Application and Use of Low-cost Sensors for Air Quality Monitoring in Urban Areas

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SailBri Cooper Inc.

Air & Waste Management Association
Ontario Section

05/13/2021

Outline:

SailBri Cooper, Inc.

- SCI Sensor Introduction
- Sensor Application in the U.S.
- Air Quality Sensor Network Application

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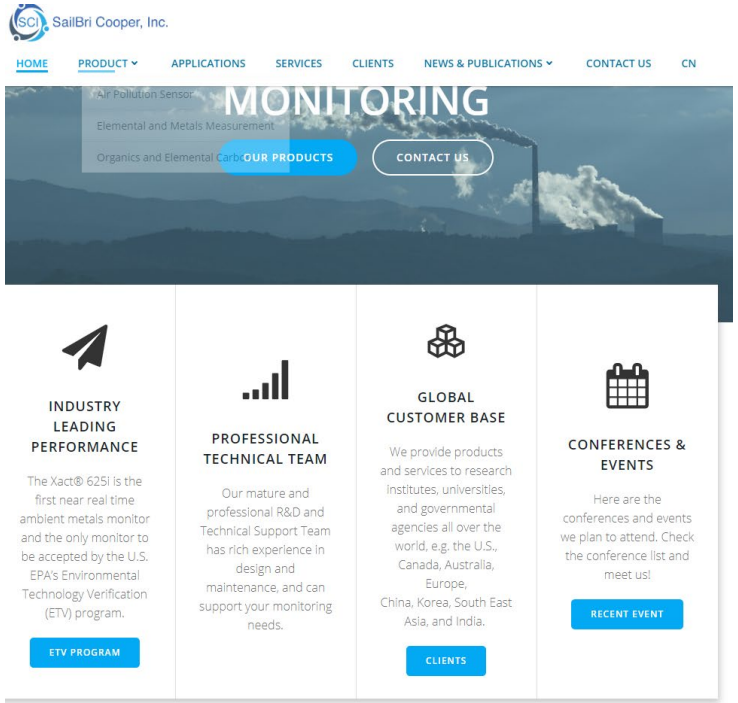


Sailbri Cooper Incorporated (SCI)

Sailbri is a world leader in near real time metals measurement through Cooper Environmental's line of Xact® monitoring products for ambient air, stack emissions and water. The Xact® 640 was the world's first and only multi-metal continuous emissions monitor to be accepted by the U.S. EPA. The Xact® 620 was also the world's first commercially available near real time ambient metals monitor and the Xact® 625 was the first real time metals monitor to be verified by the U.S. EPA through its Environmental Technology Verification program. SCI is also a world leader in ambient air carbon measurement via its subsidiary Sunset Laboratories which pioneered the thermal optical method for organic and elemental carbon measurement (OC-EC). SCI is continuing its tradition of innovation through the introduction of a line of low cost sensor products capable of monitoring criteria pollutants (SO2, NO2, CO, O3, PM10, PM2.5) and hazardous gases (HF, HCl, H2S, Cl2 and VOC's). These sensors are available at a low cost with a good comparability to reference and standard laboratory methods.

SCI-608 – Criteria Pollutant Monitoring

Read more

Sci-700 – Hazardous Gas Monitoring

Read more

SCI-901 Dust Sensor (PM monitor)/SCI-902 Air Quality Sensor (PM+Gases Monitor)

Read more

Xact® 625i Ambient Continuous Multi-Metals Monitor

Read more

Xact® 920 Continuous Water Analyzer for Metals

Read more

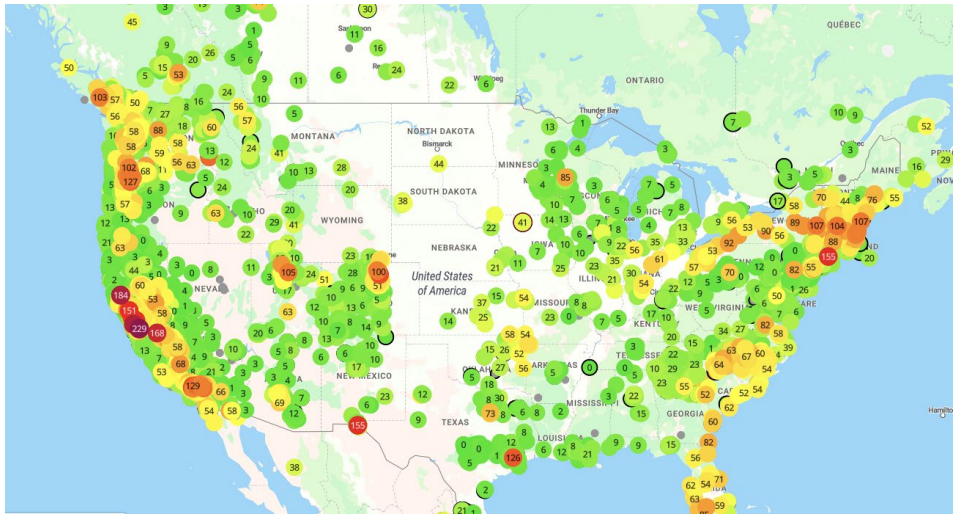
Xact® 640 Multi-Metals Monitor

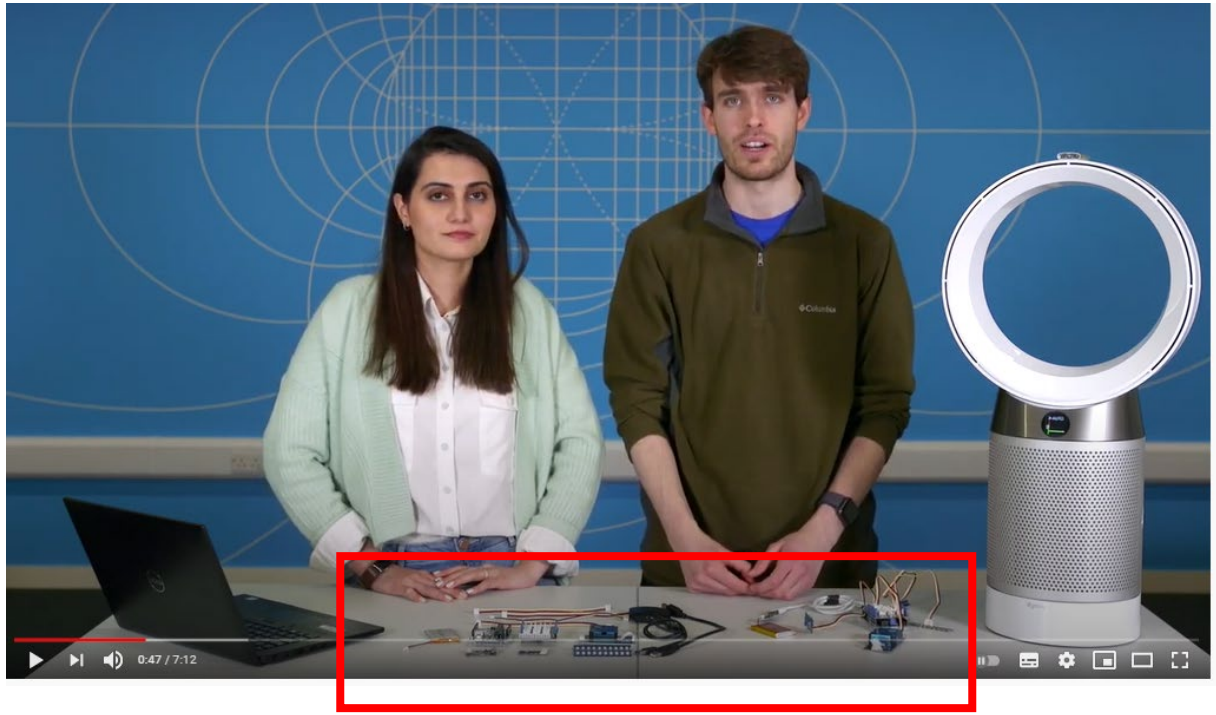
Read more

Xact® 825 Quantitative Aerosol Generator (QAG)

Read more

Low-Cost Air Quality Sensor





[Credits: https://www.youtube.com/watch?v=USHUJzfM5K0](https://www.youtube.com/watch?v=USHUJzfM5K0)

New Paradigm for Air Pollution Monitoring

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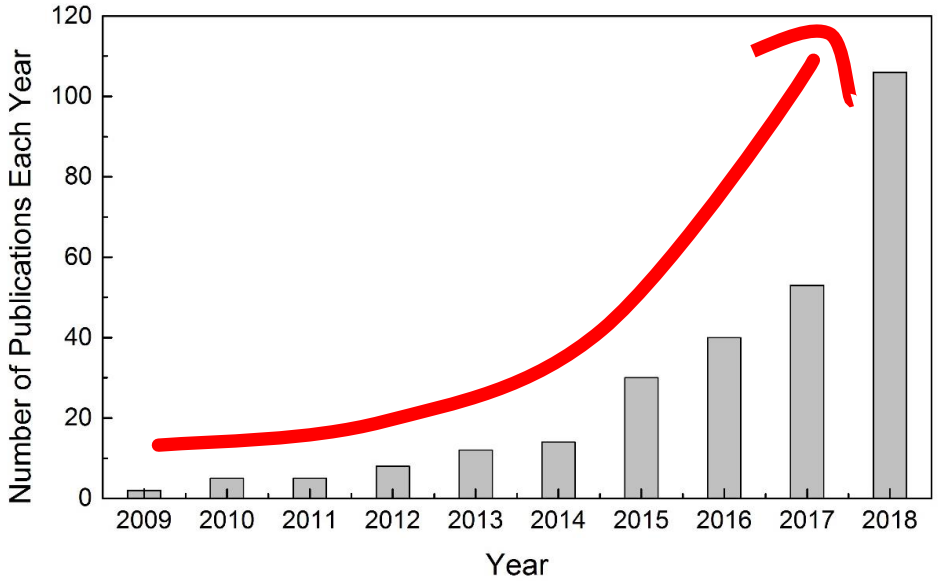
Advantages:

- Data with high spatial and temporal resolutions
- Low cost
- Easy to deploy
- Provides enhanced risk assessment/epidemiological data

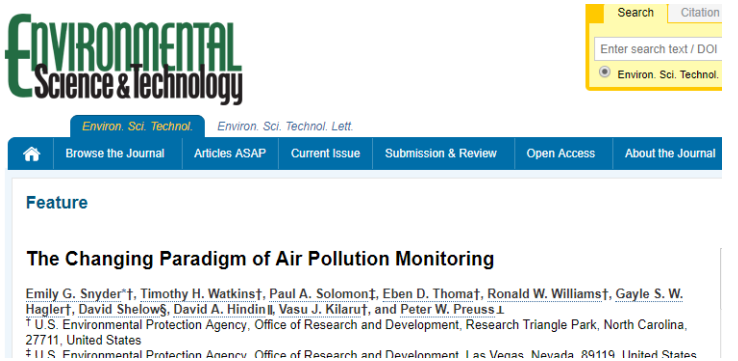
Disadvantages:

- Data Reliability
- Gas cross-interferences
- Meteorological impacts (T, RH)
- Sensor lifetime uncertainty



The number of papers published each year related to "low-cost air quality sensors". Data from Web of Science Core Collection 2009 – 2019

-- Credits to: Dr. Jiayu Li



*"Data of poor or unknown quality is **less useful** than no data since it can lead to wrong decisions"--- Snyder, et al. ES&T, 2013*

Sensor Selection: Finding a needle in a haystack

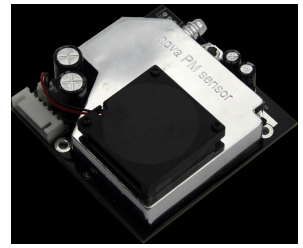
SailBri Cooper, Inc.

