AIR QUALITY SENSORS & DATA QUALITY 101

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AQ-SPEC, SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

ASIC India, August 18, 2022

OVERVIEW

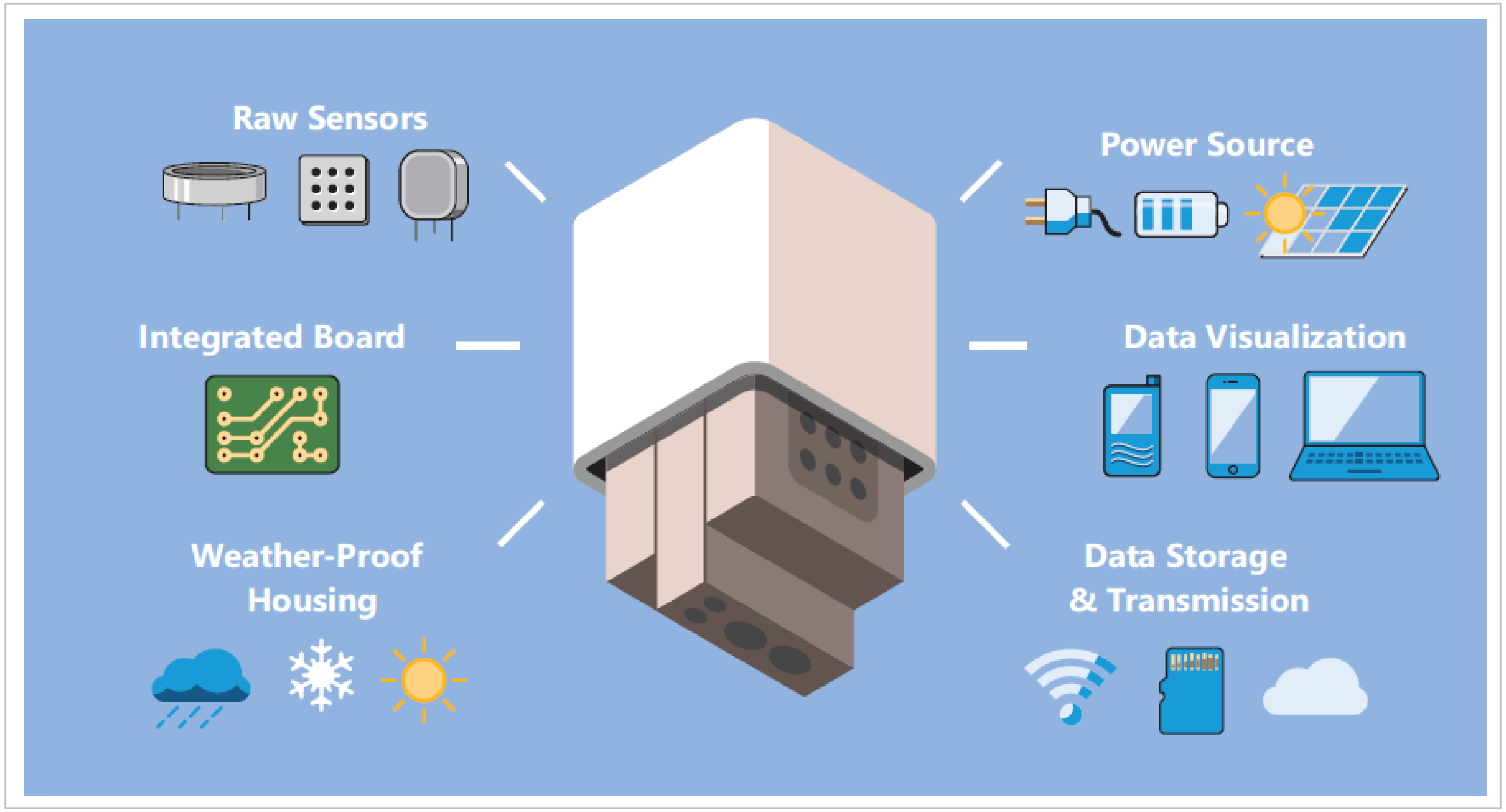
- What is an air quality sensor?
- Choosing a sensor
- Sensor evaluation and performance
- Calibrating sensors
- Other data quality concerns
- Resources to support air quality sensor use

AIR QUALITY SENSORS

- Typical cost: $200 – $2000
- Available for various particulate and gas-phase pollutants
- Commercial and “DIY” solutions
- Varied operational setups (e.g., wearable, portable, stationary outdoor/indoor)

- **Key Challenges**
  - Understanding data quality and performance
  - Successful use to ensure high quality data
  - Making sense of the data

TYPICAL COMPONENTS OF A SENSOR SYSTEM

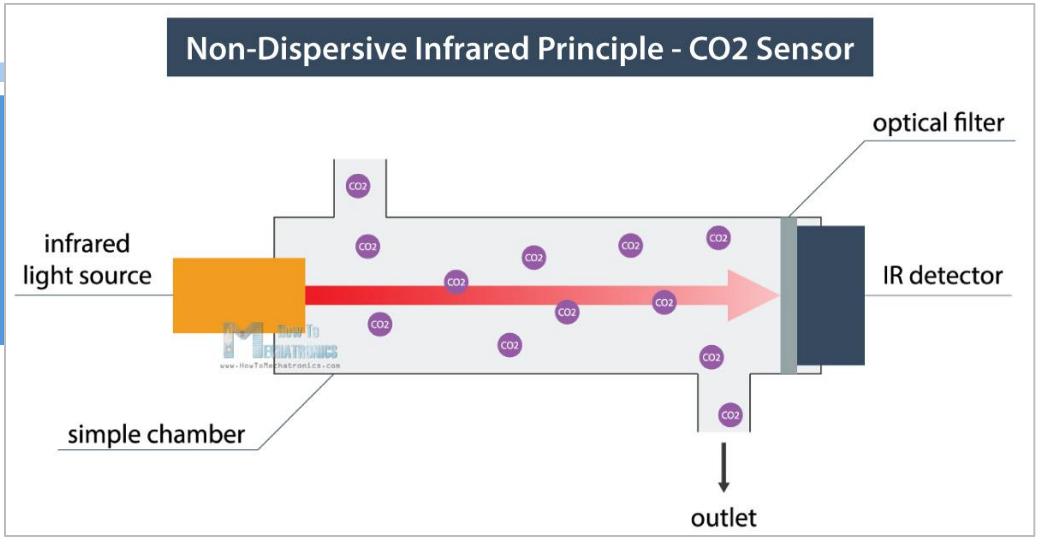


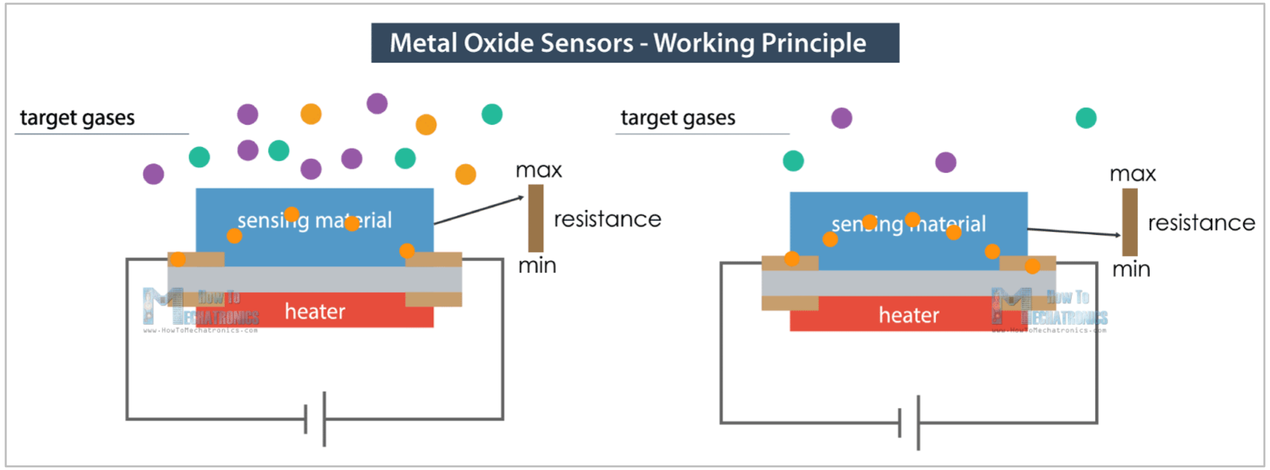
From: "Community in Action: A Comprehensive Guidebook on Air Quality Sensors"
http://www.aqmd.gov/aq-spec/special-projects/star-grant

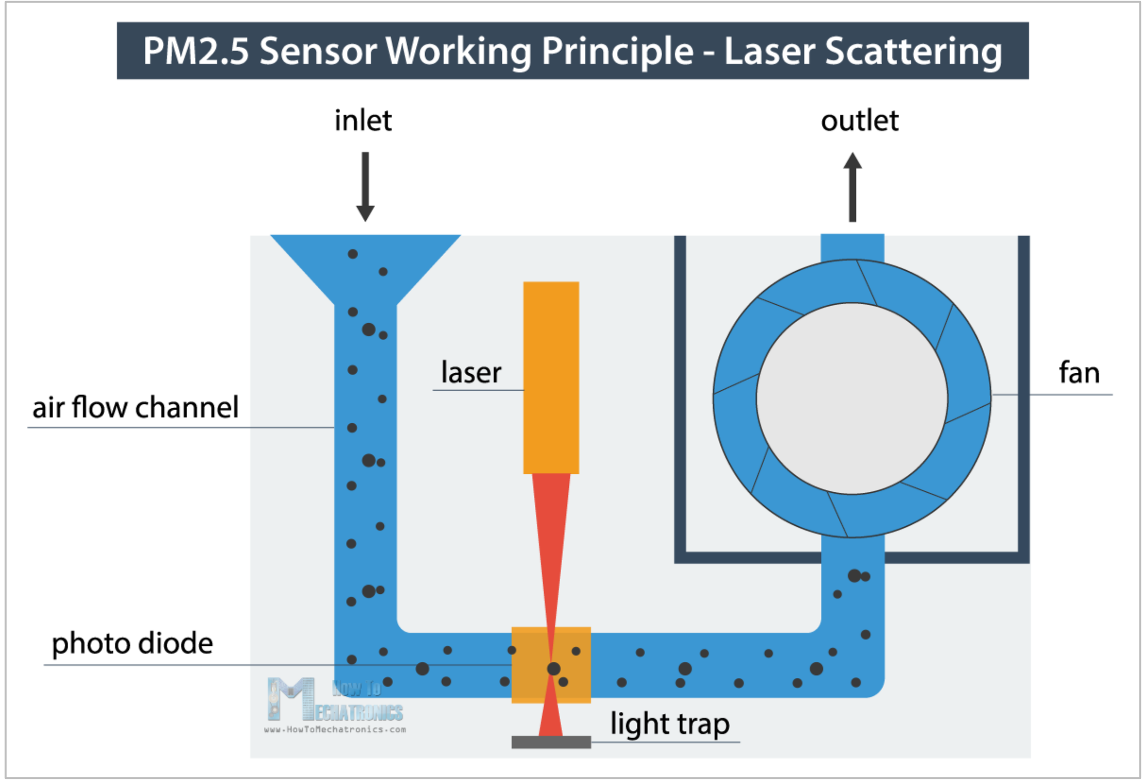
HOW THE SENSORS WORK

Working principles:

- Gases: resistance, current, voltage, or UV/IR light intensity
- Particles/PM$_{1/2.5/10}$: light-scattering signal (Nephelometric)







https://howtomechatronics.com/projects/diy-air-quality-monitor-pm2-5-co2-voc-ozone-temp-hum-arduino-meter/

HOW DO SENSORS DIFFER FROM CONVENTIONAL EQUIPMENT?

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Sensors

- $ - $$
- Smaller and more portable
- Less time required for setup and maintenance
- Lower accuracy
- Typical applications: educational/informational, consumer use, personal exposure, indoor air quality, and smart cities

Conventional Monitoring Equipment

- $$$ - $$$$
- Larger and less portable, often sited at stationary sites or on large mobile platforms
- Highly skilled staff required to setup and maintain instruments
- Higher accuracy
- Data is suitable for regulatory enforcement/action
- Category may also include research-grade instruments

STRENGTHS & LIMITATIONS OF AIR QUALITY SENSORS

Strengths

- Lower cost enables the deployment of high-density networks – increasing the **spatial and temporal resolution** of air quality data
- Sensors are accessible, which can increase **education and awareness** around air quality issues
- Sensors are well-suited for **preliminary investigations or supplemental information**

