ASIC Air Sensor International Conference

High resolution mapping of on-road air pollution using a large taxi-based mobile sensor network in Shanghai

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Outline

1 Background

- **Urban air pollution** is one of the greatest threats to human health in the modern world, as 55% of the world's population lives in cities, yet **more than 80%** of them are exposed to air quality levels that **exceed** World Health Organization limits.
- Due to the uneven distribution of emission sources, complex flow pattern, physical and chemical transformation, the pollution patterns in urban environment has **great spatial and temporal variability**.
- However, ***Air quality monitoring stations* (AQMS)** have **limitations** to cover high spatiotemporal resolution of air pollutants variation.
- The **portable stationary** (high density sensor network) and **mobile measurements** can capture the **fine-scale spatial variation with high temporal resolution** of air quality data, which is of great significance for urban air quality management, exposure assessment, epidemiological studies and environmental equity.

WHO: WHO Global Urban Ambient Air Pollution Database, [online] Available from: https://www.who.int/phe/health_topics/outdoorair/databases/cities/en/, 2016

Liu, H. and He, K.: Traffic optimization: A new way for air pollution control in China's urban areas, Environ. Sci. Technol., 46(11), 5660–5661, doi:10.1021/es301778b, 2012.

Apte, J. S. etal.: High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data, Environ. Sci. Technol., 51(12), 6999–7008,445 doi:10.1021/acs.est.7b00891, 2017.

Apte, J. S. etal.: Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India, Atmos. Environ., 45, 4470-4480, https://doi.org/10.1016/j.atmosenv.2011.05.028, 2011.

Boogaard, H. et al. Contrast in air pollution components between major streets and background locations: Particulate matter mass, black carbon, elemental composition, nitrogen oxide and ultrafine particle number, Atmos. Environ., 45, 650-658, https://doi.org/10.1016/j.atmosenv.2010.10.033, 2010.

2 Literature Review

2.1 Specifications of Measurements

Stationary Air Quality Monitoring System

Mobile Air Quality Monitoring System

Compliance monitor
***Air Quality Monitoring Station* (AQMS)**

“Professional” monitor
***Mini/Nano Air Station* (MAS/NAS)**

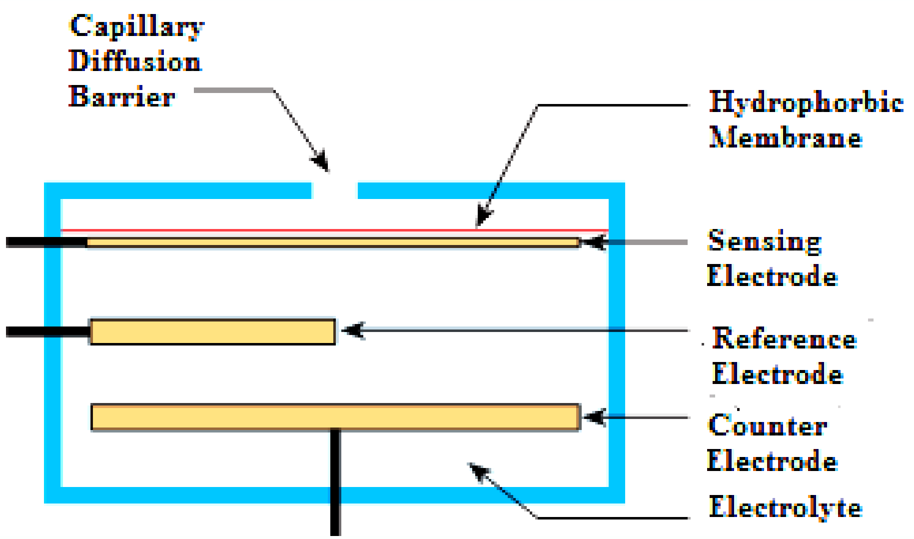
Airborne-based monitoring

Vehicle-based monitoring

2 Literature Review

2.2 Specifications of Mobile Air Sensors

2.2.1 Specifications of Gas Sensor (Electrochemical Sensor)



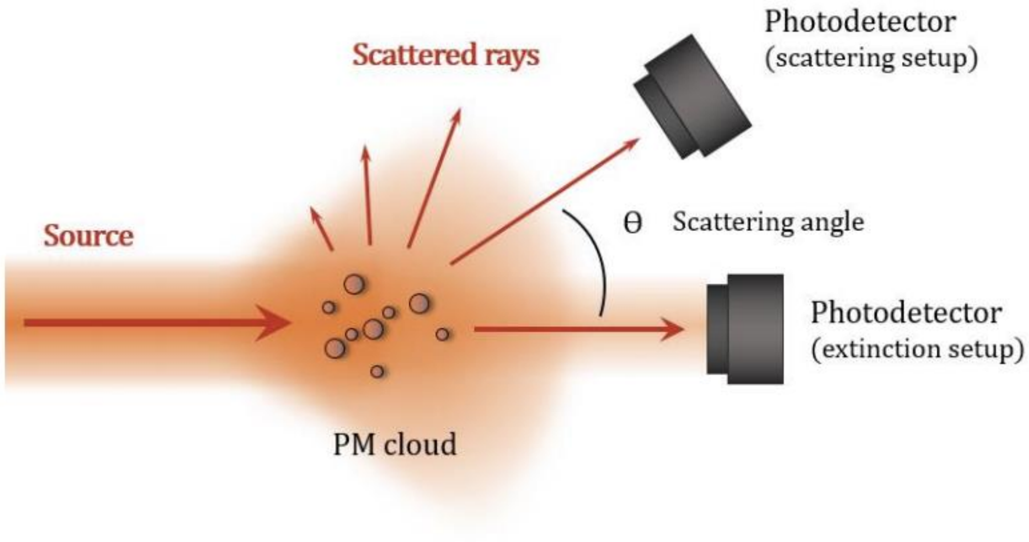
Manufacturer	Concentration Range Limitation	Response Time	Operating Life
Alphasense CO-A4	20 ppm	T_{90}(s)< 15	>36 months
Alphasense NO_2-A43F	5 ppm	T_{90}(s)< 10	>24 months

https://www.intlsensor.com/pdf/electrochemical.pdf

2 Literature Review

2.2 Specifications of Mobile Air Sensors

2.2.1 Specifications of PM Sensor



https://hal.archives-ouvertes.fr/hal-03052755/document

Manufacturer	Concentration Range Limitation	Response Time	Operating Life
Plantower PMS5003	0.3 ~ 10 (μm)	≤8 (s)	≥ 36 months
Met One ES-642 Dust Monitor	0.1 ~ 100 (μm)	≤1 (s)	≥ 24 months

3 Research Objectives

(1) To improve the **durability** of using **mobile sensors** for the **complex-built environment**.

(2) To develop and evaluate a suitable and optimized ***Quality Assurance and Quality Control*** **(QAQC) protocol** for sensor calibration and validation to **improve data quality** with **big data approach**.

(3) To study and demonstrate the relations between **urban features and air quality** to investigate the impact of the built urban environment by using **sensor based mobile measurements** in a megacity.