PM: PLANTOWER 攀藤科技 · SENSIRION THE SENSOR COMPANY · Alphasense THE SENSOR TECHNOLOGY COMPANY · 诺方电子 Eirtronics · Winsen 炜盛科技

O_3: MEMBRAPOR · EC Sense Easy Gas Sensors · Alphasense THE SENSOR TECHNOLOGY COMPANY · CITY TECHNOLOGY ENGINEERING SAFETY · EMEA TECH

NO_2: MEMBRAPOR · Honeywell | S-Series · EC Sense Easy Gas Sensors · Alphasense THE SENSOR TECHNOLOGY COMPANY · CITY TECHNOLOGY ENGINEERING SAFETY · DD Scientific

CO: SGX SENSORTECH · MEMBRAPOR · Honeywell | S-Series · EMEA TECH · EC Sense Easy Gas Sensors · Alphasense THE SENSOR TECHNOLOGY COMPANY · CITY TECHNOLOGY ENGINEERING SAFETY · FIGARO



SO_2: MEMBRAPOR · Honeywell | S-Series · EC Sense Easy Gas Sensors · Alphasense THE SENSOR TECHNOLOGY COMPANY · CITY TECHNOLOGY ENGINEERING SAFETY · itg

Sensor Screening

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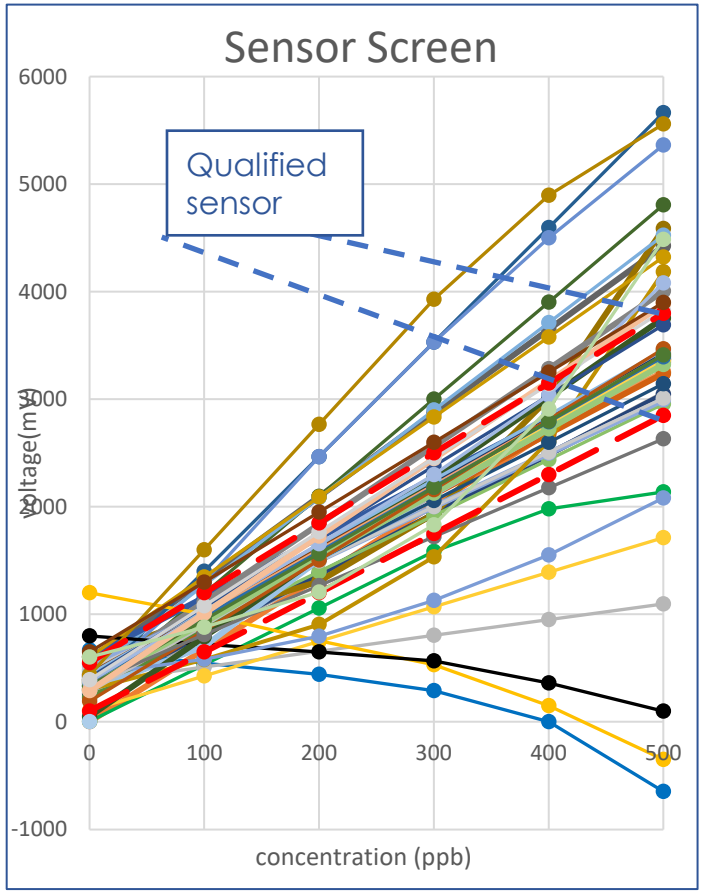
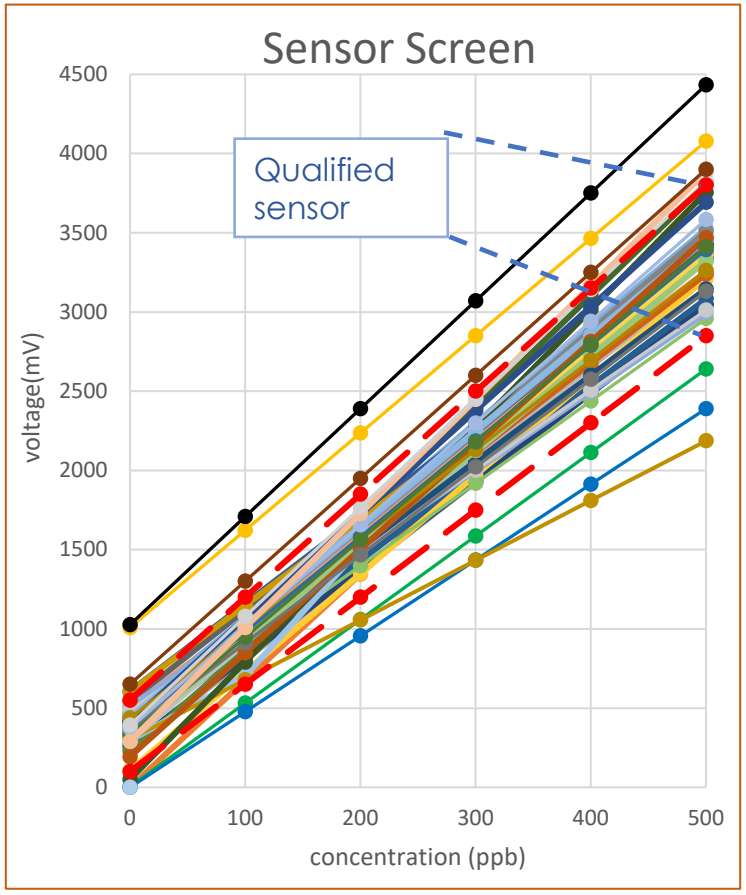
2015



2018

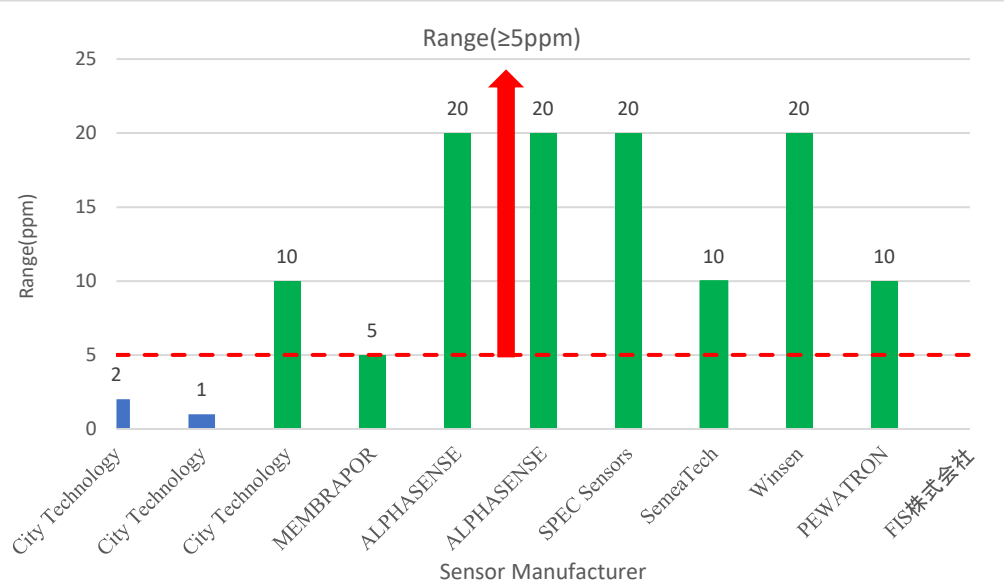


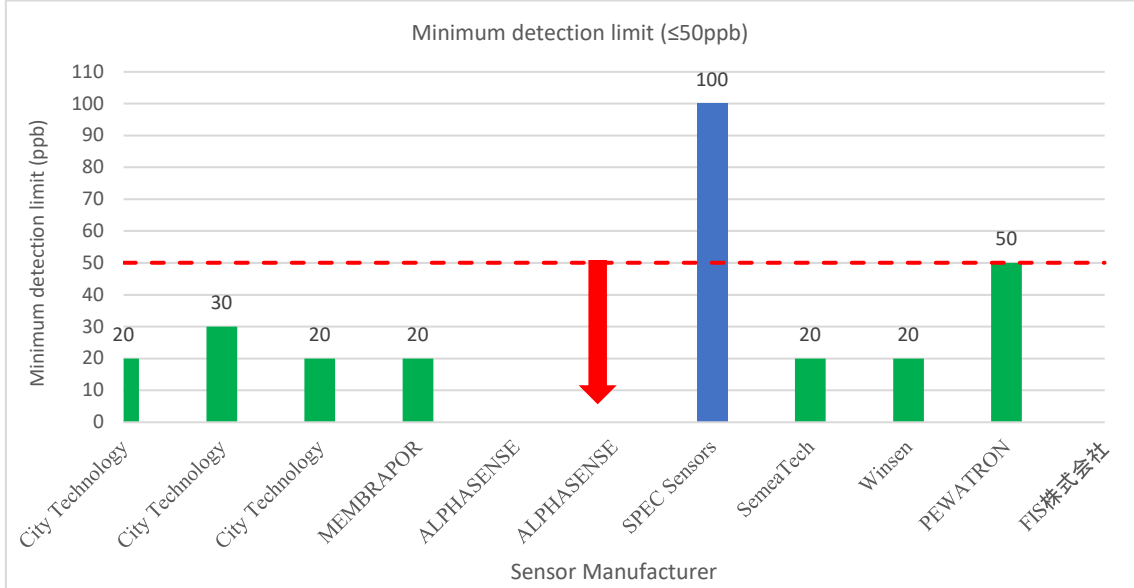
- Input of standard gas for sensor batch screening
- One-time sensor pass rate increases from 42% to **95%**

Preliminary Selection： Ozone Sensor Case

SailBri Cooper, Inc.

O_3

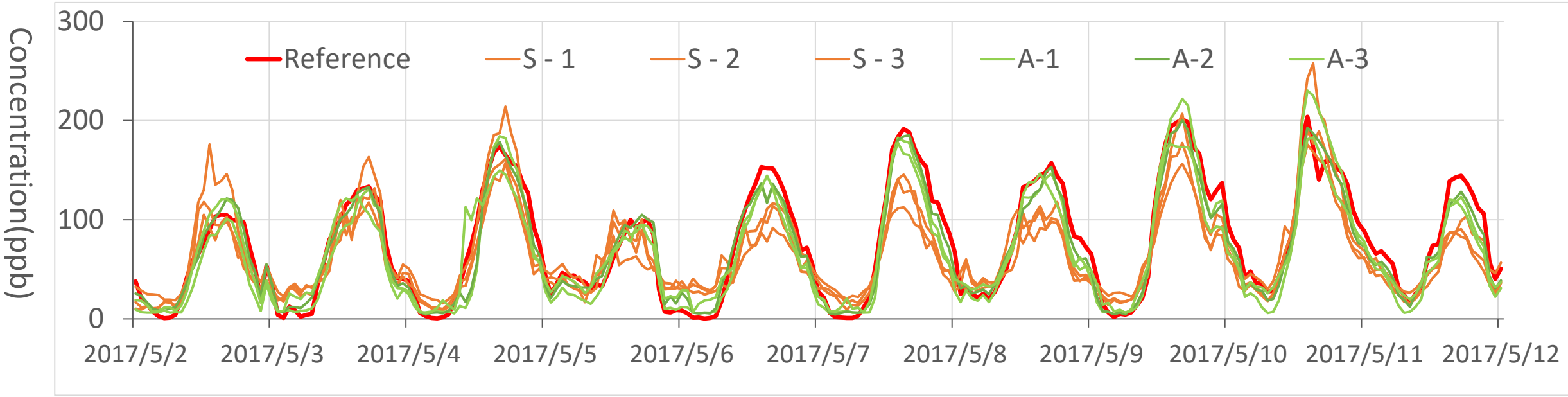


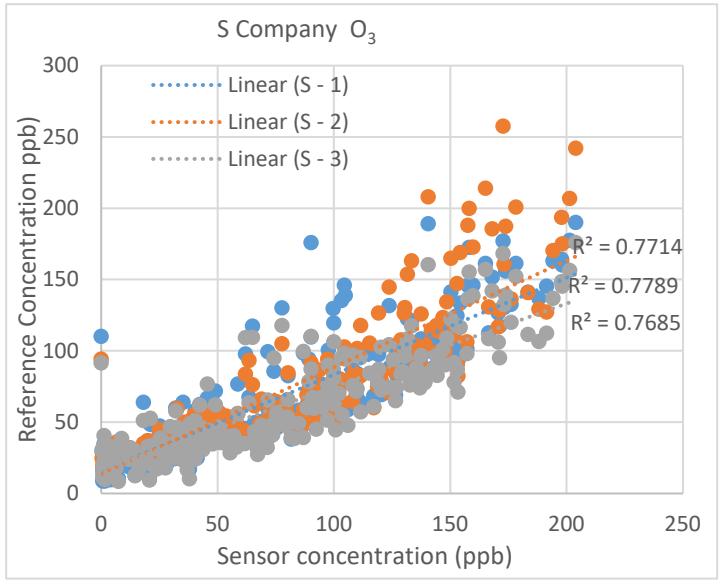


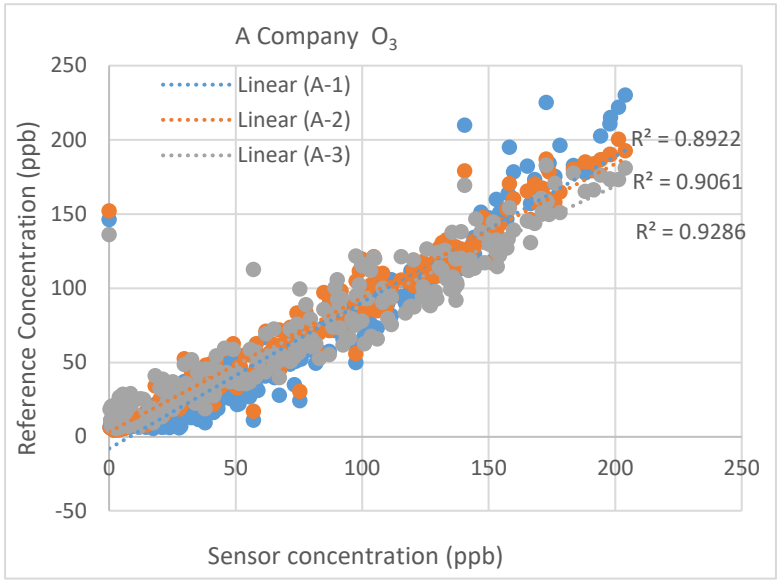
Preliminary selection result： Manufacturers

