Maximizing Sensor Data Quality

Photo credit:
Polidori A., Papapostolou V., Collier-Oxandale A., Hafner H., and Blakey T. (2021) Community in Action: A Comprehensive Guidebook on Air Quality Sensors.

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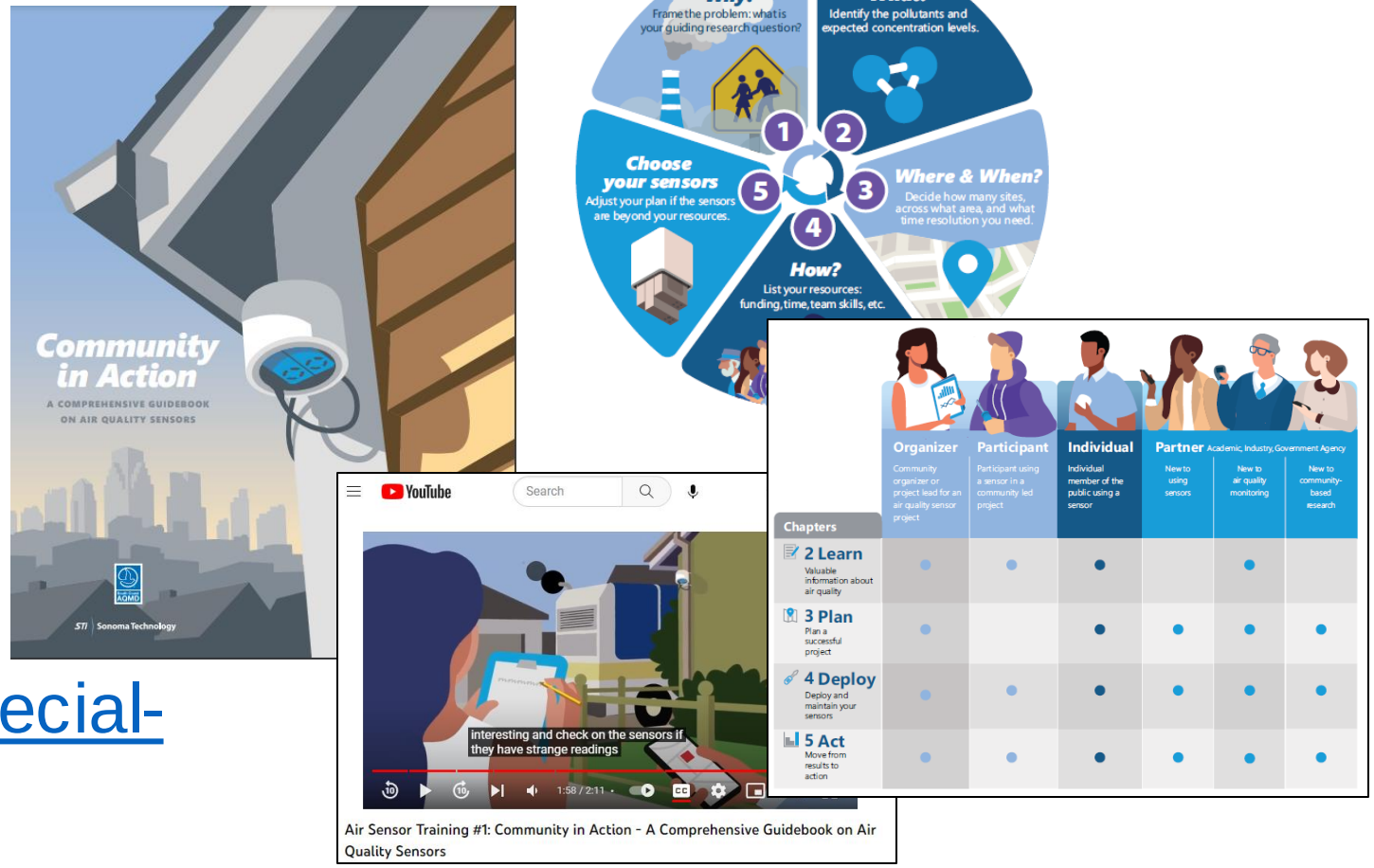
Sensor Educational Toolkit

- Product of US EPA STAR grant
- Engaging videos
- Resources for data analysis and interpretation
- Digestible sensor guidebook
- Aspects covered
  - Project planning
  - Sensor installation and deployment advice
  - Limitations and opportunities



www.aqmd.gov/aq-spec/special-projects/star-grant

Planning a Sensor Project

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Application	Implementation
Informational/Educational	Sensors given to individuals, liberal setup and operation
Personal Exposure	Sensors given to individuals, sensors move with them
Area Characterization	Sensor network set up in a broad area, consistent setup and operation
Source Identification/Characterization	Sensors strategically set up around and downwind of a source, consistent setup and operation
Supplemental to Regulatory	Sensors set up between regulatory monitor locations to fill in gaps, consistent setup and operation