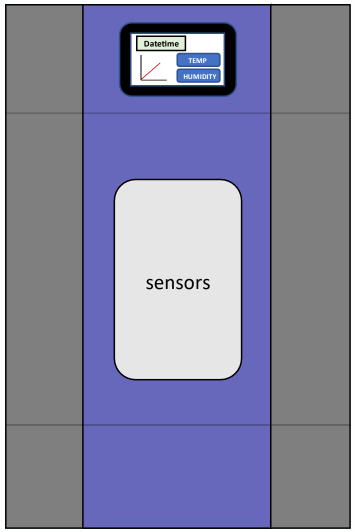
(4) To analyze the **urban traffic emission** in **spatial and temporal resolution**.

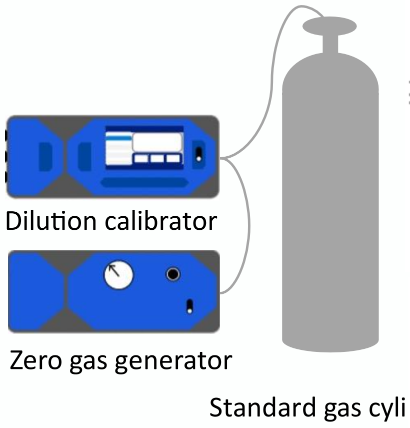
4 Methodology

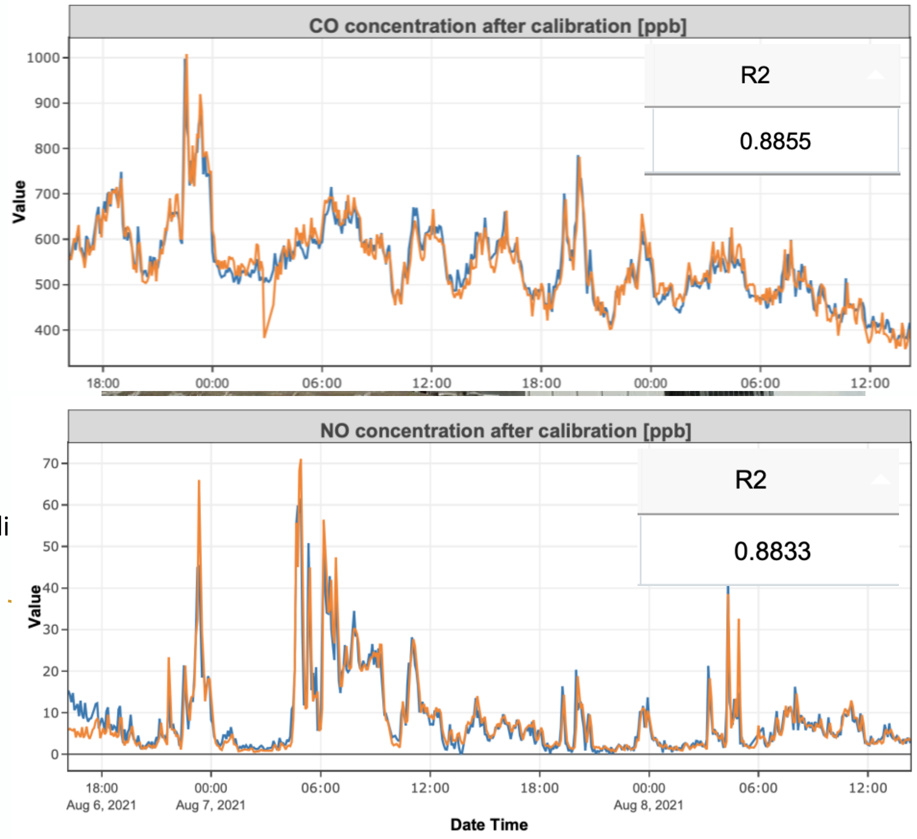
4.1 *Quality Assurance and Quality Control* (QAQC) of Sensors

4.1.1 Pre-deployment Protocol

- Standard Sensor Calibration and Validation







Real-time data acquisition and visualization

Environment control chamber

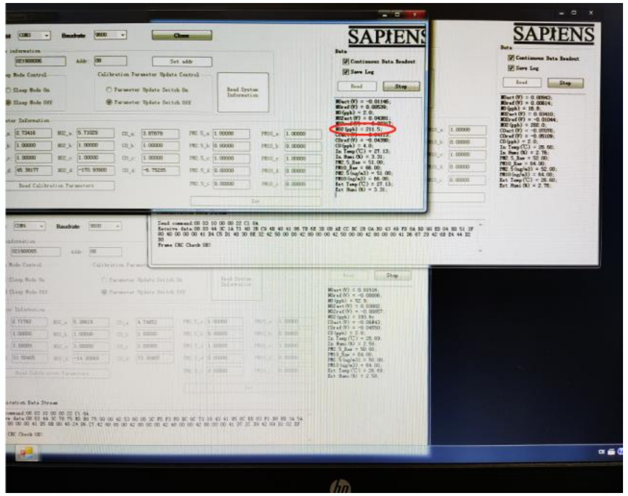
Sensor calibration

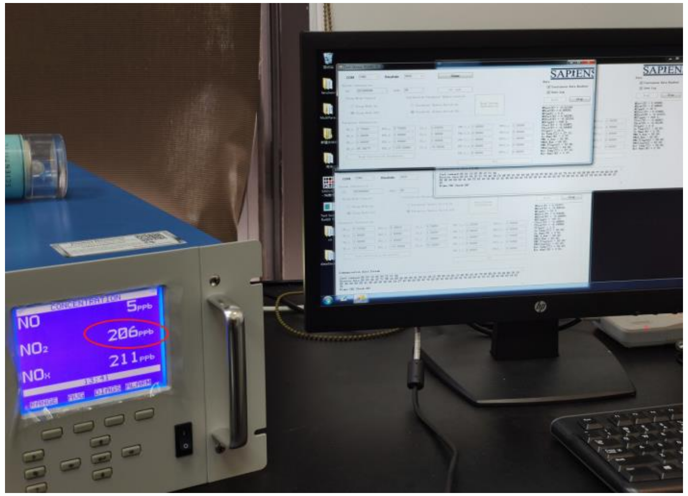
4 Methodology

4.1 *Quality Assurance and Quality Control* (QAQC) of Sensors

4.1.2 Laboratory Routine & Remote QAQC Protocol

- Randomly recalling some sensors every two weeks to check the drift rate.
- Sensor troubleshooting to ensure the quality of data.
- 15% sensor drift as threshold for new parameter update through lab routine test protocol.
- Cloud real time data streaming every two weeks.
- Outlier detection through algorithms.