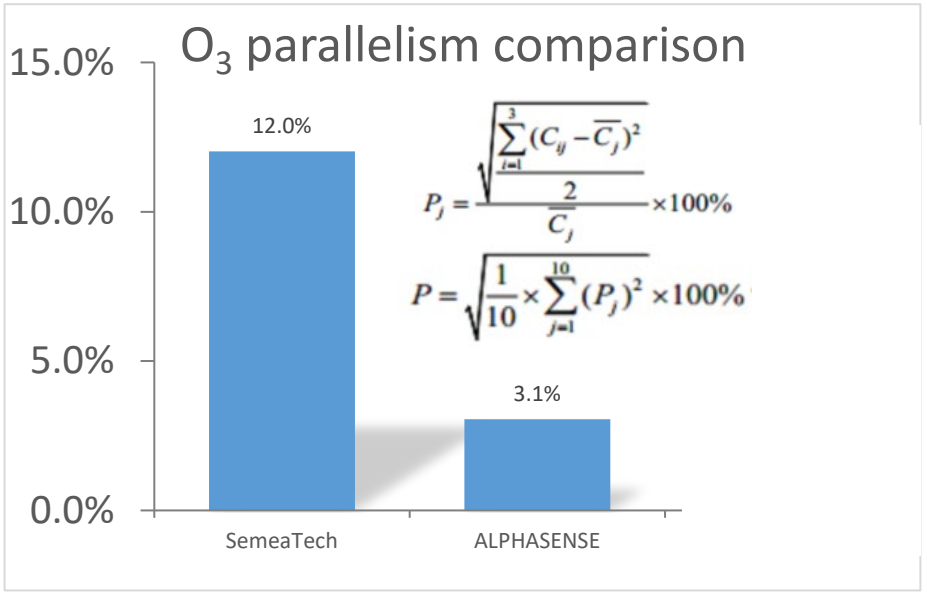
Sensor Manufacturer	Parameter	Product Number	Operating Principle	Range	Detection Limit
CITY TECHNOLOGY ENGINEERING SAFETY	O_3	A3OZ	Electrochemical	0-10 ppm	20ppb
MEMBRAPOR	O_3	O3/C-5	Electrochemical	0-5 ppm	< 0.02 ppm
alphasense THE SENSOR TECHNOLOGY COMPANY	O_3	OX-B431	Electrochemical	0-20ppm	
Eirtronics	O_3	7O3-1	Electrochemical	0–1 ppm	0.02ppm
Winsen 炜盛科技	O_3	ME4-O3-E4	Electrochemical	0-20ppm	20ppb

Field Test : O_3 Sensor Case









Simulated Environmental Calibration - Chamber

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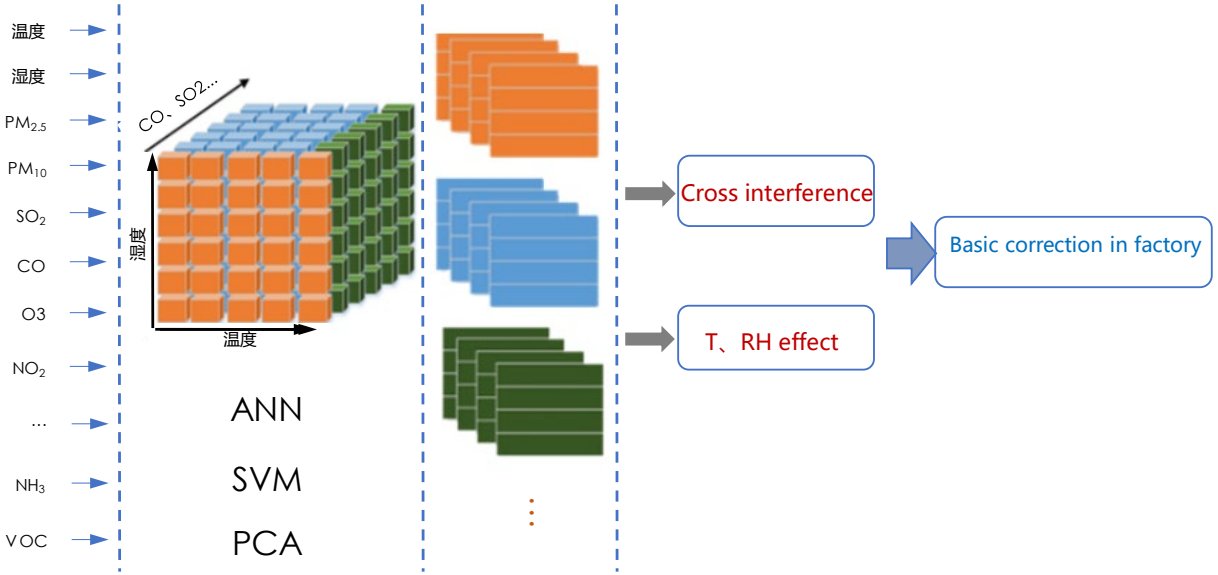


➢**Temperature，humidity，gas cross-interference**

- Component：$PM_{2.5}$、PM_{10}、SO_2、NO_2、O_3、CO…

➢**Simulation of concentration，temperature，and humidity changes**

- Temperature:-20℃~55℃ Humidity: 15%~95%

➢**Simulation of gas cross-interference**

- Dynamic simulation of gas cross-interference to build a gas cross-interference model

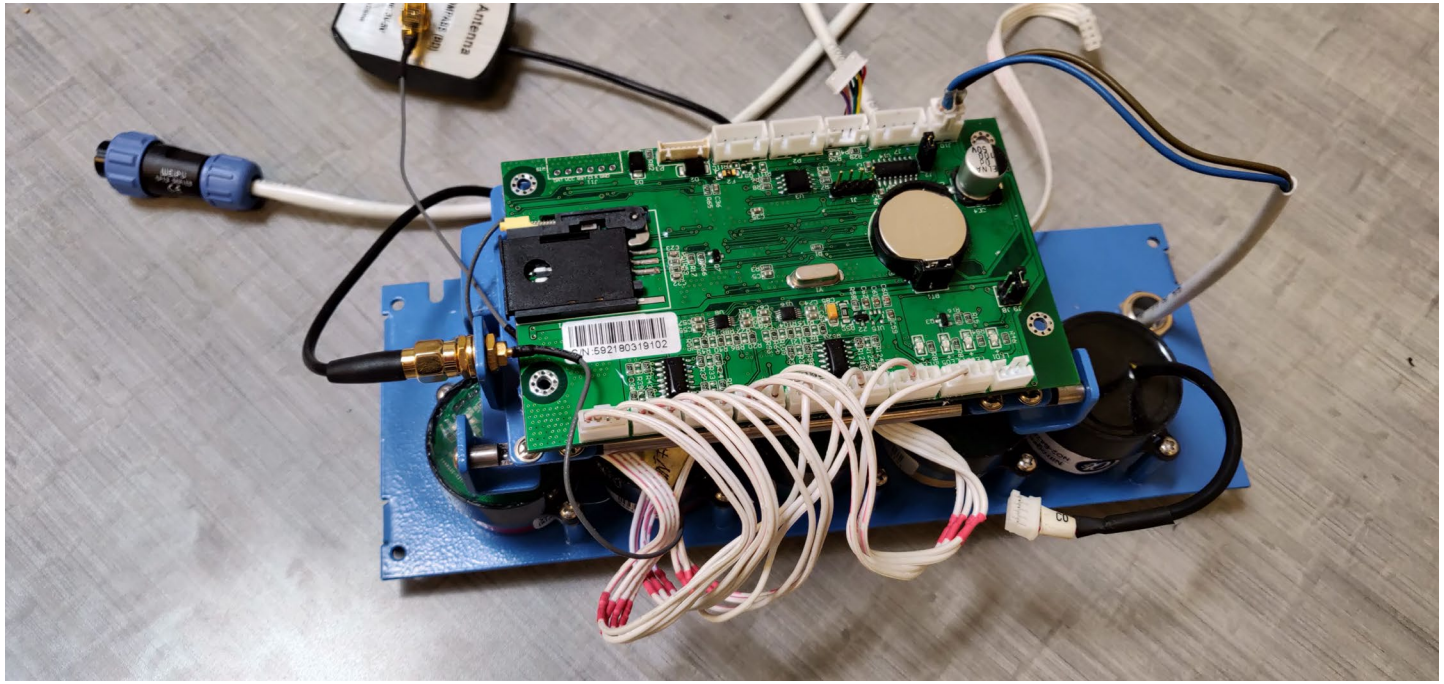
Simulation of different environment and pollution factors in the chamber

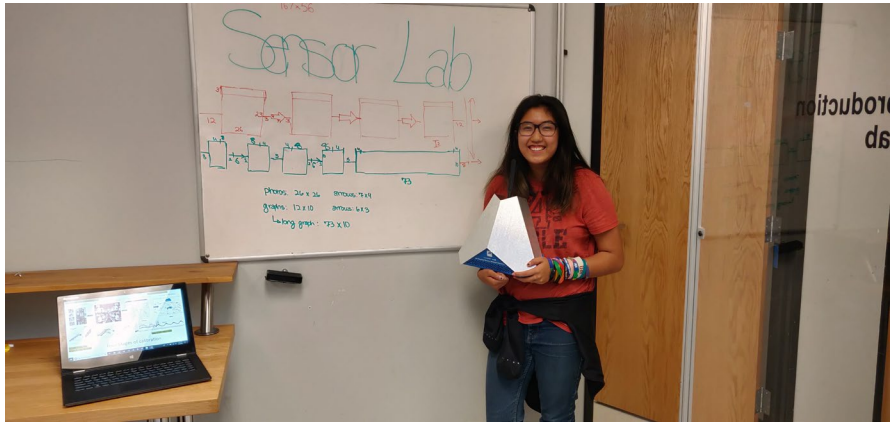
-- Cui, et al. APR, 2021

Sensor Application

SCI-608: $PM_{2.5}$, PM_{10}, O_3, NO_2, CO, SO_2

SailBri Cooper, Inc.





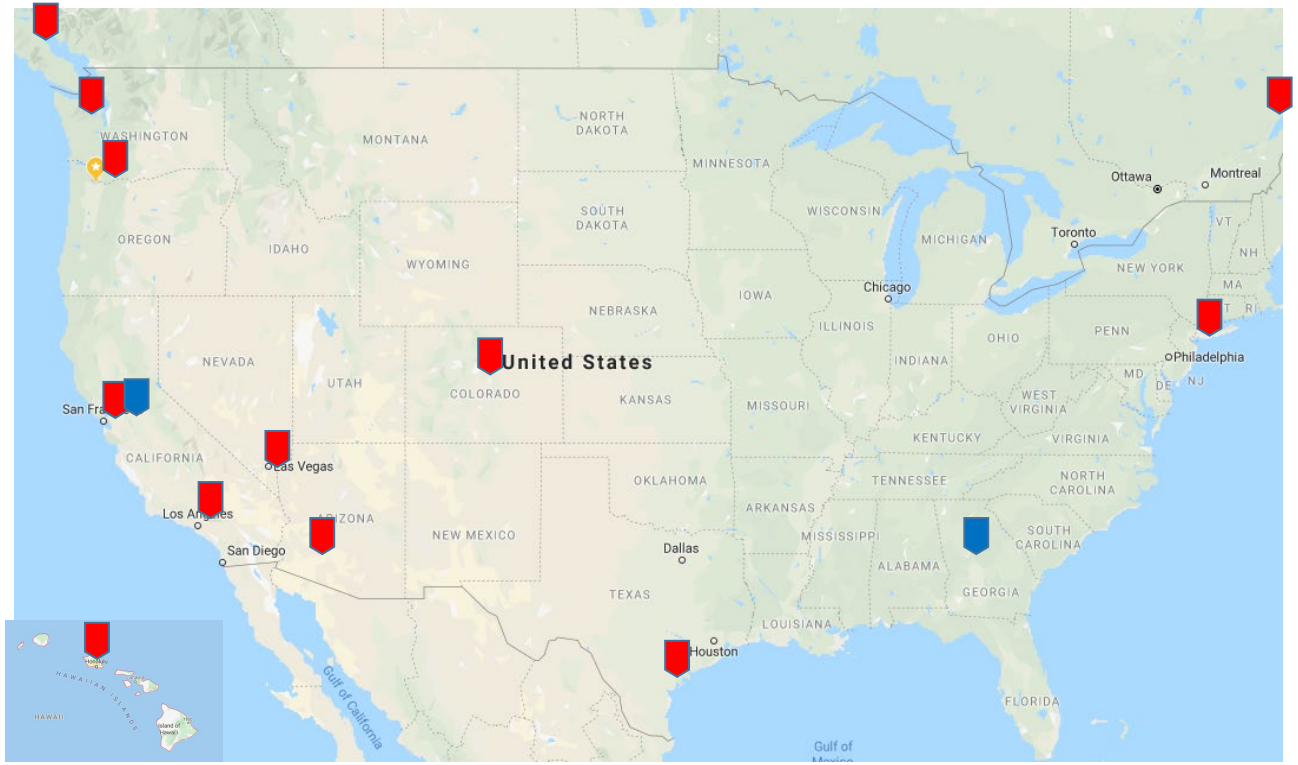
Sensor Nodes in the U.S.

SailBri Cooper, Inc.

