ASSESSMENT OF PERSONAL EXPOSURE TO PARTICULATE EMISSIONS IN URBAN MICROENVIRONMENTS

Phuong Thi Minh Tran, Max Gerrit Adam, Rajasekhar Balasubramanian*

Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576
*E-mail: ceerbala@nus.edu.sg

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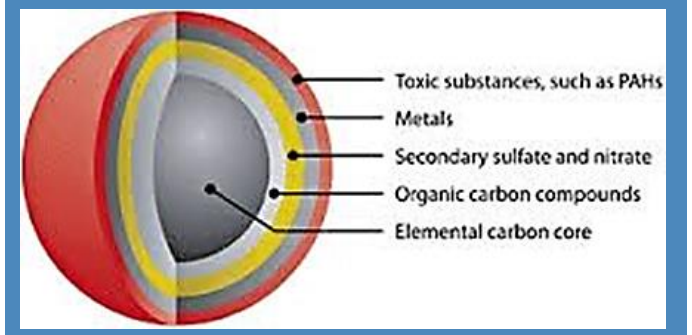
OUTLINE

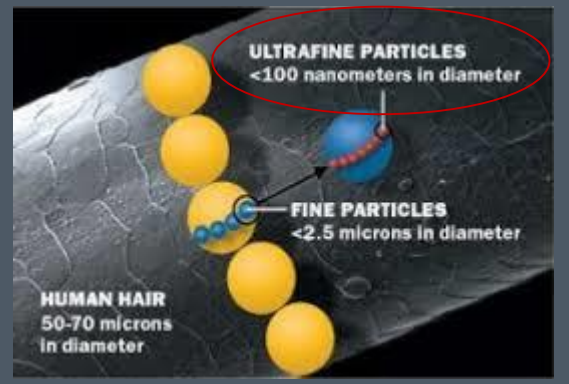
1. Introduction (5)
2. Methodology (4)
3. Result and Discussion (10)
4. Conclusion (1)

PARTICULATE MATTER (PM)



$PM_{2.5}$ (≤ 2.5µm) consists of a broad range of chemical pollutants

BLACK CARBON (BC) produced by incomplete combustion



ULTRAFINE PARTICLES (UFPs, ≤ 0.1 µm) much higher surface area

PARTICULATE MATTER (PM)

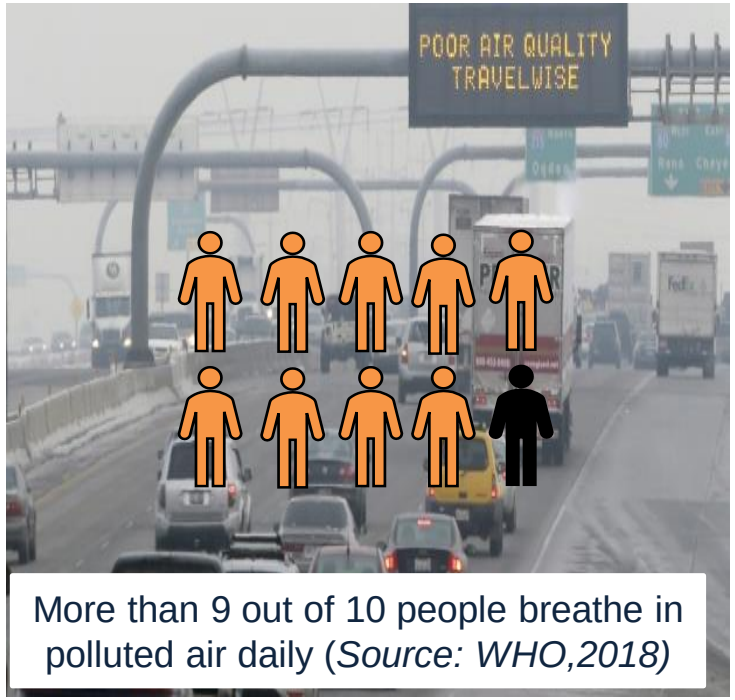
Human Health

7

MILLION deaths a year are linked to exposure to $PM_{2.5}$
(Source: WHO,2018)

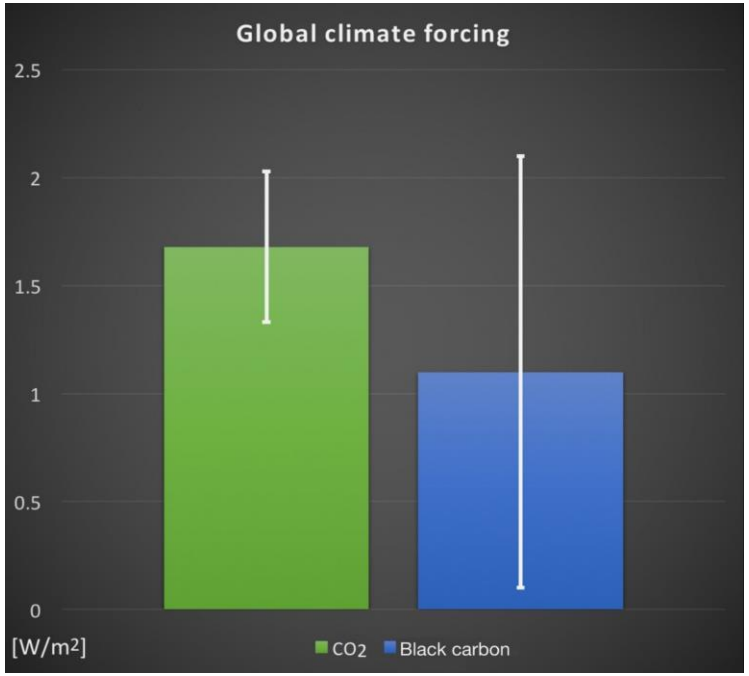
(Source: Amman, Nov 2015)

Urban Air Quality



More than 9 out of 10 people breathe in polluted air daily (*Source: WHO,2018)*

Climate Change



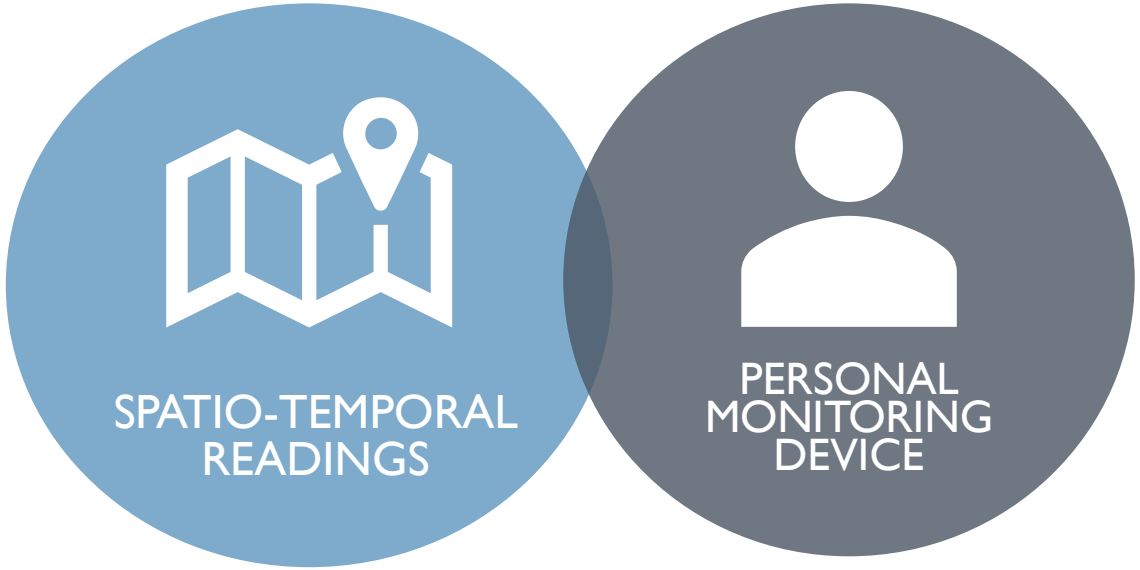
(Source: European Geosciences Union, 2016)

Popular monitoring methods

- FIXED MONITORING STATION

Temporal variability

- MOBILE PM INSTRUMENTS



• MOBILE PM INSTRUMENTS

- Most of the PM studies using mobile instruments have focused mainly on **commuters' exposure** (e.g.,Chan *et al.*, 2002; Moreno *et al.*, 2015; Good *et al.*, 2016; Rivas *et al.*, 2017; Shirmohammadi *et al.*, 2017).
- People are **mobile** and experience their own unique personal exposure to air pollution in different **micro-environments** (MEs) daily.

- **Characteristics and contributions** of these MEs to the daily personal exposure in an urban area are not well understood.

- **Personal exposure** also depends on **physical health factors** (e.g., gender, age, height, body weight) and **time-activity patterns** of individuals

The **integrated assessment** of health risks associated with inhalation of PM across **diverse MEs** over 24-hours exposure needs to be examined on a day-to-day basis.
In this regard, using a **mobile platform** paired with **real-time PM monitors** and a global positioning system (**GPS**) tracking is a powerful approach to accurately characterize individuals' exposure.

Aims of this study:

To characterize the spatio-temporal patterns of the personal exposure to $PM_{2.5}$, UFPs, BC, Lung Deposited Surface Area (LDSA) and identify pollution hotspots

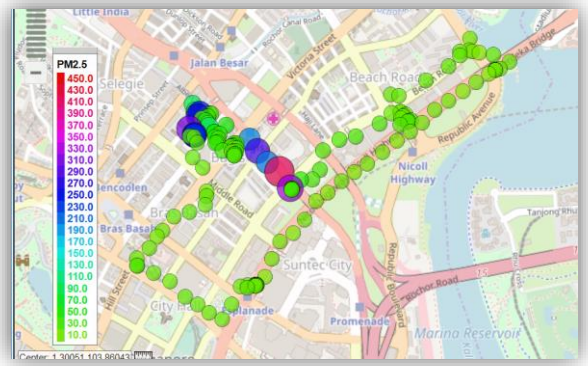
To quantify the emission profiles of these pollutants in the identified hotspots

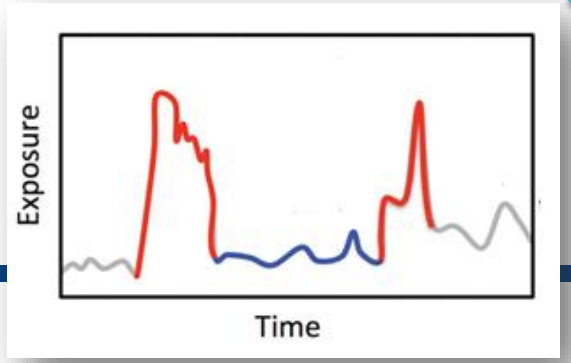
To estimate potential health risks associated with $PM_{2.5}$ inhalation over the 24-hour daily exposure

