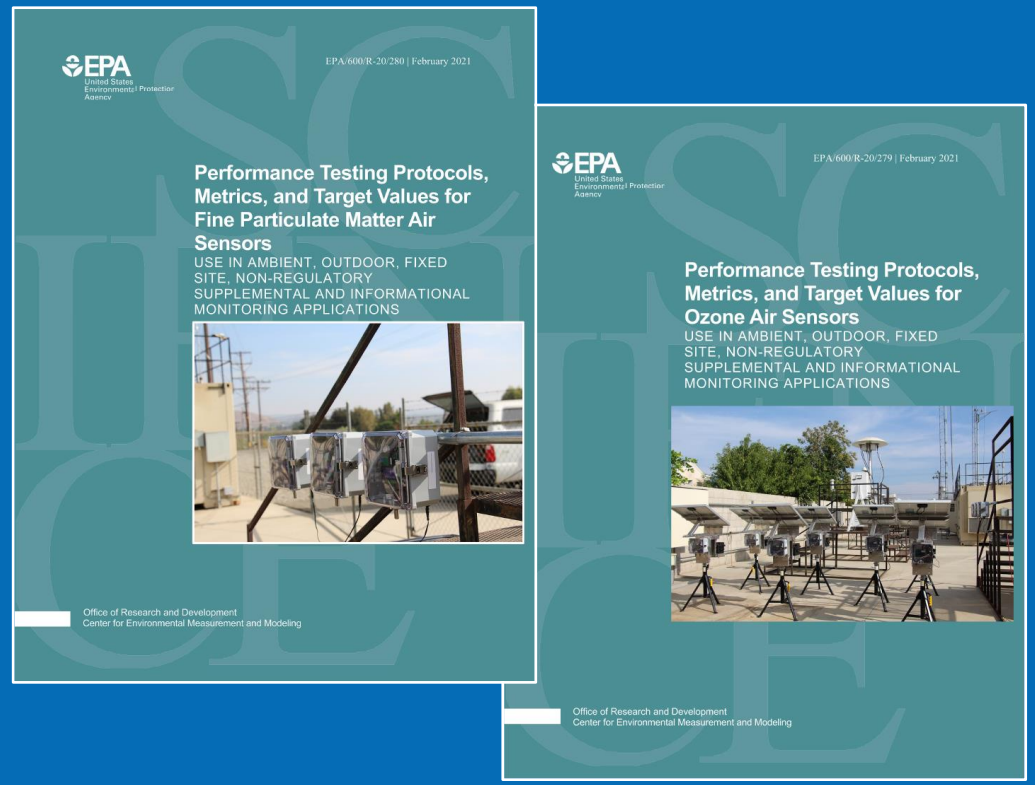
EPA United States Environmental Protection Agency

EPA Tools and Resources Webinar: Air Sensor Performance Testing Protocols, Metrics, and Target Values for $PM_{2.5}$ and Ozone

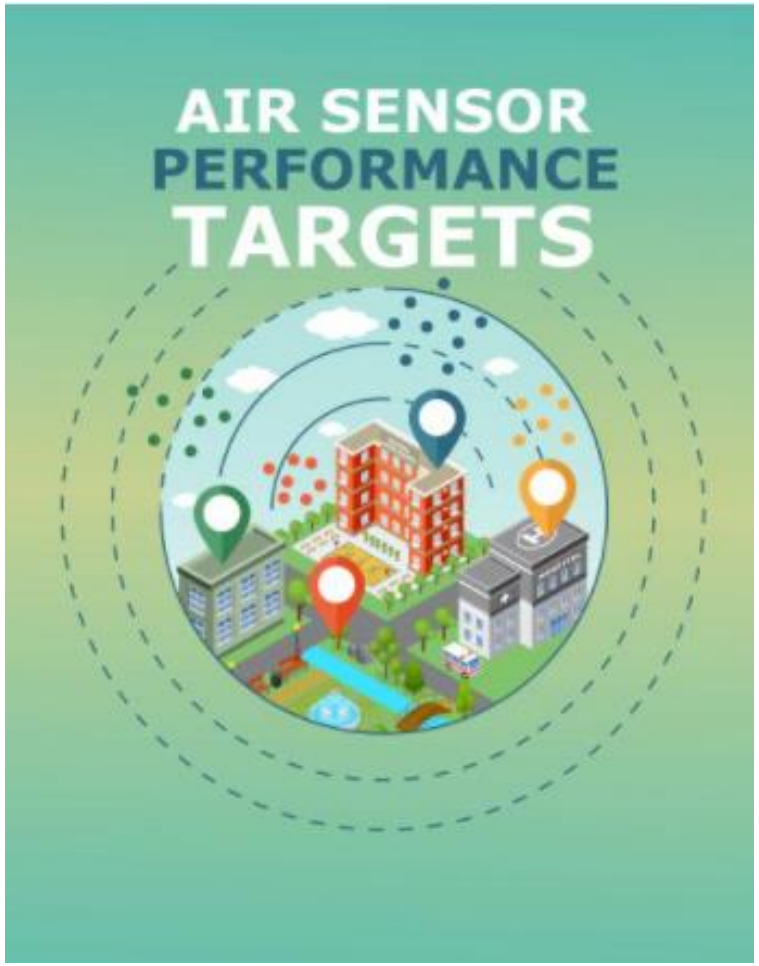
Rachelle Duvall and Andrea Clements
US EPA Office of Research and Development

March 24, 2021



Presentation Outline

- Background
- Motivation
- Problem and impact
- Approach
- Overview of the reports
- Anticipated outcomes
- Take home message
- Future plans
- Resources
- Contact



Background

- **Air sensors**
  - Non-regulatory technologies that measure air quality
  - Term describes integrated set of hardware and software that uses one or more sensing components to detect or measure pollutants
- **General features of air sensors**
  - Lower in cost, more portable, and easier to operate than regulatory monitors
  - Provide relatively quick or instant measurements
  - Allow for data collection in more locations

Air sensors have encouraged innovation in air monitoring approaches

User Community and Applications

- **Availability and use of air sensors has dramatically increased over the years**
  - Broad user community with different levels of experience
  - Many different application areas which continue to expand

Broad User Community

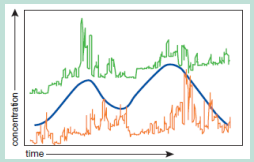
- Citizen scientists
- Individuals
- Cities and community groups
- Schools
- Air quality and health agencies
- Medical professionals
- Researchers
- Academia
- Federal government agencies

Example Applications of Air Sensors

- Air quality trends
- Supplemental monitoring
- Air quality forecasting
- Citizen science
- Education
- Environmental awareness
- Hot-spot detection
- Epidemiological studies
- Model verification

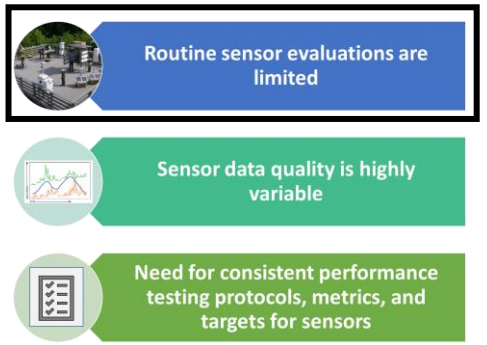
Motivation for this Work

Routine sensor evaluations are limited



Sensor data quality is highly variable

Need for consistent performance testing protocols, metrics, and targets for sensors



