Supplementary Material (SM)

Assessment of the Integrated Personal Exposure to Particulate Emissions in Urban Micro-environments: A Pilot Study

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Included in this supplement is additional information on the following topics:

1. Instrument characteristics.

Table S1. Instrument characteristics

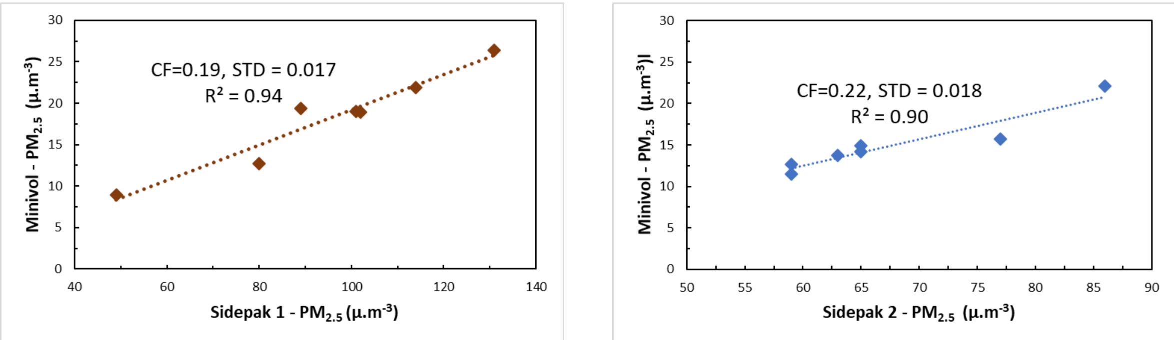
Parameters	Instrument	Accuracy	Logging interval	Model	Manufacturer
$PM_{2.5}$ (µg m^{-3})	Sidepak	±0.001 mg m^{-3}	1s	AM520	TSI
Np (# cm^{-3}) LDSA (µg^2 cm^{-3})	Discmini	±30 % typical for size and number ±5E^2 ccm^{-1} absolute in number	1 s	Discmini	Testo
BC (µg m^{-3})	MicroAeth	±0.1 µg BC m^{-3}	10s	AE51	Aethlabs
RH (%) T (°C)	Blue Gizmo Temperature and Humidity Datalogger	±3% ±0.5°C	30s	BG-Log-TempRH	Acez
GPS	Qstarz BT-Q1000 Bluetooth GPS Travel Recorder XT	<3m	1 min	BT-Q1000	Qstarz

2. The Sidepak calibration

The Sidepak measurements were calibrated to the average aerosol concentration from a gravimetric sampler (MiniVol, Airmetrics, USA) following the recommended calibration procedure by the manufacturer (TSI, 2016). The MiniVol sampler draws ambient air continuously for 24 h through a 47-mm QMA quartz fiber filter at a pre-calibrated flow rate of 5 l/min via a $PM_{2.5}$ inlet. Before and after sampling, filters were kept in a dry box at a constant temperature and humidity for at least 24 hours before weighing with a microbalance (Sartorius AG, Goettingen, Germany). Calibration factors were calculated as follows:

$$CF = \frac{24 - h\ gravimetric\ concentration}{24 - h\ average\ Sidepak\ concentration}$$

The 24-h gravimetric concentrations and 24-h average Sidepak concentrations were highly correlated (R^2=0.94 and R^2= 0.90) and the mean calibration factors were 0.19 (standard deviation (STD) of 0.017); and 0.22 (STD of 0.018) for Sidepak 1 and Sidepak 2, respectively.



(a) (b)

Fig. S1. Calibration data of Sidepak 1 (a) and Sidepak 2 (b) versus the Minivol measurements. The dot lines show the linear regression fit to the data.

The similar method was used for the laser photometer calibration in many previous studies (e.g. Zhu *et al.*, 2007; Kurmi *et al.*, 2008; Jiang *et al.*, 2011; Dacunto *et al.*, 2013). Our CF estimates of 0.19 and 0.22 are roughly of the same magnitude as obtained in the aforementioned studies (CF = 0.23 - 0.7). It should be noted that the magnitude of CFs depends on the physical, chemical and optical characteristics of aerosol particles (such as the size, chemical composition, density, and refractive index) which differ substantially from day to day and across sampling site locations.