Micro-environments
Time, Location, Temperature, Relative Humidity

Pollutant concentrations:
$PM_{2.5}$, BC, UFP, LDSA

Health characteristics:
Activity level, inhalation rate





ENVIRONMENTAL MONITORING

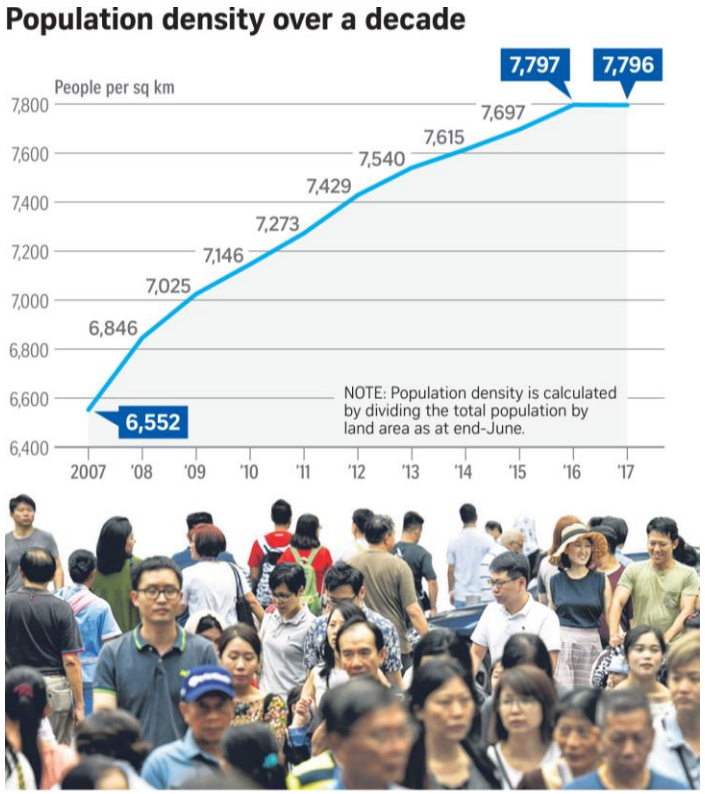
Researchers
Agencies

HEALTH MONITORING

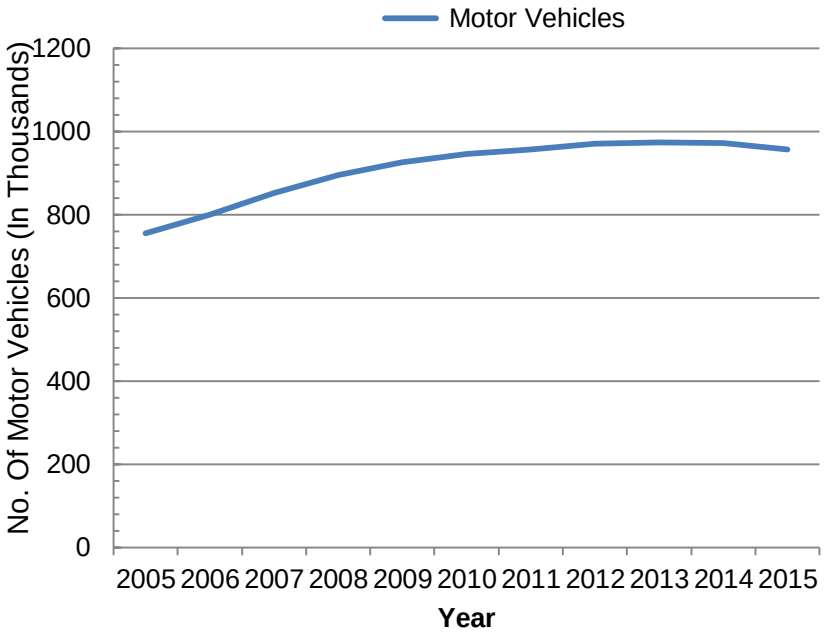
Population
Occupational hazards

THE STUDY AREA

Singapore



Source: Department of Statistics,2017



Source: LTA,2015

- Third most densely populated country
- Increased motor vehicle population
- Streets located in between buildings and next to walkways
- Poor dispersion & high human exposure

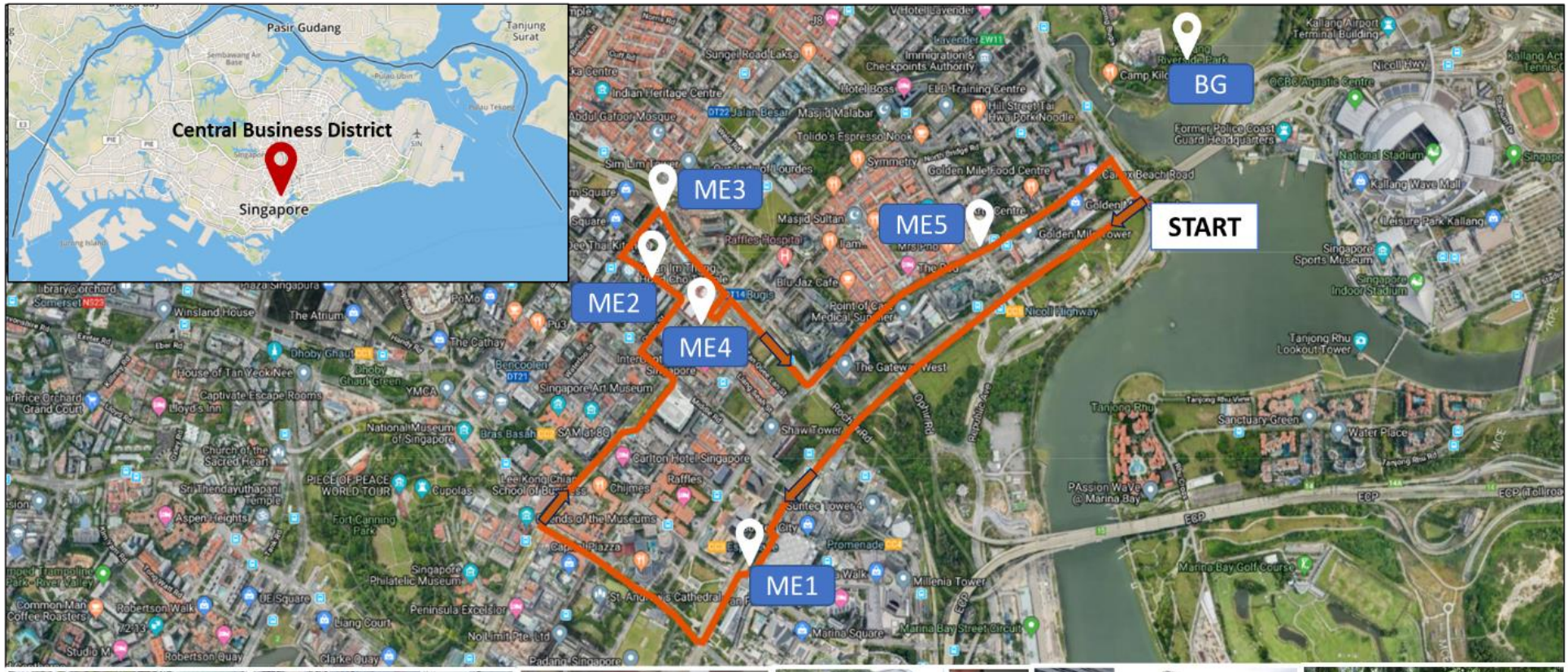
THE STUDY AREA

Singapore

Central Business District (CBD)

7-km route

MEs		Characteristics
ME1	Outdoor Smoking Area	Lesser smokers in the morning
ME2	Buddhist Temple	Prayer area with elevated incense smoke (close at night)
ME3	Hawker Centre	An open-air complex with selling a whole range of food.
ME4	Bus Stop	12 bus services, 7 lane road, with a bus lane.
ME5	Traffic Intersection	4-way intersection crossing over of Beach Road and Ophir Road
BG	Background site	Kallang Riverside park



DATA COLLECTION

- Typical weekdays and weekends
- Morning (7:30 to 10:00), afternoon (11:30-14:00) and evening (18:00 –20:30)
- From August 2017 to February 2018.
- Monitoring types:
  - ✓ 7-km: ~ 2.5 hour sampling duration for 1 round
  - ✓ Each selected MEs: 1-hour sampling duration
  - ✓ 24-hours personal exposure (4 days)

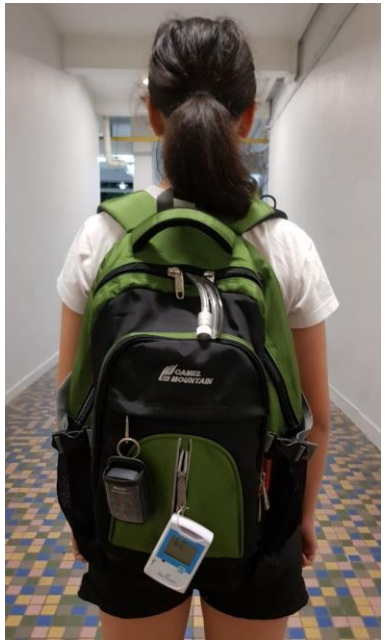


Illustration of field backpack with instrument

MEASURED PARAMETERS AND INSTRUMENT

SidePak
$PM_{2.5}$ (µg/m³)

DiSCmini
Np (#/cm³)
and LDSA (µm²/cm³)

MicroAeth AE51
BC (µg/m³)

Blue Gizmo
T (°C)
and RH (%)

GPS sensor

EXPOSURE ASSESSMENT

Integrated $PM_{2.5}$ exposure

$$Integrated\ PM_{2.5}\ inhaled\ dose(\ \mu g\ ) = \sum_{i=1}^{n}\left(Mass\ Concentration\ C_i\left(\frac{\mu g}{m^3}\right) * Inhalation\ Rate\ IR\left(\frac{m^3}{hour}\right) * Exposure\ Time\ t_i\ (hrs)\right)$$

IR= 1.3x10^{-2} m^3.min^{-1} = 0.78 m^3/hour = 18.72 m^3/day

(EPA's Exposure Factor Handbook -Table 6.17 for young adults aged 21-31 years with light activity level)

Toxicological risk of $PM_{2.5}$

Dose response Assessment → Exposure Assessment → Risk characterization

LADD (µg.kg^{-1}.day^{-1}): Lifetime Average Daily Dose

$$\text{LADD} = \frac{CA \times IR \times FR \times FA \times ED \times EF}{BW \times AT}$$

