Center for Advancing Research in Transportation Emissions, Energy, and Health

Use and Applications of Low-cost Air Quality Sensors

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South Coast AQMD

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

- Established in July 2014
- Fully funded by SCAQMD
- Main Goals & Objectives
  - Provide guidance & clarity
  - Promote successful evolution and use of sensor technology
  - Minimize confusion
- Sensor Selection Criteria
  - Commercially available
    - *Optical*
    - *Electrochemical*
    - *Metal oxide*
  - Real- or near-real time
  - Criteria pollutants & air toxics











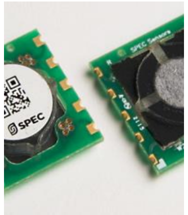


Field Testing

- Started in September, 2014
  - 40+ sensors evaluated to date
- Approach
  - Sensor tested in triplicates
  - Two month deployment
  - < ~ $2,000: purchase
  - > ~ $2,000: lease or borrow
- Location
  - Rubidoux station (main)
    - Inland site
    - Fully instrumented

South Coast AQMD

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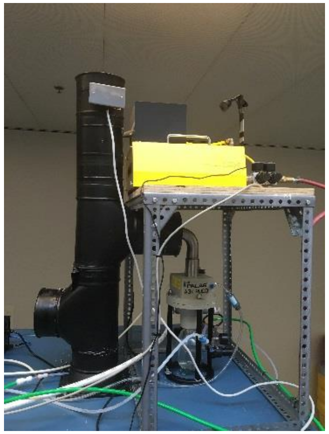
Air Quality Sensor Performance Evaluation Center

Laboratory Testing

Aerosol Test



Gas Test

Laboratory Testing (cont.)

T and RH controlled: T (0-50 ^{0}C); RH (5-95%)

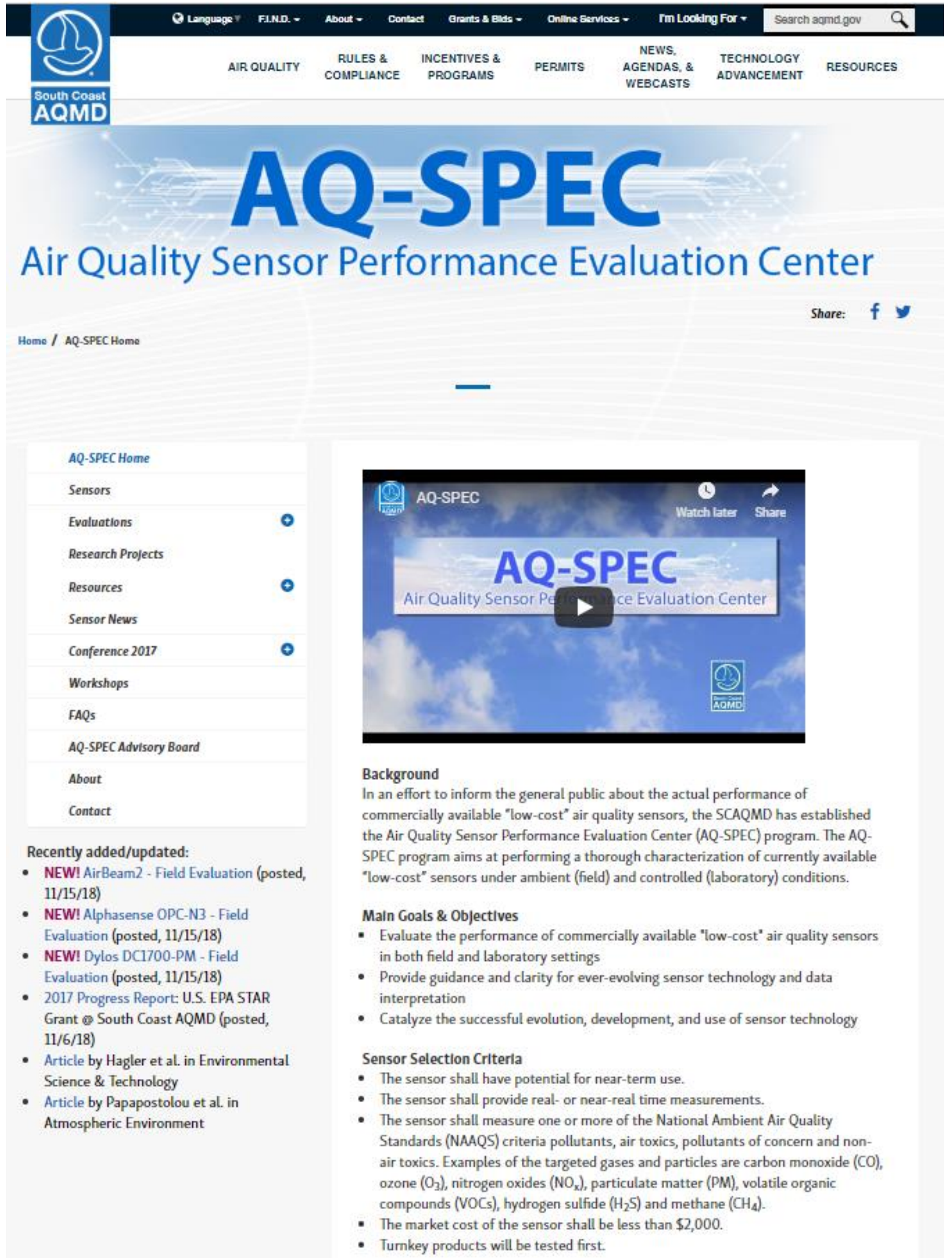
Particle testing

- Particle generation systems
- Particle monitors: mass concentration and size distribution

Gas testing

- Gas generation / dilution system
- Gas monitors: CO, NO_X, O_3, SO_2, H_2S, CH_4/NMHC, and **VOCs**

www.aqmd.gov/aq-spec



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South Coast AQMD

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AQ-SPEC

Air Quality Sensor Performance Evaluation Center

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- Sensors
- Evaluations
- Research Projects
- Resources
- Sensor News
- Conference 2017
- Workshops
- FAQs
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Recently added/updated:

- NEW! AirBeam2 - Field Evaluation (posted, 11/15/18)
- NEW! Alphasense OPC-N3 - Field Evaluation (posted, 11/15/18)
- NEW! Dylos DC1700-PM - Field Evaluation (posted, 11/15/18)
- 2017 Progress Report: U.S. EPA STAR Grant @ South Coast AQMD (posted, 11/6/18)
- Article by Hagler et al. in Environmental Science & Technology
- Article by Papapostolou et al. in Atmospheric Environment

AQ-SPEC Watch later Share

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Background

In an effort to inform the general public about the actual performance of commercially available "low-cost" air quality sensors, the SCAQMD has established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) program. The AQ-SPEC program aims at performing a thorough characterization of currently available "low-cost" sensors under ambient (field) and controlled (laboratory) conditions.

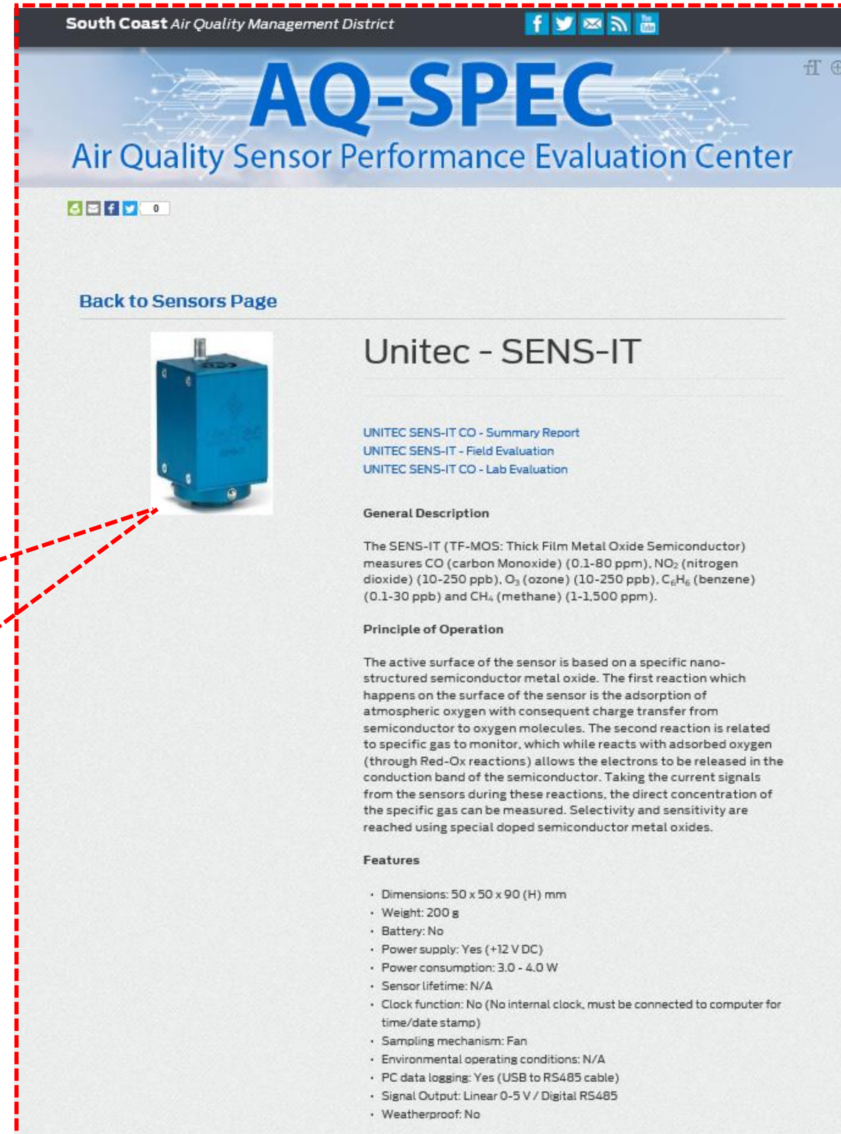
Main Goals & Objectives

- Evaluate the performance of commercially available "low-cost" air quality sensors in both field and laboratory settings
- Provide guidance and clarity for ever-evolving sensor technology and data interpretation
- Catalyze the successful evolution, development, and use of sensor technology

Sensor Selection Criteria

- The sensor shall have potential for near-term use.
- The sensor shall provide real- or near-real time measurements.
- The sensor shall measure one or more of the National Ambient Air Quality Standards (NAAQS) criteria pollutants, air toxics, pollutants of concern and non-air toxics. Examples of the targeted gases and particles are carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), hydrogen sulfide (H_2S) and methane (CH_4).
- The market cost of the sensor shall be less than $2,000.
- Turnkey products will be tested first.

www.aqmd.gov/aq-spec



PM Sensors

Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	AethLabs (microAeth)	Optical	BC (Black Carbon)	~$6,500	R^2 ~ 0.79 to 0.94		
	Air Quality Egg (Version 1)	Optical	PM	~$200	R^2 ~ 0.0		
	Air Quality Egg (Version 2)	Optical	PM	~$240	$PM_{2.5}$: R^2 ~ 0.79 to 0.85 PM_{10}: R^2 ~ 0.31 to 0.40		
	Alphasense (OPC-N2)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$450	$PM_{1.0}$: R^2 ~ 0.63 to 0.82 $PM_{2.5}$: R^2 ~ 0.38 to 0.80 PM_{10}: R^2 ~ 0.41 to 0.60	R^2 ~ 0.99	PDF (1,291 KB)
	Dylos (DC1100)	Optical	$PM_{(0.5-2.5)}$	~$300	R^2 ~ 0.65 to 0.85	R^2 ~ 0.89	PDF (1,384 KB)
	Foobot	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.55		
	HabitatMap (AirBeam)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.65 to 0.70	R^2 ~ 0.87	PDF (1,144 KB)
	Hanvon (Hanvon N1)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.52 to 0.79		
	MetOne (Neighborhood Monitor)	Optical	$PM_{2.5}$	~$1,900	R^2 ~ 0.53 to 0.67		
	Moji China (Airnut)	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.81 to 0.88		
	Naneos (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	$PM_{1.0}$: R^2 ~ 0.1 $PM_{2.5}$: R^2 ~ 0.2		
	Origins (Laser Egg)	Optical	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: R^2 ~ 0.58 PM_{10}: R^2 ~ 0.0		
	Perkin Elmer (ELM)	Optical	PM	~$5,200	R^2 ~ 0.0		
	PurpleAir (PA-I)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$150	$PM_{1.0}$: R^2 ~ 0.93 to 0.95 $PM_{2.5}$: R^2 ~ 0.77 to 0.92 PM_{10}: R^2 ~ 0.32 to 0.44	$PM_{1.0}$: R^2 ~ 0.95 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.97	PDF (1,072 KB)
	PurpleAir (PA-II)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: R^2 ~ 0.96 to 0.98 $PM_{2.5}$: R^2 ~ 0.93 to 0.97 PM_{10}: R^2 ~ 0.66 to 0.70	$PM_{1.0}$: R^2 ~ 0.99 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.95	PDF (1,328 KB)
	RTI (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	R^2 ~ 0.65 to 0.90	R^2 ~ 0.99	PDF (1,087 KB)
	Shinyei (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	R^2 ~ 0.80 to 0.90	R^2 ~ 0.93	PDF (1,156 KB)
	Speck	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.32		
	TSI (AirAssure)	Optical	$PM_{2.5}$	~$1,500	R^2 ~ 0.82		

Results (PM)

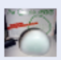
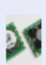
Most PM sensors showed:

- Minimal down time
- Moderate intra-model variability
- Strong correlation (R2) with EPA “approved” instruments (e.g., FEM)

However…

- Sensor “calibration” is needed in most cases
- Very small particles (e.g. < 0.5 µm) are not detected
- Bias in algorithms used to convert particle counts to particle mass

Gaseous Sensors

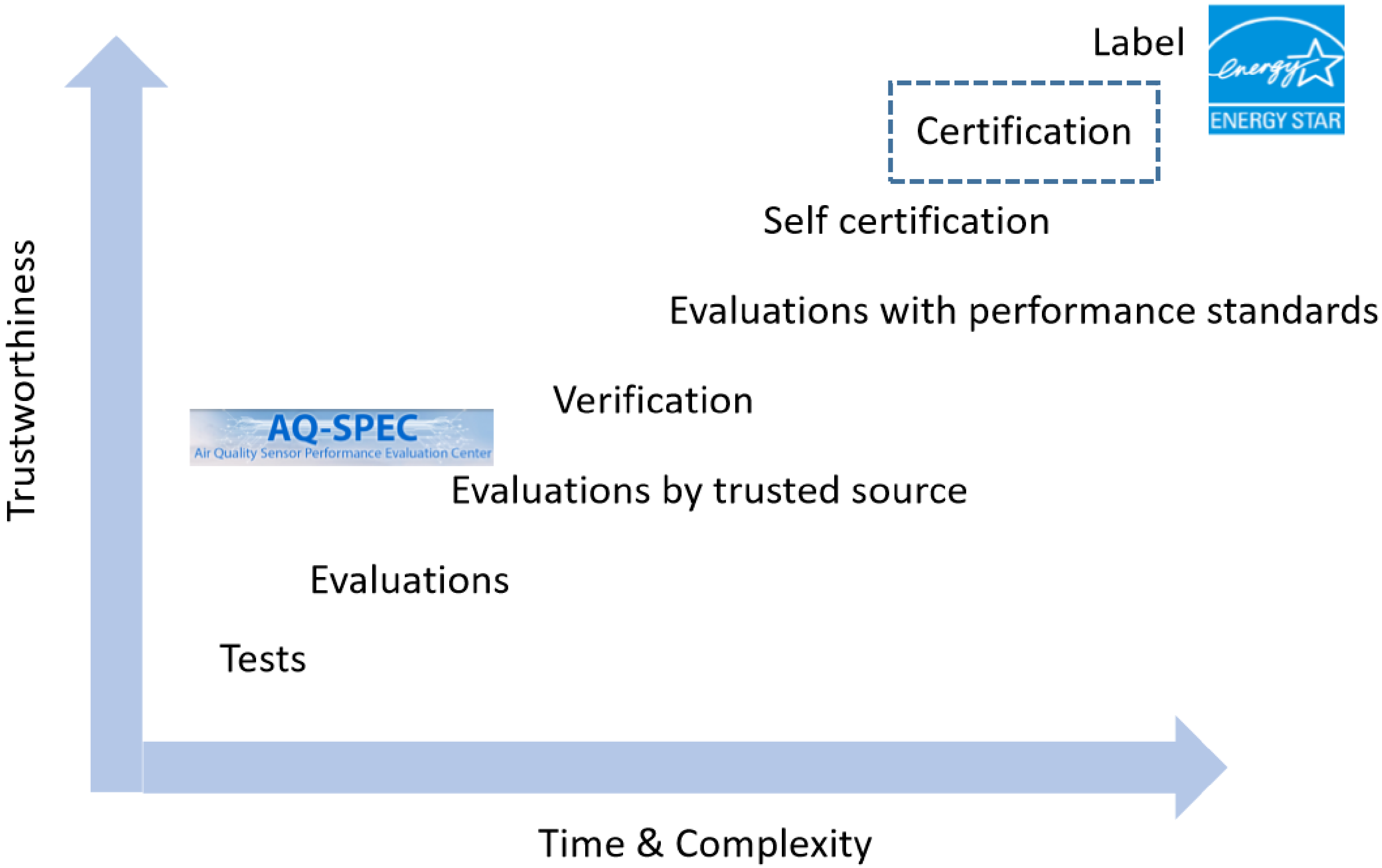
Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	**2B Technologies** (POM)	UV absorption (FEM Method)	O_3	~$4,500	R^2 ~ 1.00	R^2 ~ 0.99	PDF (1,295 KB)
	**Aeroqual** (S-500)	Metal Oxide	O_3	~$500	R^2 ~ 0.85	R^2 ~ 0.99	PDF (1,197 KB)
	**Air Quality Egg** (Version 1)	Metal Oxide	CO, NO_2 & O_3	~$200	CO: R^2 ~ 0.0 NO_2: R^2 ~ 0.40 O_3: R^2 ~ 0.85		
	**Air Quality Egg** (Version 2)	Electrochem	CO & NO_2	~$240	CO: R^2 ~ 0.0 NO_2: R^2 ~ 0.0		
	**Air Quality Egg** (Version 2)	Electrochem	O_3 & SO_2	~$240	O_3: R^2 ~ 0.0 to 0.20 SO_2: R^2 n/a		
	**AQMesh** (v.4.0) (Discontinued)	Electrochem	CO, NO, NO_2 & O_3	~$10,000	CO: R^2 ~ 0.42 to 0.80 NO: R^2 ~ 0.0 to 0.44 NO_2: R^2 ~ 0.0 to 0.46 O_3: R^2 ~ 0.46 to 0.83		
	**Perkin Elmer** (ELM)	Metal Oxide	NO, NO_2 & O_3	~$5,200	NO: R^2 n/a NO_2: R^2 ~ 0.0 O_3: R^2 ~ 0.89 to 0.96		
	**Smart Citizen Kit**	Metal Oxide	CO, NO_2	~$200	CO: R^2 ~ 0.50 to 0.85 NO_2: R^2 ~0.0		
	**Spec Sensors**	Electrochem	CO, NO_2 & O_3	~$500	CO: R^2 ~ 0.84 to 0.90 NO_2: R^2 ~ 0.0 to 0.16 O_3: R^2 ~ 0.0 to 0.24		
	**UNITEC** (SENS-IT)	Metal Oxide	CO, NO_2 & O_3	~$2,200	CO: R^2 ~ 0.33 to 0.43 NO_2: R^2 ~ 0.60 to 0.65 O_3: R^2 ~ 0.72 to 0.83	CO: R^2 ~ 0.99 O_3: R^2 ~ 0.82 to 0.90	CO: PDF (1,283 KB) O_3: PDF (1,177 KB)

Results (Gases)

<u>Most gaseous sensors showed</u>:

- Acceptable data recovery
- Wide intra-model variability range
- CO; NO; O3 (when measured alone): good correlation with FRMs
- O3 + NO2: potential O3/NO2 interference
- SO2; H2S; VOC: difficult to measure with available sensors

Sensor Performance Testing: What is Needed?



