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 ($PM_{2.5}$) and ozone (O_3)
- Additional pollutants including PM_{10}, nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2)
  - 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

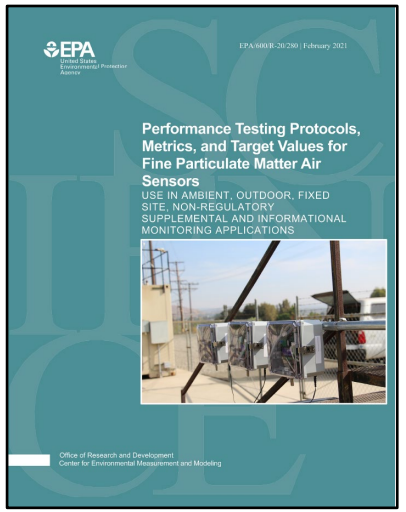
Issue/Motivation

- **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

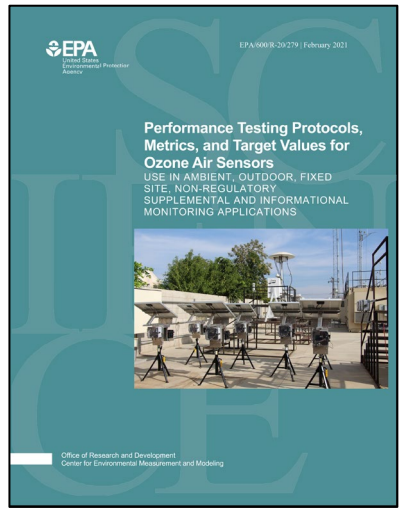
Sensor Evaluation Results:
U.S. EPA: www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance
AQ-SPEC: www.aqmd.gov/aq-spec/evaluations
AIRLAB: https://airlab.solutions/en/projets/challenge-microcapteurs-edition-2021-90

Recap of Published Reports for $PM_{2.5}$ and O_3 Air Sensors

- U.S. EPA published two reports in 2021 outlining **recommended testing protocols**, **metrics**, and **target values** to evaluate the performance of $PM_{2.5}$ and O_3 sensors
- Testing protocols are specifically for:
  - Ambient, outdoor, fixed site environments
  - Non-regulatory supplemental and informational monitoring (**NSIM**) applications



Fine Particulate Matter ($PM_{2.5}$) Report



Ozone (O_3) Report

NSIM Category	Definition	Examples
Spatiotemporal Variability	Characterizing a pollutant concentration over a geographic area/and or time	Daily trends, gradient studies, air quality 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 $PM_{2.5}$ and O_3 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	O_3	$PM_{2.5}$
Test Sites	2 deployments at 1 site **OR** 2 different sites	2 deployments at 2 different sites
Season and Pollutant Level	1 deployment during O_3 season (goal 1-day, 1-hour average O_3 level of ≥ 60 ppbv) **AND** 1 deployment anytime	2 different climate regions for each site (goal 1-day, 24-hour average $PM_{2.5}$ level of ≥ 25 µg/m³)

Performance Metric	O_3	$PM_{2.5}$
Effect of Interferents	Carbon monoxide (CO): 35 ppmv ± 5% Nitrogen dioxide (NO_2): 100 ppbv ± 5% Sulfur dioxide (SO_2): 75 ppbv ± 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 ± 10% Mid concentration: 70 ppbv O_3 ± 5%	Low concentration: 10 µg/m³ $PM_{2.5}$ ± 10% Mid concentration: 35 µg/m³ $PM_{2.5}$ ± 5%
Accuracy at High Concentration	High concentration: 125 ppbv O_3 ± 10%	High concentration: 150 µg/m³ $PM_{2.5}$ ± 10% Higher concentration: 250 µg/m³ $PM_{2.5}$ ± 10%

Recap of Published Reports for $PM_{2.5}$ and O_3 Air Sensors
Metrics and Target Values

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

Performance Metric		O_3 Target Value	$PM_{2.5}$ Target Value
Precision	Standard Deviation (SD) **OR** Coefficient of Variation (CV)	≤ 5 ppbv ≤ 30%	≤ 5 μg/m^3 ≤ 30%
Bias	Slope	1.0 ± 0.2	1.0 ± 0.35
	Intercept (b)	-5 ≤ b ≤ 5 ppbv	-5 ≤ b ≤ 5 μg/m^3
Linearity	Coefficient of Determination (R^2)	≥ 0.80	≥ 0.70
Error	Root Mean Square Error (RMSE)	≤ 5 ppbv	RMSE ≤ 7 μg/m^3 **or** NRMSE ≤ 30%

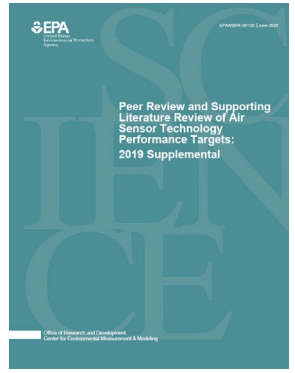
- Exploratory graphs also recommended to understand potential impacts of meteorological parameters (T, RH, dew point)
- **No target values recommended for enhanced testing protocols** – recommend that testers report results