CA (µg m^{-3}): average integrated conc. of $PM_{2.5}$ obtained from 4-day measurements

$$\text{RfD} = \frac{RfC \times IR}{BW}$$

RQ: Risk Quotient

$$\text{RQ} = \frac{LADD}{RfD}$$

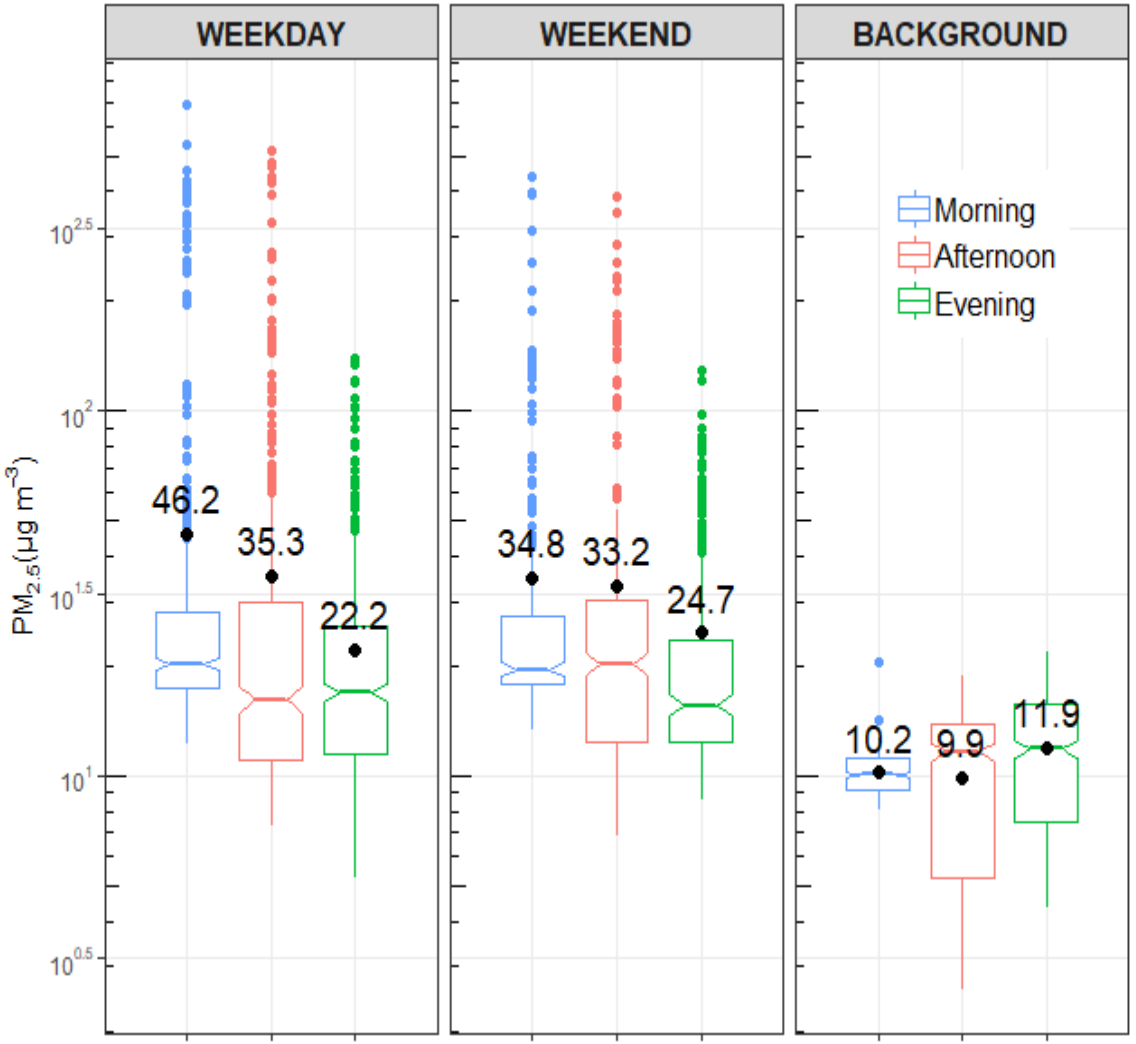
RfD (µg.kg^{-1}.day^{-1}) : Reference Dose

RfC: Reference concentration: 5 µg.m^{-3} of diesel PM

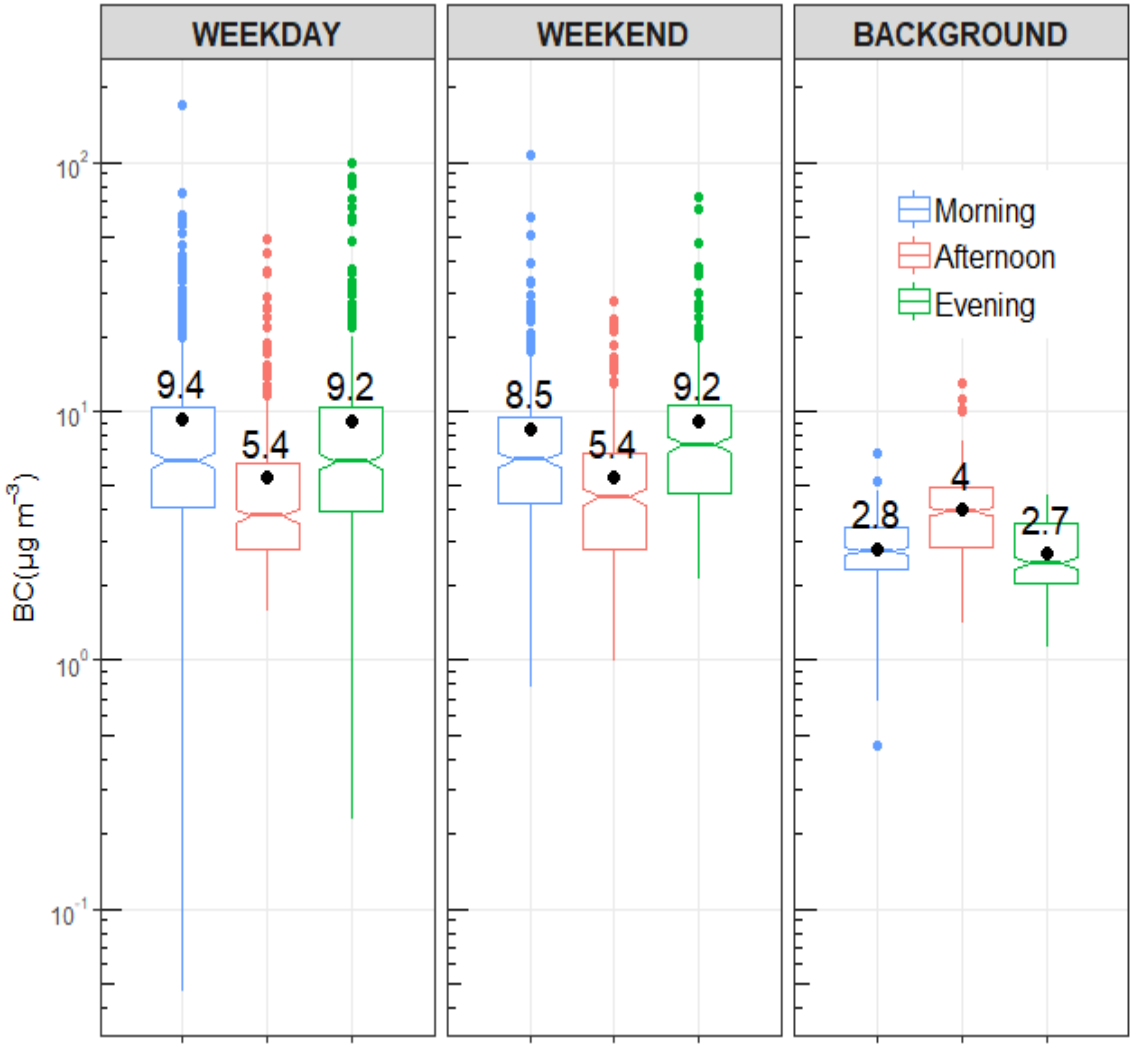
(IRIS, USEPA https://www.epa.gov/iris)

GENERAL CHARACTERISTICS OF PARTICLE EMISSIONS AT CBD

$PM_{2.5}$ (µg/m³)

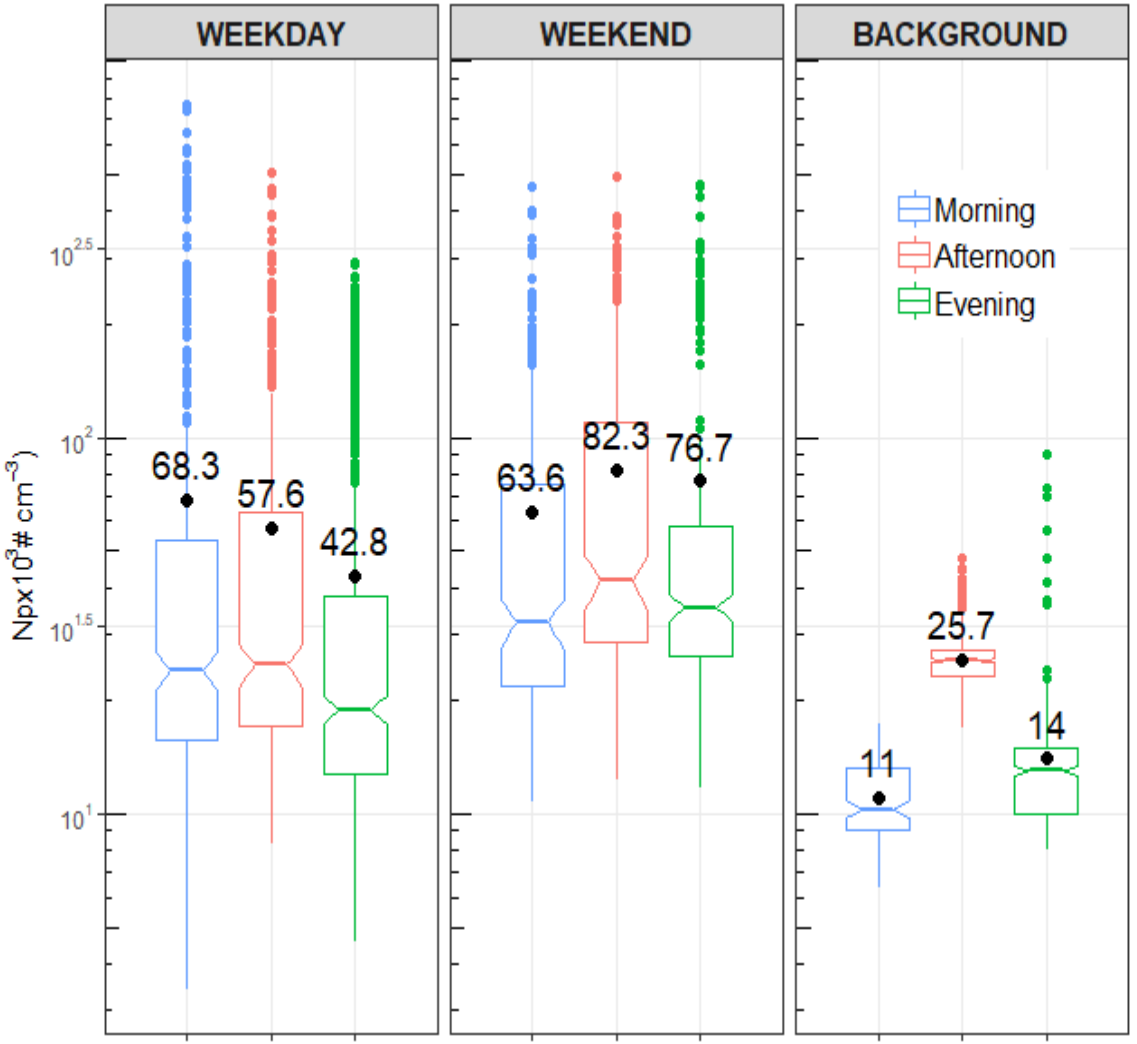


BC (µg/m³)