4 Methodology

4.2 Vehicle-based Mobile Sensor Network

4.2.1 Basic Information for Shanghai Mobile Sensor Network

- Deployment started from December 2019.
- Compact and multipollutant solutions for $PM_{2.5}$, NO_2 and CO.
- GPS/ traffic speed data and real time transmission.
- Mounted on the tailfins of 125 taxis and 20 buses.
- Over 20 million data points a month. (5s resolution)

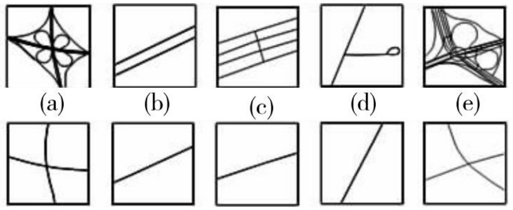
Figure 2.The mobile devices installed on a taxi's rear fins.

4 Methodology

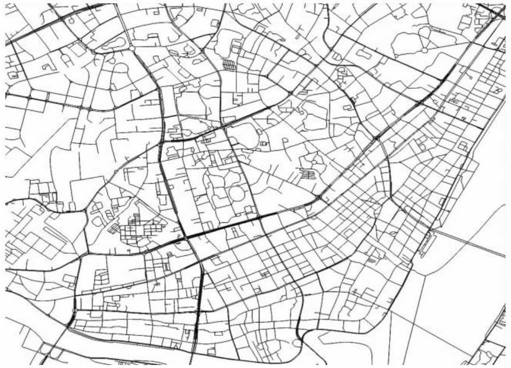
4.2 Vehicle-based Mobile Sensor Network

4.2.2 Roadway network segmentation and sensor data assignment through GIS

- Segment initialization (grid size (length=200m), multisided road)
- Joint segment selection (buffer=10m)
- Map matching using selected segments
- Data assignment



Before



After

Trunk

Motorway

Primary

Secondary

Tertiary

5 Results

Vehicle-based Mobile Sensor Network

5.1 Roadway Coverage

- Overall, more than 8 days can cover 60% all type roads. (except for Feb.)
- 1-month measurements can cover more than 75% major road segments (200m). (except for Feb.)
- 25 taxis' operating can reach 75% coverage of trunk roads
- The coverage of the all-road sections can reach 75% when 75 vehicles are running during a month.

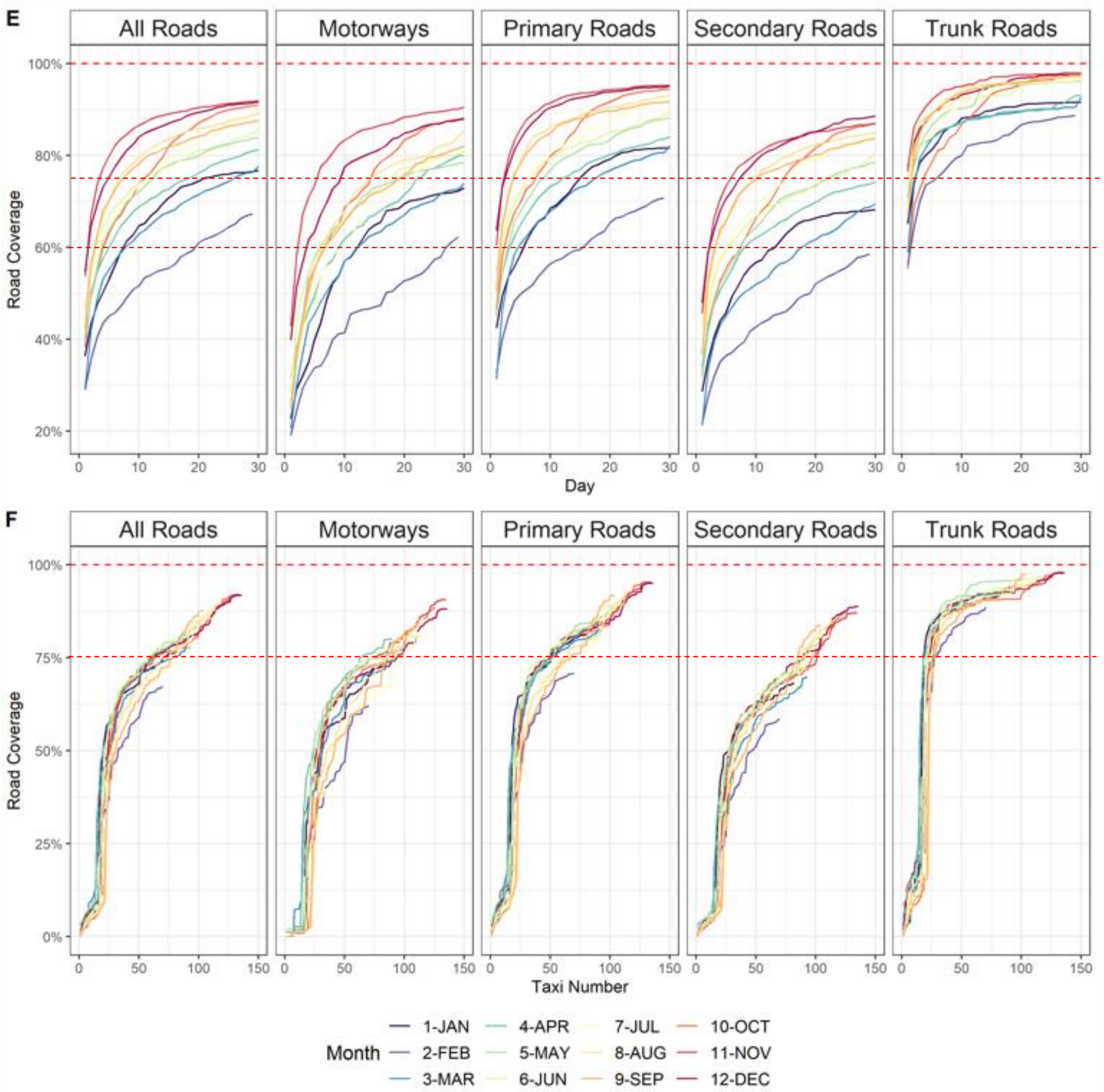


Figure 3. The day and cumulative number of taxis over 12 months (e,f).

5 Results

Vehicle-based Mobile Sensor Network

5.2 Spatial Analysis

- A strong correlation between the number of vehicles running and CO emission.
- The concentration of NO_2 is correlated with the speed of the vehicle.
- The concentration of $PM_{2.5}$ varies may relate to the fewer pollution sources near the seaside, the different types of land use in various areas, and the use restrictions on vehicle types.