SCI-608 have been installed over 10 cities in North America

Portland, OR

Las Vegas, NV



New York City, NY

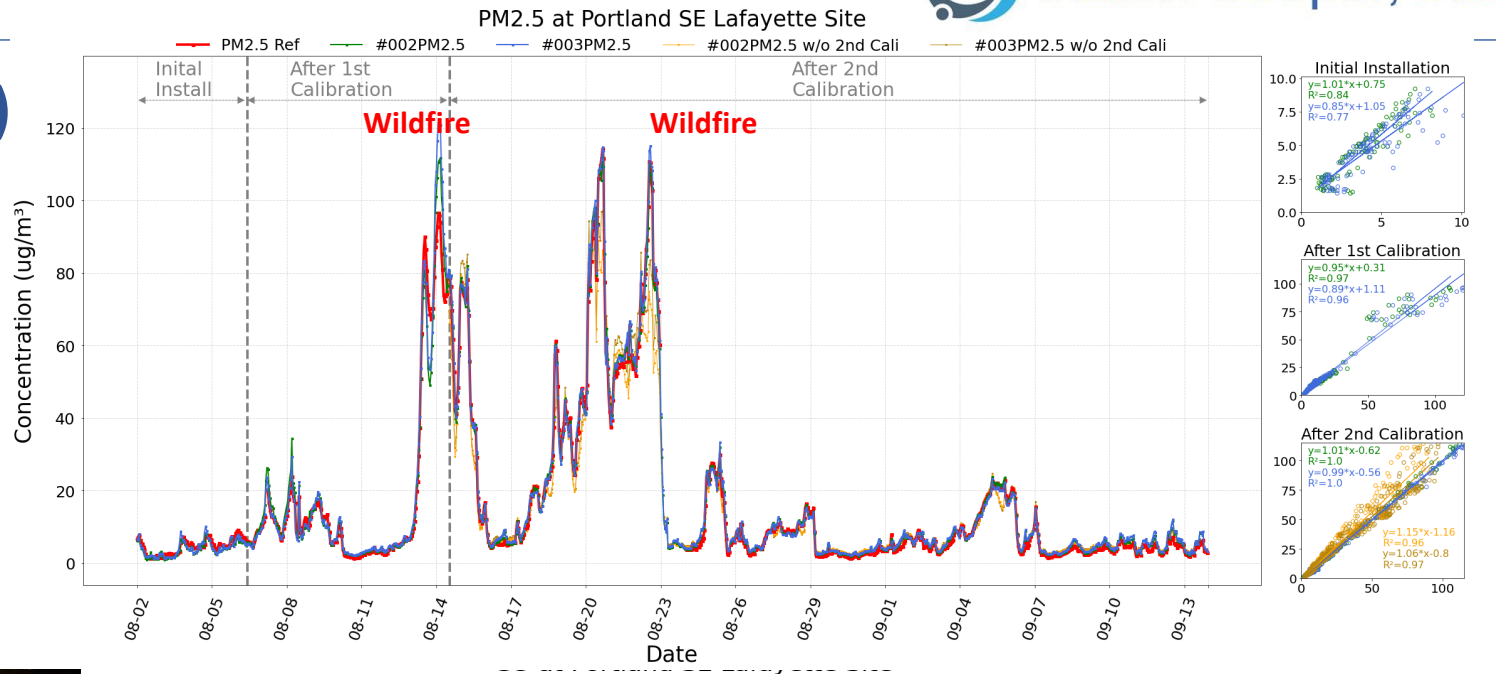
Atlanta, GA

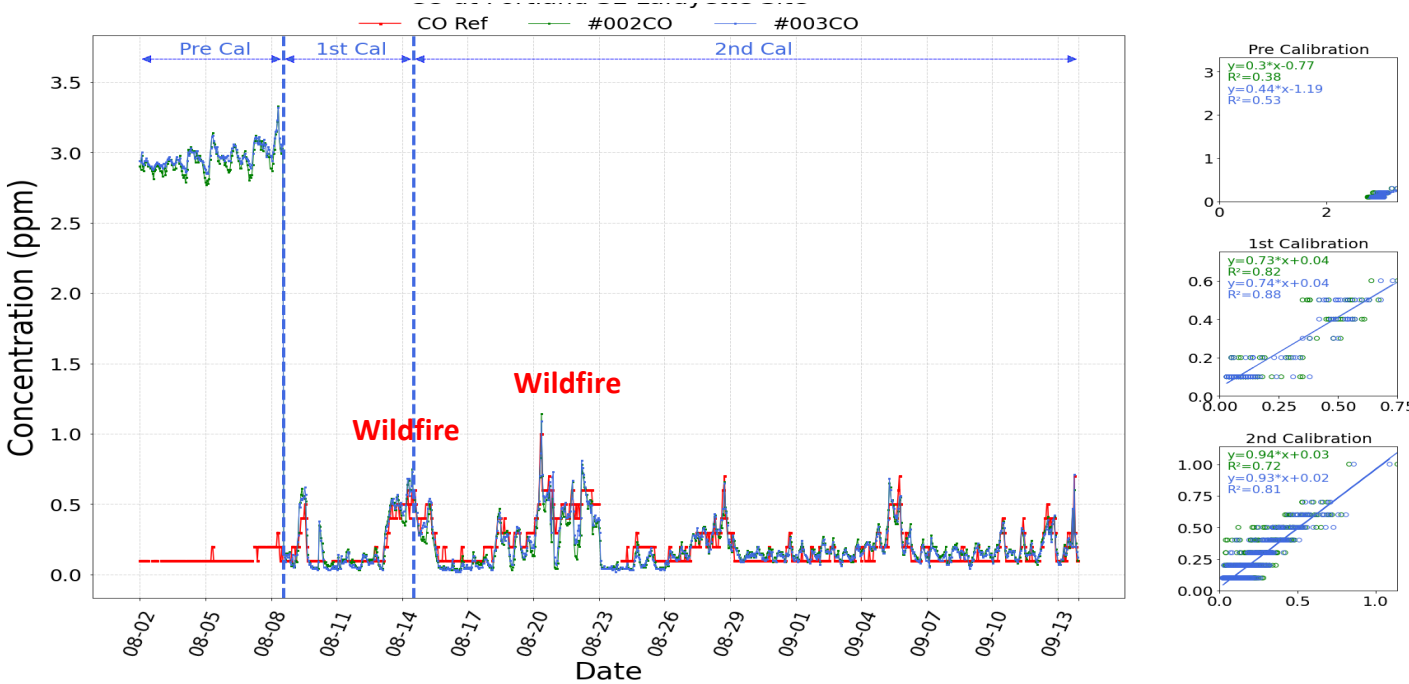
SCI-608 in wildfires

SailBri Cooper, Inc.

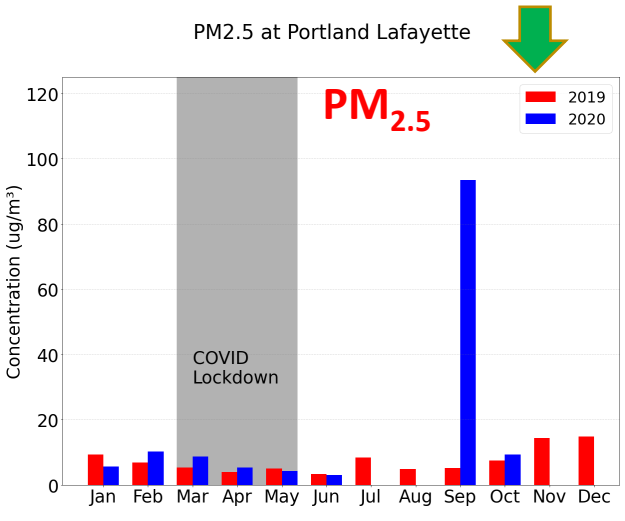
- Portland SE Lafayette Site (OR DEQ)
- Good co-relationship between two sensors (blue and green) and FEM (red), especially after calibration
- No FEM/FER for PM_{10}

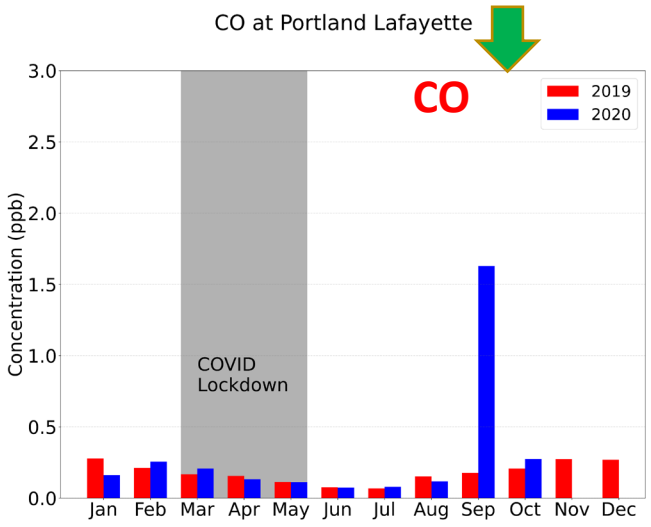
Portland metro area on Aug. 14, 2018

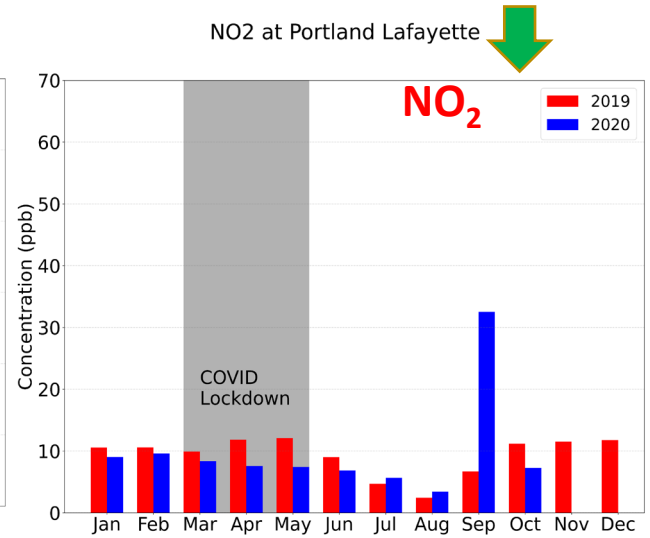


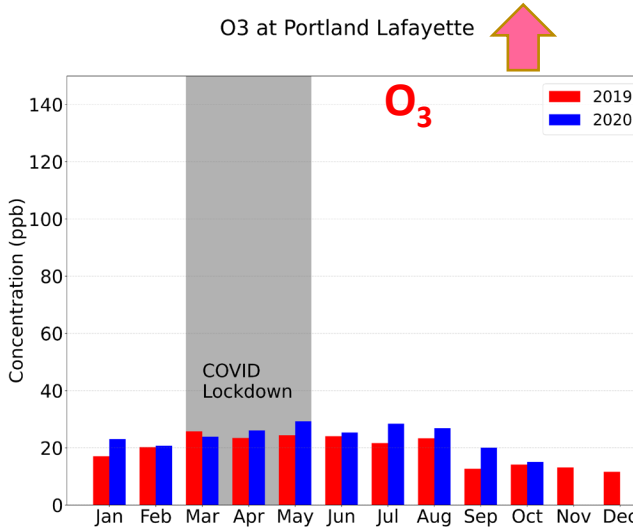


SCI-608 data during Covid-19 lockdown in Portland, OR









- Monthly average sensor data in 2019 and 2020
- Monitoring site located in East Portland residential area
- All air pollutants decreased during the lockdown period, except O_3
- Air pollutant concentrations in Portland area were very low

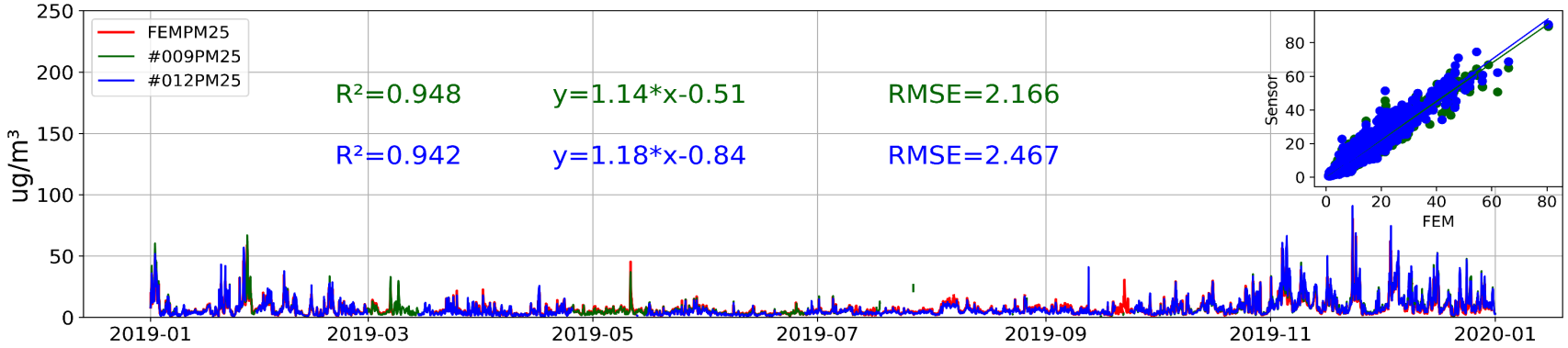
SCI-608 @ Portland, OR (1 Year Data)

SailBri Cooper, Inc.