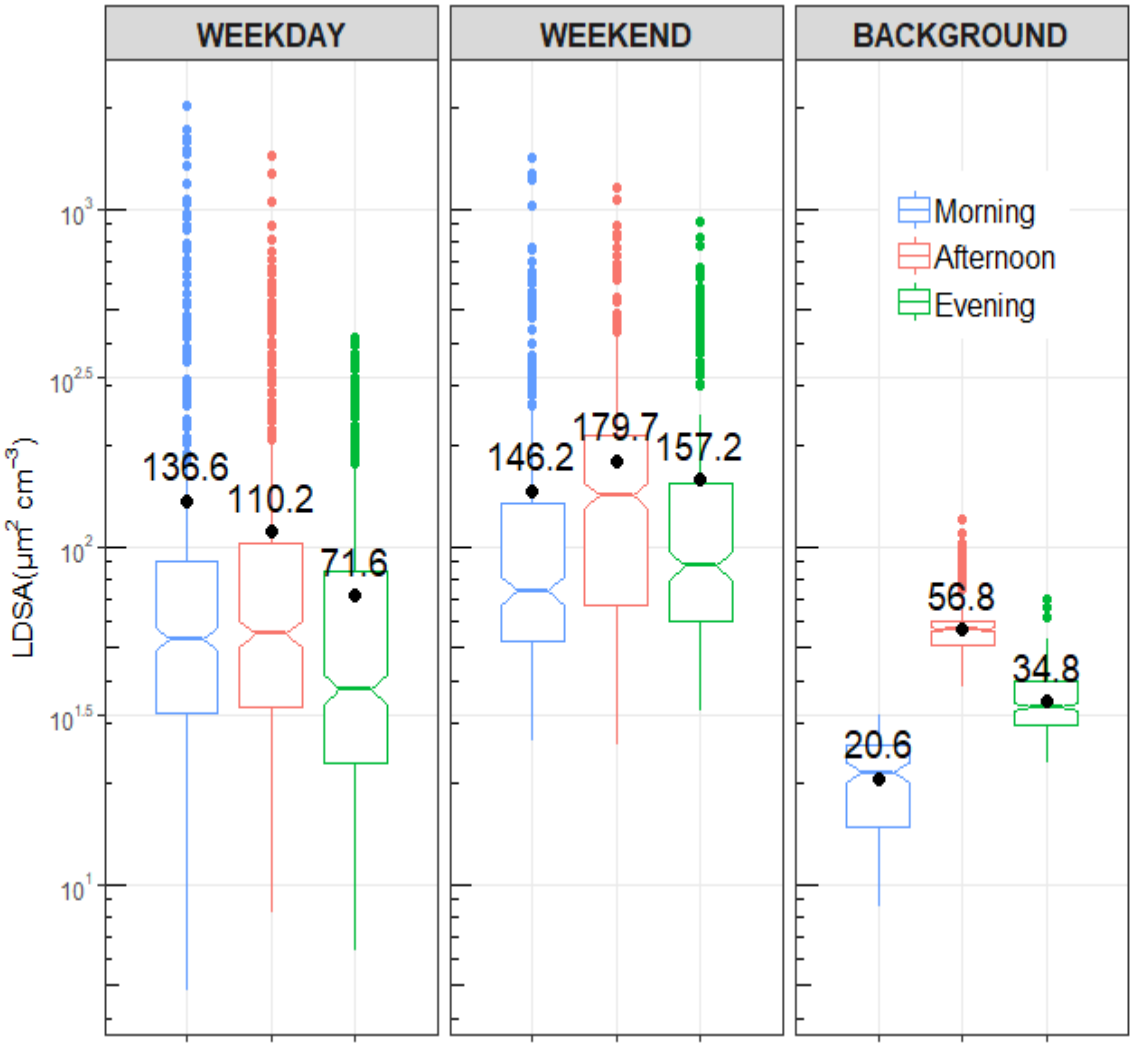


GENERAL CHARACTERISTICS OF PARTICLE EMISSIONS AT CBD

Np x 10^3 (#/cm^3)

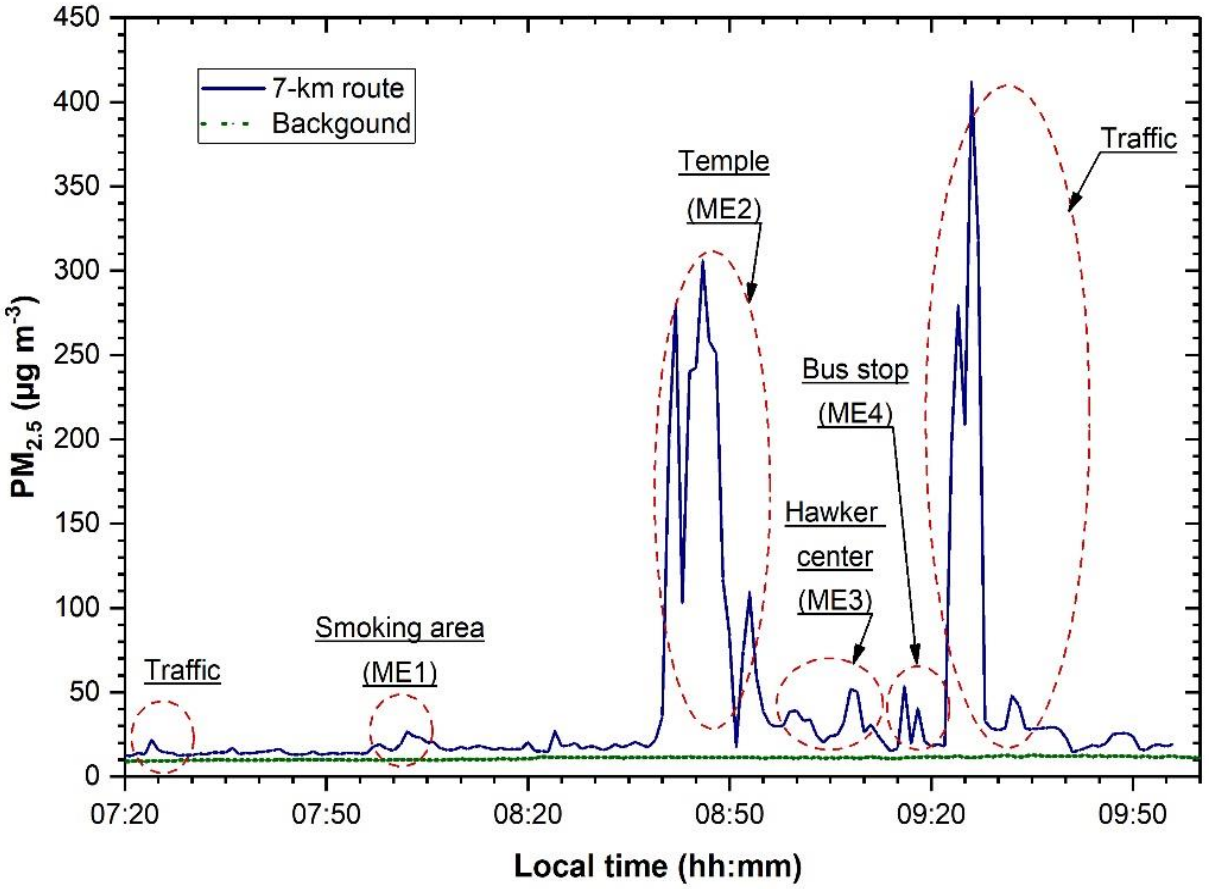


LDSA ($\mu m^2/cm^3$)

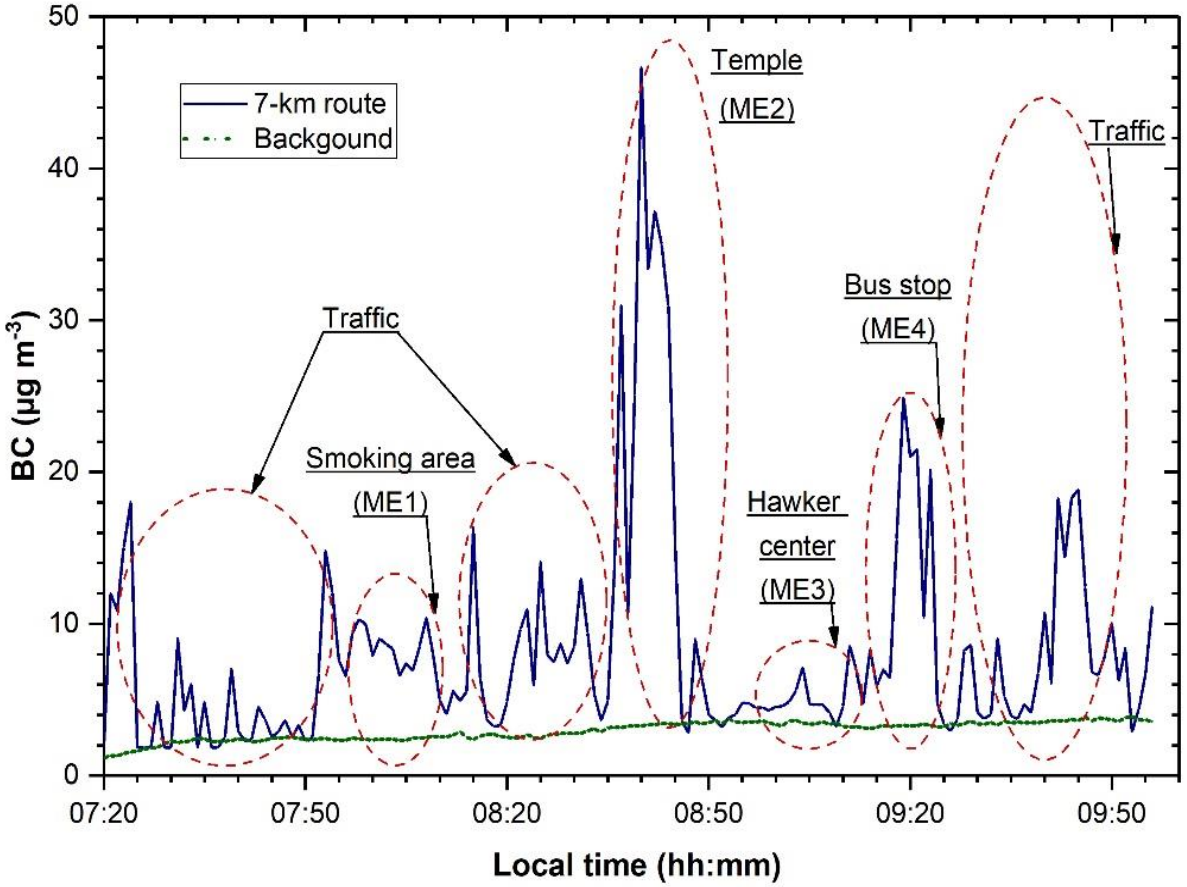


SPATIAL AND TEMPORAL VARIATION OF PM CONCENTRATIONS (TIME SERIES)

$PM_{2.5}$ (µg/m³)