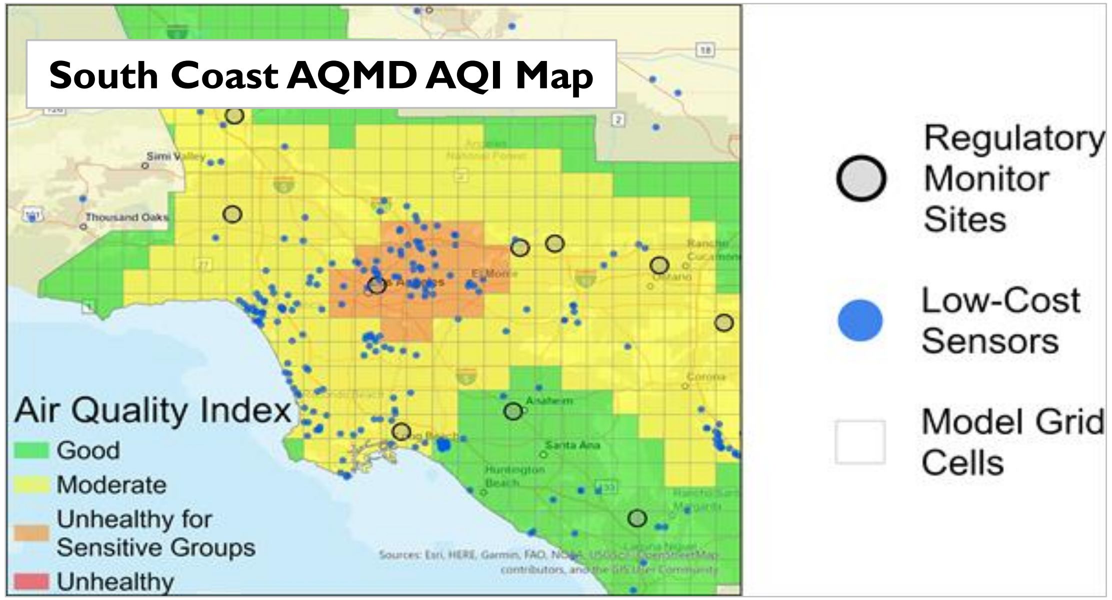
Limitations

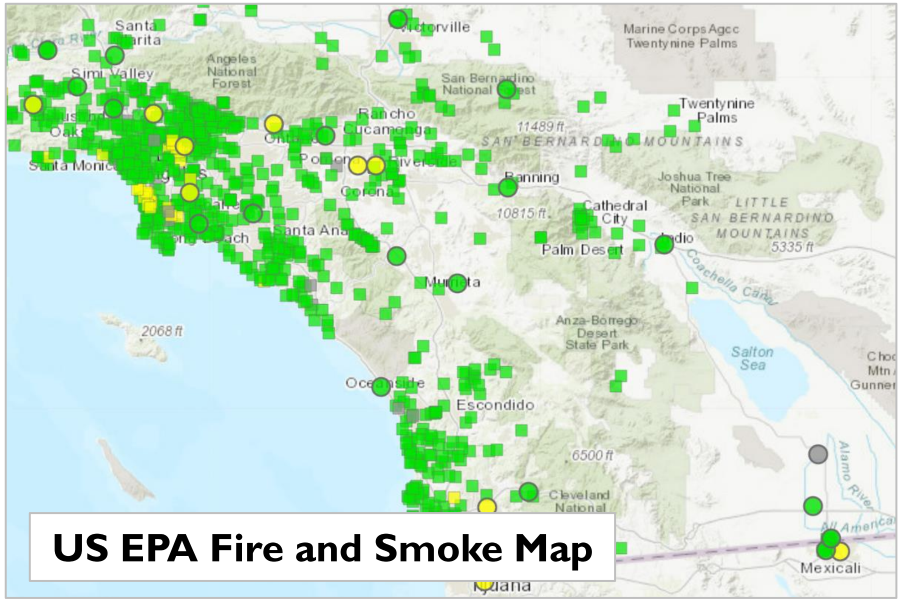
- **Data quality and reliability**
- Sensors (esp. gas sensors) can be **cross-sensitive** to other pollutants and environmental factors
- Some sensors have a relatively **high lower limit of detection**
- Data quantity (sensors and networks can result in **large amounts of data** collected that require strategic data storage and management as well as data processing/analysis/visualization)

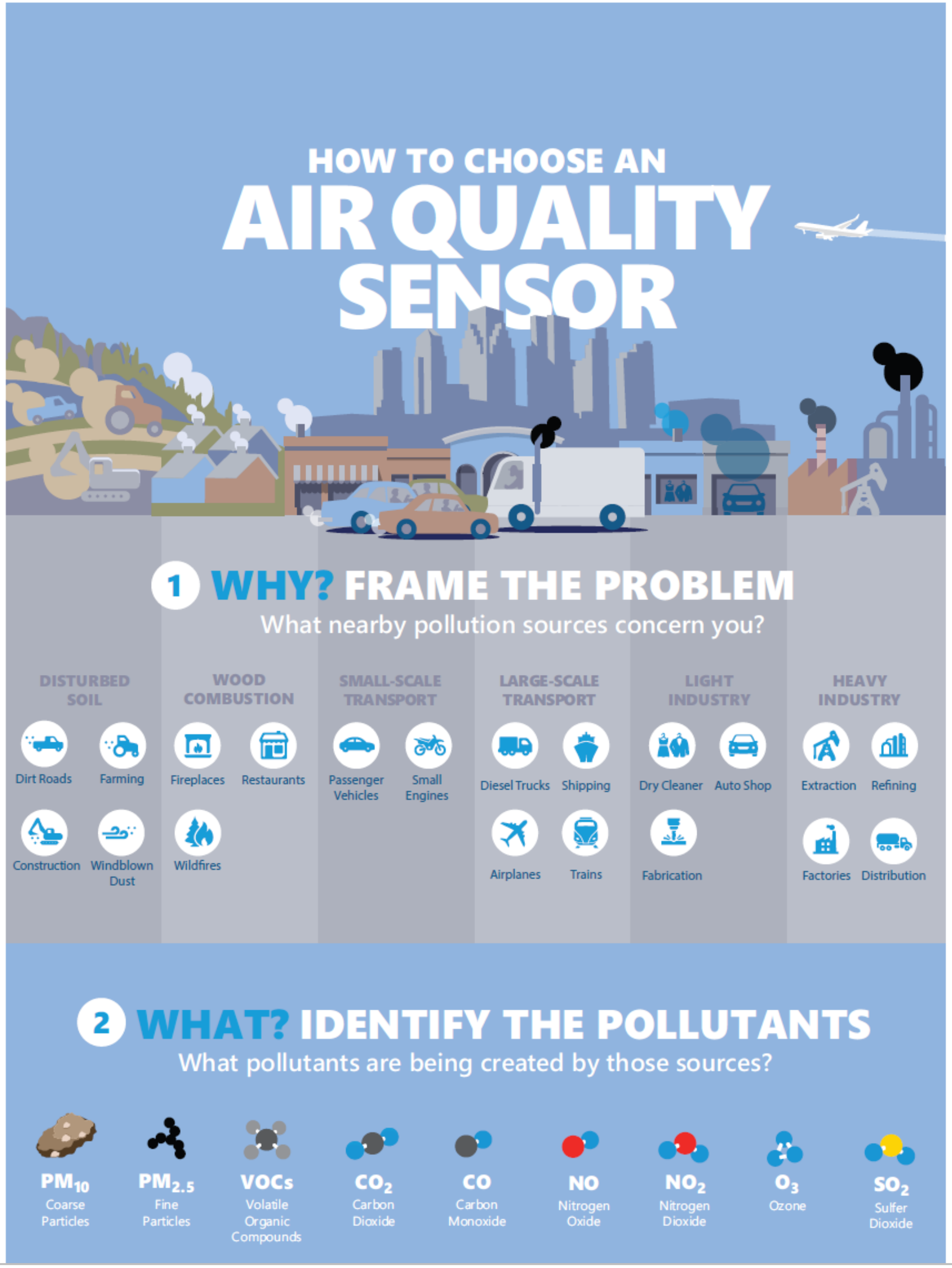
HOW THEY ARE BEING USED CURRENTLY

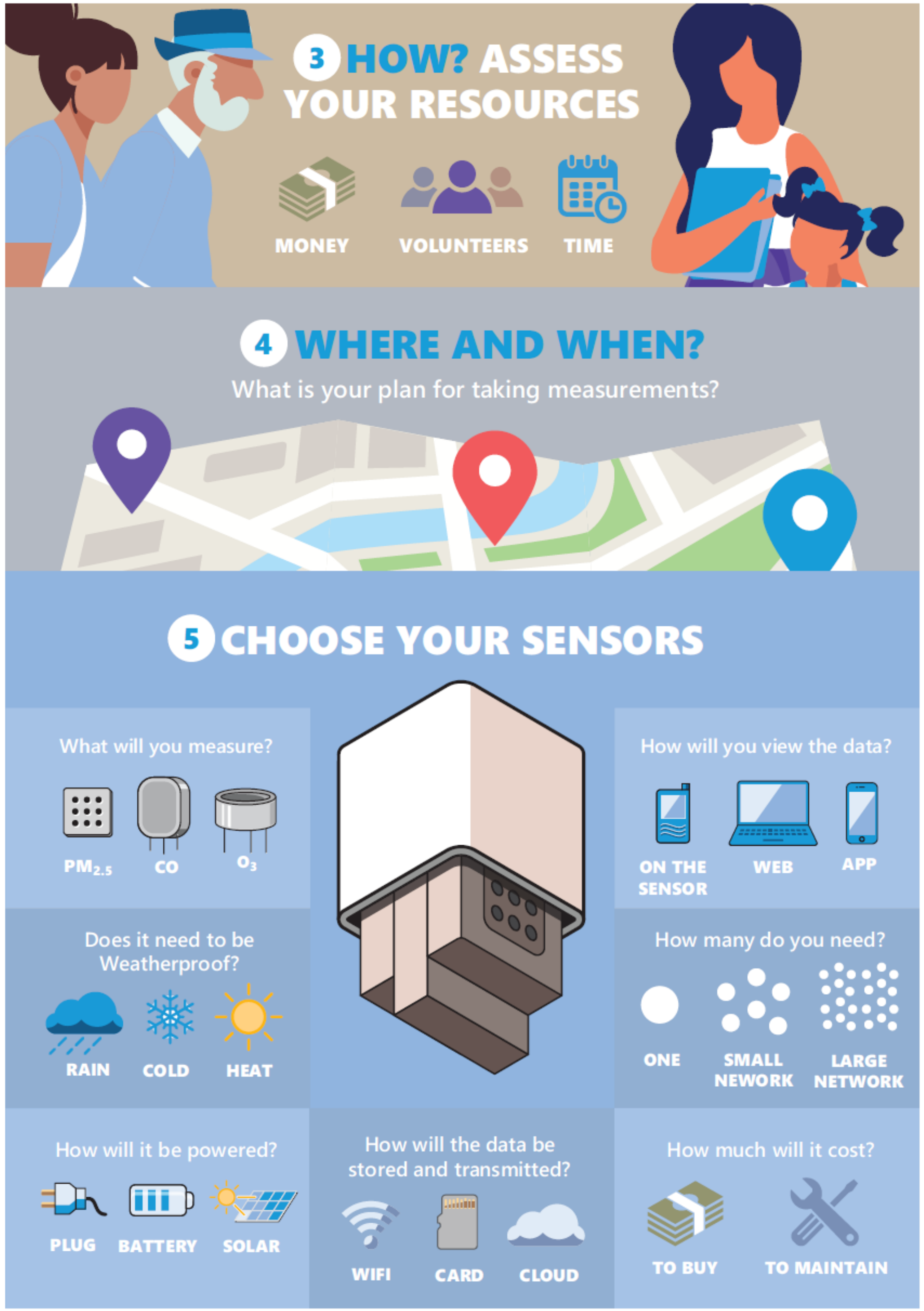
Examples of the integration of sensor data with data from regulatory air monitoring stations

- PurpleAir PA-II sensor data is being combined with regulatory station data and modelling to increase the spatial resolution of the South Coast AQMD AQI (Air Quality Index) map (https://aqmd.gov/aqimap)
- PurpleAir PA-II sensor data is being combined with data from regulatory and temporary monitors, as well as satellites, to provide timely data around wildfire smoke exposure in the US EPA's Fire and Smoke map (https://fire.airnow.gov/)









From: "Community in Action: A Comprehensive Guidebook on Air Quality Sensors"
http://www.aqmd.gov/aq-spec/special-projects/star-grant

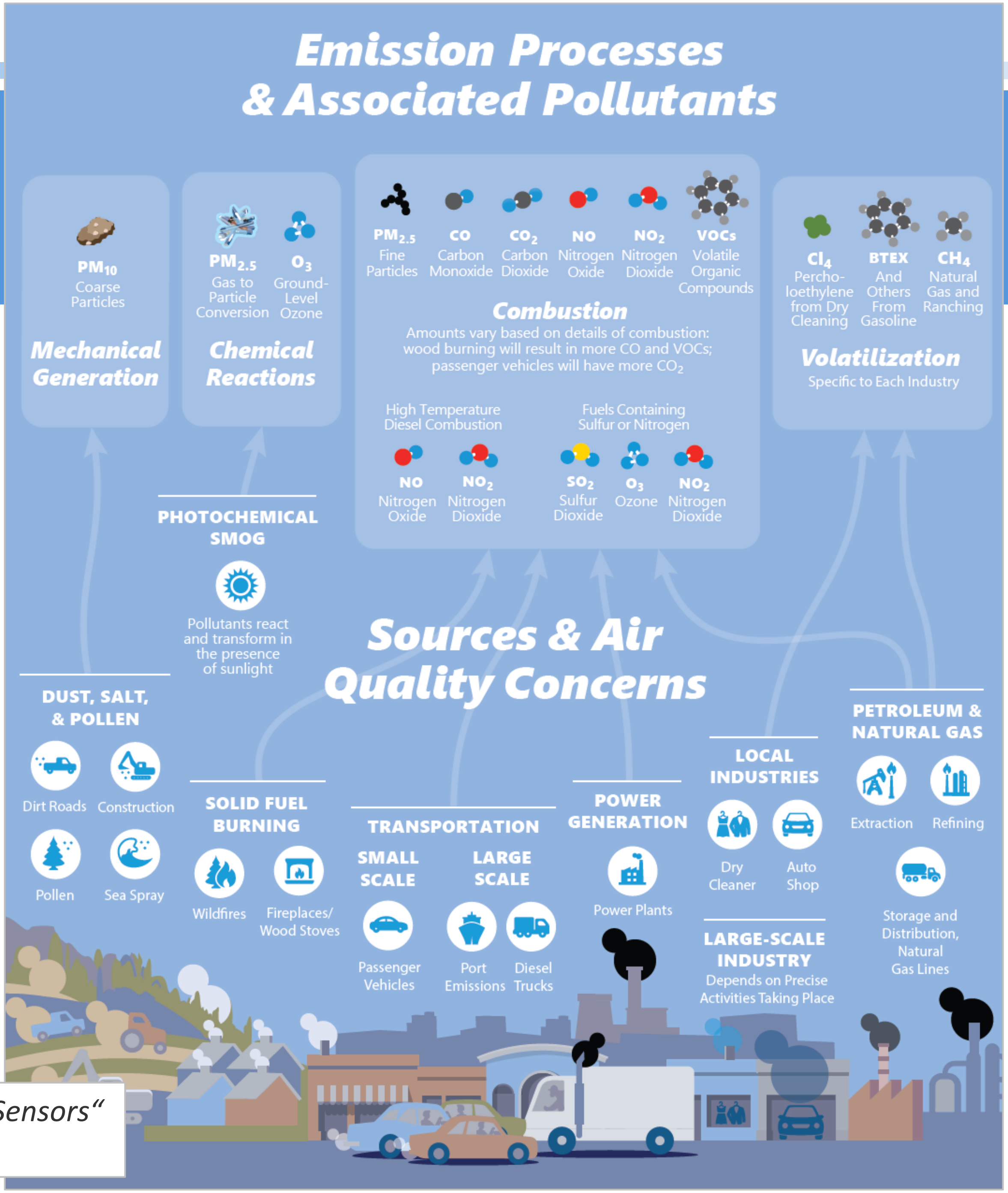
CHOOSING A SENSOR

Frame the problem

- What sources are you concerned about?
- Where/when are you concerned about these emissions?
- Is there a temporal or seasonal pattern to this air quality issue?
- Etc.

