Advanced Topics in Using Sensors to Measure Air Quality

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Supporting the Los Angeles Public Library Air Sensor Loan Program

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Outline

Air Sensors vs. Regulatory Monitors

What is the difference between an air sensor and a regulatory monitor?

Using Air Sensor Evaluations

How can I use online air sensor evaluation documents to:
- Decide which sensor I should use, or
- Understand how my sensor compares to regulatory methods?

Collocation of a Sensor with a Regulatory Monitor

How are regulatory monitor and air sensor comparisons made?

Siting an Air Sensor

What should I keep in mind when deciding where to put a sensor to collect air quality measurements?

Quality Assurance and Quality Control

What steps should I take to make sure I am collecting data of good quality?

Data Analysis

How do I analyze my data and interpret my findings?

Additional Resources

Air Sensors vs. Regulatory Monitors

What is the difference between an air sensor and a regulatory monitor?

Air Sensors vs. Regulatory Monitors

Video Length: 3 minutes, 30 seconds

If the video will not play, please visit: https://youtu.be/whP6CDWJ-fM

https://www.epa.gov/air-sensor-toolbox/videos-air-sensor-measurements-data-quality-and-interpretation

Air Sensors vs. Regulatory Monitors

How sensors compare with regulatory monitors:

	Regulatory Monitors	Air Sensors
Typical Purchase Cost	$15,000 to $40,000 (U.S. Dollars)	$100 to $5,000 (U.S. Dollars)
Staff Training	Highly trained technical staff	Little or no training
Operating Expense	Expensive	Inexpensive
Siting Location	Fixed location (building/trailer needed)	Portable (with basic weather protecting)
Data Quality	Known and consistent quality in a variety of conditions	Unknown and may vary from sensor to sensor in different weather conditions and pollution environments
Operating Lifetime	10+ Years (calibrated and operated to maintain accuracy)	Short (1 year) or Unknown (may become less accurate over time)
Use for Regulatory Monitoring	Yes	No

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

Comparing Your Sensor Data with Regulatory Monitor Data

Air sensor data may not always match regulatory monitor data (shown on AirNow.gov) or other state/local/tribal websites for many reasons, as shown below.

Regulatory Monitors	**Air Sensors**
Regulatory monitors are run by highly trained technical staff who follow strict guidelines to maintain high quality data that is regularly checked.	Air sensors have variable accuracy and may become less accurate over time.
Regulatory monitors are placed based on specific criteria (for example, population, distance to a specific source, or traffic levels).	Air sensors can be placed anywhere (for example, they could be placed close or far away from a specific source).
The AQI, shown on AirNow, is based on regulatory monitor data averaged to times that match the NAAQS averaging time periods.	Air sensors that report AQI values may calculate AQI based on shorter time periods (for example, minute or hourly values).

AQI = Air Quality Index
NAAQS = National Ambient Air Quality Standards

Using Air Sensor Evaluations

How can I use online air sensor evaluation results to:

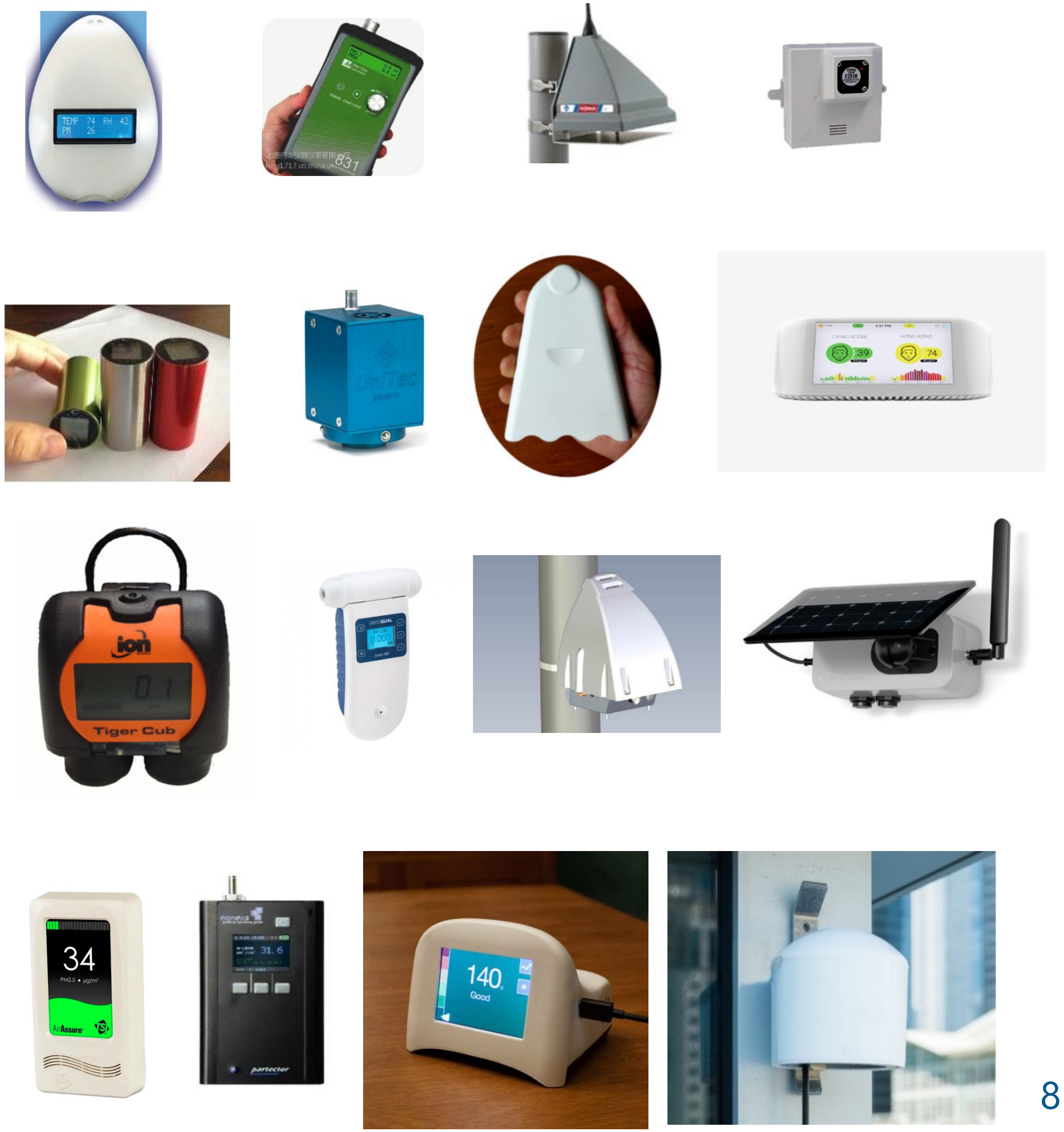
- Decide which sensor I should use?
- Understand how my sensor compares to regulatory monitors?

Air Sensors

There are many air sensors on the market. How do we know which ones perform well? How do they compare to regulatory monitors?

Air sensors are evaluated to understand how they perform under ambient (field) and controlled (laboratory) conditions. Results are often shared for the public to use.

Using these results can help you decide which air sensor may best suit your needs and help you understand how the sensor performs.



Where to Find Sensor Evaluation Results

South Coast Air Quality Management District AQ-SPEC: http://www.aqmd.gov/aq-spec

- Detailed information about laboratory and field tests of air sensors
- Summary tables comparing basic sensor performance

EPA Sensor Evaluations: https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance

- Detailed information about laboratory and field tests of air sensors
- Easy-to-view summary tables with information about air sensor performance

How to Interpret Sensor Evaluation Results

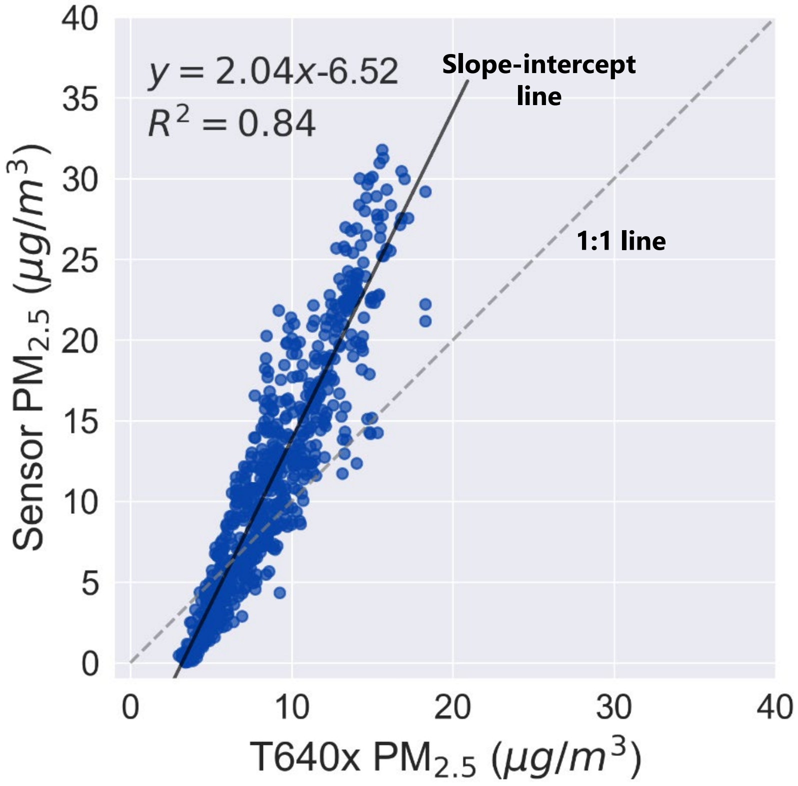
One way to compare air sensor data with regulatory monitor data is to plot the data in a **scatter plot.**

The black line going through the data is the slope-intercept line, developed by a linear regression function. This line is represented by the equation **y = mx + b** where:

- **y** is the sensor measurement,
- **x** is the regulatory monitor measurement,
- **m** is the slope, and
- **b** is the y-intercept

A measure of how close the data points are to the slope-intercept line, represented by $\mathbf{R^2}$, is the called the coefficient of determination. This value describes the amount of scatter in the data. $\mathbf{R^2}$ ranges from 0 and 1, where values closer to 1 indicate stronger correlation and less scatter.