3. The microAeth AE51 versus the Aethalometer AE33 measurements

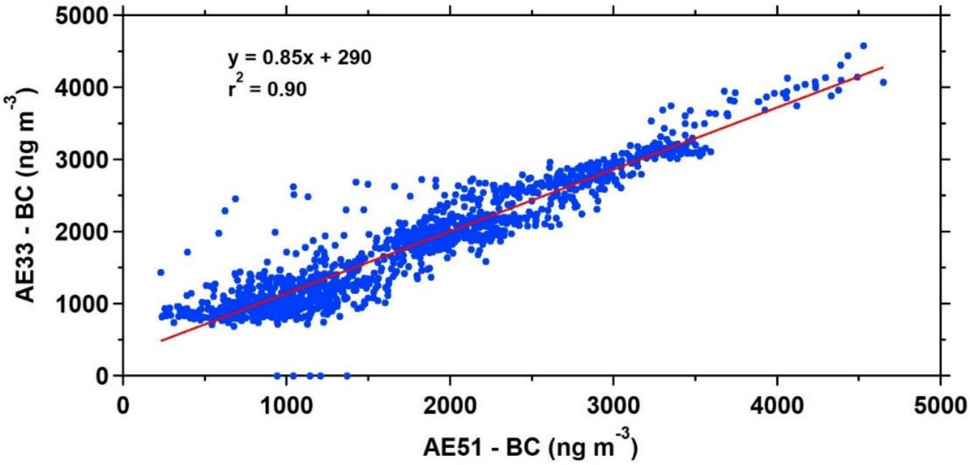


Fig. S2. Inter-comparison of the microAeth AE51 versus the Aethalometer AE33 measurements. The red line shows the linear regression fit to the data.

4. Human health risk assessment

a. Lifetime average daily dose

$$\text{LADD} = \frac{CA \times IR \times FR \times FA \times ED \times EF}{BW \times AT} \quad \text{(S1)}$$

Where:

LADD (μg kg^{-1} day^{-1}) is the 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^{-1}) is the Inhalation Rate (18.72m^3 day^{-1} for young adults aged 21-31 years with light activity level).

FR is the factor of retention which was assumed as 1 for the worst-case scenario and potential impact on people's health.

FA is the deposition fraction which was assumed as 0.46 for fine particles in the human respiratory system (Behera *et al.*, 2015).

ED (year) is the exposure duration, which was assumed as 70 years (Cal/EPA, 2003; Los Angeles International Airport 2014; Cal/EPA, 2015). It should be noted that the estimated potential non-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 the exposure frequency (365 days/year).

BW (kg) is the body weight (70kg for adults)

AT (days) is the average life time (70 (years $life^{-1}$) x 365 (days $year^{-1}$) = 25550 days)

b. Toxicological risk

$$\text{RQ} = \frac{LADD}{RfD} \quad \text{(S2)}$$

Where:

RQ is the non-carcinogenic risk quotient. If the estimated RQ is <1, health risk posed by hazards is not a threat to public health; and If RQ > 1, the hazards that cause adverse health effects are detrimental to public health.

RfD ($\mu g\ kg^{-1}\ day^{-1}$) is the reference dose.

$$RfD = \frac{RfC \times IR}{BW} \qquad \text{(S3)}$$

Where:

RfC ($\mu g\ m^{-3}$) is the reference concentration.

With a lack of information regarding the reference concentration (RfC) of $PM_{2.5}$, we used the 5 $\mu g\ m^{-3}$ of diesel particulate matter (DPM) obtained from the Integrated Risk Information System (US-EPA) to calculate the reference dose to $PM_{2.5}$. The DPM is a component of ambient particulate matter, and its reference dose has been established in the literature (US-EPA, 2003; de Oliveira *et al.*, 2012). We understand that there is some debate as to whether the PM emitted from diverse micro-environments is more or less toxic than that of diesel. We are guided by the outcome of several studies which revealed similar health effects such as exacerbated asthma and respiratory ailments after the high-level intake of both diesel and ambient $PM_{2.5}$ (White *et al.*, 2005; Ostro *et al.*, 2008; Patel *et al.*, 2010).