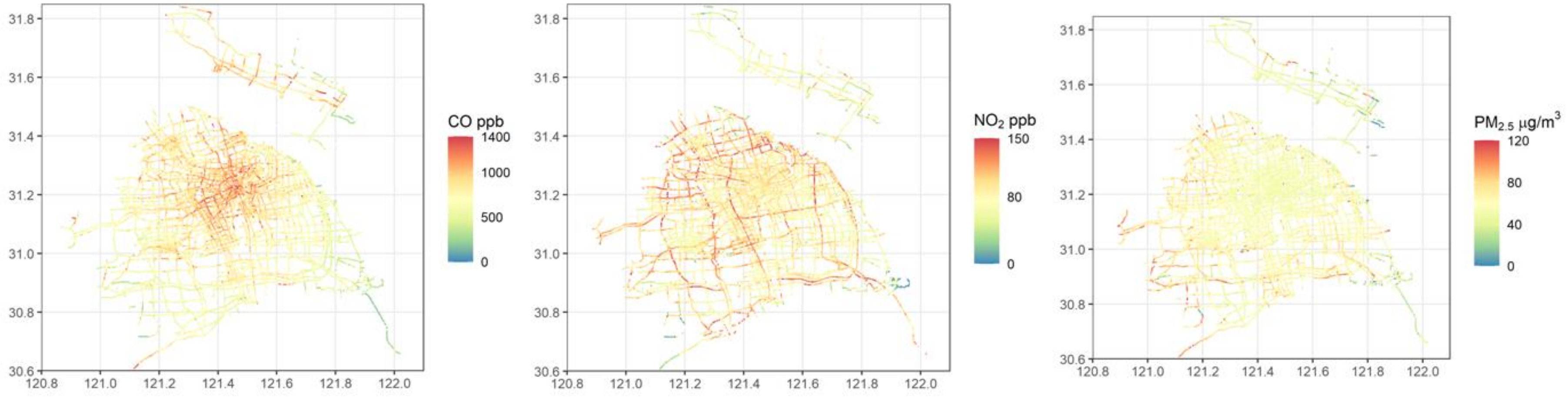


Figure 4. Spatial distribution of the average hourly concentrations of CO (ppb), NO_2 (ppb) and $PM_{2.5}$ ($\mu g\ m^{-3}$) in Shanghai from January 2020 to December 2020.

5 Results

Vehicle-based Mobile Sensor Network

5.3 Temporal Analysis

- Daily profile on weekdays (Mon. to Sat.) and weekends (Sun.).
- Peak and non-peak hours during a day.
- The concentration data statistic and overall distribution.

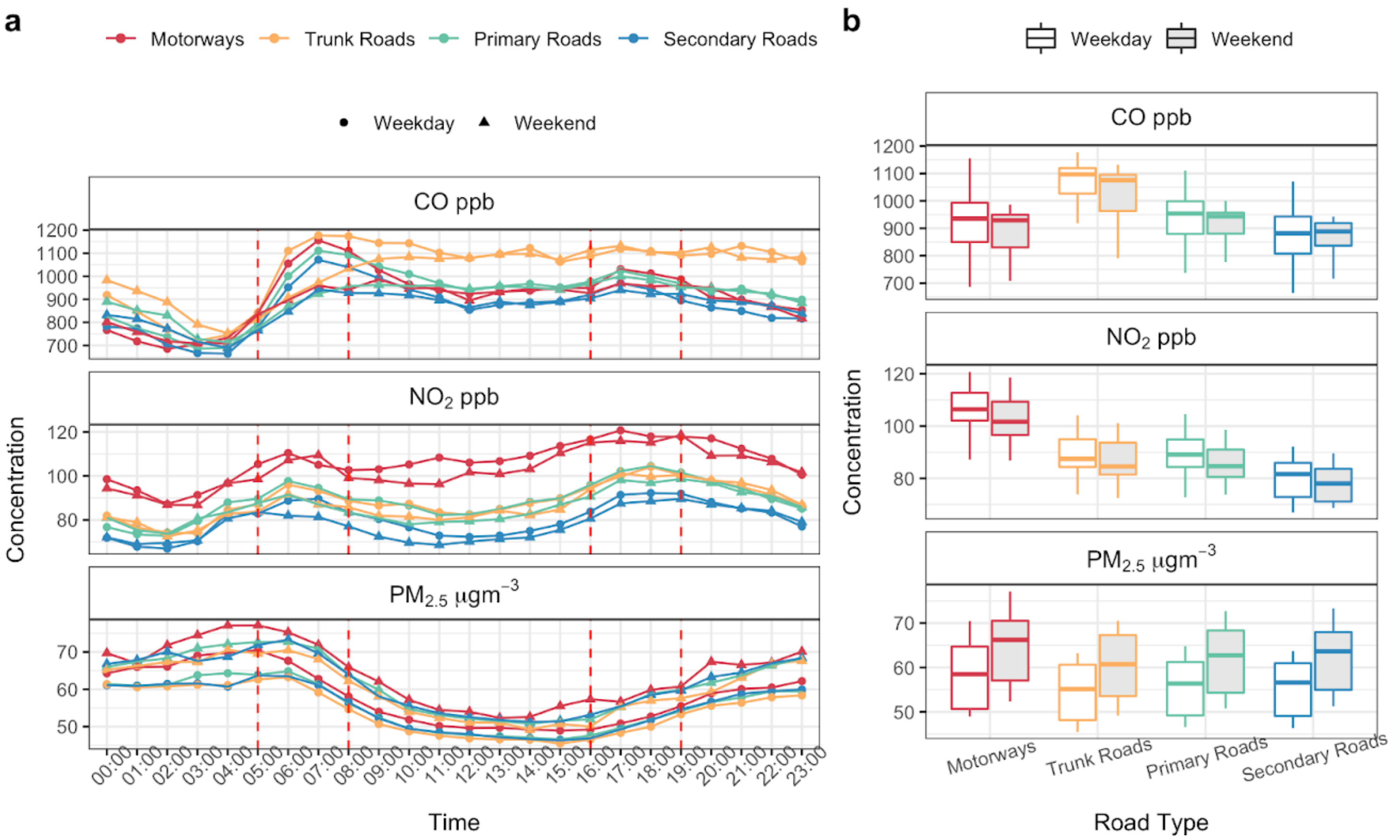


Figure 6. Daily cycles of the three pollutant concentrations measured by the mobile devices during peak/non-peak hours, weekdays/weekends, in each month in 2020. (a) Diurnal concentration change among different road types and between weekdays (dots) and weekends (triangles), with the dashed red line for peak hours from 05:00 to 08:00 and 16:00 to 19:00. (b) Statistics and overall distribution of four types of road, each box extending from the 25th to the 75th percentile, weekday (unshaded) and weekend (shaded).

5 Results

Vehicle-based Mobile Sensor Network

5.4 Traffic-related local pollution contribution

- Low percentiles can represent the background concentrations that are not affected by peak signals and present slow varied trends (Bukowiecki et al., 2002; Brantley et al., 2014). We followed these works and used 5th percentile values to estimate background signals.
- The background contribution of CO on all type of roads exceeds the ambient air quality standard of China, which requires an overall reduction from emission sources.
- The control of NO_2 concentration should be considered from the reduction of traffic-related sources.
- $PM_{2.5}$ display a homogeneous on-road distribution characteristics.

$$C_{LC,i,t} = C_{T,i,t} - C_{BG,i,t}$$

$$P_{LC,i,t} = \frac{C_{LC,i,t}}{C_{T,i,t}}$$

$\mathbf{C_{BG,p,t}}$ the background air pollutant concentration
$\mathbf{C_{LC,i,t}}$ the local air pollutant concentration
$\mathbf{C_{T,i,t}}$ raw measurement
$\boldsymbol{P_{LC,i,t}}$ the local emission contribution.

