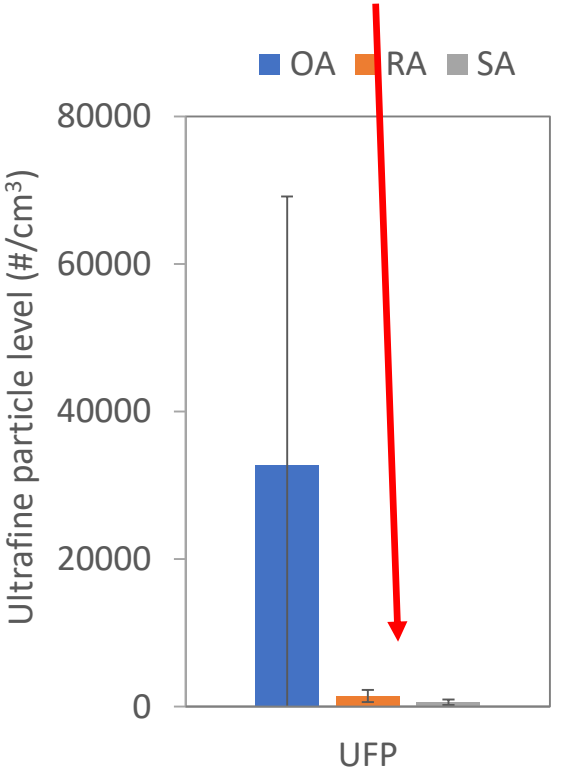
Relatively strong indoor sources of PM2.5, PM10



Few indoor sources of BC, likely infiltration indicator



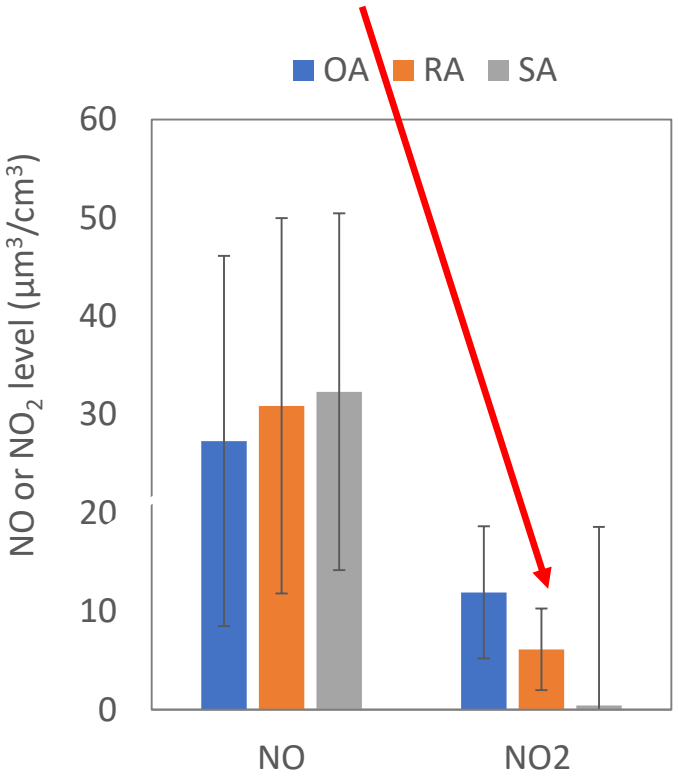
Few indoor sources of UFP



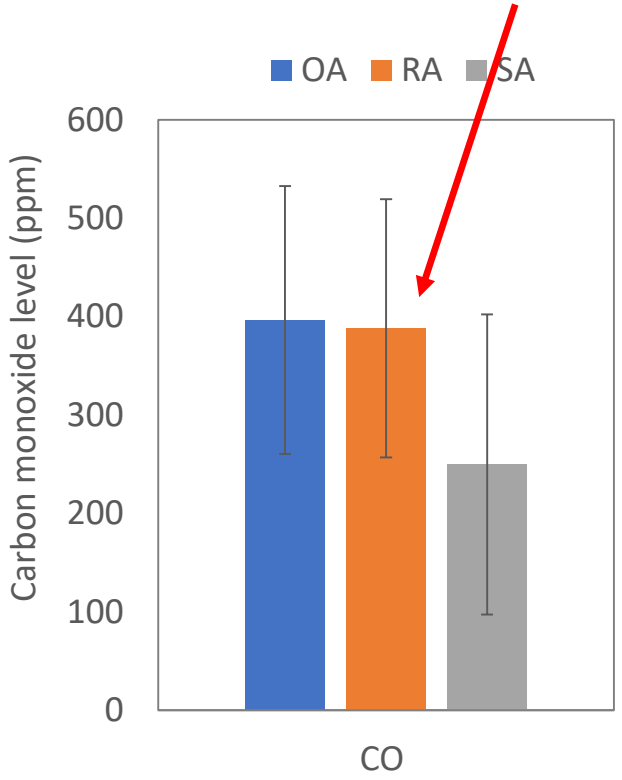
Comparison of supply and return

Infiltration and other indoor sources create differences in supply and return air

Few indoor sources of NO_2, likely infiltration indicator

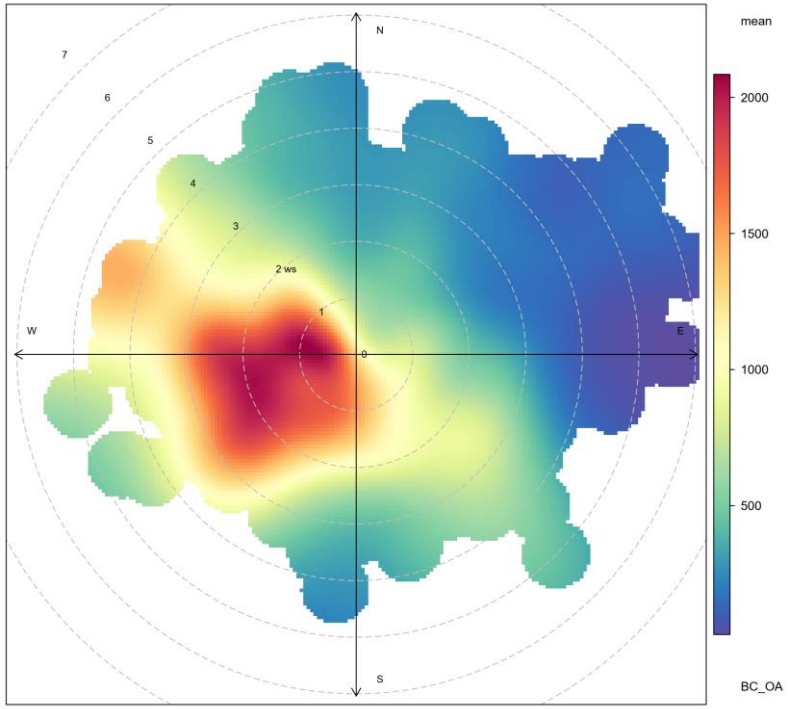


Few sources of CO

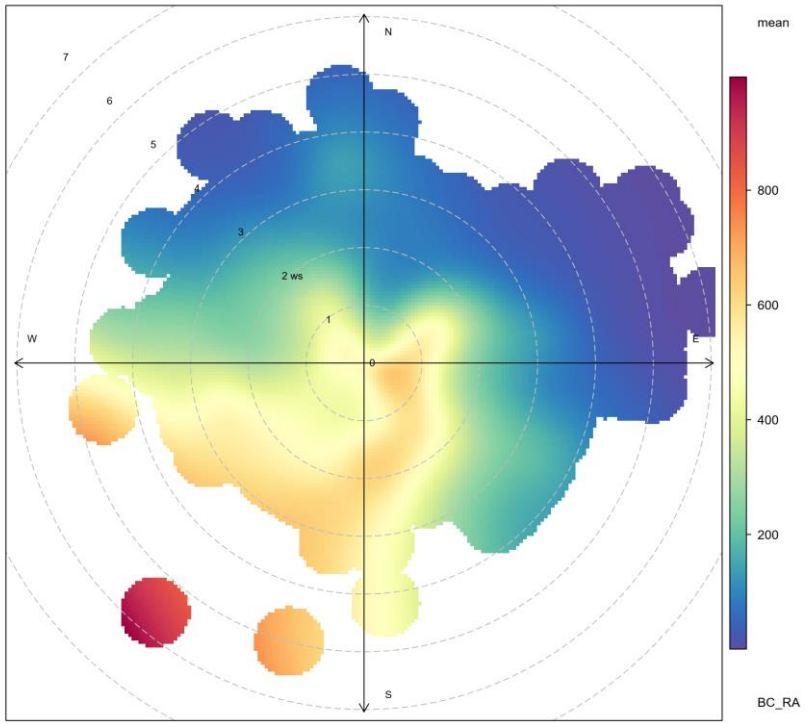


Pollutant polar plots as assessment tool

BC levels in ng/m^3



Polar plot for BC in outdoor air



Polar plot for BC in return (indoor) air

Goal 3. Evidence for infiltration

Summary of Goal 2 objectives

Building shell appears protective

- I/O ratio (indoors/outdoors) – in this case, return/outdoor
- **Generally a relative indicator** of indoor vs. outdoor origin (Chen et al. 2011)

Compound	Indoor/outdoor ratio
Black carbon	0.17
Ultrafine particles	0.044
$PM_{2.5}$	0.42
PM_{10}	0.62
NO_2	0.51

- Higher $PM_{2.5}$, PM_{10} I/O ratios generally assumed to indicate indoor sources
- The lower BC, UFP I/O ratios imply building is protective (less so for BC)
- High NO_2 I/O ratio, given no indoor sources, implies infiltration for gases and certain particles

Goal 4. Spatial variation of air pollution

Goals of HTMS Phase II:

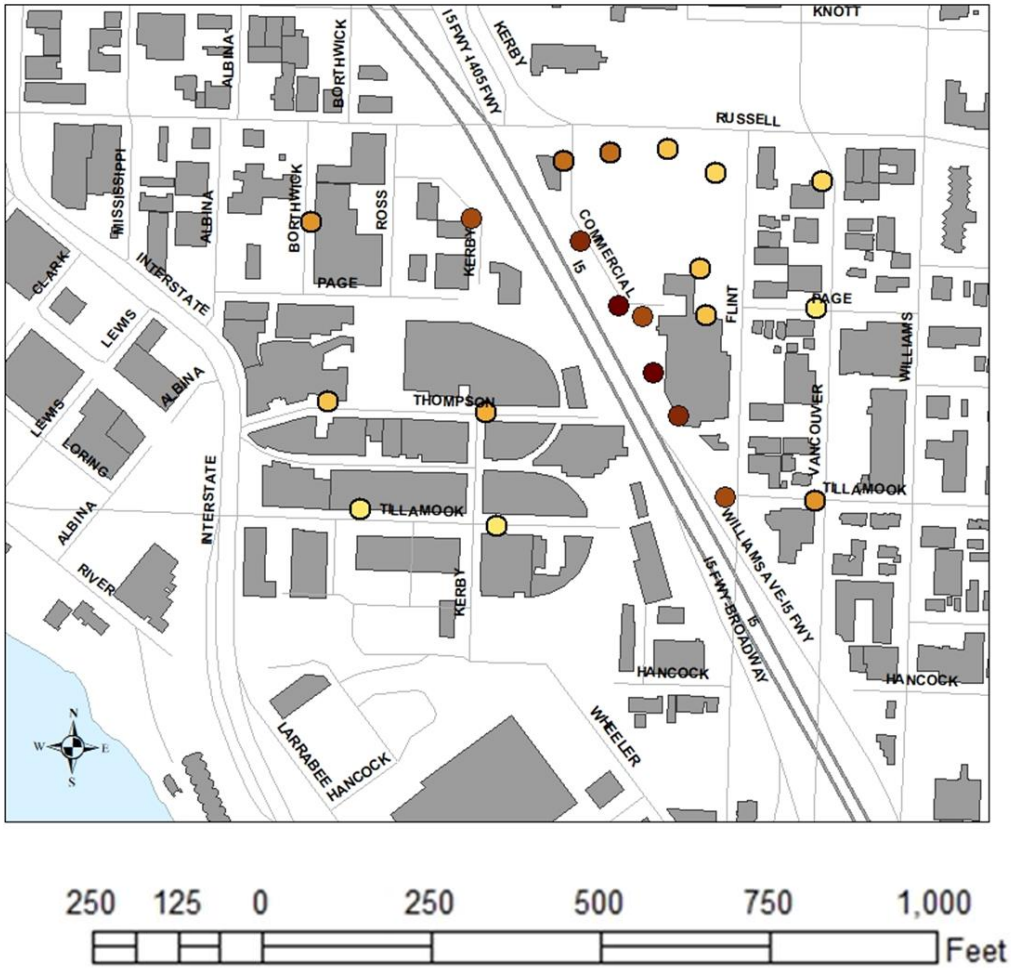
4. How do air pollution levels vary spatially in the near vicinity of HTMS?