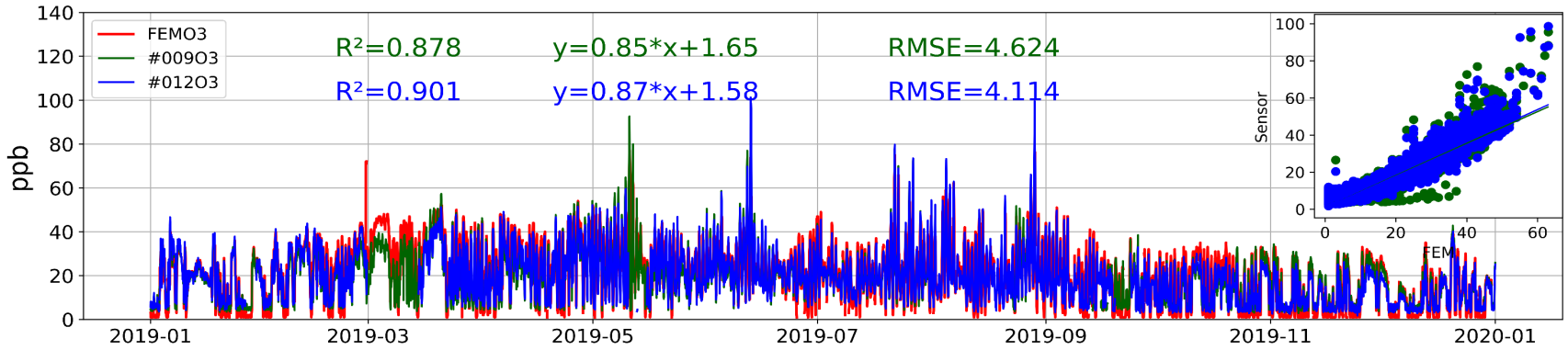
Long-term Evaluation:

Sensors at PortLand SE Lafayette Site

$PM_{2.5}$



O_3



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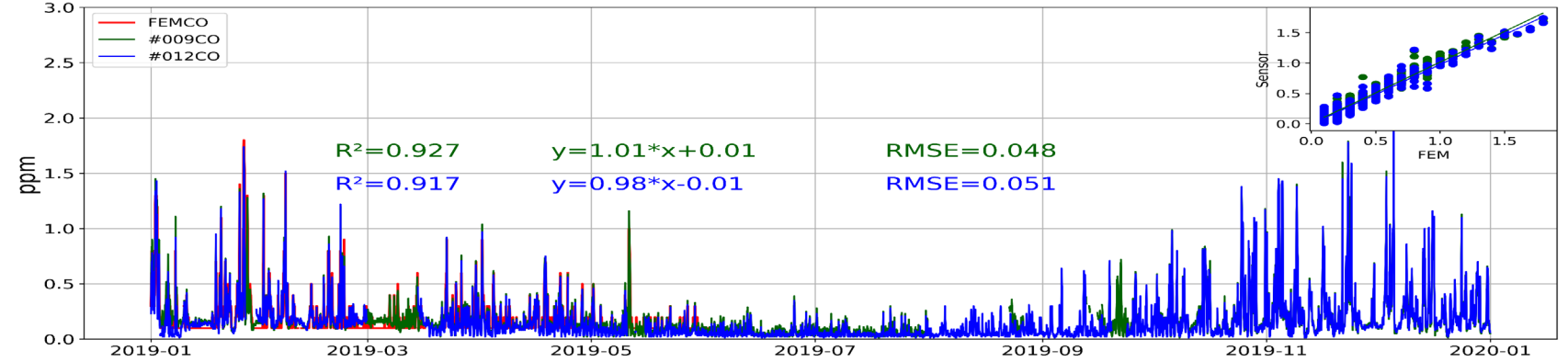


SCI-608 @ New York City, NY

SailBri Cooper, Inc.

- Two SCI-608 Sensor at Queens College site
  - AQS Site ID: 36-081-0124

- Sensor Data
  - 2 mins resolution
  - $PM_{2.5}$, PM_{10}
  - O_3, CO, NO_2, SO_2

Thermo Scientific 1405 DF

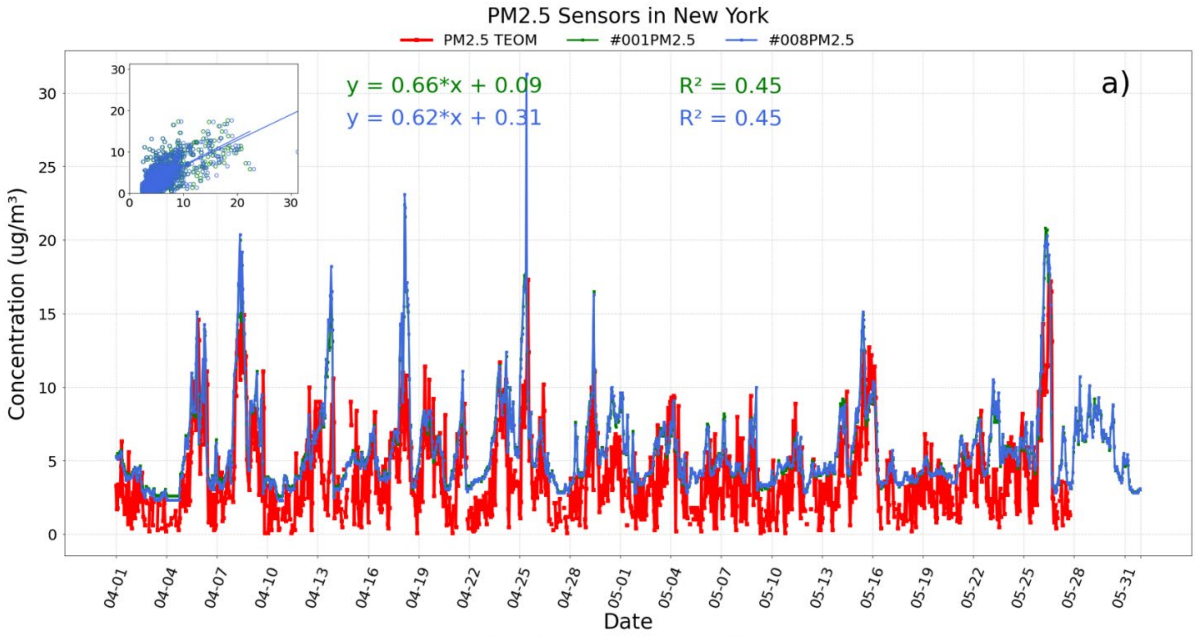
Teledyne T640

- Data Period:
  - Start on 10/28/2019
  - April 1 to May 31, 2020

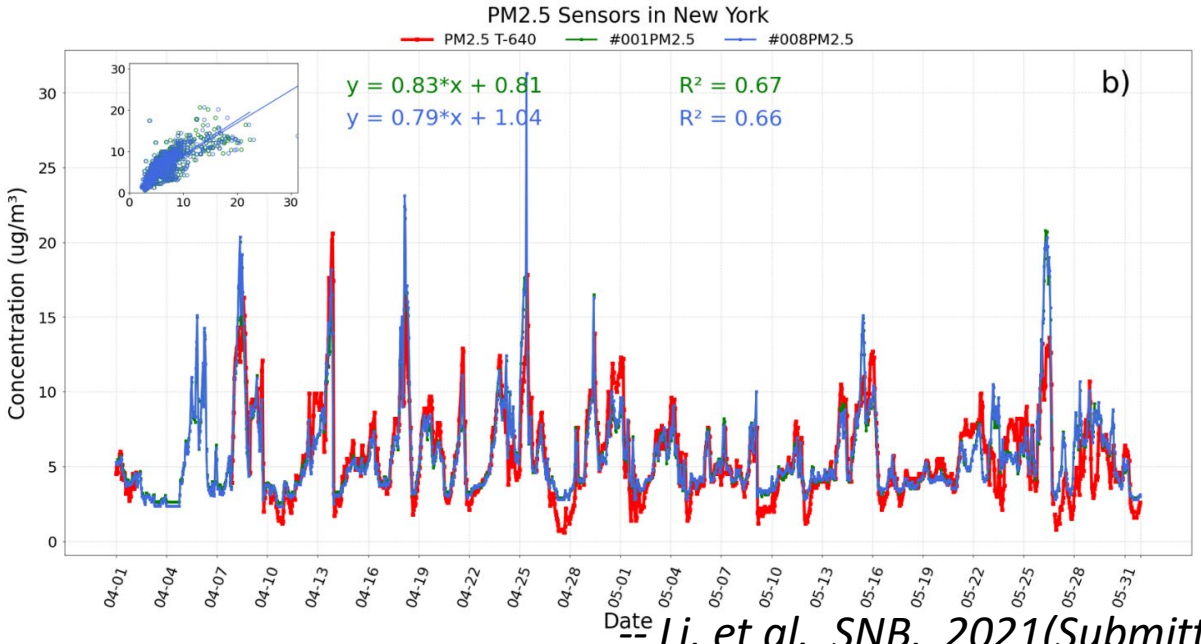
SCI-608 @ New York City, NY

SailBri Cooper, Inc.

Thermo Scientific 1405 DF vs Sensor : R^2 =0.45



Teledyne T640 vs Sensor : R^2 =0. 67



-- *Li, et al. SNB, 2021(Submitted)*

Sensor test data from AQ-SPEC

SailBri Cooper, Inc.

BAM-1020 (Principle: beta ray attenuation)

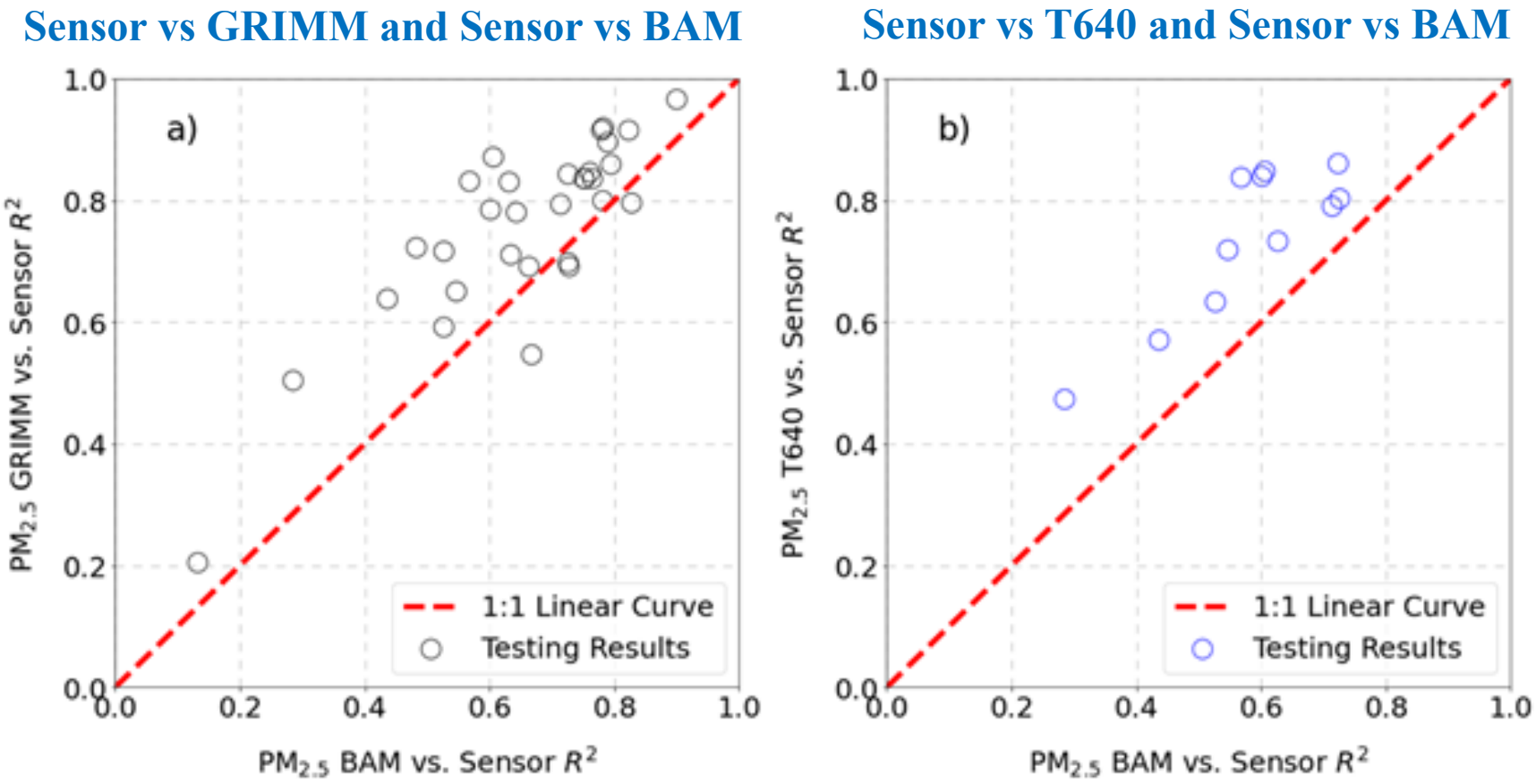
API T-640 (Principle: light scattering)

Grimm 180 (Principle: light scattering)

Many thanks to SC- AQSPEC for doing this valuable work!

Sensor test data from AQ-SPEC

SailBri Cooper, Inc.