5. Statistical summary of the weekday and weekend $PM_{2.5}$, BC, Np and LDSA measured at CBD and background location

Table S2. Statistical summary of the weekday and weekend $PM_{2.5}$, BC, Np and LDSA measured at CBD and background locations

Monitoring parameters				Statistical parameters						
				Mean	95th percentile	Median	Min	Max	SD	ANOVA significance p-value
	CBD			32.5	2.1	18.7	5.3	693.4	54.4	<0.0001
		WD		33.5	3.0	18.4	5.3	693.4	60.5	<0.0001
			M-WD	46.2	248.3	20.2	12.3	693.4	84.9	<0.0001
			A-WD	35.3	120.0	16.2	7.3	514.8	64.3	
			E-WD	22.2	56.0	17.1	5.3	138.6	17.9	
		WK		31.0	2.7	19.1	6.8	436.0	42.6	
$PM_{2.5}$ ($\mu g\ m^{-3}$)			M-WK	34.8	122.7	19.5	13.4	436.0	24.7	0.0069
			A-WK	33.2	139.8	20.2	6.8	385.0	47.6	
			E-WK	24.7	70.7	15.6	8.6	129.4	21.0	
	BG			10.7	0.2	10.4	2.6	21.7	4.2	
			M-BG	10.2	12.0	10.1	8.1	20.4	1.3	<0.0001
			A-BG	9.9	16.0	11.6	2.6	18.7	4.6	
			E-BG	11.9	20.6	11.8	4.4	21.7	5.1	
	CBD			7.7	0.4	5.5	0.0	171.0	8.9	<0.0001
		WD		7.8	0.5	5.2	0.0	171.0	9.8	<0.0001
			M-WD	9.4	27.4	6.3	0.1	171.0	12.0	<0.0001
			A-WD	5.4	25.1	3.8	1.6	49.5	5.0	
			E-WD	9.2	24.8	6.3	0.2	99.3	11.3	
		WK		7.6	0.5	5.8	0.8	106.6	7.3	
BC ($\mu g\ m^{-3}$)			M-WK	8.5	11.7	6.4	0.8	106.6	9.2	<0.0001
			A-WK	5.4	20.7	4.5	1.0	27.6	3.7	
			E-WK	9.2	20.7	7.3	2.1	72.6	7.8	
	BG			3.2	0.1	2.9	0.5	13.0	1.3	
			M-BG	2.8	4.2	2.7	0.5	6.7	0.9	<0.0001
			A-BG	4.0	6.2	3.9	1.4	13.0	1.5	
			E-BG	2.7	4.1	2.4	1.1	4.6	0.9	
	CBD			62.4	3.3	28.6	3.4	770.0	84.8	<0.0001
		WD		55.0	4.2	22.4	3.4	770.0	83.9	<0.0001
			M-WD	68.3	328.2	24.0	3.4	770.0	113.9	<0.0001
			A-WD	57.6	228.9	24.9	8.3	505.0	76.5	
			E-WD	42.8	183.2	18.9	4.6	292.4	56.2	
		WK		74.5	5.4	37.3	10.7	494.7	85.0	0.0180
Np x 10^3 (# cm^{-3})			M-WK	63.6	208.0	32.2	10.7	462.1	76.7	
			A-WK	82.3	261.8	41.5	12.3	494.7	85.7	
			E-WK	76.7	289.4	35.4	11.7	470.6	93.3	
	BG			18.7	0.5	17.0	6.3	90.0	8.5	
			M-BG	11.0	15.4	10.3	6.3	17.4	2.6	<0.0001
			A-BG	18.3	32.6	23.9	0.0	47.7	12.3	
			E-BG	14.0	17.9	13.4	7.9	89.6	7.3	
	CBD			125.5	7.2	63.5	4.9	2027.3	183.1	<0.0001
		WD		103.1	9.3	48.8	4.9	2027.3	185.0	<0.0001
			M-WD	136.6	689.4	53.4	4.9	2027.3	275.0	<0.0001
			A-WD	110.2	472.3	55.1	8.2	1439.7	164.3	
			E-WD	71.6	272.6	37.8	6.3	414.1	80.8	
		WK		161.7	11.1	96.3	25.9	1408.1	174.0	
LDSA ($\mu g^2\ cm^{-3}$)			M-WK	146.2	581.4	74.0	26.4	1408.1	157.2	0.0447
			A-WK	179.7	491.7	141.7	25.9	1148.4	165.0	
			E-WK	157.2	498.2	87.6	32.3	916.1	162.0	
	BG			42.2	1.0	41.5	8.6	119.7	16.1	
			M-BG	20.6	29.9	21.4	8.6	31.9	6.5	<0.0001
			A-BG	56.8	70.4	56.7	38.4	119.7	9.5	
			E-BG	34.8	47.0	33.5	22.9	69.5	7.3	