Megan Duenas

Graham Pridham

Goal 4. Spatial variation of air pollution

2/27-3/12/2018 Tubman Passive NO2 Study



NO2__ppb_

- 14.0
- 14.1 - 22.6
- 22.7 - 23.0
- 23.1 - 23.7
- 23.8 - 24.2
- 24.3 - 25.4
- 25.5 - 26.5
- 26.6 - 28.2
- 28.3 - 29.3
- 29.4 - 38.0

Goal 4. Spatial variation of air pollution

Tubman 08/29-09/11

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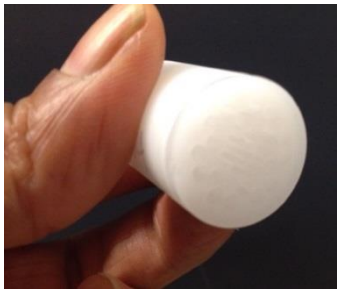


NO2 (ppb)

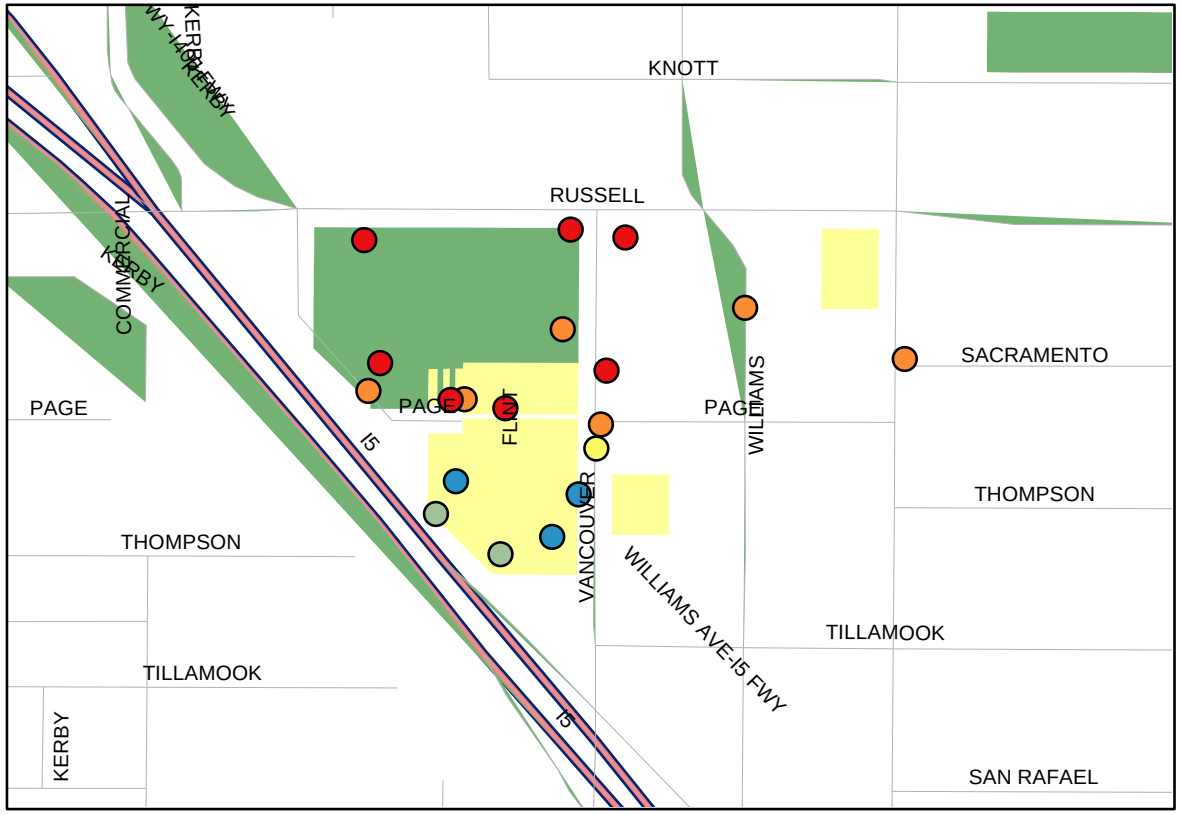
- 0.0 - 2.0
- 2.1 - 9.0
- 9.1 - 16.0
- 16.1 - 22.0
- 22.1 - 27.0

PSU Concentration (ppb) = 14.5

0 75 150 300 Meters

Goal 4. Spatial variation of air pollution

Tubman Fire Season 09/20-10/02



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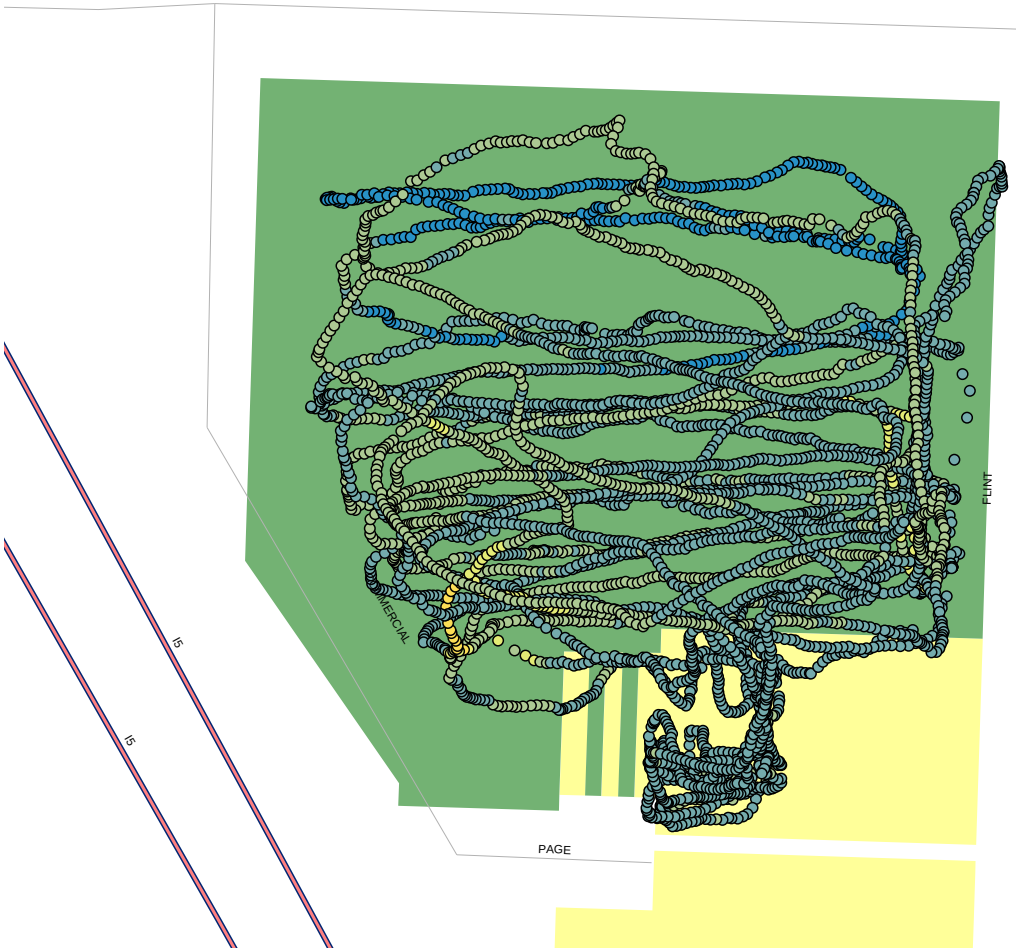
NO2 (ppb)

- 0.0 - 2.0
- 2.1 - 9.0
- 9.1 - 16.0
- 16.1 - 22.0
- 22.1 - 27.0

0 75 150 300 Meters

PSU NO2 (ppb) = 18.8

Goal 4. Spatial variation of air pollution



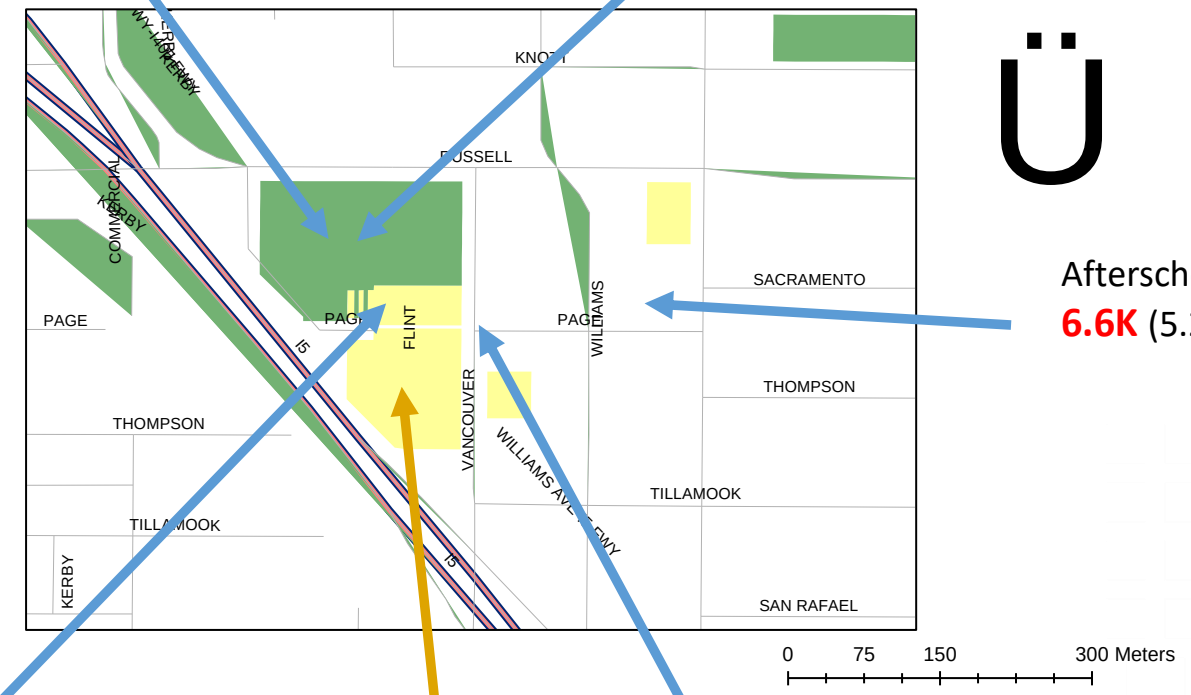
Goal 4. Spatial variation of air pollution

Tubman 10/15/18

Morning:
8-9AM: **39K** (18/11)
9-10AM:**43K** (25/107)

Afternoon:
1-2PM : **14K** (12-98)

Ultrafine Particles
Median (min/max)
/cm3



Afterschool:
6.6K (5.2/12.2)

BB court 11:15-12:45PM
15K (13/27)

Inside school:
0.3K (0.2-2.6)

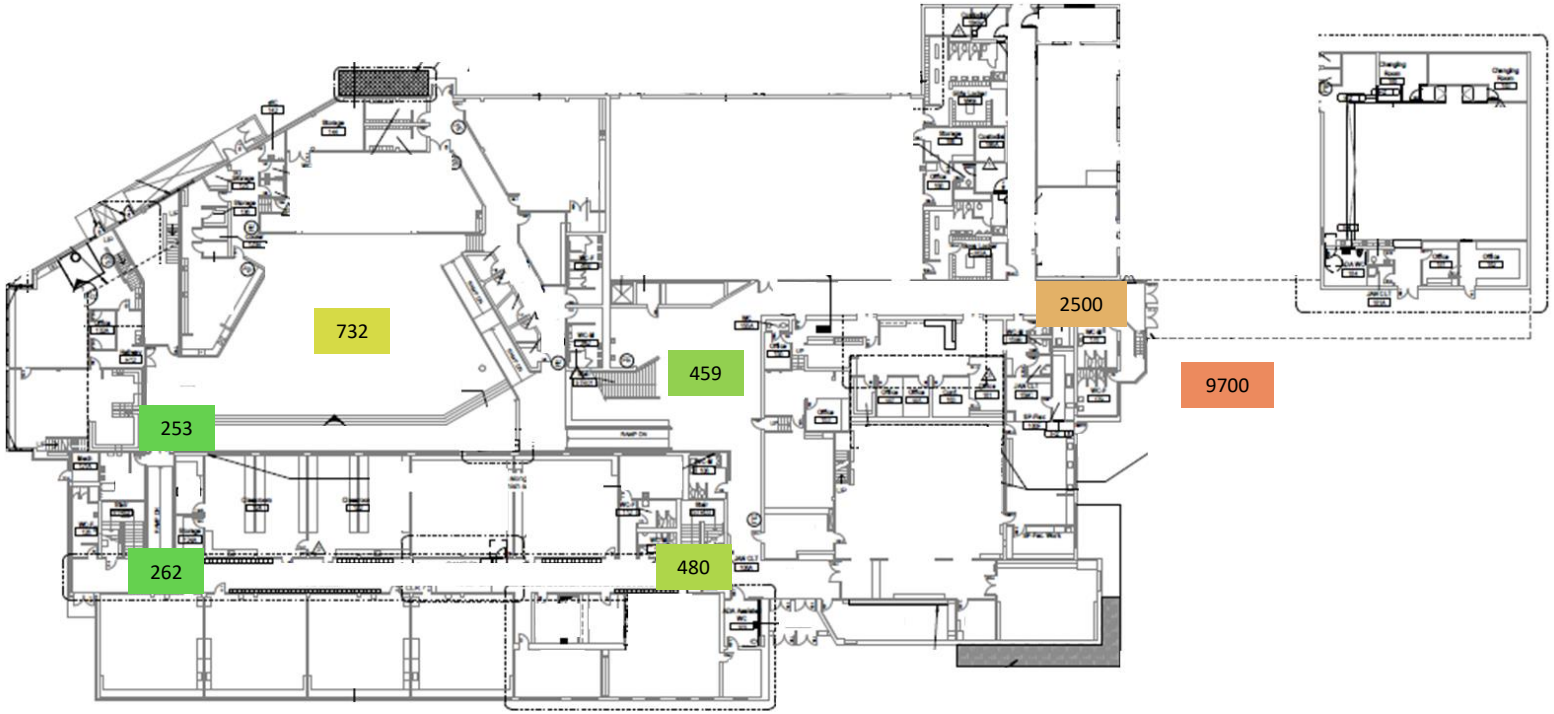
Dismissal 3:45-4:15PM
6.6K (5.2/12.2)

Goal 4. Spatial variation of air pollution

		Ultrafine particle counts *Median value (min/max) x 1000 particle/cm3*	
Location	**Time**	**10/10/2018**	**10/15/2018**
Morning transects were done in **Lillis Albina City Park** where the middle schoolers play at recess. There were a total of 4 transects per hour. The first transect started at the north end of the park and I moved south.	8AM - 9 AM	13 (11/41)	39 (18/110)
	9-10AM	26 (16/84)	43 (25/107)
Lunch sampling was done in Lillis Albina City Park and the **basketball court** at HTMS.	11:15 AM-12PM	10 (6.6/84)	15 (13/37)
	12PM-12:45 PM	8 (6.5/29)	16 (11/21)
Afternoon transects were done in **Lillis Albina City Park** where the middle schoolers play at recess. There were a total of 4 transects per hour. The first transect started at the north end of the park and I moved south.	1PM-2PM	13 (7.3/33)	14 (12/98)
Dismissal **Front of school,** just south of N Page St	3:45 PM -4:15 PM	6.8 (6.7/7.3)	6.6 (5.2/12.2)
Neighborhood Began east on N Russel Street then walked south on N Vancouver, north on Williams Ave, south on NE Rodney and then returned back to HTMS walking west on Tillamook.	after 4:15 PM	NA	5.4 (4.6/14)

