# **₽EPA**

# Highlights on U.S. EPA Efforts on Developing Performance Testing Protocols and Targets for Air Sensors

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# Outline

- Issue/motivation
- Recap of published reports for fine particulate matter (PM<sub>2.5</sub>) and ozone (O<sub>3</sub>)
- Additional pollutants including PM<sub>10</sub>, nitrogen dioxide (NO<sub>2</sub>), carbon monoxide (CO), and sulfur dioxide (SO<sub>2</sub>)
  - Literature reviews and workshop outcomes
  - Approach
- Anticipated outcomes and timeline
- Additional resources

 $PM_{2.5}$  = inhalable particles with diameters that are generally less than 2.5 micrometers  $PM_{10}$  = inhalable particles with diameters that are generally less than 10 micrometers



# **Issue/Motivation**

- Air sensor data quality continues to be highly variable, making it difficult to understand sensor performance
- A consistent approach for evaluating sensor performance is needed
  - Helps provide confidence in sensor data quality
  - Helps users select appropriate sensors for their application of interest
  - Encourages technology improvements and development in the marketplace

#### • U.S. EPA, AQ-SPEC, AIRLAB, and others conduct routine sensor evaluations

- Locations are not widespread
- Environmental conditions are limited
- Results may not translate for other locations/conditions

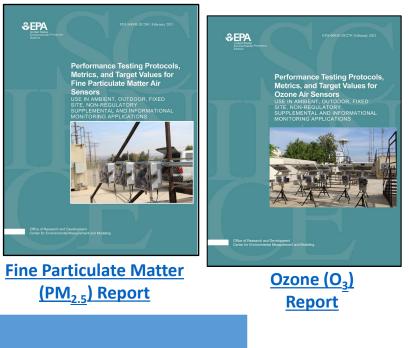
Sensor Evaluation Results:

U.S. EPA: www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance AQ-SPEC: www.aqmd.gov/aq-spec/evaluations AIRLAB: https://airlab.solutions/en/projets/challenge-microcapteurs-edition-2021-90



## Recap of Published Reports for PM<sub>2.5</sub> and O<sub>3</sub> Air Sensors

- U.S. EPA published two reports in 2021 outlining recommended testing protocols, metrics, and target values to evaluate the performance of PM<sub>2.5</sub> and O<sub>3</sub> sensors
- Testing protocols are specifically for:
  - Ambient, outdoor, fixed site environments
  - Non-regulatory supplemental and informational monitoring (NSIM) applications



NSIM Category	Definition	Examples
Spatiotemporal Variability	Characterizing a pollutant concentration over a geographic area/and or timeDaily trends, gradient studies, air qu forecasting, citizen science, education	
Comparison	Analysis of differences and/or similarities in air pollution characteristics against a threshold value or between different networks, locations, regions, time periods, etc.	Supplemental monitoring, hotspot detection, data fusion, emergency response
Long-term Trend	Change in a pollutant concentration over a period of typically years	Long-term changes, epidemiological studies, model verification

#### **Recap of Published Reports for PM<sub>2.5</sub> and O<sub>3</sub> Air Sensors** *Recommended Testing Protocols*

**Base Testing** – evaluate 3 or more identical sensors in the field for at least 30 consecutive days (*recommended test at minimum*)

**Enhanced Testing** – evaluate 3 or more identical sensors in a controlled laboratory exposure chamber under differing pollutant concentrations, temperature (T), and relative humidity (RH) levels (*test is encouraged but calls for laboratory chamber*)