Monitoring parameters		Statistical parameters						
		Mean	95th percentile	Median	Min	Max	SD	ANOVA significance p-value
RH (%)	M	74.5	85.4	75.1	57.4	86.7	6.9	<0.0001
	A	64.7	82.7	61.1	48.8	84.9	9.2	
	E	66.7	81.5	64.2	49.6	83.8	7.7	
T (^oC)	M	29.0	31.9	28.9	25.9	33.4	1.6	<0.0001
	A	31.3	34.1	32.3	25.6	35.3	2.6	
	E	29.7	32.6	29.9	26.2	33.1	1.7	

(CBD- Central Business District area, M-morning, A-afternoon, E-evening, WD-weekdays, WK-weekends, BG-background, SD -Standard Deviation).

6. Review of PM exposure studies

Table S3. PM exposure studies conducted with different transport modes in urban environments

Reference	Location	Transport modes	Metrics	Average pollutant concentration	Instruments	Monitoring time	Route length
Bekö *et al.* (2015)	Copenhagen, Denmark	Combined	Np	11.1-22.7 x 10^3 # cm^{-3}	NanoTracer PNT 1000 (Philips Aerasense)	48 hours	--
Borgini *et al.* (2015)	Milan, Italy	Combined	$PM_{2.5}$	35.1-71.3 μg m^{-3}	Sidepak (TSI, AM510)	21 hours	--
Chan *et al.* (2002)	Hong Kong, China	Bus, Tram, Taxi Light rail transit, Mass transit Railway, Railway ferry	PM_{10} $PM_{2.5}$	50 - 175 μg m^{-3} $PM_{2.5}$/PM_{10}: 63% - 78%	Dustrak (TSI 8520)	18 – 50 mins Morning and afternoon rush hours	--
Fan *et al.* (2018)	Hong Kong, China	Combined	$PM_{2.5}$	28.1±23.3 μg m^{-3}	Impactor and pump (SKC, PA)	24 hours	--
Good *et al.* (2016)	Fort Collins, US	Driving Cycling	BC CO Np $PM_{2.5}$	BC, $PM_{2.5}$, PNC were higher when cycling then driving, but CO was lower when driving	AE51 (Aethlabs) Langan (T15n) Discmini (Master Aerosol AG) PEM (SKC) and PDR 1200 (Thermo Fisher Scientific)	Weekdays Morning and evening	Within 0.48km for cycling
Hatzopoulou *et al.* (2013)	Montreal, Canada	Cycling	$PM_{2.5}$ BC Np CO	2.8-38.2 μg m^{-3} 196-4612 ng m^{-3} 7.6-60.1x10^3 # cm^{-3} 0.56-1.75 ppm	Dustrak (TSI) Micro AE51(Aethlabs) CPC (3007 TSI) Langan T15n	Weekdays morning and evening hours	16-19km