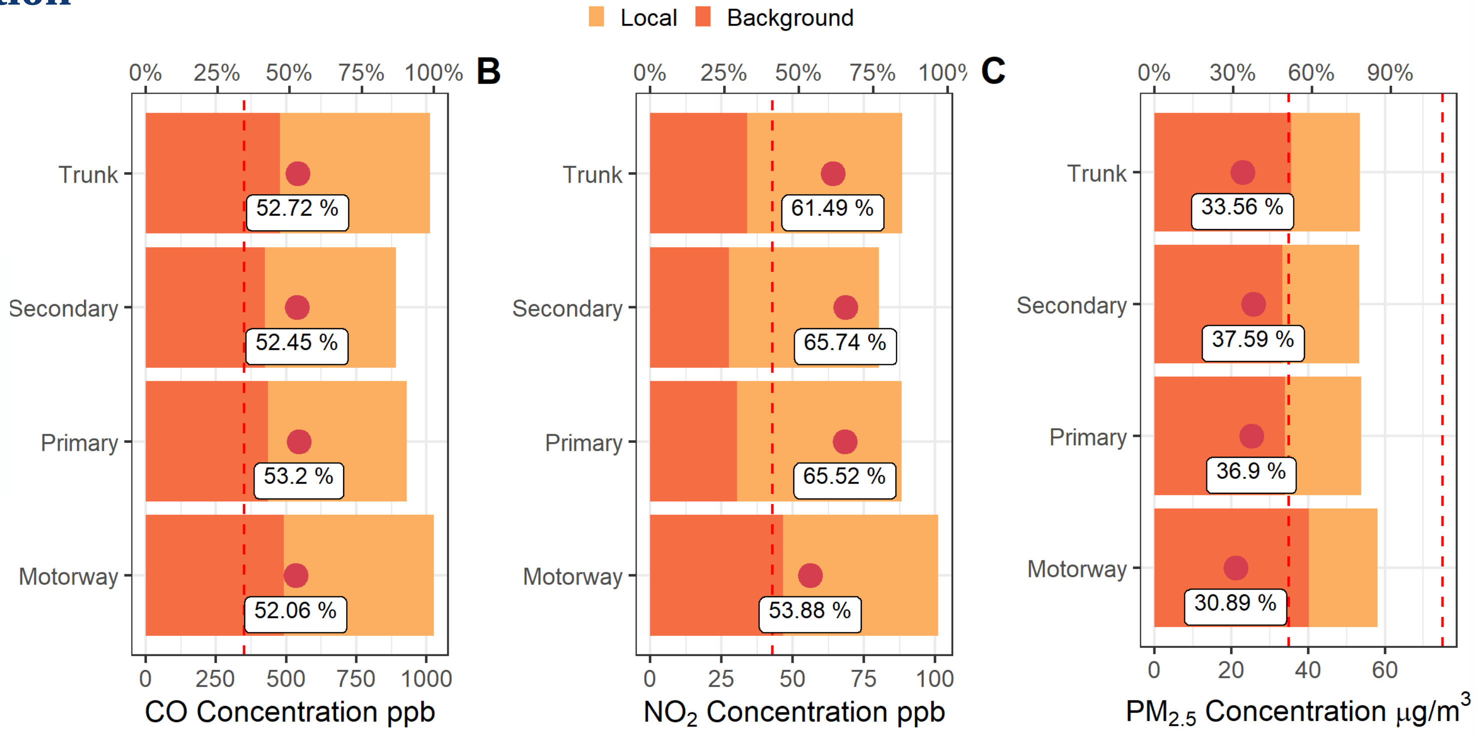


Figure 7. Local and background pollutant contributions to CO, NO_2, $PM_{2.5}$ for different road types (red for background contribution and orange for traffic-related emission contribution). The red dot is the contribution percentage for traffic-related local emissions. The dashed red line indicates the Ambient Air Quality Standard of China (after the unit conversion, the 24-hour average limitation for NO_2 is 43 ppb, CO is 350 ppb, 35 μg m^{-3} for the first level of $PM_{2.5}$ and 70 μg m^{-3} for the second level of $PM_{2.5}$).

5 Results

Vehicle-based Mobile Sensor Network

5.5 Concentration Comparison Through the Whole COVID-19 Pandemic Period

- **(I) Before COVID-19** : December 2019 and January 2020
- **(II) COVID-19 Lockdown** : February and March
- **(III) COVID-19 Recovery** : April and May
- **(IV) Post COVID-19** : June and July