Routine Sensor Evaluations are Limited

- US EPA, AQ-SPEC*, and other organizations conduct routine sensor evaluations
- Evaluations are similar but not identical
- Limitations of the evaluations
  - Locations are not widespread
  - Environmental conditions are limited
  - Results may not translate for other locations and conditions
- Evaluations show sensor performance is highly variable based on
  - Sensor make/model
  - Temperature, relative humidity, and season

US EPA AIRS Site (*North Carolina*)

AQ-SPEC Evaluations at Rubidoux Air Monitoring Site (*California*)

IMPACT:

- ✓ **How do we (experts and other) interpret** the results?
- ✓ **Difficult for consumers to predict how a sensor may perform** in their location if pollutant levels and environmental conditions are much different

*AQ-SPEC = Air Quality Sensor Performance Evaluation Center, South Coast Air Quality Management District (http://www.aqmd.gov/aq-spec)

Sensor Data Quality is Variable

Routine sensor evaluations are limited

Sensor data quality is highly variable

Need for consistent performance testing protocols, metrics, and targets for sensors

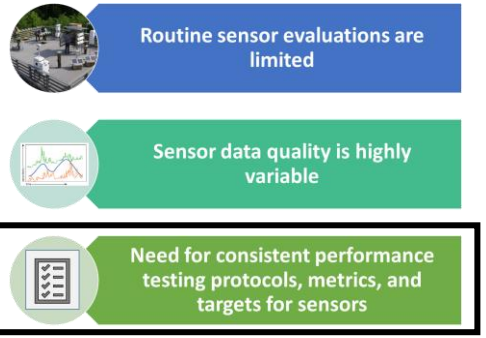
Key challenges related to sensors:

Ability to measure pollutant of interest	• Does the sensor measure the pollutant of interest accurately and reliability within the expected concentration range of the application?
Performance under different environmental conditions	• How do factors such as relative humidity, temperature, and different pollutant concentrations and types impact sensor measurements?
Ability to measure target pollutant in a pollutant mixture	• Will the sensor measure the target pollutant in a mixture of other pollutants?
Performance over time	• How does the sensor response change over time? • When do the sensor readings become inaccurate or unreliable?
Performance out-of-the-box	• How does the sensor perform out-of-the-box? • Are corrections or adjustments needed to provide more accurate data?

IMPACT:

- ✓ **Lack of confidence** in data quality
- ✓ **Users do not know which sensor will appropriately fit** their desired application

Need for consistent performance testing protocols, metrics, and targets for sensors



- **Under Clean Air Act**, for compliance with National Ambient Air Quality Standards (NAAQS), **monitoring instruments must meet applicable requirements** in the Code of Federal Regulations (CFR) Part of Title 40, Protection of Environment (e.g., 40 CFR Parts 50, 53, 58)
  - **Sensors likely will not meet the stringent requirements**
- Consistent testing protocols have **not** been available to uniformly evaluate and compare different sensor technologies
- Different data quality parameters (i.e., **performance metrics**) are used to summarize sensor performance evaluations
- **Performance targets** (*i.e., testable performance metrics*) **do not** exist

Title 40 Protection of Environment

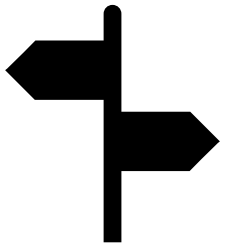
IMPACT:

- ✓ **Confusion on what procedures are needed** to appropriately evaluate sensor performance
- ✓ **Hard to compare sensor performance** if different testing procedures are used and different data quality metrics are reported
- ✓ **No benchmark (target) to guide technology** improvements

Problem and Impact

- **Understanding sensor performance** and how technologies compare to each other is important but challenging
- **Difficult to confidently respond to data** with unknown quality
  - How can these data be trusted or interpreted?
- **Hard to inform decisions** based on data with unknown quality
- Public **lacks understanding of sensor performance**
  - If data are brought to a decision maker, it might be disregarded based on quality issues
  - Potential for public distrust or lack in confidence in decision makers

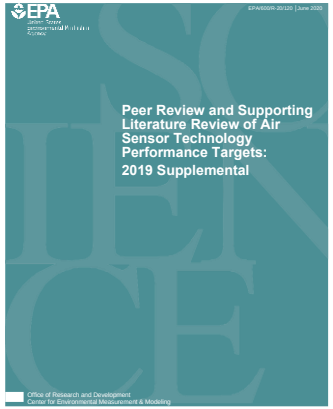
Could EPA provide guidance to help address these issues? If so, what would the guidance look like?



Approach

- **Reviewed published, peer-reviewed literature focusing on:**
  - Performance attributes (*e.g., precision*) to characterize instruments used to monitor air pollutants
  - Quantitative performance metrics (*e.g., standard deviation*) that describe performance attributes
  - Field and laboratory sensor performance evaluations
- **In coordination with ECOS, hosted workshop in 2018**
  - Convened panel of experts from regulatory agencies, academia, and international organizations
  - Attendees: states, tribes, federal agencies, academics, sensor manufacturers, general public, international groups, and many others
  - Gathered perspectives on:
    - State of air sensor technologies
    - Potential approaches for setting performance targets/standards
    - Lessons learned from other organizations in the process of establishing performance targets for measurement technologies

First Literature Review



Second Literature Review

2018 Deliberating Performance Targets for Air Quality Sensors Workshop

Workshop website: https://www.epa.gov/air-research/deliberating-performance-targets-air-quality-sensors-workshops

Approach – Continued

- **2018 workshop identified several possible actions**
  - Document best practices
  - Share quality assurance results and sensor data
  - Develop common performance lexicon, performance targets, and test protocols

- **Strategy**
  - **Develop recommendations** (*in the form of reports*) on evaluating sensor performance
  - Focus initially on **fine particulate matter and ozone sensors**
  - Use a **single tier** for recommended target values
  - Focus on **non-regulatory supplemental and informational monitoring (NSIM) applications** in ambient, outdoor, fixed site environments
  - Pursue **voluntary approach** rather than certification

Journal article summarizing the 2018 workshop findings

Contents lists available at ScienceDirect

Atmospheric Environment: X

journal homepage: www.journals.elsevier.com/atmospheric-environment-x

Deliberating performance targets workshop: Potential paths for emerging $PM_{2.5}$ and O_3 air sensor progress

R. Williams[a], R. Duvall[a,*], V. Kilaru[a], G. Hagler[a], L. Hassinger[b], K. Benedict[c], J. Rice[c], A. Kaufman[c], R. Judge[d], G. Pierce[e], G. Allen[f], M. Bergin[g], R.C. Cohen[h], P. Fransioli[i], M. Gerboles[j], R. Habre[k], M. Hannigan[l], D. Jack[m], P. Louie[n], N.A. Martin[o], M. Penza[p,q], A. Polidori[r], R. Subramanian[s], K. Ray[t], J. Schauer[u], E. Seto[v], G. Thurston[w], J. Turner[x], A.S. Wexler[y], Z. Ning[z]

HIGHLIGHTS

- Certification standards do not exist for low-cost air sensors.
- Some sensor performance targets are being considered by various organizations.
- Lack of standards impacts data quality and confidence in using sensor data.
- In literature, reported sensor performance attributes are highly variable.
- Possible next steps include recording best practices and quality assurance results.