If the **slope-intercept line** is the same as the **1:1 line**, there is perfect agreement between sensor and regulatory monitor data.



The 1:1 line, shown here as a dashed line, represents perfect agreement between sensor and regulatory monitor data (or y = x).

Learn More: https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

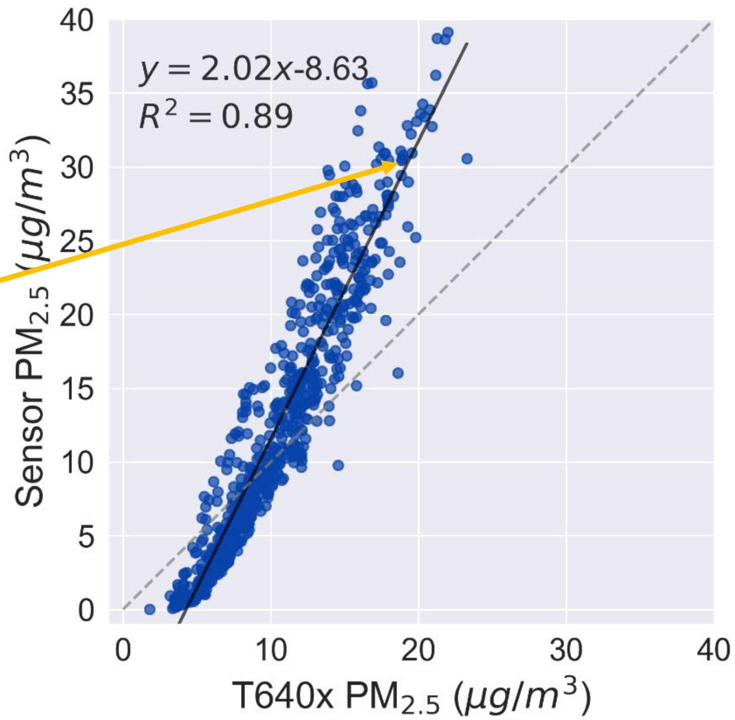
How to Interpret Sensor Evaluation Results

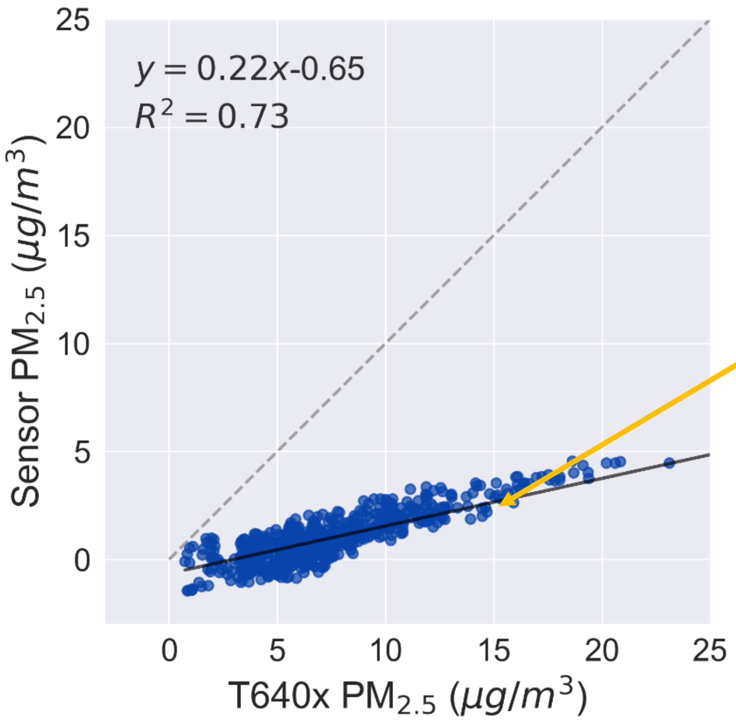
The slope-intercept line can help understand if a sensor **over-reports** or **under-reports** measurements relative to regulatory monitors.

In this plot, the slope is >1 (m=2.02) and data points show sensor measurements are higher than regulatory monitor measurements above 8.5µg/m^3. This is an example of sensor that **over-reports** measurements.

In this plot, the slope is <1 (m=0.22) and all data points show sensor measurements are less than regulatory monitor measurements. This is an example of a sensor that **under-reports** measurements.

Here, the sensor measures 30 µg/m^3 whereas the regulatory monitor (T640x) measures 20 µg/m^3





Here, the sensor measures 2.5 µg/m^3 whereas the regulatory monitor measures 15 µg/m^3

How to Interpret Sensor Evaluation Results

South Coast Air Quality Management District

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Evaluation Summary

Sensor Description

Manufacturer/Model: HabitatMap/ AirBeam2

Pollutants: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} mass concentration

Time Resolution: 1-minute

Type: Optical

- Overall, the HabitatMap AirBeam2 sensors showed moderate accuracy as compared to the reference instrument for $PM_{1.0}$ and $PM_{2.5}$, for a conc. range between 0 to 300 µg/m³. Accuracy was fairly constant over the range of $PM_{1.0}$ and $PM_{2.5}$ concentrations tested.
- The AirBeam2 sensors exhibited high precision for all T/RH combinations and all PM concentrations.
- The AirBeam2 sensors (IDs: F4F1, 6FE0 and 63CC) showed low intra-model variability.
- Data recovery was ~ 77% and 100% from all units in the field and in the laboratory, respectively
- For $PM_{1.0}$ and $PM_{2.5}$, the AirBeam2 sensors showed strong correlations with GRIMM ($PM_{1.0}$ $R^2 \sim 0.75$) and moderate to strong correlations with the FEM GRIMM, FEM BAM and FEM T640 from the field ($PM_{2.5}$ $0.68 < R^2 < 0.79$) and very strong correlations with GRIMM in the laboratory studies ($R^2 > 0.99$ for $PM_{1.0}$ and $PM_{2.5}$).
- The same three AirBeam2 units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

Field Evaluation Highlights

- Deployment period 07/20/2018 - 09/19/2018: the three AirBeam2 sensors showed moderate to strong correlations with the $PM_{1.0}$ and $PM_{2.5}$ mass concentration as monitored by FEM GRIMM, FEM BAM and FEM T640. PM_{10} mass conc. showed no correlations with the corresponding GRIMM, FEM BAM and T640 data
- The units showed very low intra-model variability and data recovery of ~77%.

1-hr mean, all ref. instr.

AirBeam2 vs FEM GRIMM

AQ-SPEC is a testing center that has evaluated a number of air sensors. They generate both the summary report shown here and some more detailed reports which show more figures to better interpret the results.

Concentration range encountered during the test.

Description of how the sensor performed under different temperatures (T) and relative humidity (RH) conditions.

R^2 (coefficient of determination) for comparisons between the sensor and regulatory monitor measurements.

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

How to Interpret Sensor Evaluation Results

AQ-SPEC Sensor Evaluation Table

PM Sensors						
Sensor Image	**Make** (Model)	**Est. Cost** (USD)	**Pollutant(s)**	***Field R^2**	***Lab R^2**	**Summary Report**
	Clarity (Node)	$1300	$PM_{2.5}$	0.73 to 0.76	0.99	PDF (1,030 KB)
	Dylos (DC1100 Pro)	$300	$PM_{(0.5-2.5)}$	0.65 to 0.85	0.89	PDF (1,384 KB)
	Dylos (DC1700-PM)	$475	$PM_{2.5}$	0.58 to 0.68	0.95	PDF (823 KB)
			PM_{10}	0.15 to 0.18	-	
	Ecowitt (WH415B)	$100	$PM_{2.5}$	0.39		
	Edimax (AirBox)	$249	$PM_{2.5}$	0.85		
	Edimax (Edigreen Home)	$299	$PM_{2.5}$	0.82		
	Elitech (Temtop LKC	$140	$PM_{2.5}$	0.91		