Sensor Certification

- PM2.5 and O3 sensors seems to be good candidates
- Field testing
  - Establish various testing centers across the US and/or around the world
    - Different RH/T environments (P also seems to impact performance)
    - Different PM composition
    - Wide range of concentrations
    - Consistent use of FRM/FEM instruments for comparison purposes
- Lab (chamber) testing
  - Account for a wide/representative RH/T range
  - Specific aerosol composition (e.g., Arizona road dust)
  - Specific range of concentrations
  - Ability to test for multi-pollutant interference (e.g., O3/NO2)
  - Consistent use of FRM/FEM instruments for comparison purposes
- Standardized testing protocols
- Well established performance parameters and standards
- Certification model: Multi-tier vs pass/fail

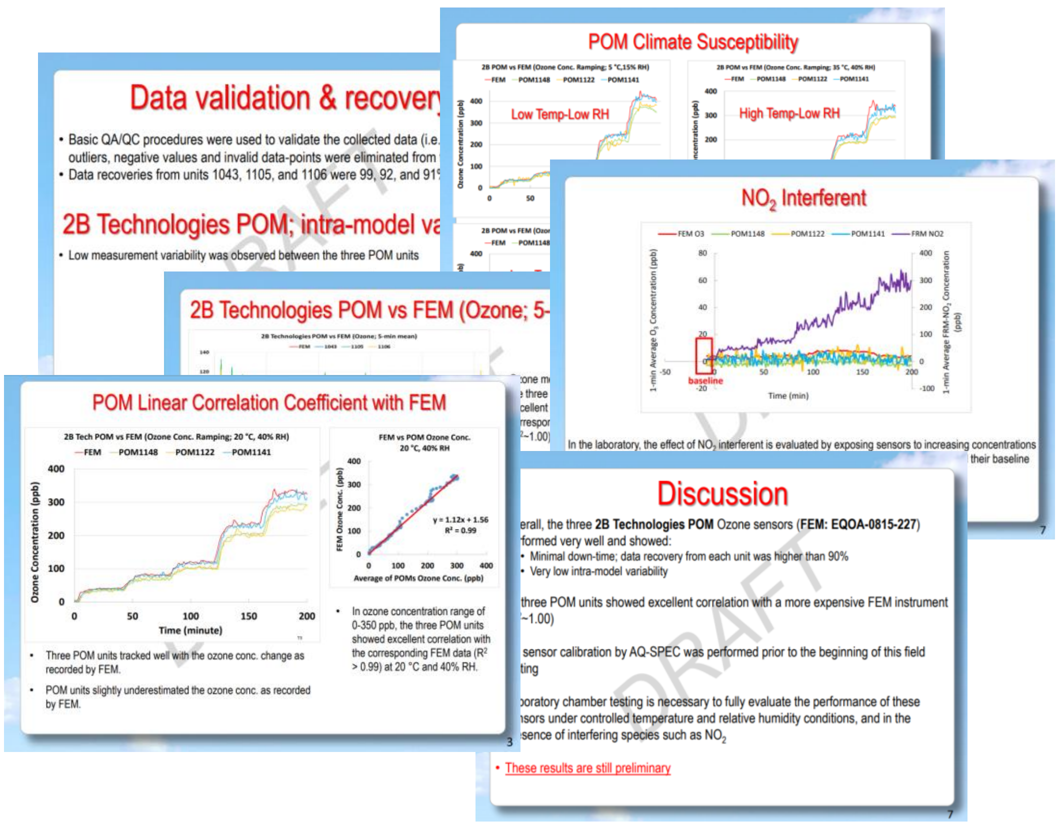
Sensor Certification

- <u>Tiered</u>: different performance targets for different sensor applications. Example:

Tier	Uses	Pollutants	Precision	Accuracy	Sensitivity
I	Regulatory or compliance monitoring	ozone, $PM_{2.5}$			
II	Fenceline and community monitoring	ozone, $PM_{2.5}$, VOC			
III	Area or source characterization; supplement monitoring networks	ozone, $PM_{2.5}$, NO2, VOC			
IV	Information, personal monitoring, and education	ozone, $PM_{2.5}$, NO2, CO, VOC and others			

Sensor Certification

- <u>Pass / Fail</u>:
  - One set of performance targets
  - Target specific user / application (e.g., community monitoring)
  - Easier to understand for non-technical audience
  - Helps translating complexity into a simple choice



Sensor Certification

- A sensor certification program is desirable but very expensive / time consuming to implement
  - Multiple field testing locations
  - Multiple laboratory testing facilities
  - Extended testing time

- The U.S. EPA is leading the way at the National level
  - E-Enterprise

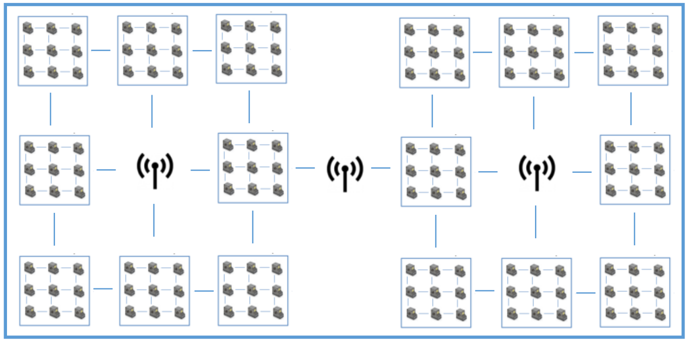
- On-going discussion in California between CARB, SCAQMD, BAAQMD and other air districts
  - Sensor performance verification
  - ASTM method development
  - Other models

Sensor Deployment Challenges

Sensor Unit

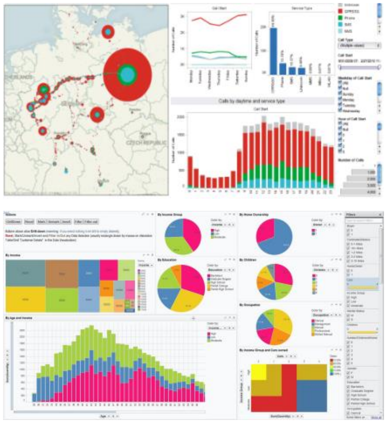
- Assume you have a “certified” PM2.5 sensor

Sensor Network



- Design and configuration
- Data communication (e.g., cell; wi-fi; LoRa; other)
- “Calibration” procedures
- QA/QC requirements
- Other

Network Data



- Backend application and data handling procedures
- Validation and other QA/QC requirements
- Correction algorithms / models
- Time averaging
- Analysis and interpretation
- Integration with existing network and other available data

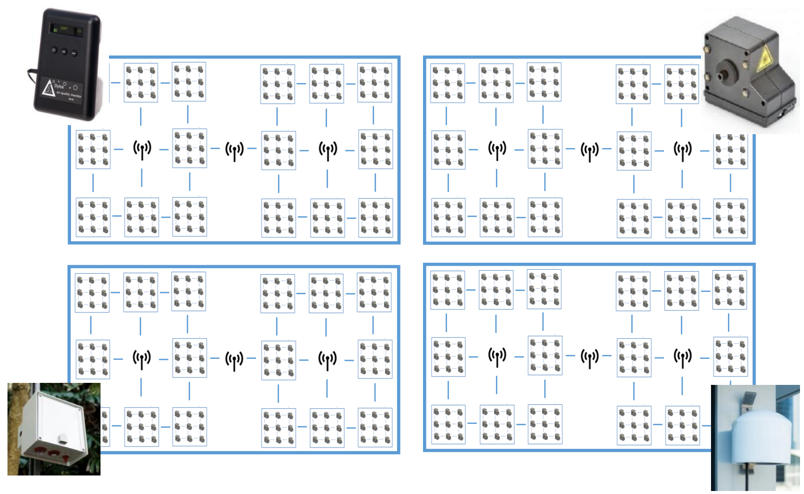
Different sensor networks comprised of the same “certified” sensor may still produce inconsistent data / results

Sensor Deployment Challenges

Sensor Units

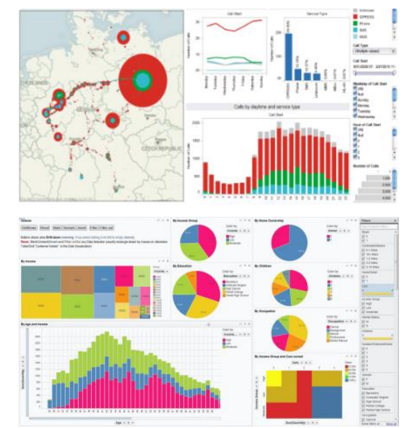
- Assume you have 4 different “certified” PM2.5 sensors

Sensor Networks



- Design and configuration
- Data communication (e.g., cell; wi-fi; LoRa; other)
- “Calibration” procedures
- QA/QC requirements
- Other

Networks Data



- Backend application and data handling procedures
- Validation and other QA/QC requirements
- Analysis and interpretation
- Mapping
- Correction algorithms / models
- Time averaging
- Integration with existing network data

Different sensor networks comprised of different “certified” sensors measuring the same pollutant(s) will probably produce inconsistent data / results

SCAQMD Sensor Monitoring Projects

Fence-line

9 PM sensors

IoT vendor platform

Cellular to SaaS

API Access

Regional network

~ 100 nodes to measure: O_3, NO_2, & PM

Cellular to PaaS

API access

US EPA STAR Grant

~ 400 PM sensors in 14 communities

Wi-Fi connected

Data sent to : PurpleAir Map; AQMD Azure

Other projects

MATES V

ROSE/NASA Project

Mobile monitoring

AB617 community monitoring

SCAQMD Rule 1180 implementation

SCAQMD Sensor Monitoring Projects

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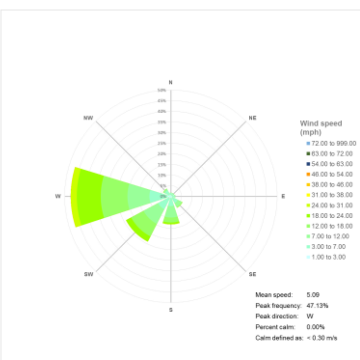
Fenceline Monitoring (Rainbow Disposal Facility)

14 Acre Waste Transfer Facility

Pre School Campus

Head Start Academy

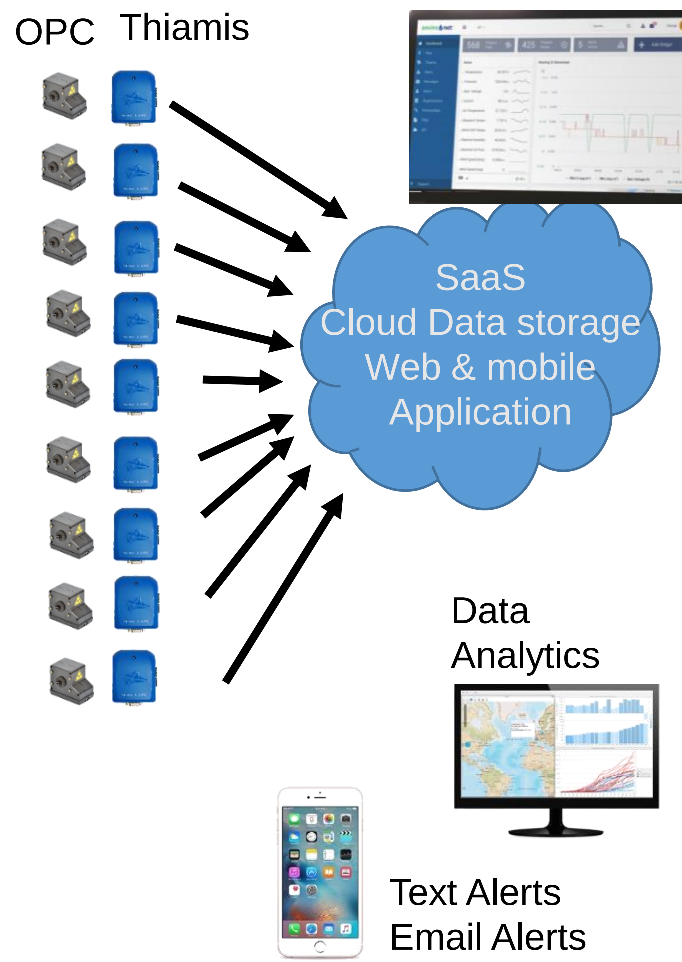
Elementary School



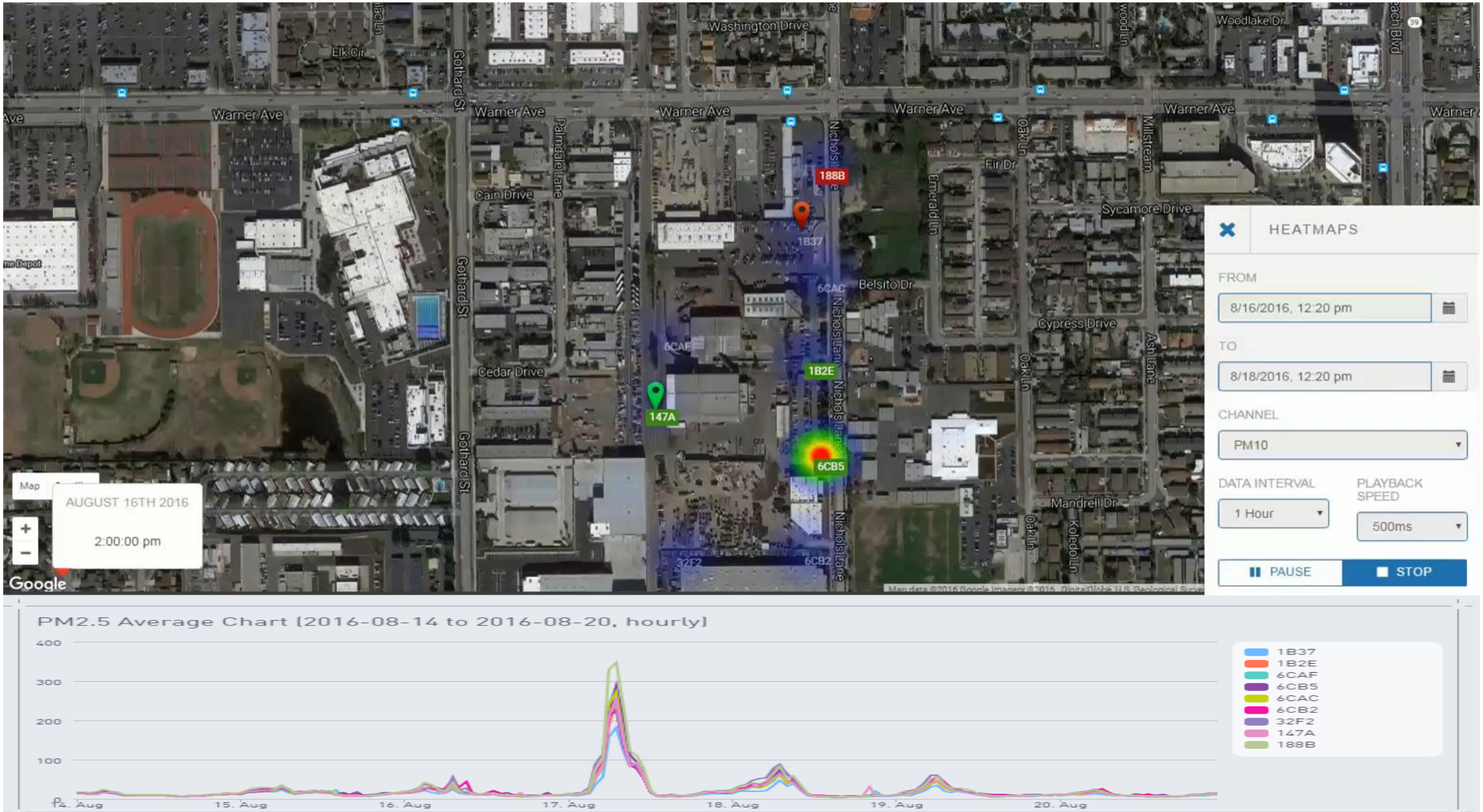
Fenceline Monitoring
(Rainbow Disposal Facility)

Fence-line Monitoring

- 9 sensors measuring PM
- Wireless connectivity
- Power independence
- Remote access to data / device



Fenceline Monitoring
(Rainbow Disposal Facility)



SCAQMD Sensor Monitoring Projects

Fence-line	**Regional network**	US EPA STAR Grant	Other projects
9 PM sensors	**~ 100 nodes to measure: O_3, NO_2, & PM**	~ 400 PM sensors in 14 communities	MATES V
IoT vendor platform	**Cellular to PaaS**	Wi-Fi connected	ROSE/NASA Project
Cellular to SaaS	**API access**	Data sent to : PurpleAir Map; AQMD Azure	Mobile monitoring
API Access			AB617 community monitoring
			SCAQMD Rule 1180 implementation

Regional Monitoring Network (AQY Sensors: $PM_{2.5}$, O_3, and NO_2)

- 100 AQY installed in Southern California
- AQY measures temperature, relative humidity, and air pollutants: O_3, NO_2, and $PM_{2.5}$
- Project leads:
  - Aeroqual
    - www.aeroqual.com
  - SCAQMD
    - www.aqmd.gov

Measuring
AIR QUALITY
in your community

Aeroqual is a New Zealand-based company that helps communities make better air quality decisions by providing them with reliable instruments that measure the quality of their air.