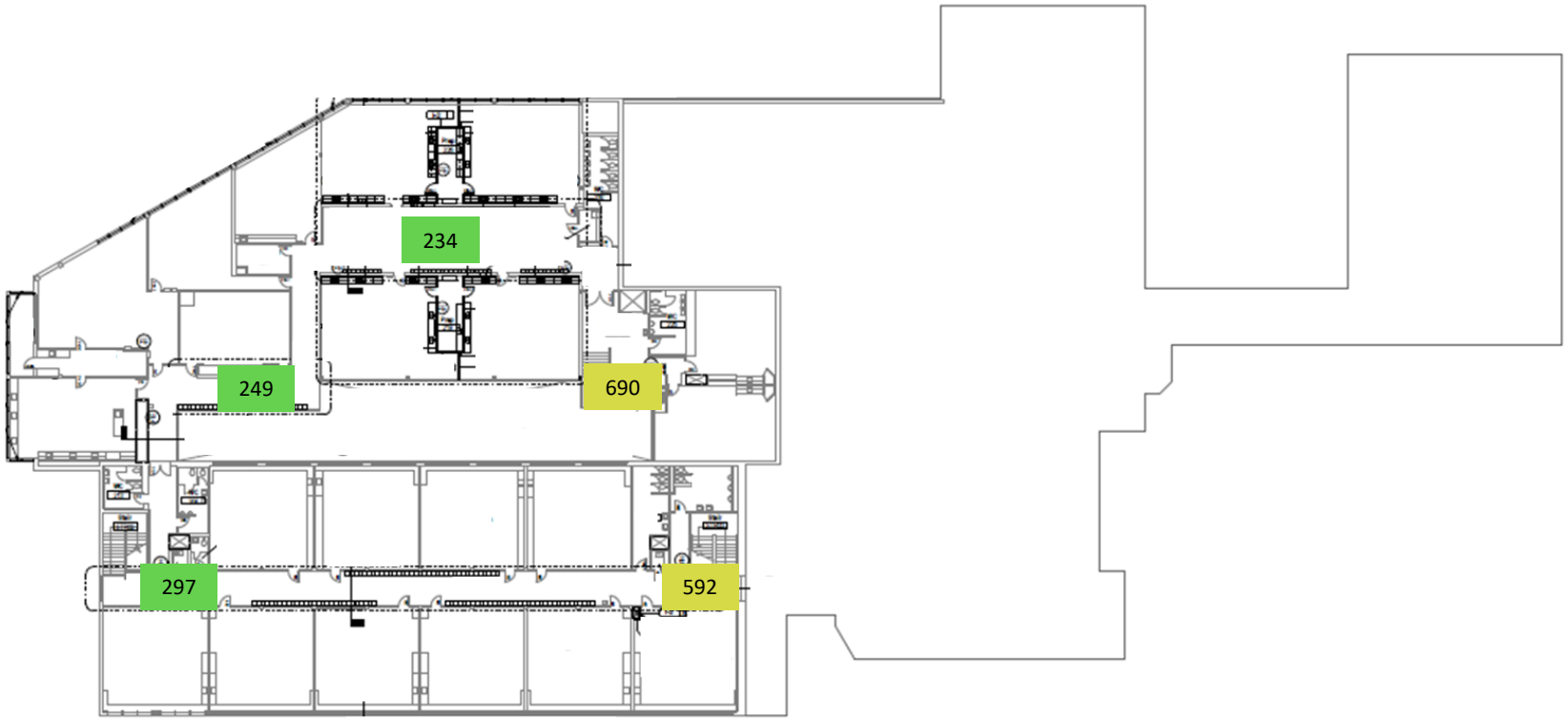
Indoor/outdoor levels: UFP

First floor



Indoor/outdoor levels: UFP

Second floor



Goal 4. Spatial variation of air pollution

Summary of Goal 4

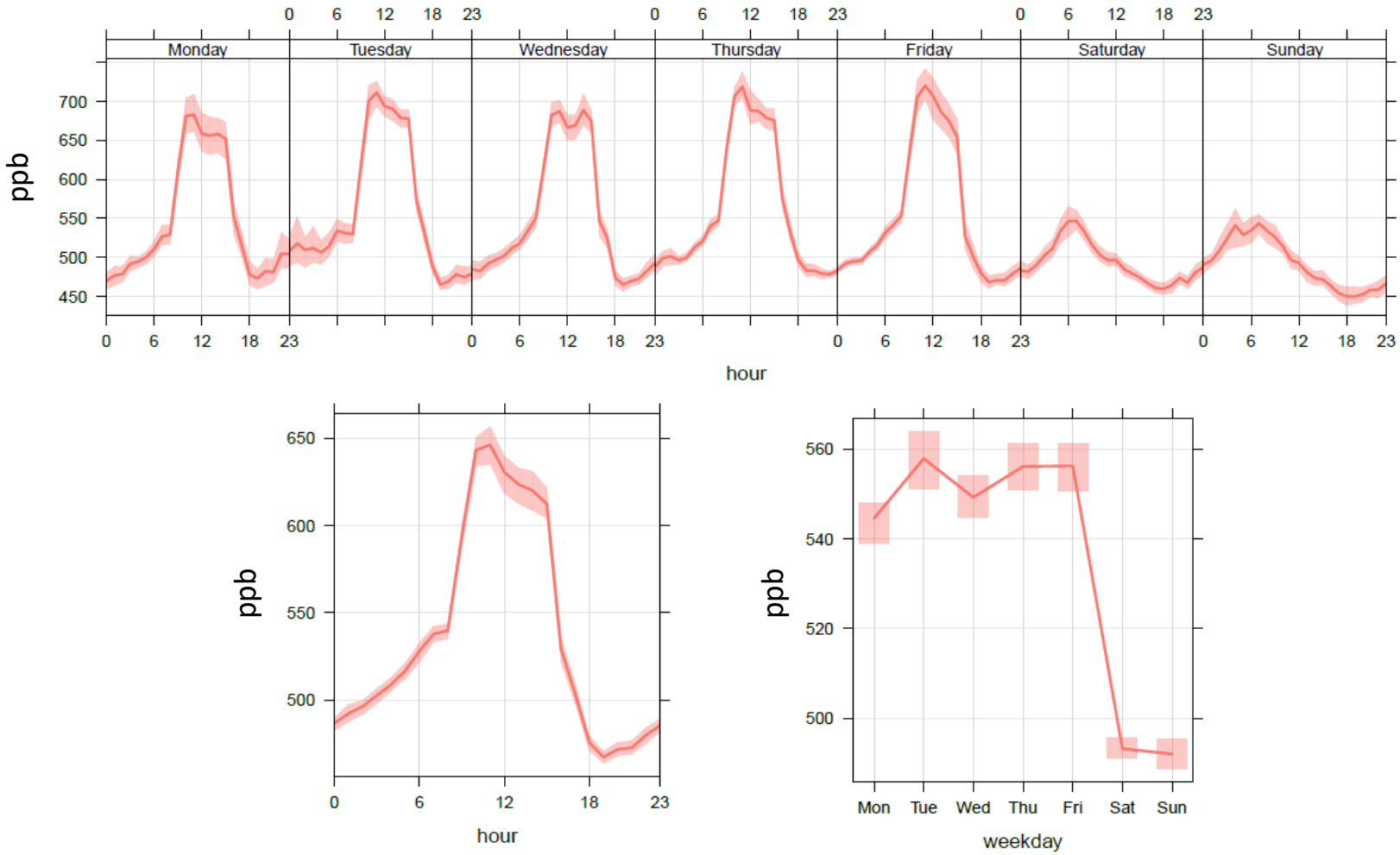
- Outdoor levels of NO2 and UFP elevated at HTMS compared to urban background in the **morning and near freeway**
- UFP and NO2 level are significantly reduced indoors compared to outdoor levels

Supplemental slides

Supplemental slides

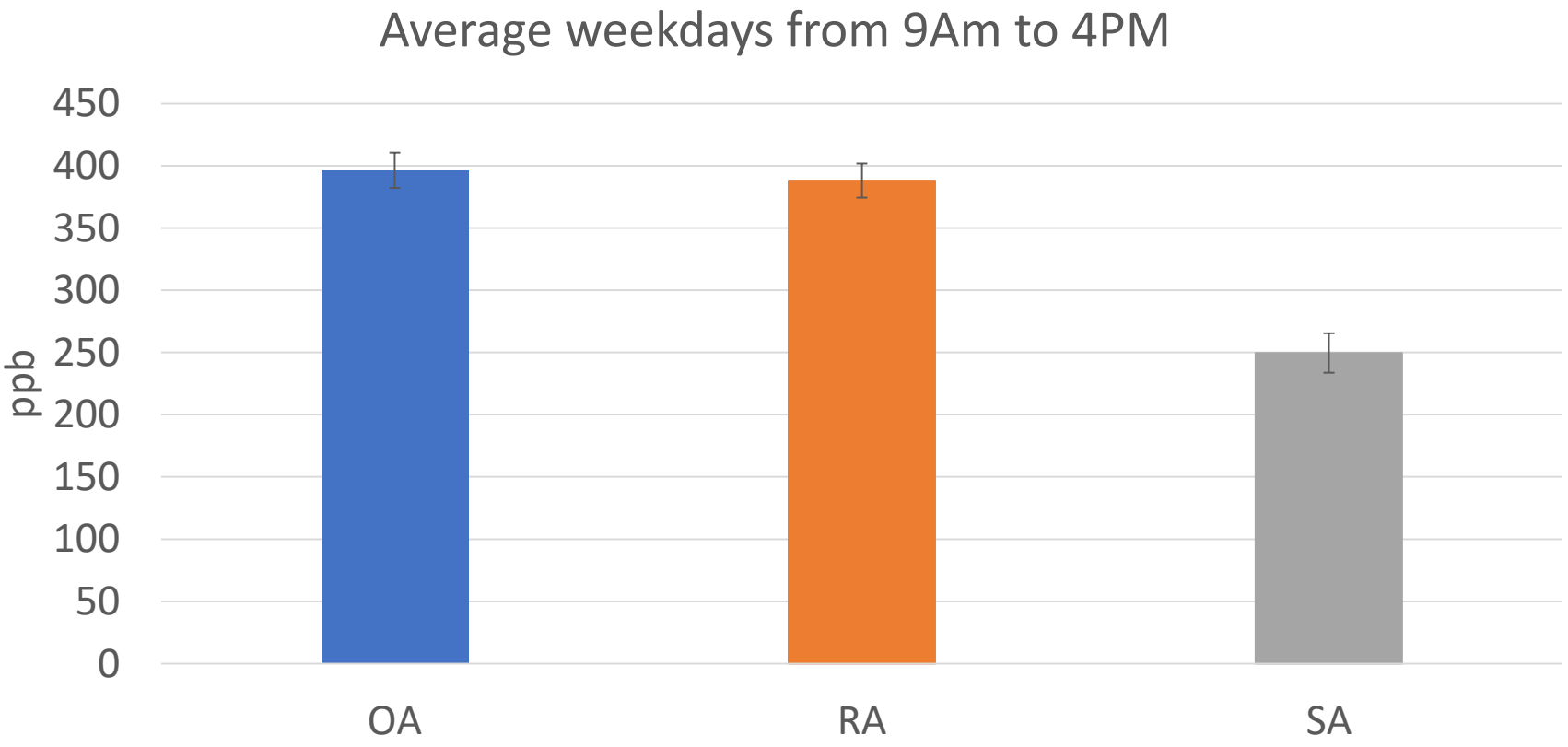
Detailed results from AHU sampling of RA, OA, SA