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

Results from field tests

Results from lab tests

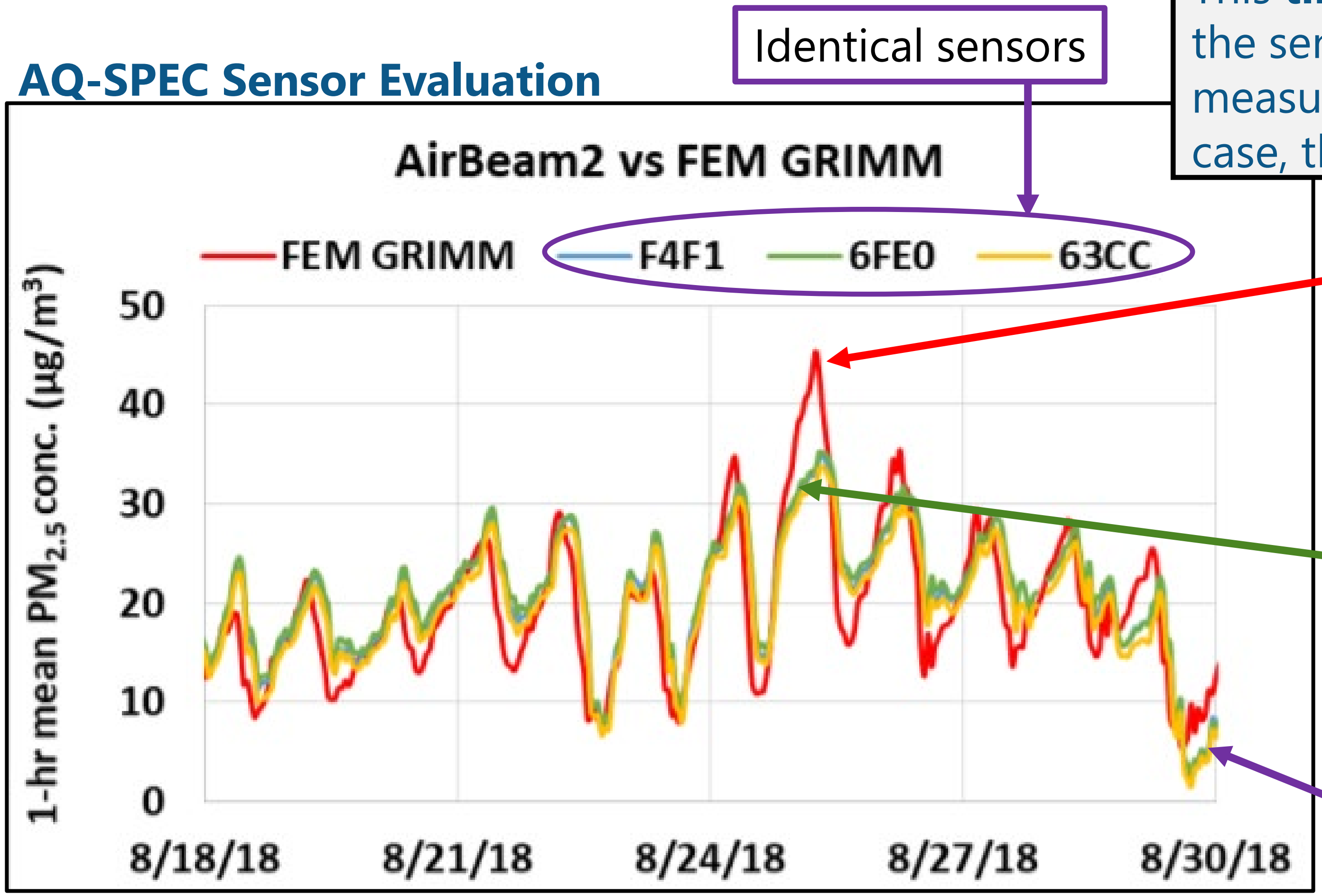
Sensors may be tested outdoors (**field**) or under controlled conditions within a chamber (**lab**). Sensors operated outdoors may be influenced by things like relative humidity. If you are operating your sensor outdoors, these results may be most important.

Some summary tables list the coefficient of determination, $\mathbf{R^2}$, to help quickly identify sensors with strong correlation with regulatory monitors. $\mathbf{R^2}$ values closer to 1 indicate stronger correlation and less scatter.

$\mathbf{R^2}$ is just one indicator of performance. It is important to look at the summary report for more detail (for example, impact of changing relative humidity).

How to Interpret Sensor Evaluation Results

AQ-SPEC Sensor Evaluation



This **time series plot** helps to show whether or not the sensors capture the same variation in pollutant measurements as the regulatory monitor. In this case, the variations are well captured.

In this plot, the regulatory monitor measurements are shown in red.

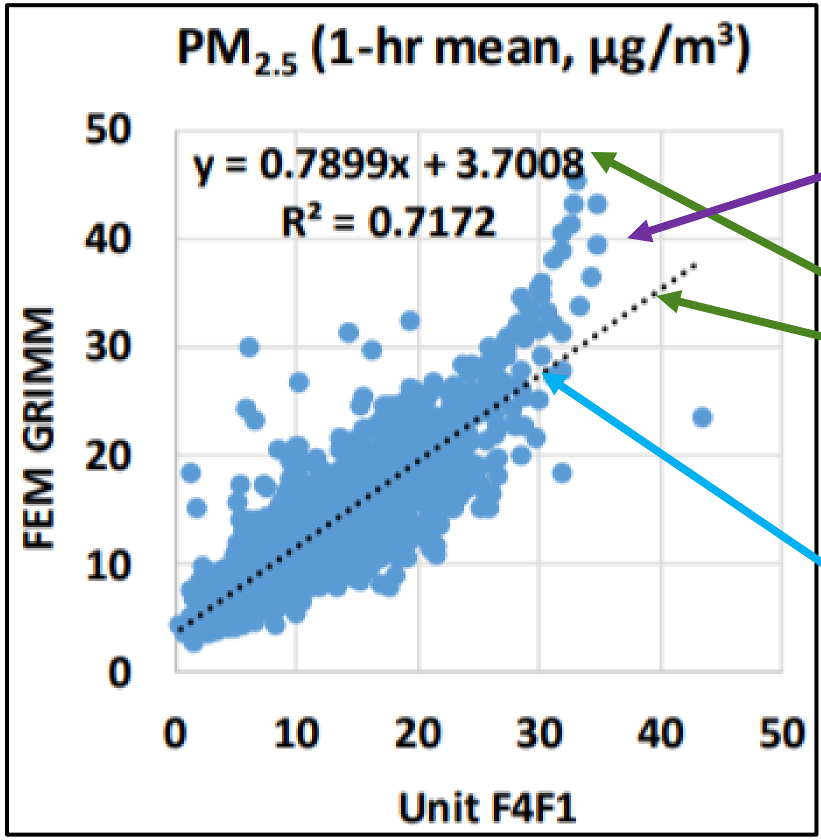
The sensor measurements are shown in blue, green, and yellow.

In this case, the three identical sensors (identified by their serial numbers) produce very similar measurements.

http://www.aqmd.gov/docs/default-source/aq-spec/field-evaluations/airbeam2---field-evaluation.pdf?sfvrsn=18

How to Interpret Sensor Evaluation Results

AQ-SPEC Sensor Evaluation



This **scatter plot** is different from the one previously discussed. In this case, the regulatory monitor is shown on the y-axis and the sensor is shown on the x-axis. That makes the interpretation a little different.

Notice the hook shape on this plot. One should be careful in interpreting the measurements when readings are this high.

Slope-intercept line is represented by the dotted line. In this case, **y= mx + b** is defined by:

- **y** = regulatory monitor measurement
- **x** = sensor measurement
- **m** = slope
- **b** = intercept

*In this case, **m** and **b** will be different than if the x and y-axes were flipped.

Here, the sensor measures 27.4 µg/m^3 whereas the regulatory monitor measures 30 µg/m^3.

http://www.aqmd.gov/docs/default-source/aq-spec/field-evaluations/airbeam2---field-evaluation.pdf?sfvrsn=18

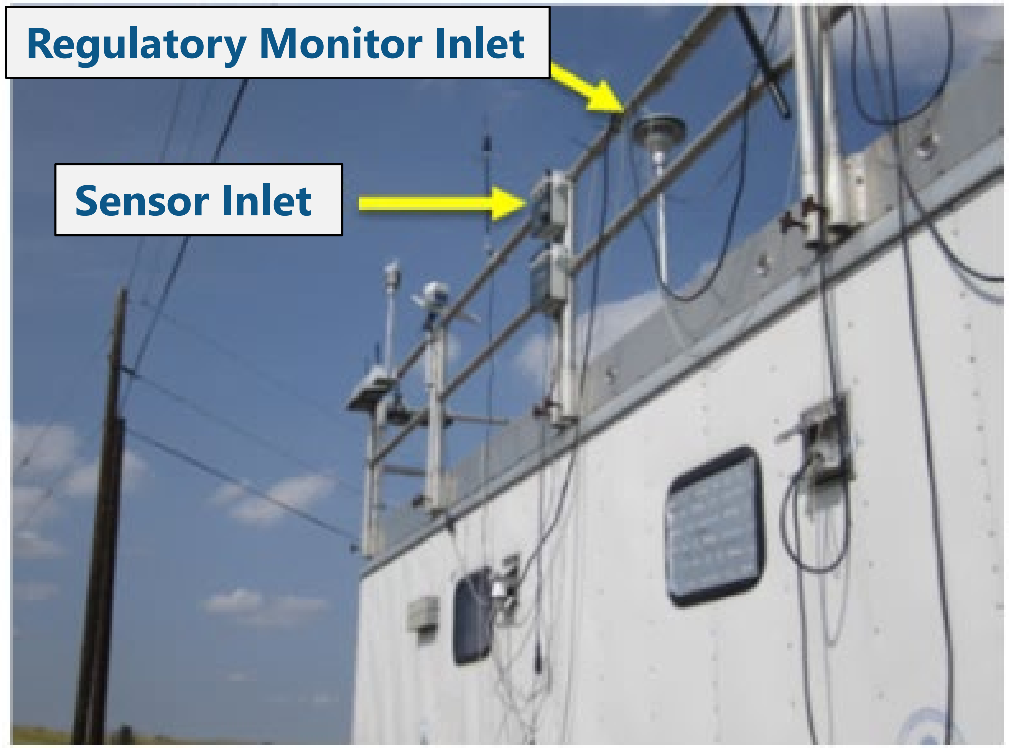
Collocation of a Sensor with a Regulatory Monitor

How are regulatory monitor and air sensor comparisons made?