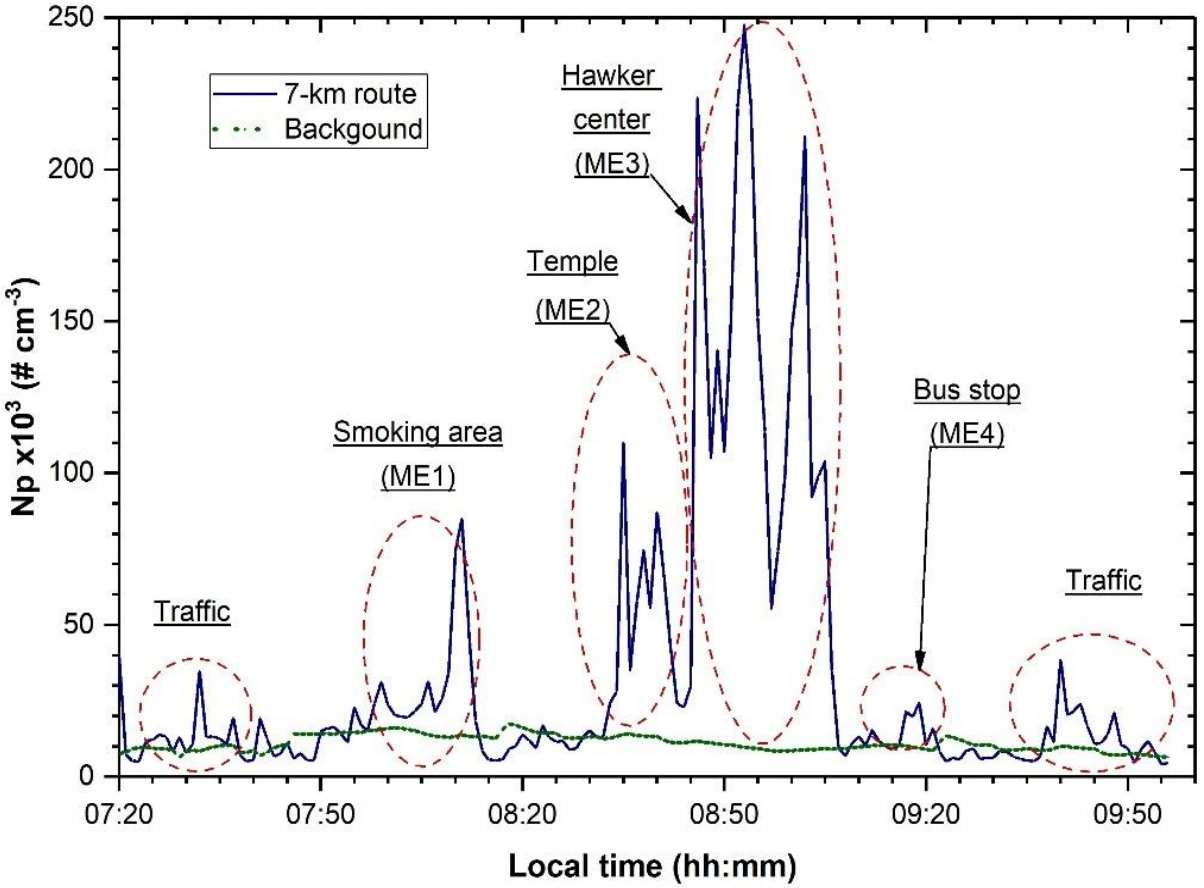
BC (µg/m³)



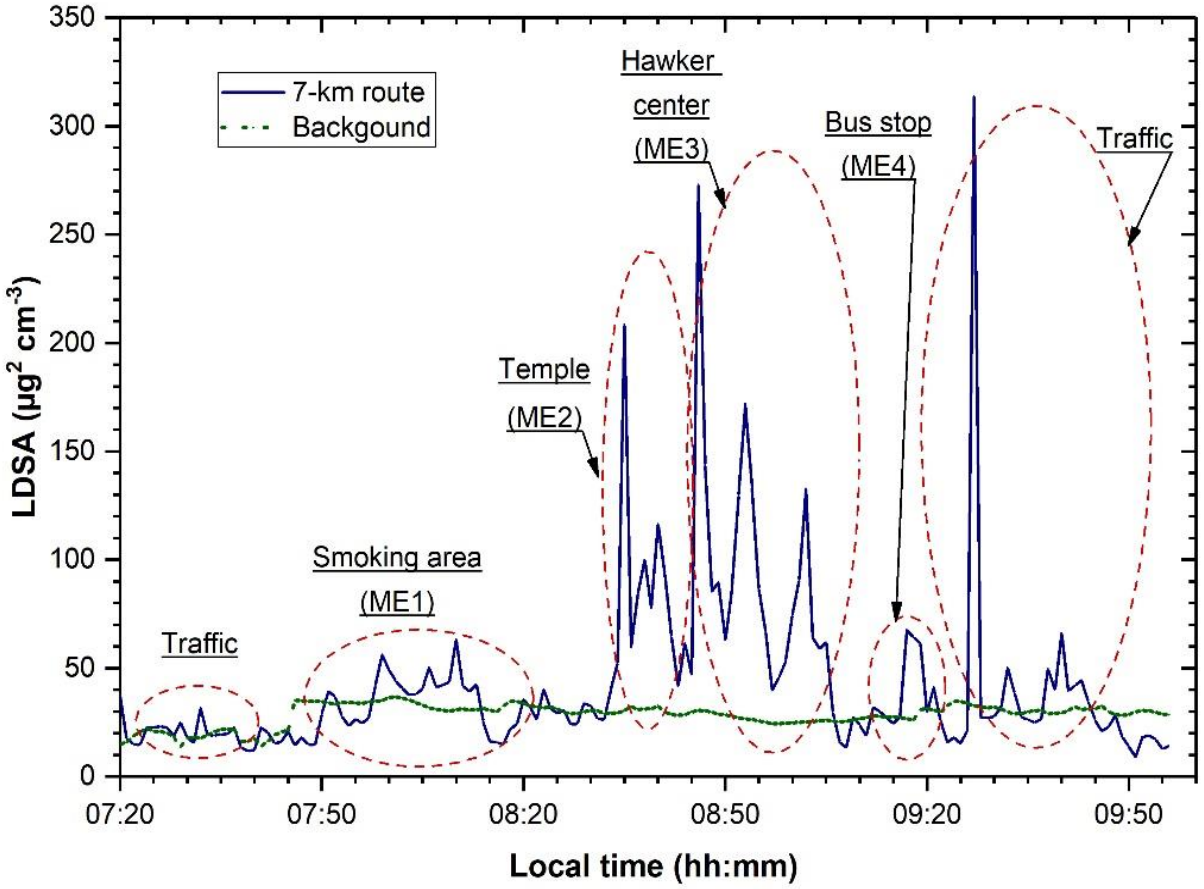
Measurements conducted on 2 Jan 2018 during morning hours

SPATIAL AND TEMPORAL VARIATION OF PM CONCENTRATIONS (TIME SERIES)

Np x 10^3 (#/cm^3)



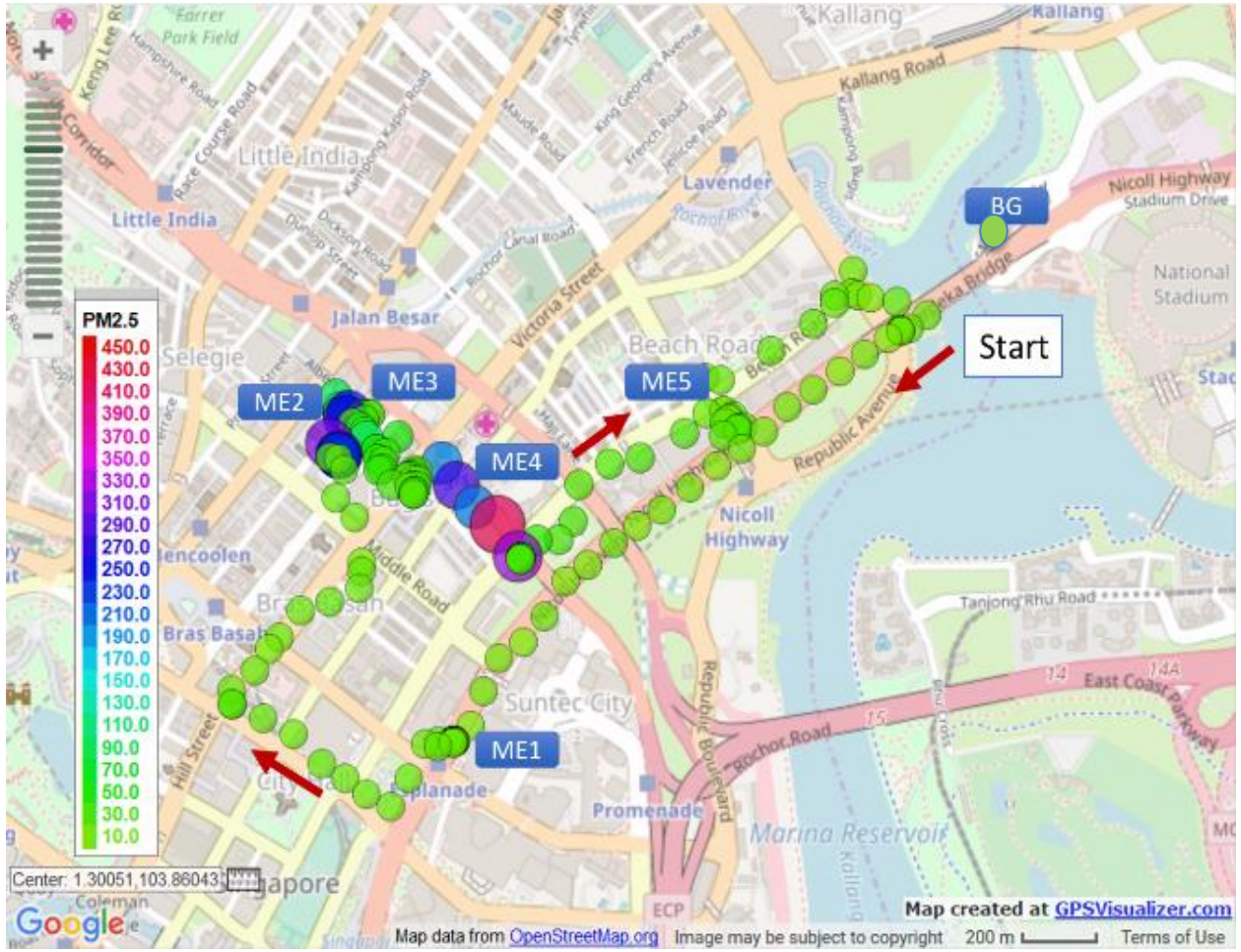
LDSA (µm^2/cm^3)