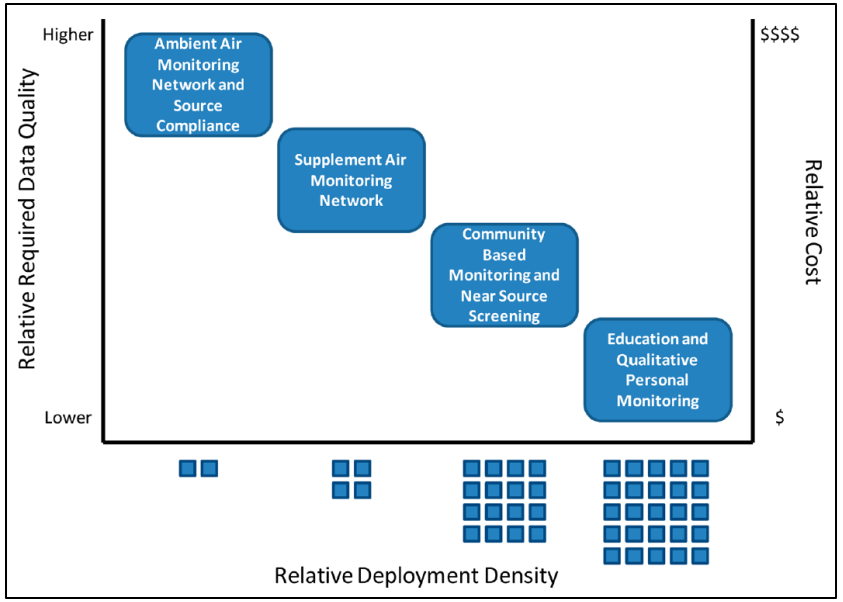
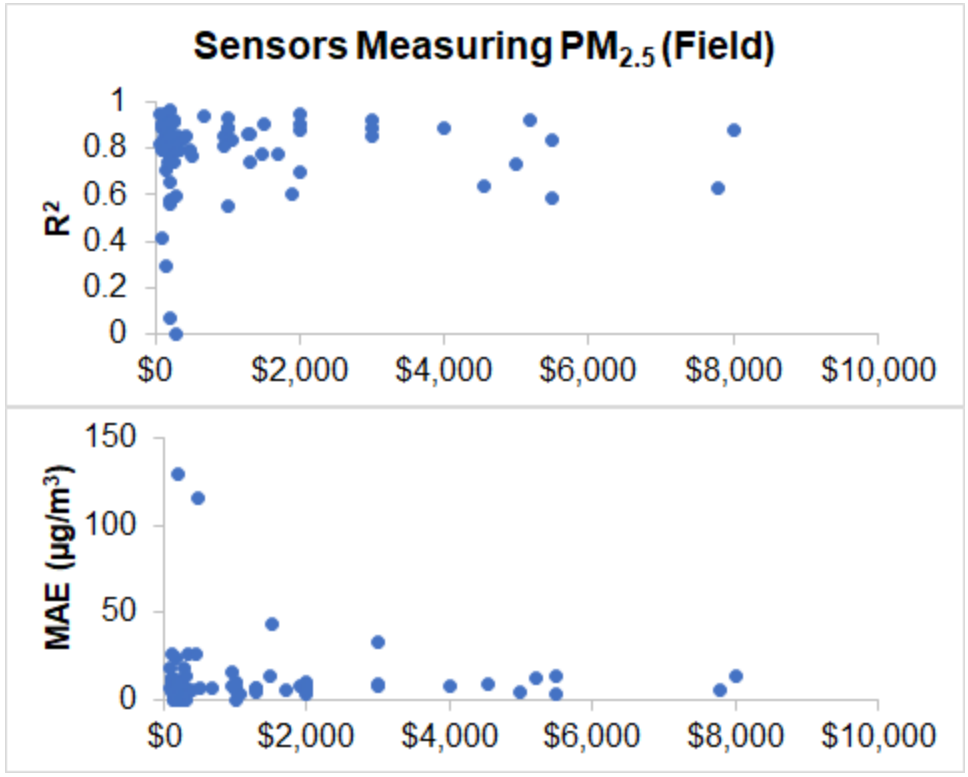
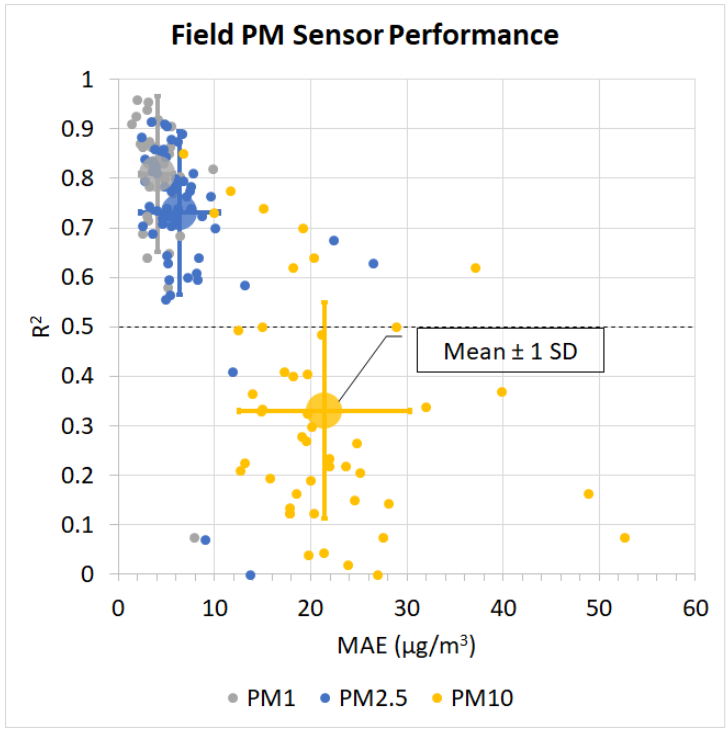
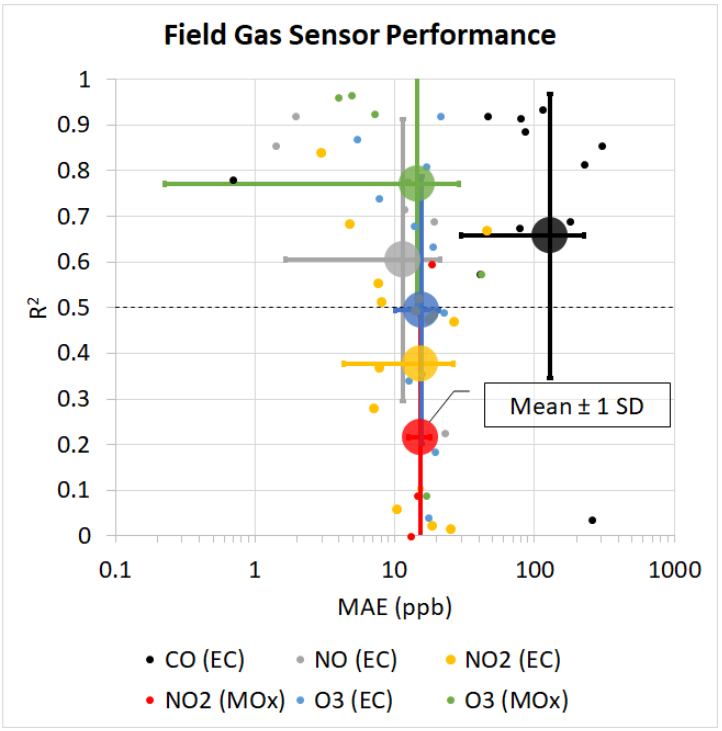