What Is Sensor Collocation?

Collocation refers to the process of operating a regulatory monitor and non-regulatory monitor (air sensor)

- At the same time
- At the same location
- Under real-world conditions
- For a defined evaluation timeframe



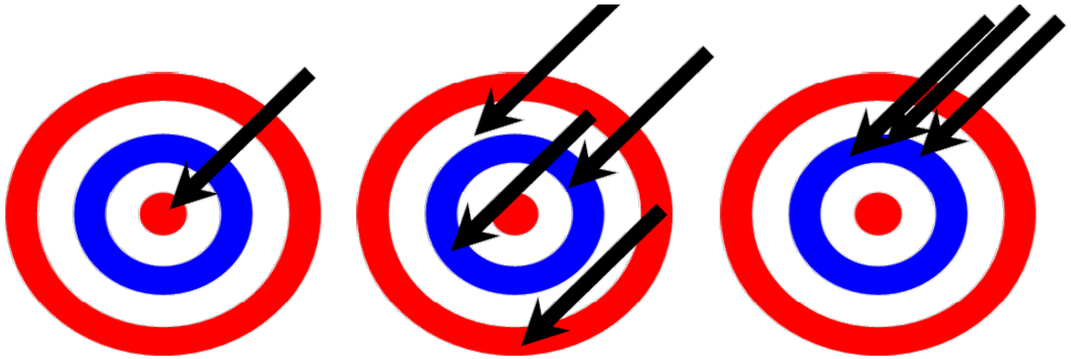
Air sensors located near regulatory monitors in Denver, Colorado

Image credit: U.S. EPA

https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide

Why Collocate?

- Collocating air sensors with regulatory monitors can help users:
  - Evaluate how a sensor performs against regulatory monitors that have known data quality
  - Evaluate important parameters such as **accuracy**, **precision**, and **bias**



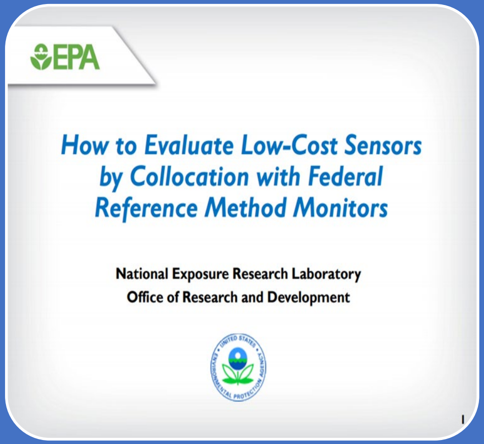
Accuracy: How close to the "true" measurement

Precision: Being able to consistently predict the same measurement

Bias: A systematic (common) error of reporting a measurement higher or lower than the true measurement

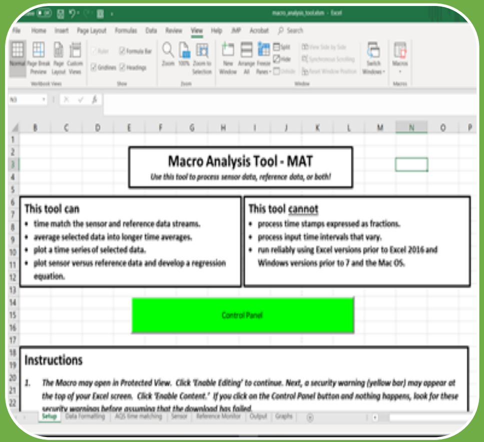
https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide

Further Information and Resources



Air Sensor Collocation Instruction Guide

- Step-by-step guide to collocation process
- https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide



Macro Analysis Tool

- EPA's Excel-based macro analysis tool to help non-experts compare data from air sensors with data from regulatory monitors and interpret their results
- https://www.epa.gov/air-research/instruction-guide-and-macro-analysis-tool-evaluating-low-cost-air-sensors-collocation

Setting up an Air Sensor

What should I keep in mind when deciding where to put a sensor to collect air quality measurements?

Sensor Siting – Basics

- **Sensor siting** refers to how or where a sensor is placed to collect measurements in a given location or setting

- Common ways sensors are sited:

  Stationary: sensors placed at a fixed location or spot that does not move

  Mobile: sensors are moved around

- **Sensor Siting** is important because…
  - It helps provide data that represent the location where measurements are collected
  - Makes sure that the air <u>OR</u> source of interest is measured without being impacted by other factors

https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook

What Factors Can Impact Stationary Measurements?

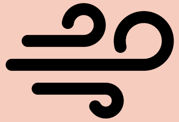
Buildings and other structures can impact air pollution concentrations by causing air pollution to collect in some areas

Surrounding environment can have potential effects when you choose a monitoring location

Emissions from local sources close by may misrepresent or skew the measurements (for example, smoking, barbequing, idling cars)

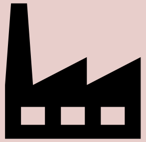
https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook

Things to Keep in Mind When Collecting Stationary Measurements



Allow free air flow to the sensor by making sure it is far enough away from:

- The ground (1-2 meters or 3-7 feet above the surface)
- Building surfaces, if possible (ideally at least 1 meter or about 3 feet away)



Avoid local pollution emission sources if you are trying to measure more general community levels of pollutants

Avoid sources of gases that can react with your pollutant of interest

- For example, ozone is depleted from the air quickly by certain gases, such as those that come from vehicle tailpipes

https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook

Things to Keep in Mind when Collecting Mobile Measurements

Place Sensor Near Breathing Zone

Measure near the breathing zone to better represent inhalation exposures

TIP:
To represent the air you breathe, clip sensor to backpack shoulder straps, a chest strap, or lanyard

CAUTION!
Avoid strangulation risks and keep the sensors from knocking into other objects

Secure Loose Objects

Clothing, hair, and other loose items can interfere with measurements by:

- Blocking the sensor inlets/outlets or,
- Introducing additional PM

TIPS:

- Avoid blocking the sensor inlet
- To avoid fabric debris, wear clothing (such as nylon) that does not shed fibers

How fast you are moving can impact sensor measurements

If one person is riding a bike and one is standing still in the same location, measurement may be different due to the wind blowing past the sensor inlet

TIP:
To compare results between studies involving motion, make sure both activities are done under similar conditions (both are walking or both are on a bike)

Direct sunlight can impact measurements

Protect the sensor from direct sun shining into the sensor inlet as this may impact measurements

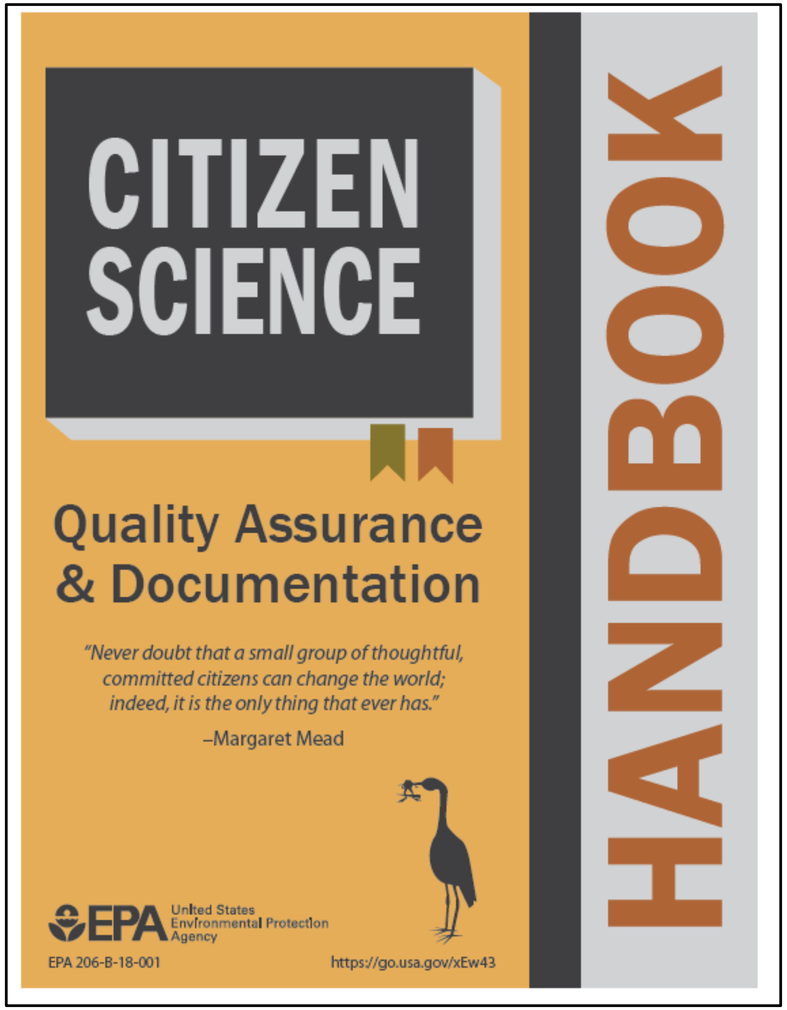
TIP:
Clip the sensor to yourself or another object so that the sensor inlet faces downward rather than upward toward the sky

Photo source: Olivia Ryder, Sonoma Technology (photos 1 and 2); habitatmap.org (photos 3 and 4).