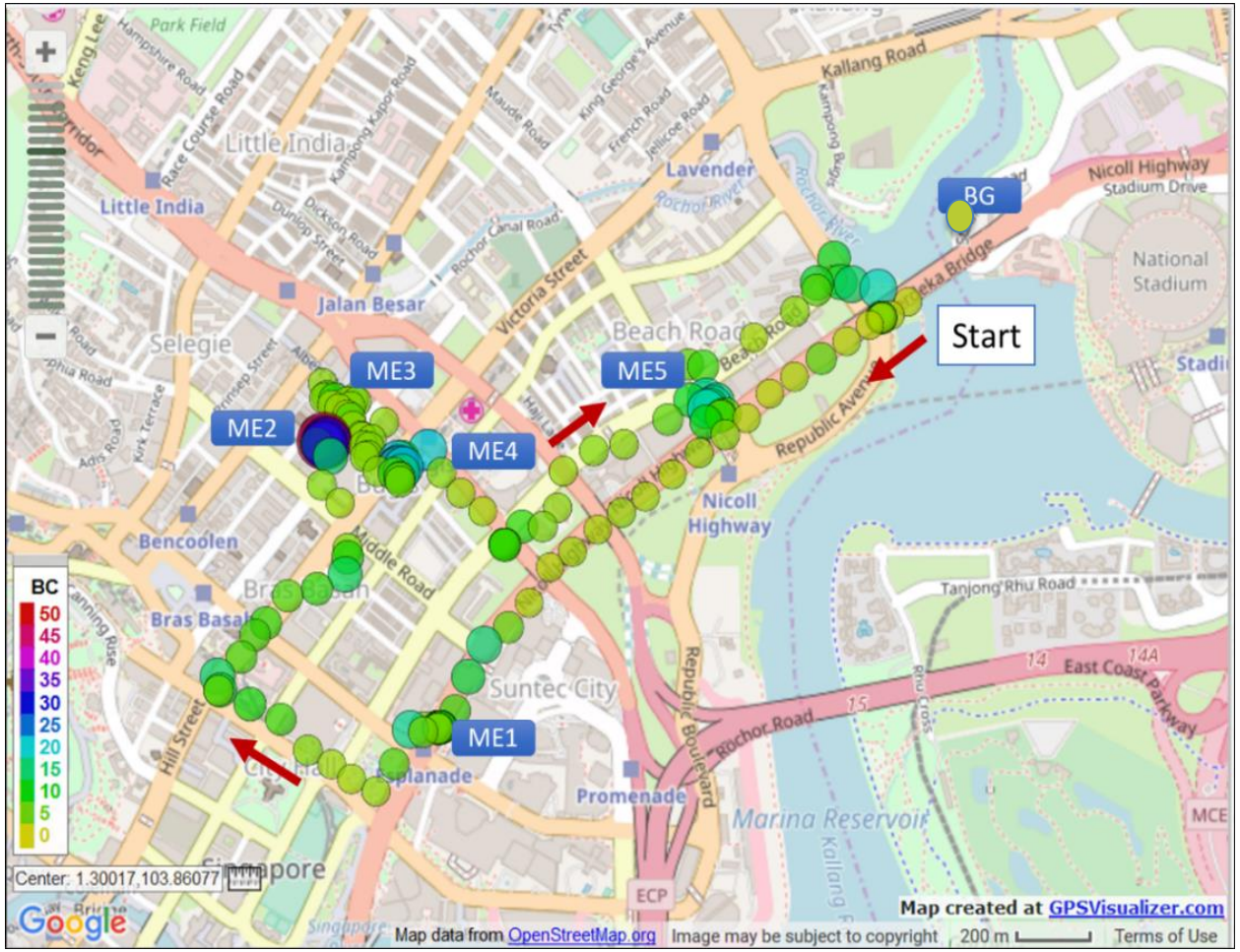
Measurements conducted on 2 Jan 2018 during morning hours

SPATIAL AND TEMPORAL VARIATION OF PM CONCENTRATIONS (SPATIAL MAPS)

$PM_{2.5}$ (µg/m³)



BC (µg/m³)

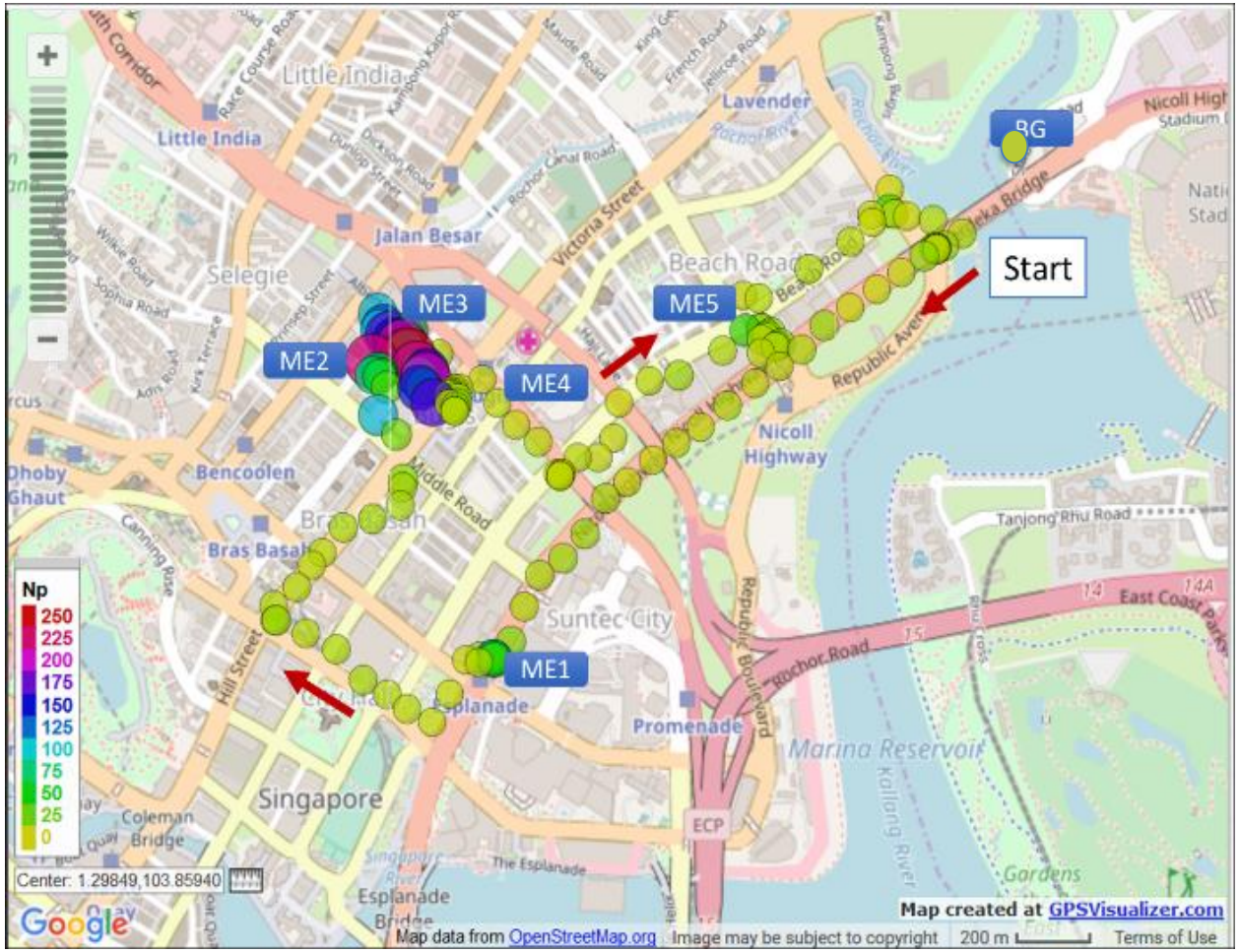


Measurements conducted on 2 Jan 2018 during morning hours

ME1	Outdoor Smoking Area	ME4	Bus Stop
ME2	Buddhist Temple	ME5	Traffic Intersection
ME3	Hawker Centre	BG	Background

SPATIAL AND TEMPORAL VARIATION OF PM CONCENTRATIONS (SPATIAL MAPS)

Np x 10^3 (#/cm^3)



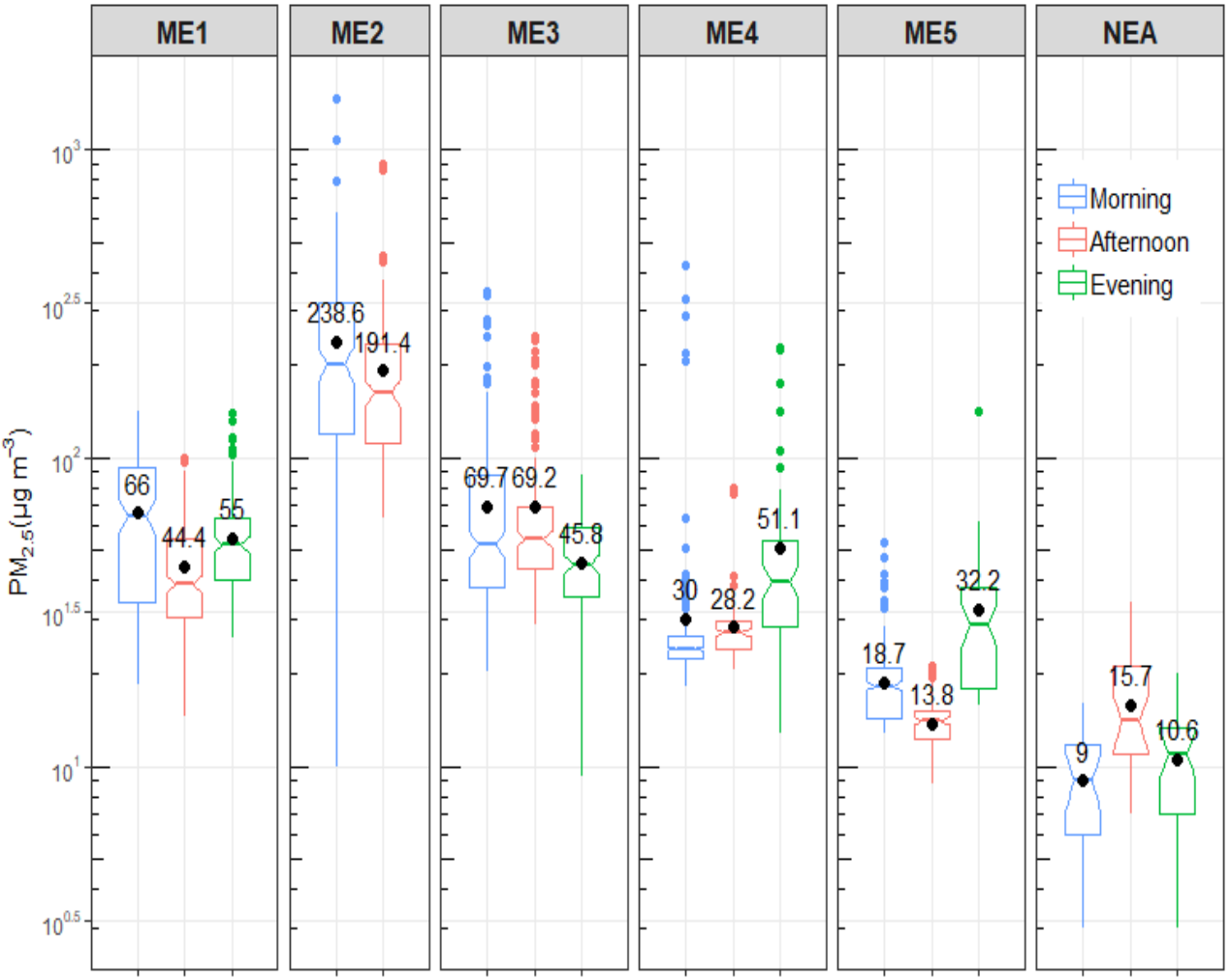
LDSA (µm^2/cm^3)