- 43 field reports
- There are inconsistencies between different types of FEMs, which can influence public assessment of sensor performance

-- Li, et al. SNB, 2021(Submitted)

SCI-608 in Community Monitoring

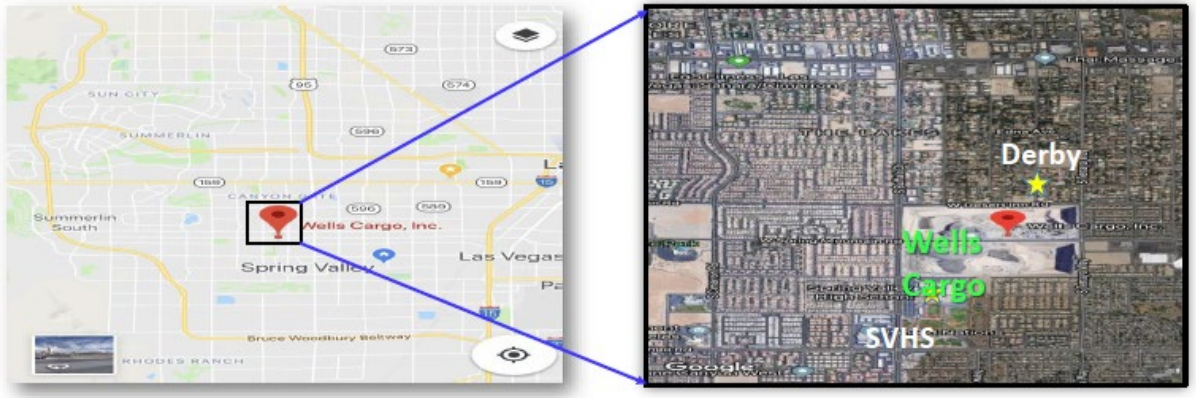


Figure 1. Sensor Location. The map indicates location of two monitoring sites, SVHS and Derby, relative to the Wells Cargo plant. Both sites are within 100 m from the Wells Cargo.

Figure 2. Asphalt Plant and community protest against its dust emissions

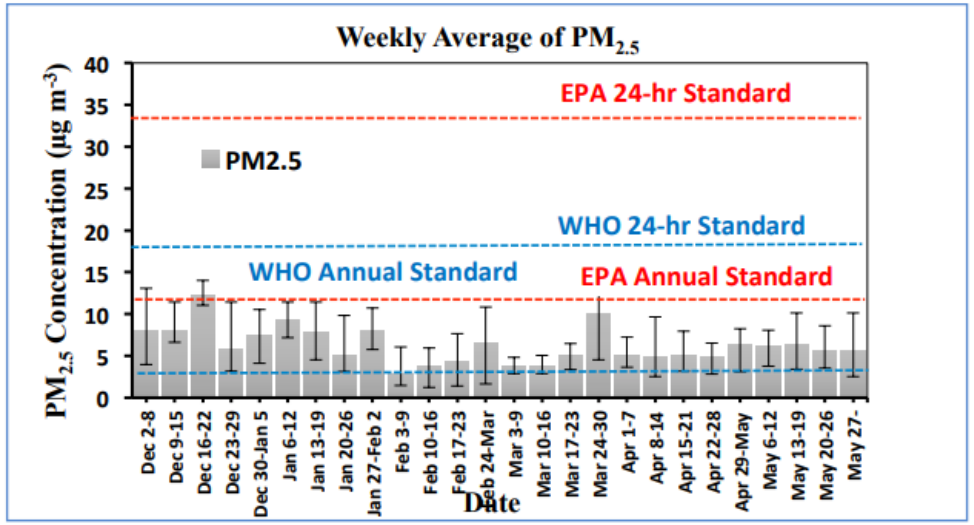
(a) (b)

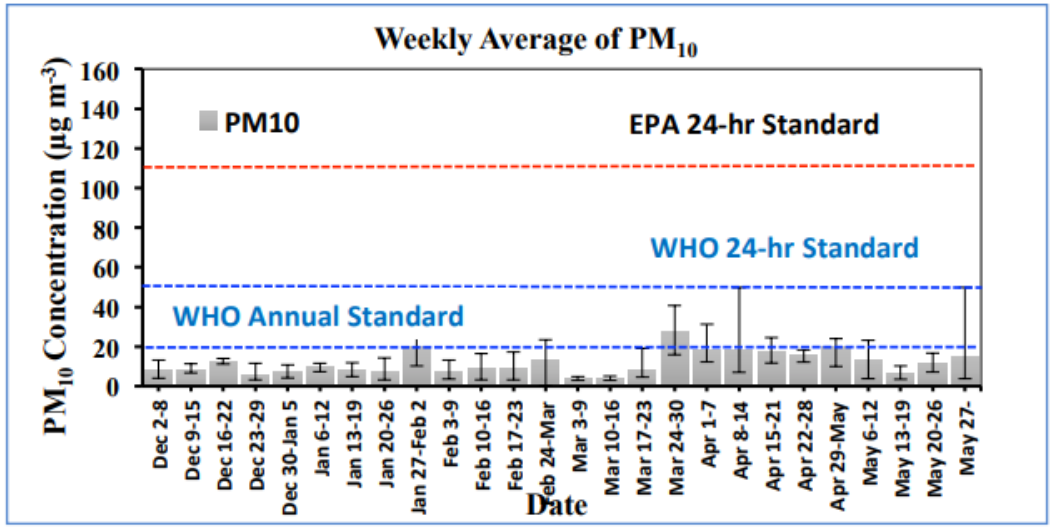
Figure 4. Illustration of (a) NFRM and (b) SCI 608 air quality monitors at the SVHS and Darby site, respectively.

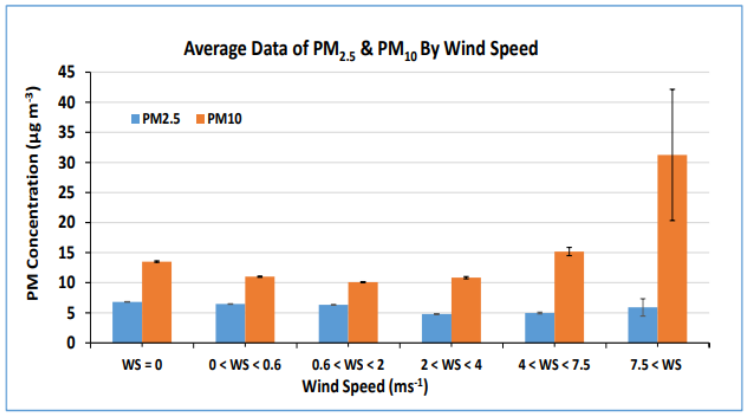
- Residents concerned about dust pollution from asphalt Wells Cargo plant in Las Vegas, NV
- Two SCI-608 sensor were deployed in upwind and downwind site

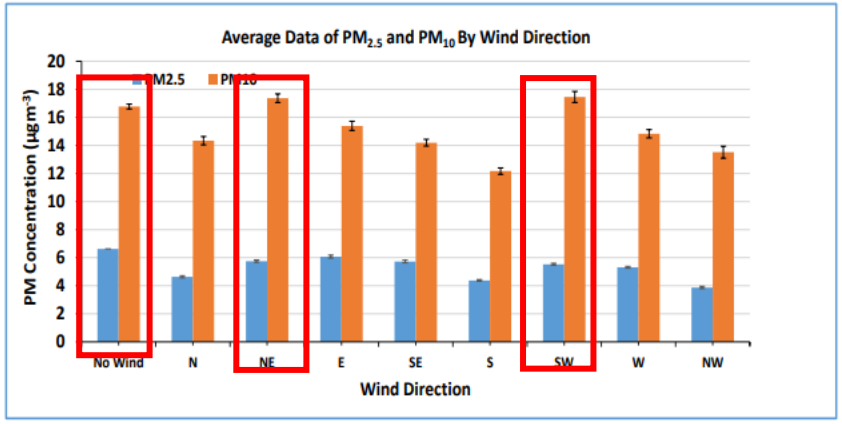
Gebremariam Gebreselassie, Aman. "Community Exposure to Particulate Matter and Its Impact for Students and Residents Near a Construction Asphalt Plant: A Case Study." (2019).

SCI-608 in Community Monitoring









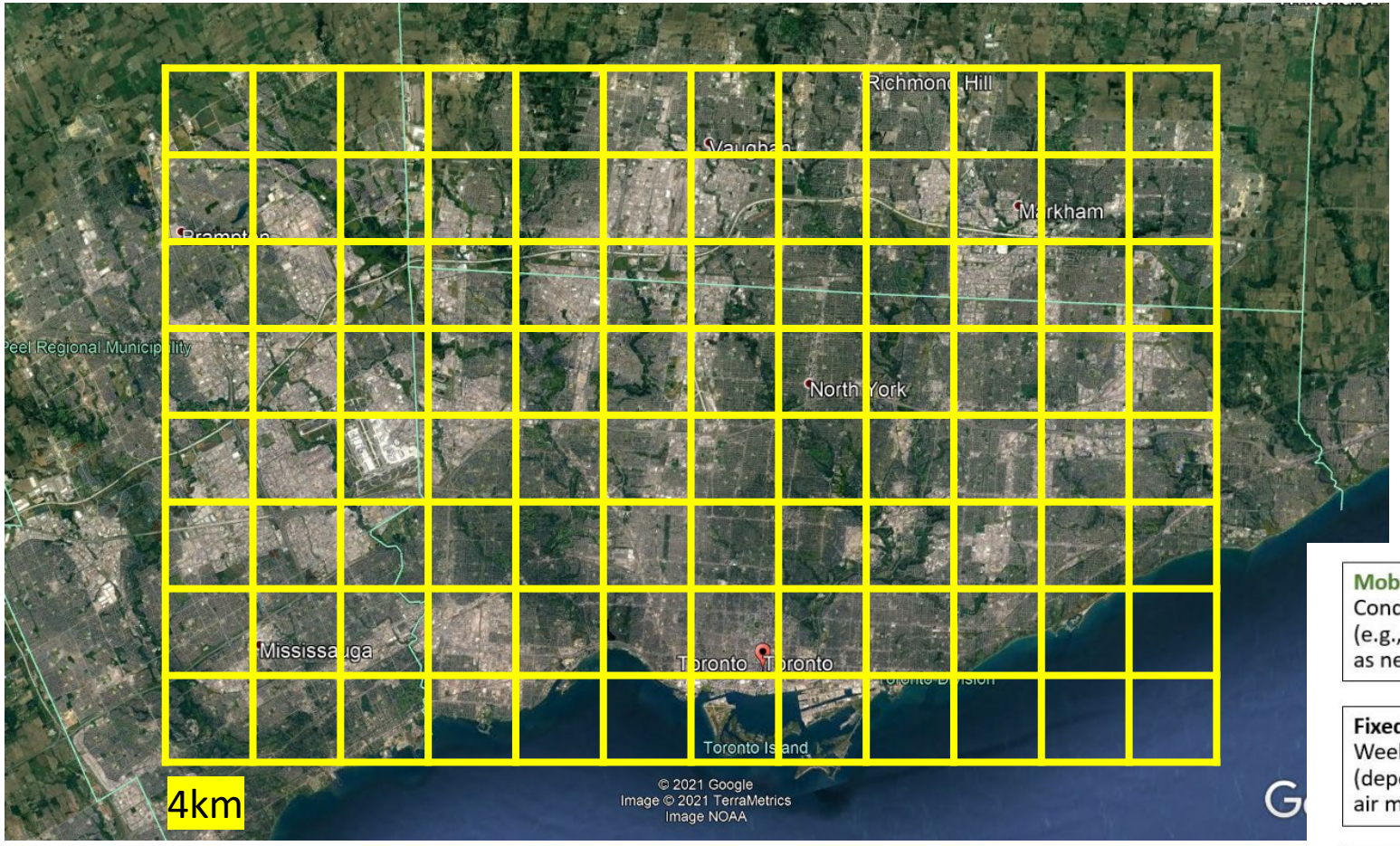
- PM data show no violation to the U.S. EPA air quality standards
- The asphalt plant does increase the short-term and long-term exposure of schoolchildren and community to PM pollution, especially during windy conditions.

Gebremariam Gebreselassie, Aman. "Community Exposure to Particulate Matter and Its Impact for Students and Residents Near a Construction Asphalt Plant: A Case Study." (2019).

Air Quality Sensor Networks Application

Air Quality Sensor Network

SailBri Cooper, Inc.



- **How to conduct the sensor calibration ?**

  …….