Figure credit: Snyder et al., 2013

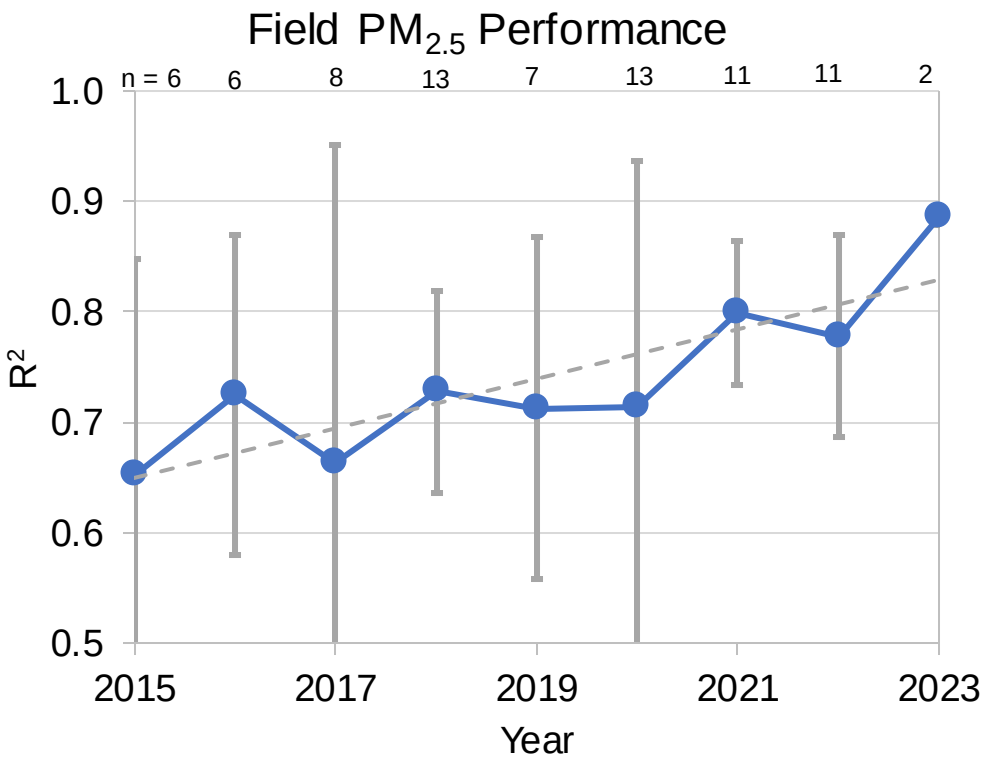
Sensor Performance in General

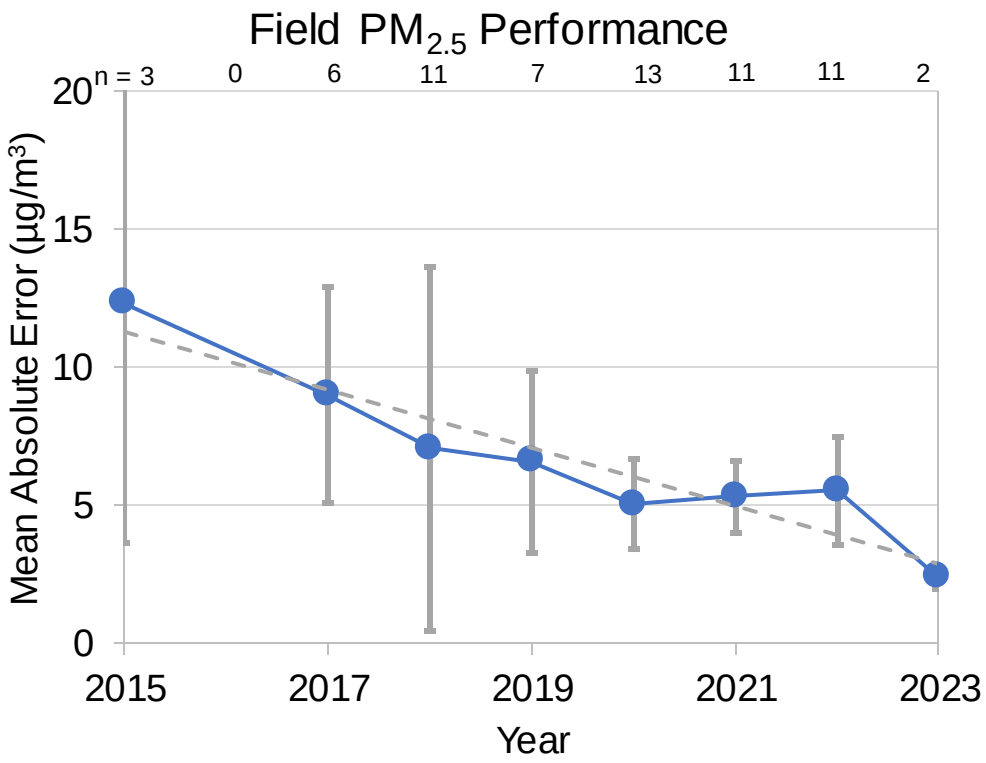






Sensor Performance Improvements





Quality Considerations: Single Sensor

PM

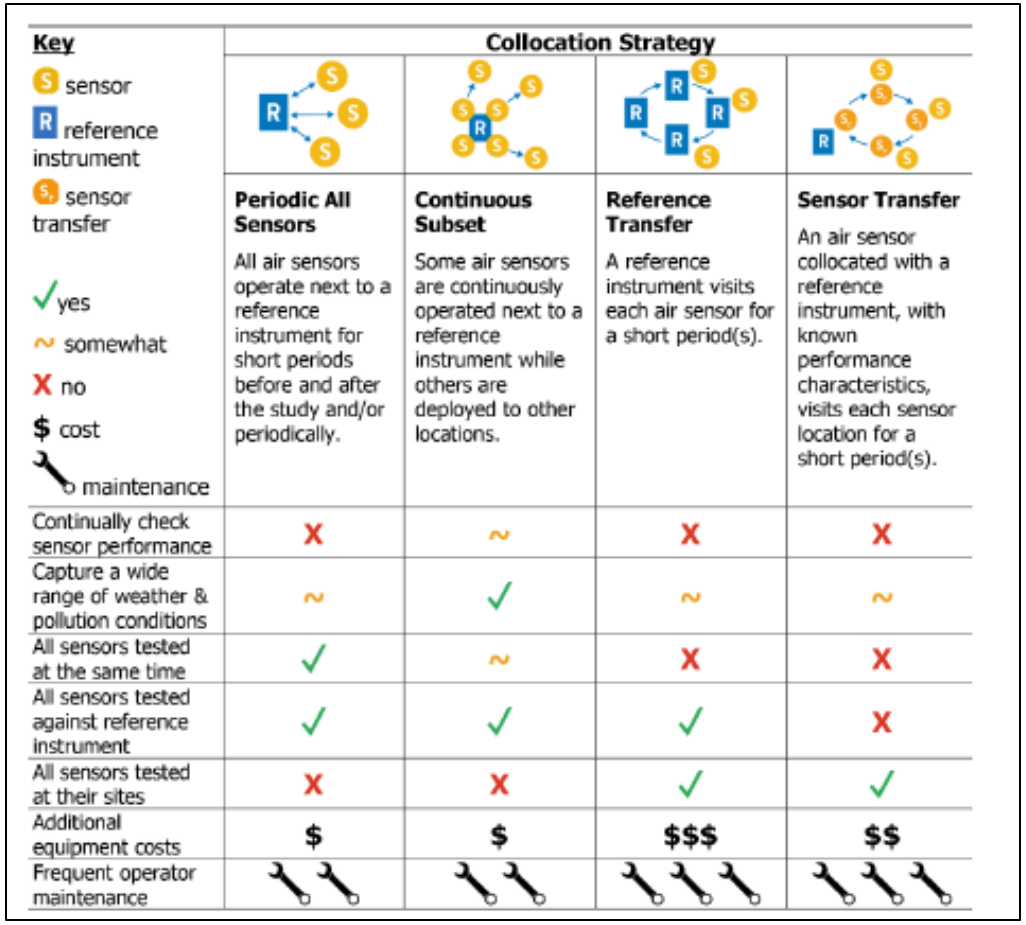
- Size range of particles of interest
  - Most PM sensors are responsive to D_p ~0.3 to 10 µm
- OPC vs. nephelometer
  - Marketed behavior vs. invariant response
- Sampling mechanism
  - Passive, fan, or pump
- Sample conditioning
  - Humidity control
- Varying sensor response to composition change
  - Calibration function