Reference	Location	Transport modes	Metrics	Average pollutant concentration	Instruments	Monitoring time	Route length
Menon and Nagendra (2017)	Chennai, India	Walking	PM_{10} $PM_{2.5}$ PM_1	137±31.8 μg m^{-3} 56.4±11.7 μg m^{-3} 33.3±7.4 μg m^{-3}	Grimm dust monitor (1.109)	50 mins Morning, afternoon, evening hours, weekdays, weekends	2.12km
Betancourt *et al.* (2017)	Bogota, Colombia	Walking, cycling, bus, car, taxi, motorcycle	$PM_{2.5}$ BC Np	17-34.8 μg m^{-3*} 10.5-30.7 μg m^{-3*} 5-57 x 10^3 # cm^{-3}	Dustrack 8520 and Dustrack DRX (TSI) AE51 (Aethlabs) Discmini (Matter Aerosol)	60-70 mins and 100 to 140 mins Weekdays, morning rush hours	4.5-4.9km
Moreno *et al.* (2015)	Barcelona, Spain	Bus, tram, subway and walking	$PM_{2.5}$ Np BC CO_2 CO	23-32 μg m^{-3*} 3.7-5.9 x 10^4 # cm^{-3*} 4.4-9.6 μg m^{-3*} 425-479 ppm* 0.7-1.1 ppm*	PEM Dustrack (TSI, 8533) Nanotracer (Philips Aerasense) AE51 (Aethlabs) IAQ-Calc (TSI, 7574)	Start at 10 am on weekdays 80-120 mins	8.4-9km
Rivas *et al.* (2017)	London, UK	Car, bus, walk and underground	BC Np PM_{10} $PM_{2.5}$ PM_1	2 μg m^{-3*} 7.33x 10^3 # cm^{-3*} 28.5 μg m^{-3*} 13.6 μg m^{-3*} 10.1 μg m^{-3*}	AE51 (Aethlabs) P-trak (TSI 8525) Grimm EDM 107	Morning, afternoon and evening hours weekdays	7.7-12.2km
Strak *et al.* (2010)	Utrecht, Netherlands	Cycling	PM_{10} Soot Np	14.5 – 118.7 μg m^{-3} 1.1 – 16.0 (10^{-5} m^{-1}) 18.1 -58.4 x10^3 (# cm^{-3})	Harvard impactor Smoke Stain Reflectometer (M43D, UK) CPC (3007 TSI)	1 hour Morning rush hour	7.7-8km
Tan *et al.* (2017)	Singapore	Bus Subway Taxi Walking	$PM_{2.5}$ BC Particle-bound polycyclic	27±7 μg m^{-3*} 3.6±3.4 μg m^{-3*} 75±48 ng m^{-3*} 28.9±3.8 x10^3 # cm^{-3*}	Dustrak (TSI 8534) Diffusion Charging Sensor (EcoChem Analytics DC-2000CE)	3 hours for all 4 modes of transport	1.5km for consecutive measurements for all 4

Reference	Location	Transport modes	Metrics	Average pollutant concentration	Instruments	Monitoring time	Route length
			aromatic hydrocarbon Np Active surface area CO	138±36 $mm^2\ m^{-3*}$ 0.7±1.1 ppm^*	CPC (TSI 3007) AE51 (Aethlabs) Photoelectric Aerosol Sensor (EcoChem Analytics PAS-2000CE) Langan T15n		modes of transport
Thai *et al.* (2008)	Vancouver, Canada	Cycling	$PM_{2.5}$ PM_{10}	7-34 µg m^{-3} 26-77 µg m^{-3}	Grimm dust check (1.108) P-trak (TSI 8525)	2 hours	20km

* *Data for walking mode*

--: *not applicable*

7. **Statistical summary of $PM_{2.5}$, BC, Np, LDSA concentrations measured during 1-hour personal exposure assessment**