Quality Assurance and Quality Control

What steps should I take to make sure
I am collecting data of good quality?

Citizen Science Handbook (2019)



- ✓ The **Citizen Science Handbook** provides information on collecting and using environmental data for citizen science projects
- ✓ This is a good resource to help you **understand how you can go about making sure the data you collect is of good quality**
- ✓ Having some level of data quality documentation can help you make use of your data

https://www.epa.gov/sites/production/files/2019-03/documents/508_csqapphandbook_3_5_19_mmedits.pdf

What Are Quality Assurance and Quality Control?

Quality Assurance

Planned steps you perform to manage the project and collect, assess, and review data

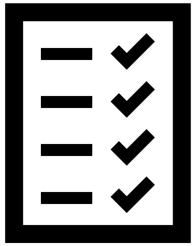
Quality Control

Steps you take to limit error from instruments or in measurements during a project

https://www.epa.gov/sites/production/files/2019-03/documents/508_csqapphandbook_3_5_19_mmedits.pdf

Why Do We Care about Quality Assurance and Quality Control?

Collecting data for a big project is fun and valuable but to make conclusions from data, you need to carefully document these activities.



https://www.epa.gov/sites/production/files/2019-03/documents/508_csqapphandbook_3_5_19_mmedits.pdf

Key Questions to Ensure Quality Assurance

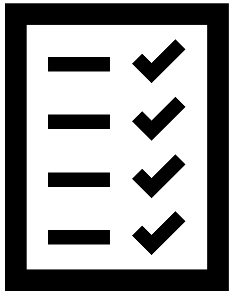
You can address the elements of quality assurance and documentation by answering these key questions:

1	**What is the purpose of the project, and the question you want to answer?**
2	**How and where are you planning to collect samples, data, or other information?**
3	**How are you training the volunteers to collect samples, data or other information?**
4	**How will you control for errors in the field, in the laboratory, or during data analysis?**
5	**How will you check your data and determine if it is useful?**
6	**Where do the data go and who will look at the data?**

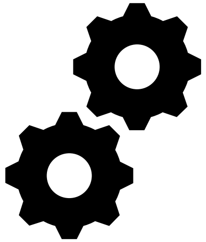
https://www.epa.gov/sites/production/files/2019-03/documents/508_csqapphandbook_3_5_19_mmedits.pdf

Examples of Quality Assurance and Quality Control for Air Sensors

- **Quality Assurance**
  - Planning out what to do to routinely check data
  - Checking and reviewing data periodically
  - Periodically collocating sensors with regulatory monitors
    - Air Sensor Collocation Instruction Guide (https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide)



- **Quality Control**
  - Regular maintenance of sensor device
  - Periodically cleaning sensor device



Data Analysis

How do I analyze my data and interpret my findings?

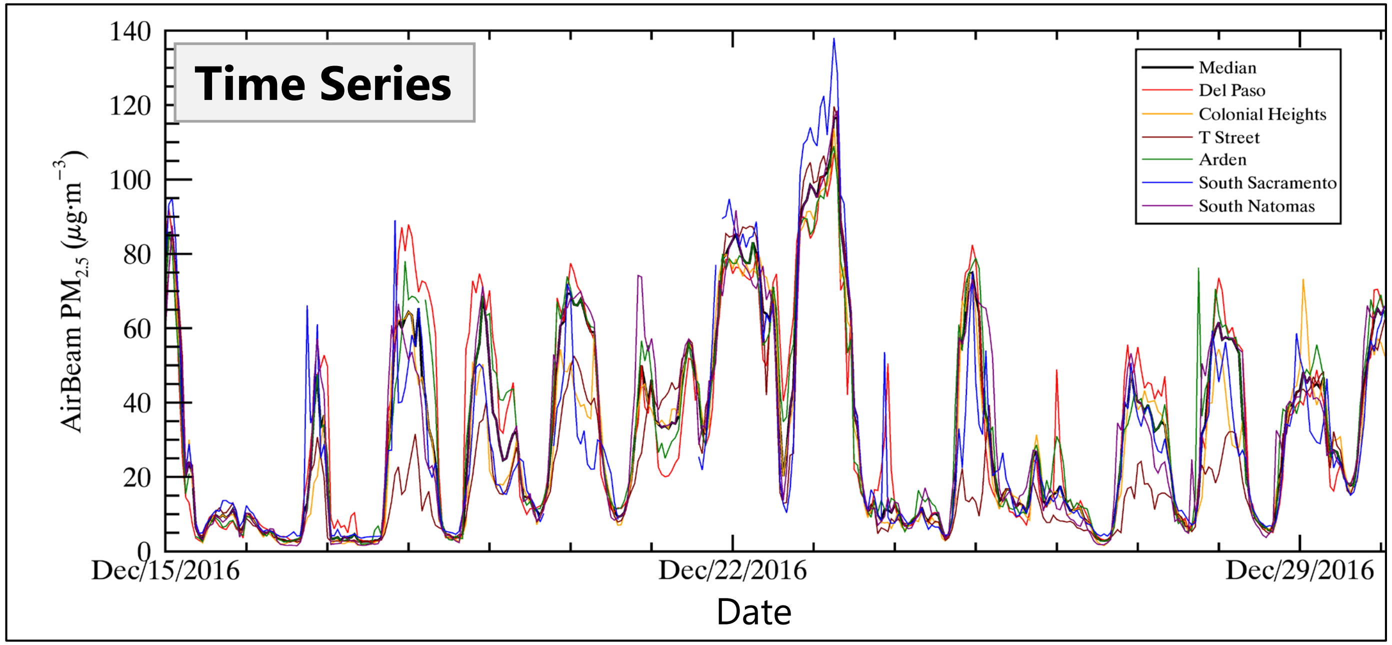
Data Analysis – How to Look at the Data

- Many types of plots can be used to look at your data
- The plots you decide to use will be based on the questions you are trying to answer with your study, for example:
  - Are PM measurements higher near a roadway?
  - Are PM measurements higher in the summer or winter?
  - How does my sensor perform against a regulatory monitor?

- Plots highlighted in the next slides include:
  - **Time series plots**
  - **Scatter plots**

Data Analysis – Time Series Plots

- A common data visualization is a **time series** plot
- **Time series** plots show how measurements change over time



Time series plots can help answer many questions, for example:

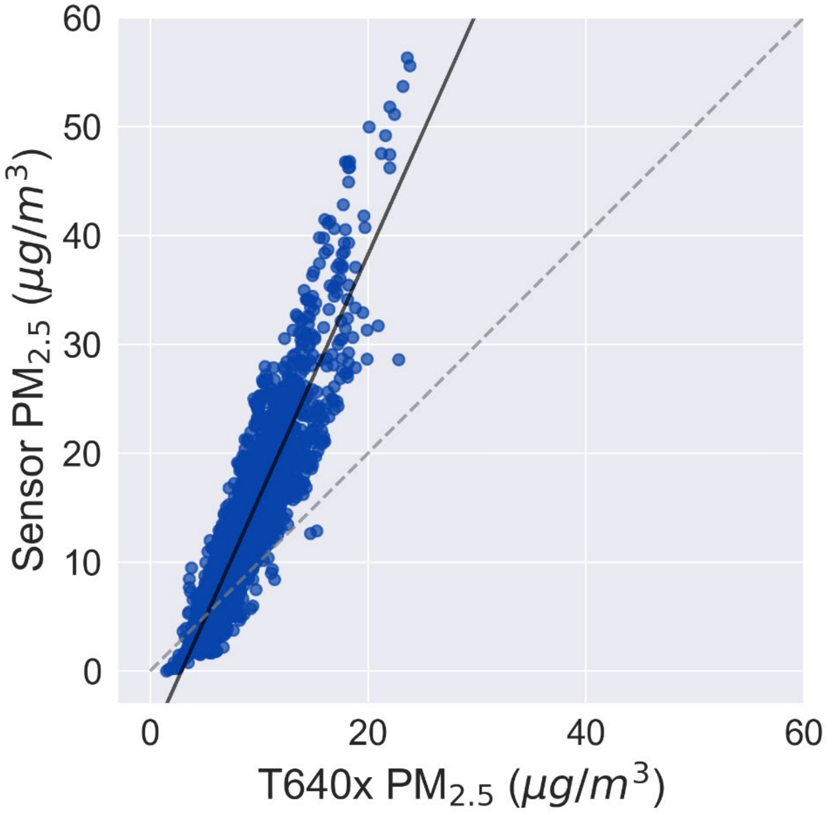
– When are high and low measurements occuring when comparing different sites?

– Are measurements higher during certain times (for example, does $PM_{2.5}$ increase next to the road during rush hour)?

