2018 Air Sensors International Conference (ASIC)

Air Quality Sensor Performance Evaluation Center (AQ-SPEC): Lessons Learnt and New Challenges

Andrea Polidori, Vasileios Papapostolou, and Brandon Feenstra

^*South Coast Air Quality Management District, Diamond Bar, California*

Sensor Performance Evaluation

- Main organizations
  - JRC
  - EPA / ORD
  - SCAQMD (AQ-SPEC)
- Field and/or laboratory testing
- Parameters evaluated
  - FRM/FEM vs sensor correlation (R2)
  - Intra-model variability
  - Accuracy
  - Precision
  - Other
- <u>No recommendation on potential use and application</u>

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

- Established in July 2014
- Main Goals & Objectives
  - Provide guidance & clarity
  - Promote successful evolution and use of sensor technology
  - Minimize confusion
- Sensor Selection Criteria
  - Commercially available
  - Real- or near-real time
  - Criteria pollutants & air toxics
  - < ~ $2,000: purchase
  - > ~ $2,000: lease or borrow











AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Field Testing

- Co-location with FRM/FEM
- Process:
  - Sensor tested in triplicates
  - Two month deployment
- Locations:
  - Rubidoux station (main)
    - Inland site
    - Fully instrumented
- <u>40+ sensors evaluated to date</u>

South Coast AQMD

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Laboratory Testing

<u>T and RH controlled</u>: 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 <u>VOCs</u>

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

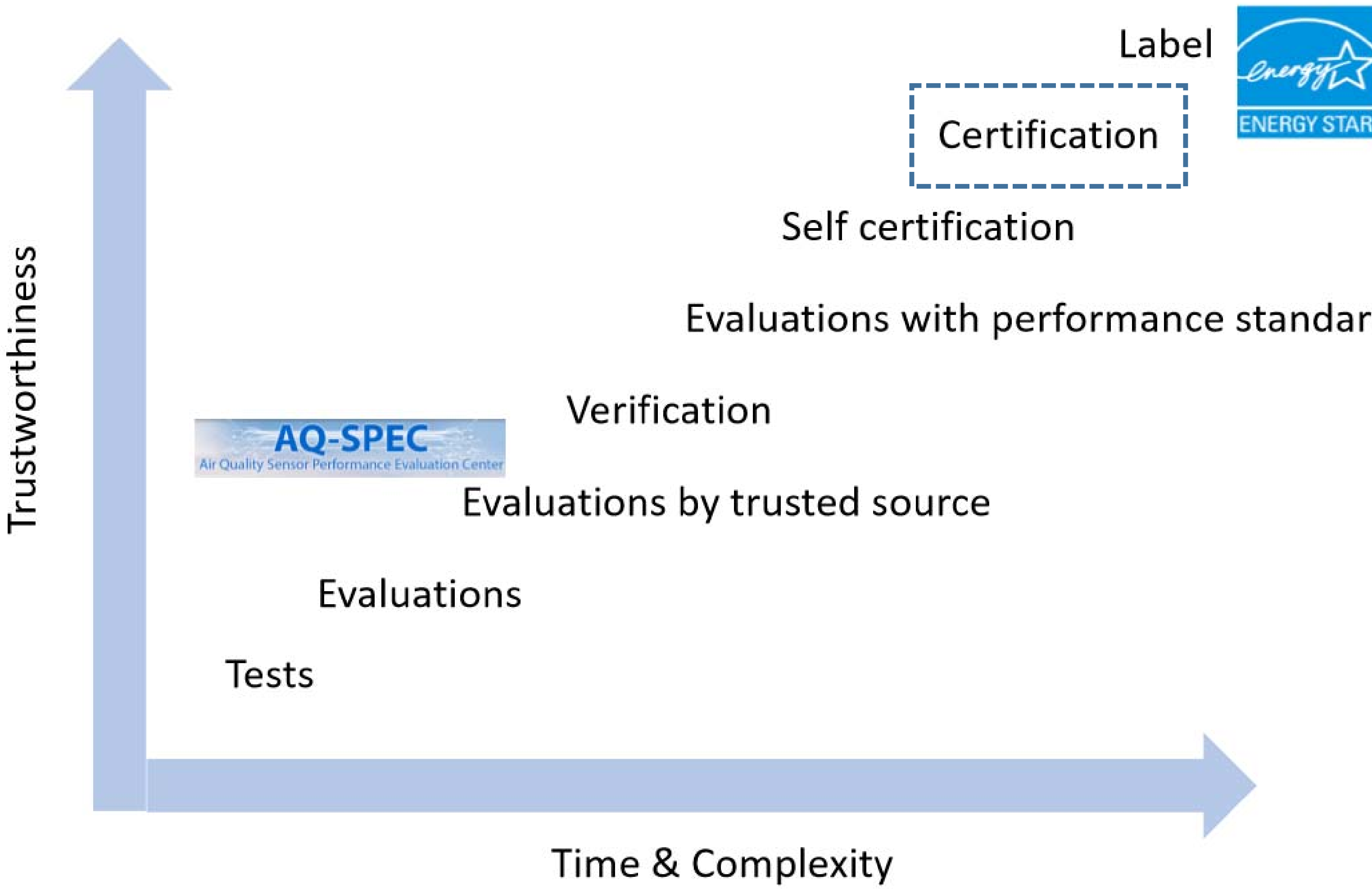
Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	**2B Technologies** (POM)	UV absorption (FEM Method)	O_3	~$4,500	R^2 ~ 1.00	R^2 ~ 0.99	PDF (1,295 KB)
	**Aeroqual** (S-500)	Metal Oxide	O_3	~$500	R^2 ~ 0.85	R^2 ~ 0.99	PDF (1,197 KB)
	**Air Quality 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