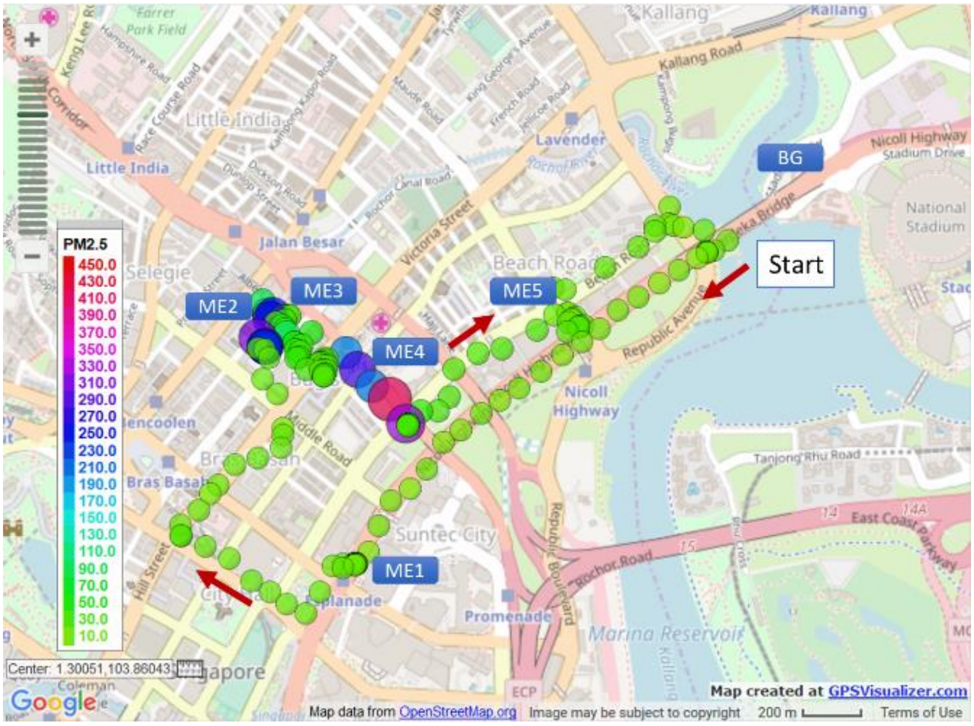
Table S4. Statistical summary of $PM_{2.5}$, BC, Np, LDSA concentrations during 1-hour sampling at 5 selected micro-environments (MEs) and at the background location

Monitoring parameters		Statistical parameters				
		Mean	Median	Minimum	Maximum	SD
$PM_{2.5}$ (µg m^{-3})	ME1-M	66.03	64.68	18.48	140.80	34.05
	ME1-A	44.39	38.94	14.52	99.66	18.31
	ME1-E	55.02	52.36	26.18	139.26	20.70
	ME2-M	238.60	201.52	9.90	1465.20	136.23
	ME2-A	191.39	162.25	63.36	897.60	122.71
	ME3-M	69.70	52.36	20.24	345.40	51.95
	ME3-A	69.23	54.56	28.60	246.40	45.20
	ME3-E	45.79	45.10	9.24	88.44	18.91
	ME4-M	29.95	24.08	18.14	421.80	17.82
	ME4-A	28.18	27.16	20.56	79.52	7.84
	ME4-E	51.12	39.76	12.70	226.34	11.70
	ME5-M	18.66	18.20	12.70	53.14	5.71
	ME5-A	13.77	14.02	8.74	21.06	2.31
	ME5-E	32.16	28.87	15.78	141.62	8.35
	NEA-M	8.95	9.00	3.00	16.00	3.79
	NEA-A	15.71	14.00	7.00	34.00	6.81
	NEA-E	10.57	11.00	3.00	20.00	4.26
	BG-M	6.19	6.16	5.28	6.82	0.36
	BG-A	12.98	13.86	6.82	19.80	4.85
	BG-E	13.94	14.08	9.90	18.92	2.91
BC (µg m^{-3})	ME1-M	9.14	8.83	4.56	15.02	2.15
	ME1-A	5.79	4.60	1.98	34.73	3.31
	ME1-E	15.08	14.03	10.04	29.92	3.66
	ME2-M	16.24	13.87	2.98	60.28	9.33
	ME2-A	25.64	23.82	9.16	80.12	11.47
	ME3-M	8.47	7.25	0.00	26.42	4.46
	ME3-A	3.06	2.77	1.63	9.97	1.22
	ME3-E	9.20	9.77	3.21	13.39	2.95
	ME4-M	14.08	11.47	1.12	89.19	11.10
	ME4-A	20.86	14.70	4.74	180.92	13.92
	ME4-E	19.24	16.30	9.30	56.65	11.08
	ME5-M	5.76	4.73	1.56	50.90	2.24
	ME5-A	3.55	2.07	0.37	36.35	2.31
	ME5-E	4.09	3.85	1.96	8.29	1.78
	BG-M	3.16	3.27	2.39	3.73	0.38
	BG-A	3.78	3.57	1.59	6.19	1.34
	BG-E	2.45	2.38	1.72	4.18	0.44
	NUS-M	1.89	1.81	1.08	2.70	0.50
	NUS-A	1.21	1.00	0.78	2.19	0.40