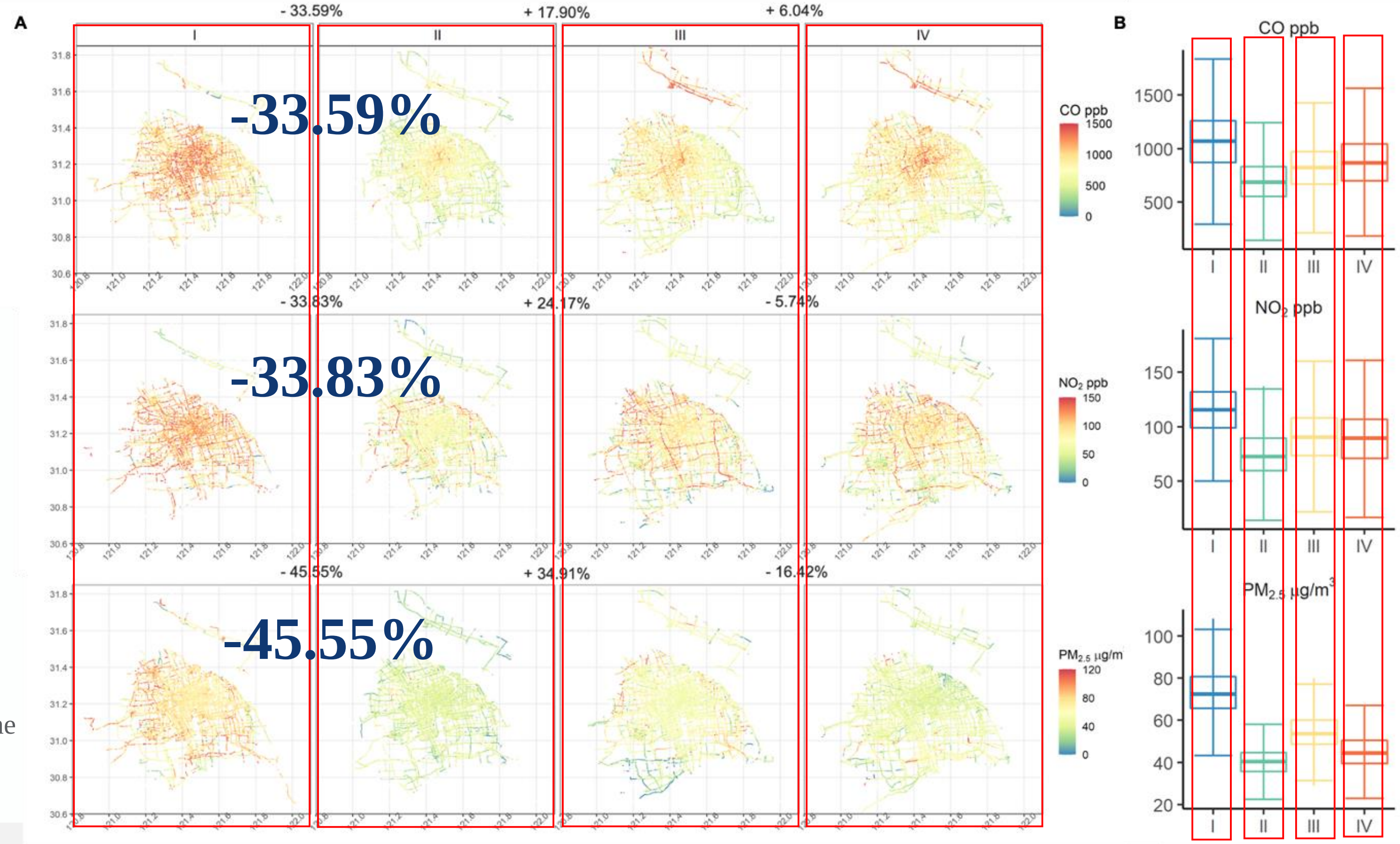


Figure 8. a: Spatial changes of CO, NO_2 and $PM_{2.5}$ concentrations in four phases of the COVID-19 pandemic. b: Boxplot for pollutant concentration distribution during each period of the COVID-19 pandemic.

6 Discussion and Conclusion

Vehicle-based Mobile Sensor Network

- This study carried out a **vehicle-based low-cost mobile platform air monitoring activity** in Shanghai, China, which is **accurate and high spatiotemporal resolution** of pollutant concentration.
- It is a valuable tool for policymakers and environmental protection agencies to implement effective policies for the **future development of cities**.
- Our analysis provides new insights into changes in urban air quality, particularly during the **COVID-19 epidemic period**.
- In the following research, the data measured by mobile platform will combined with **traffic emission inventories**, **urban geographical features**, **meteorological information**, and other factors to study the horizontal relationship between them and establish relevant models, which can be applied to **air pollution prediction** on other fields.

Thanks for your attention

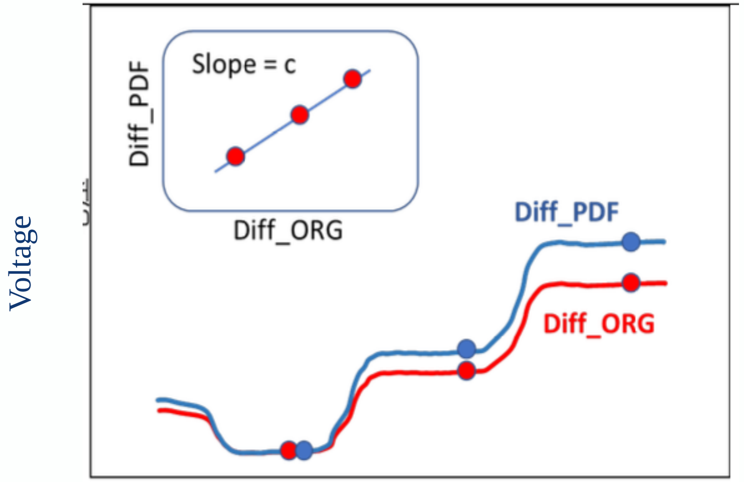
Any Question?