Identify the key pollutants of concern

- Including expected concentration ranges



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CHOOSING A SENSOR

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Assess your resources

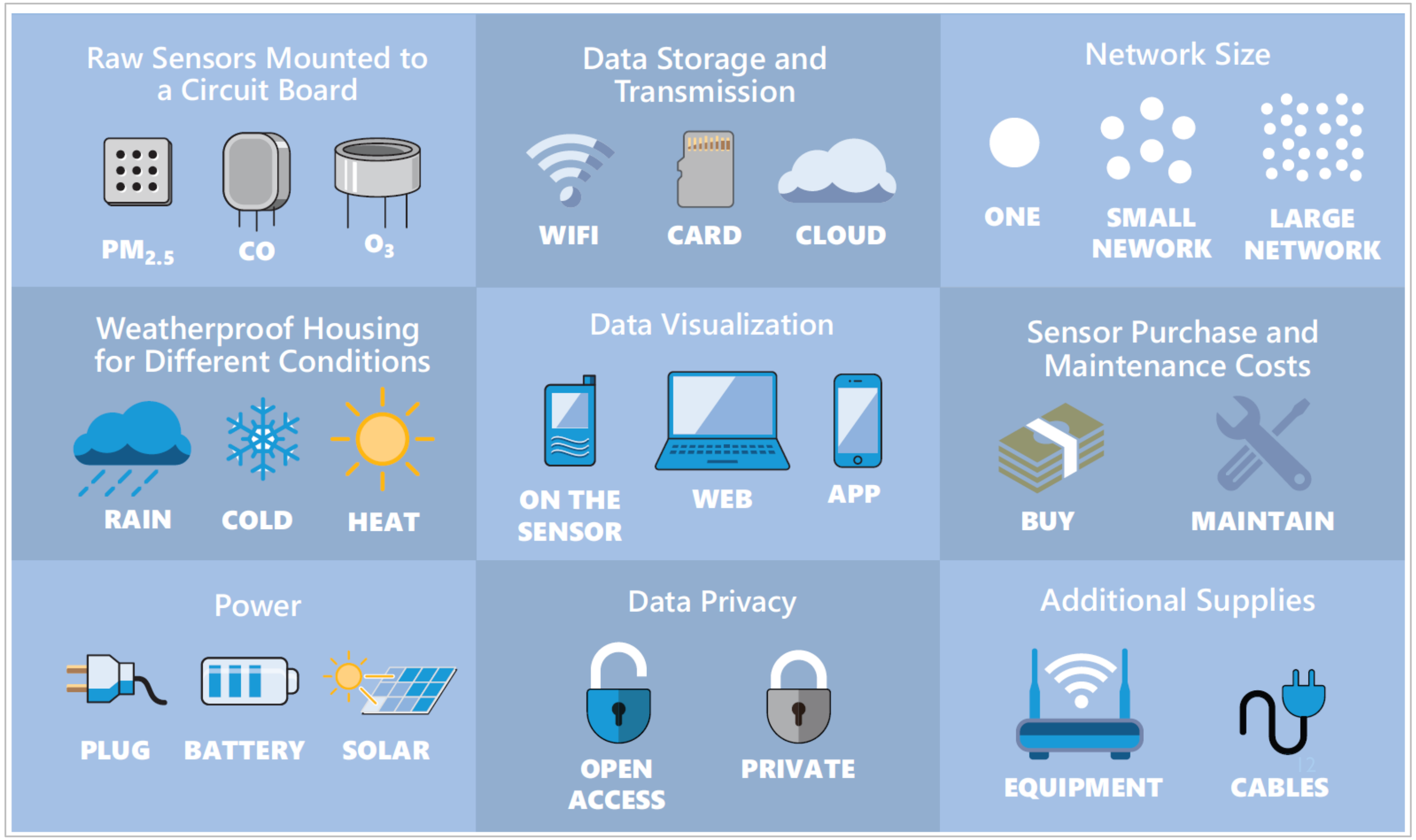
- Funding, staffing, volunteers, technical expertise, etc.
- Some sensors require ongoing subscription costs, but may offer data storage/visualization solutions (as well as additional technical support) that meet your project's needs
- Other sensors may be lower cost, but more staff time may be required to manage and analyze data

Where/when will you take measurements

- Identify ideal sampling locations and timeframes, which will help to clarify the number of sensors needed/size of the network
- Consider power availability and needs (e.g., is solar power necessary?)
- Consider data storage and transfer needs (e.g., the availability of Wi-Fi and cellular networks)
- What types of weather/environmental conditions are the sensors likely to encounter?

CHOOSE A SENSOR

- Finally based on your project's objectives and needs
  → **choose a sensor**
- Note, selection can also be informed by reports or publications detailing sensor performance
- NEXT: sensor evaluation



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AQ-SPEC
(AIR QUALITY SENSOR PERFORMANCE EVALUATION CENTER)

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- Availability, interest, and use of air quality sensors continues to increase
- AQ-SPEC was established in 2014
- Evaluated 190+ sensors to date, with publicly-available reports on website

Main Goals:

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

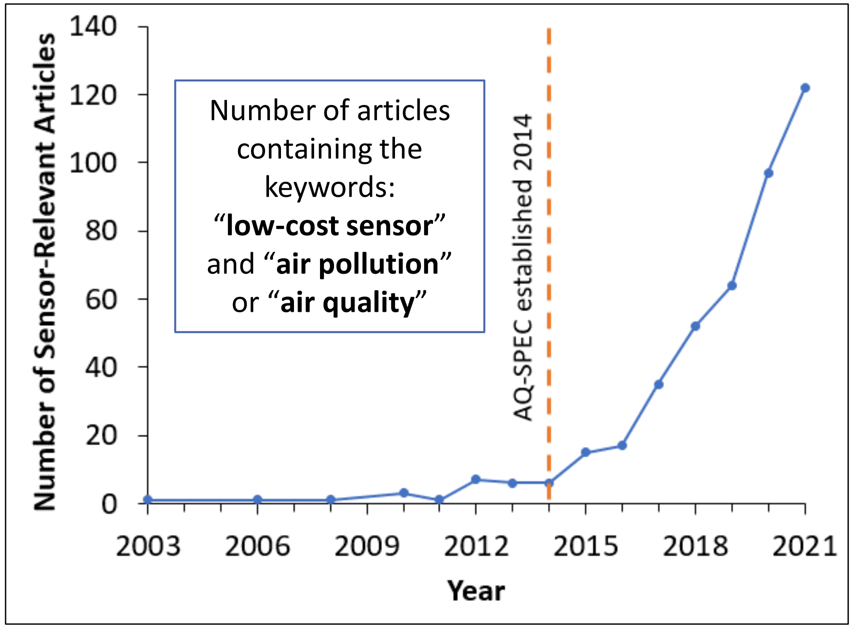


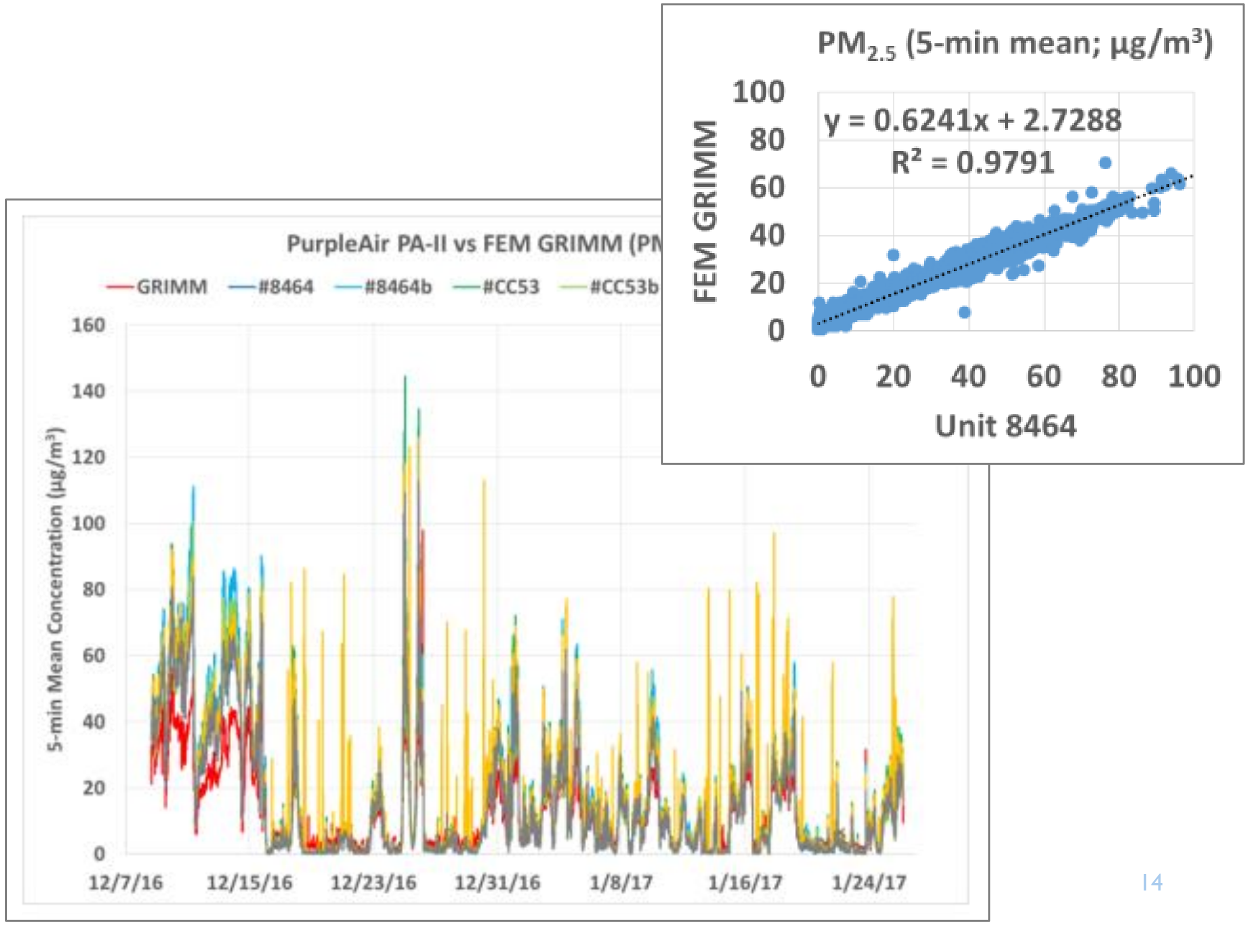
Figure adapted from Giordano et al., 2021

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

http://www.aqmd.gov/aq-spec/evaluations

SENSOR EVALUATION

- Evaluation typically involves comparing sensor data to data from a high-quality reference instrument either in the laboratory or in the field
- Using these datasets, we can then evaluate their performance through several statistics that provide an indication of how a certain sensor model may perform for a user
- Users can either learn about sensor performance from existing entities/reports or evaluate a sensor themselves



Example plots comparing sensor and reference data, from AQ-SPEC reports

AQ-SPEC – FIELD EVALUATIONS

- Field testing exposes sensors to complex, unpredictable climates and particle distributions and compositions
- Sensor triplicate is co-located at a South Coast AQMD air monitoring station equipped with regulatory-grade reference monitors (e.g., FEM $PM_{2.5}$, also $PM_{1.0}$ and PM_{10}) for 8 weeks
- Field testing results indicative of sensor performance if used for stationary, ambient monitoring

Regulatory air monitoring station

Sensor testing shelter (for those not weather-resistant)

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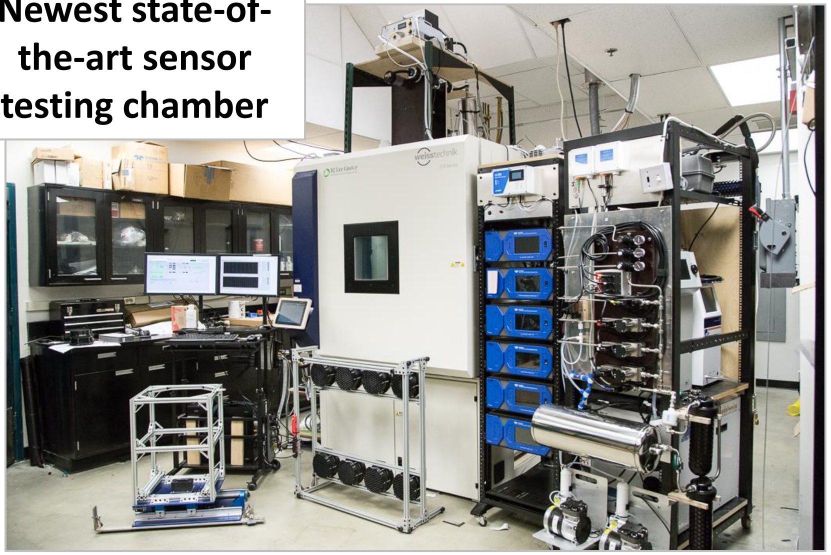
AQ-SPEC – LABORATORY EVALUATIONS

- Lab testing exposes sensors to controlled climates and simple particle distributions and compositions, but testable range of climates and concentrations is much broader than field
- Sensor triplicate is installed in one of South Coast AQMD AQ-SPEC sensor testing chambers, equipped with temperature and RH control, zero-air generators, particle generators, and regulatory-grade reference monitors (e.g., FEM $PM_{2.5}$, also $PM_{1.0}$ and PM_{10})
- Lab testing results allow for clearer investigation of sensor precision and influence from climate and extreme pollutant concentrations

Newest state-of-the-art sensor testing chamber



PM concentration ramp

Pollutant / Level	**PM ($\mu g/m^3$)**
Very Low	10
Low	15
Medium	50
High	150
Very High	300