We're working with the South Coast Air Quality Management District to set up a network of air quality instruments across Central and Southern California.

OUR TECHNOLOGY: Aeroqual AQY

- The Aeroqual AQY is a low-cost, low-power air quality monitoring instrument designed to provide real time data of air quality.
- AQY push data to the Aeroqual Cloud Server. This allows the instruments to be deployed in networks and work together to measure a community's air quality.
- All the device needs is a standard power connection, and to be placed where there is good access to the surrounding air.

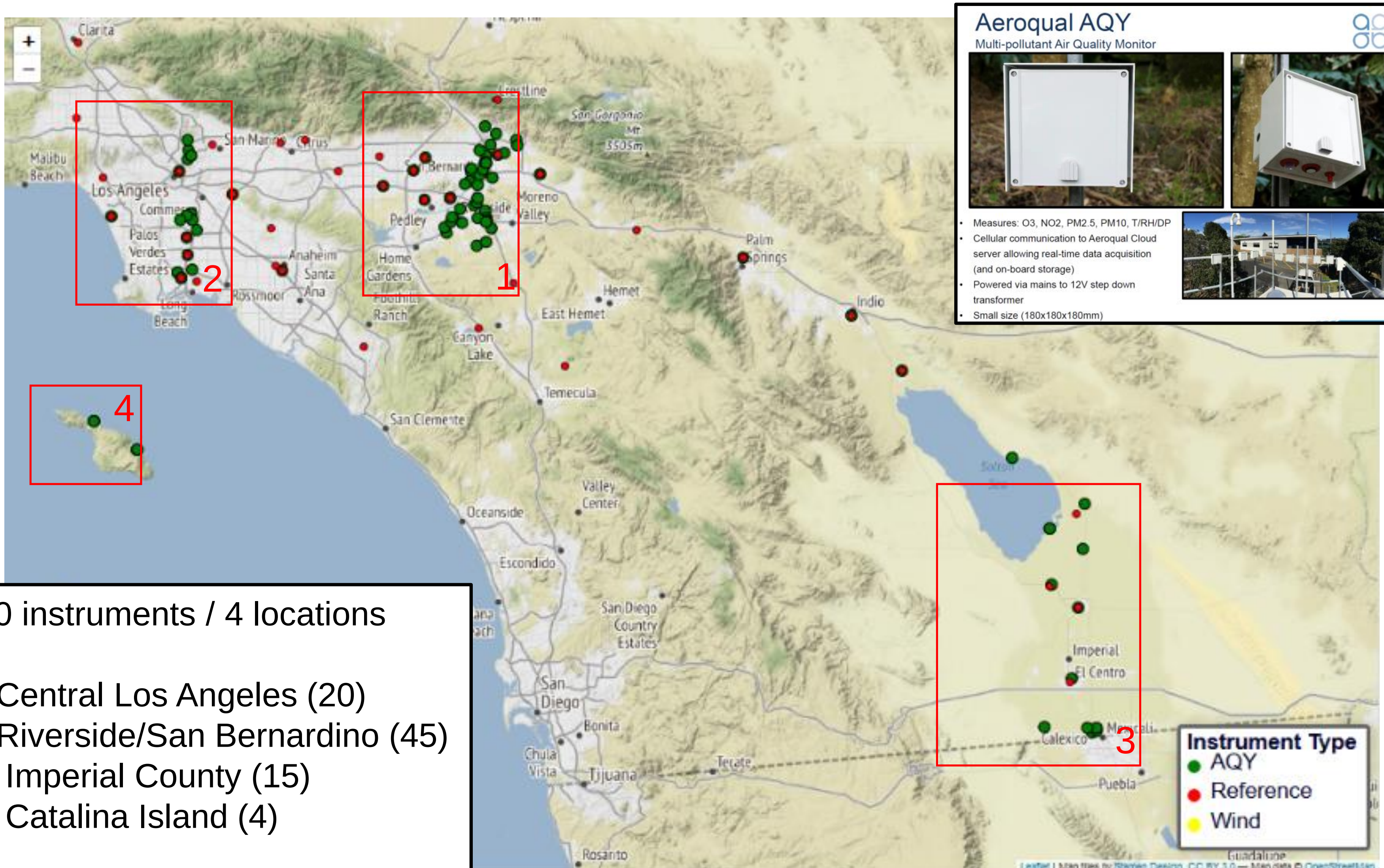
WHAT IT MEASURES

Ozone • Nitrogen Dioxide • Particulate Matter ($PM_{2.5}$, PM_{10}) • Temperature, humidity and dew point

KEY COMPONENTS

Wi-fi and cellular enabled • On board data processing and storage
Weather resistant • Air quality sensors

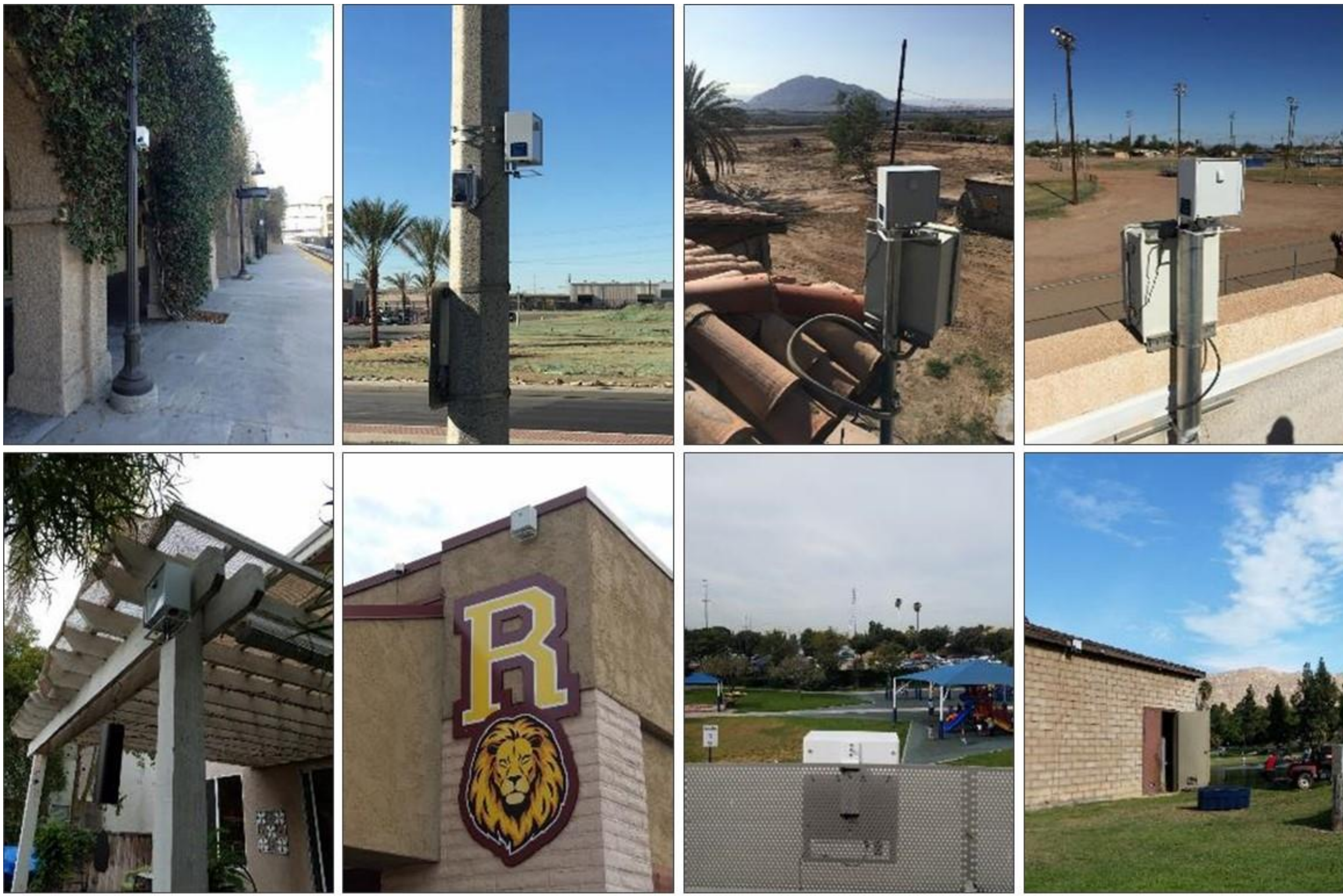
Regional Monitoring Network
(AQY Sensors: $PM_{2.5}$, O_3, and NO_2)



100 instruments / 4 locations

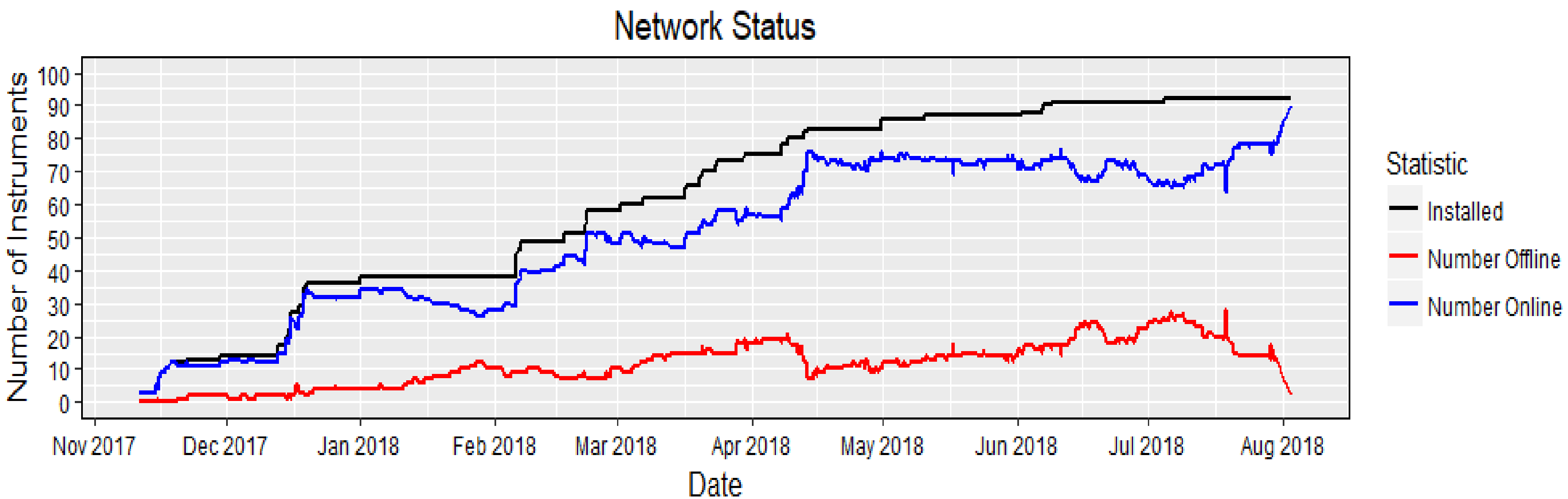
1- Central Los Angeles (20)
2- Riverside/San Bernardino (45)
3 - Imperial County (15)
4 - Catalina Island (4)

Regional Monitoring Network
(AQY Sensors: $PM_{2.5}$, O_3, and NO_2)



Regional Monitoring Network (AQY Sensors: Network Status)

- Sensors online via cellular network (AT&T)
- Online statistics monitored to provide metrics on deployment rate, and network uptime
- Sensor replacements due to failure over 9 months have been low: 5 x O_3 sensors; 3 x $PM_{2.5}$ sensors



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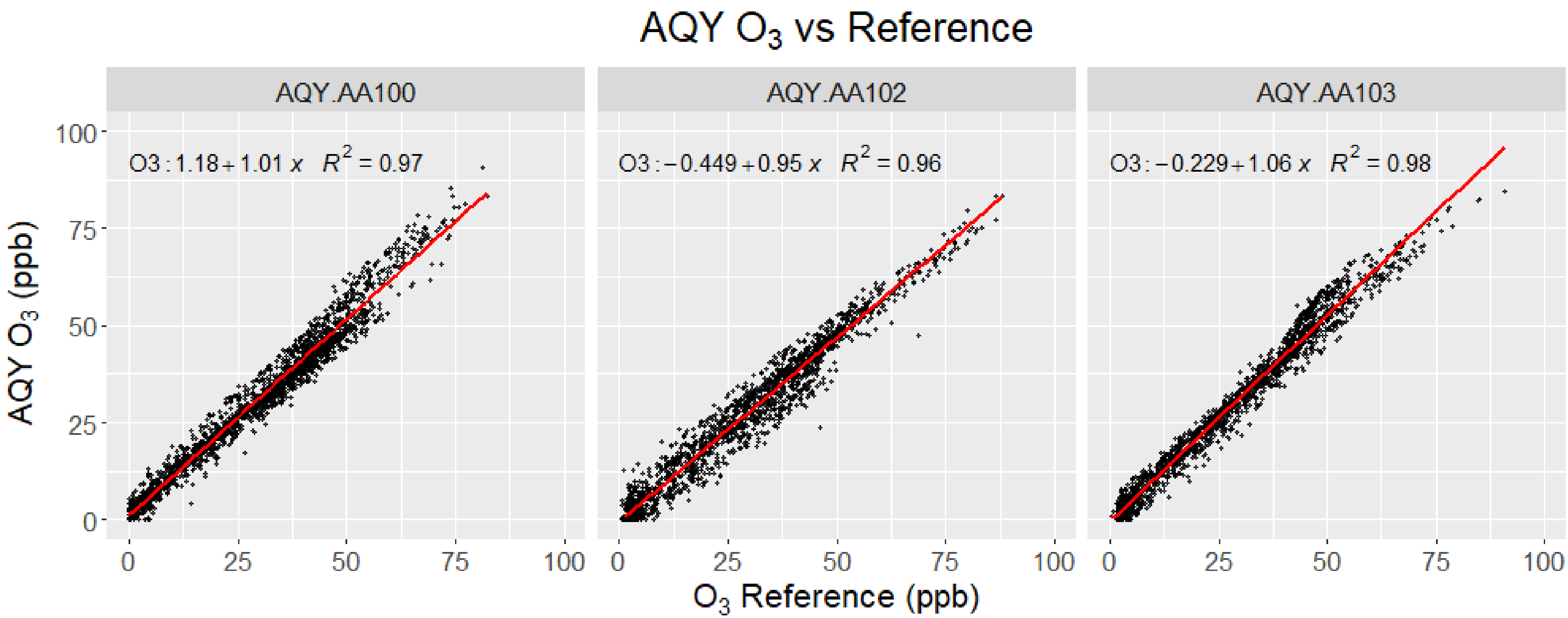
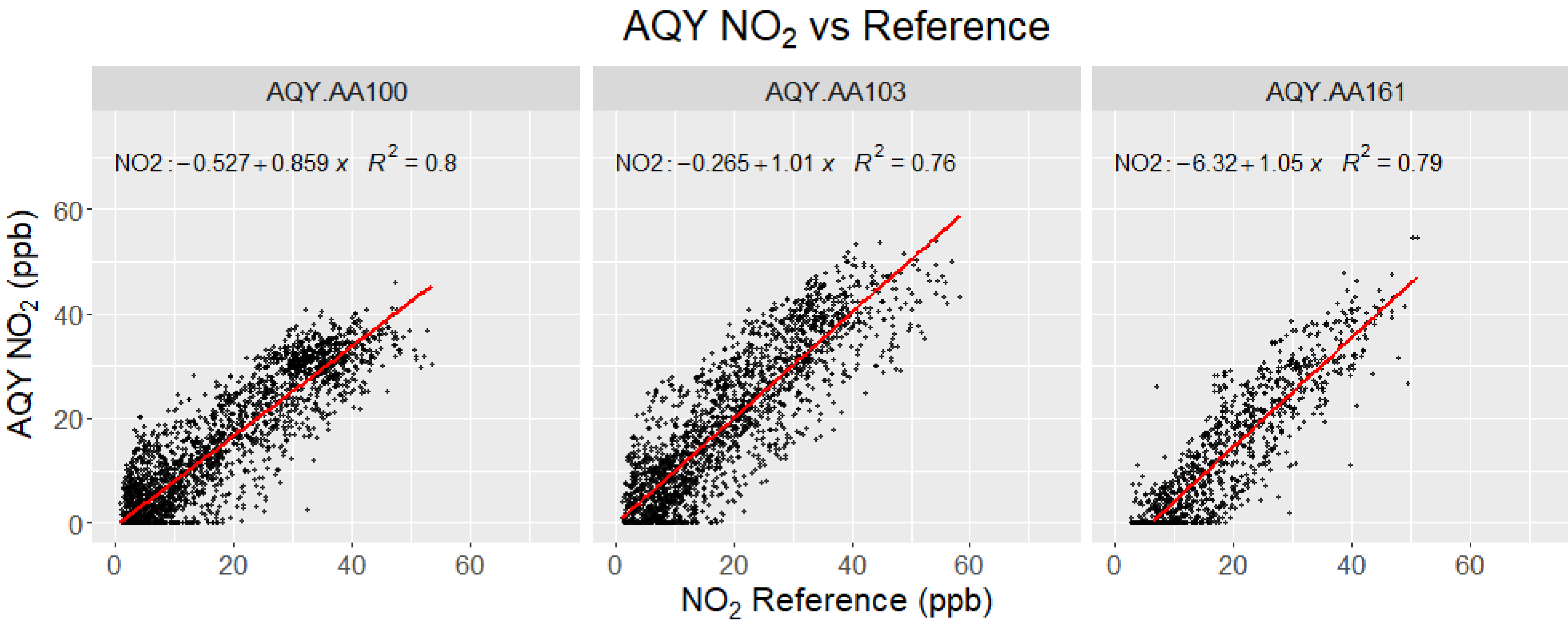
Regional Monitoring Network (AQY Sensors: O_3 Collocation Data)