ARTICLE INFO

Keywords:
Low-cost air quality sensors
Performance targets
$PM_{2.5}$

ABSTRACT

The United States Environmental Protection Agency held an international two-day workshop in June 2018 to deliberate possible performance targets for non-regulatory fine particulate matter ($PM_{2.5}$) and ozone (O_3) air sensors. The need for a workshop arose from the lack of any market-wide manufacturer requirement for

* Corresponding author. U.S. Environmental Protection Agency, 109 T.W. Alexander Drive, MD E343-02, Research Triangle Park, NC 27711, USA.
E-mail address: duvall.rachelle@epa.gov (R. Duvall).

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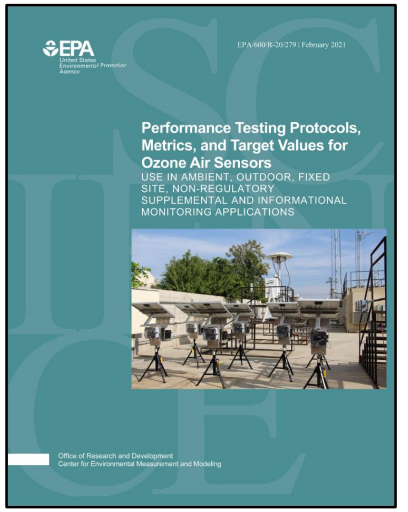
Results

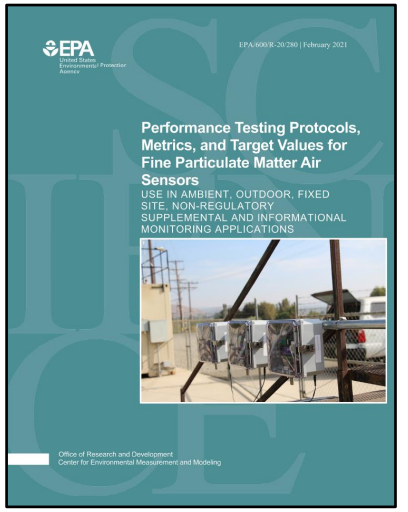
- EPA developed **two reports** that outline recommended performance testing protocols, metrics, and target values for air sensors

- Pollutants of focus are **ozone (O_3)** and **fine particulate matter ($PM_{2.5}$)** due to widespread use, understanding of technologies, and data availability

- Goal is to provide a consistent approach for performance testing **and** reporting results to help users identify sensors that meet their needs



Ozone Report



Fine Particulate Matter Report

Intended Audience:

- ✓ Testing organizations
- ✓ Sensor manufacturers
- ✓ Sensor developers

Overview of Reports

- **General layout of the O_3 and $PM_{2.5}$ reports is similar**
  - Introduction – *background, motivation, and objectives*
  - Testing Protocols – *step-by-step instructions for set up, testing, and data collection*
  - Performance Metrics – *recommended metrics and instructions on how to calculate and report each*
  - Target Values – *recommended targets for each performance metric to gauge air sensor performance*
  - Appendices – *provide definitions, supporting information for the recommendations, checklists for data collection, and reporting templates*
  - Fillable reporting templates (PowerPoint files) – *facilitate documentation of test results*

Summary of Information in the Appendices

Appendix A	Definitions
Appendix B	Supporting Information for Testing Protocols
Appendix C	Supporting Information for Performance Metrics
Appendix D	Supporting Information for Target Values
Appendix E	Base Testing Checklist
Appendix F	Example Reporting Template for Base Testing
Appendix G	Enhanced Testing Checklist
Appendix H	Example Reporting Template for Enhanced Testing

Focus and Applications of the Reports

- **Testing protocols are specifically for:**
  - Ambient, outdoor, fixed site environments
  - Non-regulatory supplemental and informational monitoring (NSIM) applications

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 • Hot-spot 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

Overview of the Testing Protocols

- **Two testing protocols are recommended**

Base Testing (Field)	Enhanced Testing (Laboratory)

• Evaluate sensors in the field – ambient, outdoor, fixed site environment
• Purpose
  • Obtain information on sensor performance in real-world, ambient, outdoor conditions
  • Provides consumers information on how they might expect a sensor to perform in similar conditions
	• Evaluate sensors in a controlled laboratory exposure chamber
	• Purpose
	  • Evaluate sensors over a wider range of conditions that may be more difficult to capture in the field
	  • Characterize certain performance parameters that are difficult to test in the field

Testers are encouraged to conduct base testing <u>at minimum</u>. Enhanced testing is also encouraged although it calls for a controlled laboratory exposure chamber.

Overview of Base Testing Protocol

- **Field deployment of 3 or more identical air sensors** with collocated Federal Reference Method or Federal Equivalent Method (FRM/FEM) monitors
- Testers have different **options for field sites**
  - Set up their own FRM/FEM monitors at an outdoor, ambient site
  - Establish collaborations with state/local/tribal agencies who manage existing air quality monitoring sites
- Collect measurements for **at least 30 consecutive days**
- **2 field deployments** recommended to evaluate sensors under different pollutant concentrations, ambient temperatures (T), and relative humidity (RH) levels

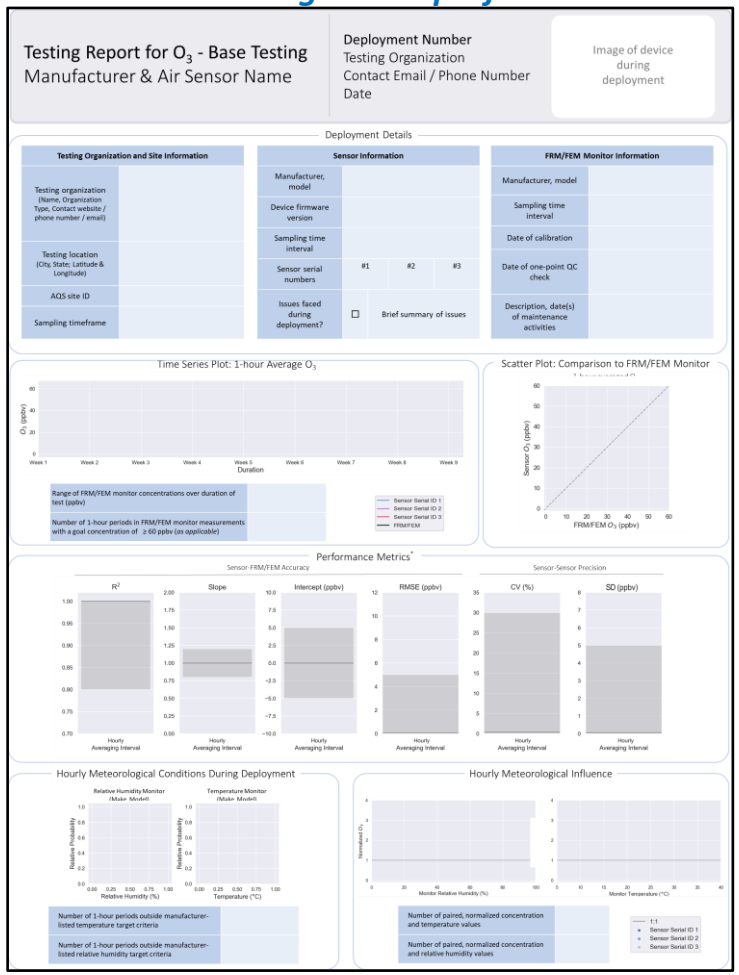
Recommended Test Site Selection Criteria