Source: https://www.mdpi.com/1424-8220/19/21/4701/pdf

Data Analysis – Scatter Plots

- A common data visualization is a **scatter plot**
- **Scatter plots** show the relationship between two variables, one on the x-axis and one on the y-axis



Scatter plots can help answer many questions, for example:

- Is there a relationship between two pollutants of interest?
- How does an air sensor compare to a regulatory monitor?

Data Analysis – What Should I Look for in the Data?

It is important to regularly check on data throughout the collection phase.

Review your data regularly to identify any potential problems that may occur (for example, your sensor may get unplugged and stop recording data).

- Are measurement ranges and peak values within typical levels for the site?
- Are there abnormally high or low measurements (**outliers**)?
- Do you see **expected patterns**?
- **Drift or shift**

Bolded terms are explained further in the next slides

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

Outliers

Outliers – data points that look out of place, as in, much lower or higher than nearby data points

	A	B
1	Timestamp	PM 2.5 (ug/m^3)
2	12/7/2016 18:15	33.57
3	12/7/2016 18:20	35.91
4	12/7/2016 18:25	105.69
5	12/7/2016 18:30	110.24
6	12/7/2016 18:35	37.44
7	12/7/2016 18:40	38.16
8	12/7/2016 18:45	38.51
9	12/7/2016 18:50	39.18
10	12/7/2016 18:55	37.32
11	12/7/2016 19:00	38.16
12	12/7/2016 19:05	37.72
13	12/7/2016 19:10	38.14
14	12/7/2016 19:15	0.00
15	12/7/2016 19:20	37.55
16	12/7/2016 19:25	36.57

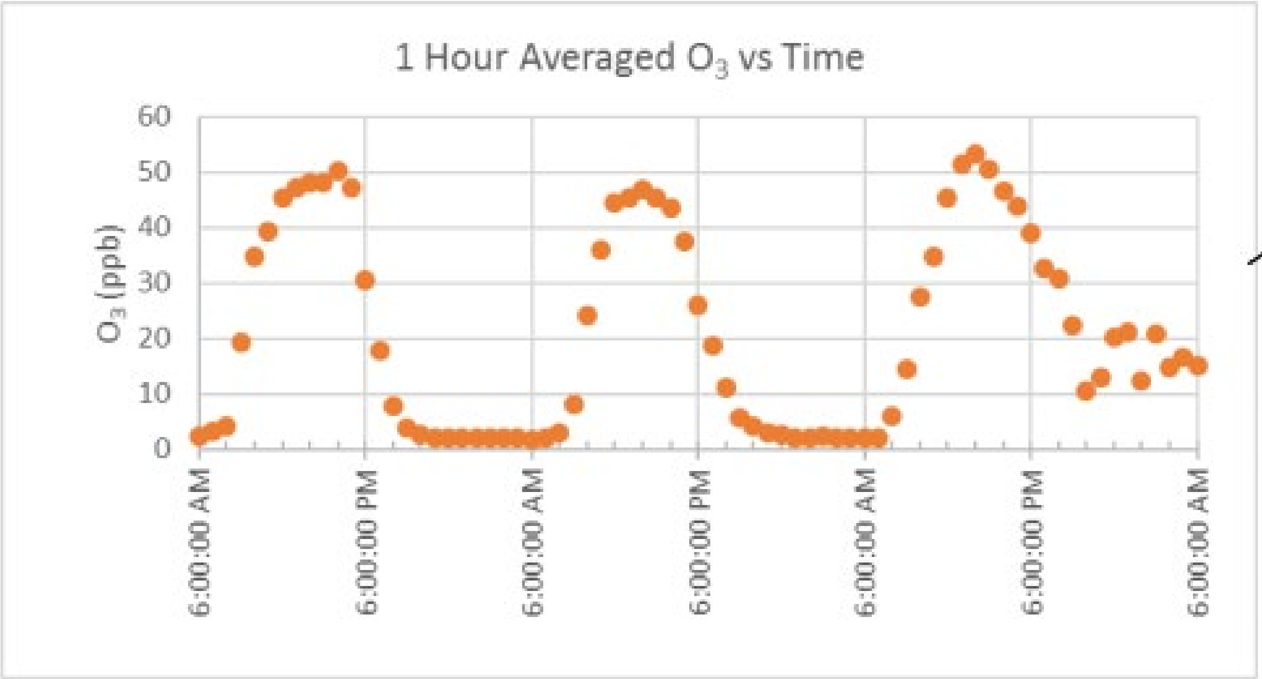
Field notes confirm I was visiting the sensor and left my car idling. That likely explains these high values.

This zero value is unusual. I wonder if this is a problem with the sensor or maybe data communication. I will keep an eye on the data to see if it happens again.

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

Expected Patterns

Expected Patterns – could be seasonal, day/night, or weekday/weekend patterns. Absence of expected patterns may indicate a problem with your sensor or with your measurement approach.

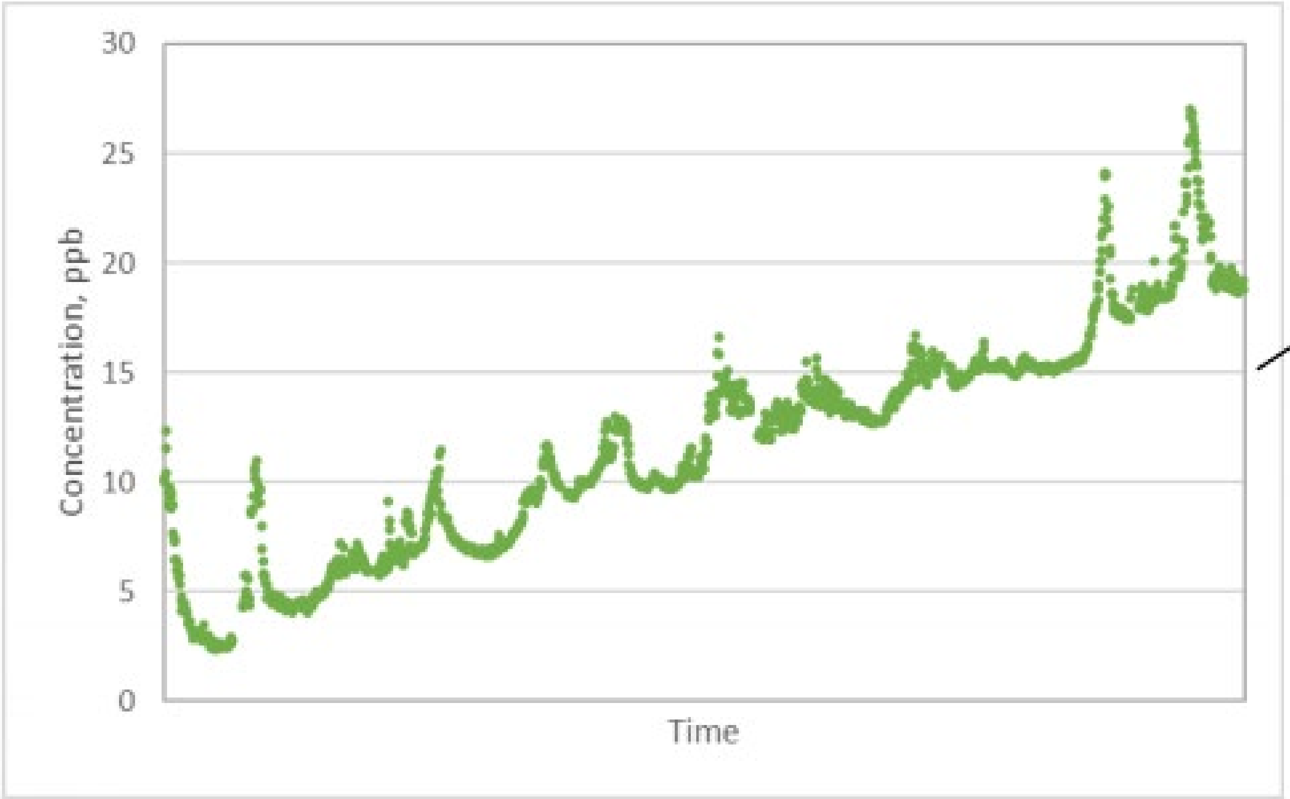


Ozone measurements peak in late afternoon

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

Drift or Shift

Drift or Shift – a gradual (**drift**) or sudden (**shift**) change in a sensor's response characteristics over time – can be positive or negative – may lead you to wrongly conclude that **measurements** have increased or decreased over time.



Measurements reported by the sensor are increasing gradually over time. It looks like the sensor's response is drifting.