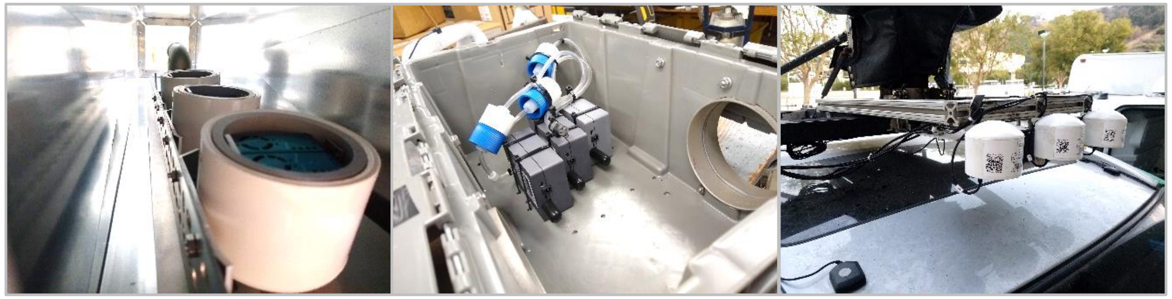
Temp/RH	**Low (15%)**	**Medium (40%)**	**High (65%)**
Low (5 °C)	5 °C, 15%	5 °C, 40%	5 °C, 65%
Medium (20 °C)	20 °C, 15%	20 °C, 40%	20 °C, 65%
High (35 °C)	35 °C, 15%	35 °C, 40%	35 °C, 65%

Climate test conditions

Original sensor testing chamber

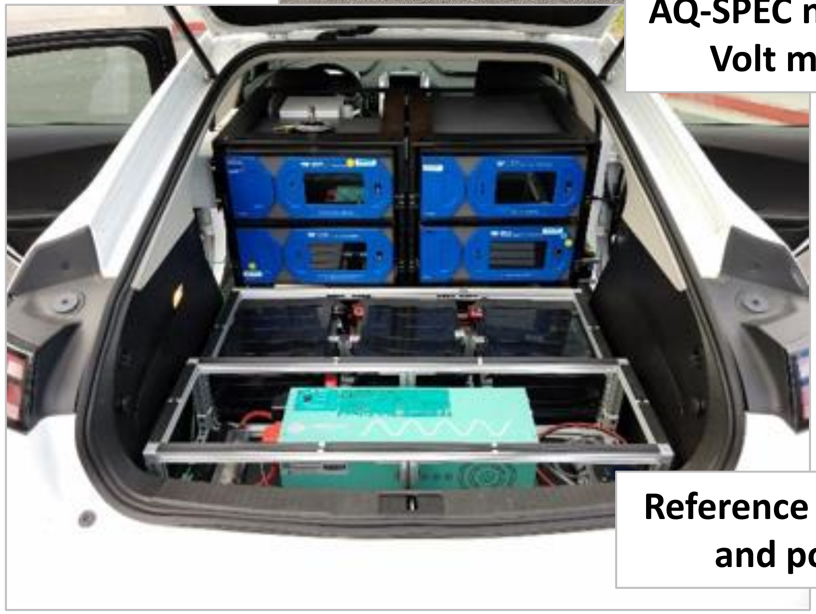
AQ-SPEC – MOBILE EVALUATIONS (NEW)

- Mobile testing exposes sensors to complex, unpredictable climates and particle distributions and compositions, *with the added effects* of vibrations and wind turbulence
- Sensor triplicate is installed in/on mobile platform equipped with regulatory-grade reference monitors (e.g., FEM $PM_{2.5}$, also PM_1, PM_{10}, ultrafine counts) for 1 in-cabin test scenario and 3 ambient-monitoring test scenarios



Sensors installed in different mobile test scenarios

AQ-SPEC next-gen Chevrolet Volt mobile platform



Reference instrumentation and power system

AQ-SPEC EVALUATION REPORTS

- AQ-SPEC evaluates PM and gas-phase sensors
- Reports are available on the AQ-SPEC website: http://www.aqmd.gov/aq-spec/evaluations
- Summary Table for PM Sensors: http://www.aqmd.gov/aq-spec/evaluations/summary-pm
- Summary Table for Gas-Phase Sensors: http://www.aqmd.gov/aq-spec/evaluations/summary-gas
- Reports provide insight into performance characteristics such as: linearity, accuracy, precision, intra-sensor variability, co-pollutant interference, and temperature and humidity influences
- Website also includes evaluation protocols

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OTHER PROTOCOLS & RESOURCES

Other Evaluation Protocols and Performance Targets

- US EPA Office of Research and Development (ORD), Air Sensor Performance Targets and Testing Protocols: https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols
- ASTM International, Testing Standards: http://www.aqmd.gov/aq-spec/evaluations/astm-test-standards, https://www.astm.org/workitem-wk64899, https://www.astm.org/workitem-wk74360
- European Testing Standard: https://www.en-standard.eu/pd-cen-ts-17660-1-2021-air-quality-performance-evaluation-of-air-quality-sensor-systems-gaseous-pollutants-in-ambient-air/

Other Sensor Evaluations

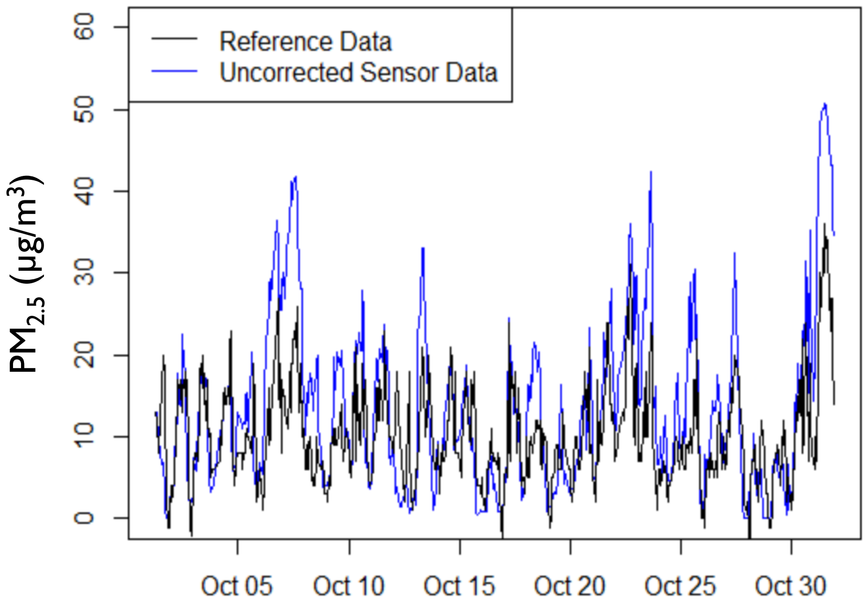
- US EPA Office of Research and Development (ORD), previously published evaluations: https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance

Other Resources

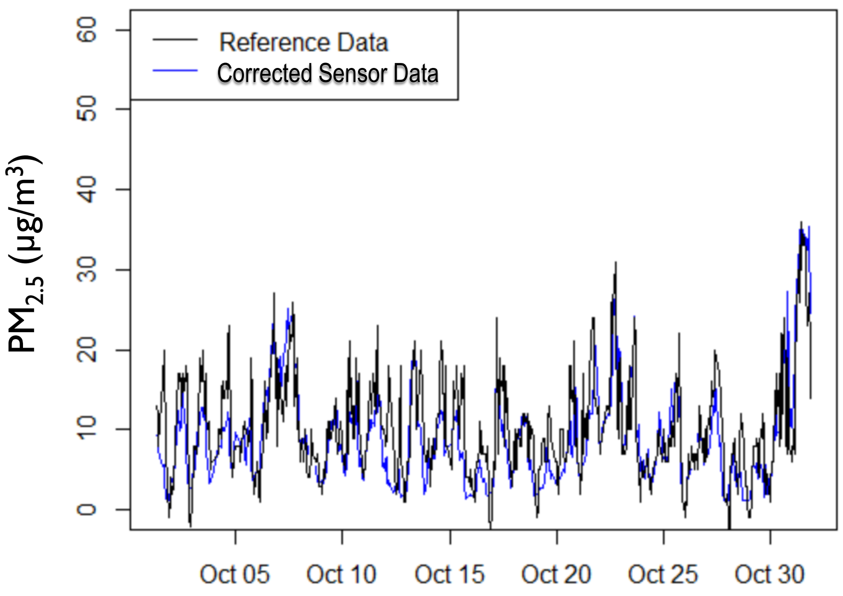
- US EPA Office of Research and Development (ORD), Excel Macro Tool for comparing sensor and reference data, https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-macro-analysis-tool
- US EPA Office of Research and Development (ORD), python package supporting sensor performance evaluation: https://pypi.org/project/sensortoolkit/

SENSOR CALIBRATION

- Sensor calibration enables the user to develop a correction that can reduce bias, improve the accuracy of sensor data, and/or reduce the effects of co-interferents (e.g., temperature, humidity, or other pollutants)



Example of how applying a correction can improve accuracy of sensor data



OVERVIEW OF FIELD CALIBRATION (TYPICAL APPROACH)

- Sensors are physically co-located with high-quality reference instruments, often before and after a field deployment so drift can be assessed, often at a regulatory monitoring station
- The co-located data is then used to develop a calibration or correction model to improve the sensor data collected during the field deployment
- Calibration models can range from simple linear models to more complex machine learning models
- A variation on field calibration may involve normalizing the data from all sensors to a single sensor and then co-locating that single sensor to develop a correction model that can then be applied to the normalized data from all sensors

OTHER APPROACHES TO SENSOR CALIBRATION

Types	Overview	Pros	Cons
Factory Calibration	High throughput batch calibrations, resulting in correction factors (often linear)	All sensors in a batch calibrated under the same conditions	Occurs once by manufacturer
Laboratory Calibration	Calibration by end users in chamber systems designed to mimic real world conditions	Relatively quick, replicable, sensors can be calibrated in batches	May not fully capture the field conditions (e.g., dynamic changes in environment conditions or the background pollutant mixtures)
Field Calibration	Sensors are co-located with high quality reference instrumentation for a defined period, calibration models typically developed through linear regression, multiple linear regression, or machine learning techniques using the co-located dataset	Able to account for typical field conditions (environmental conditions and background pollutant mixtures)	Time and labor intensive, will likely need to be repeated at regular intervals or before and after a field deployment

- *None of these approaches are well-suited to be applied to large-scale, long-term sensor networks*
- *Newer approaches include global correction equations, remote calibration, and calibration using mobile platforms*

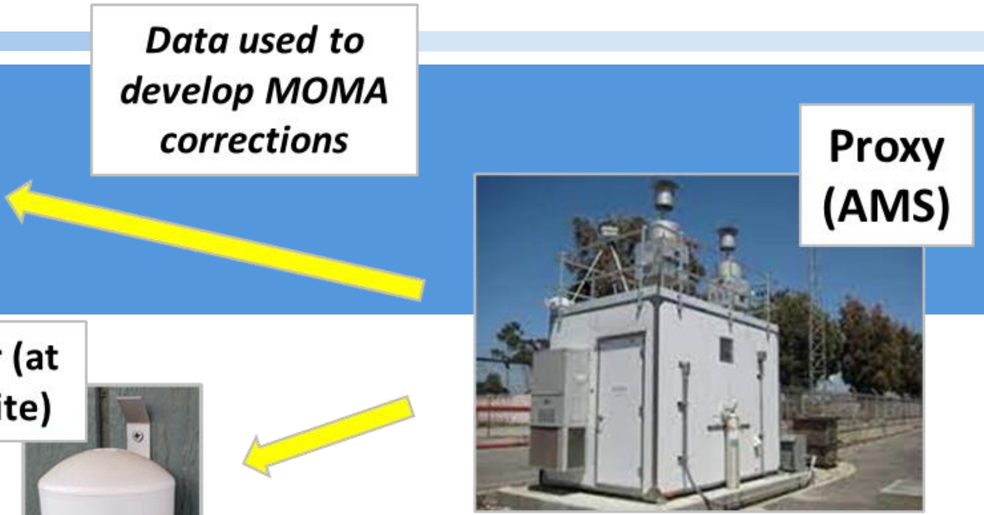
KEY CONSIDERATIONS FOR CALIBRATION

- Conditions expected to be experienced in the field should be experienced or simulated during calibration
- Long-term deployments may require adjustments to calibrations as seasons change
- Calibrations should account for key interferents (e.g., humidity effects for PM sensors)
- Consider a sensor's operating principles as some sensors can experience drift over time (e.g., due to a loss in sensitivity as a sensor ages – especially true for gas-phase sensors)

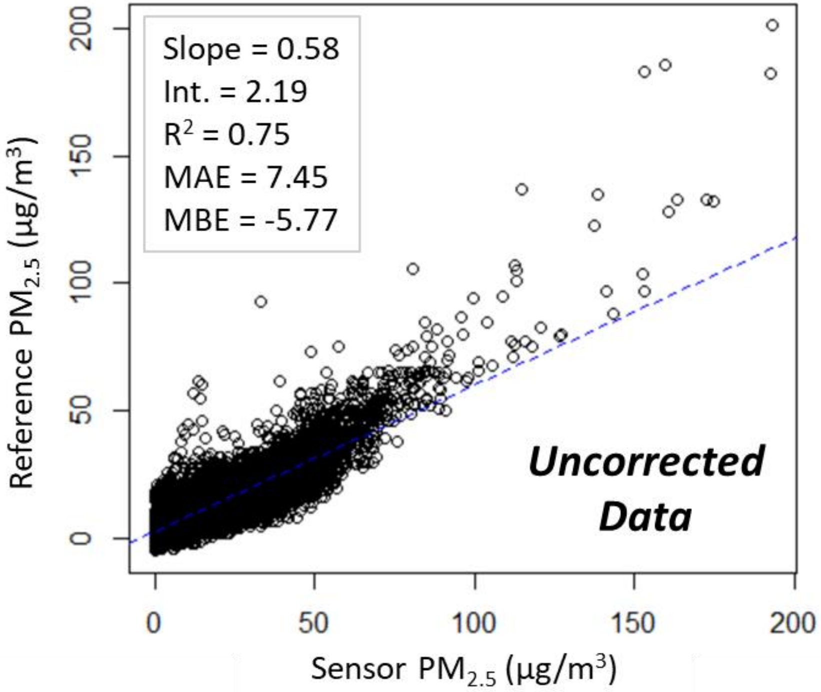
More Information:

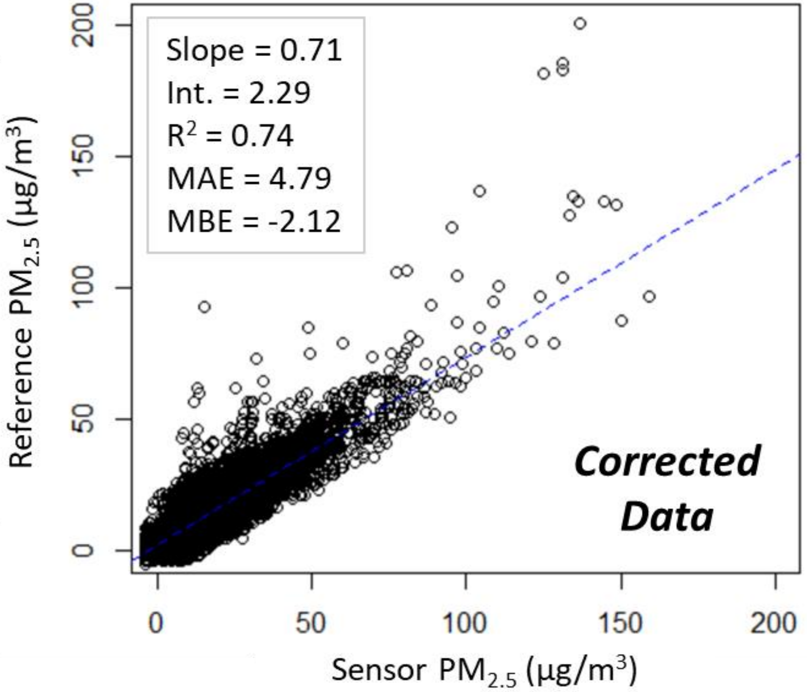
- See Chapter 4 of "Community in Action: A Comprehensive Guidebook on Air Quality Sensors": http://www.aqmd.gov/aq-spec/special-projects/star-grant
- US EPA Office of Research and Development (ORD), Air Sensor Collocation Instruction Guide: https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide

REMOTE CALIBRATION



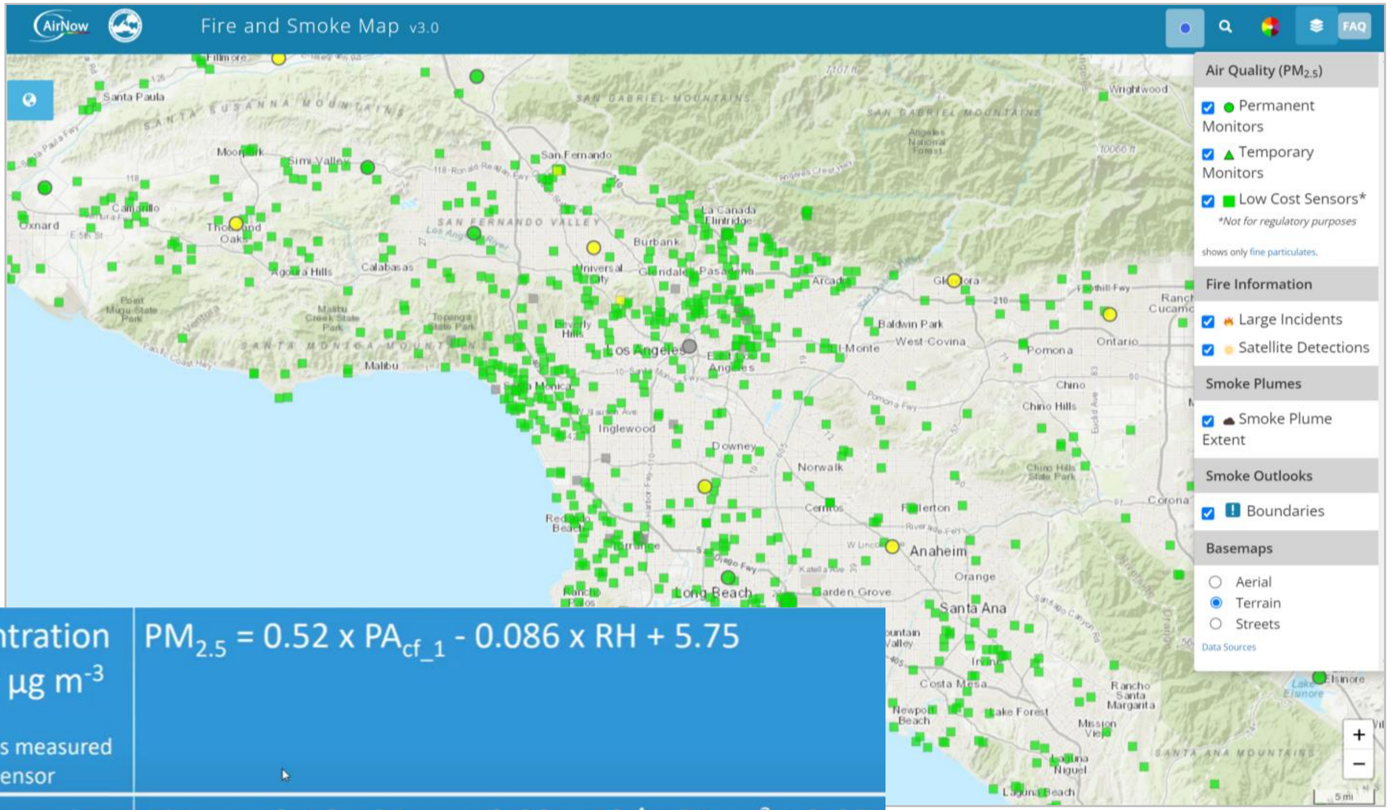
- Exploring a remote calibration technique called MOMA (MOment MAtching)
- Data from "proxy" sites, typically, the nearest regulatory air monitoring stations, is used to develop corrections for sensor data at regular intervals
- Method developed for Aeroqual AQY sensors
- Currently piloting this method with $PM_{2.5}$ data from PurpleAir PA-II sensors





GLOBAL CALIBRATION (EXAMPLE)

- The US EPA has developed a procedure to process and correct data from PurpleAir PA-II PM sensors in order to display this data alongside data from regulatory instruments
- To correct the data, a single correction equation has been developed and is applied to all PA-II sensors nationwide



Low Concentration $PA_{cf\_1} \le 343\ \mu g\ m^{-3}$ ~176-185 $\mu g\ m^{-3}$ as measured by the corrected sensor	$PM_{2.5} = 0.52 \times PA_{cf\_1} - 0.086 \times RH + 5.75$
High Concentration $PA_{cf\_1} > 343\ \mu g\ m^{-3}$ ~207 $\mu g\ m^{-3}$ as measured by the corrected sensor	$PM_{2.5} = 0.46 \times PA_{cf\_1} + 3.93 \times 10^{-4} \times PA_{cf\_1}^{2} + 2.97$

Latest public version of correction:
https://www.epa.gov/air-sensor-toolbox/technical-approaches-sensor-data-airnow-fire-and-smoke-map →

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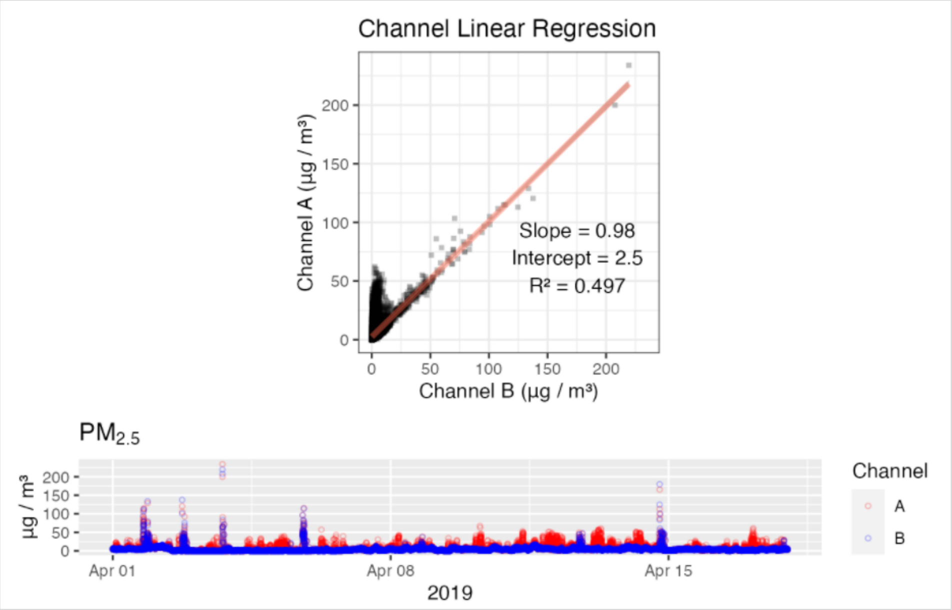
IMPORTANCE OF QA/QC MEASURES

From: "Community in Action: A Comprehensive Guidebook on Air Quality Sensors"
http://www.aqmd.gov/aq-spec/special-projects/star-grant

Examples of typical failure modes for PurpleAir sensors

- Moderate/extreme noise from one or both duplicate sensors
- Baseline shifts or jumps in one or both duplicate sensors
- Zero or flatlining data



Source: https://mazamascience.github.io/AirSensor/articles/articles/purpleair_failure_modes.html

Check	What to look for	Action/Interpretation
Low values	Long periods (10s of minutes) of a zero concentration or negative values.	The sensor may be malfunctioning.
Missing data	Data gaps or no signal at all.	The sensor may have lost power, lost connection to the Internet, or may be malfunctioning.
Sticking	Four or more minutes with exactly the same, non-zero concentration.	The sensor may be malfunctioning.
Sensor-to-sensor	One sensor over a period of time is reporting much higher or lower concentrations than nearby sensors.	Check to see if one of the sensors is located near a source because higher concentrations near a source might be expected. A series of unusual readings in an area at just one sensor may indicate a problem with that sensor.
Very high values	Very high, possibly erratic, concentrations.	This behavior may be seen during start up periods for sensors that need time to warm up. For particle measurements, this could indicate high humidity interference. This could also indicate the sensor is operating in weather conditions beyond those recommended by the sensor manufacturer (e.g., extreme cold).

Possible causes: physical obstruction of sensor, failure of one or both sensors, electronics issues that affect data logged

QC CONSIDERATIONS FOR SENSOR DATA PROCESSING

Sensor-specific

- Manufacturer-designated bounds
- Environmental operating limits (temperature and humidity)
- Unique features that can be leveraged (e.g., duplicate channels within a single sensor unit)
- Common failure modes (e.g., "sticky values" or flatlining)
- Behavior that may indicate a failure/drift or an actual air quality event, such as wildfires (e.g., extended elevated readings)

Pollutant-specific

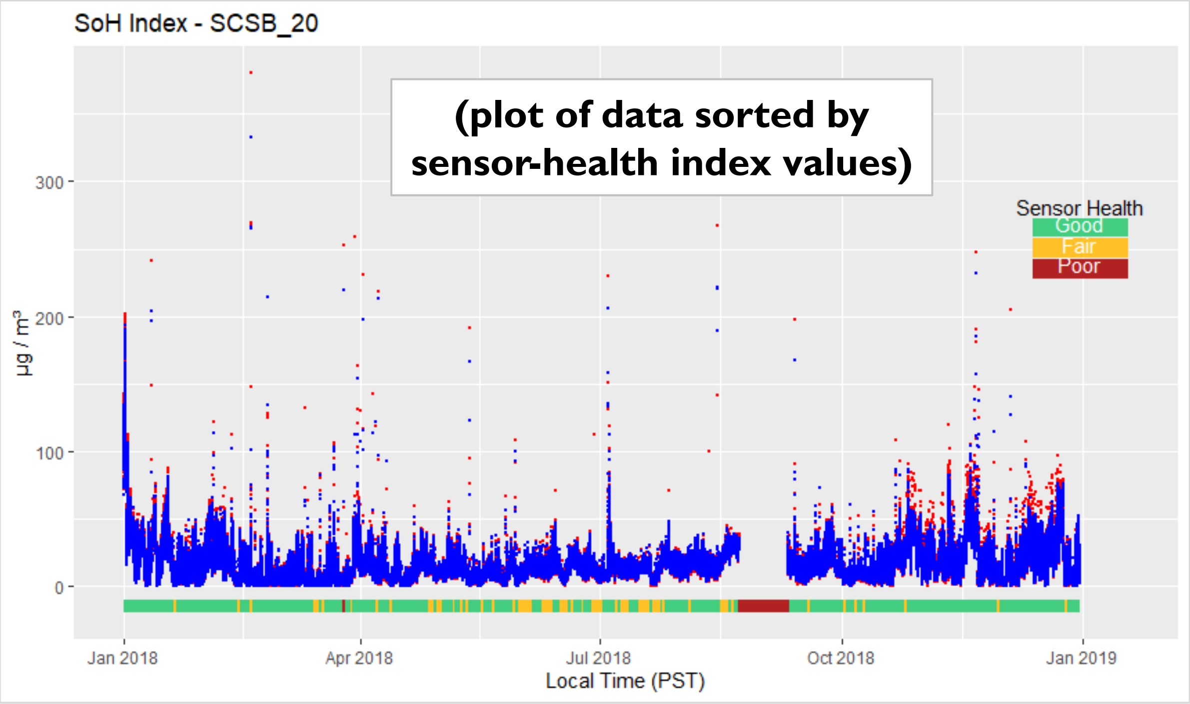
- Typical ranges
- Typical trends (e.g., diurnal trends)

Actions

- Invalidate – clear malfunctions
- Flag – data indicating failure OR an air quality event of interest
- Requirements – for criteria that must be met (e.g., for completeness)
- Adjust value – in some cases values may be adjusted (e.g., to zero)