Base Testing	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 $\mu g/m^3$)

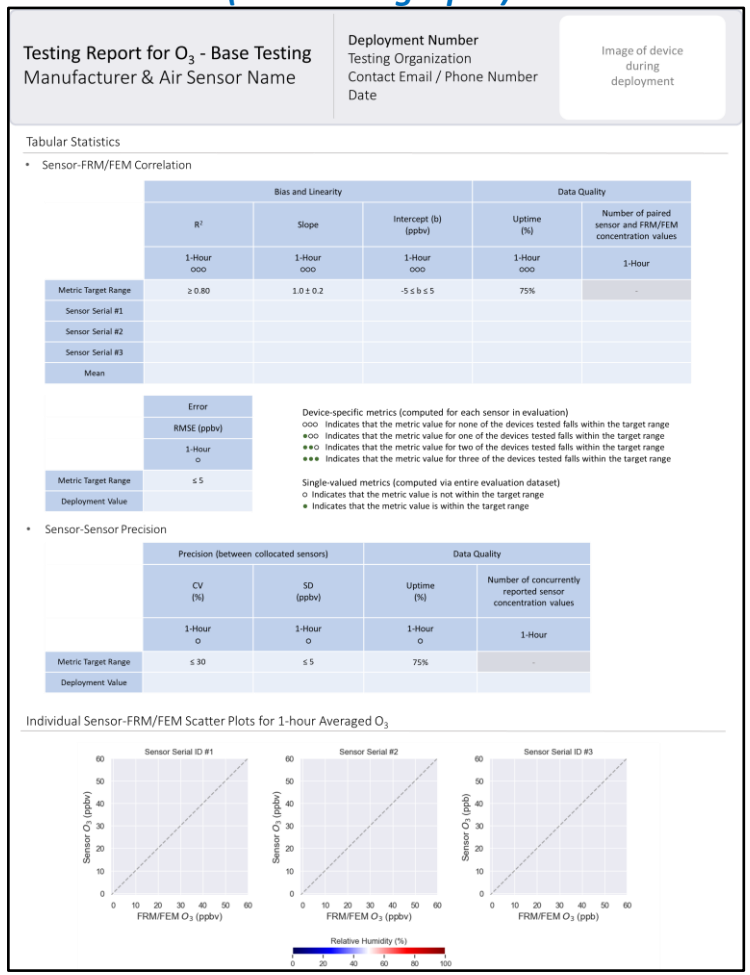
Example O_3 Reporting Template – Base Testing

- **Fillable template provided (*PowerPoint file*)**

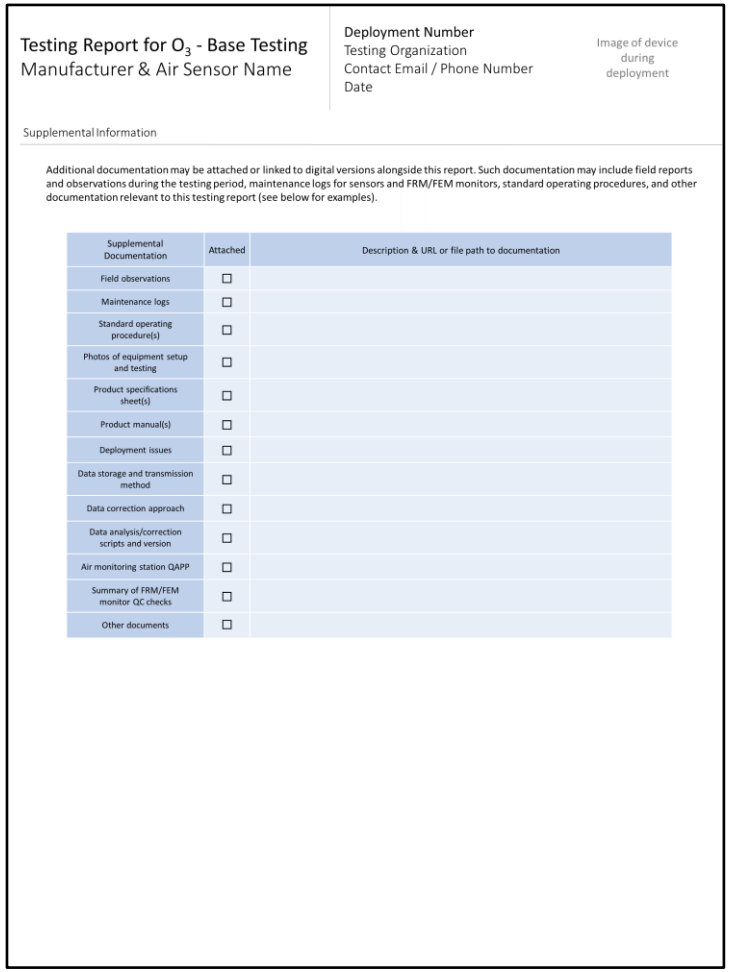
Details on deployment, visual plots summarizing sensor performance



Summary performance statistics (table and graphs)