Carbon Dioxide – time variation

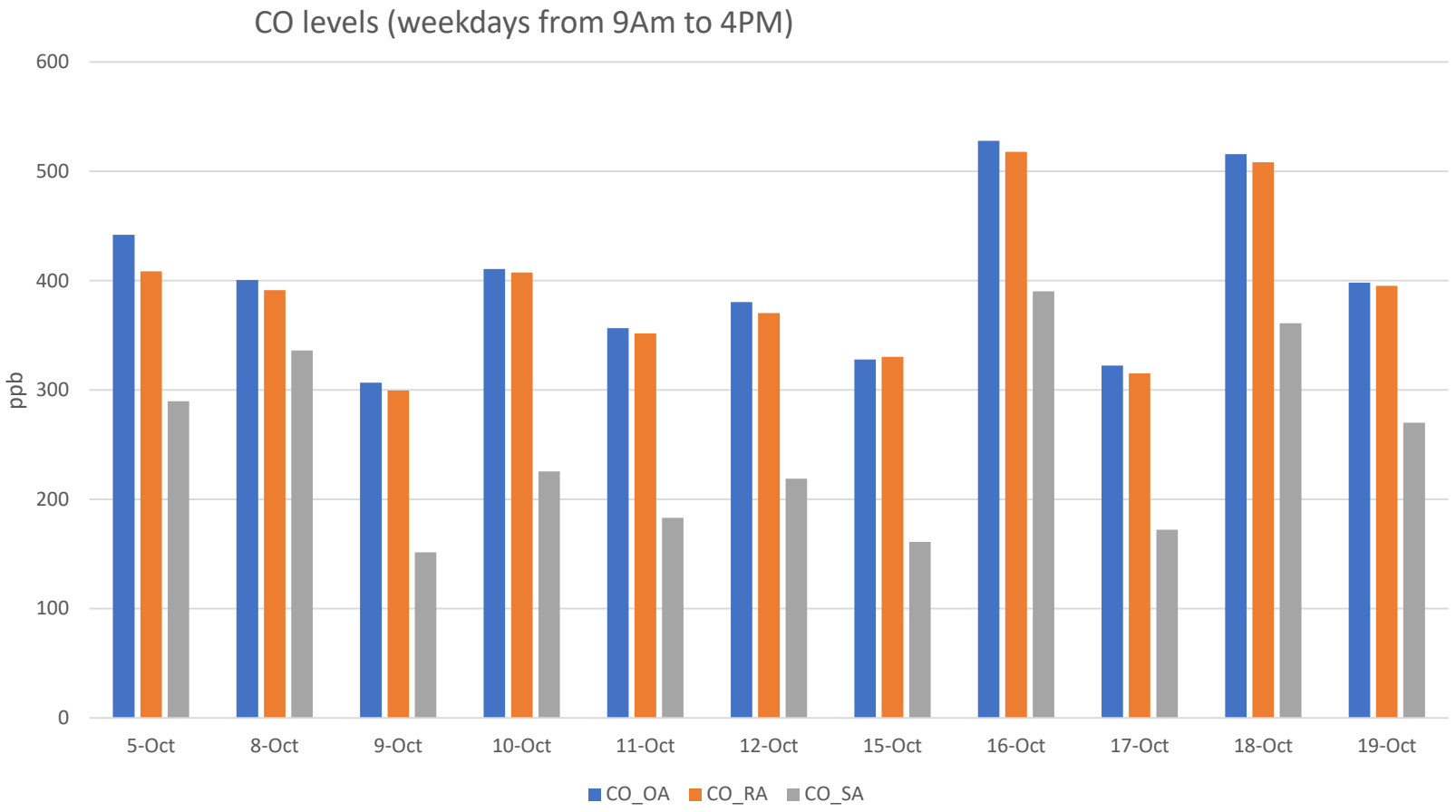


Mean and 95% confidence interval in mean

Carbon Monoxide - avg

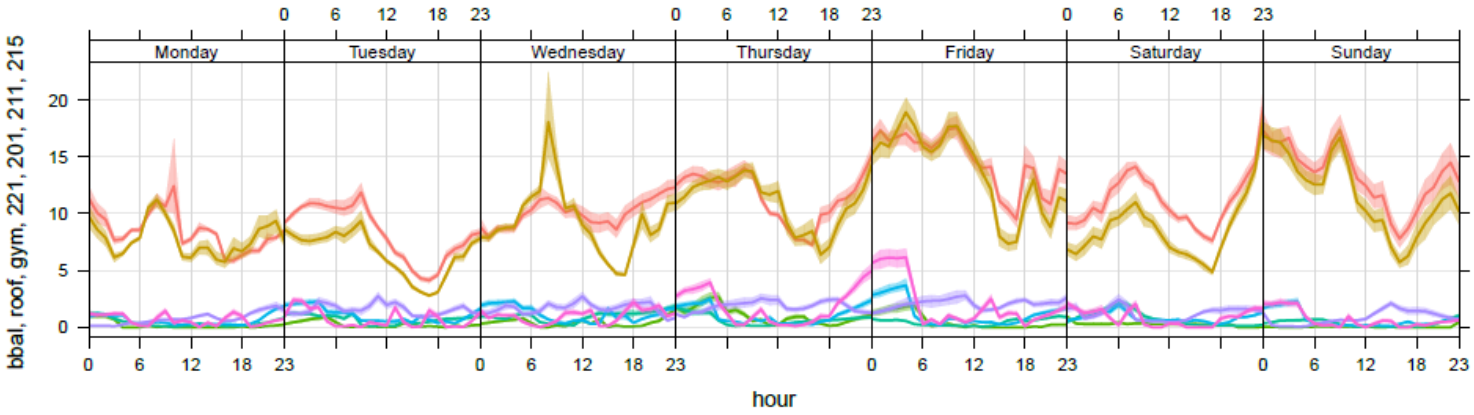


Carbon Monoxide – daily avg

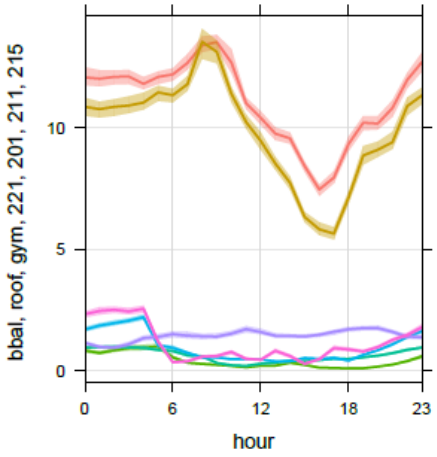


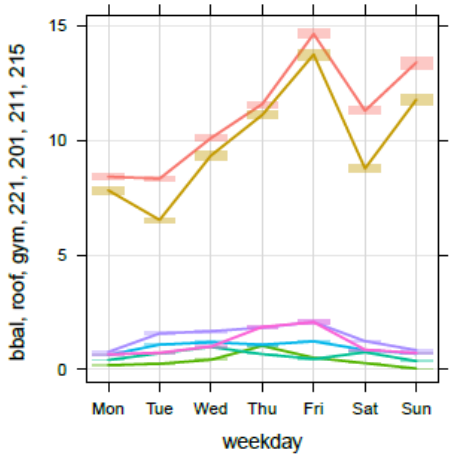
PurpleAir data

PM2.5 in µg/m^3



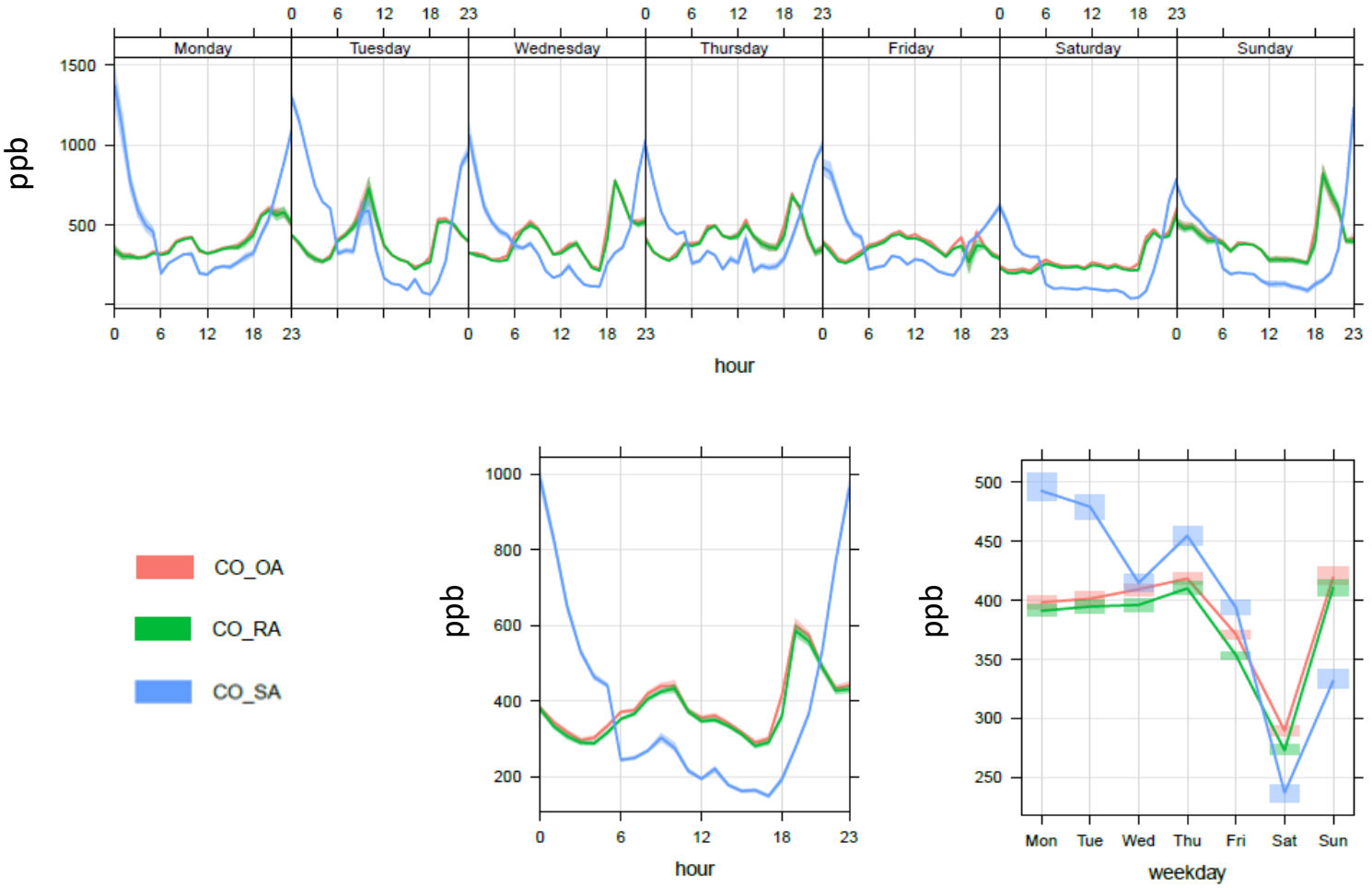
- Room 215
- Room 221
- Room 211
- Room 201
- Gymnasium
- Penthouse
- Basketball field





Mean and 95% confidence interval in mean

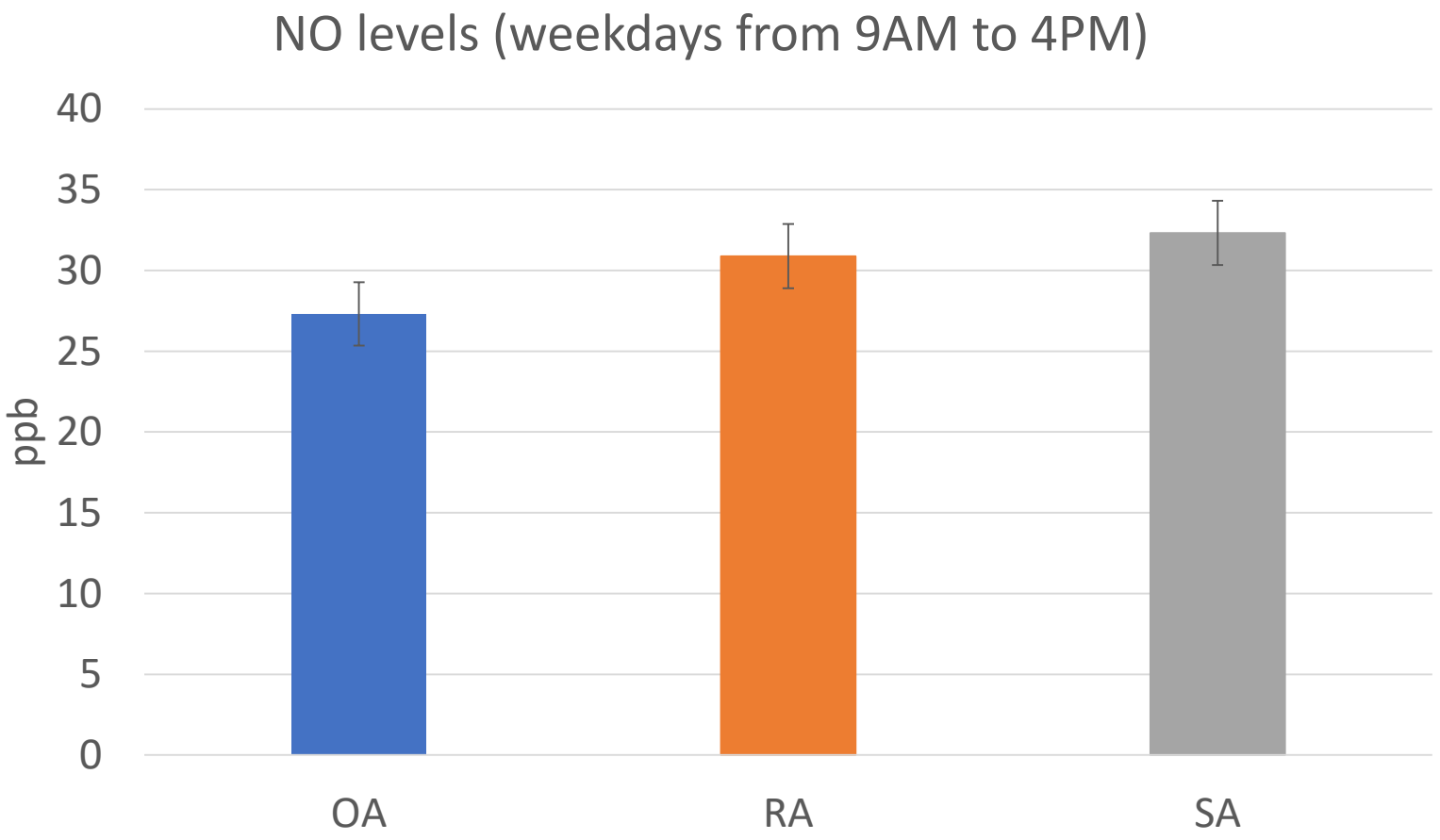
Carbon Monoxide – time variation



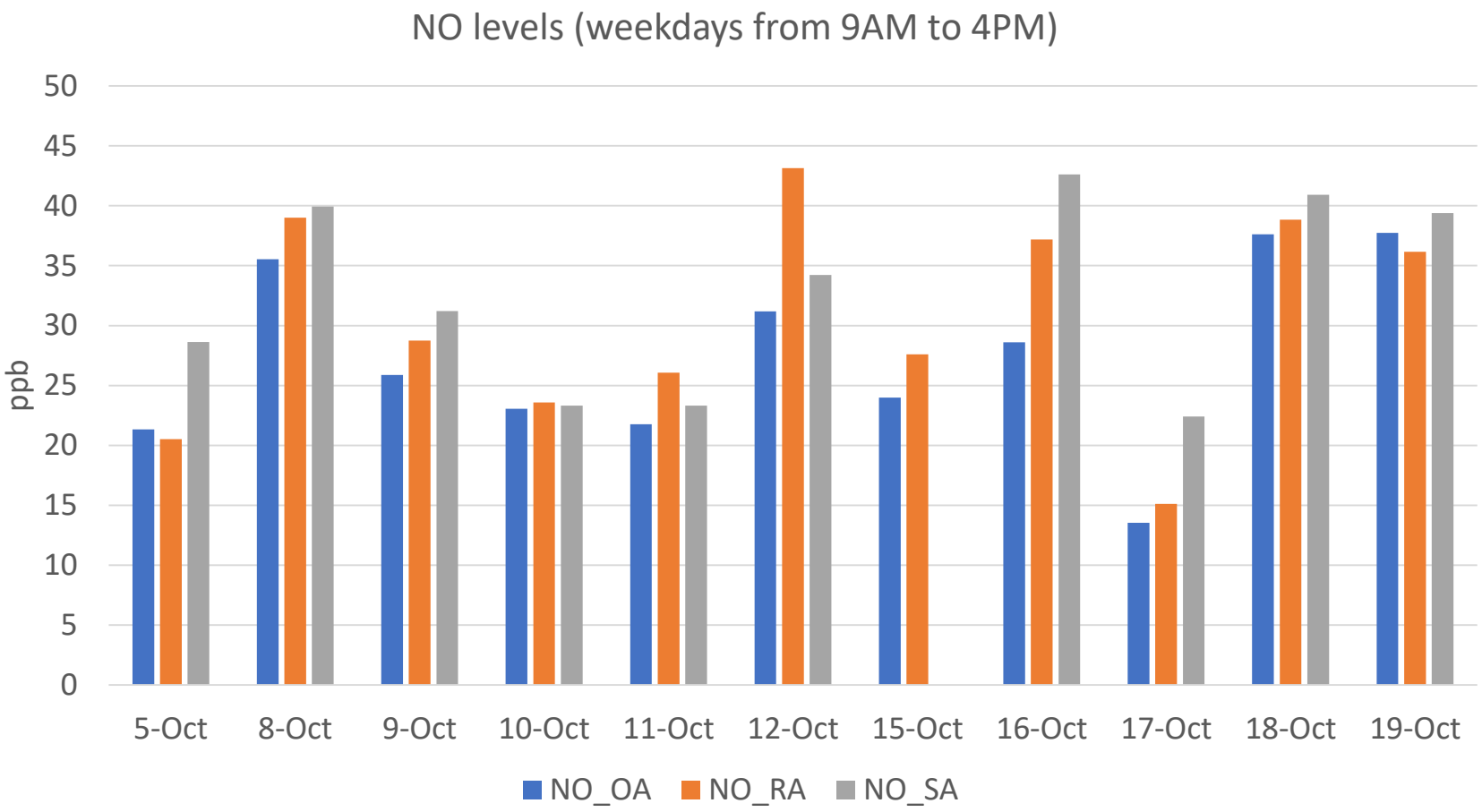
Mean and 95% confidence interval in mean