EXAMPLE: SENSOR "STATE-OF-HEALTH" (SOH) METRICS

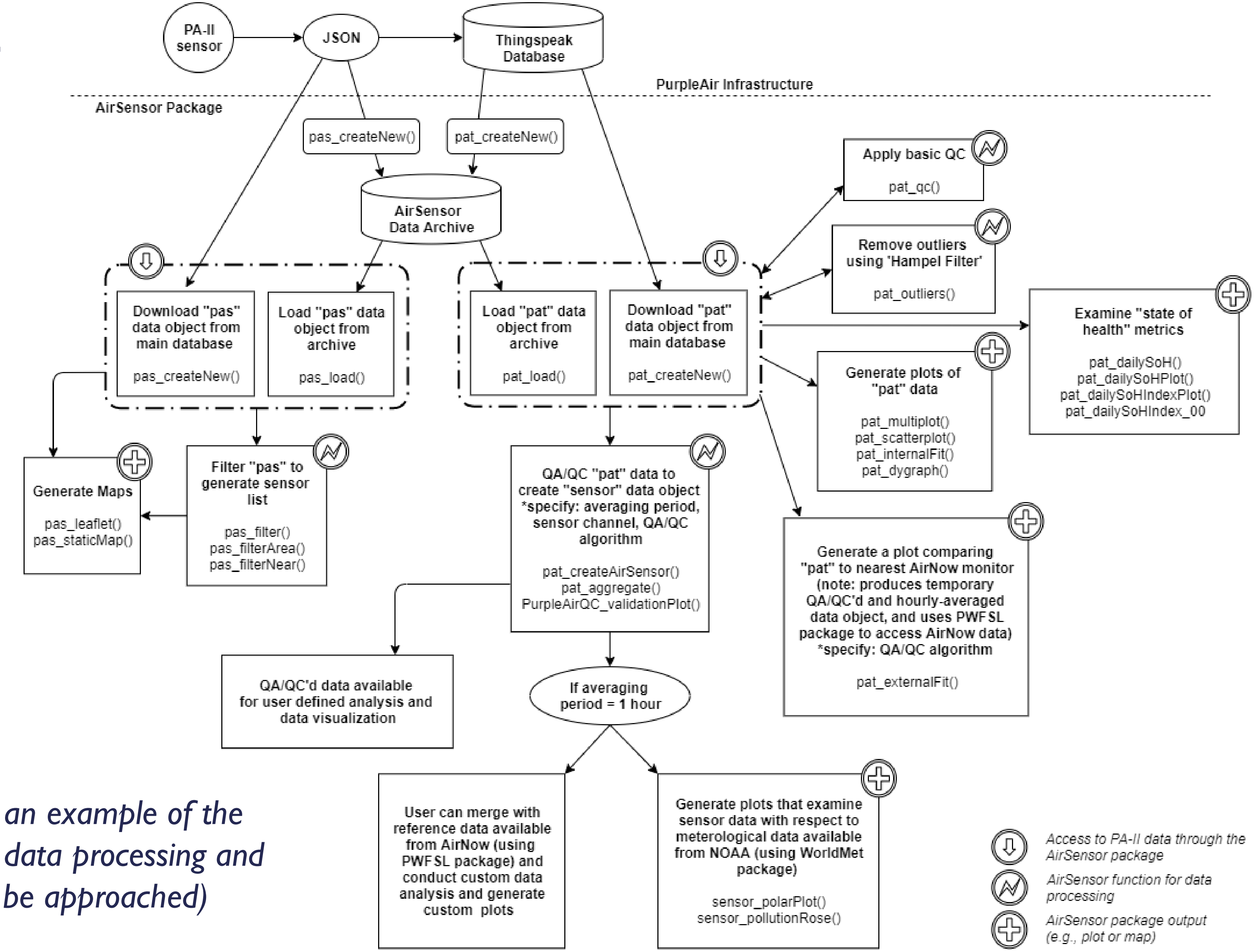
- A number of metrics are available to track sensor health on a daily basis
- These provide continuous insight into factors such as data validity and completeness



Daily SOH Metrics	Description (from the AirSensor documentation)
Percent Reporting	The number of sensor readings recorded per hour are summed over the course of a calendar day. This is then divided by the number of samples the sensor would record in an ideal day (24 * 3600 / samplingInterval) to return a percentage of each day that the sensor is reporting data.
Percent Valid	The number of valid (i.e., not NA or out-of-spec) sensor measurements are summed over the course of a calendar day, then divided by the total number of measurements the sensor actually recorded during that day (including NA and out-of-spec values) to return a percentage of the total recorded measurements that are considered plausible.
Percent DC	This function calculates the daily percentage of DC signal recorded by the pm25_A, pm25_B, humidity, and temperature channels. The data are flagged as DC signal when the standard deviation of an hour of data from each channel equals zero. The number of hours with a DC signal are summed over the day and a daily DC percentage for each channel is returned.
AB Fit	This function calculates daily linear model values between the pm25_A and pm25_B channels. A daily r-squared value is returned in addition to the coefficients of the linear fit (slope and intercept)
AB t-test	This function calculates a t-test between the pm25_A, pm25_B. A t-statistic and a p-value will be returned for each day. All returned values are expected to hover near 0 for a properly functioning sensor.
Other fit	This function calculates a daily linear model between the pm25_A, pm25_B, humidity, and temperature channels. One r-squared value for each channel pair except pm25_A, pm25_B, and humidity, temperature will be returned for each day. All returned values are expected to hover near 0 for a properly functioning sensor.
Index value	This function calculates a multi-metric index based on the data in SoH dataframe passed in. A tibble is returned containing a state of health index for each day. The returned table contains columns: datetime, index, and index_bin. The index column contains a value normalized between 0 and 1 where 0 represents low confidence in the sensor data and 1 represents high confidence. The index_bin is one of 1, 2, or 3 and represents poor, fair, and good data respectively. The index is calculated in the following manner: if the A or B channel percent reporting is < minPctReporting, then the index = 0, otherwise, index = pm25_A_pm25_B_rsquared.The breaks are used to convert index into the indenx_bin poor-fair-good values.

Learn more: http://www.aqmd.gov/aq-spec/special-projects/airsensor

Diagram of AirSensor Package Functions



DATA ACCESS

DATA PROCESSING

DATA VISUALIZATION

(this provides an example of the typical steps in data processing and how it can be approached)

Learn more: http://www.aqmd.gov/aq-spec/special-projects/airsensor AirSensor Manual: https://cran.r-project.org/web/packages/AirSensor/AirSensor.pdf

EXAMPLE: QA/QC ALGORITHMS

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STEP 1: Remove values outside of the bounds, applied prior to all algorithms

Function: pat_qc()
Bounds

- humidity – [0:100]
- temperature – [-40:185]
- $PM_{2.5}$ – [0:2000]

Optional Function: pat_outlier()
(additional Hampel filter)

STEP 2: Leverage the duplicate channels (A & B) in the PurpleAir sensor and apply one of the algorithms currently available, or define a new algorithm:

"PurpleAirQC_hourly_AB_00"
- Invalidate data where: min_count < 20
- No further QC

"PurpleAirQC_hourly_AB_01"
- Invalidate data where: min_count < 20
- Invalidate data where: p-value < 1e-4 & mean_diff > 10
- Invalidate data where: pm25 < 100 & mean_diff > 20

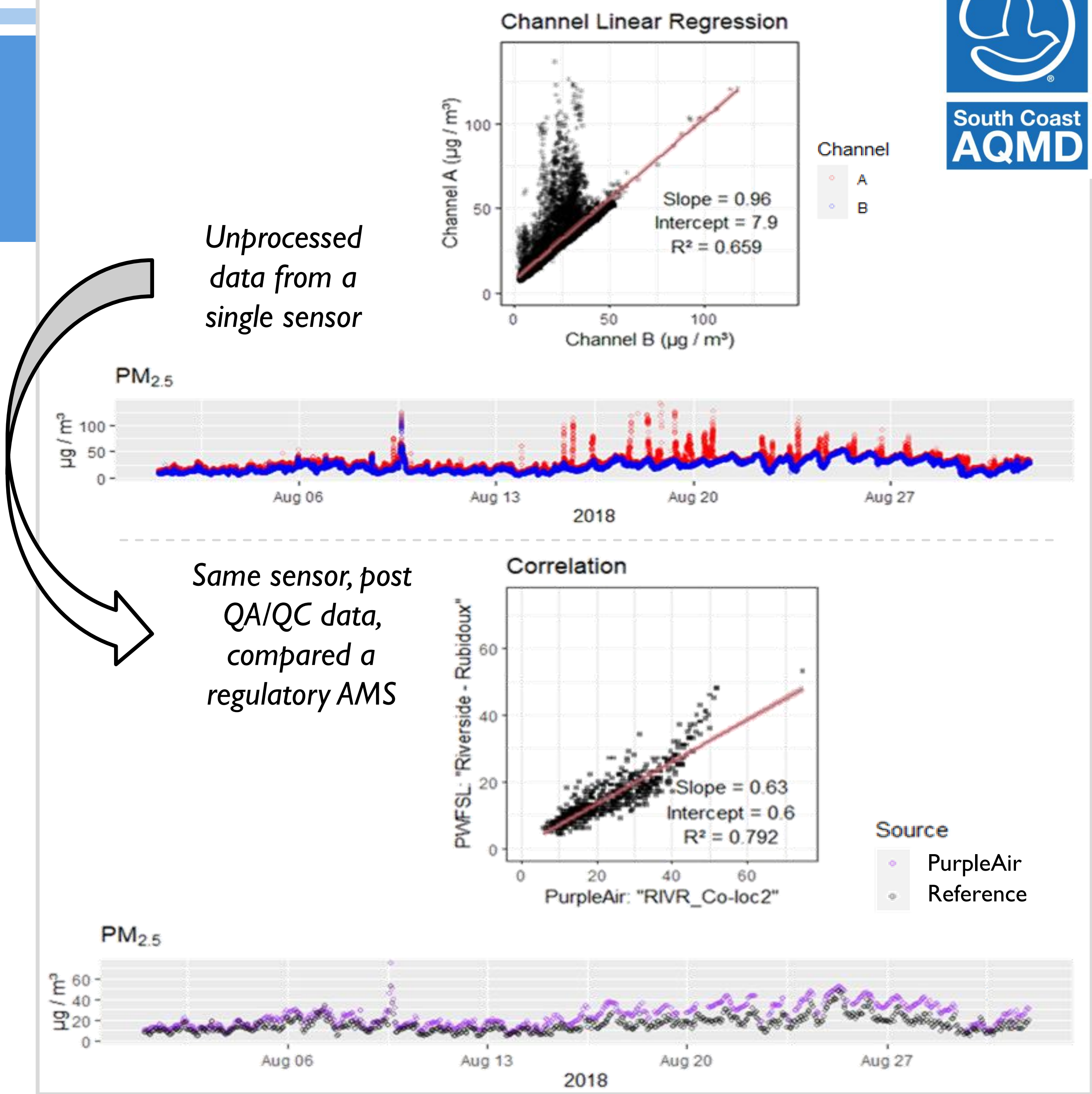
"PurpleAirQC_hourly_AB_02"
- Invalidate data where: min_count < 20
- Invalidate data where: A/B hourly Median Absolute Deviation > 3
- Invalidate data where: A/B hourly pct_diff > 0.5

"PurpleAirQC_hourly_AB_03" (algorithm used in the Fire and Smoke Map)
- Invalidate data where: min_count < 20
- Invalidate data where: A/B hourly difference > 5 AND A/B hourly percent difference > 70%
- Invalidate data where: A/B hourly data recovery < 90%

STEP 3: Average Channels A and B together for all data not invalidated, producing hourly data

EXAMPLE: QA/QC APPLIED

- The top plot depicts high-time resolution data from a sensor co-located at a regulatory air monitoring station
- Here there is disagreement between the duplicate channels (i.e., noise in the Channel A data, though in general trends agree)
- Filtering, applying a QA/QC Algorithm, and aggregating the data results in the processed data (bottom plot)
- The result is post-QA/QC data, for which trends agree fairly well with the corresponding regulatory data



One more example of QC rules, developed for Aeroqual AQY sensors

QC Rule	Logic	Action
High/Low Value Check	If $PM_{2.5}$ concentration value > 300 µg/m^3 for > 4 hr	Flag
High/Low Value Invalid	If $PM_{2.5}$ concentration value > 900 µg/m^3 for > 24 hr If $PM_{2.5}$ concentration value < 0.5 µg/m^3 for > 24 hr	Invalidate
Out of Bounds	If value is out of range of sensor manufacture specs O_3 > 200 ppb; NO_2 > 500 ppb; $PM_{2.5}$ > 1000 µg/m^3; Temp < -10 or > 60 °C; or RH < 0 or > 100 %	Invalidate
Flatline	If rolling Std Dev < 1 for > 12 hours	Invalidate
Temperature Exceedances	If temp <-15 or >110 ° F, concentration data flagged as "High Temp"	Flag
Negative Data Filter	If concentration value < - 5 ppb for O_3	Invalidate
Negative value replacement	If concentration value > -5 ppb and < 0 for O_3 ; set to zero	Set to zero
High Noise Check	Run Hampel Filter*; sensors with > 10% of data identified as outliers	Flag
Offline	No data from sensor > 12 hours	Flag
Data Averaging	Require 75% valid data recovery to generate time averages Require 45 valid data points for 1-hr average from 1-min data Require 18 valid hourly averages to generate a 24-hr average	Requirement
Correlation Check	Purple Air: If R^2 between A/B < 0.5 for 36 hour Community: If R^2 between sensor/community < 0.5 for 36 hour	Flag