Criteria	0 <sub>3</sub>	PM <sub>2.5</sub>	
Test Sites	2 deployments at 1 site <u>OR</u> 2 different sites	2 deployments at 2 different sites	
Season and Pollutant Level	1 deployment during O <sub>3</sub> season (goal 1-day, 1-hour average O <sub>3</sub> level of ≥ 60 ppbv) <u>AND</u> 1 deployment anytime	2 different climate regions for each site (goal 1-day, 24-hour average $PM_{2.5}$ level of $\ge 25 \ \mu g/m^3$ )	
Performance Metric	<b>O</b> <sub>3</sub>	PM <sub>2.5</sub>	
Effect of Interferents	Carbon monoxide (CO): 35 ppmv $\pm$ 5% Nitrogen dioxide (NO <sub>2</sub> ): 100 ppbv $\pm$ 5% Sulfur dioxide (SO <sub>2</sub> ): 75 ppbv $\pm$ 5%	Not included in testing	
Effect of RH	40% RH vs. 85% RH	40% RH vs. 85% RH	
Effect of T	20°C vs. 40°C	20°C vs. 40°C	
Drift (at Day 1 vs Day 60)	Low concentration: 15 ppbv $O_3 \pm 10\%$ Mid concentration: 70 ppbv $O_3 \pm 5\%$	Low concentration: 10 $\mu g/m^3$ $PM_{2.5}\pm 10\%$ Mid concentration: 35 $\mu g/m^3$ $PM_{2.5}\pm 5\%$	
Accuracy at High Concentration	High concentration: 125 ppbv O <sub>3</sub> ± 10%	High concentration: 150 $\mu$ g/m <sup>3</sup> PM <sub>2.5</sub> ± 10% Higher concentration: 250 $\mu$ g/m <sup>3</sup> PM <sub>2.5</sub> ± 10%	

#### **Recap of Published Reports for PM<sub>2.5</sub> and O<sub>3</sub> Air Sensors** *Metrics and Target Values*

Target values only recommended for base testing (*field deployment*)

Performance Metric		O <sub>3</sub> Target Value	PM <sub>2.5</sub> Target Value
Precision	Standard Deviation (SD)	≤ 5 ppbv	≤ 5 μg/m³
	<u>OR</u>		
	Coefficient of Variation (CV)	≤ 30%	≤ 30%
Bias	Slope	$\textbf{1.0}\pm\textbf{0.2}$	$1.0\pm0.35$
	Intercept (b)	-5 ≤ b ≤ 5 ppbv	-5 ≤ b ≤ 5 μg/m³
Linearity	Coefficient of Determination (R <sup>2</sup> )	≥ 0.80	≥ 0.70
Error	Root Mean Square Error (RMSE)	≤ 5 ppbv	RMSE ≤ 7 µg/m <sup>3</sup> <u>or</u> NRMSE ≤ 30%

- Exploratory graphs also recommended to understand potential impacts of meteorological parameters (T, RH, dew point)
- No target values recommended for enhanced testing protocols recommend that testers report results

#### Additional Pollutants – PM<sub>10</sub>, NO<sub>2</sub>, CO and SO<sub>2</sub> Literature Reviews and Workshop

- Reviewed published, peer-reviewed literature, focusing on:
  - Performance attributes to characterize instruments used to monitor air pollutants
  - Quantitative performance metrics that describe performance attributes
  - Field and laboratory sensor performance evaluations



	Contents lists available at ScienceDirect	AT AT
	Atmospheric Environment	Đ
ELSEVIER	journal homepage: http://www.elsevier.com/locate/atmosenv	
Deliberating	Performance Targets: Follow-on workshop discussing PM <sub>10</sub> ,	Chec
0	d SO <sub>2</sub> air sensor targets	
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- <u>Second Workshop on Deliberating Performance Targets for Air</u> <u>Quality Sensors</u>
  - Gathered perspectives from different stakeholders on nonregulatory performance targets for sensors measuring PM<sub>10</sub> NO<sub>2</sub>, CO, and SO<sub>2</sub>
  - Discussed technical issues associated with establishing targets for these sensors

#### Additional Pollutants – PM<sub>10</sub>, NO<sub>2</sub>, CO, and SO<sub>2</sub> Workshop Outcomes

- Different use cases of interest many involve monitoring near a source
  - **PM<sub>10</sub>**: Dust sources (storms, construction, agriculture), fire plumes
  - NO<sub>2</sub>: Near roads, fenceline monitoring, mobile monitoring
  - CO: Combustion sources (roadways, industrial facilities), occupational, indoors
  - SO<sub>2</sub>: Industrial sources (coal-fired power plants, refineries, smelters), combustion sources, volcanoes
- Testing considerations will vary for each pollutant