STAR Lab

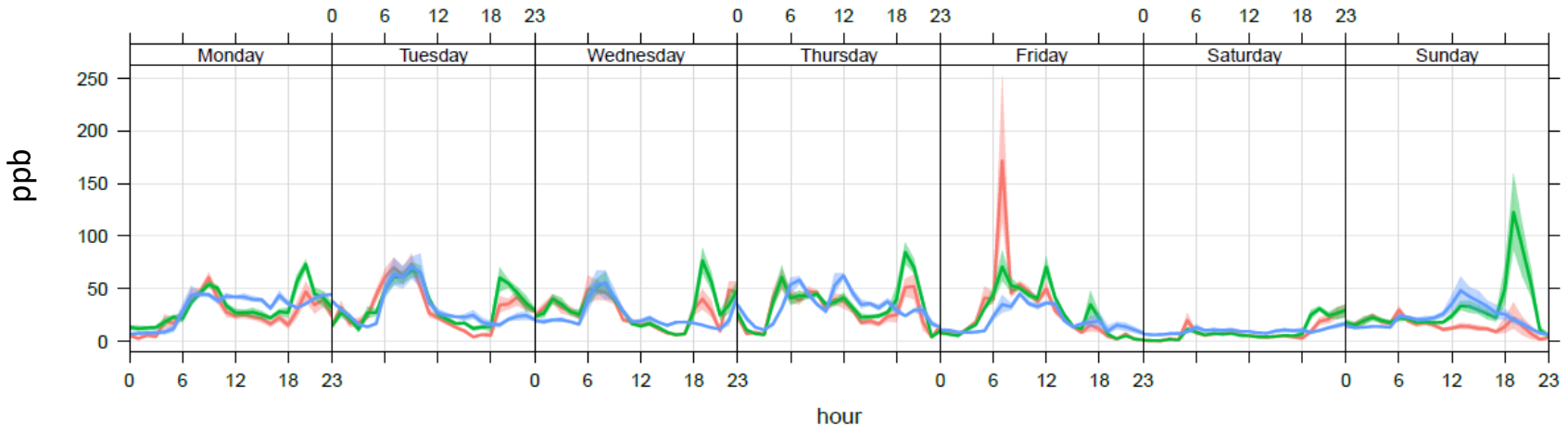
Nitric Oxide - avg

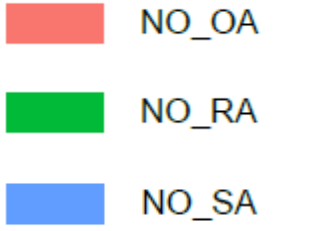


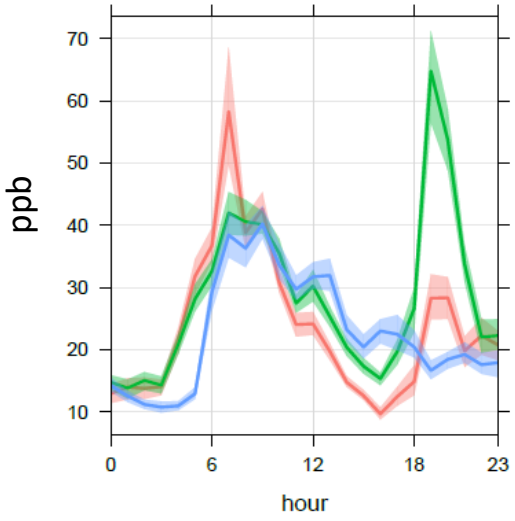
Nitric Oxide – daily avg

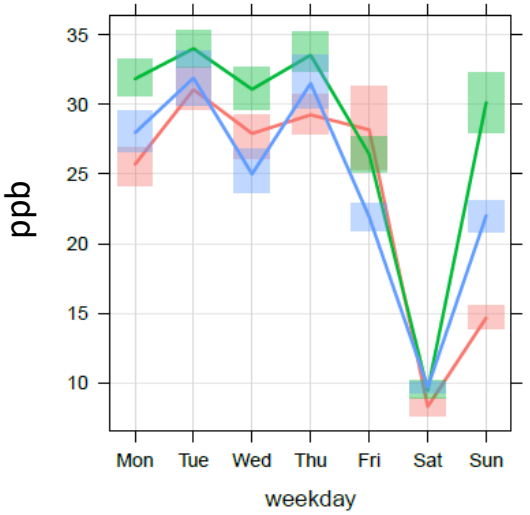


Nitric Oxide – time variation

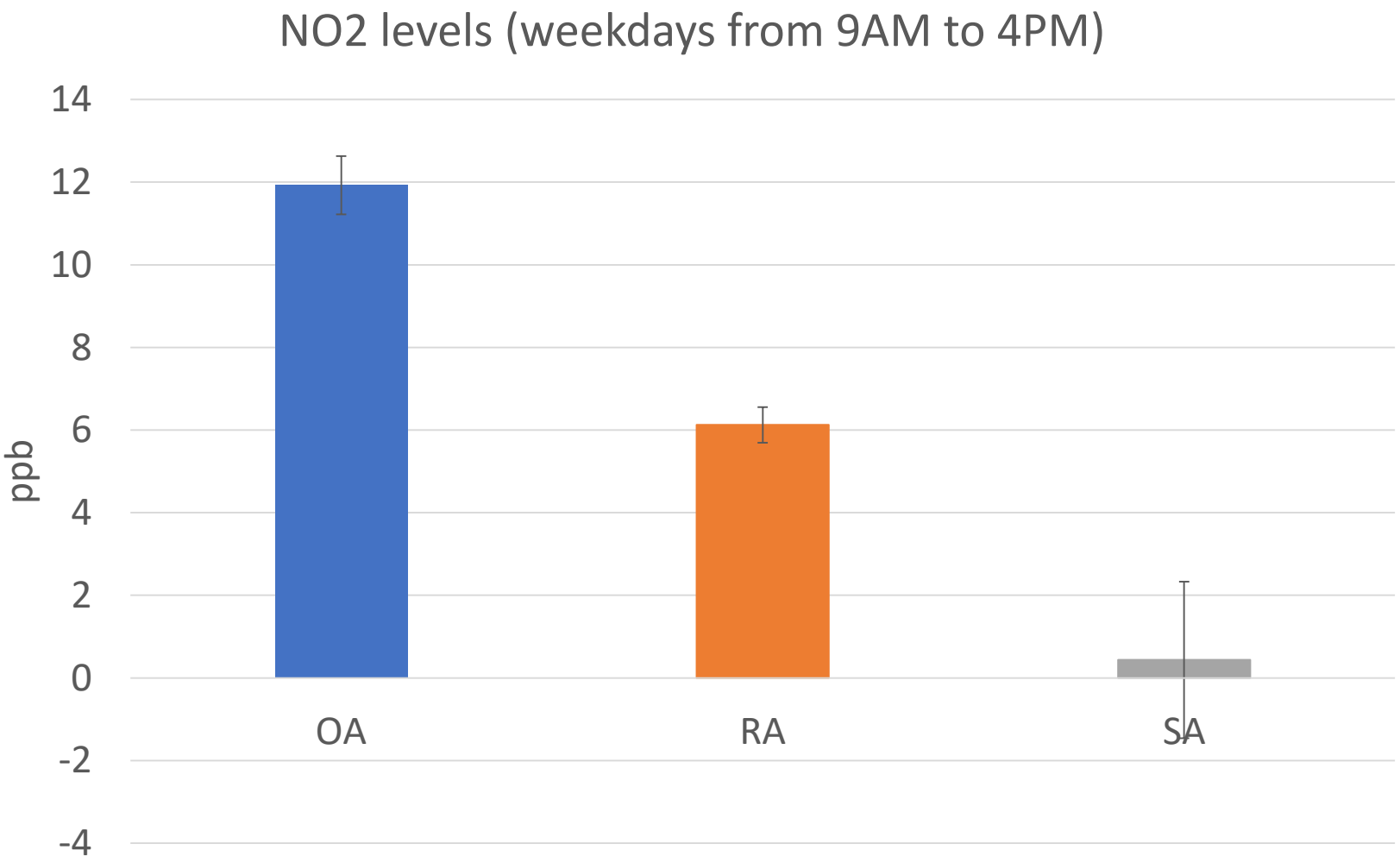




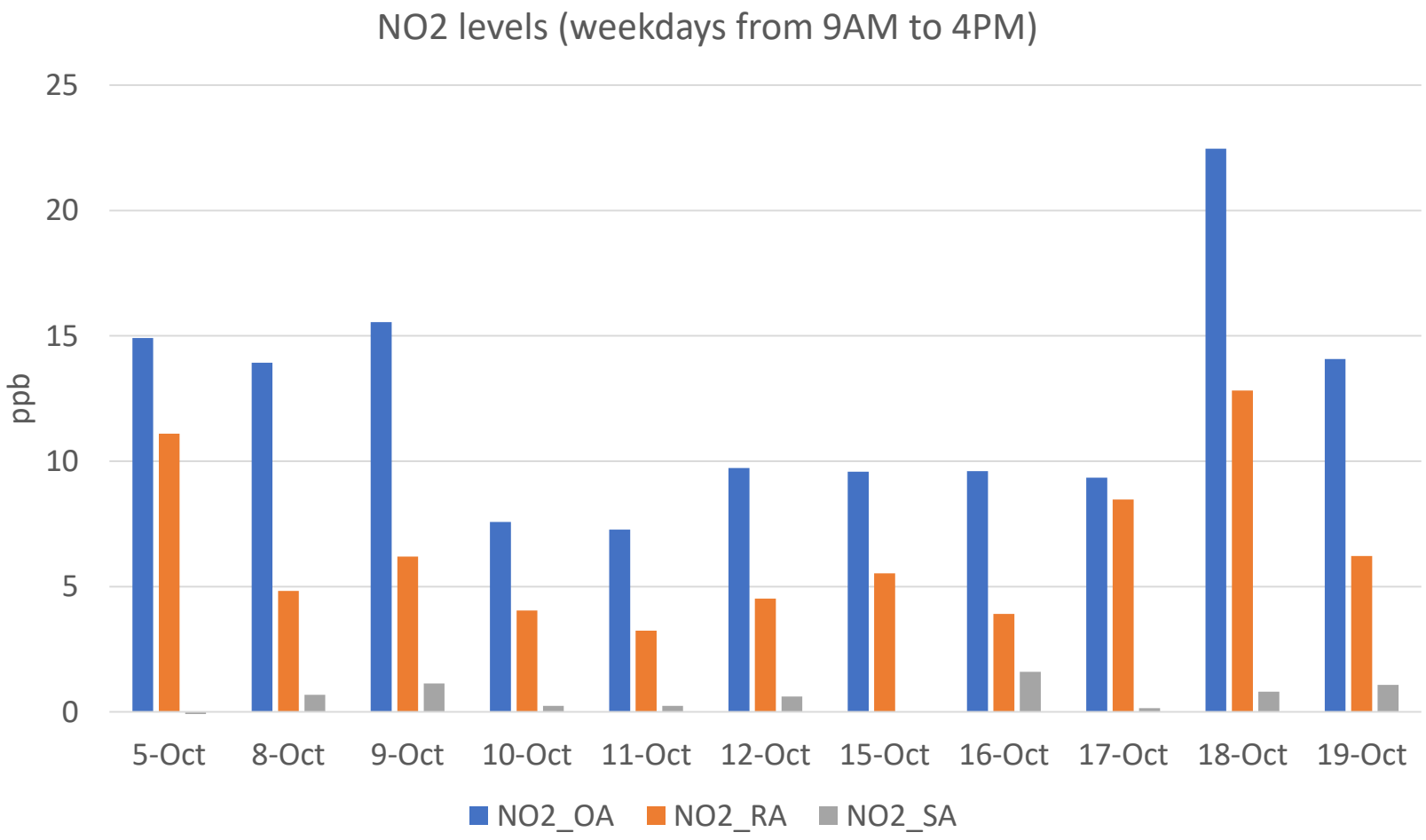




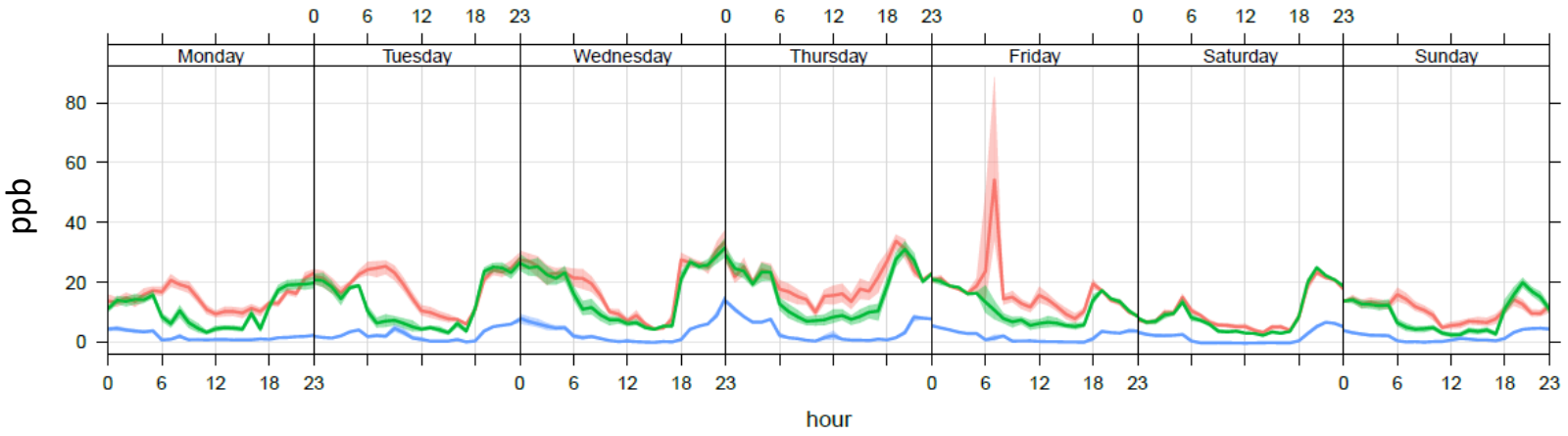
Nitrogen dioxide - avg

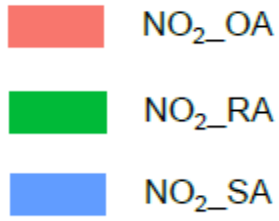


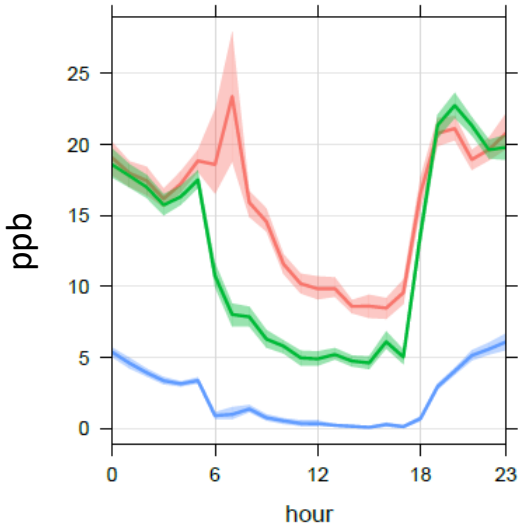
Nitrogen dioxide – daily avg