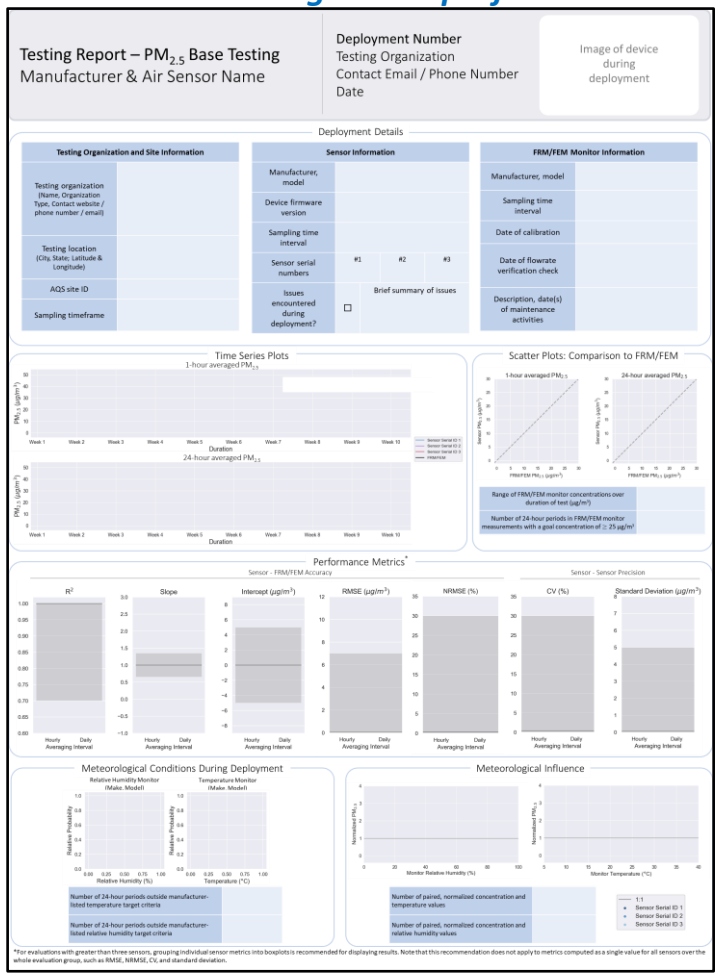
Supplemental materials



Example $PM_{2.5}$ Reporting Template – Base Testing

- **Fillable template provided (*PowerPoint file*)**

Details on deployment, visual plots summarizing sensor performance



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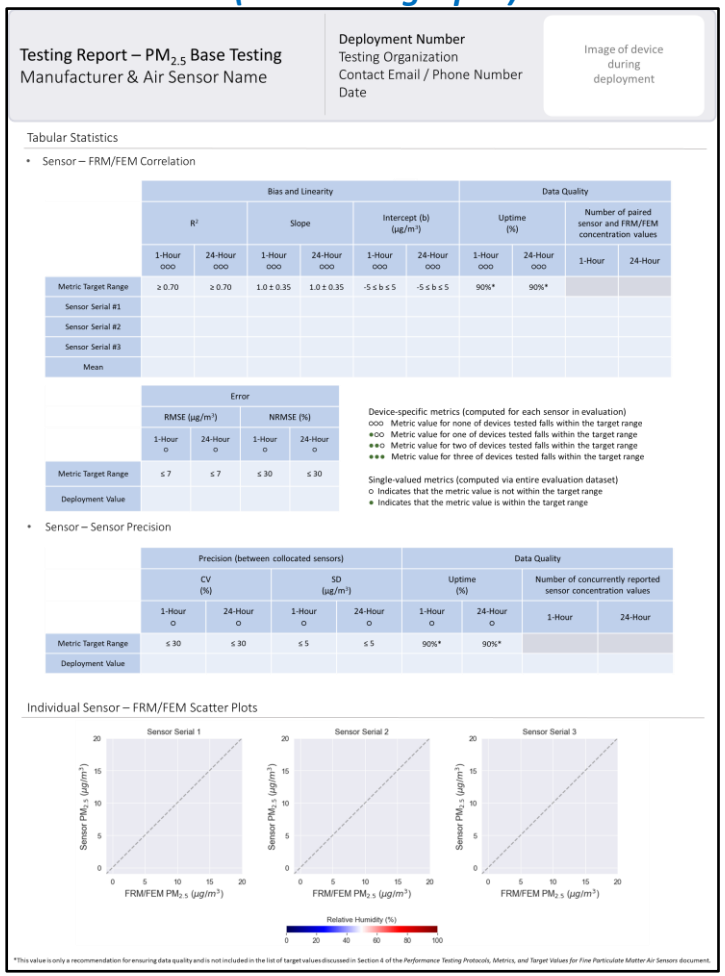

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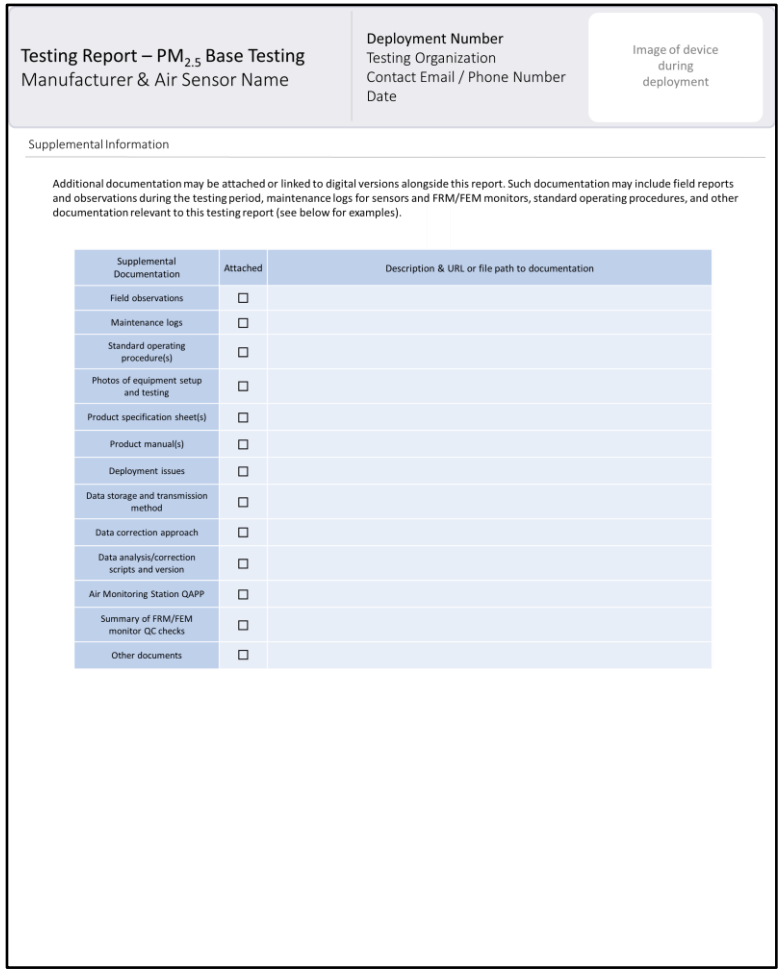


Overview of Enhanced Testing Protocol

- **Laboratory testing of 3 or more identical air sensors** in controlled laboratory conditions
- Evaluate sensors under **different pollutant concentrations, T, and RH levels**

Recommended Test Conditions

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 Relative Humidity (RH)	40% RH vs. 85% RH	40% RH vs. 85% RH
Effect of Temperature (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/m^3 $PM_{2.5}$ ± 10% Mid Concentration: 35 µg/m^3 $PM_{2.5}$ ± 5%
Accuracy at High Concentration(s)	High concentration: 125 ppbv O_3 ± 5%	High concentration: 150 µg/m^3 $PM_{2.5}$ ± 5% Higher concentration: 250 µg/m^3 $PM_{2.5}$ ± 5%