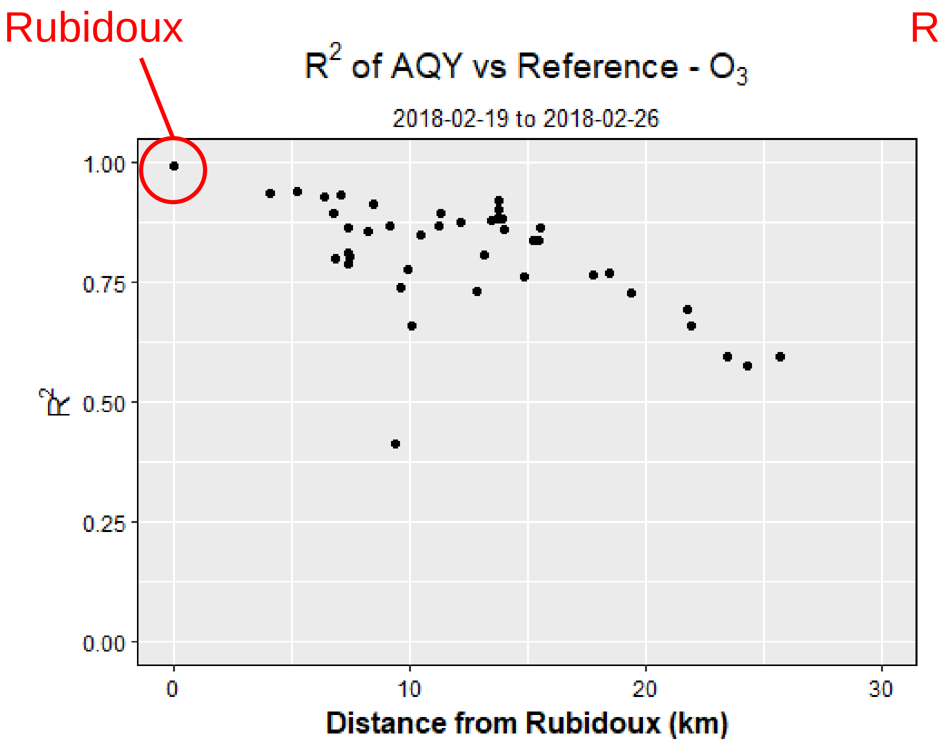
- Hourly averaged data (Jan 1 – April 30, 2018)
- Collocation data collected at SCAQMD's Rubidoux station
- Fan degradation corrected data (active method)

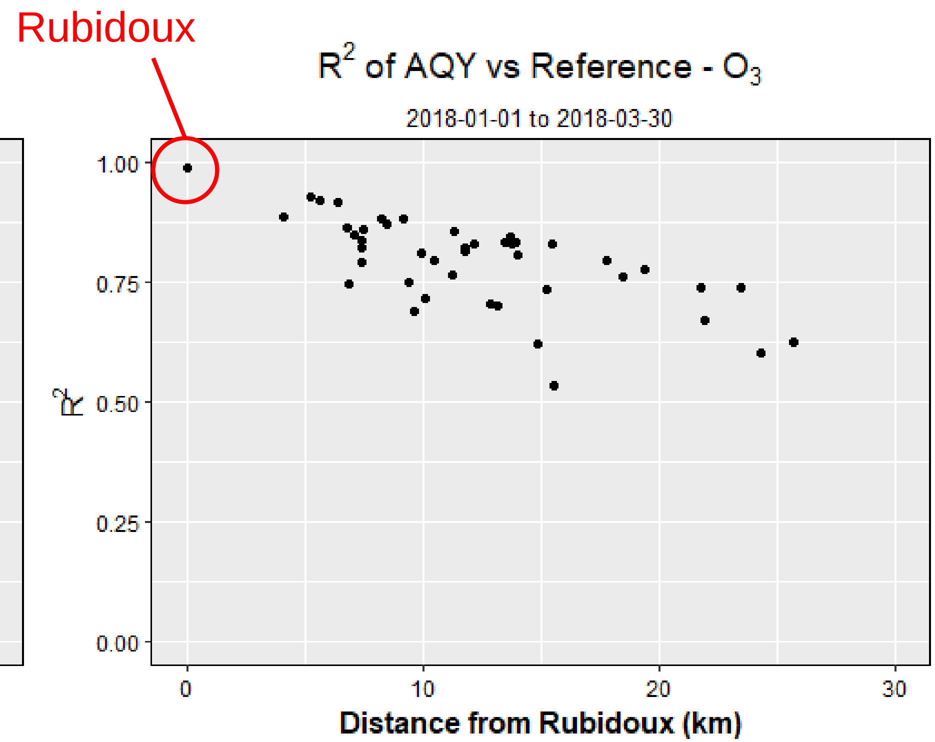
Regional Monitoring Network (AQY Sensors: NO_2 Collocation Data)



- Hourly averaged data (Jan 1 – April 30, 2018)
- Collocation data collected at SCAQMD's Rubidoux station
- NO_2 data corrected for O_3 interference

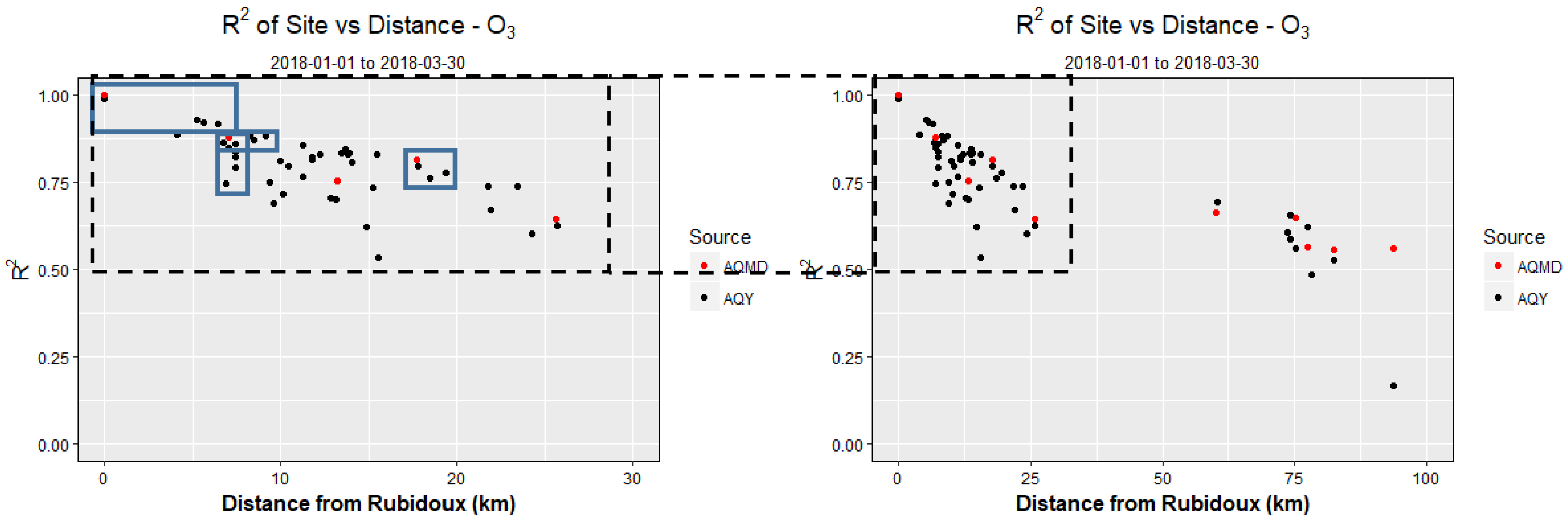
Regional Monitoring Network
(R^2 (AQY vs Reference) vs Distance: O_3)





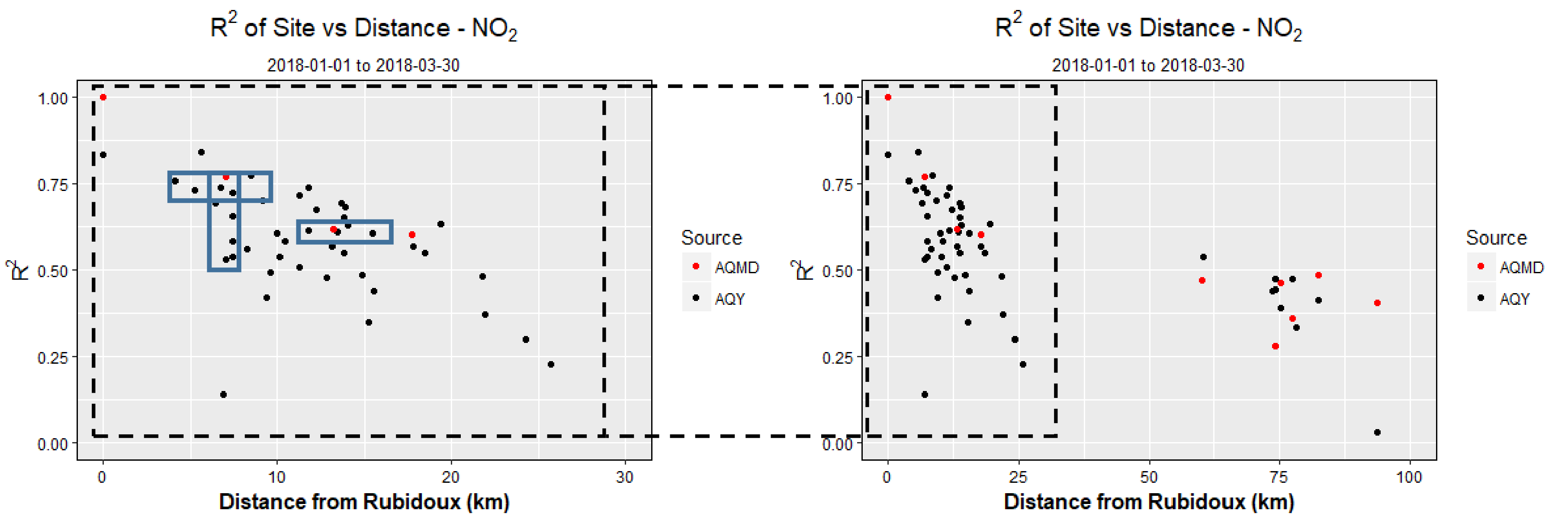
- A one week ‘snapshot’ is similar to the 3 month period

Regional Monitoring Network
(R^2 (AQY vs Reference) vs Distance: O_3)



- DQO = 90% (R^2)
- Correlation not always linear with distance; site location and characteristics also a factor
- How often should the sensor data be corrected using this procedure? Quarterly so far

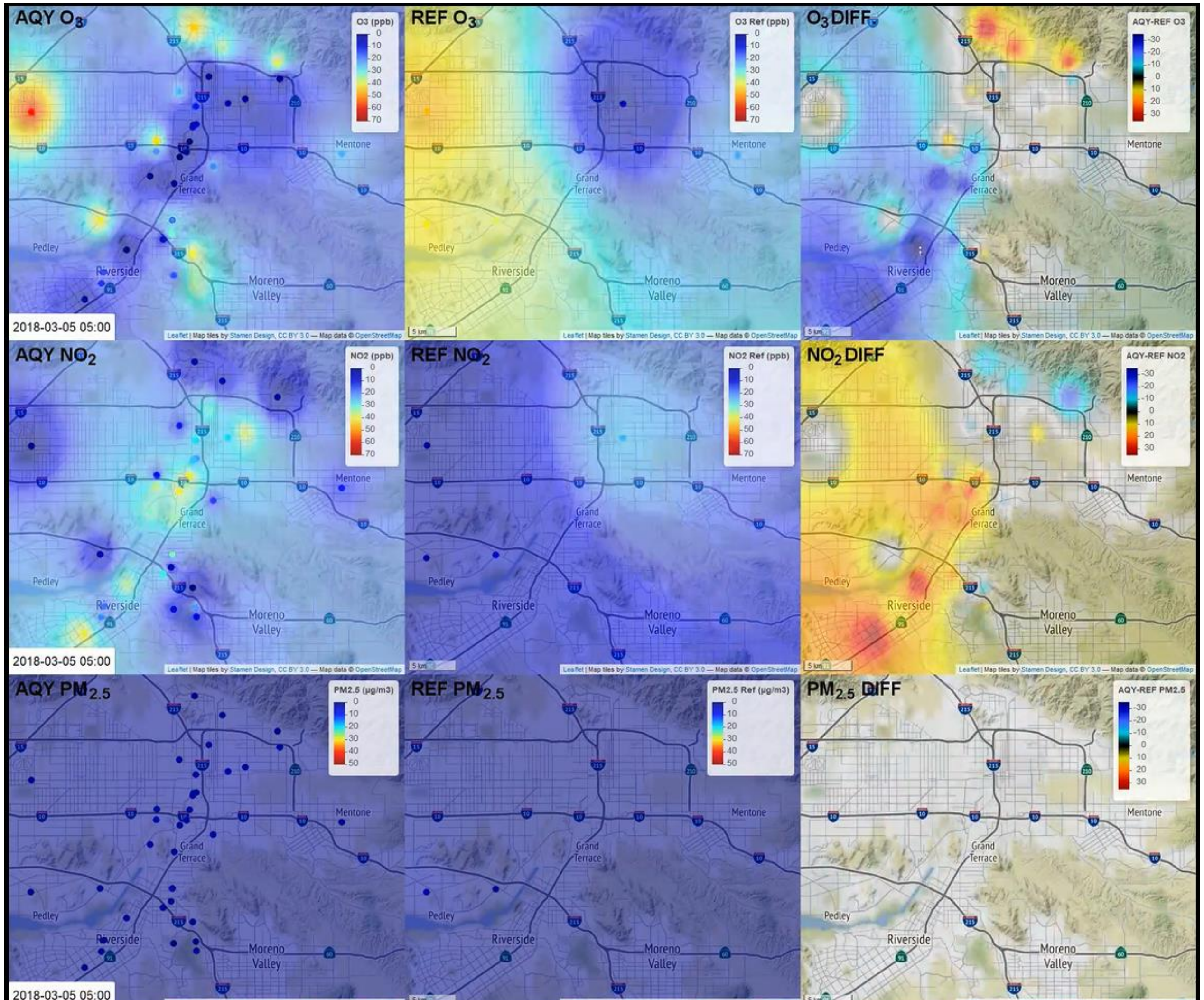
Regional Monitoring Network
(R^2 (AQY vs Reference) vs Distance: NO_2)



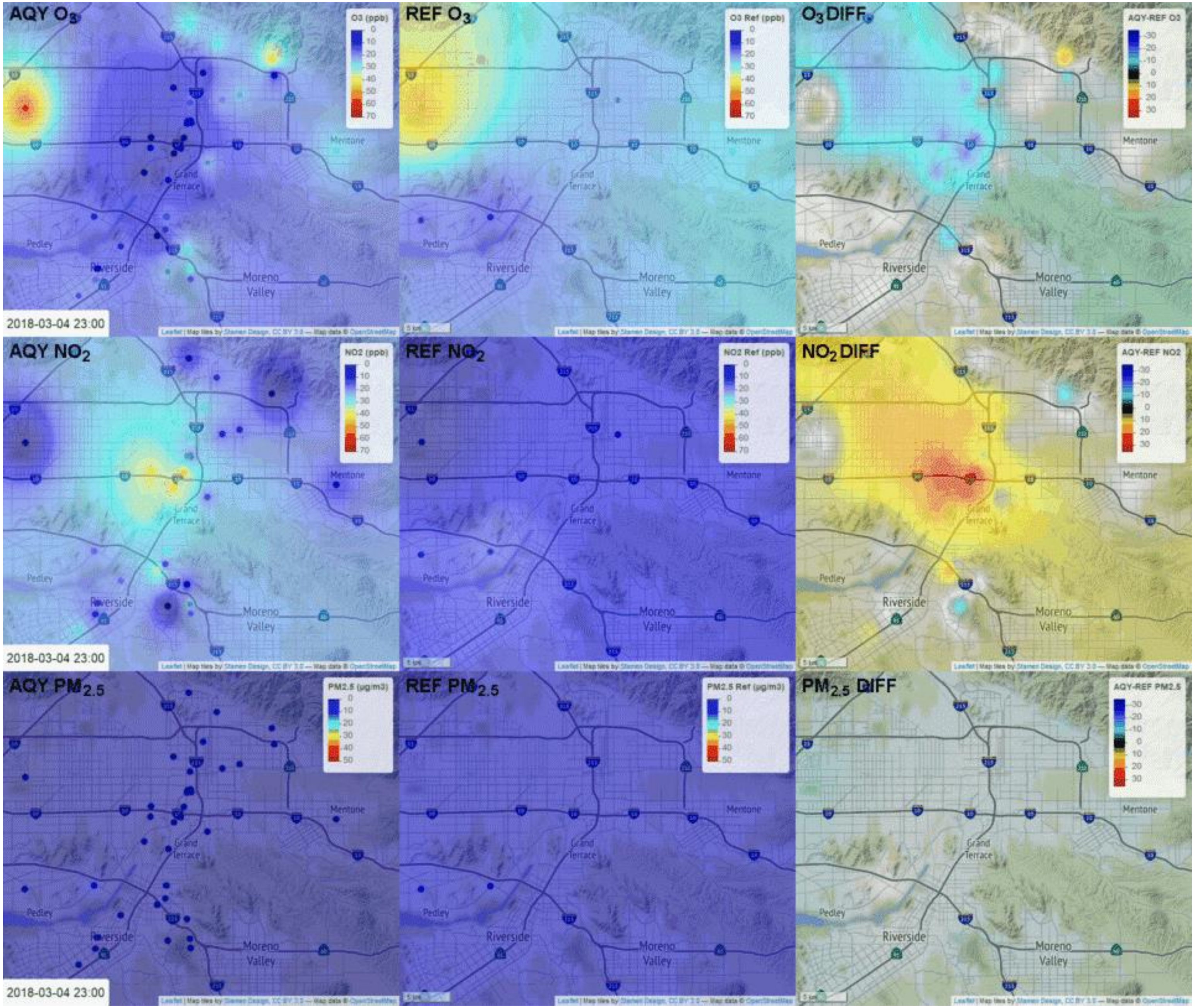
- DQO = 90% (R^2)
- R^2 drops more rapidly with distance (compared to O_3 plot)
- Greater site variation than O3 due to various sources in the area

Regional Monitoring Network
(O_3, NO_2 and $PM_{2.5}$ Maps*)

- Higher granularity for maps obtained using sensor data
- Elevated NO_2 along the freeway
- $PM_{2.5}$ is more homogeneously distributed throughout the Basin