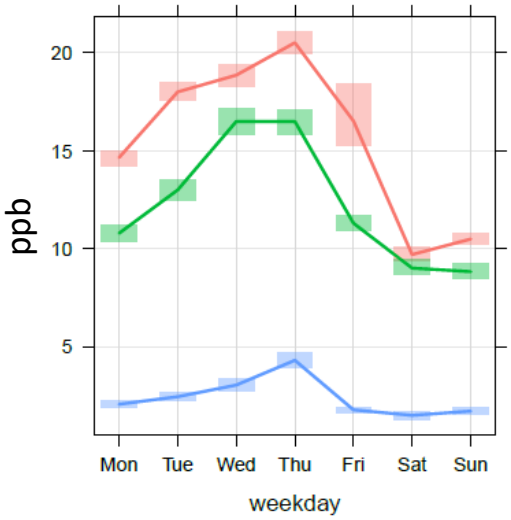


Nitrogen dioxide – time variation

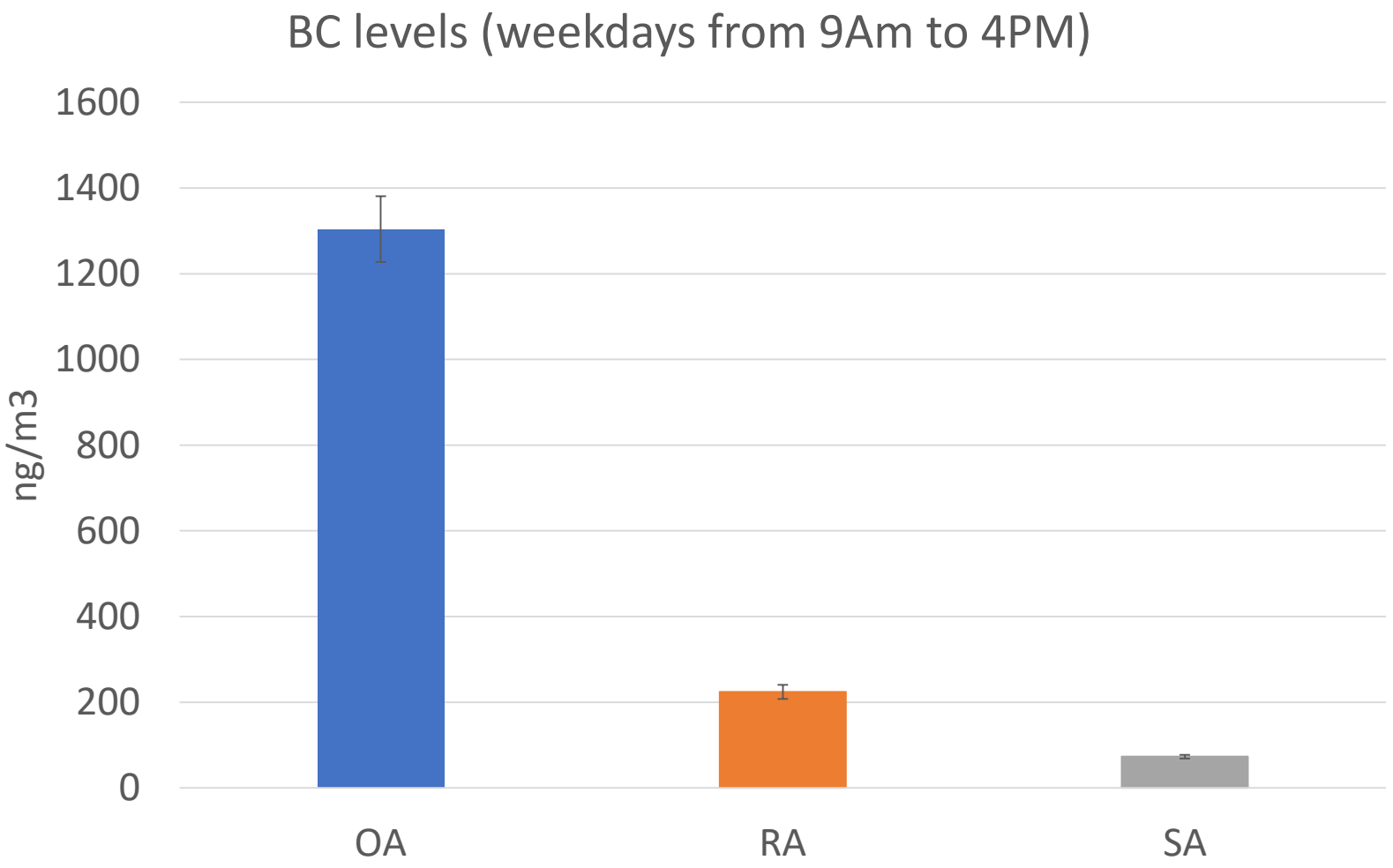




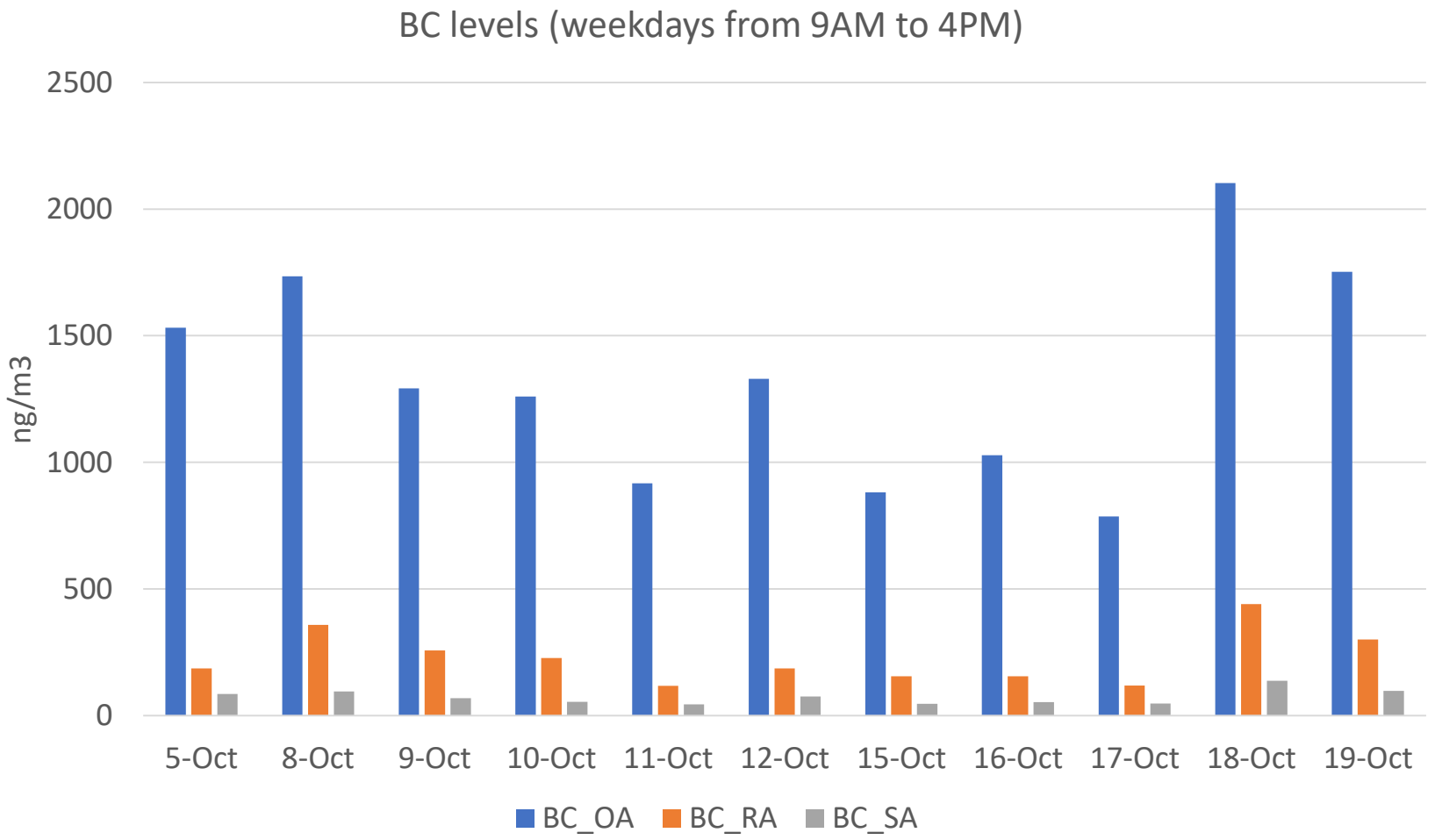




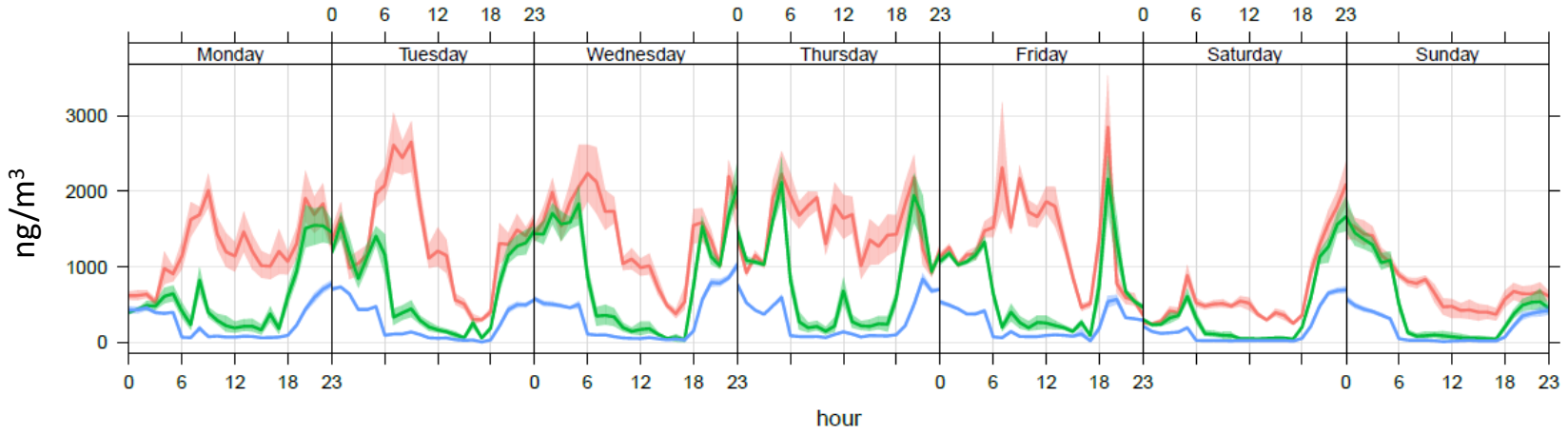
Black carbon - avg

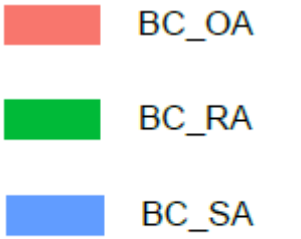


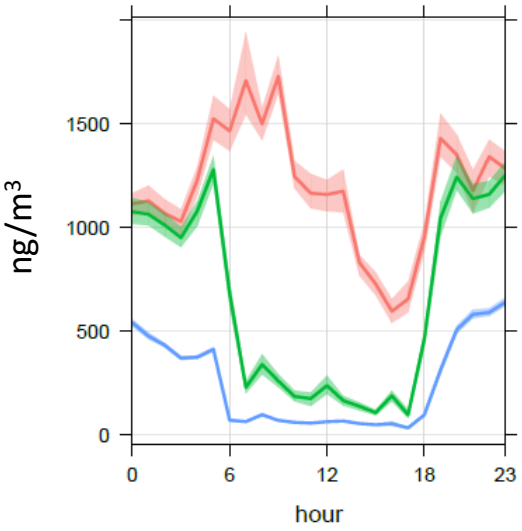
Black carbon – daily avg

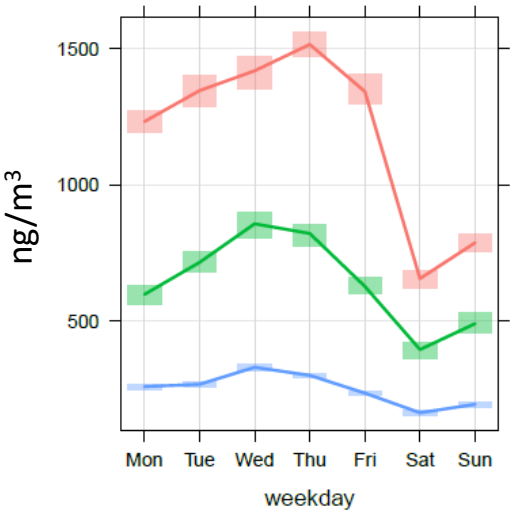


Black carbon – time variation



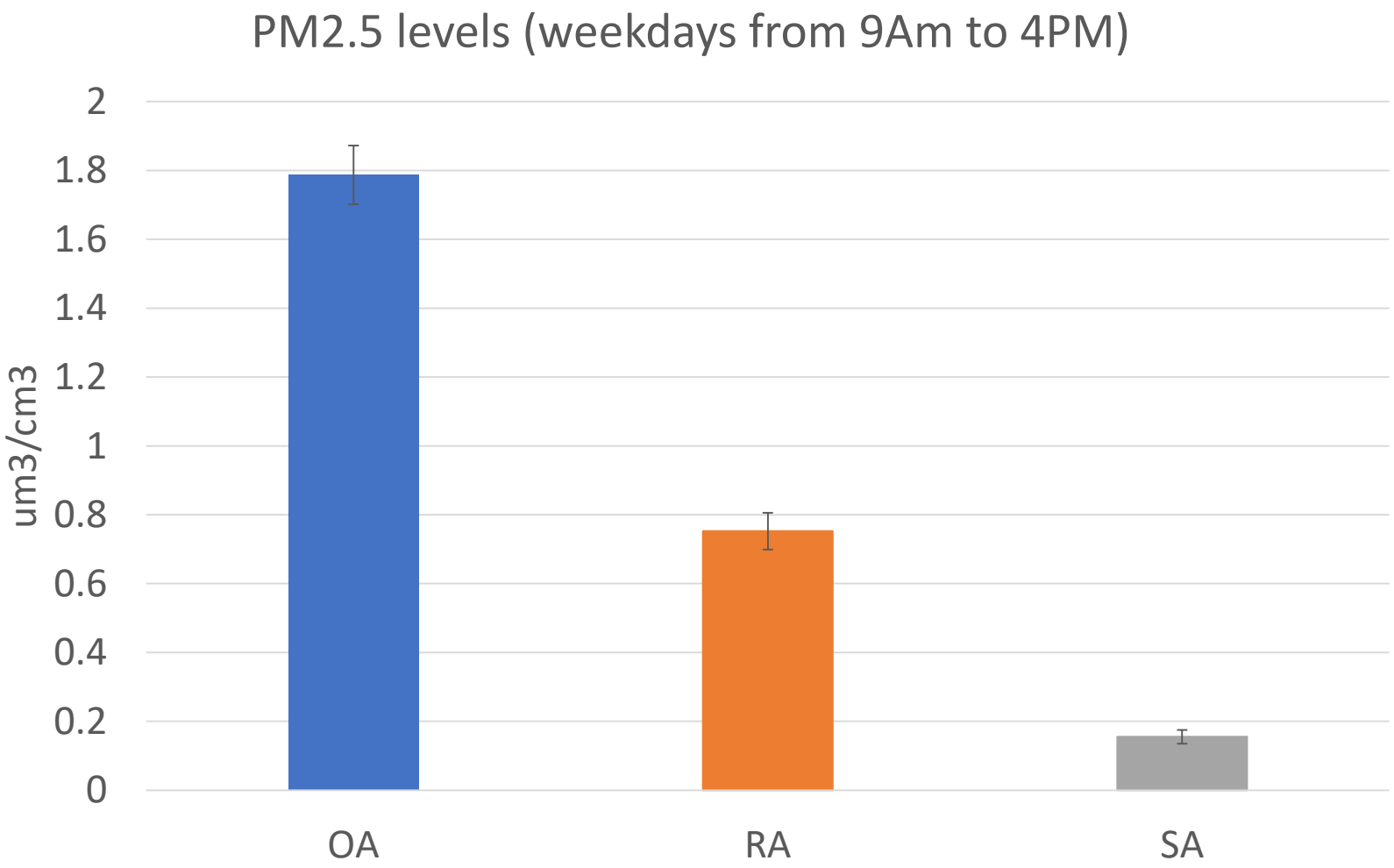




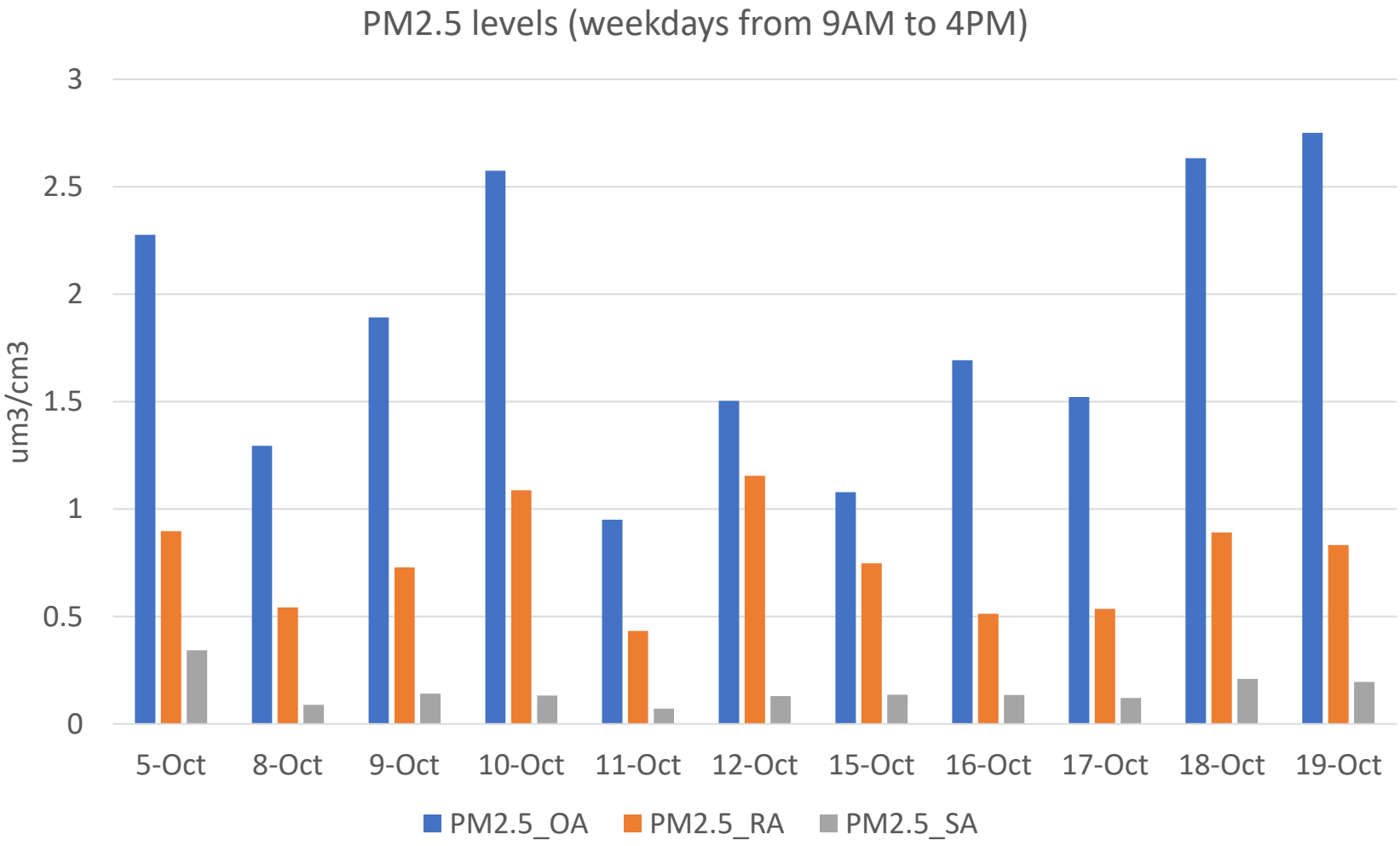


STAR Lab

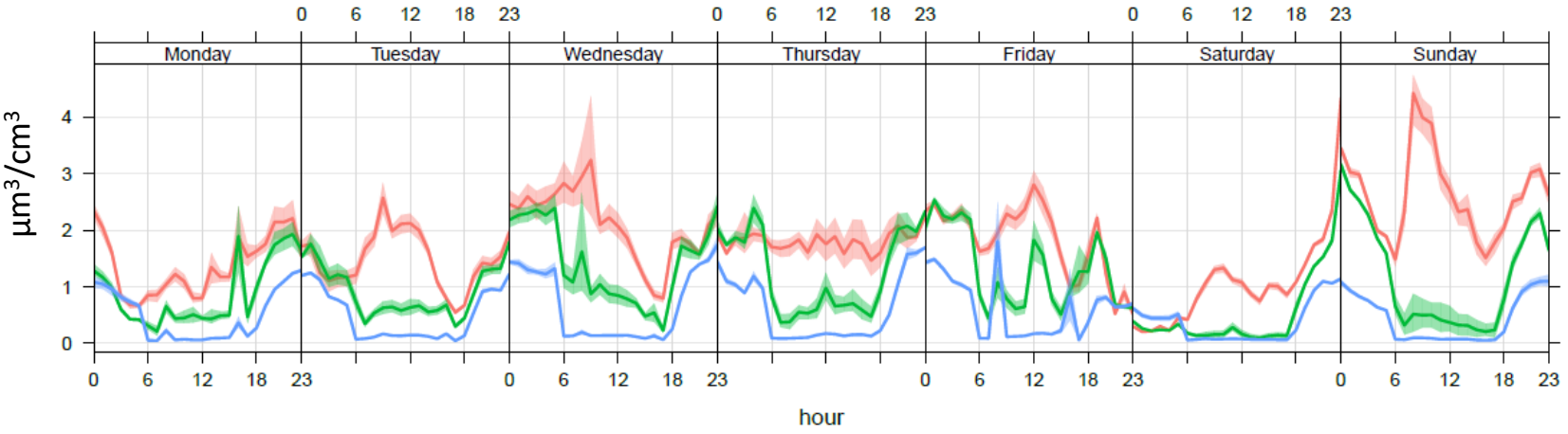