Measurements conducted on 2 Jan 2018 during morning hours

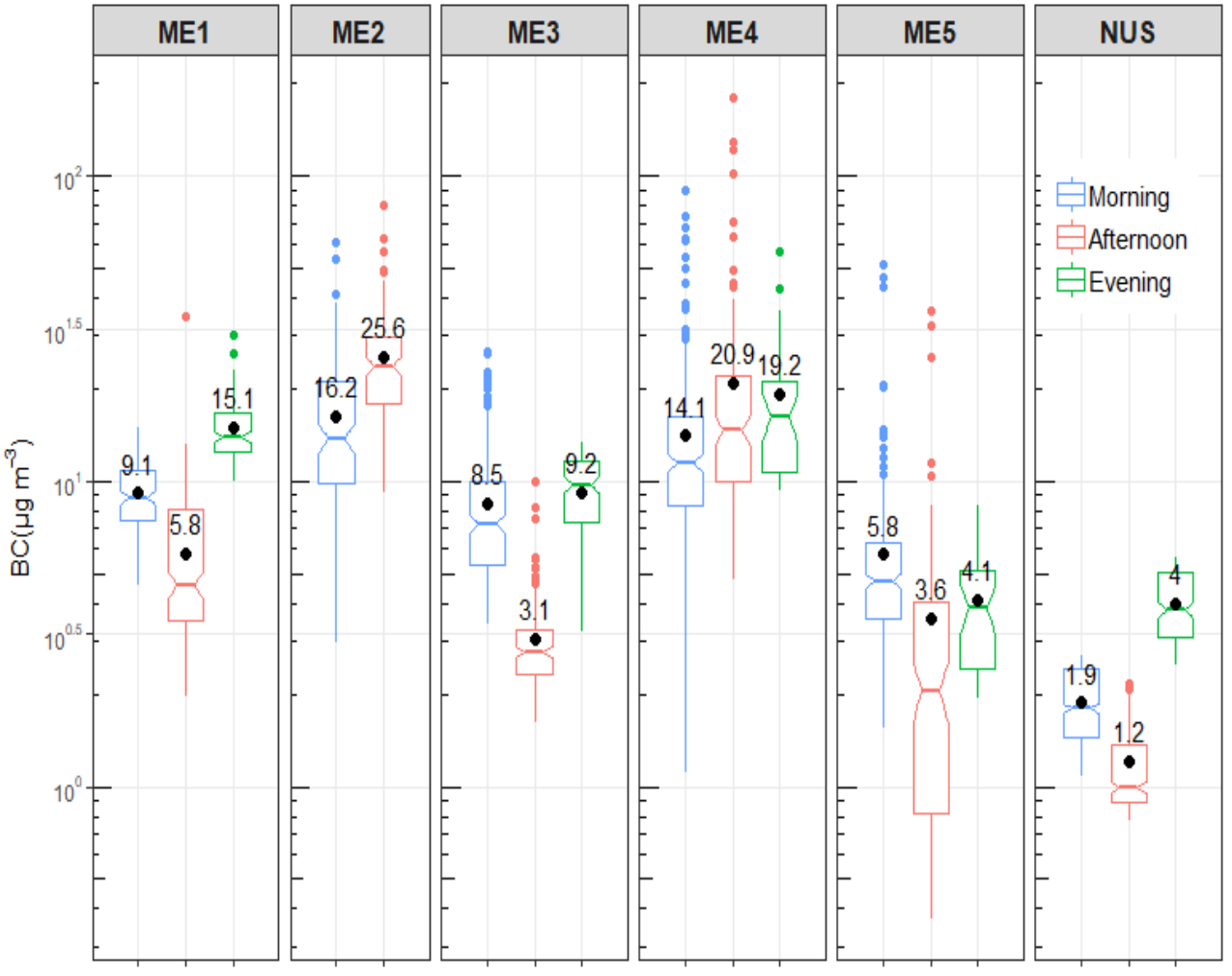
ME1	Outdoor Smoking Area	ME4	Bus Stop
ME2	Buddhist Temple	ME5	Traffic Intersection
ME3	Hawker Centre	BG	Background

1-HOUR EXPOSURE AT DIFFERENT SELECTED MES

$PM_{2.5}$ (µg/m³)



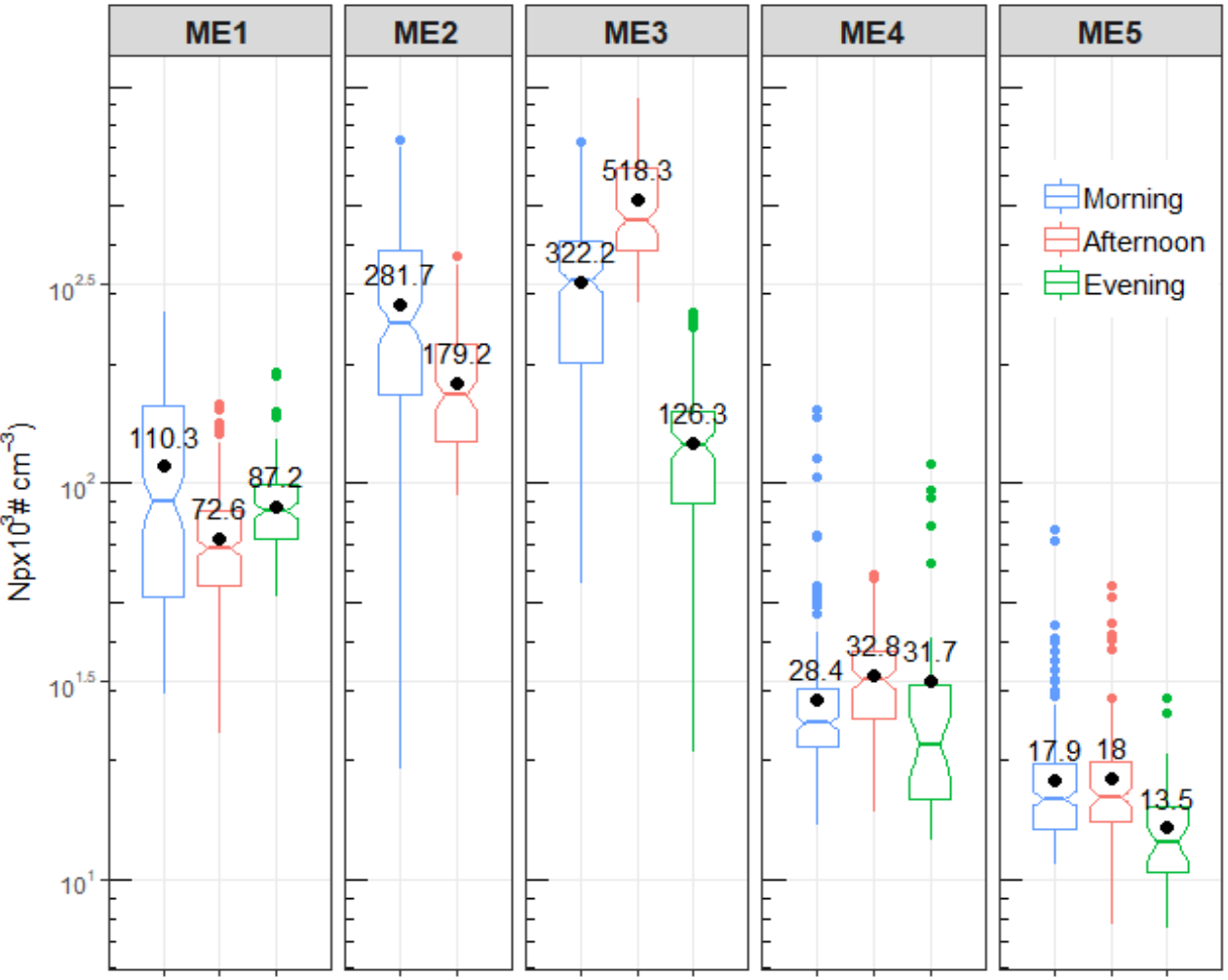
BC (µg/m³)



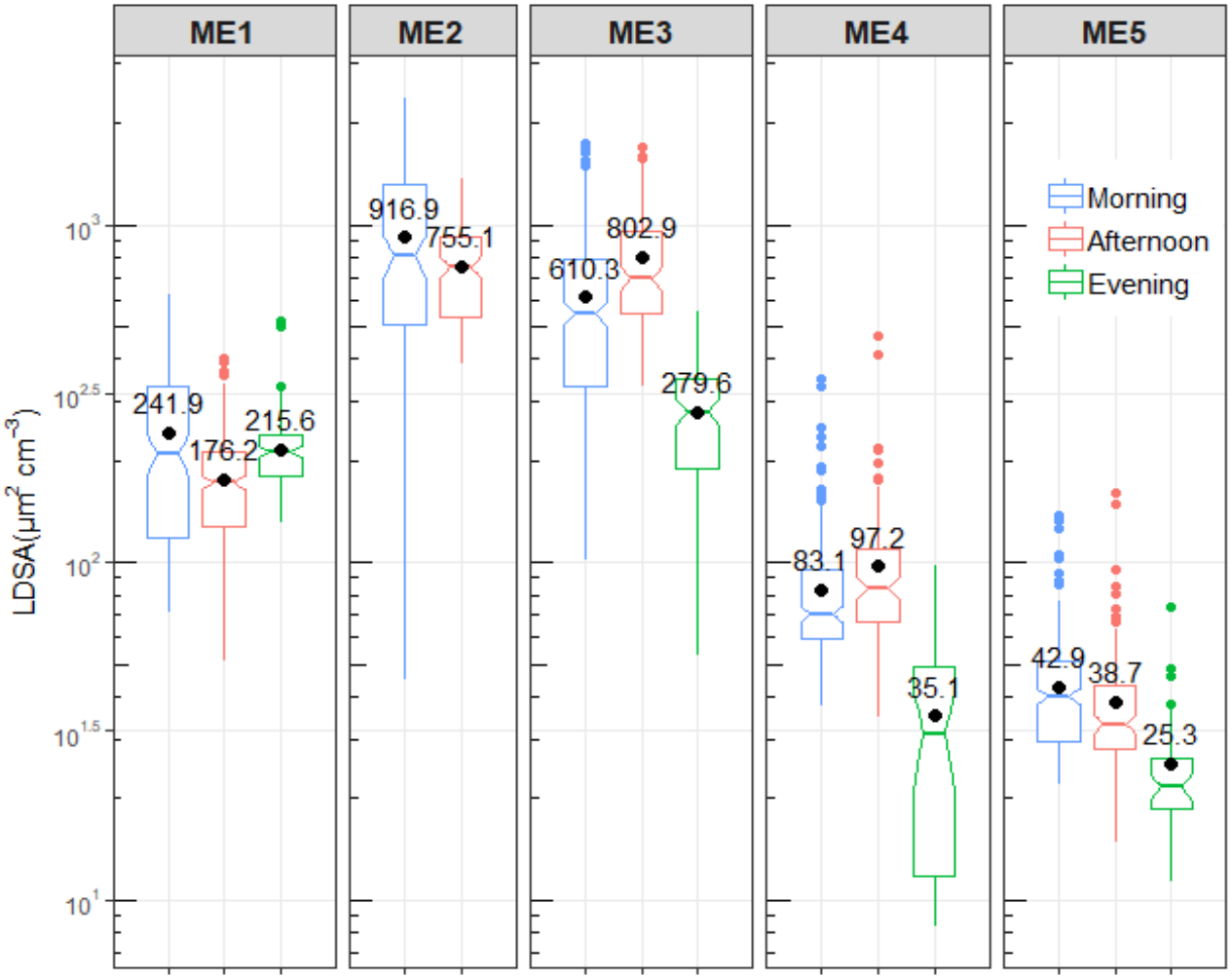
ME1	Outdoor Smoking Area	ME4	Bus Stop
ME2	Buddhist Temple	ME5	Traffic Intersection
ME3	Hawker Centre	NEA	NEA Monitoring station
NUS	NUS Laboratory		

1-HOUR EXPOSURE AT DIFFERENT SELECTED MES

Np x 10^3 (#/cm^3)