Gas

- Working principle
  - Electrochemical cell vs. metal oxide
- Climate effects
  - Temperature
  - Humidity
- Interferences
- Lifespan/drift

Quality Considerations: Network of Sensors

- Same as for a single sensor, and…
- Network size/density
- Spatial distribution strategy
- Communications reliability
- Power reliability
- Managing drift/calibrations
- Outlier sensor dilemma

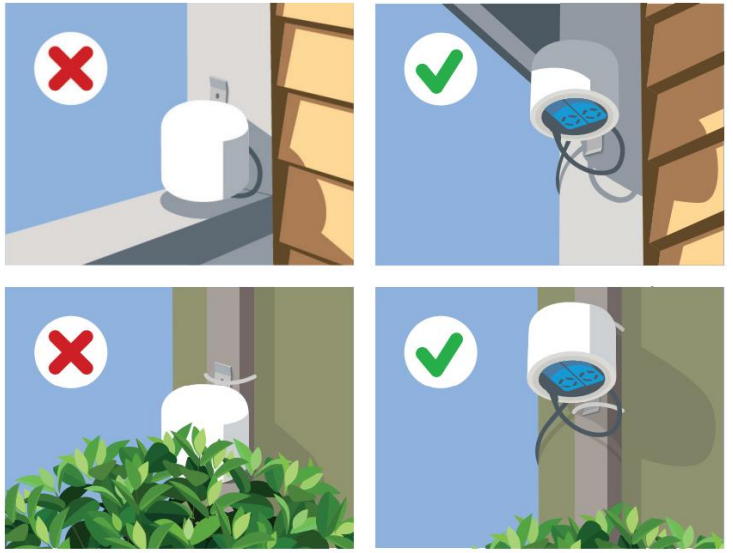


Key	Collocation Strategy			
S sensor R reference instrument S_t sensor transfer ✓ yes ~ somewhat X no $ cost maintenance	**Periodic All Sensors** All air sensors operate next to a reference instrument for short periods before and after the study and/or periodically.	**Continuous Subset** Some air sensors are continuously operated next to a reference instrument while others are deployed to other locations.	**Reference Transfer** A reference instrument visits each air sensor for a short period(s).	**Sensor Transfer** An air sensor collocated with a reference instrument, with known performance characteristics, visits each sensor location for a short period(s).
Continually check sensor performance	X	~	X	X
Capture a wide range of weather & pollution conditions	~	✓	~	~
All sensors tested at the same time	✓	~	X	X
All sensors tested against reference instrument	✓	✓	✓	X
All sensors tested at their sites	X	X	✓	✓
Additional equipment costs	$	$	$$$	$$
Frequent operator maintenance	🔧🔧	🔧🔧	🔧🔧🔧	🔧🔧🔧

Figure credit: US EPA. (2022) The Enhanced Air Sensor Guidebook

Quality Considerations: Sampling

- Siting
  - Height
    - Breathing height, or 2+ m AGL?
  - Location/Sources/Obstructions
    - Ambient, or near emission?
    - 1+ meter horizontal distance
    - Protected from elements
    - Unobstructed air flow
- Spatial Distribution
  - Gridded
  - Judgmental
  - Adaptive/Hotspot ID
  - Mobile/Wearable
- Temporal
  - High time resolution; capture transient events
  - Low time resolution; higher confidence in each measurement



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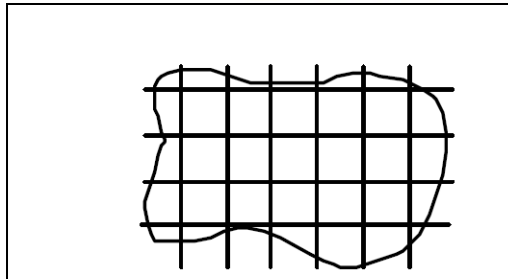
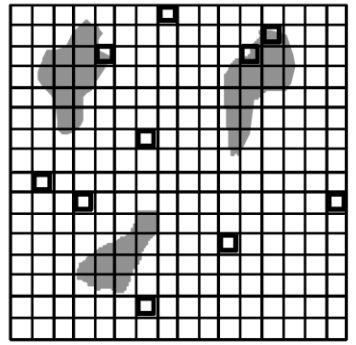
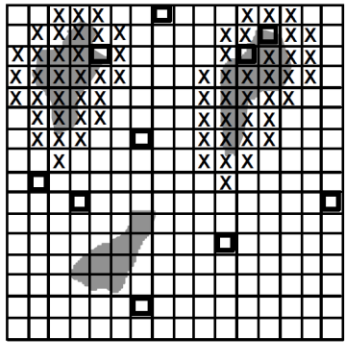