*Inverse distance weighted interpolation



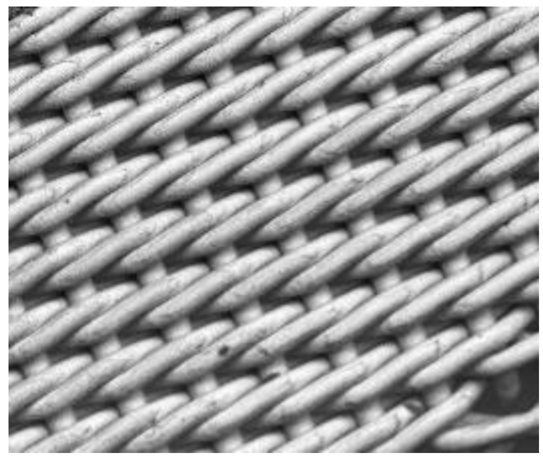
AQY O_3
REF O_3
O_3 DIFF
AQY NO_2
REF NO_2
NO_2 DIFF
AQY $PM_{2.5}$
REF $PM_{2.5}$
$PM_{2.5}$ DIFF
2018-03-04 23:00
2018-03-04 23:00
2018-03-04 23:00
Pedley
Riverside
Moreno Valley
Grand Terrace
Mentone

Regional Monitoring Network
(AQY Sensors Improvement)

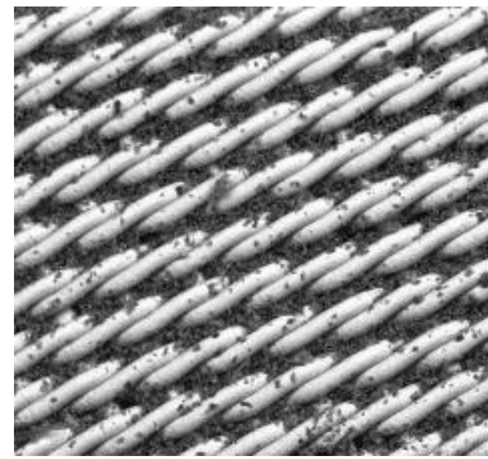
Problem: The project has shown PM accumulates on the O_3 sensor inlet mesh over time reducing flow and sensitivity

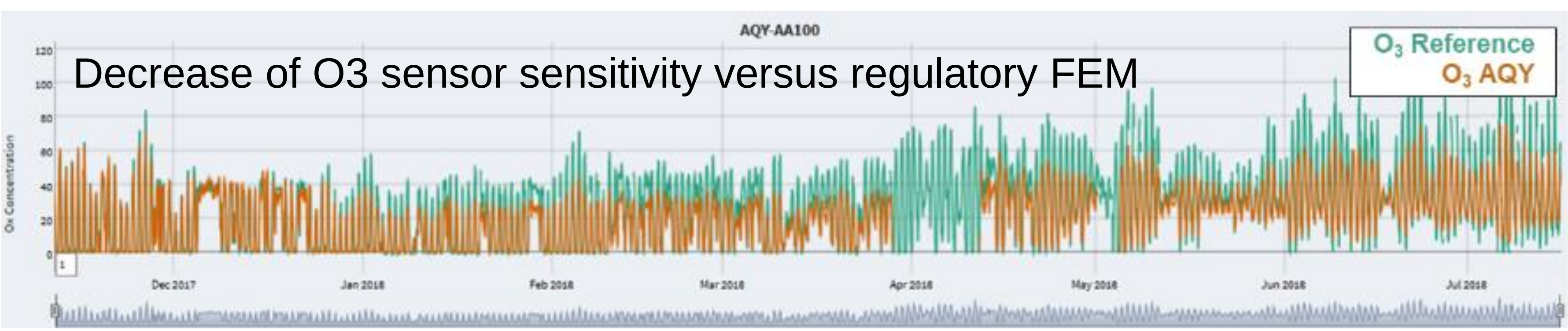
O3 sensor inlet

mesh at start



mesh after 6 months



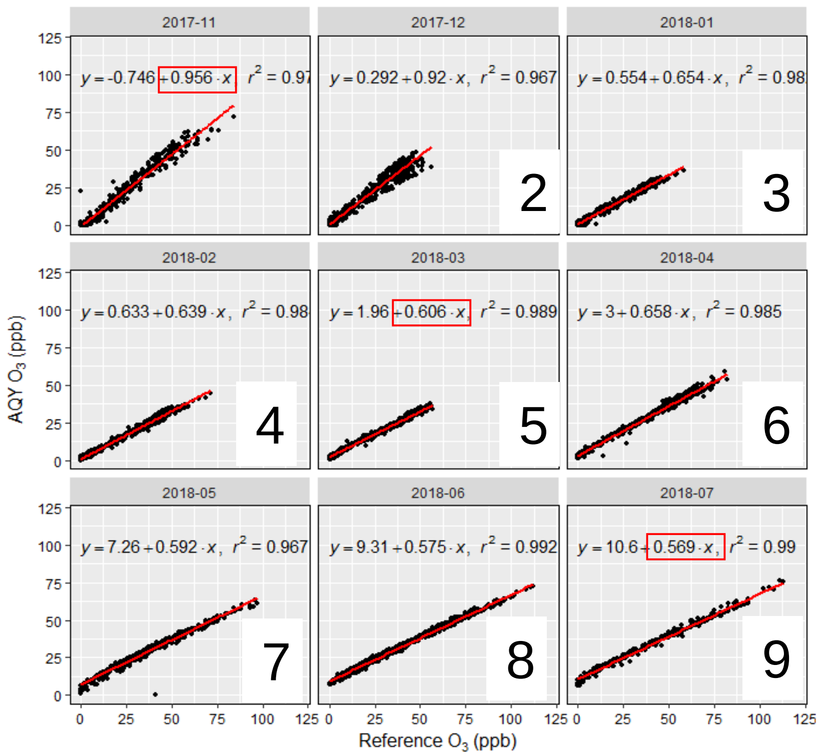


Decrease of O3 sensor sensitivity versus regulatory FEM

Regional Monitoring Network (AQY Sensors Improvement)

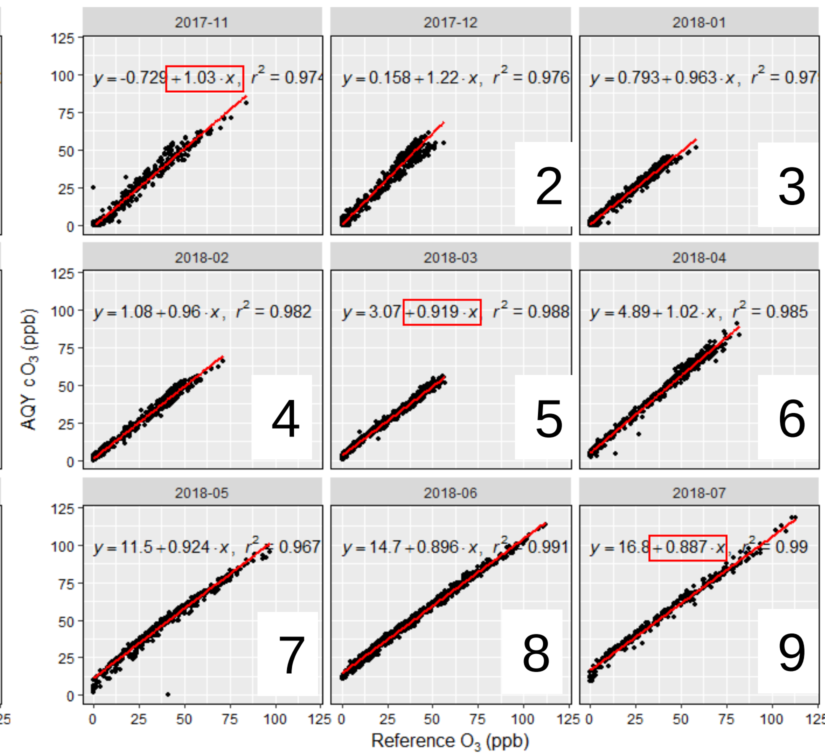
Solution: use O3 sensor air flow data to correct O3 slope. Results in stabilisation of drift and extension of re-calibration time from 2 months to > 6 months.

O3 sensor vs FEM



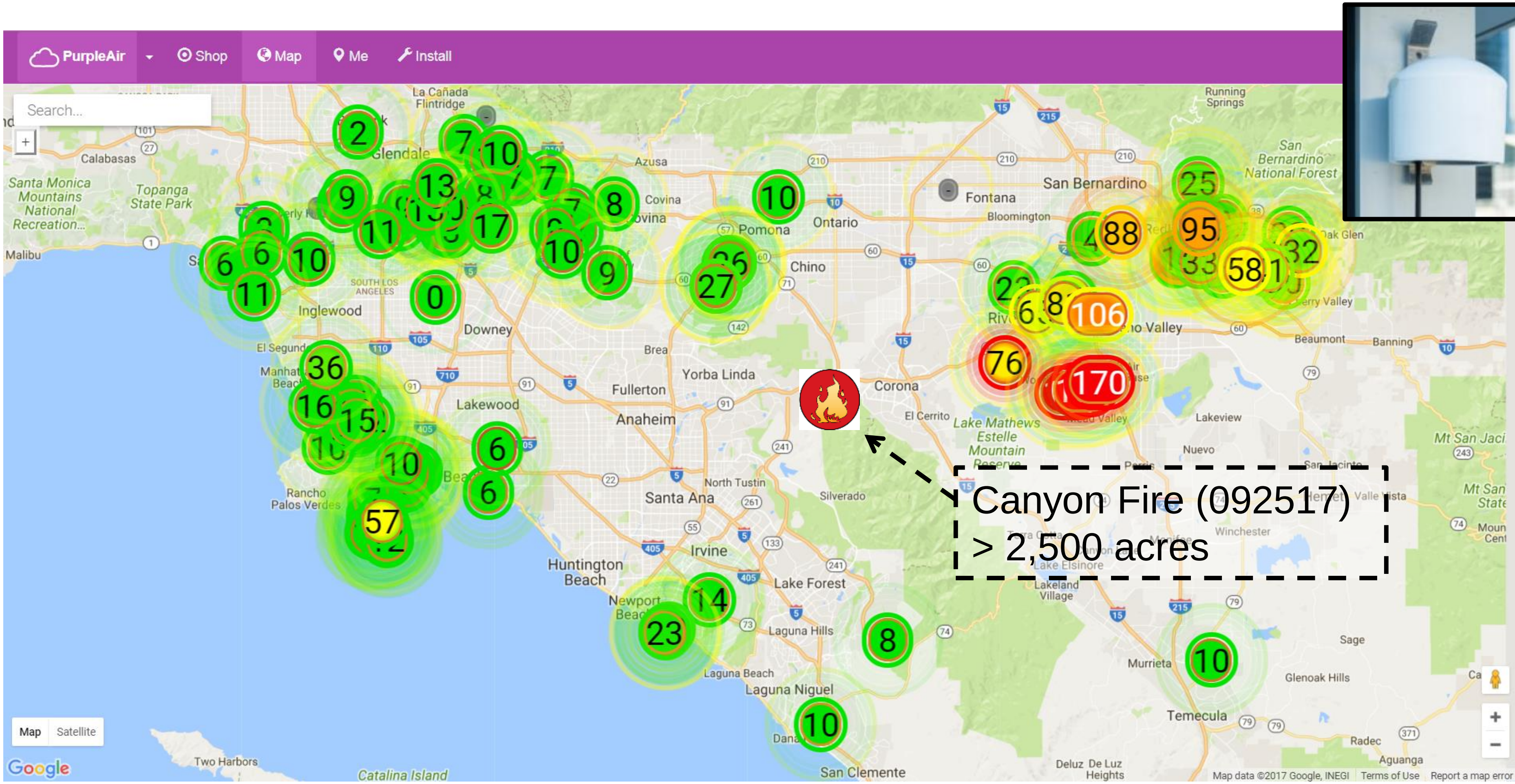
Sensor vs FEM slope decreased from 0.96 to 0.57 in 9 months

Flow corrected O3 sensor vs FEM



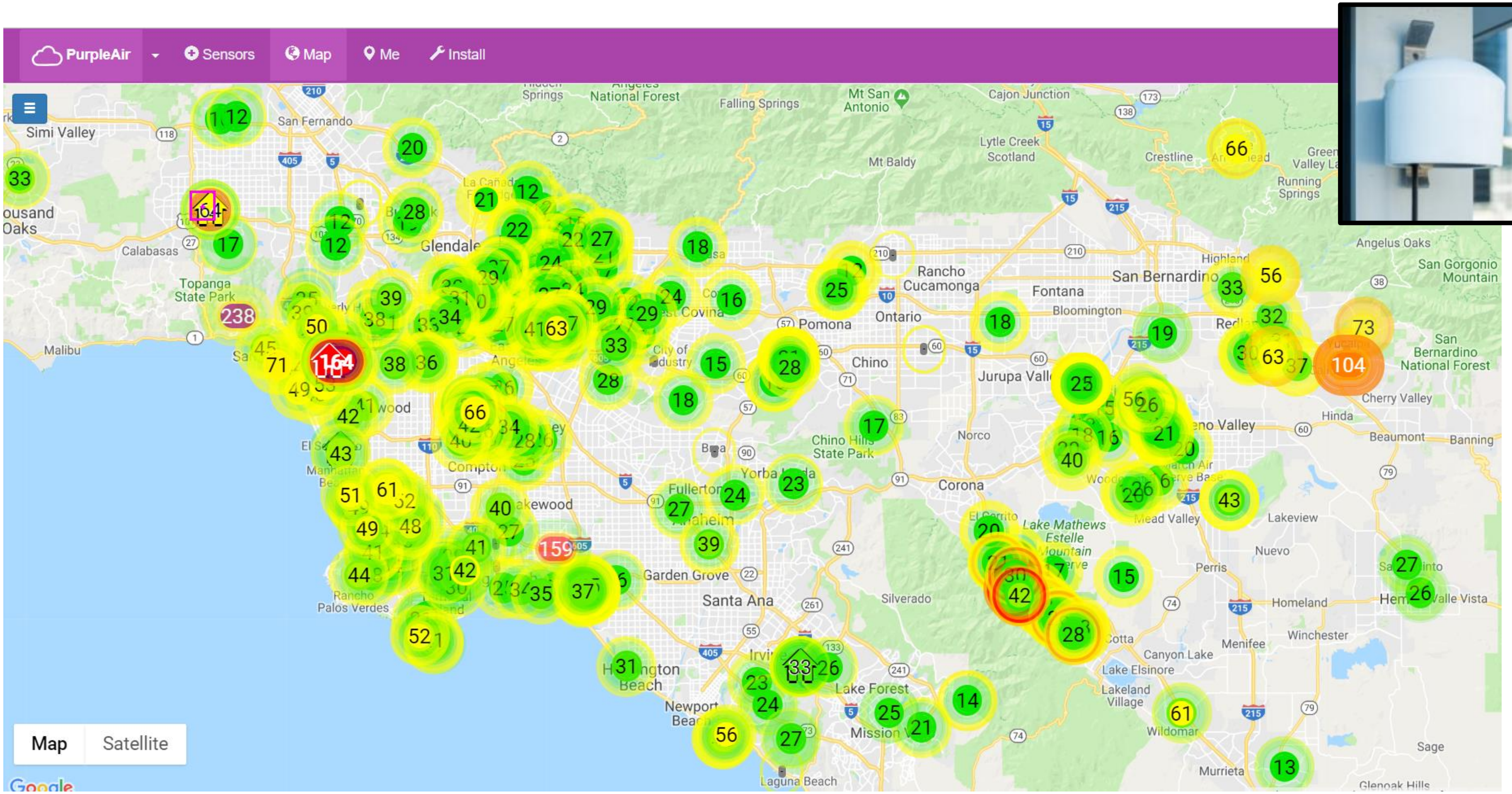
Sensor vs FEM slope more stable. Slope = 0.89 at 9 months

Regional Monitoring Network
(PM Sensor Network - 2017)



Note: Values are reported as AQI units

Regional Monitoring Network
(PM Sensor Network - 2018)



Note: Values are reported as AQI units

SCAQMD Sensor Monitoring Projects

Fence-line

- 9 PM sensors
- IoT vendor platform
- Cellular to SaaS
- API Access

Regional network

- ~ 100 nodes to measure: O_3, NO_2, & PM
- Cellular to PaaS
- API access

US EPA STAR Grant

- **~ 400 PM sensors in 14 communities**
- **Wi-Fi connected**
- **Data sent to : PurpleAir Map; AQMD Azure**

Other projects

- MATES V
- ROSE/NASA Project
- Mobile monitoring
- AB617 community monitoring
- SCAQMD Rule 1180 implementation

U.S. EPA STAR project

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

- Provide communities with the knowledge necessary to select, use and maintain low-cost sensors and to correctly interpret the collected data
- Three year study:
  - SCAQMD (PI)
  - University of California Los Angeles (UCLA; Co-PI)
  - Sonoma Technology Inc. (STI; Co-PI)
  - BAAQMD
  - Santa Barbara County APCD
  - Other CAPCOA agencies
  - Community Groups
  - Leisure World (Seal Beach, CA)
  - Aeroqual Ltd, Auckland, New Zealand
  - University of Auckland (New Zealand)

South Coast AQMD

UCLA

STi Sonoma Technology, Inc.

- 14 CA communities
- EJ areas
- 300+ subjects
- 400+ sensors

U.S. EPA STAR Project

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

- Four specific aims:
  1. Develop educational material for communities
  2. Evaluate / identify candidate sensors for deployment
  3. Deploy selected sensors in California communities
  4. Communicate the lessons learned to the public

- On-going activities:
  - Wide Spread Sensor Deployment across California
    - 300+ PM sensors
    - 100 Aeroqual (AQY) nodes (i.e., PM, O_3, NOx)
  - Cloud Based Platform Development
    - Data ingestion and storage
    - Data visualization and mapping
    - Data dissemination

South Coast AQMD

UCLA

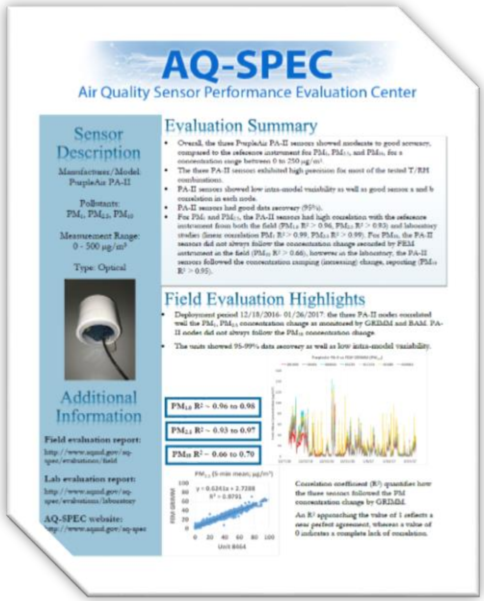
STi Sonoma Technology, Inc.