Additional Pollutants – PM_{10}, NO_2, CO and SO_2

Literature Reviews and Workshop

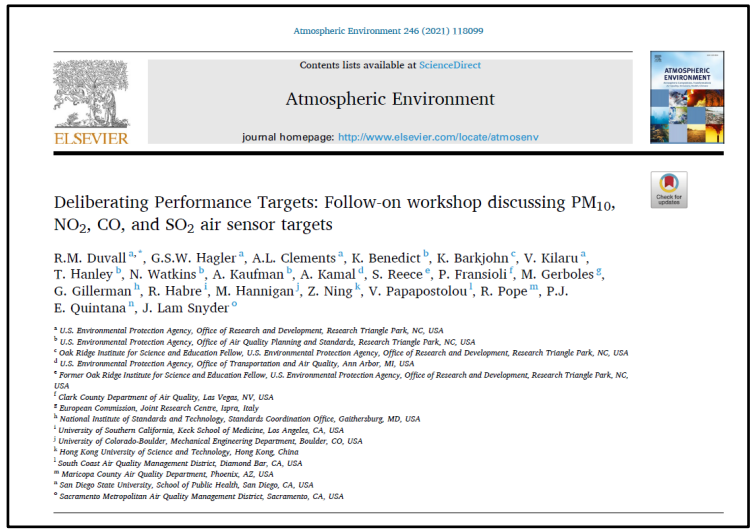
- **Reviewed published, peer-reviewed literature, focusing on:**
  - Performance attributes to characterize instruments used to monitor air pollutants
  - Quantitative performance metrics that describe performance attributes
  - Field and laboratory sensor performance evaluations

First Peer Review



Second Peer Review

- Second Workshop on Deliberating Performance Targets for Air Quality Sensors
  - Gathered perspectives from different stakeholders on non-regulatory performance targets for sensors measuring PM_{10}, NO_2, CO, and SO_2
  - Discussed technical issues associated with establishing targets for these sensors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Deliberating Performance Targets: Follow-on workshop discussing PM_{10}, NO_2, CO, and SO_2 air sensor targets

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Additional Pollutants – PM_{10}, NO_2, CO, and SO_2
Workshop Outcomes

- Different use cases of interest – many involve monitoring near a source
  - **PM_{10}**: Dust sources (storms, construction, agriculture), fire plumes
  - **NO_2**: Near roads, fenceline monitoring, mobile monitoring
  - **CO**: Combustion sources (roadways, industrial facilities), occupational, indoors
  - **SO_2**: Industrial sources (coal-fired power plants, refineries, smelters), combustion sources, volcanoes
- Testing considerations will vary for each pollutant

Pollutant	Testing Consideration Examples
PM_{10}	• Most currently available devices do not actually measure PM_{10} • In ambient setting, need for testing under conditions where $PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratio vary • In laboratory setting, difficult to generate PM_{10} particles
NO_2	• Sensor performance is highly variable and stability of sensors over time is uncertain • Subject to interferences
CO and SO_2	• Ambient levels very low across the U.S. • Not all regulatory monitors can detect low concentrations

Additional Pollutants – PM_{10}, NO_2, CO and SO_2
Approach

- **Developing supplemental reports to the previously released reports**
  - Supplement Report #1: Focused on PM_{10} sensors – complement to the $PM_{2.5}$ report
  - Supplement Report #2: Focused on NO_2, CO, and SO_2 sensors – complement to the O_3 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_{10}, NO_2, CO, and SO_2
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

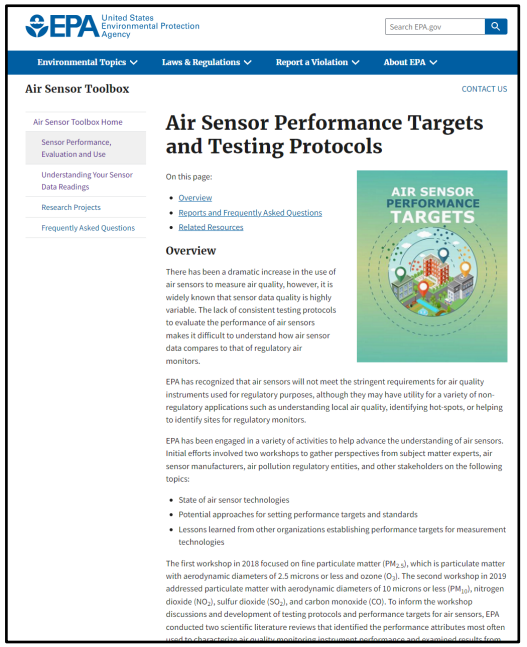
Anticipated Outcomes and Timeline

- Provide a **consistent approach** for evaluating PM_{10}, NO_2, CO, and SO_2 sensors
- Recommend target values that can help **encourage innovation** and **product improvements**
- Promote **education on important considerations for testing** sensors measuring PM_{10}, NO_2, CO, and SO_2
- 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 **does not** constitute certification or endorsement by the U.S. EPA.

Additional Resources

- **EPA Air Sensor Toolbox (*https://www.epa.gov/air-sensor-toolbox*)**
  - 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 (*https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols*)**
  - 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 (https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance)**
  - 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.

Thank You for Listening!

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