Systematic Grid Sampling - Square Grid

Figure credit: EPA/240/R-02/005



Population Grid with Shaded Areas of Interest and Initial Simple Random Sample

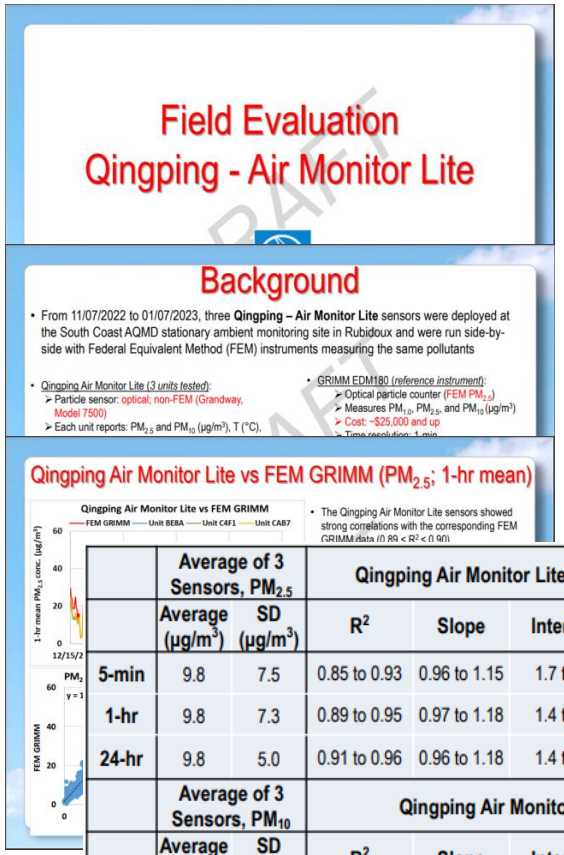


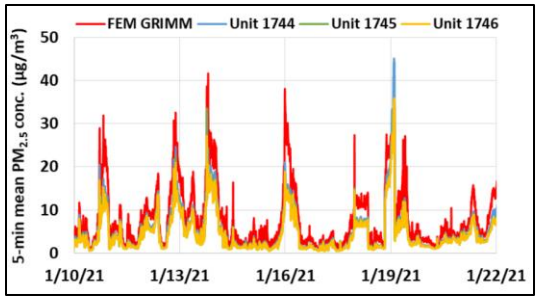
Final Adaptive Cluster Sampling Results

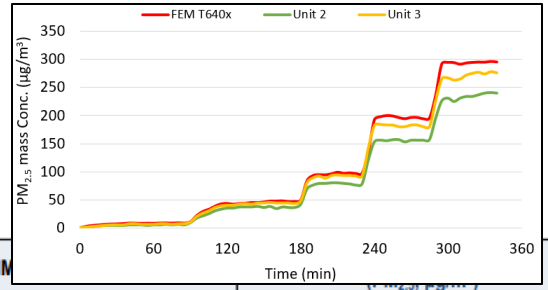
X = Sampling unit

Quality Considerations: Sensor Performance

- Precision, bias, completeness, etc.
- Resources for judging which sensors could meet project data quality needs:
  - Manufacturer spec sheets
  - Academic literature
  - 3rd party sensor evaluations → AQ-SPEC sensor reports