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

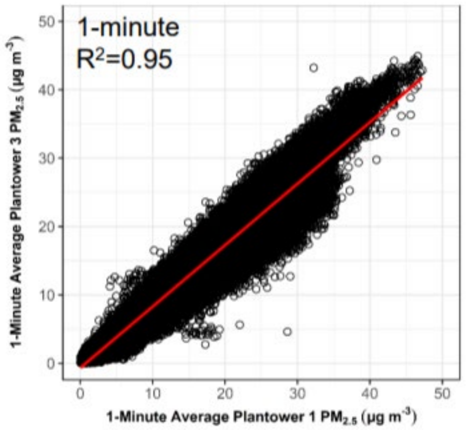
Data Analysis – Data Averaging

Importance of data averaging

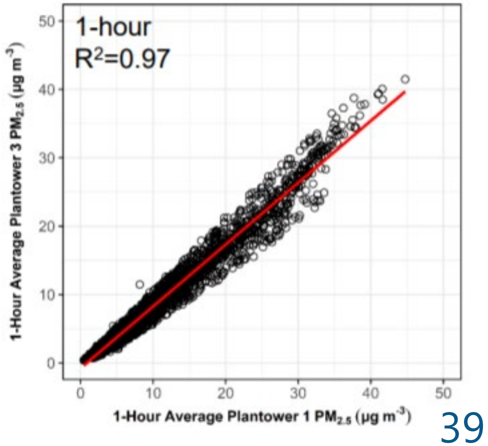
- Data are often averaged, or aggregated, to make it easier to compare to measurements from another instrument, health-based benchmarks (for example, AQI), or environmental standards (like the NAAQS).
- Data averaging helps improve the quality, usefulness, and manageability of your data.

Averaging times vary by application

- To examine pollutant measurements trends, 1-hour or 24-hour averages are useful.
- A shorter averaging period (a few minutes) may be needed to connect spikes in measurements with sources that may be causing them (for example, indoor PM spikes observed while cooking could relate to specific activities like frying food).



This is the same data shown at different averaging intervals.

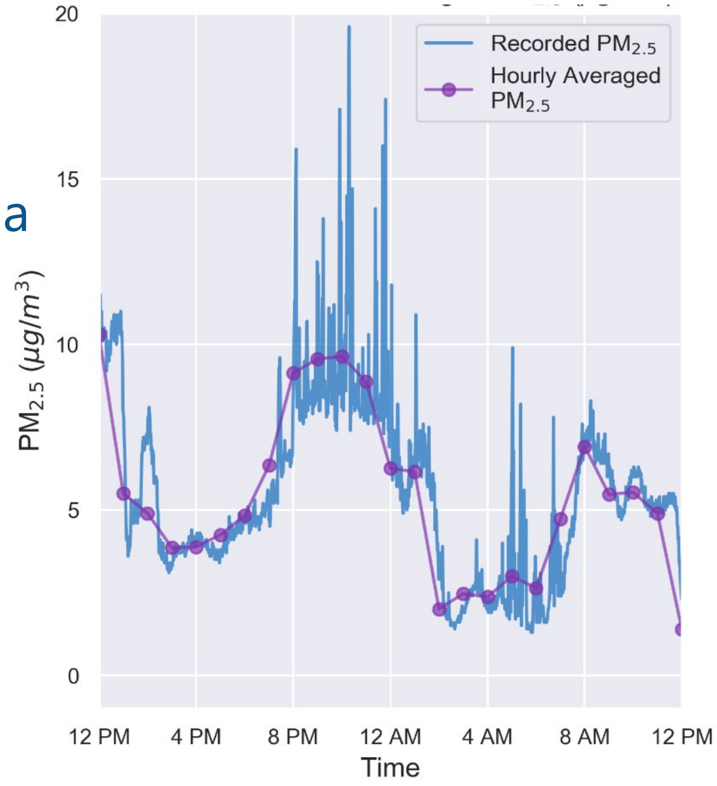


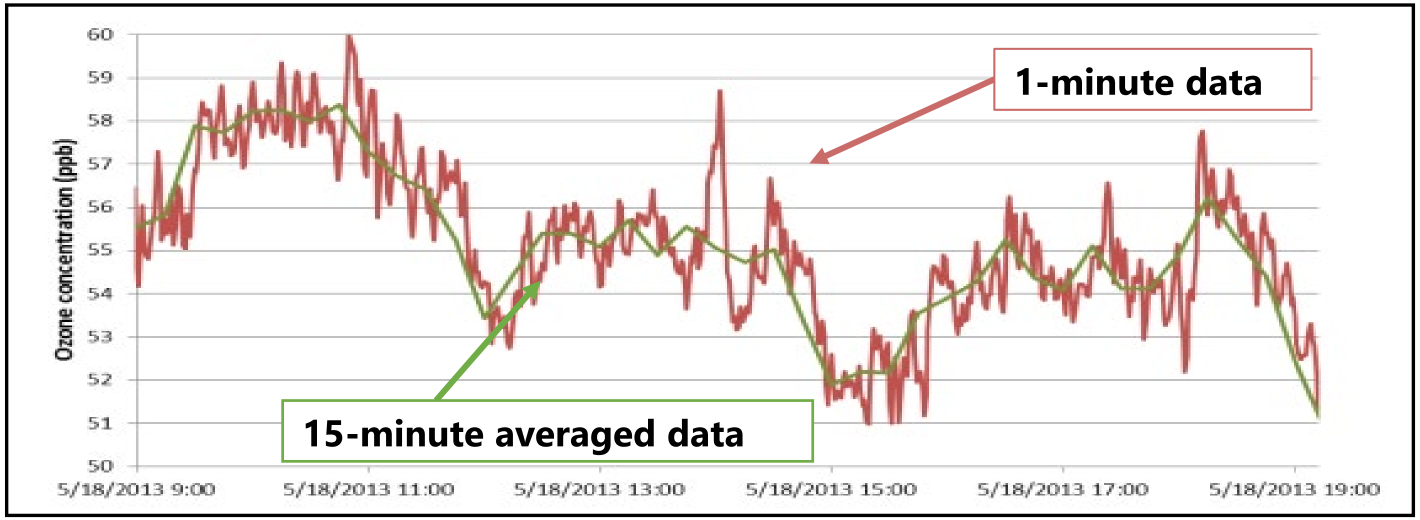
Source: U.S. EPA Air Sensor Guidebook

Data Analysis – Why Average Data?

Data averaging can help interpret sensor data

- High time resolution data (for example, 1-minute data) can be noisy and highly variable. Sometimes this variation can be real (for example, a smoker walks by) or can just be electronic signal noise.
- Averaging data to longer time averages (for example, 1-hour) can smooth out short term events and reduce the noise. The reduced variability may better represent the trends within the data.

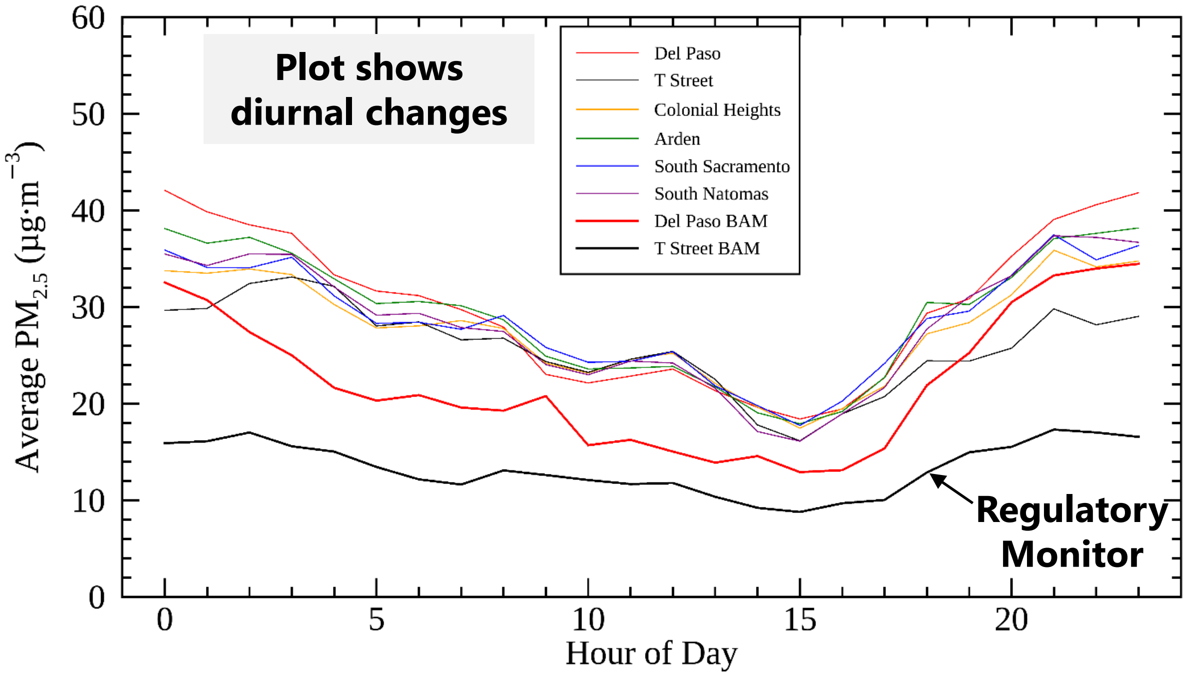




Source: U.S. EPA Air Sensor Guidebook

Data Analysis – Temporal Variability

- **Temporal Variability** = changes over time - for example, diurnal (during the day), weekly, monthly, annually, or seasonal
  - Averaged hourly measurements may smooth spikey data and make it easier to examine how pollution varies over a day (see plot)
  - If a study is long enough, 1-hour or 24-hour data can be used to explore day-of-week, monthly, and seasonal variations



Temporal variability plots can help answer many questions, for example:

- How do measurements change, on average, over a day/week/month?
- Are there patterns to measurements changes (for example, are $PM_{2.5}$ measurements higher at different times of day, such as during morning rush hour)?

Source: https://www.mdpi.com/1424-8220/19/21/4701/pdf

Data Analysis – Why Average Data?