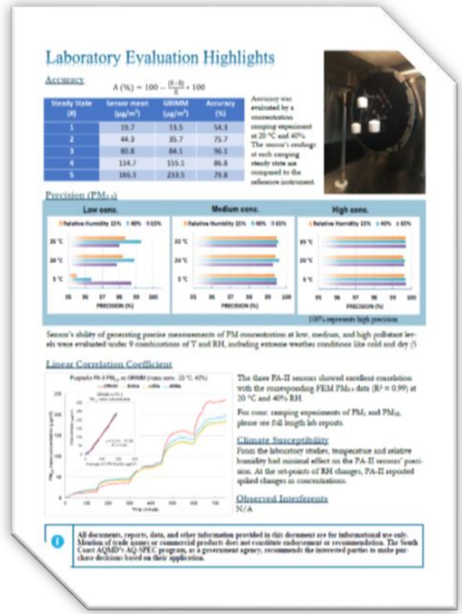
U.S. EPA STAR Project

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

PM Sensors

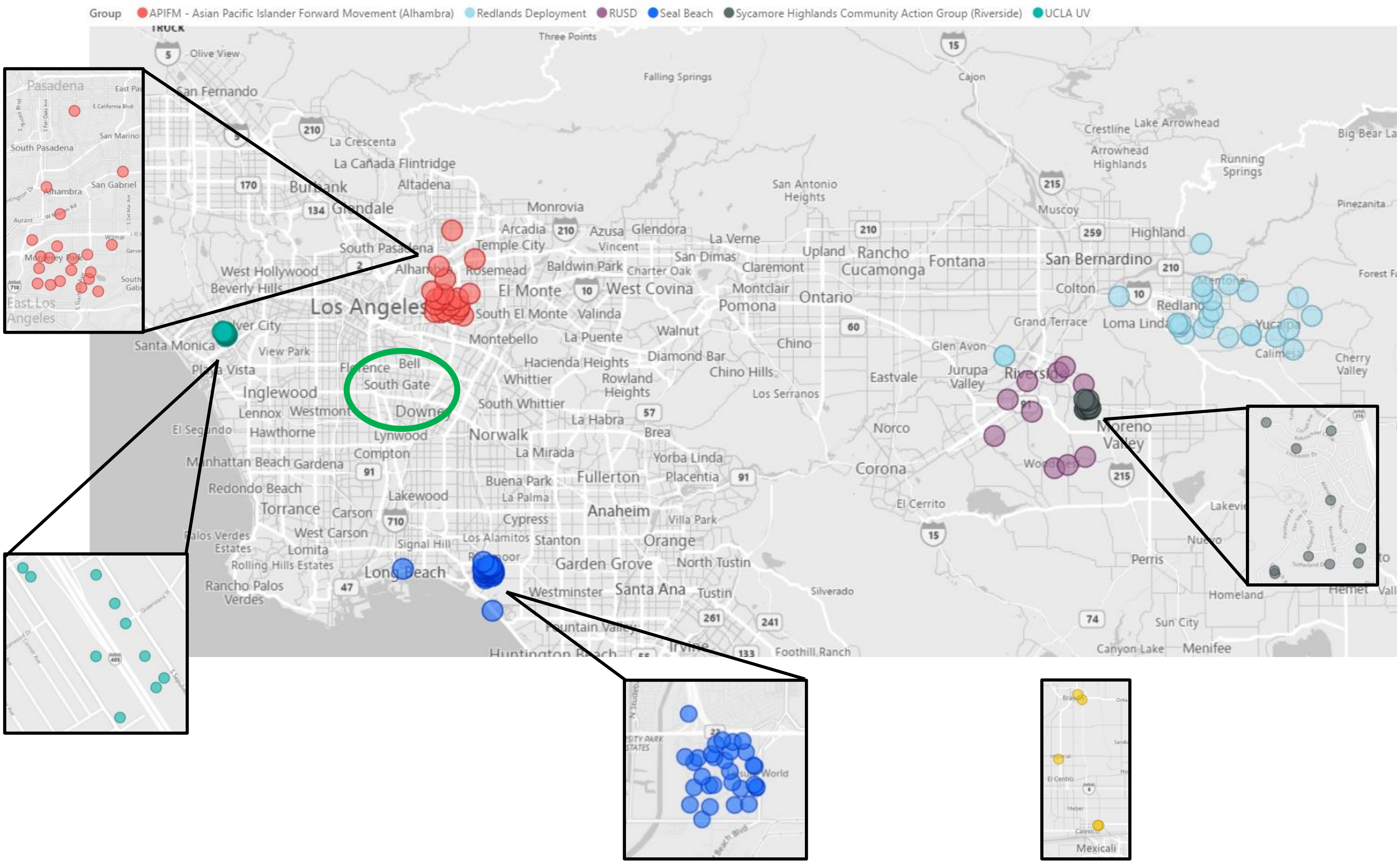
Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	Moji China (Airnut)	Optical	$PM_{2.5}$	~$150	$R^2 \sim 0.81$ to 0.88		
	Naneos (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	$PM_{1.0}$: $R^2 \sim 0.1$ $PM_{2.5}$: $R^2 \sim 0.2$		
	Origins (Laser Egg)	Optical	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: $R^2 \sim 0.58$ PM_{10}: $R^2 \sim 0.0$		
	Perkin Elmer (ELM)	Optical	PM	~$5,200	$R^2 \sim 0.0$		
	PurpleAir (PA-I)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$150	$PM_{1.0}$: $R^2 \sim 0.93$ to 0.95 $PM_{2.5}$: $R^2 \sim 0.77$ to 0.92 PM_{10}: $R^2 \sim 0.32$ to 0.44	$PM_{1.0}$: $R^2 \sim 0.95$ $PM_{2.5}$: $R^2 \sim 0.99$ PM_{10}: $R^2 \sim 0.97$	PDF (1,072 KB)
	PurpleAir (PA-I-Indoor)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$180	$PM_{2.5}$: $R^2 \sim 0.75$ PM_{10}: $R^2 \sim 0.36$ to 0.46		
	PurpleAir (PA-II)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: $R^2 \sim 0.96$ to 0.98 $PM_{2.5}$: $R^2 \sim 0.93$ to 0.97 PM_{10}: $R^2 \sim 0.66$ to 0.70	$PM_{1.0}$: $R^2 \sim 0.99$ $PM_{2.5}$: $R^2 \sim 0.99$ PM_{10}: $R^2 \sim 0.95$	PDF (1,328 KB)
	RTI (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	$R^2 \sim 0.65$ to 0.90	$R^2 \sim 0.99$	PDF (1,087 KB)
	SainSmart (Pure Morning P3)	Optical	$PM_{2.5}$	~$170	$R^2 \sim 0.73$	$R^2 \sim 0.99$	PDF (1,186 KB)
	Shinyei (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	$R^2 \sim 0.80$ to 0.90	$R^2 \sim 0.93$	PDF (1,156 KB)
	Speck	Optical	$PM_{2.5}$	~$150	$R^2 \sim 0.32$		
	TSI (AirAssure)	Optical	$PM_{2.5}$	~$1,500	$R^2 \sim 0.82$	$R^2 \sim 0.99$	PDF (5,647 KB)
	uHoo	Optical	$PM_{2.5}$	~$300	$R^2 \sim 0.0$		



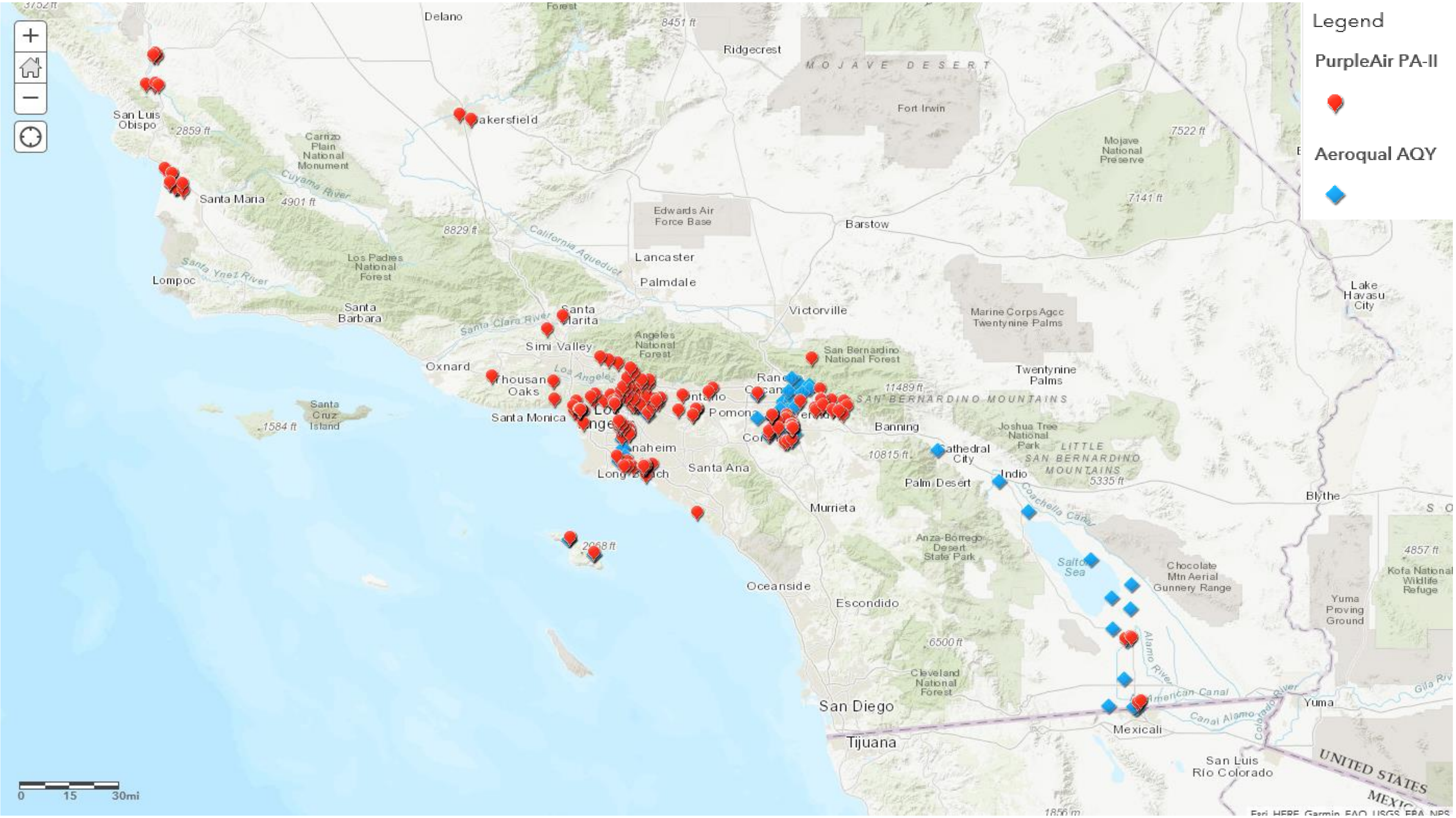


www.aqmd.gov/aq-spec

U.S. EPA STAR Project
($PM_{2.5}$ (PurpleAir) Sensors in SoCal Communities)



U.S. EPA STAR Project
($PM_{2.5}$ (PurpleAir) Sensors in California)



U.S. EPA STAR Project (Community recruitment)

LOW-COST AIR SENSORS STUDY

Purpose of study

Low-cost air sensors present an exciting opportunity to supplement data from fixed monitoring stations to help us better understand local-scale air pollution and climate change. This study aims to determine how low-cost sensors compare to traditional air monitoring devices, explore how air quality changes in the community given diurnal wind patterns across the freeway, and gain a better understanding of users' experience with these low-cost sensors. In the changing climate, we want to determine if low-cost sensors can produce reliable data compared to standard devices and whether they serve as useful tools for the future of air-quality monitoring.

About the sensors

The sensors used in this study will be the PurpleAir II sensors (shown on the right). The sensors will be mounted outdoors throughout the community and inside select apartments. They will require connection to a wireless internet connection for transmitting data in real-time. This sensor has shown promising results in laboratory and field testing for accuracy, ease of use, and ability to track diurnal variations in air quality. Everyone in the complex, as well as the general public, will be able to view the real-time sensor data on the PurpleAir website, helping you become informed about the air quality in your area and plan outdoor activities accordingly.

Eligibility for participating

If interested in participating, you must be planning to live to in your apartment until at least November 2018 and be able to provide wi-fi to the sensor. You must also be willing to fill out short questionnaires about your perception of sensors and sensor data and feedback about using the device and keep a simple log-book regarding your use of the sensor. You will also need to participate in 1-2 brief focus group sessions or on-on-one interviews to discuss your experience with the project. Participants will receive a $100 gift card upon completion.

• Yifang Zhu, PhD • UCLA Fielding School of Public Health • Department of Environmental Health Sciences • 650 Charles E. Young Drive

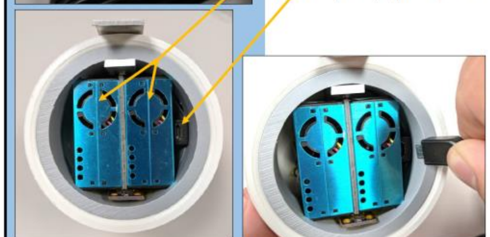
HOW YOU CAN GET INVOLVED

- Attend an educational workshop
- Volunteer to host an air quality monitor
- Requires a covered patio with a power outlet and wireless internet nearby
- Take care of the operating air monitor for about 2 years
- Monitor your air quality online anytime

NM 9/2017

U.S. EPA STAR Project
(Sensor installation guide)

Wi-Fi Setup and Registration



Get familiar with the PurpleAir PA-II Air Quality Sensor.

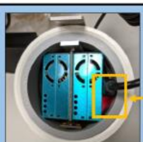
"**Location Name**" - It will be used during Registration (Take a photo or write it down)

"**Device ID**" - It will be used during Registra-tion (Take a photo or write it down)

Two sensors

Micro USB port to plug in the power chord.

1



Plug in the power chord and ensure that the power is turned on.

You will see a red light if it is on.

2

Go to (**A**) to set up on a cell phone or tablet
Go to (**B**) to set up on a laptop that uses Wi-Fi.

iPhone/iPad

Android Phone/ Tablet (Samsung, LG, Motorola, Google, etc.)

iPhone/iPad

Android Phone/ Tablet

<u>(A) Cell Phone or Tablet Set Up</u>

1. Go to "Settings" and Click on "Wi-Fi" settings.

2. On the list of WiFi network names, find "AirMonitor_xxxx" (xxxx will be actual letters and numbers like "9f66")

3. Click on or touch "AirMonitor_xxxx."

This is what it will look like if connected correctly.

<u>(B) Laptop or Computer Set Up (Windows)</u>

1. Click on the **Wi-Fi icon** in the bottom right corner of the screen.

2. On the list of WiFi network names, find "AirMonitor_xxxx" (xxxx will be actual letters and numbers like "9f66")

3. Click on or touch "AirMonitor_xxxx."

2

<u>Laptop or Computer Set Up (Windows) *continued*</u>

4. Go to "Settings "and Click on "Wi-Fi" settings.

This is what it will look like if connected correctly.

Wi-Fi is now set up and you are ready to set up the sensor!

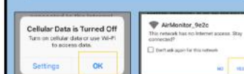
3

1. On your cell phone, tablet, or laptop open on an internet browser like:

2. In the **internet browser bar**, type: **<u>http://192.168.4.1</u>**

This will connect you to the sensor.

Tip: You may get disconnected during this step. It is okay. Just repeat Step 2.



Tip: You *may* see some messages pop up on your <u>*phone or tablet*</u>. Just click "OK" or "Yes". The pop ups will be small boxes in the middle of the screen.

Once you have connected to the sensor through "192.168.4.1" then you will see this.

This page shows your sensor's data so all of the numbers will be different than this example photo.

U.S. EPA STAR Project
(Sensor installation guide)

4

Now you are ready to connect your sensor to your home Wi-Fi network.

1. Click or press on "WiFi Settings".

Tip: You may get disconnected during this step. It is okay. Just repeat Step 2 and 3.

2. Once you are in the "WiFi Settings", click or touch the name of your Wi-Fi network.

3. Type in your Wi-Fi network password.

TIP: If you do not see your Wi-Fi network name, then click "Refresh".

4. Click or touch "Save".

The screen will change and you will see a window that looks like this. It should say ***"Restarting WiFi…"***

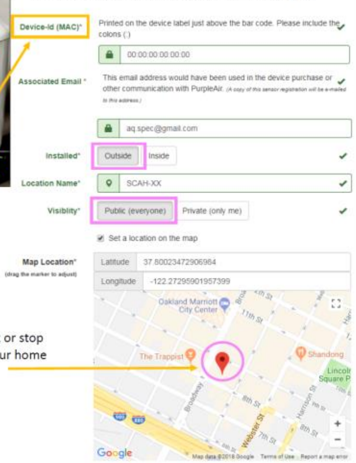
Your cell phone, tablet, or laptop will automatically reconnect to your home Wi-Fi network and the air sensor name will no longer be seen in your Wi-Fi settings.

Online Registration

1. On your cell phone, tablet, or laptop open on an internet browser like:

2. In the internet browser bar, type: www.purpleair.com/register

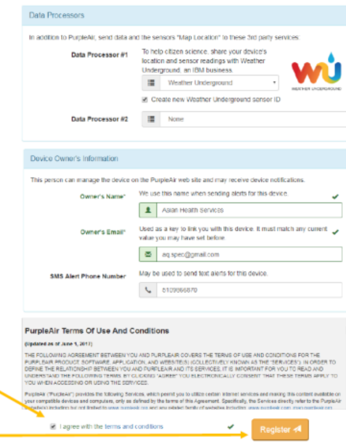
Enter the following information on the web page.