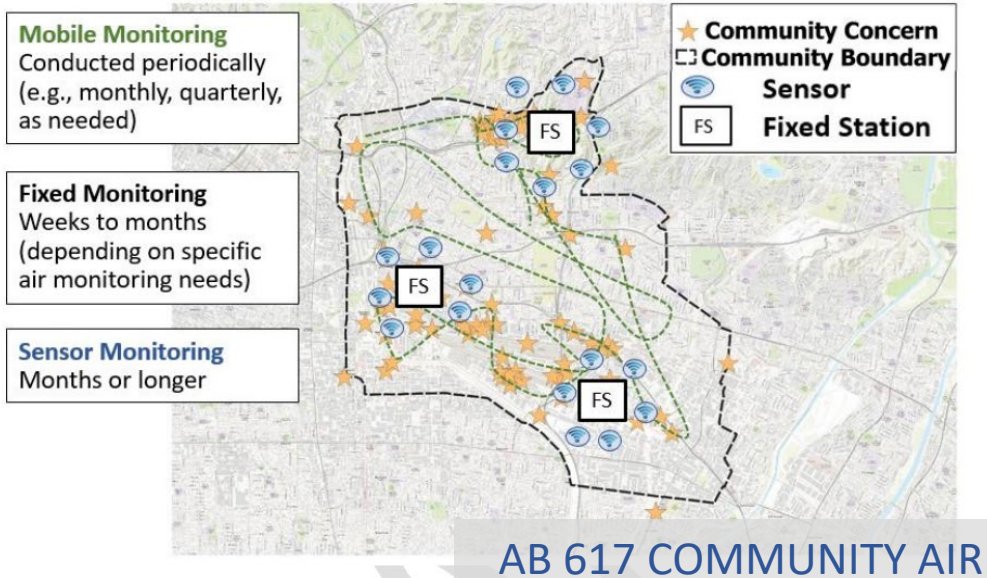


Figure 5 - Overview of the Monitoring Approach Proposed in this CMP

Sensor Nodes @ Phoenix, AZ

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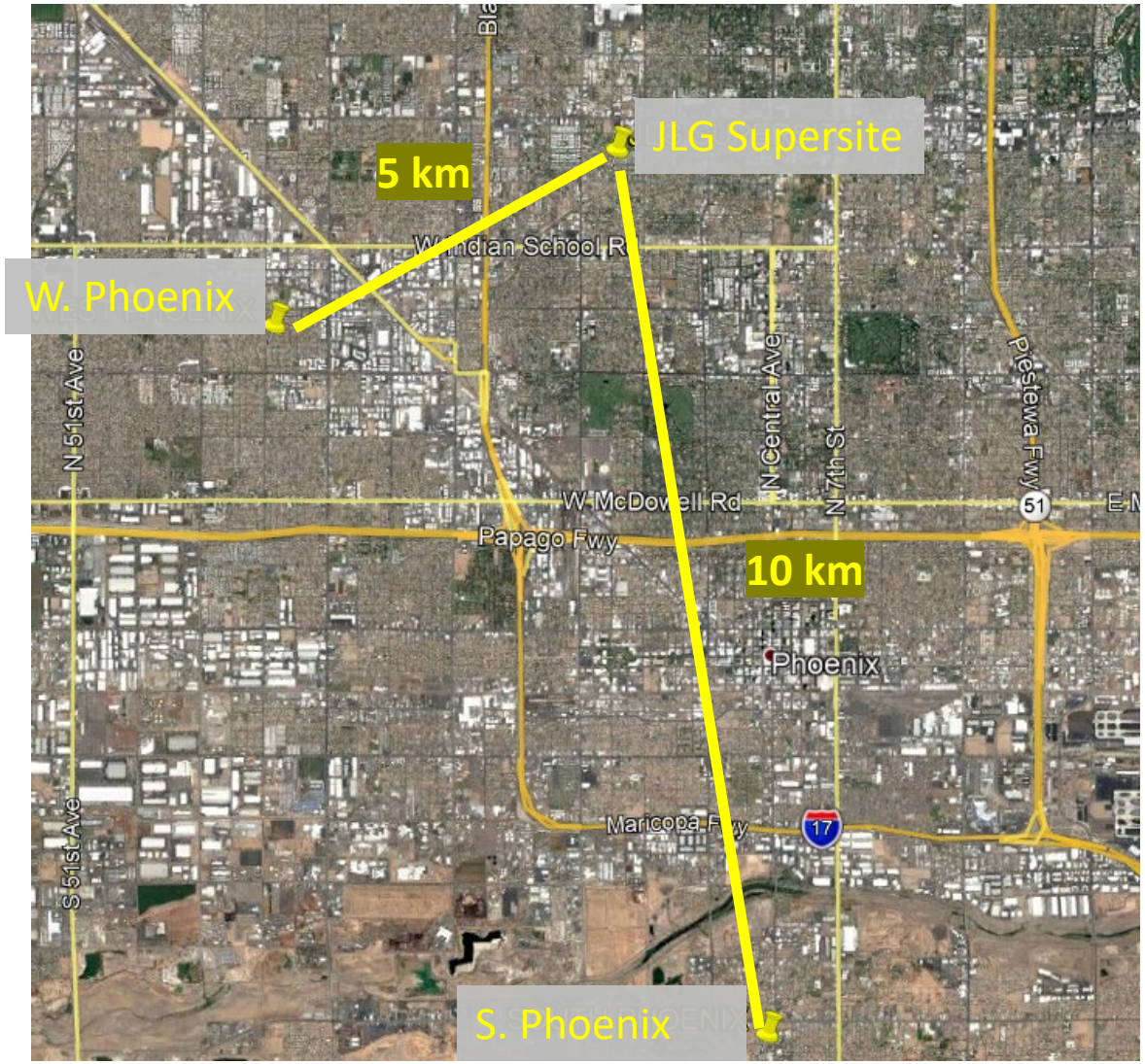
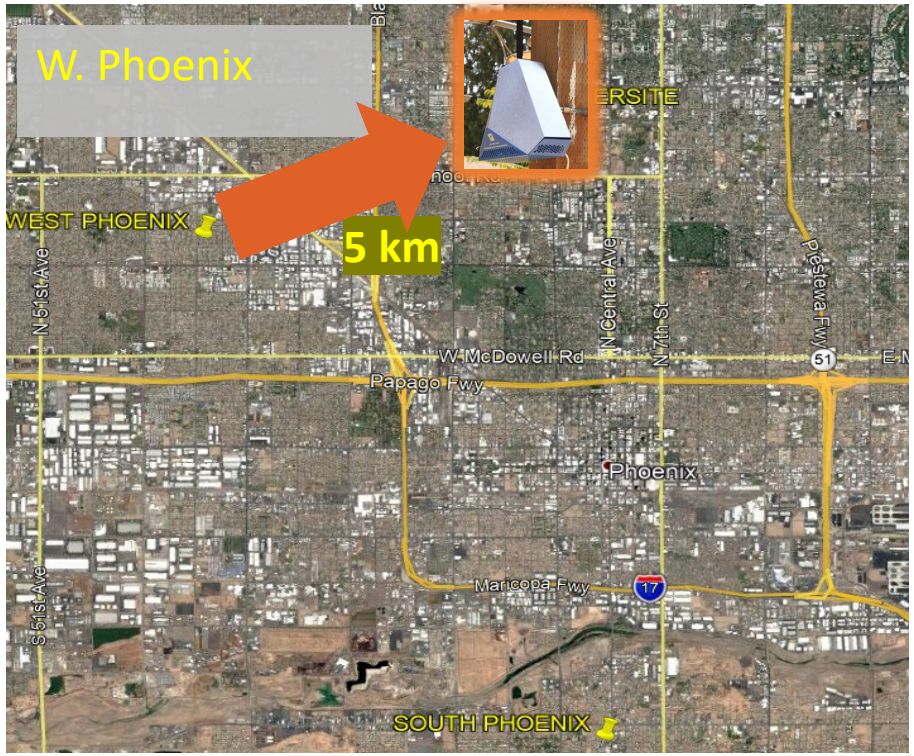


Site Name	PM2.5	PM10	CO	O3	NO2
JLG	√	√	√	√	√
W. PHX	√	√	√	√	
S. PHX	√	√	√	√	√

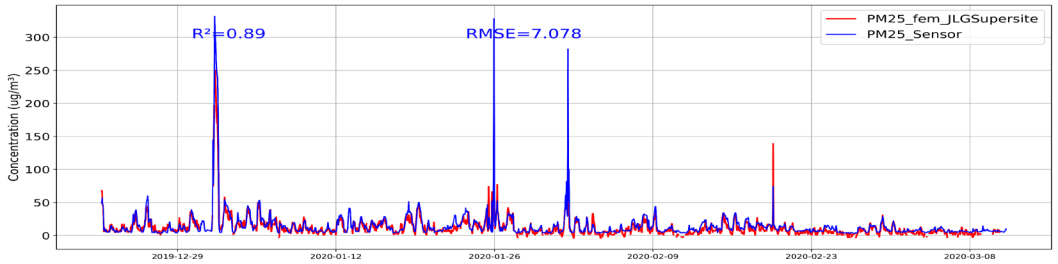
Sensor Data vs JLG Reference Data

SailBri Cooper, Inc.

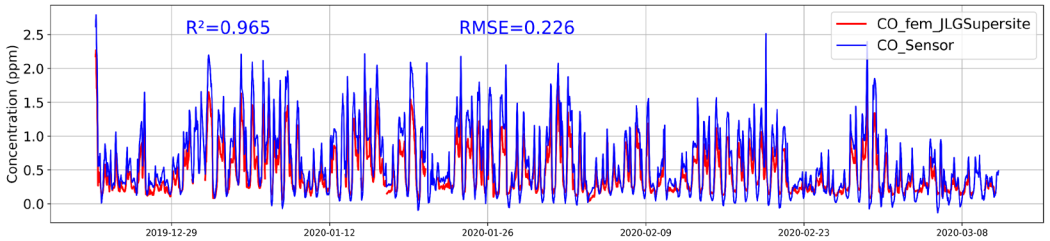
Sensor data was calibrated by the data from West Phoenix site



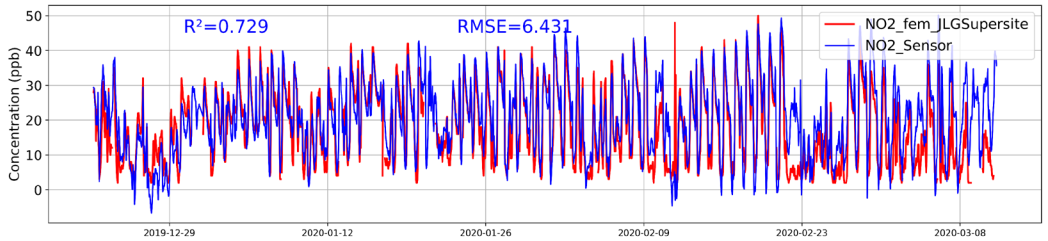
$PM_{2.5}$



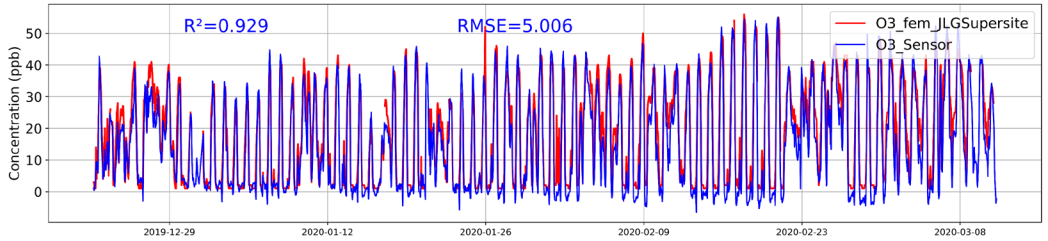
CO



NO_2



O_3



Site Name	Dis. From JLG	$PM_{2.5}$		CO		NO_2		O_3	
		R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE
W. PHX	5 km	**0.89**	7.08	**0.96**	0.23	**0.73**	6.43	**0.93**	5.01

Sensor Data vs JLG Reference Data

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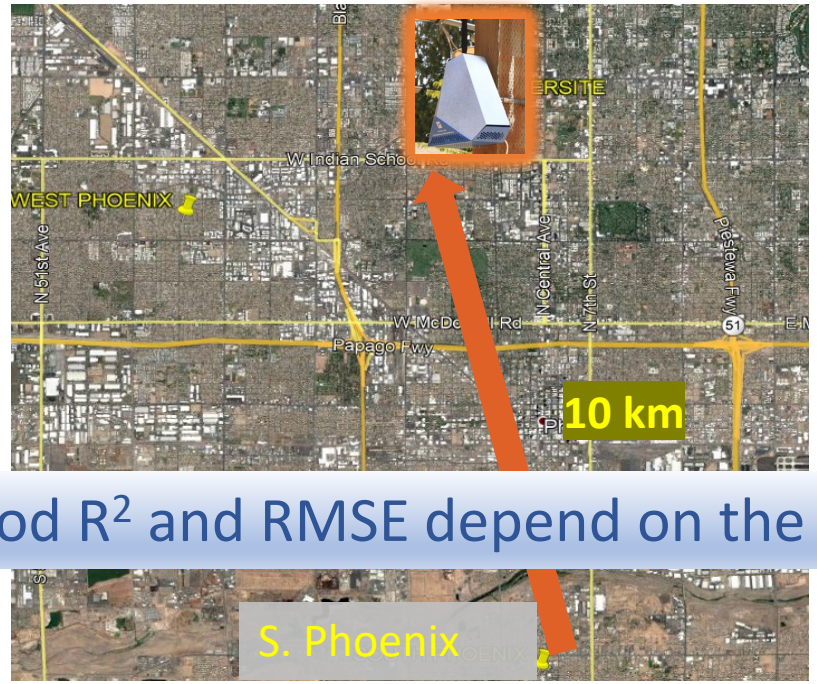
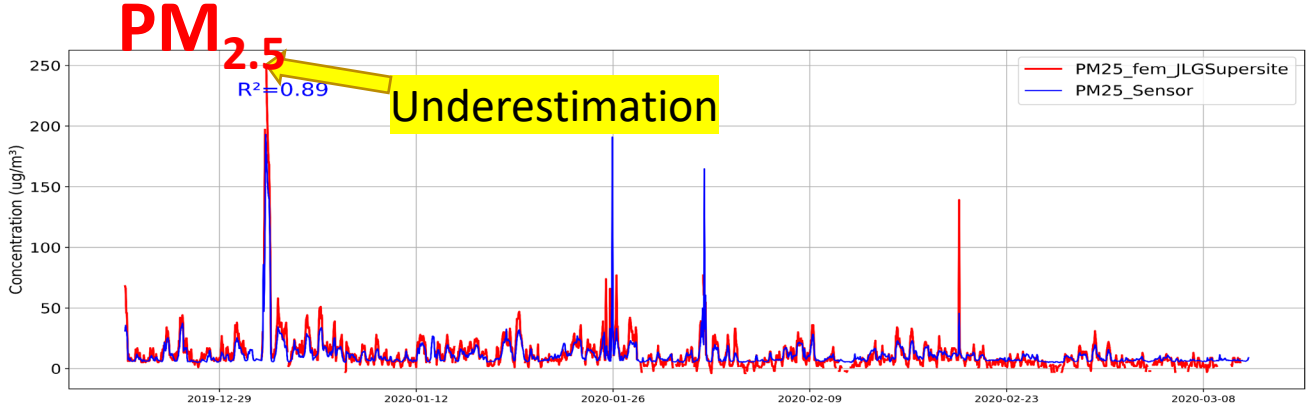
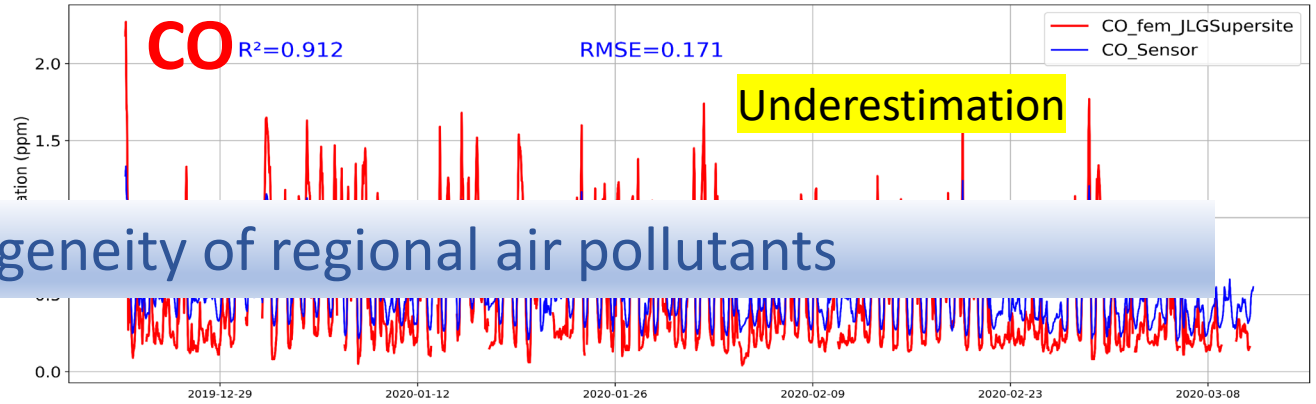
Sensor data was calibrated by the data from South Phoenix site