Data averaging allows you to compare sensor data to the Air Quality Index (AQI)

- **AQI** tells you how clean or polluted the outdoor air is and what health effects may be of concern
- **AQI** values are calculated using the averaging times listed in the National Ambient Air Quality Standards **(NAAQS)**
  - $PM_{2.5}$: 24-hour averaging time
  - Ozone: 8-hour averaging time

AQI Chart:

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Hourly ozone values (in ppb) from a sensor

Hour	Ozone
0:00	38.33
1:00	36.75
2:00	41.83
3:00	40.67
4:00	38.08
5:00	35.92
6:00	33.33
7:00	35.75
8:00	38.08
9:00	48.00
10:00	53.63
11:00	50.25
12:00	60.75
13:00	58.00
14:00	65.25
15:00	71.63
16:00	35.83
17:00	35.63
18:00	41.00
19:00	44.67
20:00	40.57
21:00	37.40
22:00	35.75
23:00	38.40

Data averaged to 8-hours as per NAAQS

Hour	Ozone	AQI
0:00	37.58	34
8:00	55.70	51
16:00	38.66	42

AQI estimated using the AQI calculator:
https://www.airnow.gov/aqi/aqi-calculator/

Flagging Data

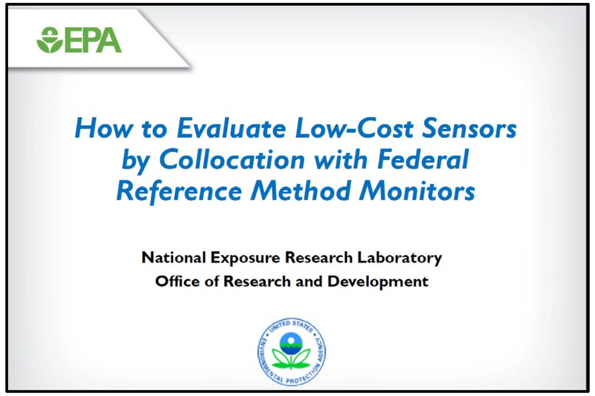
- Regulatory monitoring requires that data **qualifiers**, or notes about the data, be added to data sets to explain **missing data**, **null data**, and **invalid data**.
- This approach is **ALSO** useful for sensor data.
- Common qualifiers include
  - Quality assurance issues – “exceeds upper range”
  - Null data – “machine malfunction”, “voided by operator”, “power failure”
  - Informational – “fireworks”, “high winds”, “traffic disruption”

Data Flags	Definition
A	Fog conditions
B	Exceeds upper concentration range
C	Power outage

Date and Time	$PM_{2.5}$ (µg/m³)	Data Flag
7/7/18 5:27 AM	18	
7/7/18 5:28 AM	26	
7/7/18 5:29 AM	69	
7/7/18 5:30 AM	23	
7/7/18 5:31 AM	45	
7/7/18 5:32 AM	17	
7/7/18 5:33 AM	57	
7/7/18 5:34 AM	229	A, B
7/7/18 5:35 AM	230	A, B
7/7/18 5:36 AM	222	A, B
7/7/18 5:37 AM		C
7/7/18 5:38 AM		C
7/7/18 5:39 AM		C
7/7/18 5:40 AM		C

https://aqs.epa.gov/aqsweb/documents/codetables/qualifiers.html

Further Information


EPA

How to Evaluate Low-Cost Sensors by Collocation with Federal Reference Method Monitors

National Exposure Research Laboratory
Office of Research and Development

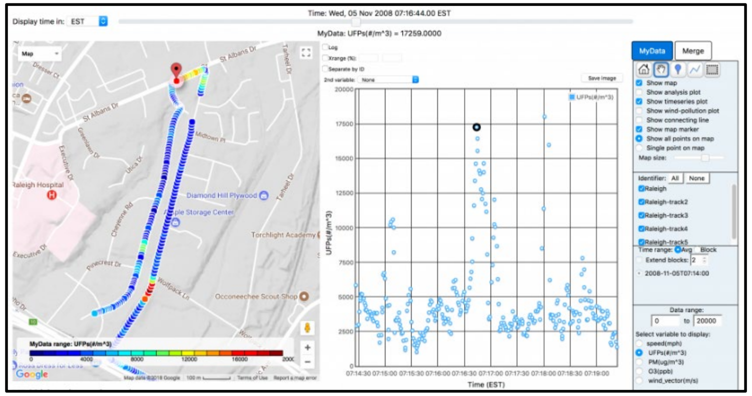
EPA's Collocation Instruction Guide – Topics:

- Background on regulatory monitors and air sensors
- What is collocation and its purpose?
- Steps involved in collocation:
  1) Planning a sensor evaluation – *what sensors to evaluate, supplies needed, etc.*
  2) Making measurements – *setting up sensors, how long to collect data, etc.*
  3) Data recovery and review – *importance of reviewing data, things to look for, etc.*
  4) Data comparison – *compare data to regulatory monitor, Macro Analysis Tool, etc.*
  5) Using Sensors – *collect measurements, adjust sensor data, etc.*
- Additional data quality information
  - Data quality parameters (accuracy, bias, precision) and how to calculate them

https://www.epa.gov/sites/production/files/2018-01/documents/collocation_instruction_guide.pdf

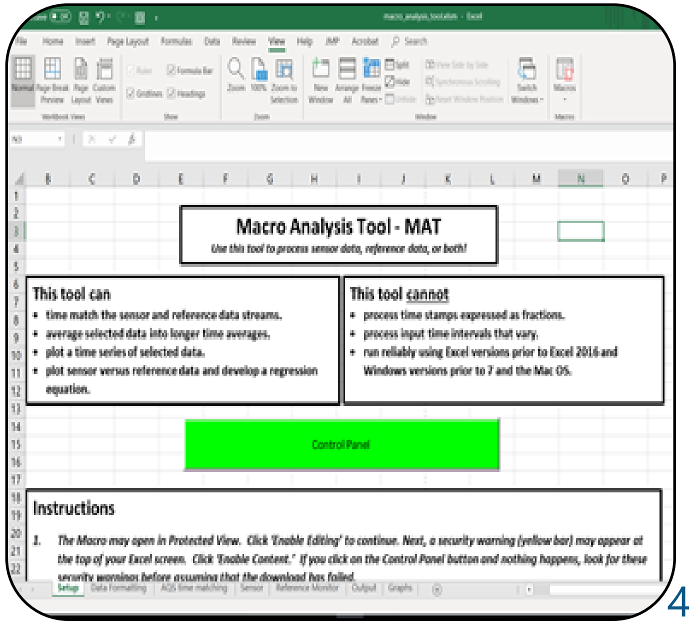
Data Analysis Tools

EPA's RETIGO (Real Time Geospatial Data Viewer)



- Free, web-based tool available at: https://www.epa.gov/hesc/real-time-geospatial-data-viewer-retigo
- Can handle large data sets (stationary and mobile measurements)
- Provides tutorials and data set examples

EPA's Macro Analysis Tool (MAT)

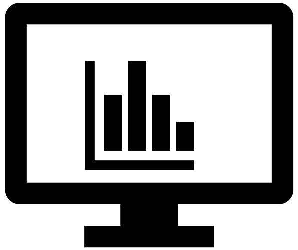


- Free, excel-based tool to help compare data from air sensors with data from regulatory monitors AND help interpret results
- Available at: https://www.epa.gov/air-research/instruction-guide-and-macro-analysis-tool-evaluating-low-cost-air-sensors-collocation

Data Analysis Tools (Continued)

- **Microsoft Excel (or similar spreadsheet programs)**
  - Can handle large data sets
  - Has statistical computing and graphing capabilities
- **R Software** programming language – R, R-Shiny
  - Free software for statistical computing and graphing
  - Can handle very large data sets
  - Code packages available for air quality data (for example, OpenAir, AirSensor)
- **Manufacturer** developed tools
  - Manufacturers may have tools associated with their sensor to analyze data
  - May have a cost to use (for example, monthly or annual fee)
  - Capable of handling large data sets
- **Local Air Quality Agency** developed tools
  - Air agencies in California and elsewhere are working on data platforms for sensors
  - Check local air quality agency website for availability

There are many other tools to analyze data!



Additional Resources

EPA Air Sensor Toolbox Webpage

https://www.epa.gov/air-sensor-toolbox

Sensor Performance, Evaluation and Use

- Sensor Evaluation Results
- Standard Operating Procedures for Sensors
- Sensor Collocation Guide
- Sensor Performance Targets and Test Protocols
- Air Sensor Guidebook
- Quality Assurance Handbook and Guidance Documents for Citizen Science Projects

Understanding Your Sensor Data Readings

- Videos on Air Sensor Measurement, Data Quality and Interpretation
- RETIGO: Visualize Your Field Data
- Sensor Collocation Macro Analysis Tool
- Air Quality Exchange: Delivering High Value Air Quality Information to the Public

Research Projects

- Overview of Current Research
- Collaborative Agreements
- Grants
- Reports and Publications
- Past Projects

Additional Resources

- Frequently Asked Questions
- Air Sensor Loan Programs
- Newsletter Articles and Fact Sheets
- Educational Resources
- Conferences, Workshops, and Webinars
- Sensor Evaluations by Other Organizations

- The Air Sensor Toolbox webpage provides a wealth of resources on air sensors
- The Air Sensor Guidebook is one of the most popular resources in the Toolbox