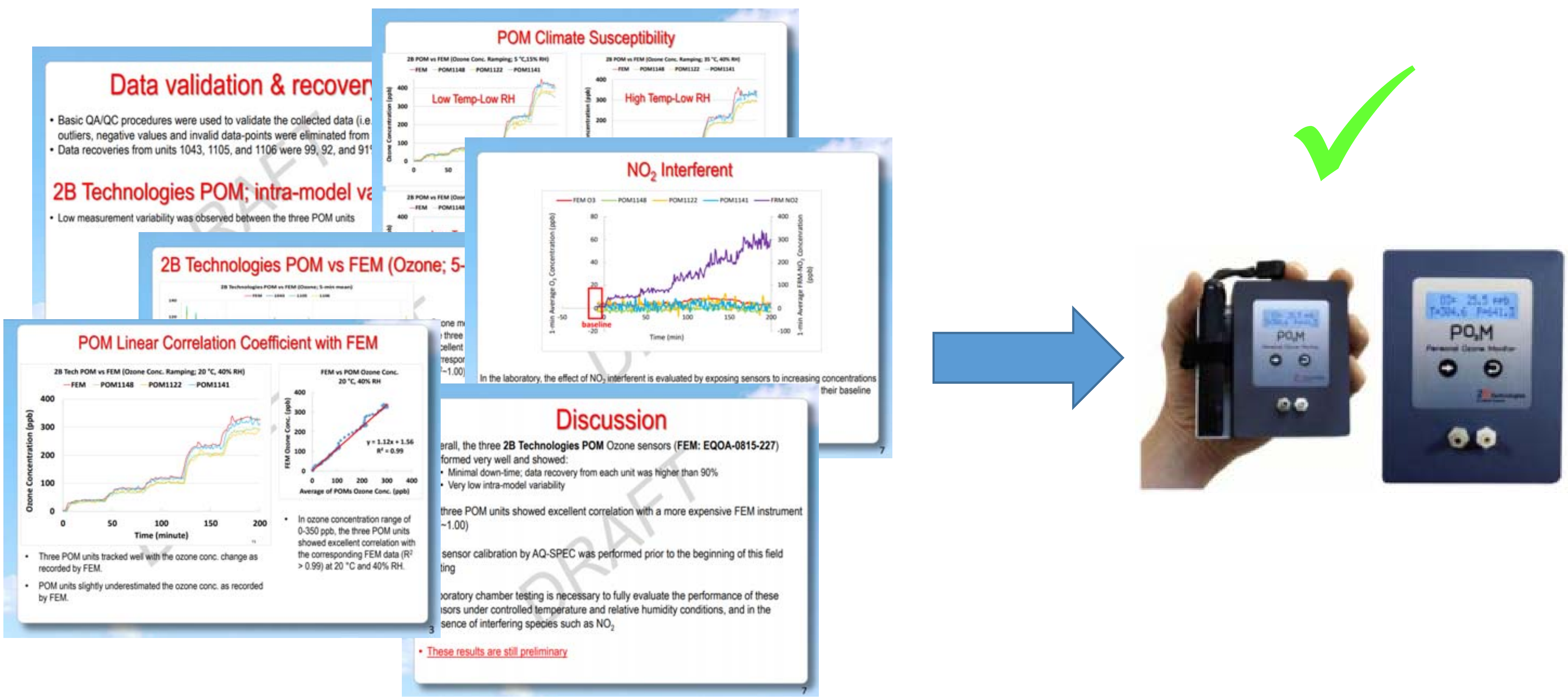
Sensor Certification

- Tiered: 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

- Pass / Fail:
  - 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

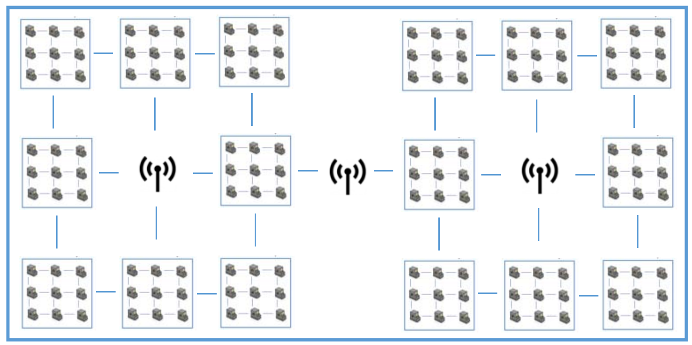
- A sensor certification program is desirable but very expensive / time consuming to implement
  - Multiple field testing locations
  - Multiple laboratory testing facilities
  - Extended testing time
- The U.S. EPA is leading the way at the National level
  - E-Enterprise