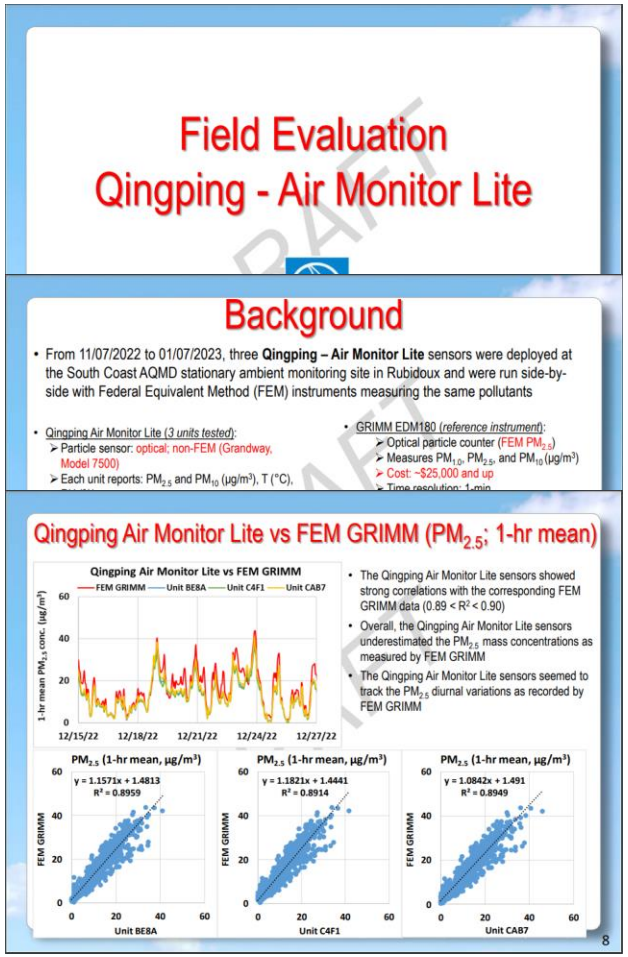






	Average of 3 Sensors, $PM_{2.5}$		Qingping Air Monitor Lite vs FEM GRIM								
	Average (µg/m³)	SD (µg/m³)	R^2	Slope	Intercept	MBE[1] (µg/m³)	MAE[2] (µg/m³)	RMSE[3] (µg/m³)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	9.8	7.5	0.85 to 0.93	0.96 to 1.15	1.7 to 1.8	-3.2 to -1.3	1.8 to 3.6	2.5 to 4.9	11.5 to 12.8	7.8 to 9.0	0.3 to 102.7
1-hr	9.8	7.3	0.89 to 0.95	0.97 to 1.18	1.4 to 1.5	-3.2 to -1.3	1.7 to 3.5	2.2 to 4.5	11.5 to 12.8	7.6 to 8.7	0.4 to 43.9
24-hr	9.8	5.0	0.91 to 0.96	0.96 to 1.18	1.4 to 1.6	-3.2 to -1.2	1.5 to 3.3	1.7 to 3.7	11.5 to 12.9	5.1 to 5.8	2.7 to 27.9
	Average of 3 Sensors, PM_{10}		Qingping Air Monitor Lite vs GRIMM & T640, PM_{10}						GRIMM & T640 (PM_{10}, µg/m³)		
	Average (µg/m³)	SD (µg/m³)	R^2	Slope	Intercept	MBE[1] (µg/m³)	MAE[2] (µg/m³)	RMSE[3] (µg/m³)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	10.2	7.8	0.37 to 0.43	1.49 to 1.63	10.4 to 13.9	-20.1 to -15.9	16.2 to 20.1	22.8 to 25.1	27.1 to 30.3	18.8 to 20.1	0.4 to 160.9
1-hr	10.2	7.5	0.40 to 0.45	1.53 to 1.66	9.8 to 13.6	-20.1 to -15.8	16.1 to 20.1	22.1 to 24.7	27.1 to 30.3	18.1 to 19.2	0.6 to 122.4
24-hr	10.2	5.2	0.43 to 0.45	1.54 to 1.84	7.7 to 13.6	-20.1 to -15.5	15.6 to 20.1	19.0 to 22.6	26.9 to 30.3	12.7 to 13.6	3.7 to 63.6