4 Methodology

4.1 *Quality Assurance and Quality Control* (QAQC) of Sensors

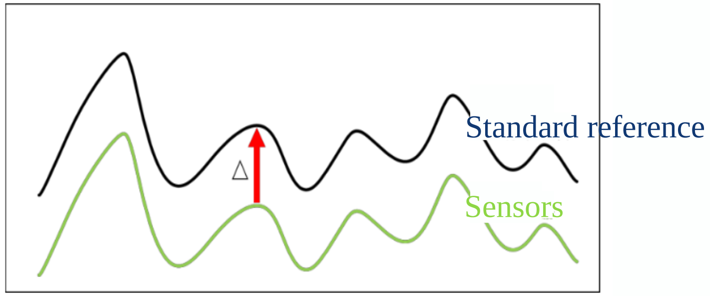
4.1.1 Pre-deployment Protocol

- Standard Sensor Calibration and Validation



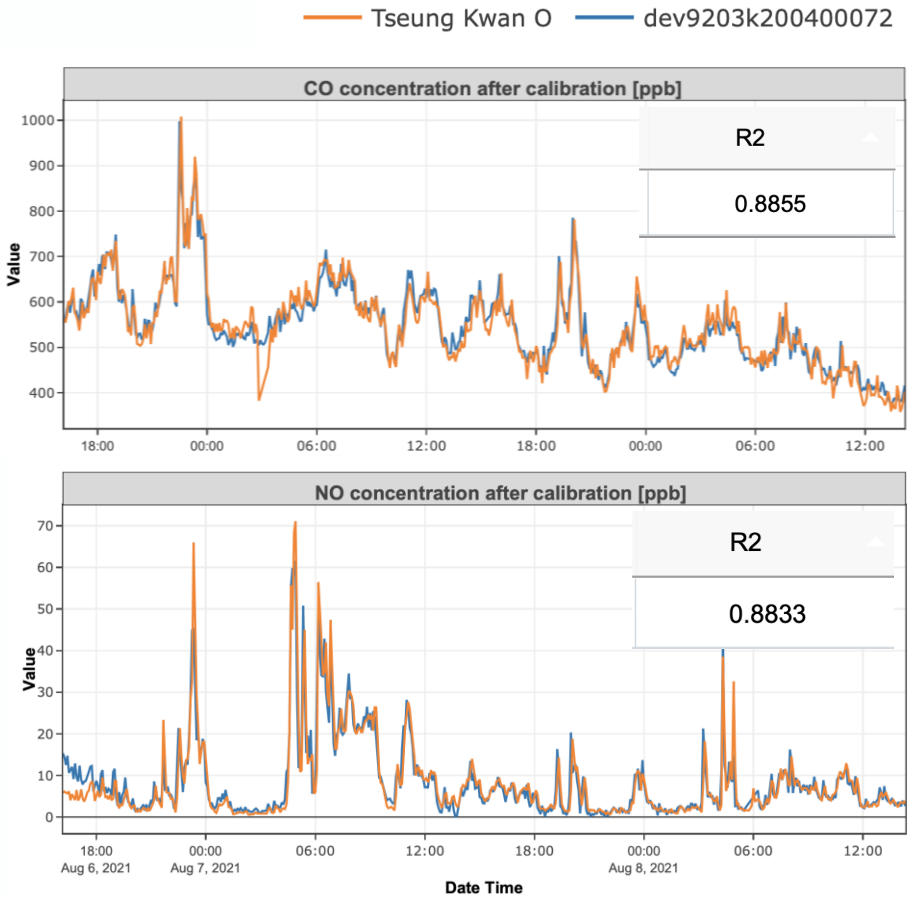
Time

Sensor calibration



Time

Field validation



4 Methodology

4.1 *Quality Assurance and Quality Control* (QAQC) of Sensors

4.1.2 Laboratory Routine Protocol

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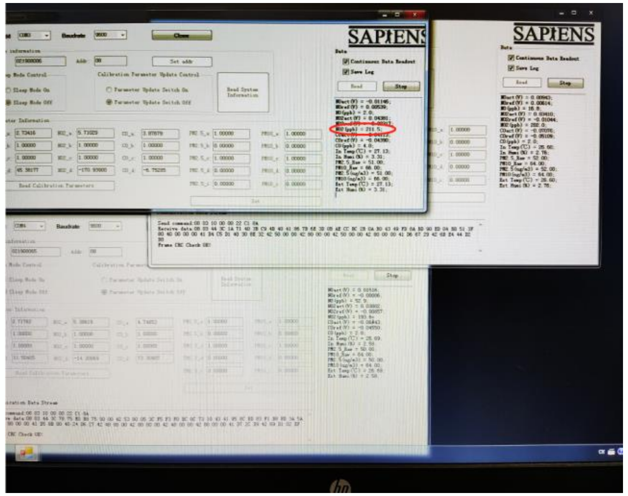
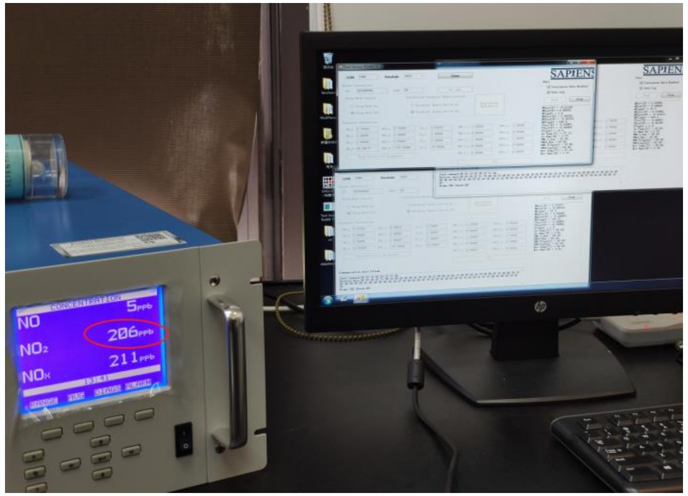




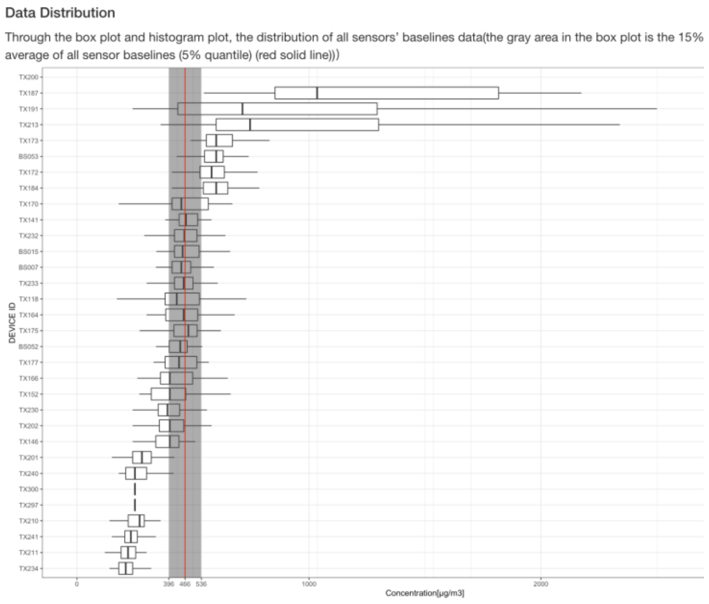
Device ID	31909013	3190902	31909014
Install time	2019.10.14	2019.10.14	2019.11.02
Recall time	2019.10.28	2019.10.28	2019.11.13
CO deviation before installation	1.27%	0.91%	-3.01%
CO deviation after recall	2.71%	0.22%	-3.74%
CO drift rate	1.42%	0.70%	-0.85%
NO_2 deviation before installation	-2.98%	-4.50%	-6.85%
NO_2 deviation after recall	-3.70%	-8.91%	-2.11%
NO_2 drift rate	0.74%	-4.62%	5.09%