- On-going discussion in California between CARB, SCAQMD, BAAQMD and other air districts
  - Sensor performance verification
  - ASTM method development
  - Other models

Sensor Deployment Challenges

Sensor Unit

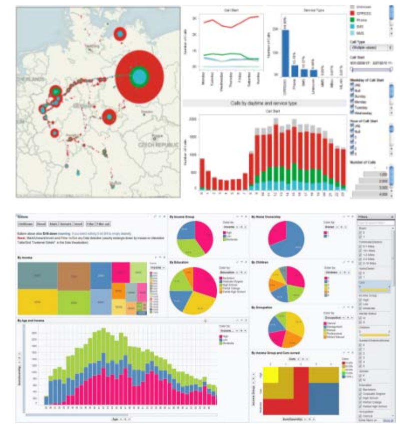
- Assume you have a “certified” PM2.5 sensor

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

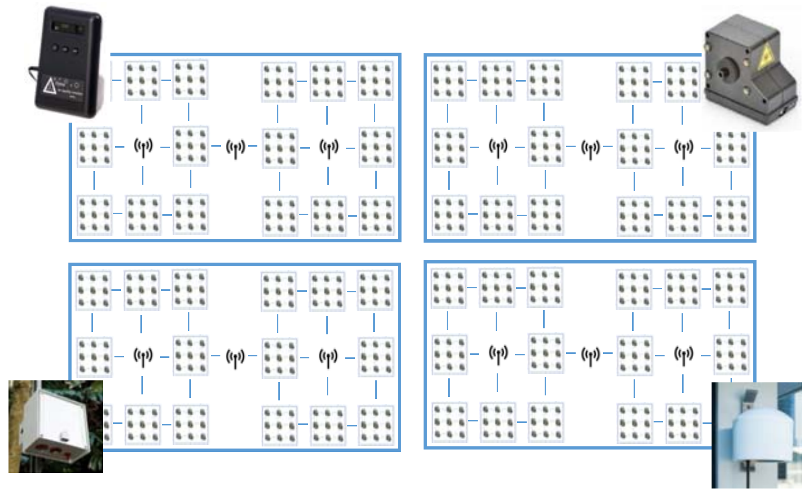
Different sensor networks comprised of the same “certified” sensor may still produce inconsistent data / results