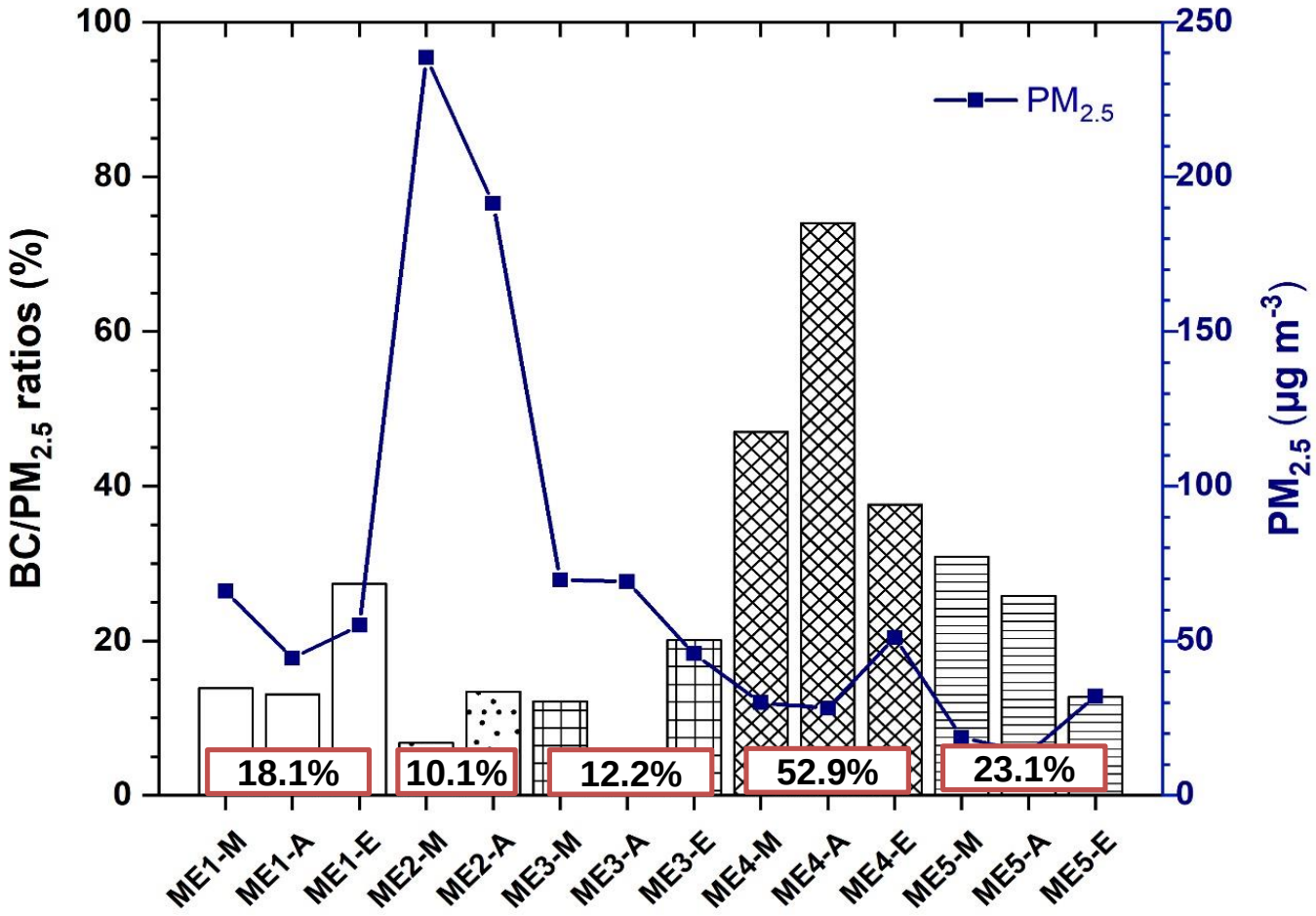


LDSA (µm^2/cm^3)



ME1	Outdoor Smoking Area	ME4	Bus Stop
ME2	Buddhist Temple	ME5	Traffic Intersection
ME3	Hawker Centre		

1-HOUR EXPOSURE AT DIFFERENT SELECTED MES



MEs	
ME1	Outdoor Smoking Area
ME2	Buddhist Temple
ME3	Hawker Centre
ME4	Bus Stop
ME5	Traffic Intersection

Ratios between mean BC and $PM_{2.5}$ concentrations (%) and mean $PM_{2.5}$ concentration (µg/m^3) at each MEs (M-Morning, A-Afternoon, E-Evening)

24 HOURS EXPOSURE ASSESSMENT

Integrated exposure to $PM_{2.5}$ based on personal exposure and ambient outdoor monitoring

Monitoring day	24-hour integrated inhaled dose of $PM_{2.5}$ (µg)		
	Personal Exposure $PM_{2.5}$ monitoring	Ambient outdoor $PM_{2.5}$ monitoring	Personal exposure / ambient outdoor ratios
Day 1	608.5	337.0	1.8
Day 2	725.3	468.0	1.5
Day 3	755.0	430.3	1.8
Day 4	586.2	280.8	2.1

Result of health risk assessment

Factors	Value	Unit
Average Integrated Concentration of $PM_{2.5,}$ CA	35.7	µg m^{-3}
Lifetime Average Daily Dose, LADD	4.4	µg kg^{-1} day^{-1}
Reference Dose, RfD	1.3	µg kg^{-1} day^{-1}
Risk Quotient, RQ	3.3	-

CONCLUSION

- The exposure concentration of **$PM_{2.5}$, BC, Np and LDSA** was measured in the CBD of Singapore using real time mobile sensors paired with a GPS receiver.
- 7-km walking route: Mean $PM_{2.5}$ conc. of 32.7 µg m^{-3}. BC accounted for 24.5% of the mass con. of $PM_{2.5}$. The measured mean values of Np and LDSA were 65.2 x 10^3 # $cm^{-3,}$ and 133.6 μg^2 cm^{-3}.
- 1 hour measurement: Extremely high conc. of **$PM_{2.5}$** and **BC**: observed at the **temple** and **bus stop**. **Hawker centre:** a polluted hotspot of **UFP** based on the number concentration of UFPs and LDSA.
- 24-hours integrated personal exposure studies: a **high possibility** of experiencing **negative health effects** due to the continued exposure to $PM_{2.5}$ in densely populated cities.
- People were actually exposed to **very different PM concentrations** in their day-to-day urban environments than those suggested by the most common nearest monitoring station.
- Emphasize the **need** of **conducting integrated personal exposure assessment** over 24 hours across urban microenvironments together with the recording of **individual time-activity patterns**.
- This study was mainly conducted in order to **propose a methodology** for assessing integrated personal exposure to PM across diverse outdoor and indoor MEs and **not to quantitatively** conclude its levels at the experimental sites investigated in the study.

Further work with participation of a large number of volunteers across a wide network of MEs would be required to provide more realistic exposure information on the city scale.

THANK YOU!

Feel free to ask any questions

QUALITY ASSURANCE / QUALITY CONTROL

$PM_{2.5}$ Calibration Sidepak: Collocated measurements of ambient air over a period of 5 days

Triplicate weighing of filter paper

Microbalance (Sartorius AG, Germany)

MiniVol (Airmetrics, USA)

Sidepak AM520 (TSI, USA)

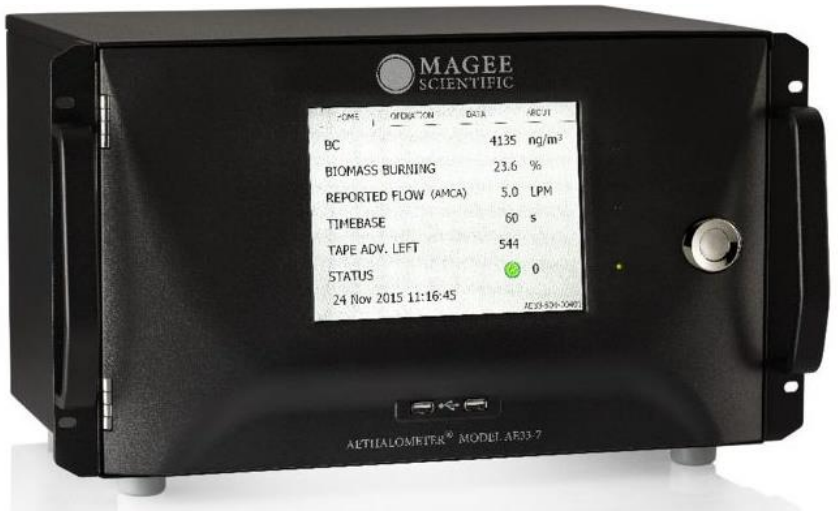
QUALITY ASSURANCE / QUALITY CONTROL

BC

- Negative or unchanging values: the Optimized Noise reduction Averaging algorithm tool (Hagler *et al.*, 2011) with delta attenuation thresholds of 0.01-0.05
- Filter loading effects: the empirical relationship of Kirchstetter and Novakov (2007) based on the optical attenuation attenuation (ATN) provided by the instrument.
- Collocated measurement of ambient air over a period of 24 hours with Aethalometer AE33

Portable Dryer

MicroAeth (AethLabs, USA)



Aethalometer AE33 (Magee Scientific, USA)

QUALITY ASSURANCE / QUALITY CONTROL

- Flow calibration
- Clock synchronized
- Zero calibration with HEPA filtered air
- Log data for about 5-10 minutes before the actual sampling
- Measurements were conducted only during non-raining days to protect the operational integrity of sensors and to avoid the potential effects on the PM concentrations, caused by high relative humidity

$$LADD = \frac{CA \times IR \times FR \times FA \times ED \times EF}{BW \times AT}$$

Where:

- ✓ LADD (μg.kg^{-1}.day^{-1}) is Lifetime Average Daily Dose.
- ✓ CA (μg.m^{-3}) is the average integrated concentration of $PM_{2.5}$ obtained from 4-day measurements.
- ✓ IR (m^3/day) is Inhalation Rate (18.72m^3.day^{-1} for young adults aged 21-31 years with light activity level).
- ✓ FR is Factor of Retention which was assumed as 1 for the worst-case scenario and potential impact on people's health.
- ✓ FA is Factor of Absorption which was assumed as 1 representing the worst-case scenario and potential impact on people's health.
- ✓ ED (year) is Exposure Duration (70 years: *Cal/EPA, 2003; Los Angeles International Airport 2014; Cal/EPA, 2015*). It should be noted that the estimated potential carcinogenic health risk would be lower if the ED for adults is to be taken as 30 years at the MEIR (maximally exposed individual resident).
- ✓ EF (days/year) is Exposure Frequency (365 days/year).
- ✓ BW (kg) is Body Weight (70kg for adults)
- ✓ AT (days) is Average life Time (70 (years. life^{-1}) x 365 (days. year^{-1}) = 25550 days)

$$RQ = \frac{LADD}{RfD}$$

Where:

- ✓ RQ is Risk Quotient. RQ estimated was appointed as RQ <1 – Hazards that not considered a threat to public health; and RQ > 1 – Hazards that cause the adverse health effects and are a detriment to public health.
- ✓ RfD (μg.kg^{-1}.day^{-1}) is Reference Dose.

$$RfD = \frac{RfC \times IR}{BW}$$

RfC (μg.m^{-3}) is the Reference Concentration.

- RfC =5 μg.m^{-3} of diesel particulate matter

24 HOURS EXPOSURE ASSESSMENT