3. Click and hold (don't unclick or stop pressing down) and drag to your home location.

Online Registration

4. Leave this information unchanged.



5. Use this exact information for Device Owner's Information.

6. Click here to "agree" with the terms and conditions.

7. Click here to complete the Registration.

U.S. EPA STAR Project
(Sensor installation survey)

English Version

The Science To Achieve Results (STAR) Grant team at the South Coast AQMD would like to thank you for your participation in the project entitled, " Engage, Educate and Empower California Communities on the Use and Applications of "Low-cost" Air Monitoring Sensors" and to invite you to participate in this very brief online survey about your sensor installation location. Completing this survey with a smart device with a camera will allow you to easily submit a picture.

Installation Survey

Moving forward, please keep an eye out for upcoming community group meetings, an email containing the electronic log note entry form, and changes for end user data visualization and accessibility!

South Coast AQMD

Unsubscribe Forward to a friend
South Coast Air Quality Management District • 21865 Copley Drive, Diamond Bar, CA 91765
909-396-2000 • www.aqmd.gov

Spanish Version

EPA STAR Grant: La encuesta de instalación del sensor ahora disponible en Español

El equipo del programa otorgante/ la beca "la ciencia para lograr resultados (STAR, por sus siglas en inglés)" de la Administración de la calidad del aire de la costa sur, (South Coast AQMD, por sus siglas en inglés) le da las gracias por su participación en el proyecto llamado ""Envolver, educar y habilitar a comunidades en California en el uso y aplicación de sensores con monitoreo de aire a bajo costo" y le invita a participar en esta encuesta muy breve acerca del lugar de instalación de su sensor. Si completa esta encuesta con un dispositivo inteligente de cámara le permitirá fácilmente someter/enviar una foto.

Encuesta de instalación

Una vez que haya oprimido el enlace de la encuesta, oprima el tabulador "Default Language", (idioma predeterminado), arriba en la esquina a la derecha de la encuesta y seleccione "Español" del menú desplegable.

Con miras al futuro, esté al pendiente de próximas reuniones en grupo, un correo electrónico con una forma llamada "electronic log note entry form", y cambios de datos finales para el usuario de visualización y accesibilidad!

South Coast AQMD

Remover su nombre Enviar a un amigo
South Coast Air Quality Management District • 21865 Copley Drive, Diamond Bar, CA 91765
909-396-2000 • www.aqmd.gov

U.S. EPA STAR Project
(Sensor installation survey)

Sensor Installation Survey

This survey is intended as a one-time survey to be completed when a community scientist installs a sensor as part of the South Coast Air Quality Management District's (SCAQMD) U.S. EPA Science to Achieve Results (STAR) grant project entitled "Engage, Educate and Empower California Communities on the Use and Applications of Low-Cost Air Monitoring Sensors."

Name*
Community Scientist Name

Email Address

Date of Installation*
8/13/18

Time of Installation
- [ ] Morning
- [ ] Afternoon
- [ ] Evening

Community Group*
Select from the following communities:

-Please Select-
- El Monte City School District
- Fresno, Central California Environmental Justice Network (CCEJN)
- Imperial County, Comite Civico del Valle, Inc. (CCV)
- Kern, Central California Environmental Justice Network (CCEJN)
- Nipomo, southern SLO County

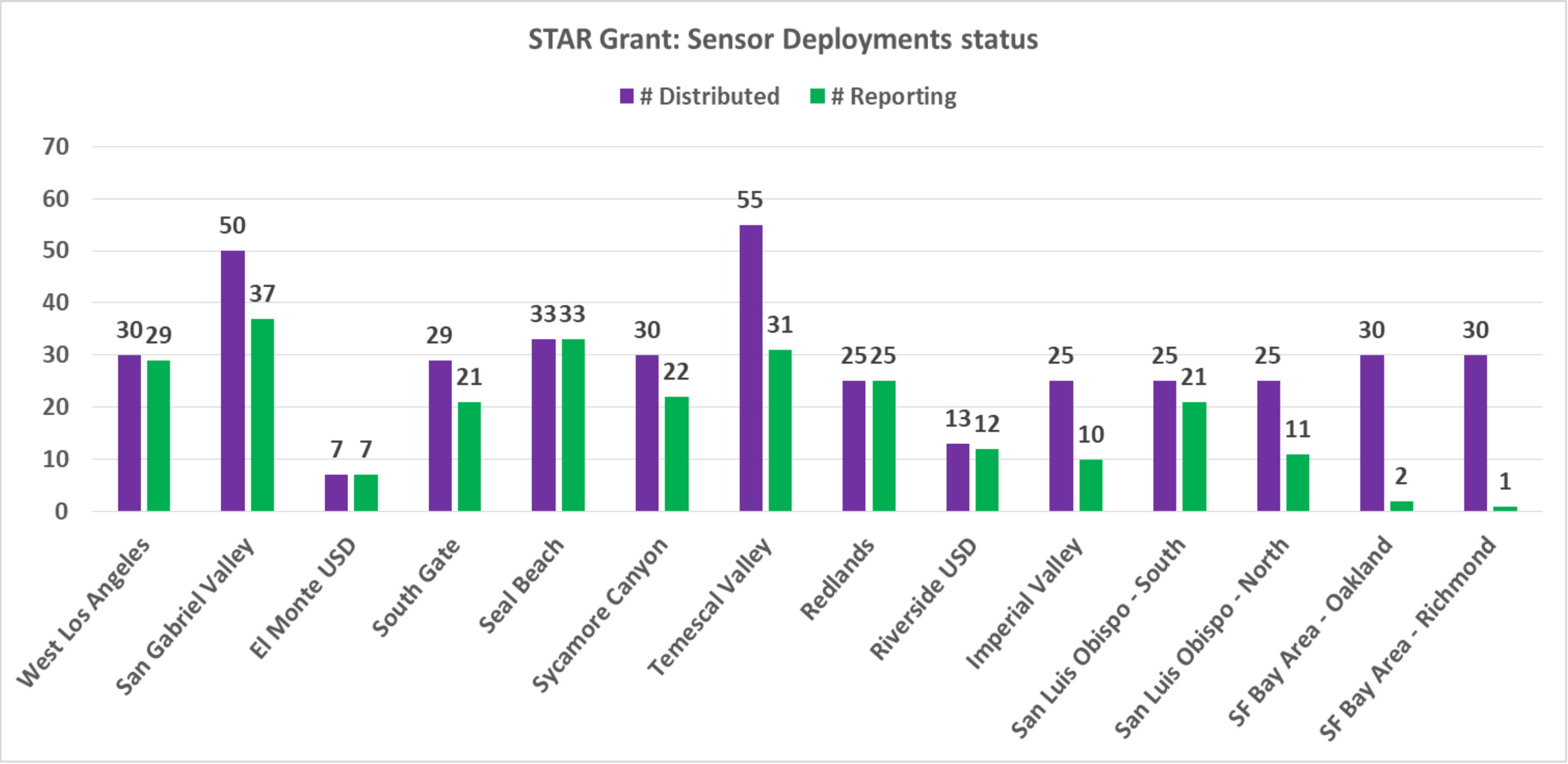
Lat: 0 Lon: 144.96552

What best describes the type of dwelling where the sensor is installed?*
- Single Family Home

What best describes the location where the sensor is installed?*
- Front Porch or Patio
- Rear Porch or Patio
- Eave of the Home
- External Wall of Home
- Balcony
- Other

What direction is the installation location facing?*
- North Facing
- South Facing

U.S. EPA STAR Project
(Sensor Deployment Across California)

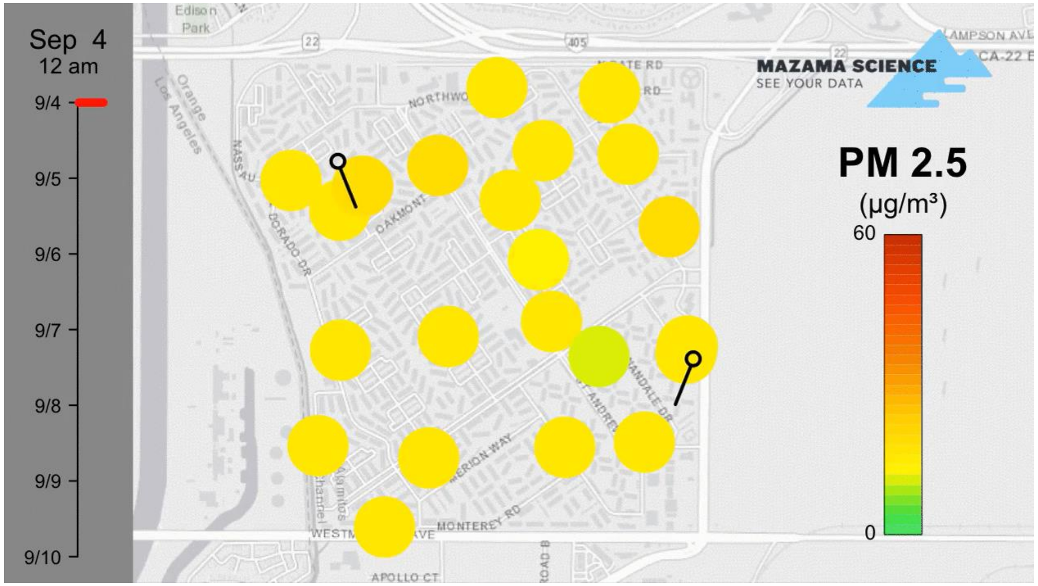


U.S. EPA STAR
(Seal Beach Community)

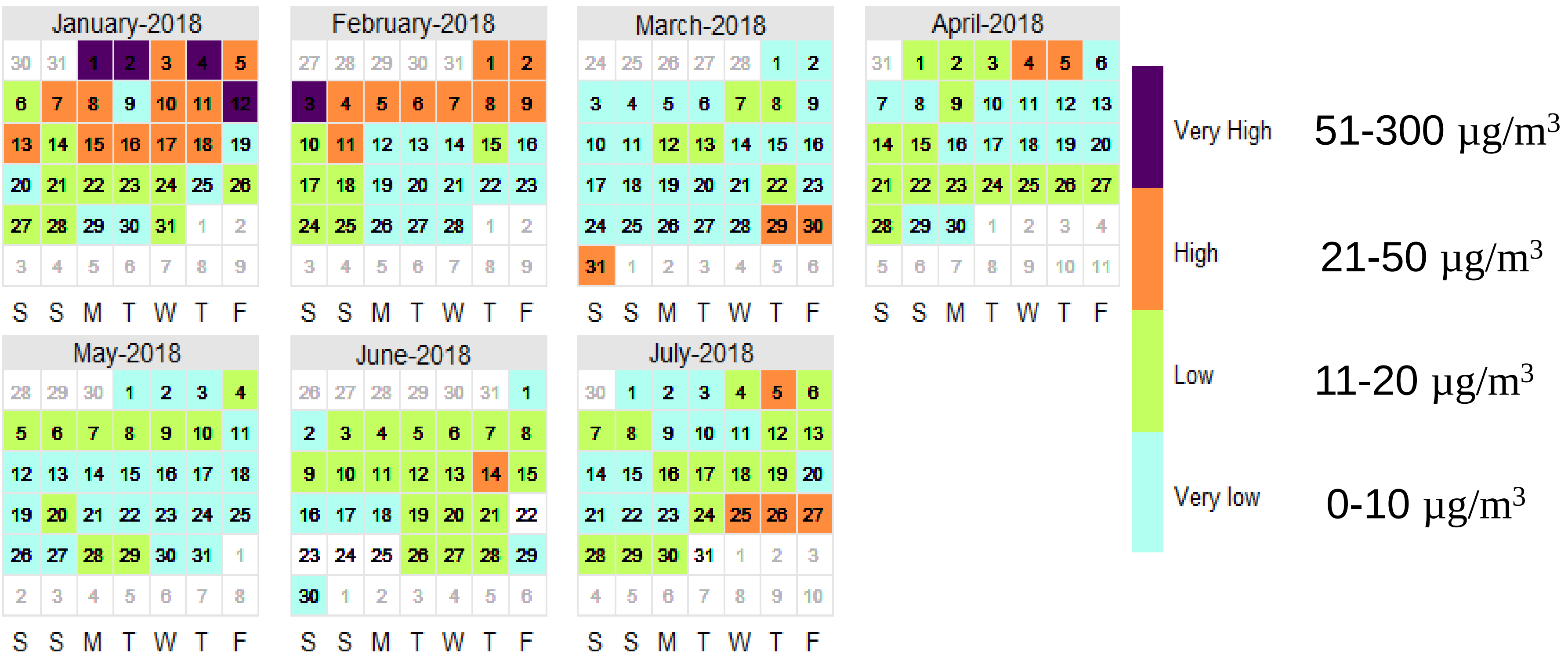
- 10,000 residents (average age 70 yrs)
- 1 km^2 area
- Borders the 405 freeway (in its most congested section)
- Borders the LADPA and AES electric generating stations
- Few miles from Port of Long Beach
- In landing path for Long Beach Airport
- Two military installations nearby

<u>What can one do with this data?</u>

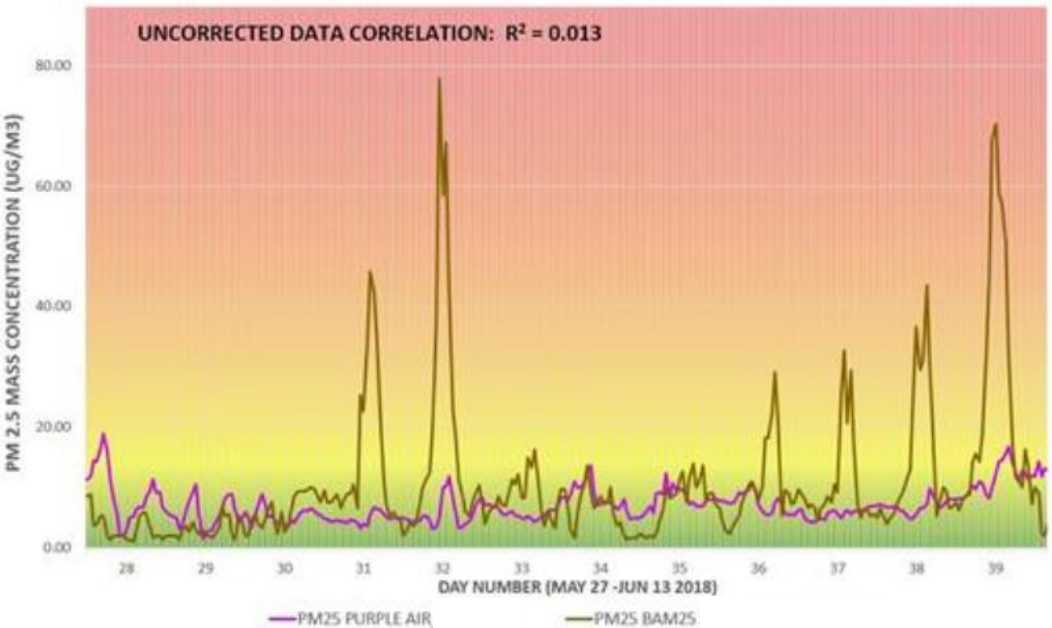
- Assess spatial and temporal variability
- Identify potential nearby PM sources
- Evaluate impact of wind speed/direction

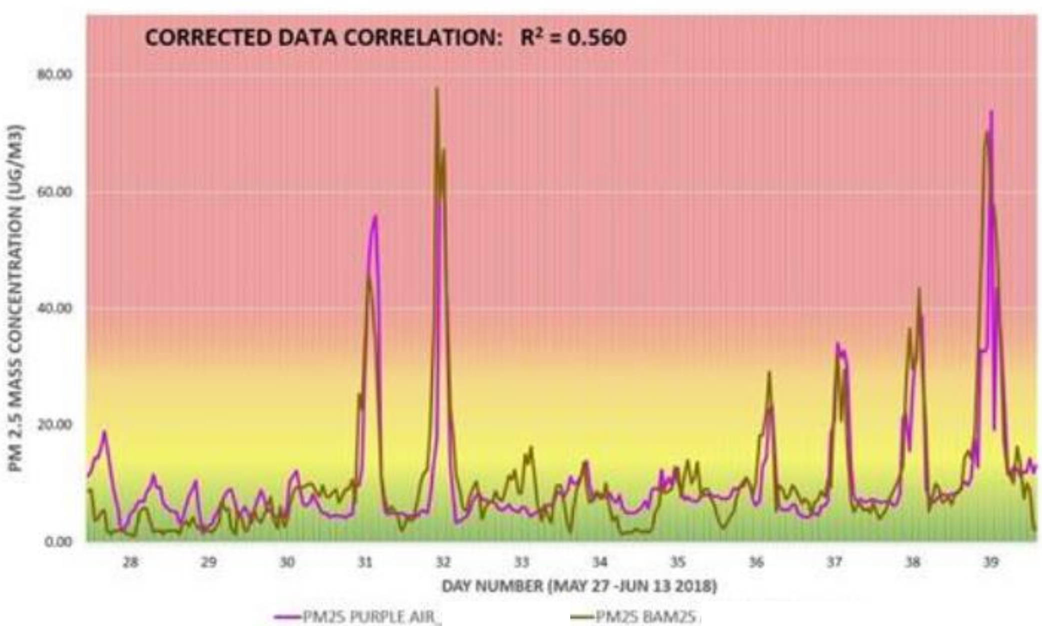


U.S. EPA STAR
(Seal Beach Community)



U.S. EPA STAR (Nipomo Community)





- Particle sensor largely underestimates actual (BAM) PM2.5 concentrations (at times)
- Particle composition is likely to affects sensor readings
- Community member developed a correction algorithm to reconcile sensor and FEM PM2.5 data

CORRECTION ALGORTHM INCORPORATING WIND VELOCITY:

Overall PurpleAir PM 2.5 Correction Factor = $(P_r)(1 + F_s\,F_d)$

$$F_s = \int_{-\infty}^{W_s} \frac{e^{-W_s^2/2}}{\sqrt{2\pi}} \quad \text{and:} \quad F_d = \frac{e^{-(W_d-\mu_d)^2/2\sigma_d^2}}{\sigma_d\sqrt{2\pi}}$$

P_r = 'Raw' (uncorrected) PurpleAir PM 2.5 readings (ug/m³)
F_s = Windspeed Correction Factor
F_d = Wind Direction Correction Factor
W_s and W_d = Wind speed and direction, individual data points
μ_s and μ_d = Mean (average) of all wind velocity data points
σ_s and σ_d = Standard Deviation of wind velocity data sets
σ_s^2 and σ_d^2 = Variance (standard deviation squared)
e = Constant (= 2.7182...) and base for natural logarithms
A_s = Windspeed adjustment applied to F_s for curve fitting

U.S. EPA STAR (Next Steps)