Quality Contribution: Sensor Performance Reports

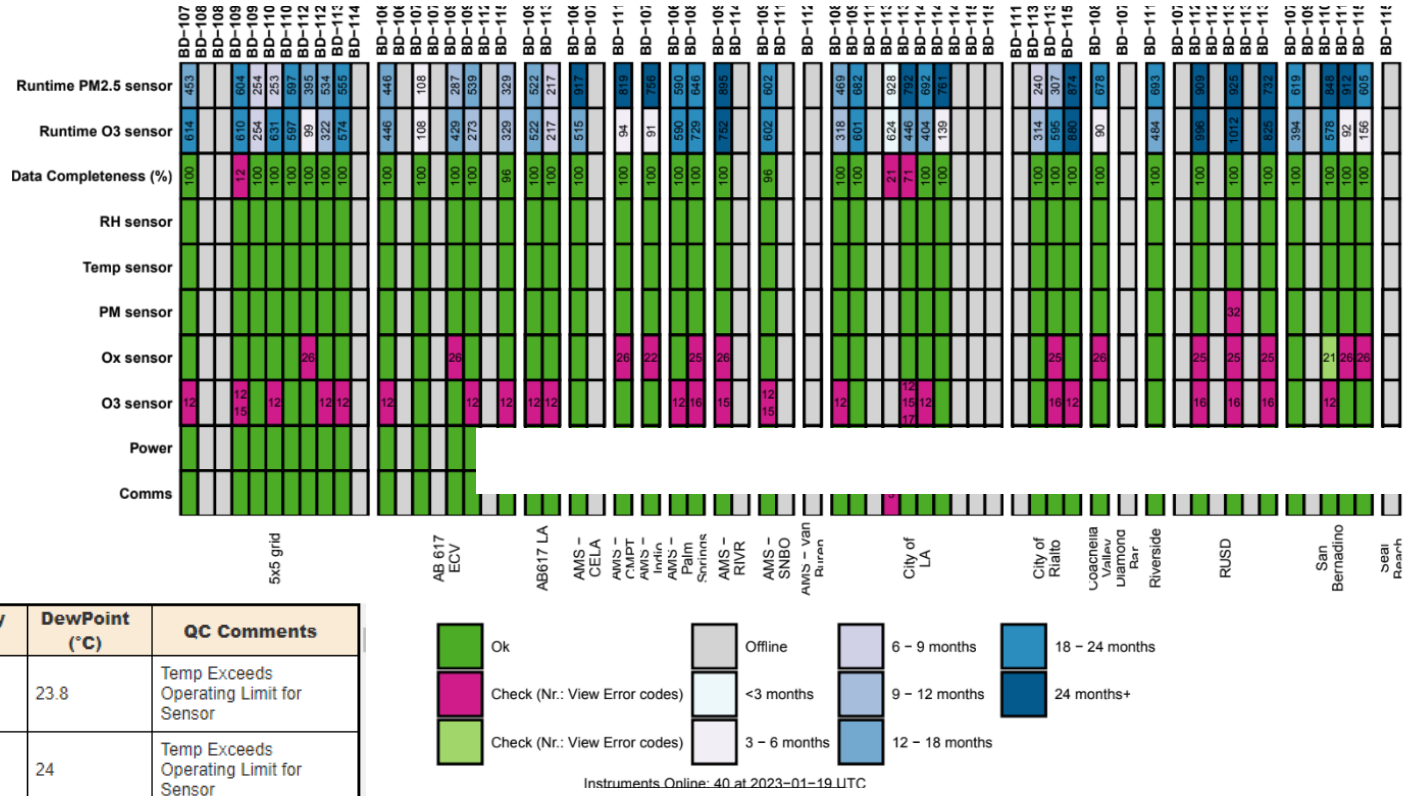


PM Sensors

Sensor Image	Make (Model)	Est. Cost (USD)	Pollutant(s)	*Field R^2	*Lab R^2	*Field MAE (µg/m³)	*Lab MAE (µg/m³)	Summary Report
	Aeroqual (AQY-R)	$5,000	$PM_{2.5}$	0.66 to 0.81		2.9 to 5.1		
	Aeroqual (AQY v0.5) Discontinued	$3,000	$PM_{2.5}$	0.84 to 0.87	0.99		28.8 to 36.0	PDF (1,178 KB)
	Aeroqual (AQY v1.0)	$4,000	$PM_{2.5}$	0.76 to 0.81	0.99	4.2 to 5.3	5.4 to 15.1	PDF (674 KB)
			PM_{10}	0.56 to 0.68		35.4 to 38.8		
	Aeroqual (S500-PM)	$1,490	$PM_{2.5}$	0.46 to 0.67	0.99	4.4 to 6.2	11.9 to 32.4	PDF (702 KB)
			PM_{10}	0.15 to 0.24		13.5 to 18.0		
	AethLabs (microAeth)	$6,500	BC (Black Carbon)	0.79 to 0.94				
	Airly	$1,000	$PM_{1.0}$	0.79 to 0.89		4.2 to 5.3		
			$PM_{2.5}$	0.83 to 0.89		4.5 to 5.0		
			PM_{10}	0.34 to 0.37		19.3 to 19.7		
	Air Quality Egg (2018 Model)	$249	$PM_{1.0}$	0.86 to 0.88	0.99	2.1 to 2.3	7.0 to 7.3	PDF (771 KB)
			$PM_{2.5}$	0.84 to 0.85	0.99	4.4 to 5.3	6.1 to 6.6	
			PM_{10}	0.12 to 0.13	-	16.4 to 19.2		
	Air Quality Egg (Version 1)	$200	PM	~ 0.0				
	Air Quality Egg (Version 2)	$240	$PM_{2.5}$	0.79 to 0.85				
			PM_{10}	0.31 to 0.40				
	Air Quality Egg (2022 Model)	$671	$PM_{1.0}$	0.84 to 0.89	-	2.9 to 3.9	-	PDF (1,039 KB)
			$PM_{2.5}$	0.88 to 0.90	0.99	6.0 to 7.1	5.0 to 8.0	
			PM_{10}	0.29 to 0.52	-	18.5 to 20.8	-	
	AirThinx (IAQ)	$1,000	$PM_{1.0}$	0.68 to 0.70		2.4 to 2.5		
			$PM_{2.5}$	0.54 to 0.57		4.8 to 5.0		
			PM_{10}	0.03 to 0.05		19.7 to 19.8		
	Airviz Inc. (Speck)	$150	$PM_{2.5}$	0.32				
	Alphasense (OPC-N2)	$310	$PM_{1.0}$	0.63 to 0.82	0.99			PDF (1,291 KB)
			$PM_{2.5}$	0.65 to 0.80	0.99			
			PM_{10}	0.45 to 0.57	0.99			

Quality Considerations: Other Good Practices

- Records/documentation
- Training/SOPs
- Automated QA/QC
- Regular data review
- Maintenance
- Calibrations



PM10 (µg/m³)	Temp (°F)	Humidity (%)	DewPoint (°C)	QC Comments
21	117.7	26.9	23.8	Temp Exceeds Operating Limit for Sensor
20.5	117.5	27.3	24	Temp Exceeds Operating Limit for Sensor
18	116	28.1	23.7	Temp Exceeds Operating Limit for Sensor
18.9	116.5	27.5	23.6	Temp Exceeds Operating Limit for Sensor
13.5	117.6	27.4	24.1	Temp Exceeds Operating Limit for Sensor

Acknowledgments and Contacts

- South Coast AQMD Management and AQ-SPEC Team:
  - Randy Lam
  - Berj Der Boghossian
  - Michelle Kuang, Ph.D.
  - Payam Pakbin, Ph.D.
  - Andrea Polidori, Ph.D.
  - Jason Low, Ph.D.

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