Sensor Deployment Challenges

Sensor Units

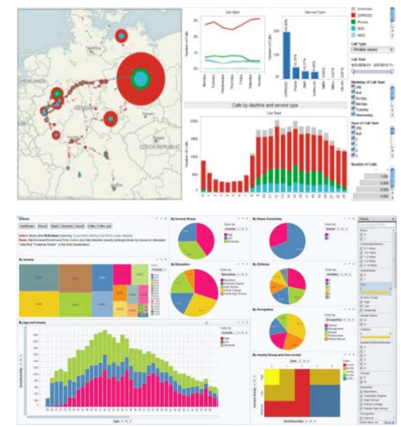
- Assume you have 4 different “certified” PM2.5 sensors

Sensor Networks



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

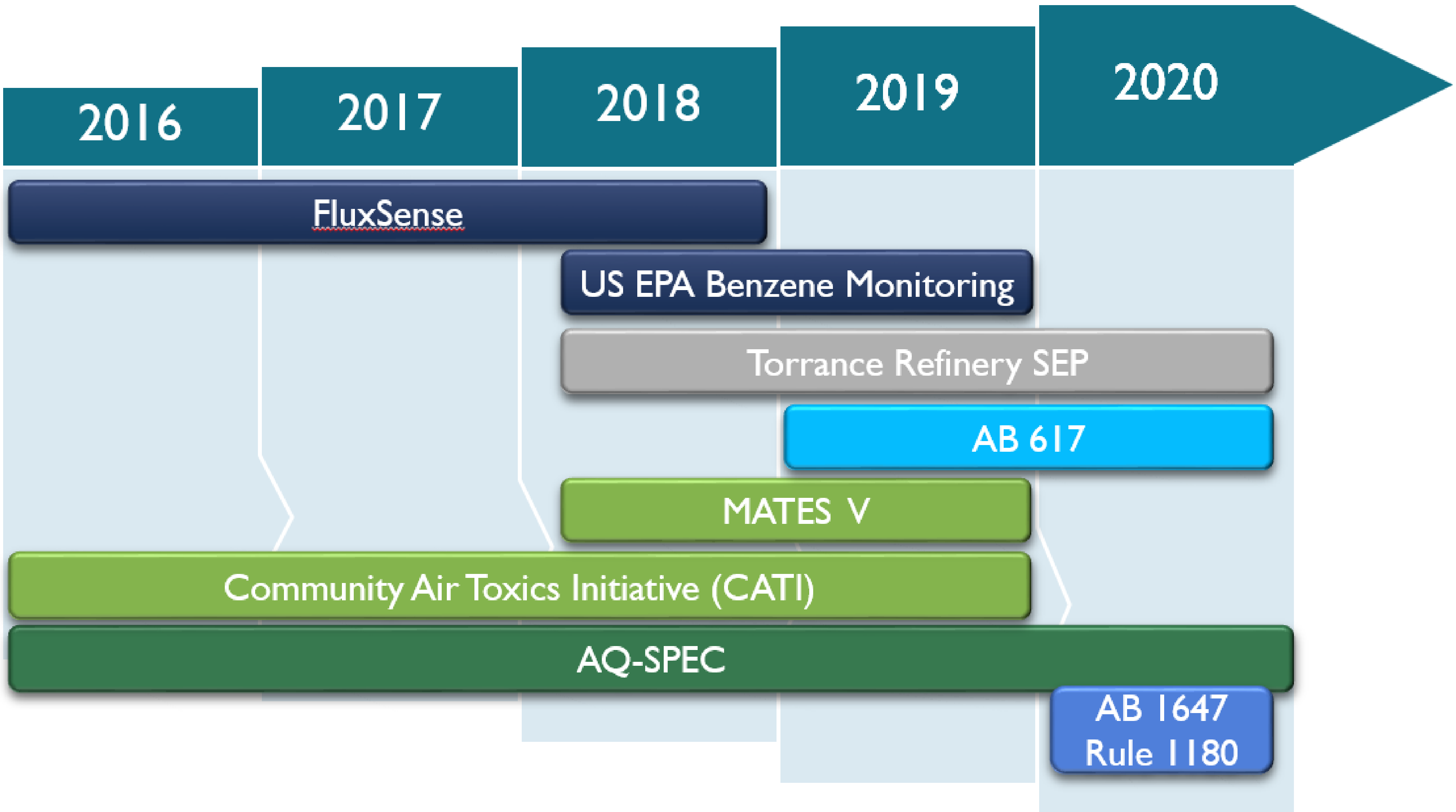
Networks Data