- Development of a cloud-based computing platform to ingest, store, analyze, and display sensor data

Data analysis workloads larger than current tools can handle

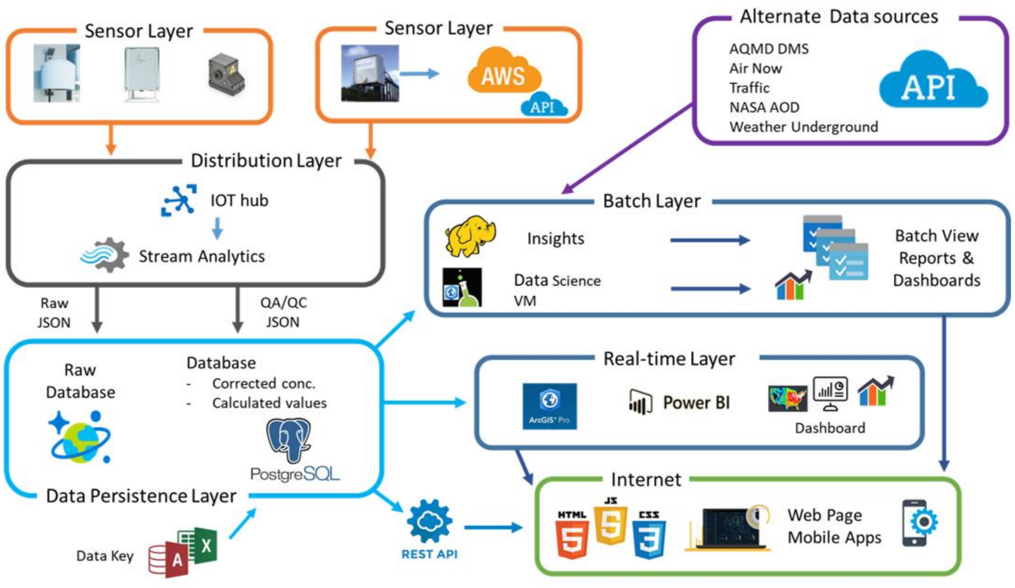
Fence-line monitoring: ~15 million rows of data

Regional monitoring network: ~40 million rows of data

STAR Grant: ~50 million rows of data

South Coast AQMD R1180: XX million rows of data

CA AB617: xx billion rows of data

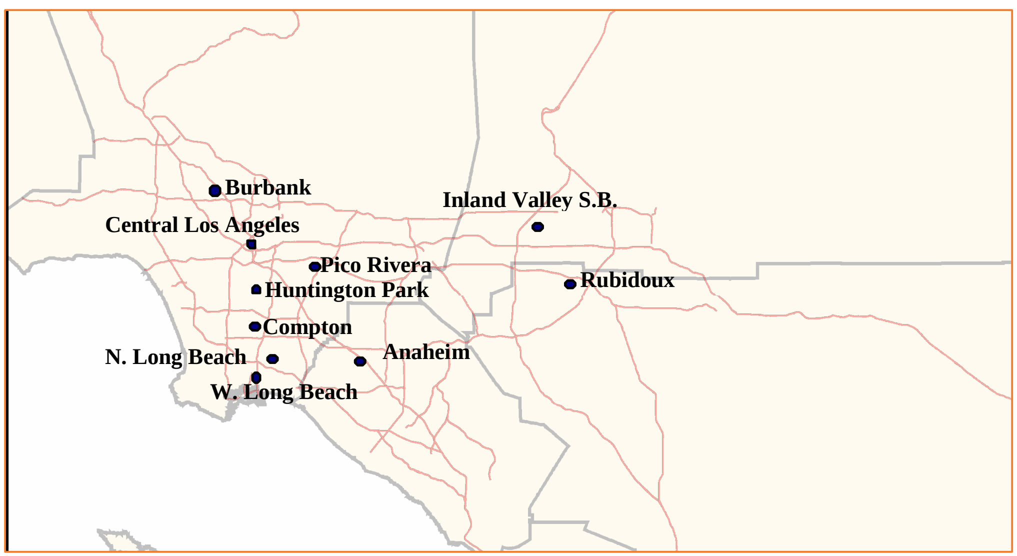


SCAQMD Sensor Monitoring Projects

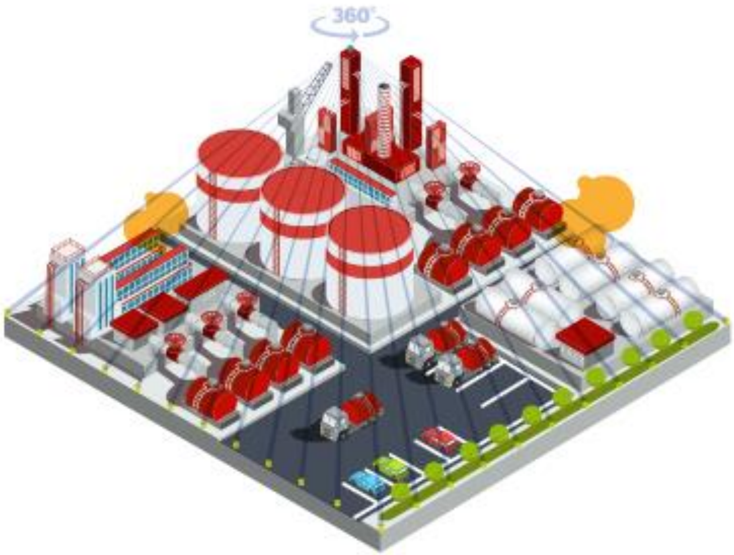
Fence-line	Regional network	US EPA STAR Grant	**Other projects**
9 PM sensors	~ 100 nodes to measure: O_3, NO_2, & PM	~ 400 PM sensors in 14 communities	**MATES V**
IoT vendor platform	Cellular to PaaS	Wi-Fi connected	**ROSE/NASA Project**
Cellular to SaaS	API access	Data sent to : PurpleAir Map; AQMD Azure	**Mobile monitoring**
API Access			**AB617 community monitoring**
			SCAQMD Rule 1180 implementation

Other Projects
MATES V (2018-2019)

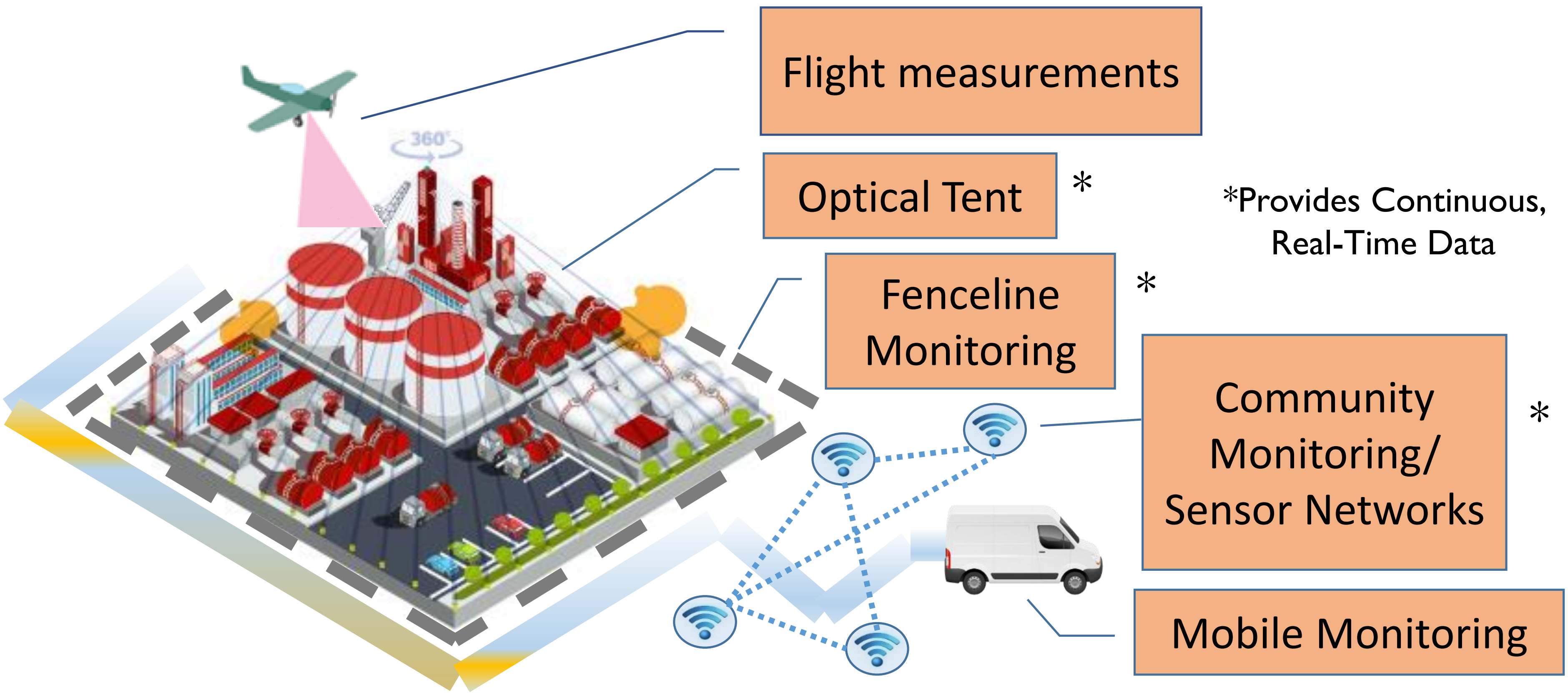
- Regional air toxics monitoring and modeling
- Advanced monitoring to find potential hotspots
- Focus on refineries and other industrial sources
- Community engagement through sensor network deployments



*Actual location of a few monitoring sites may differ



Other Projects
MATES V (2018-2019)



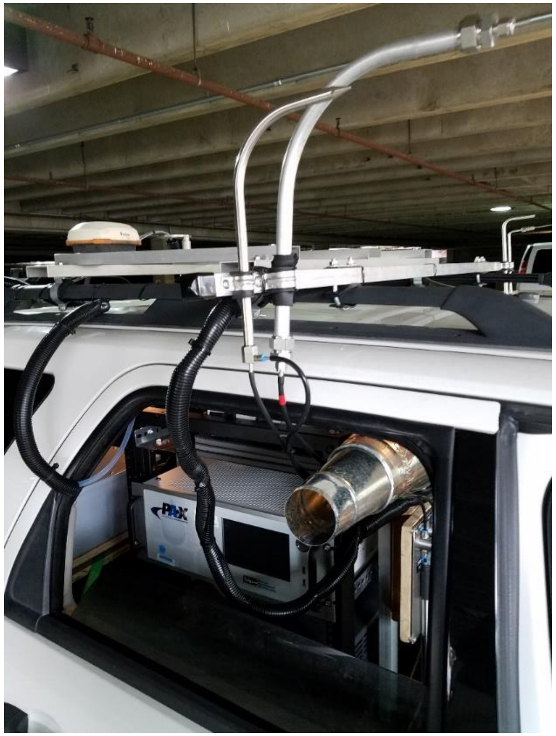
Other Projects (Mobile Monitoring)

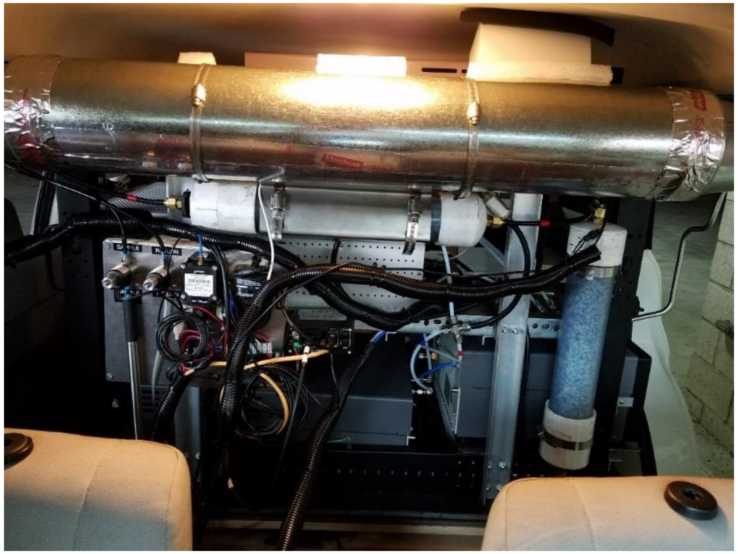
- Ford Escape PHEV (MY 2010, SCAQMD fleet vehicle)
- Mobile measurements of NAAQS criteria pollutants and air toxics
- Fast response regulatory-grade, research-grade, consumer-grade
- Vehicle speed: 30 ± 3 mph
- Extended on-road sampling periods (> 4 hours)
- Additional data parameters collected
  - GPS Coordinates
  - Wind Speed/Direction
  - 340° Video

Instruments

Pollutant	Time Resolution
BC	1 sec
Particle Mass (FEM, near-FEM, sensor)	6, 60, 80 sec
Particle Count	1 sec
CO (FRM)	1 sec
NO_2 (FEM, sensor)	6, 60 sec
O_3 (FEM, sensor)	10, 60 sec

Other Projects
(Mobile Monitoring)

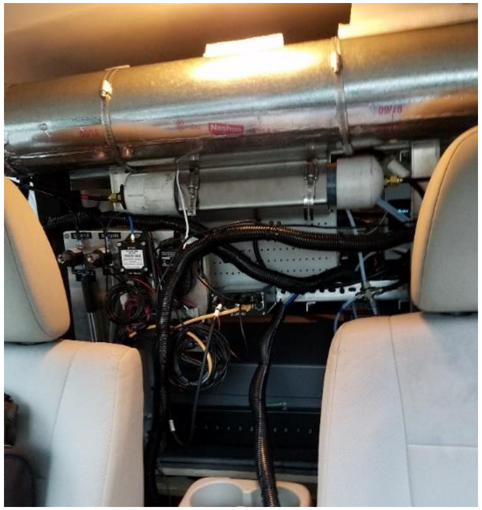




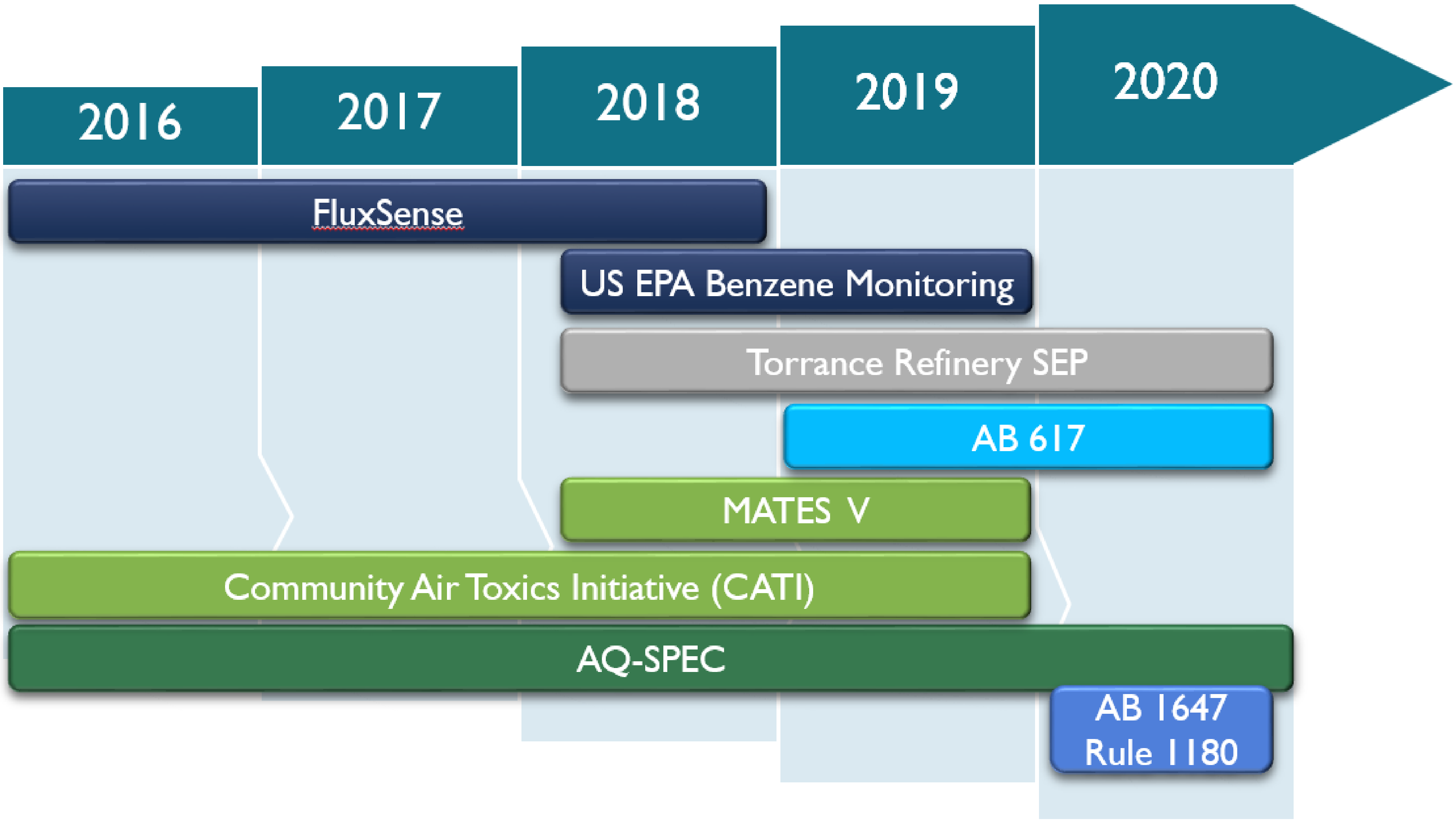
Other Projects
(Mobile Monitoring)








Current and Upcoming Air Monitoring Initiatives at the SCAQMD



Conclusions

- Sensors and sensor networks:
  - Great survey tools for hot-spots identification and to better understand spatial and temporal variations of $PM_{2.5}$, O_3, and NO_2
  - Although they do not produce actionable data their measurements can lead to action. Can be used to support community monitoring

- Need for a sensor certification program to provide users with the knowledge to appropriately select sensors for specific applications
  - Additional guidance for air districts to correctly implement current/upcoming state and local rules (e.g., AB617 and Rule 1180)

- Many challenges ahead, but it is difficult to see a future where sensors and sensor networks will not be integrated in existing ambient air monitoring networks

Thanks!

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