Pollutant	Testing Consideration Examples	
PM <sub>10</sub>	<ul> <li>Most currently available devices do not actually measure PM<sub>10</sub></li> <li>In ambient setting, need for testing under conditions where PM<sub>2.5</sub> and PM<sub>2.5</sub>/PM<sub>10</sub> ratio vary</li> <li>In laboratory setting, difficult to generate PM<sub>10</sub> particles</li> </ul>	
NO <sub>2</sub>	<ul> <li>Sensor performance is highly variable and stability of sensors over time is uncertain</li> <li>Subject to interferences</li> </ul>	
CO and SO <sub>2</sub>	<ul> <li>Ambient levels very low across the U.S.</li> <li>Not all regulatory monitors can detect low concentrations</li> </ul>	

#### Additional Pollutants – PM<sub>10</sub>, NO<sub>2</sub>, CO and SO<sub>2</sub> Approach

- Developing supplemental reports to the previously released reports
  - Supplement Report #1: Focused on PM<sub>10</sub> sensors complement to the PM<sub>2.5</sub> report
  - Supplement Report #2: Focused on NO<sub>2</sub>, CO, and SO<sub>2</sub> sensors complement to the O<sub>3</sub> report
  - Testers will be encouraged to follow the testing recommendations in the original reports with different test conditions, relevant pollutant concentrations, and/or data analysis

#### • Base Testing (Field Testing)

- Providing more specific details on where testing should occur and additional data analysis
- Focusing on testing locations with concentrations above ambient levels and higher concentration environments
- Exploring  $PM_{10}$  data as a function of the  $PM_{2.5}/PM_{10}$  ratio

#### • Enhanced Testing (Laboratory Testing)

 Test concentrations and interferents will be pollutant specific and depend on potential use case (where applicable)

Application focus is the same – ambient, outdoor, fixed site environments; NSIM applications

#### Additional Pollutants – PM<sub>10</sub>, NO<sub>2</sub>, CO, and SO<sub>2</sub> Approach Continued

- Providing more guidance on how to appropriately test sensor technologies
- Including more education and information such as
  - Appropriate measuring locations
  - Expected target pollutant concentration ranges in ambient, outdoor environments
  - Considerations for pollutant-specific applications (e.g., expected co-pollutants, known interferences)
- Performance metrics will remain the same
  - Base Testing (Field): precision, bias, linearity, and error
  - Enhanced Testing (Laboratory): Effect of temperature and humidity, drift, and accuracy
- Performance target values will be recommended as feasible and will be supported by current state of the science

## **Anticipated Outcomes and Timeline**

- Provide a consistent approach for evaluating PM<sub>10</sub>, NO<sub>2</sub>, CO, and SO<sub>2</sub> sensors
- Recommend target values that can help encourage innovation and product improvements
- Promote education on important considerations for testing sensors measuring PM<sub>10</sub>, NO<sub>2</sub>, CO, and SO<sub>2</sub>
- Help consumers make informed decisions on choosing appropriate sensors for their application of interest
- Timeline: Anticipate supplemental reports will be released in late 2022 (*posting to Air Sensor Toolbox Website*)

Similar to the  $PM_{2.5}$  and  $O_3$  reports, conducting the testing protocols for  $PM_{10}$ ,  $NO_2$ , CO, and  $SO_2$  sensors <u>does not</u> constitute certification or endorsement by the U.S. EPA.



### **Additional Resources**

- EPA Air Sensor Toolbox (<u>https://www.epa.gov/air-sensor-toolbox</u>)
  - Provides the latest science on the performance, operation, and use of air sensor monitoring systems for technology developers, air quality managers, citizen scientists and the public
- Sensor Targets and Testing Protocols (<u>https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols</u>)
  - More information about EPA's sensor targets and testing protocols, including the reports and accompanying reporting templates, presentations, and FAQs
  - Includes the newly released **Sensortoolkit\*** which is a Python code library for evaluating the performance of sensors using the targets reports
- EPA Air Sensor Evaluation Results (<u>https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance</u>)
  - Performance evaluations of sensors
  - Evaluations to be summarized using templates from the targets and testing protocols reports (*coming soon*)

\*Check out the ASIC poster titled "sensortoolkit: A Python library for standardizing the ingestion, analysis, and reporting of air sensor data for performance evaluations" for more information.





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### **Thank You for Listening!**

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