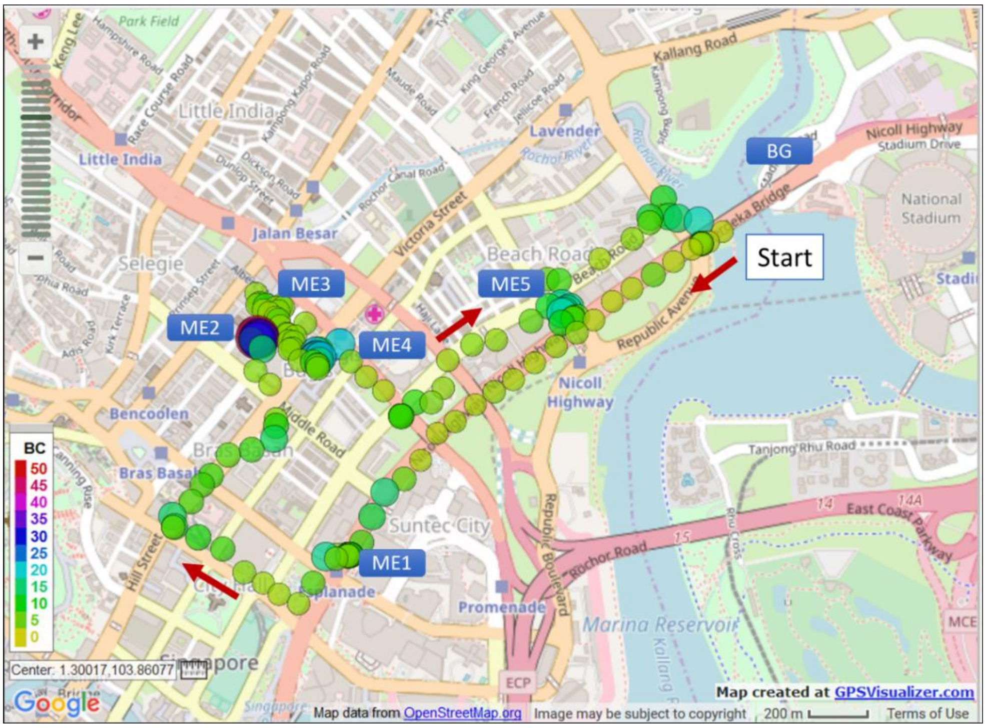
Monitoring parameters		Statistical parameters				
		Mean	Median	Minimum	Maximum	SD
	NUS-E	3.96	3.81	2.50	5.66	1.03
Np x 10^3 (# cm^{-3})	ME1-M	110.33	90.14	29.33	268.72	67.76
	ME1-A	72.56	68.84	23.38	158.32	25.23
	ME1-E	87.19	85.47	51.79	190.55	22.96
	ME2-M	281.70	253.64	18.99	734.03	161.91
	ME2-A	179.19	167.08	92.62	376.10	61.80
	ME3-M	322.24	324.62	56.04	727.72	146.92
	ME3-A	513.89	458.79	0.00	935.99	183.49
	ME3-E	126.28	125.26	21.03	268.96	62.89
	ME4-M	28.28	24.87	0.00	153.98	15.92
	ME4-A	32.75	31.97	14.79	59.12	9.86
	ME4-E	31.73	22.02	12.56	112.47	26.05
	ME5-M	17.86	16.01	10.96	76.79	7.48
	ME5-A	18.00	16.18	7.73	55.23	7.80
	ME5-E	13.52	12.39	7.58	28.68	4.85
	BG-M	11.61	11.33	8.43	17.41	2.31
	BG-A	25.71	25.82	17.99	32.34	2.76
	BG-E	13.24	14.08	8.92	17.55	2.48
LDSA (μg^2 cm^{-3})	ME1-M	248.00	211.76	70.67	622.49	144.57
	ME1-A	176.20	172.23	50.68	400.97	66.04
	ME1-E	217.19	214.51	130.72	521.31	59.51
	ME2-M	926.46	819.85	44.80	2378.39	556.15
	ME2-A	741.97	716.88	387.87	1365.76	236.97
	ME3-M	597.96	524.61	101.18	1742.21	360.40
	ME3-A	813.69	698.61	333.27	1693.53	337.52
	ME3-E	282.17	285.88	52.88	552.55	131.49
	ME4-M	83.23	70.41	37.52	347.75	42.15
	ME4-A	97.82	84.19	35.00	469.74	59.07
	ME4-E	40.16	37.07	8.37	97.79	22.83
	ME5-M	42.91	40.14	21.96	137.89	18.50
	ME5-A	38.64	33.18	14.86	161.08	21.25
	ME5-E	27.25	24.59	11.89	74.04	12.58
	BG-M	23.79	23.98	19.39	29.64	2.72
	BG-A	54.91	55.49	42.35	65.16	6.15
	BG-E	32.91	32.35	26.93	45.76	3.82