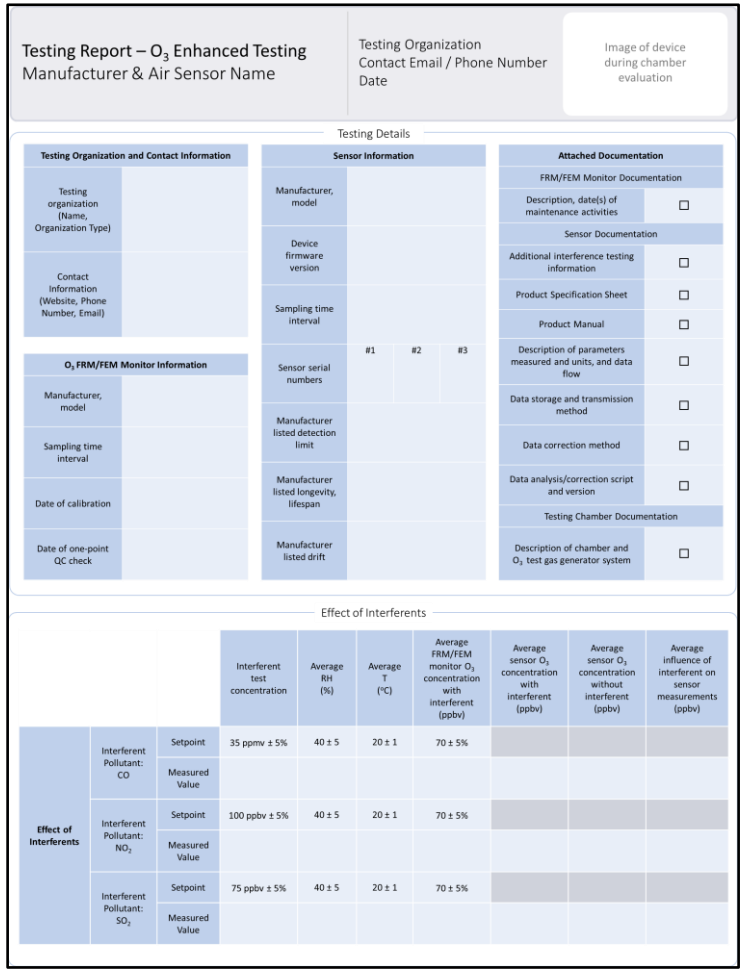
Additional Notes:

- Drift test (Day 1) conducted in laboratory chamber, sensors then operated in ambient outdoor air for 60 days, then drift test repeated in laboratory chamber (Day 60)
- Mid concentration setpoints based on the primary (health-based) NAAQS
- High concentration setpoints based on Air Quality Index (AQI) breakpoints considered important for health messaging
- Higher concentration setpoint (*for $PM_{2.5}$ only*) is relevant for events such as wildfires

Example O_3 Reporting Template – Enhanced Testing

- **Fillable template provided (*PowerPoint file*)**

Testing details including documentation, effect of interferents test



Testing Report – O_3 Enhanced Testing
Manufacturer & Air Sensor Name

Testing Organization
Contact Email / Phone Number
Date

Image of device during chamber evaluation

Testing Details

Testing Organization and Contact Information	
Testing organization (Name, Organization Type)	
Contact Information (Website, Phone Number, Email)	

O_3 FRM/FEM Monitor Information	
Manufacturer, model	
Sampling time interval	
Date of calibration	
Date of one-point QC check	

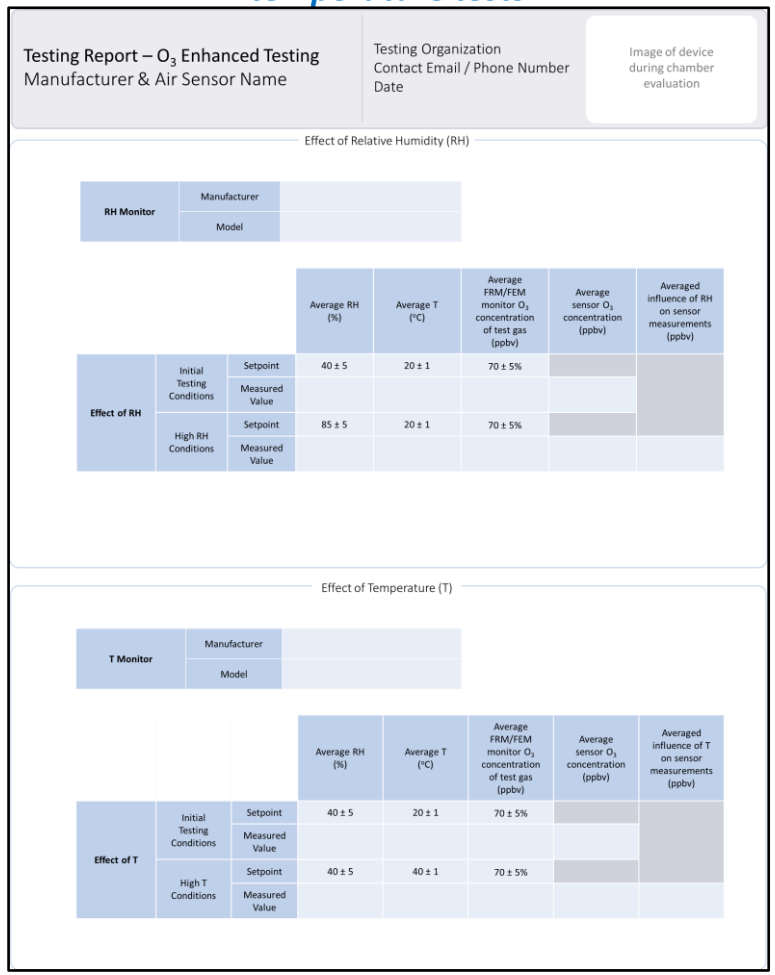
Sensor Information			
Manufacturer, model			
Device firmware version			
Sampling time interval			
Sensor serial numbers	#1	#2	#3
Manufacturer listed detection limit			
Manufacturer listed longevity, lifespan			
Manufacturer listed drift			

Attached Documentation	
FRM/FEM Monitor Documentation	
Description, date(s) of maintenance activities	☐
Sensor Documentation	
Additional interference testing information	☐
Product Specification Sheet	☐
Product Manual	☐
Description of parameters measured and units, and data flow	☐
Data storage and transmission method	☐
Data correction method	☐
Data analysis/correction script and version	☐
Testing Chamber Documentation	
Description of chamber and O_3 test gas generator system	☐

Effect of Interferents

			Interferent test concentration	Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration with interferent (ppbv)	Average sensor O_3 concentration with interferent (ppbv)	Average sensor O_3 concentration without interferent (ppbv)	Average influence of interferent on sensor measurements (ppbv)
Effect of Interferents	Interferent Pollutant: CO	Setpoint	35 ppmv ± 5%	40 ± 5	20 ± 1	70 ± 5%			
		Measured Value							
	Interferent Pollutant: NO_2	Setpoint	100 ppbv ± 5%	40 ± 5	20 ± 1	70 ± 5%			
		Measured Value							
	Interferent Pollutant: SO_2	Setpoint	75 ppbv ± 5%	40 ± 5	20 ± 1	70 ± 5%			
		Measured Value							

Effect of relative humidity and temperature tests



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Testing Organization
Contact Email / Phone Number
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Image of device during chamber evaluation

Effect of Relative Humidity (RH)