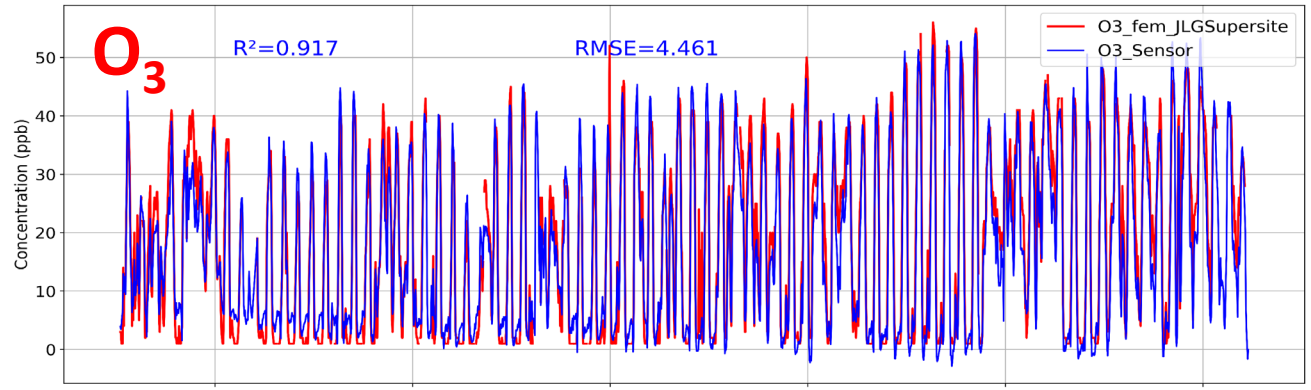


Good R^2 and RMSE depend on the homogeneity of regional air pollutants

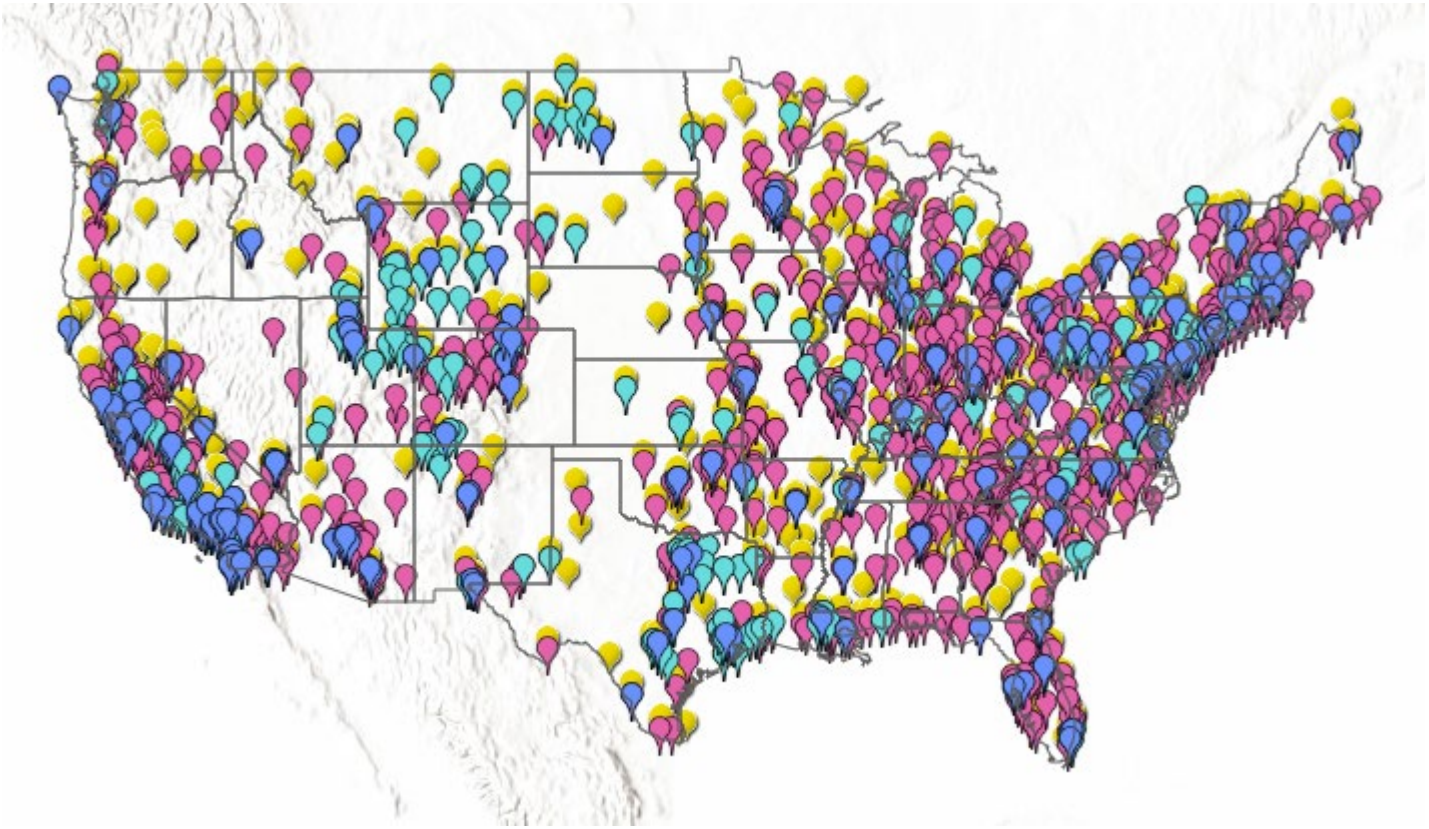
Site Name	Dis. From JLG	$PM_{2.5}$		CO		O_3	
		R^2	RMSE	R^2	RMSE	R^2	RMSE
S. PHX	11 km	0.89	7.06	0.91	0.17	0.92	4.46





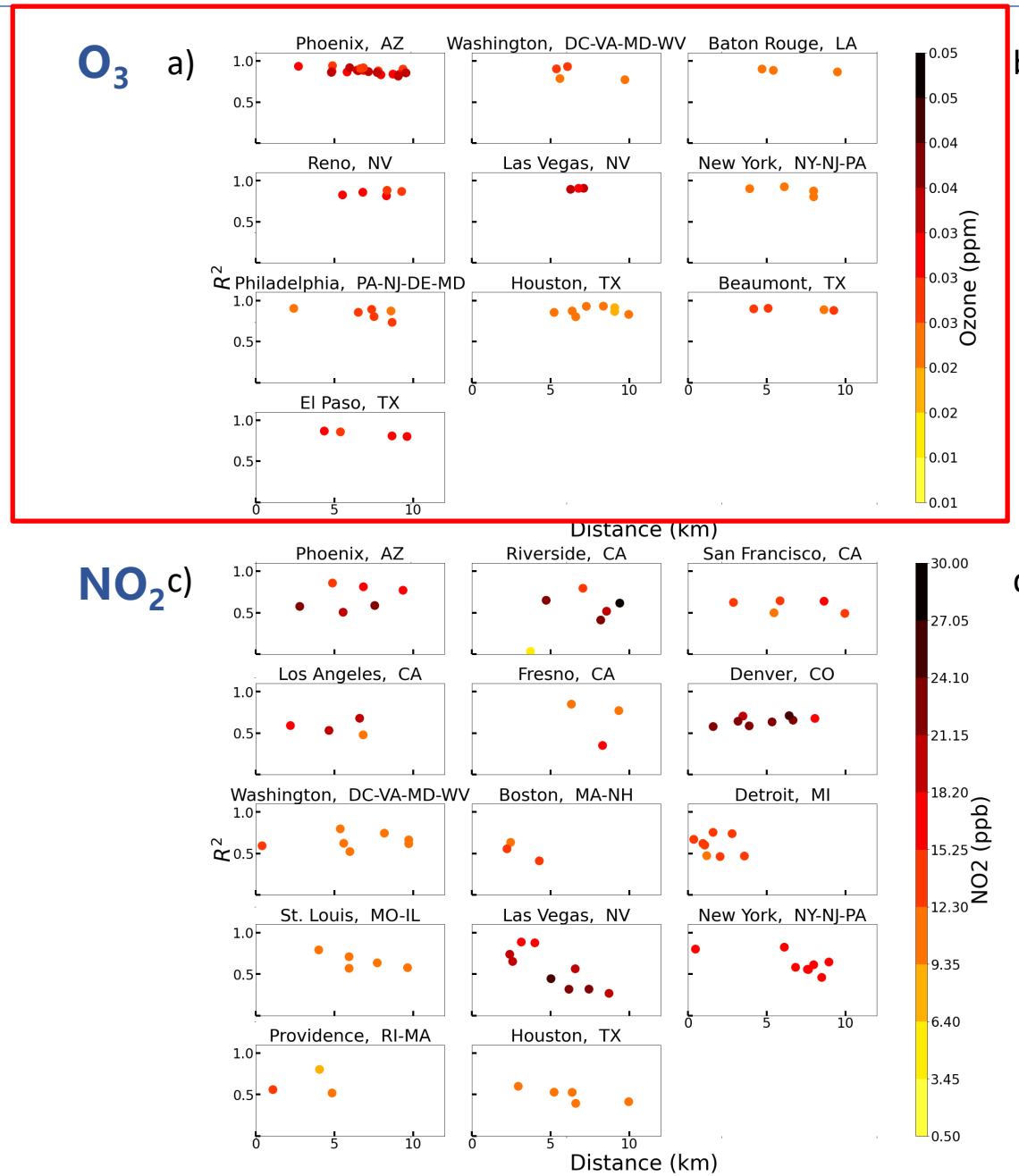


Does the optimal density of LCAQS vary by location and pollutant of interest?



- $PM_{2.5}$、 O_3 、 NO_2、CO
- EPA sites with distance between each other <10 km
- 162 sites in 22 cites
- Data from 2017 to 2019

Does the optimal density of LCAQS vary by location and pollutant of interest?



-- Li, et al. SNB, 2021(Submitted)

Take Home Messages

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- Building an air quality sensor is not an easy work
- Data quality control system is the key to the success of sensor measurement
- Machine learning technology can enhance the performance of the sensor during air pollution episodes (i.e. Wildfire, Dust storm)
- Low-cost air quality sensor is complementary to the reference station
- Sensor network deployment need more guidance from environmental agencies

remote sensing

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SailBri Cooper, Inc.

Air Quality Sensors and Their Application

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Message from the Guest Editors

The Special Issue invites submissions related to low-cost air quality sensors and their applications. Topics in this Special Issue are expected to cover a range of cutting-edge sensor technologies and applications, such as the following:

- Development and testing of next-generation sensors
- Laboratory sensor evaluations
- Field-fixed and mobile-based sensor evaluations
- Innovative sensor calibration methods
- Deployment of low-cost sensor networks at scale
- Community and fenceline air monitoring
- Mobile survey, hyperlocal mapping, modeling, and remote sensing applications
- Indoor air quality applications
- Sensors in exposure research and health effects assessments
- Sensor data fusion and data assimilation

Deadline for manuscript submissions:
30 September 2020

AGU Fall Meeting: Sensor Session

Thank You

We are looking for more collaboration opportunities !

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