PM2.5- avg

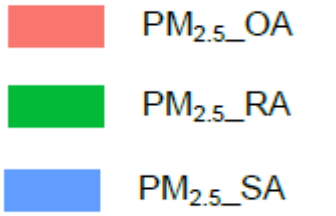


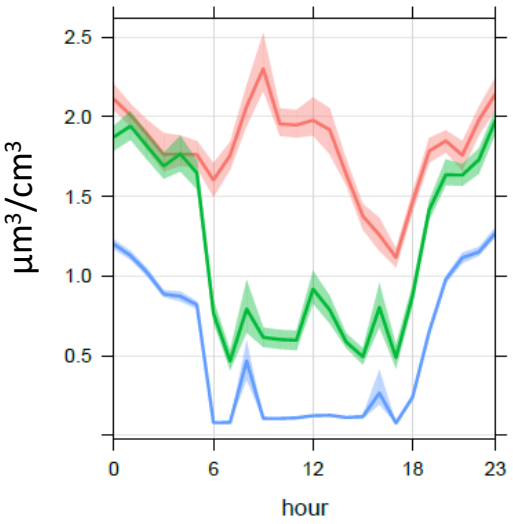
PM2.5– daily avg

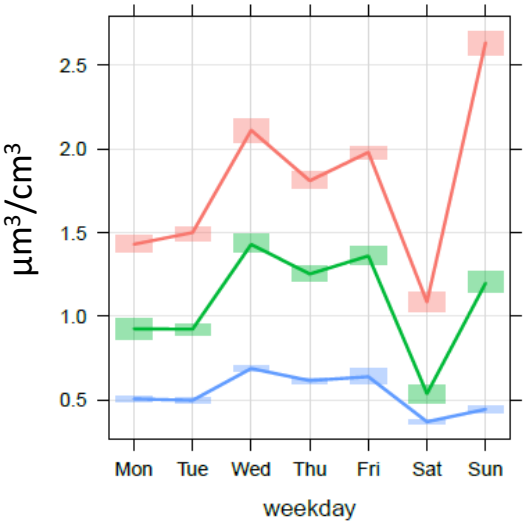


PM2.5– time variation



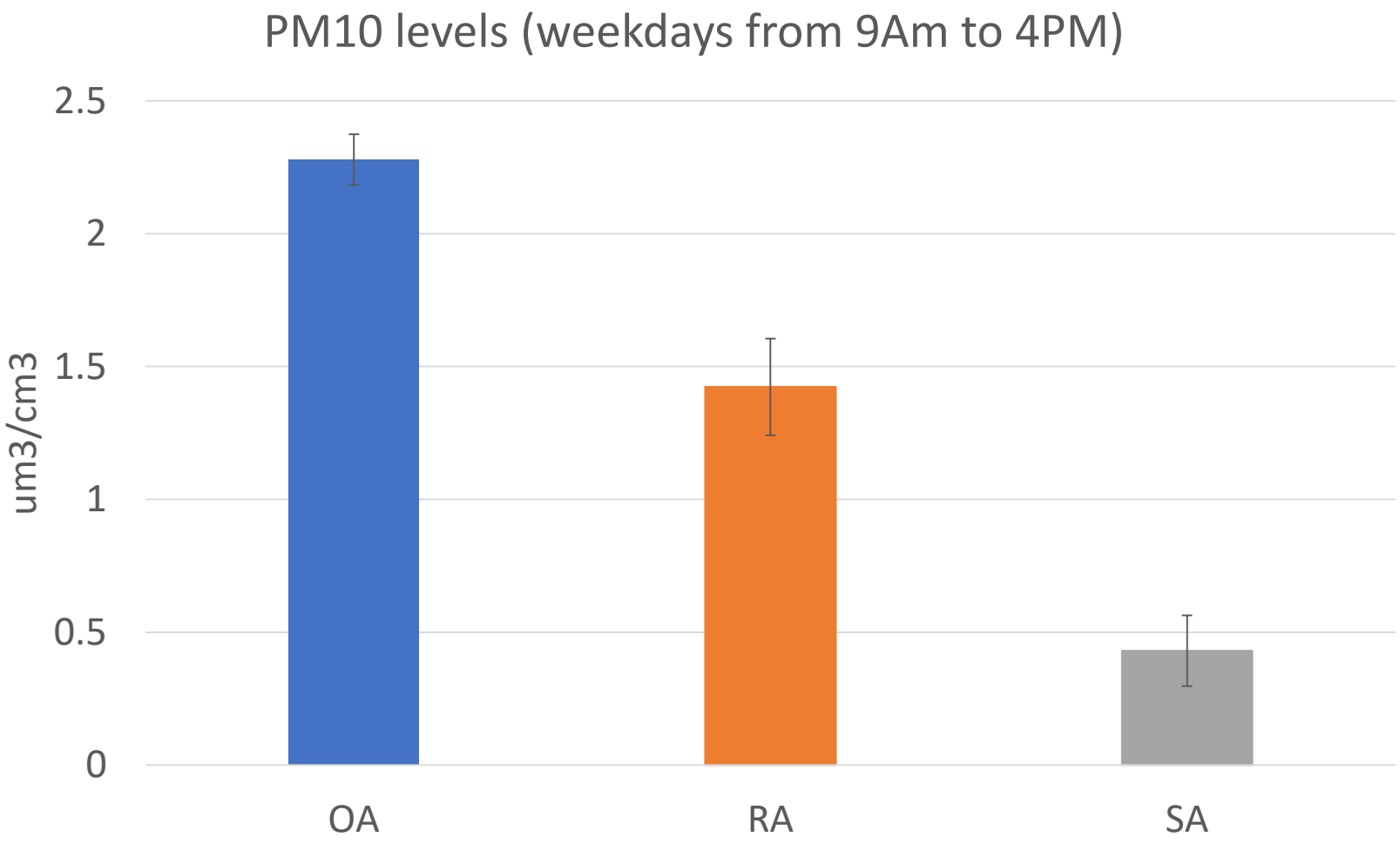




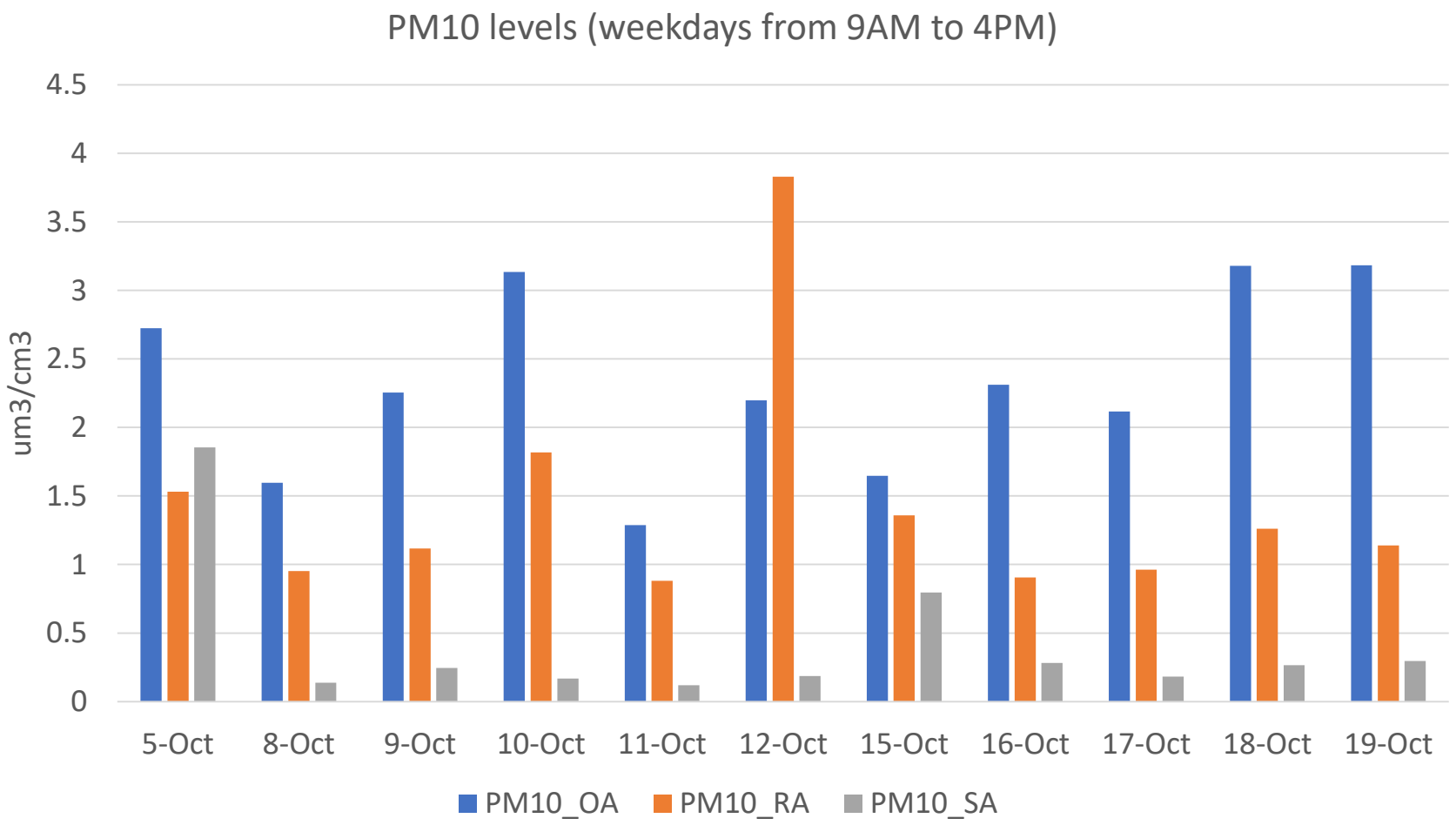


STAR Lab

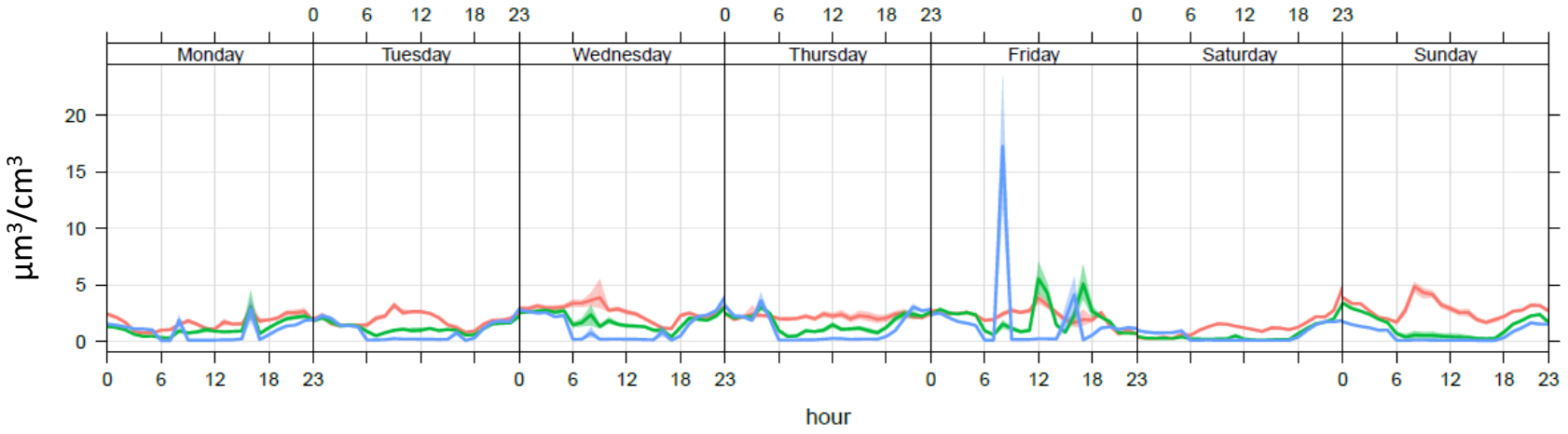
PM10– daily avg

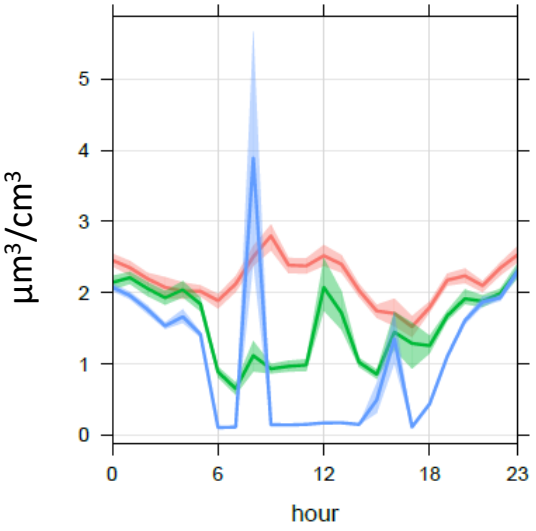


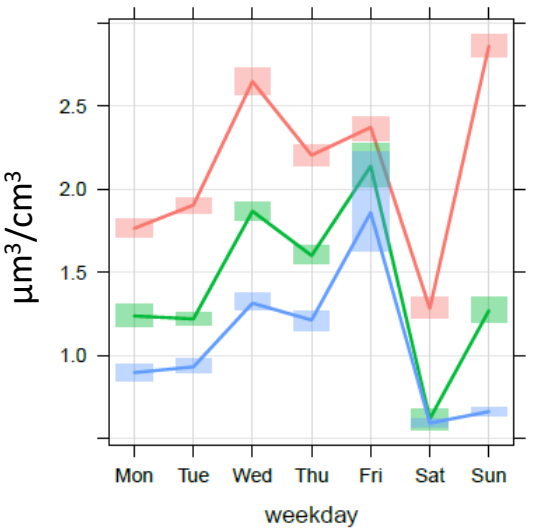
PM10- avg


PM10 levels (weekdays from 9AM to 4PM)
um3/cm3
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