RH Monitor	
Manufacturer	
Model	

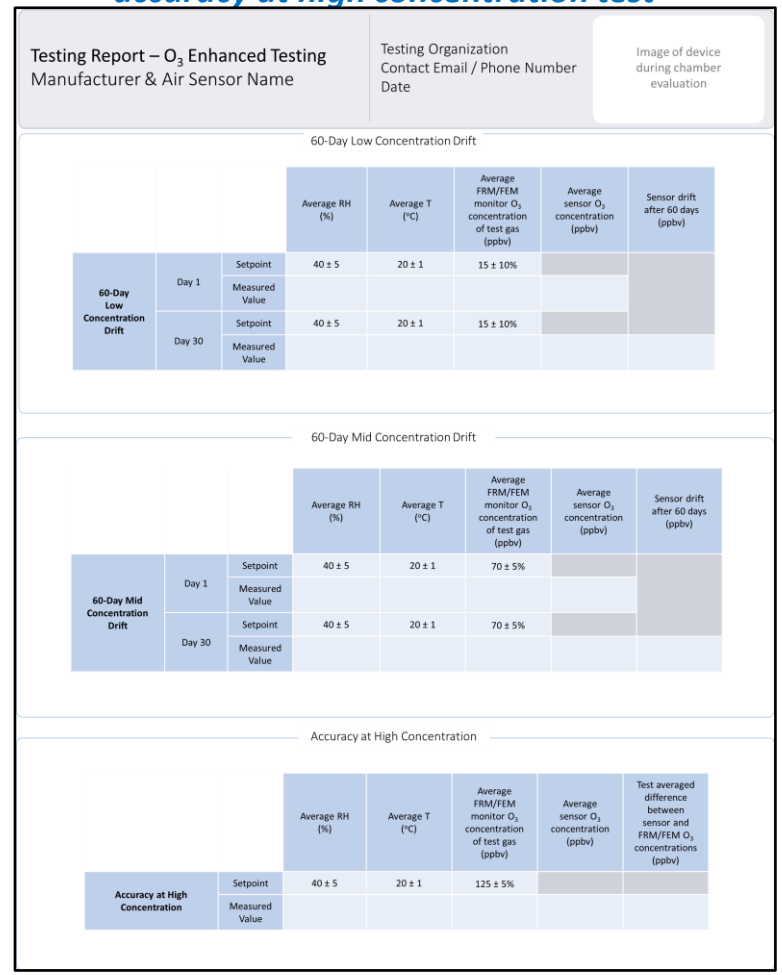
			Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration of test gas (ppbv)	Average sensor O_3 concentration (ppbv)	Averaged influence of RH on sensor measurements (ppbv)
Effect of RH	Initial Testing Conditions	Setpoint	40 ± 5	20 ± 1	70 ± 5%		
		Measured Value					
	High RH Conditions	Setpoint	85 ± 5	20 ± 1	70 ± 5%		
		Measured Value					

Effect of Temperature (T)

T Monitor	
Manufacturer	
Model	

			Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration of test gas (ppbv)	Average sensor O_3 concentration (ppbv)	Averaged influence of T on sensor measurements (ppbv)
Effect of T	Initial Testing Conditions	Setpoint	40 ± 5	20 ± 1	70 ± 5%		
		Measured Value					
	High T Conditions	Setpoint	40 ± 5	40 ± 1	70 ± 5%		
		Measured Value					

Drift test (Day 1 and Day 60) and accuracy at high concentration test



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60-Day Low Concentration Drift

			Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration of test gas (ppbv)	Average sensor O_3 concentration (ppbv)	Sensor drift after 60 days (ppbv)
60-Day Low Concentration Drift	Day 1	Setpoint	40 ± 5	20 ± 1	15 ± 10%		
		Measured Value					
	Day 30	Setpoint	40 ± 5	20 ± 1	15 ± 10%		
		Measured Value					

60-Day Mid Concentration Drift

			Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration of test gas (ppbv)	Average sensor O_3 concentration (ppbv)	Sensor drift after 60 days (ppbv)
60-Day Mid Concentration Drift	Day 1	Setpoint	40 ± 5	20 ± 1	70 ± 5%		
		Measured Value					
	Day 30	Setpoint	40 ± 5	20 ± 1	70 ± 5%		
		Measured Value					

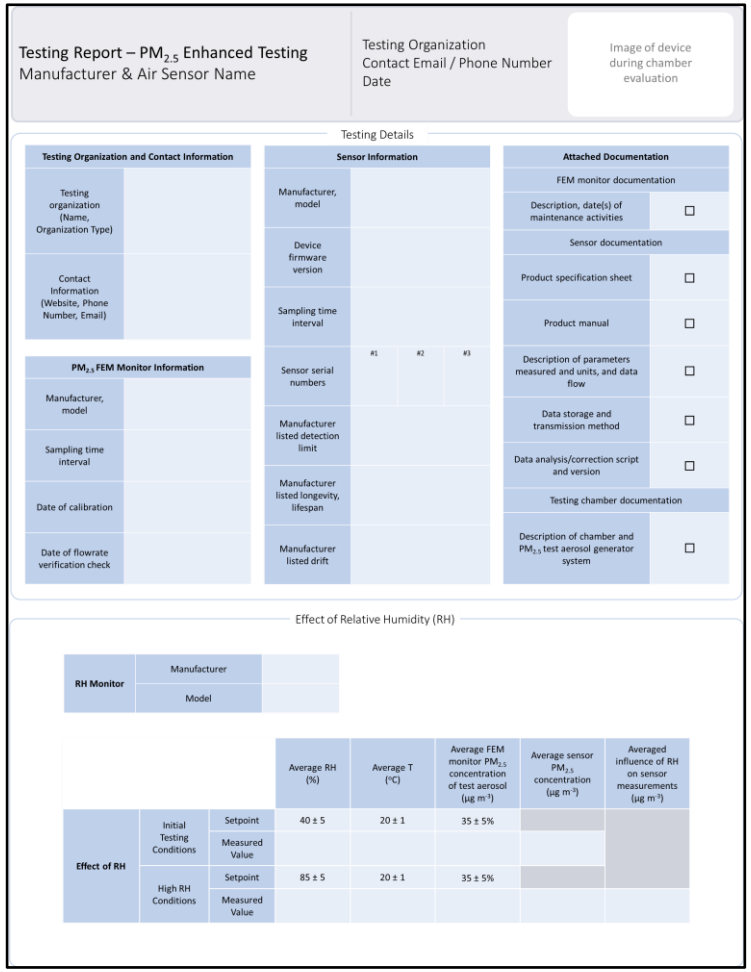
Accuracy at High Concentration

			Average RH (%)	Average T (°C)	Average FRM/FEM monitor O_3 concentration of test gas (ppbv)	Average sensor O_3 concentration (ppbv)	Test averaged difference between sensor and FRM/FEM O_3 concentrations (ppbv)
Accuracy at High Concentration		Setpoint	40 ± 5	20 ± 1	125 ± 5%		
		Measured Value					

Example $PM_{2.5}$ Reporting Template – Enhanced Testing

- **Fillable template provided (*PowerPoint file*)**

Testing details including documentation, effect of RH test



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$PM_{2.5}$ FEM Monitor Information	
Manufacturer, model	
Sampling time interval	
Date of calibration	
Date of flowrate verification check	