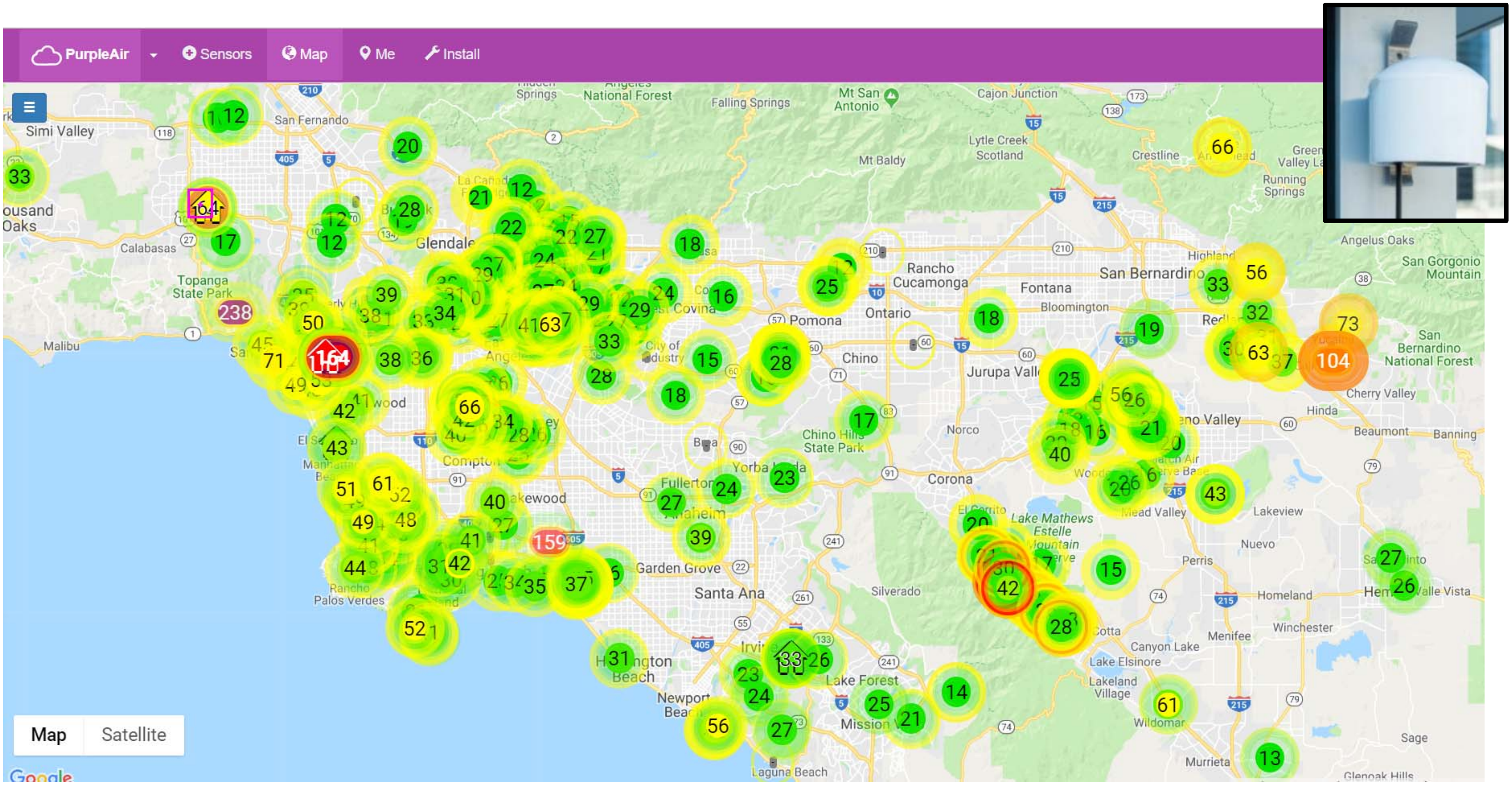
- Backend application and data handling procedures
- Validation and other QA/QC requirements
- Analysis and interpretation
- Mapping
- Correction algorithms / models
- Time averaging
- Integration with existing network data