5-Oct
8-Oct
9-Oct
10-Oct
11-Oct
12-Oct
15-Oct
16-Oct
17-Oct
18-Oct
19-Oct
PM10_OA
PM10_RA
PM10_SA

PM10- time variation





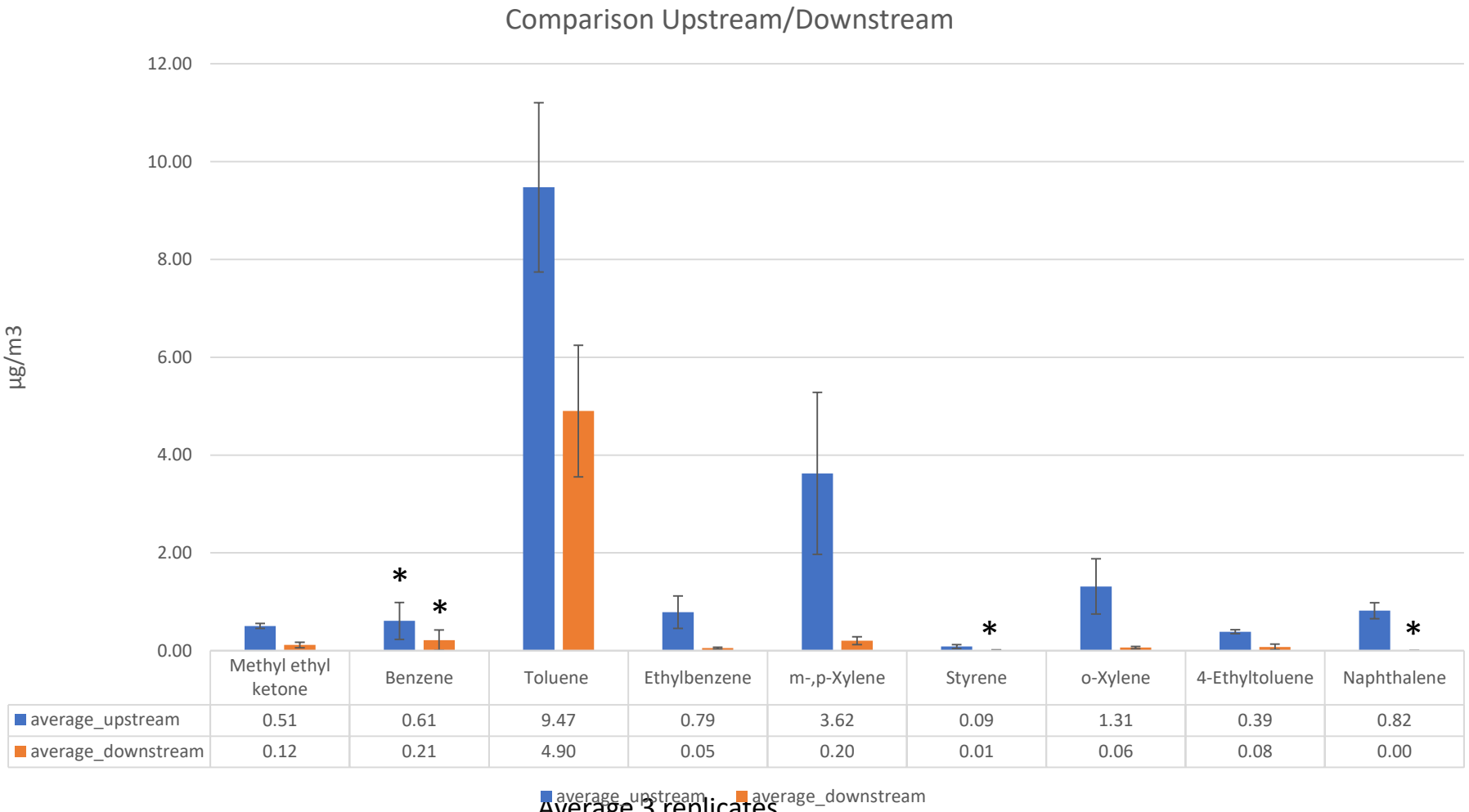


Supplemental slides

Removal efficiency sampling event 1

Carbon filters efficiency

Date: 4-6 Sept 2018



	Methyl ethyl ketone	Benzene	Toluene	Ethylbenzene	m-,p-Xylene	Styrene	o-Xylene	4-Ethyltoluene	Naphthalene
average_upstream	0.51	0.61	9.47	0.79	3.62	0.09	1.31	0.39	0.82
average_downstream	0.12	0.21	4.90	0.05	0.20	0.01	0.06	0.08	0.00

Average 3 replicates

* < MDL