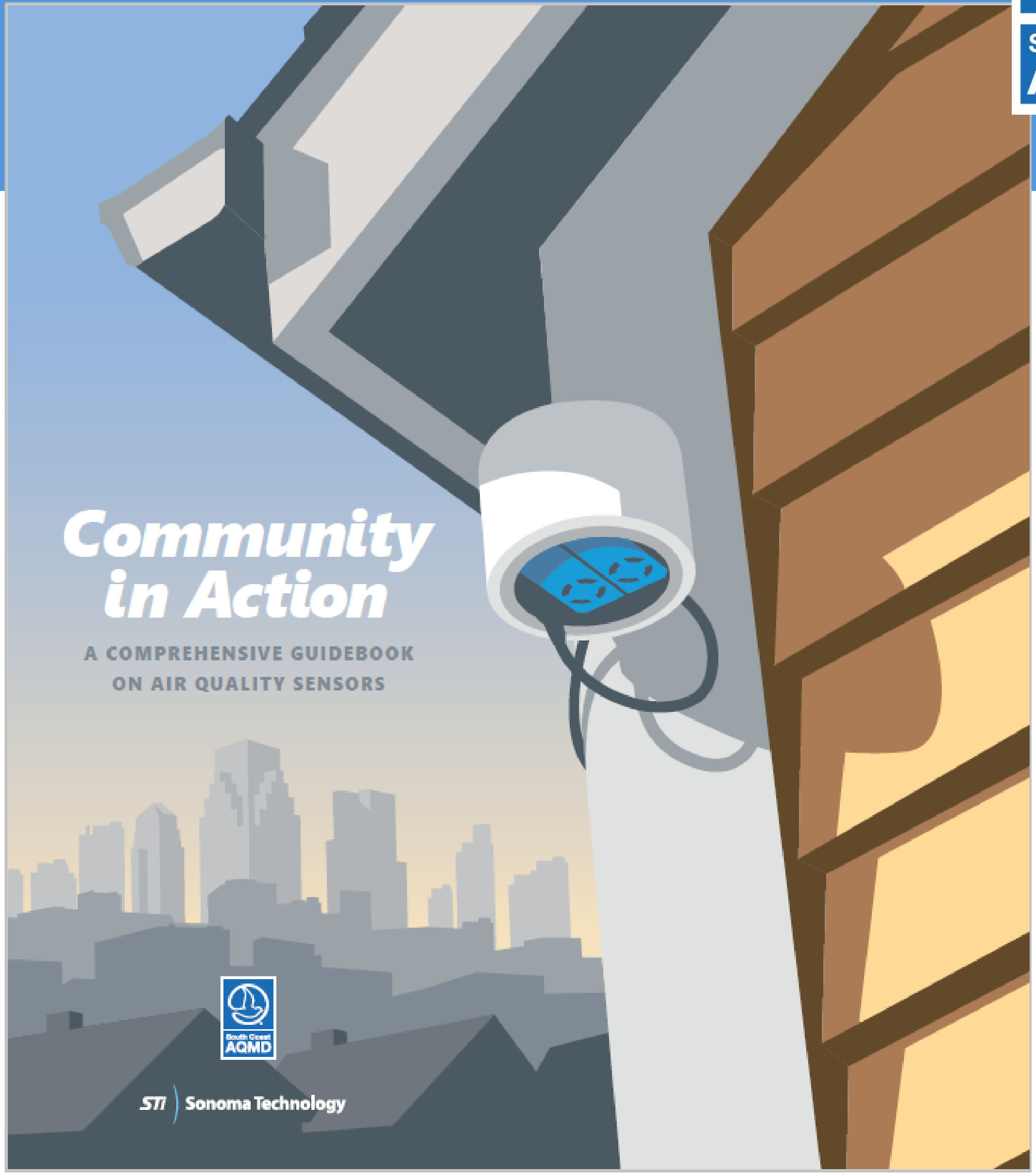
*Feenstra, et. al., (2020). "The AirSensor Open-source R-package and DataViewer Web Application for Interpreting Community Data Collected by Low-cost Sensor Networks." Environmental Modelling & Software: 104832. https://doi.org/10.1016/j.envsoft.2020.104832

FINAL NOTES ON QC AND DATA QUALITY

- Before beginning your project consider your research questions
  - The data will need to be of high enough quality to answer these questions
  - A Quality Assurance Project Plan (QAPP) developed at the start of a project can help you track and assess data quality throughout the project
  - The resource below offers guidance on developing a QAPP for community-based science or participatory science projects
- US EPA, Quality Assurance Handbook and Toolkit for Participatory Science Projects: https://www.epa.gov/participatory-science/quality-assurance-handbook-and-toolkit-participatory-science-projects

SENSOR EDUCATIONAL TOOLKIT

- Training videos (3)
- Community in Action: A Comprehensive Guidebook on Air Quality Sensors
- Data analysis & visualization tools (the AirSensor R-package and DataViewer web-based interface)
- Supplemental Resources:
    - Installation guides
    - Surveys and project forms
    - Workshop slides
    - Infographic examples
    - Examples of community reports & analysis
    - Publications



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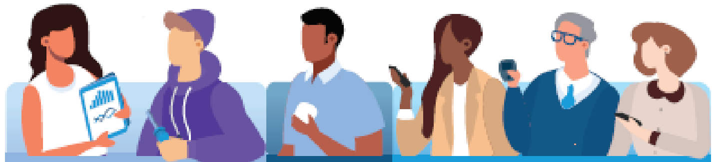
VERSATILE TOOLS

- Air Sensor Guidebook and other resources are designed to meet the needs of a broad range of users and projects
- For example, users could include:
  - An academic researcher new to community-based work
  - A community leader new to air quality and concerned about local sources
  - Staff from a government agency experienced in working with the public, but new to sensors
  - An individual interested in using sensors to better understand their own air quality

Chapter 1, "Introduction"

Table 1-1. A roadmap of the guidebook for users with different responsibilities and interests.



Chapters	Organizer: Community organizer or project lead for an air quality sensor project	Participant: Participant using a sensor in a community led project	Individual: Individual member of the public using a sensor	Partner (Academic, Industry, Government Agency): New to using sensors	Partner: New to air quality monitoring	Partner: New to community-based research
2 Learn – Valuable information about air quality	●	●	●		●	
3 Plan – Plan a successful project	●		●	●	●	●
4 Deploy – Deploy and maintain your sensors	●	●	●	●	●	●
5 Act – Move from results to action	●	●	●	●	●	●
Appendices						
A Air Quality Index	●	●	●		●	
B FAQs	●		●	●	●	●
C Purple Air Sensor	●	●	●	●	●	
D Data Analysis	●		●	●	●	
E Infographic	●					●
F Install Template				●		
G Project Template	●					●
H Log Notes	●	●	●		●	
I Liability Form	●			●	●	●
J Agency Contacts	●					●
K Sensor Tests	●			●		
L DataViewer	●	●		●	●	●
M Community Reports	●	●		●		●

Introduction 1-9

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Chapter 2, "Understanding Air Quality and Monitoring"

Particle Pollution

Particle pollution is a general term for a mixture of solid particles and liquid droplets...

Some particles are large enough to be seen as dust or dirt; others are so small that they can only be detected with an electron microscope. Particles are both directly emitted into the air and can be formed in the air from other pollutants.

Particle Size

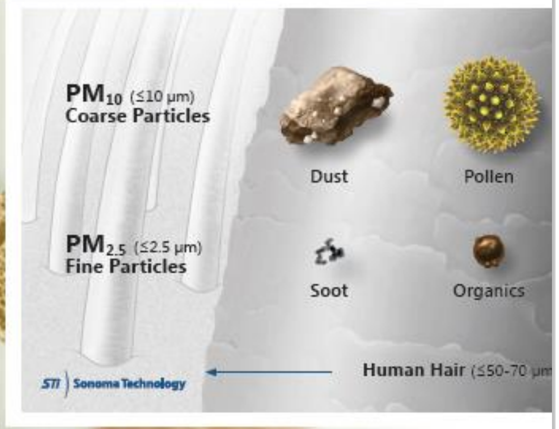
Particles in the air are referred to as particulate matter, or PM. Another term used in atmospheric science is aerosols which are small solid particles or liquid droplets suspended in air. Particles range in size and composition. Most commonly, measurements focus on two size ranges – particles less than 10 microns in diameter (coarse particles, PM_{10}) [or micrometers (µm) in aerodynamic diameter] and particles less than 2.5 microns in diameter (fine particles, $PM_{2.5}$) [or, micrometers (µm)

in aerodyn... refers to pa... particles) o... odd-shape... coarse part... properties,... particle siz...

Linking ... Health

Health rese... focused on... measurem... common d... measurem... conducted... country. PM... premature... or lung dis... irregular he...

Figure 2-1. $PM_{2.5}$ and PM_{10} particle sizes compared to a human hair.



decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing. Particle size is directly linked to the potential for causing respiratory problems. Larger particles impact the upper respiratory tract, while smaller particles can enter the lower respiratory tract and even enter the bloodstream (Figure 2-2).

The U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) to protect human health (see Appendix A). The 24-hr standards for $PM_{2.5}$ and PM_{10} are shown in **Table 2-1**. These standards stipulate that the average PM mass concentration in the outdoor air over a 24-hour time-period should not exceed a certain threshold, based on the findings of health and risk assessments. More details about the NAAQS are available on the EPA website.[2]

Table 2-1. NAAQS (2012) for $PM_{2.5}$ and PM_{10}.

Pollutant	Averaging time	Level
$PM_{2.5}$	24 hours	12 µg/m³
PM_{10}	24 hours	150 µg/m³

There are currently no EPA standards for $PM_{2.5}$ and PM_{10} at shorter time periods such as 1-minute or 1-hour. EPA reports the air quality index (AQI), based on several criteria pollutants, to inform the public about how clean or polluted the air is and what associated health effects might be a concern (see Appendix A).

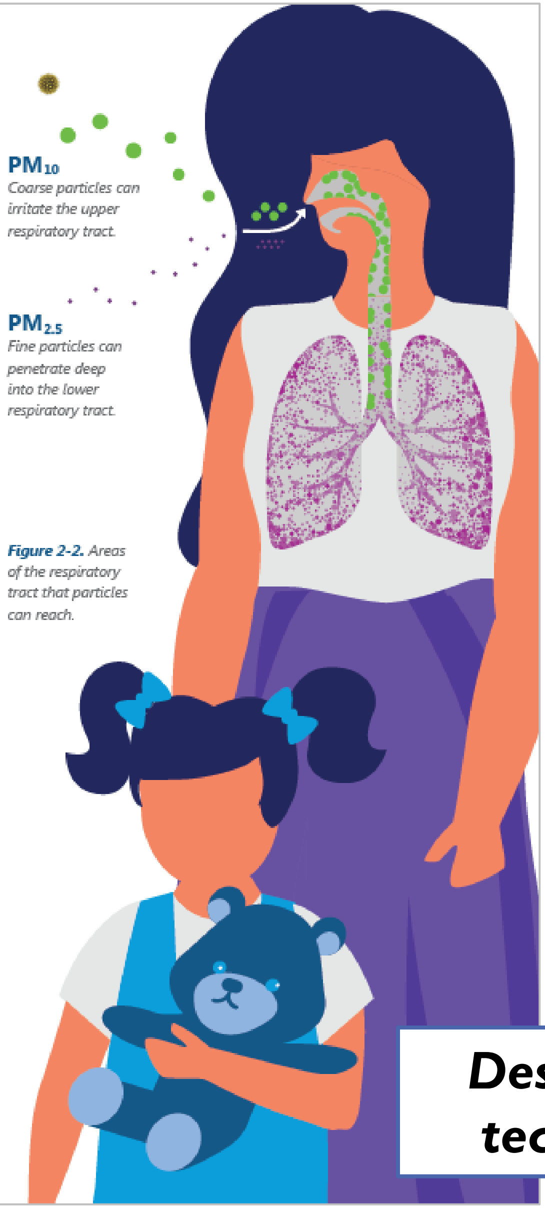


Figure 2-2. Areas of the respiratory tract that particles can reach.

WORLD HEALTH ORGANIZATION ESTIMATED WORLDWIDE DEATHS FROM AMBIENT AIR POLLUTION IN 2016

16%	25%	17%	26%
of lung cancer deaths	of COPD deaths	of ischemic heart disease and strokes	of respiratory infection deaths

People with compromised health and vulnerable populations (i.e., children, pregnant women, and the elderly) are more susceptible to the effects of air pollution.

Worldwide, the World Health Organization[4] estimated that in 2016, ambient air pollution caused about 16% of lung cancer deaths, 25% of chronic obstructive pulmonary disease (COPD) deaths, about 17% of ischemic heart disease and stroke, and about 26% of respiratory infection deaths. A 2019 paper published in the European Heart Journal[3] estimated that air pollution could be causing double the number of excess deaths a year in Europe than had been estimated previously. The researchers found that air pollution caused an estimated 8.8 million extra deaths globally. Similarly, a 2018 study[5] estimated that 8.9 million deaths were associated with long-term exposure to outdoor $PM_{2.5}$.

8.8 million extra deaths globally
European Heart Journal, 2019[3]

For Further Reading

If you would like more information on the overall burden of PM on human health nationally and globally, check out the following:

HealthData.org Global Burden of Disease Study 2017[6]

World Health Organization Ambient Air Pollution[4]

If you would like more information on the different ways in which PM exposure impacts human health, check out the following:

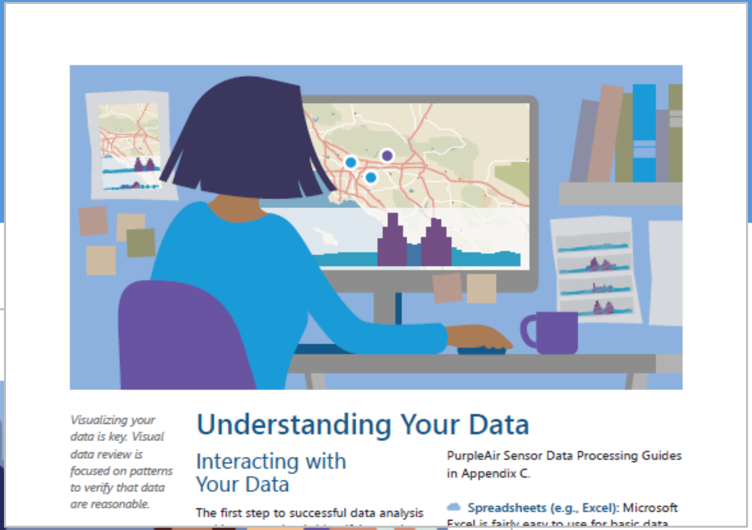
An association between air pollution and mortality in six U.S. cities[7]

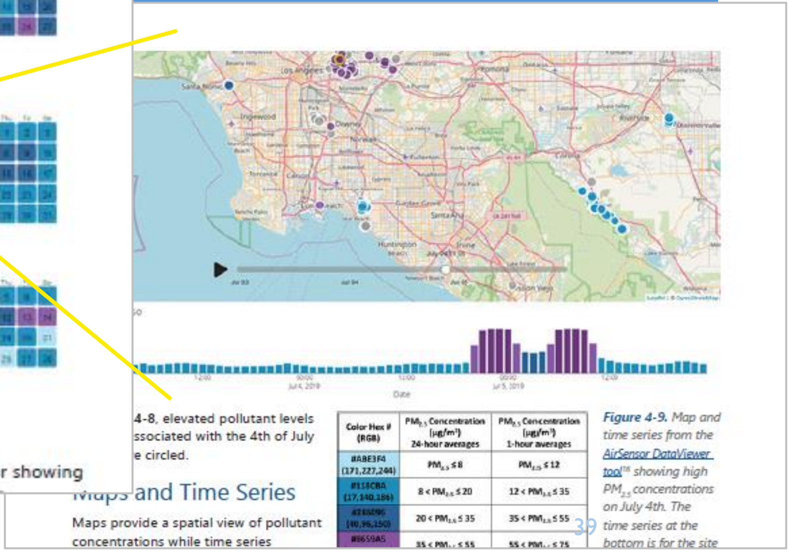
Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution[8]