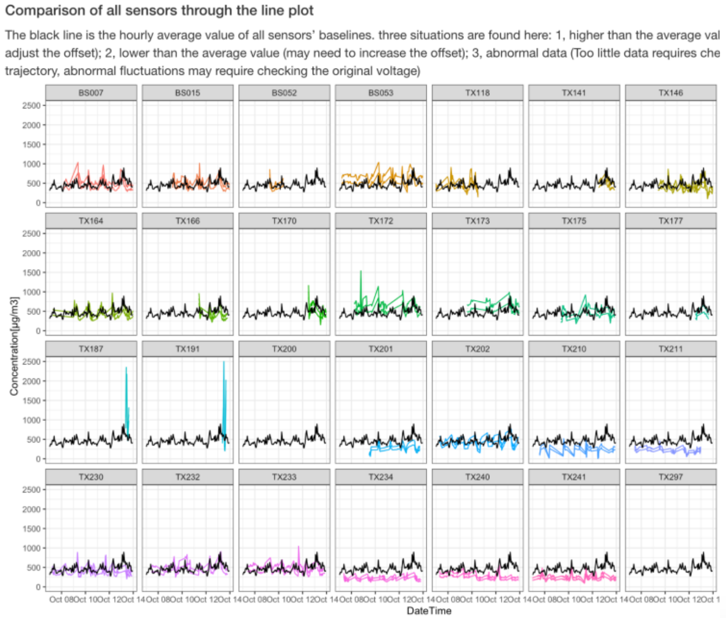
4 Methodology

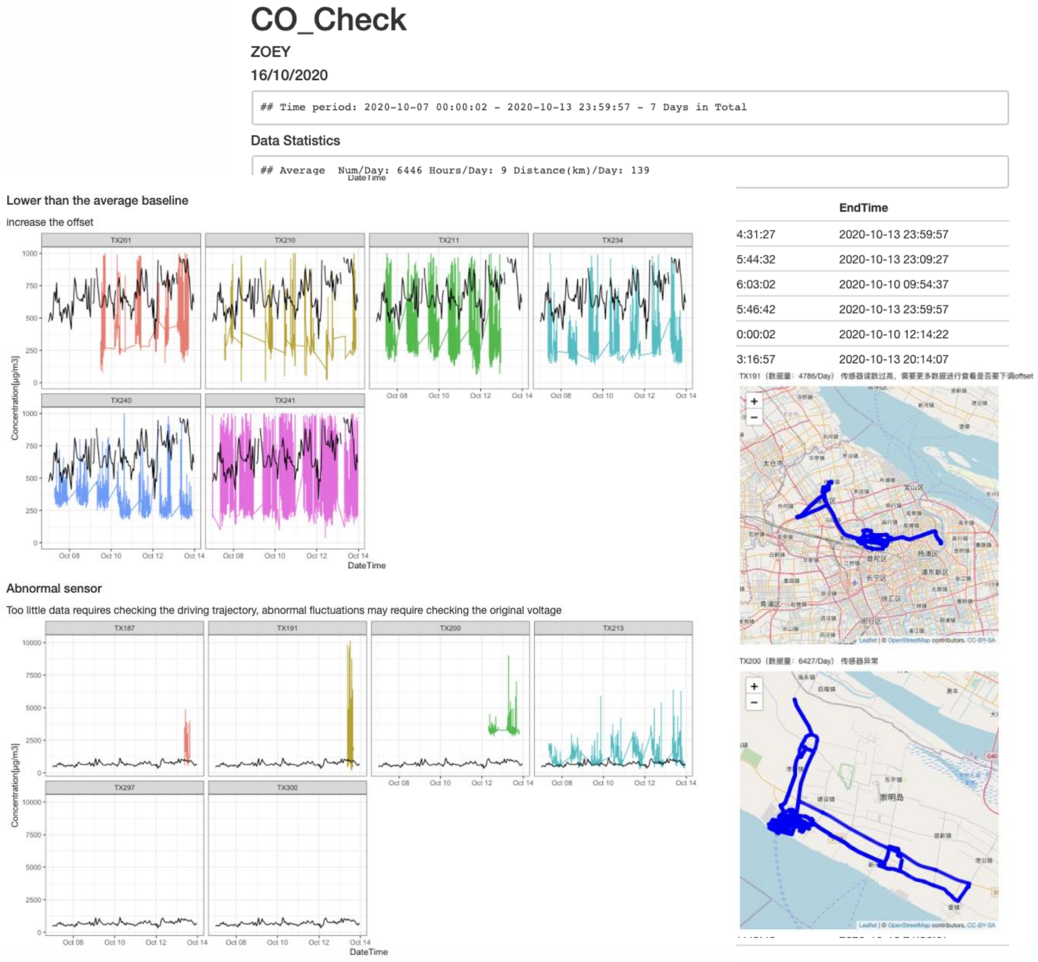
4.1 *Quality Assurance and Quality Control* (QAQC) of Sensors

4.1.3 Remote QAQC Protocol Through Big Data Approach

- Cloud real time data streaming every two weeks.
- Outlier detection through algorithms .
- Malfunctioning sensor trouble shooting with categorized







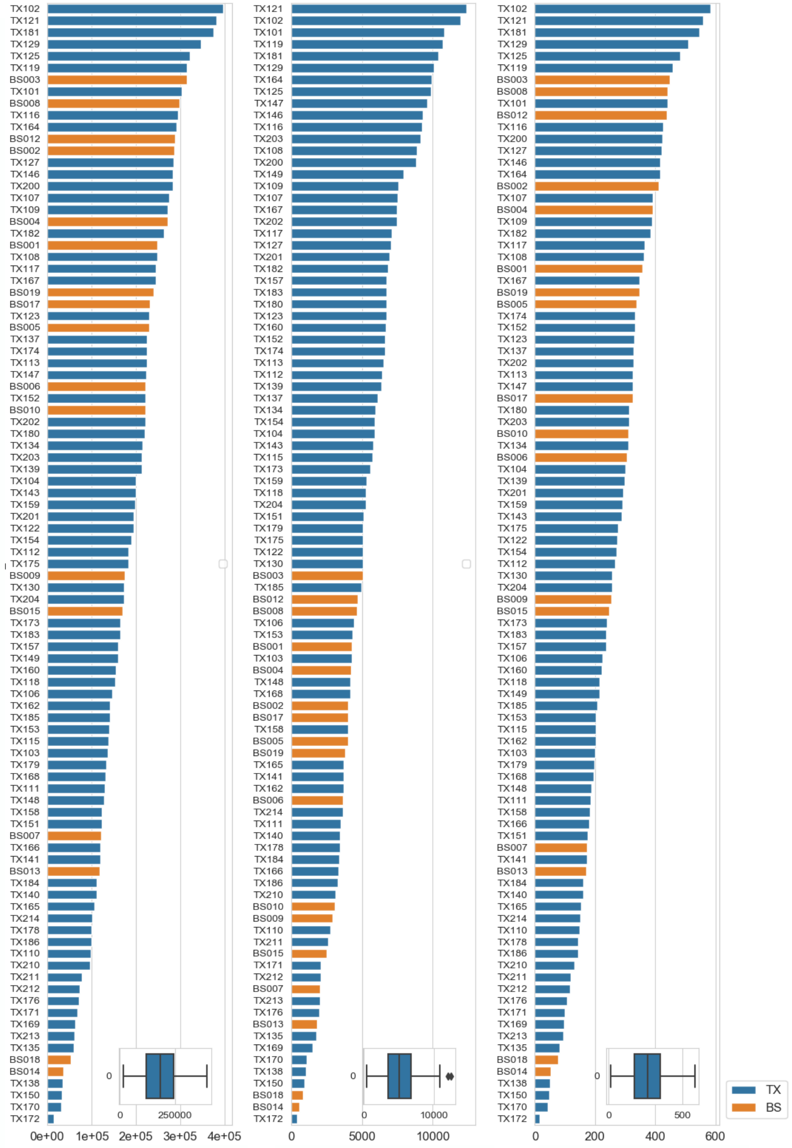
5 Results

Vehicle-based Mobile Sensor Network

5.1 Data analysis basics and strategy

- Over 100 vehicles available for most of the month.
- Average coverage >6,000 km.
- Operation time around 10 hours per day.
- Operate Bus-based and Taxi-based mobile air sensor networks.
- The bus platform can cover more hours; the taxi platform can cover long distance.

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Number of Taxis	82	70	93	92	103	115	115	123	107	126	134	136	108
Average Travelling Distance/Day (km)	563	333	506	726	768	627	647	835	633	896	741	790	672
Average Data Number/Day	6216	3843	5458	6639	6813	6471	6904	6583	6433	6896	6967	6352	6298
Average Travelling Hour/Day	10	6	9	10	10	10	11	10	10	11	11	10	10



Data points Length(km) Hour count

5 Results

Vehicle-based Mobile Sensor Network

5.2 Speed Distribution and Roadway Coverage

- The vehicle speed is lower in the city centre and higher further away from the city centre.
- The road segments in the city centre have a great amount of data, the further away from the city centre, the fewer data points.

Road type	Average monthly coverage	Average daily count	Speed (km/h)	Total length (km)	Number of segments
Trunk	95.1%	9.43	45.99±16.01	788.79	6835
Motorways	80.40%	1.64	64.64±20.21	1681.02	12800
Primary roads	87.90%	8.72	39.76±16.68	2399.09	15975
Secondary roads	78.40%	9.56	33.89±15.13	2563.01	15508
Overall	84.10%	7.30	45.10±20.85	7431.91	51118