(*M-morning, A-afternoon, E-evening, NEA- National Environmental Agency, NUS - National University of Singapore laboratory, BG-background, SD -Standard Deviation*).

8. Spatial map of $PM_{2.5}$, BC, Np and LDSA measurements



(a)



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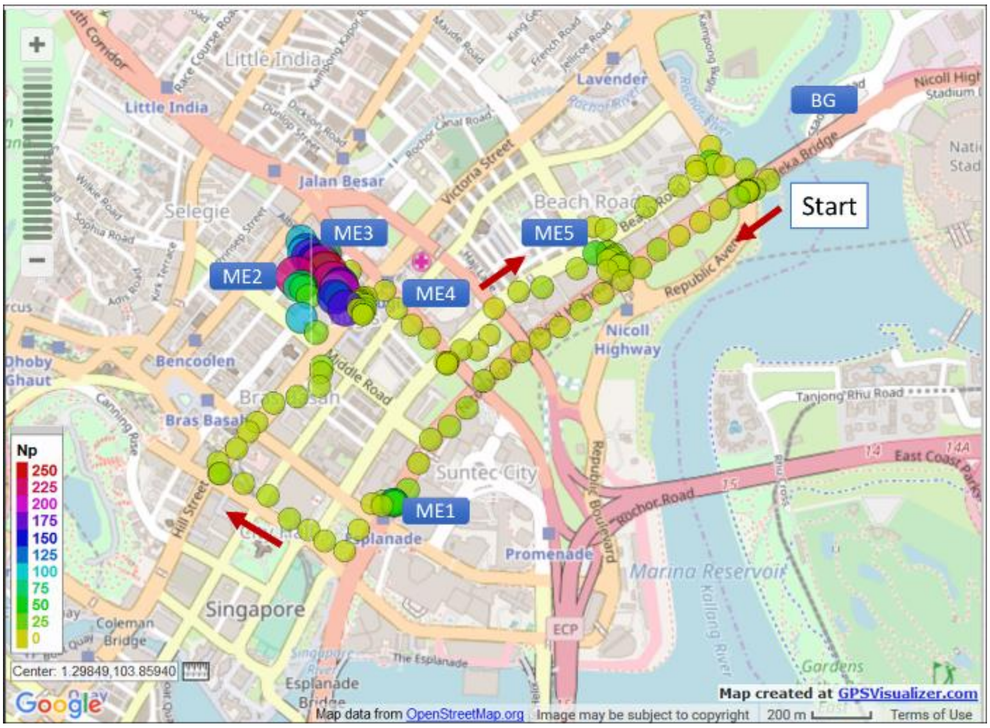

(c)

(d)

Fig. S3. Spatial map of (a) PM2.5 (µg m^{-3}); (b) BC (µg m^{-3}); (c) Np (x10^{3} #cm^{-3}), and (d) LDSA (µg^{2} cm^{-3}) concentrations. The measurements were conducted on 2 Jan 2018 during morning hours.

9. References

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