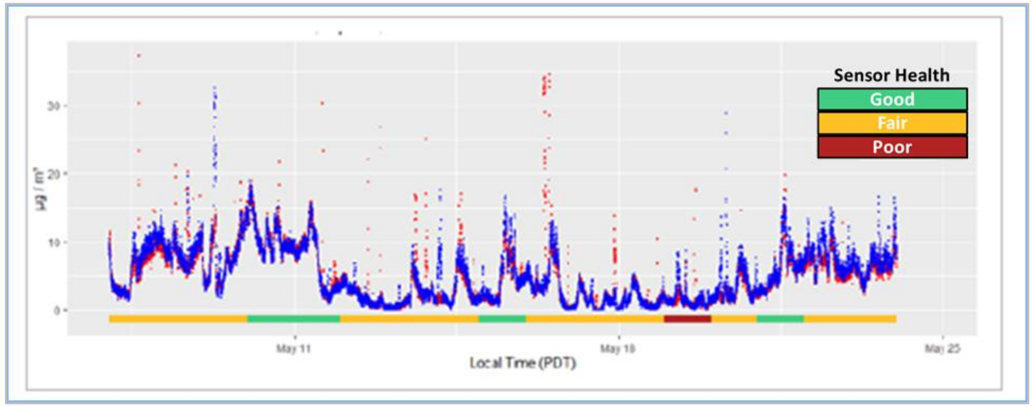
The effect of air pollution on lung development from 10 to 18 years of age[9]

Designed to support users with varied technical backgrounds and expertise

Chapter 4, Sections 1, 2, and 3







- Practical advice for siting, installing, and maintaining sensors
- Sensor co-location, correction, and calibration
- Introduction to different plot types, assessing accuracy, and useful quality control (QC) metrics/algorithms
- Ways to monitor the "State-of-Health" of deployed sensors
- Description of tools and resources available for data analysis
- Step-by-step example analysis of an air quality event (using the AirSensor DataViewer, web-based interface for exploring current and historical data)

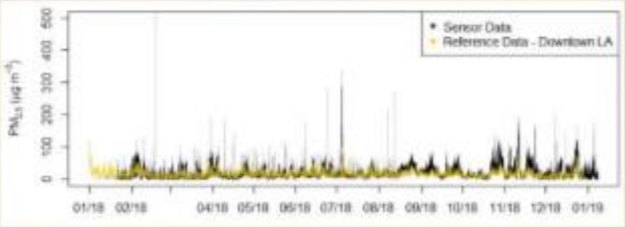
Appendix E, "Example Infographic"

What can we learn from these PurpleAir sensors about outdoor air
A QUICK LOOK AT THE APIFM PURPLEAIR SENSORS

This analysis uses all available data from January 2018 - January 2019.
Note, the results presented here are preliminary.

A YEAR OF DATA

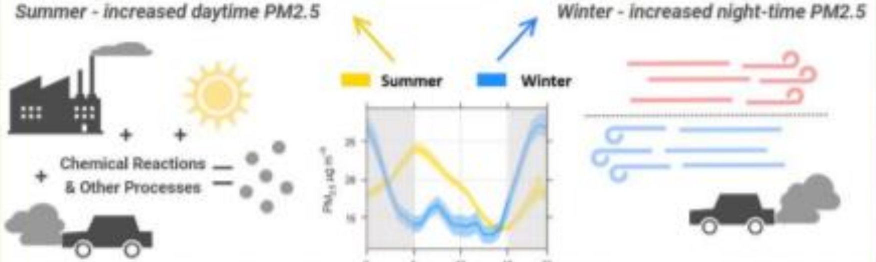
- Similar $PM_{2.5}$ trends across all 31 sensors & reference data
- Darker = overlapping
- Lighter = single sensor



WHEN IS $PM_{2.5}$ HIGHER? ...DEPENDS ON THE SEASON

Summer - increased daytime PM2.5

Winter - increased night-time PM2.5

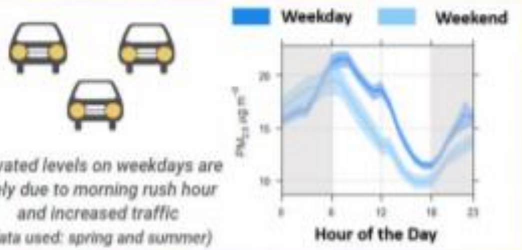


Likely due to increased "secondary organic aerosol" formation (Or, gases and smaller particles making larger particles in sunlight)*

Likely due to stronger nightly "inversions" (Or, stable conditions caused by a layer of warm air over a cold one trapping emissions)

*Applies to late morning and afternoon, but the early morning peak is likely driven by other factors

...ALSO ON THE DAY OF THE WEEK



Elevated levels on weekdays are likely due to morning rush hour and increased traffic (data used: spring and summer)

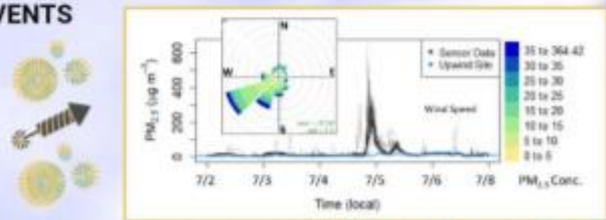
The sensor data reflects expected trends, and if sensors can show us when air quality is behaving as we might expect, can they also highlight anomalies and provide new information at sites?

February 2019 STAR Grant Workshop

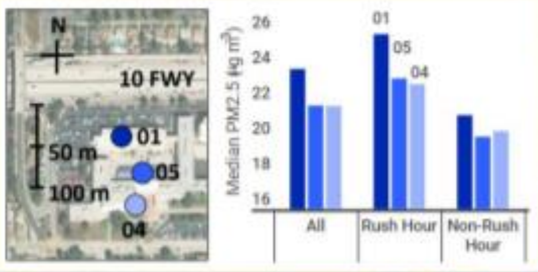
What can we learn from these PurpleAir sensors about outdoor air
A QUICK LOOK AT THE APIFM PURPLEAIR SENSORS

UNIQUE EMISSION EVENTS

- High $PM_{2.5}$ on July 4th
- Southwest winds seem to be transporting emissions from fireworks shows in and around DTLA
- Sites upwind -> lower $PM_{2.5}$



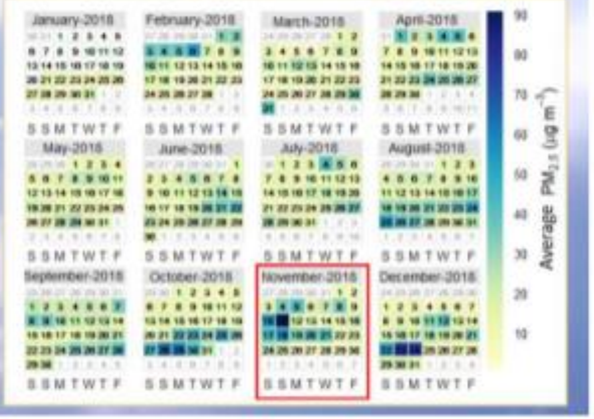
WHAT ABOUT THE 10 FWY?



- Data selected: summer, weekday, with northerly winds
- High $PM_{2.5}$ next to FWY is elevated during rush hour
- Lower levels during non-rush hour time
- Patterns such as this can help highlight when and where exposure may be the highest

Other Events...

- Average $PM_{2.5}$ for each day
- In winter months inversions may result in increased $PM_{2.5}$ for several days at a time
- In November, an additional contributing factor was the Woolsey Fire (11/8-11/21)



These sensors seem to be able to provide indicative information about local air quality and air quality trends.

Conducted as part of the US EPA STAR Grant: "Engage, Educate and Empower California Communities on the Use and Applications of Low-cost Air Monitoring Sensors"

Feel free to contact us with questions:
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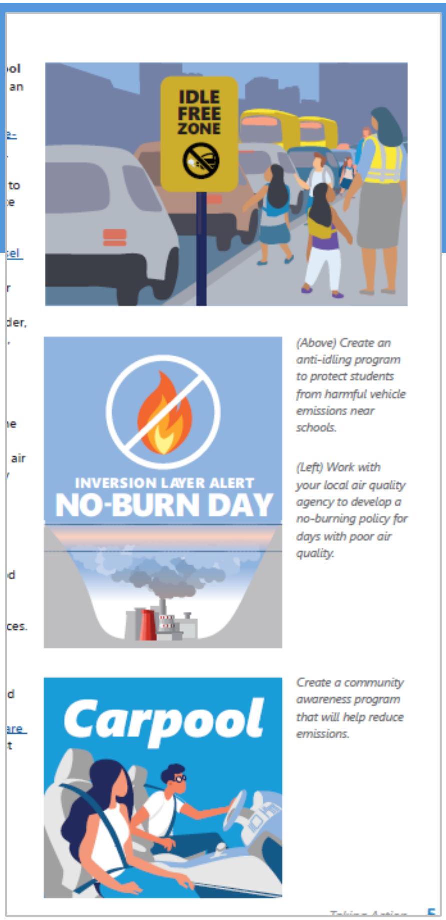
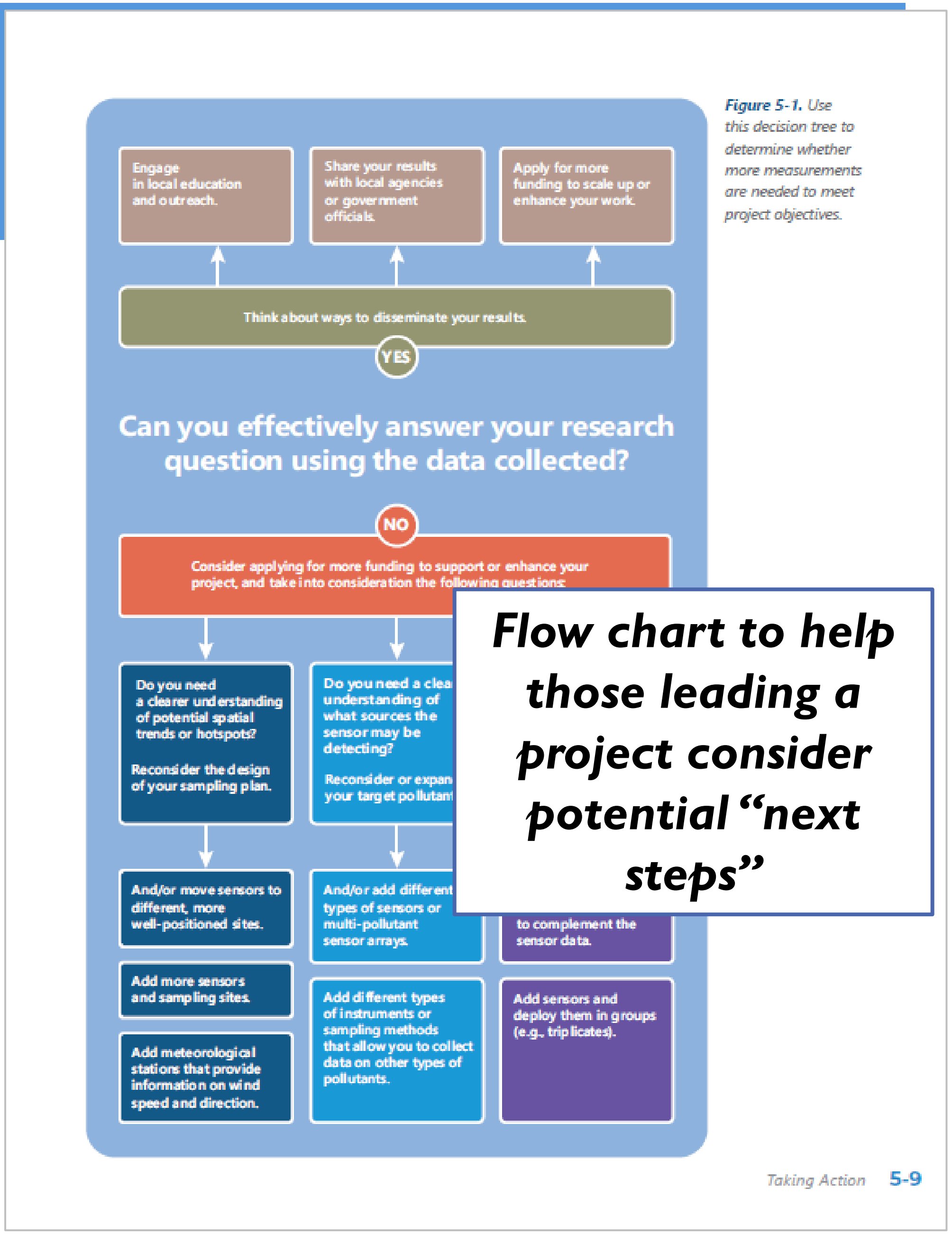
UPON A PROJECT'S COMPLETION

- Ideas for and examples of "local action"
- Advice to help determine whether additional data should be collected
- Strategies for communicating with local government agencies and/or the broader community

Chapter 5, Sections 1, 2, and 3





Flow chart to help those leading a project consider potential "next steps"

TOOLS & RESOURCES

- AQ-SPEC website: http://www.aqmd.gov/aq-spec/home
- AQ-SPEC Evaluation Reports: http://www.aqmd.gov/aq-spec/evaluations
- Summary Table for PM Sensors: http://www.aqmd.gov/aq-spec/evaluations/summary-pm
- Summary Table for Gas-Phase Sensors: http://www.aqmd.gov/aq-spec/evaluations/summary-gas
- Sensor Educational Toolkit: http://www.aqmd.gov/aq-spec/special-projects/star-grant
- Examples of sensor network deployments and data processing/analysis/visualization tools:
  - http://www.aqmd.gov/aq-spec/special-projects/aeroqual-aqy-deployments
  - http://www.aqmd.gov/aq-spec/special-projects/airsensor

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

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THANK YOU – QUESTIONS?

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AQ-SPEC
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