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

Current and Upcoming Air Monitoring Initiatives at the SCAQMD

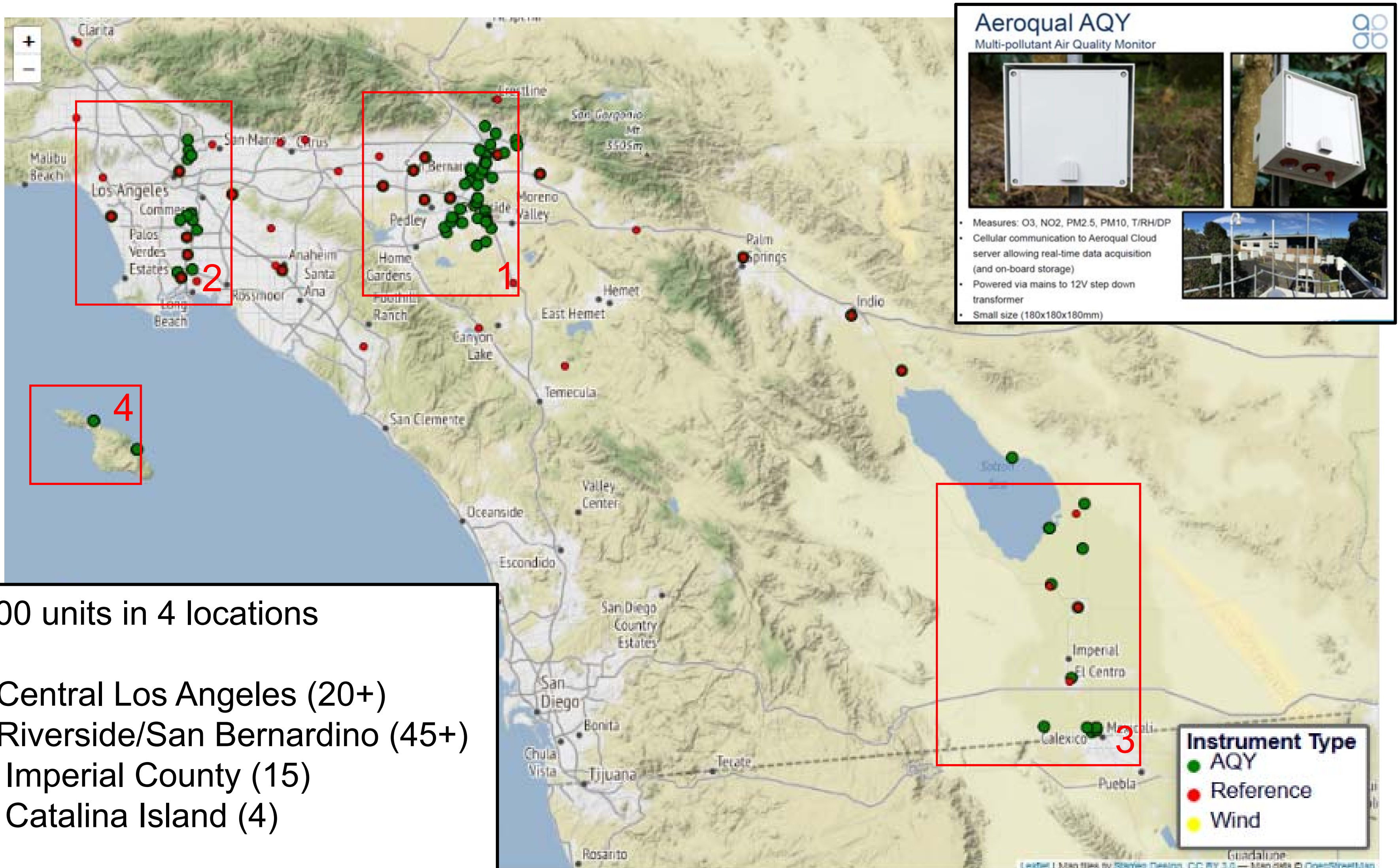


PM2.5 Sensor Networks in the SCAB (2018)
PurpleAir



Note: Values are reported as AQI units

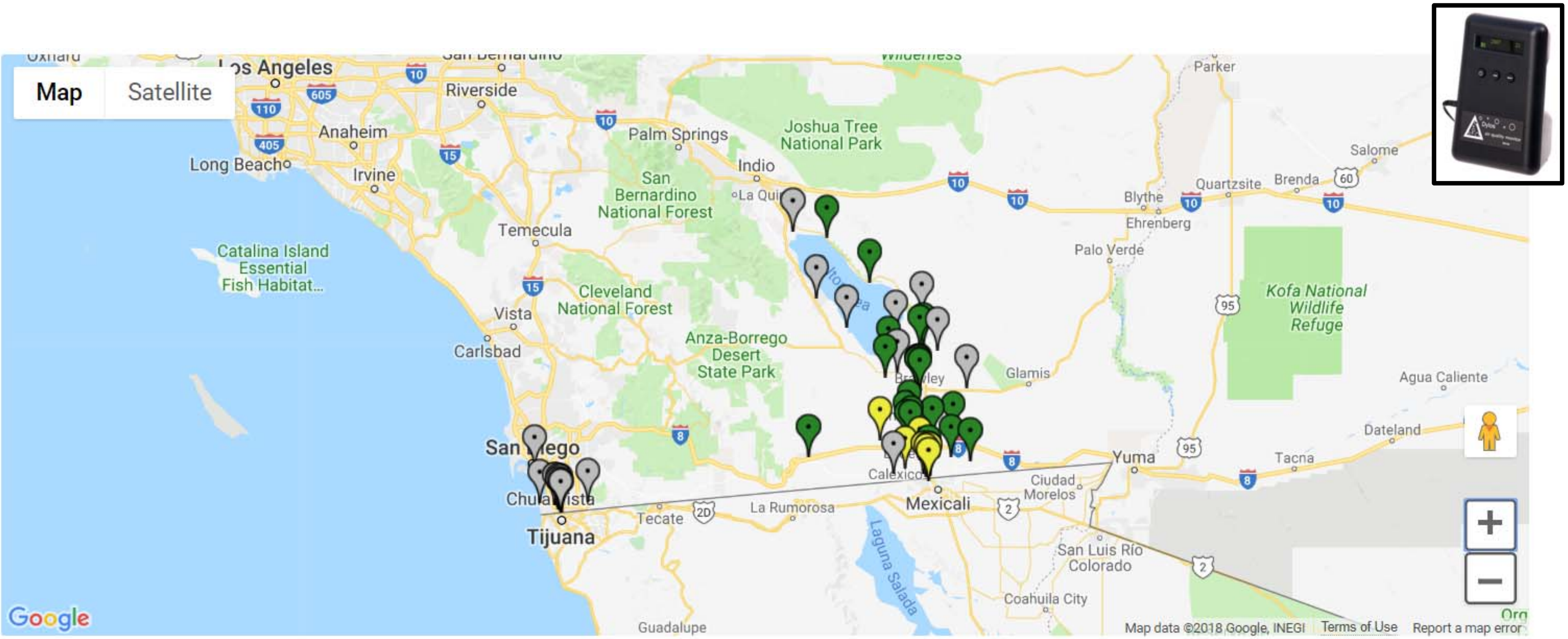
PM2.5 Sensor Networks in the SCAB (2018)
Aeroqual AQY (PM2.5, O3, and NO2)



~100 units in 4 locations

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

PM2.5 Sensor Networks in the SCAB (2018)
IVAN



IVAN IMPERIAL

Comite Civico Del Valle, Inc.

Conclusions

- Sensors and sensor networks:
  - Great survey tools for hot-spots identification and to better understand spatial and temporal variations of PM2.5, O3, and NO2
  - 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!

The AQ-SPEC Team

- *Dr. Jason Low*
- *Dr. Andrea Polidori*
- *Dr. Vasileios Papapostolou*
- *Brandon Feenstra*
- *Dr. Hang Zhang*
- *Berj Der Boghossian*
- *Dr. Michelle Kuang*
- *Dr. Ashley Collier (NEW)*
- *Dr. Wilton Mui (NEW)*