Sensor Information			
Manufacturer, model			
Device firmware version			
Sampling time interval			
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FEM monitor documentation	
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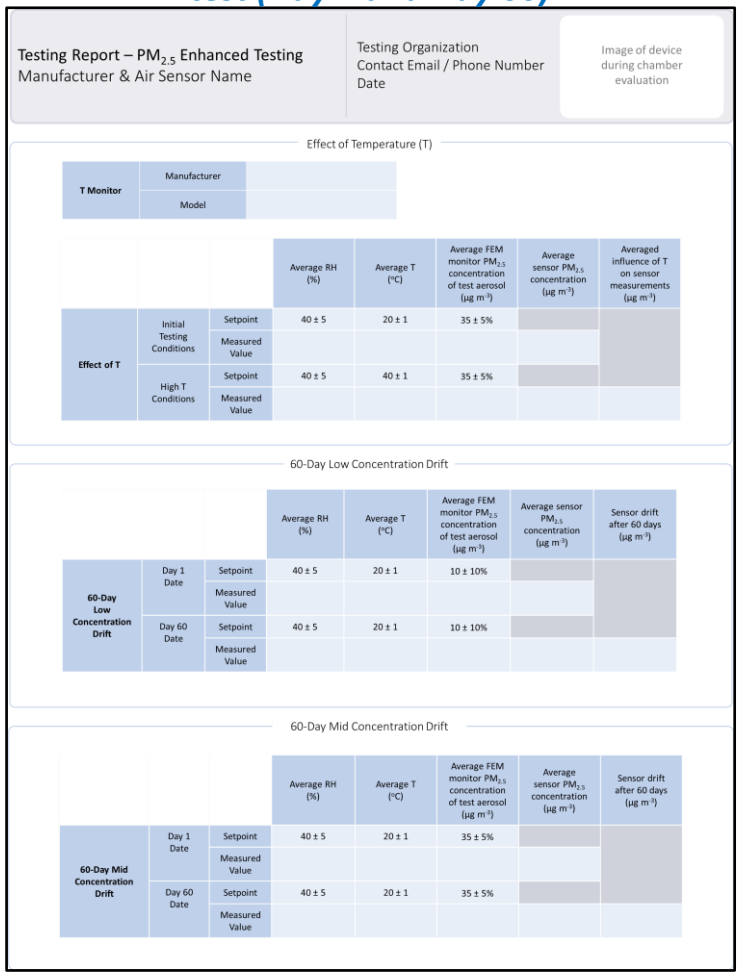
Sensor documentation	
Product specification sheet	☐
Product manual	☐
Description of parameters measured and units, and data flow	☐
Data storage and transmission method	☐
Data analysis/correction script and version	☐
Testing chamber documentation	
Description of chamber and $PM_{2.5}$ test aerosol generator system	☐

Effect of Relative Humidity (RH)

RH Monitor		
	Manufacturer	
	Model	

			Average RH (%)	Average T (°C)	Average FEM monitor $PM_{2.5}$ concentration of test aerosol (µg m^{-3})	Average sensor $PM_{2.5}$ concentration (µg m^{-3})	Averaged influence of RH on sensor measurements (µg m^{-3})
Effect of RH	Initial Testing Conditions	Setpoint	40 ± 5	20 ± 1	35 ± 5%		
		Measured Value					
	High RH Conditions	Setpoint	85 ± 5	20 ± 1	35 ± 5%		
		Measured Value					

Effect of temperature test, drift test (Day 1 and Day 60)



Testing Report – $PM_{2.5}$ Enhanced Testing
Manufacturer & Air Sensor Name

Testing Organization
Contact Email / Phone Number
Date

Image of device during chamber evaluation

Effect of Temperature (T)

T Monitor		
	Manufacturer	
	Model	

			Average RH (%)	Average T (°C)	Average FEM monitor $PM_{2.5}$ concentration of test aerosol (µg m^{-3})	Average sensor $PM_{2.5}$ concentration (µg m^{-3})	Averaged influence of T on sensor measurements (µg m^{-3})
Effect of T	Initial Testing Conditions	Setpoint	40 ± 5	20 ± 1	35 ± 5%		
		Measured Value					
	High T Conditions	Setpoint	40 ± 5	40 ± 1	35 ± 5%		
		Measured Value					

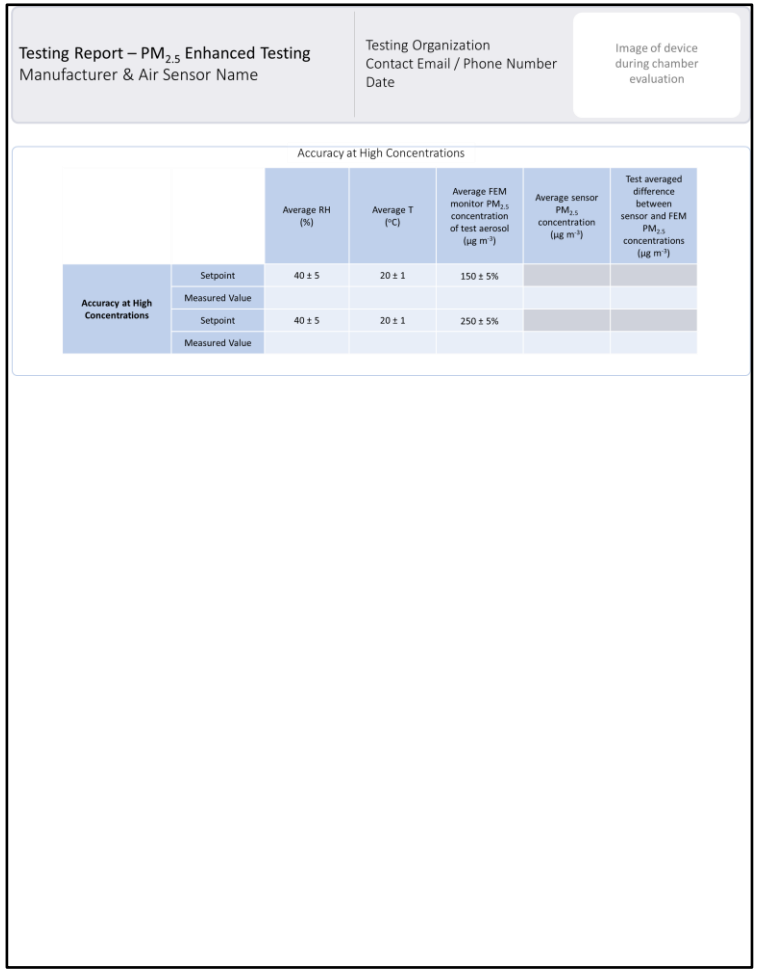
60-Day Low Concentration Drift

			Average RH (%)	Average T (°C)	Average FEM monitor $PM_{2.5}$ concentration of test aerosol (µg m^{-3})	Average sensor $PM_{2.5}$ concentration (µg m^{-3})	Sensor drift after 60 days (µg m^{-3})
60-Day Low Concentration Drift	Day 1 Date	Setpoint	40 ± 5	20 ± 1	10 ± 10%		
		Measured Value					
	Day 60 Date	Setpoint	40 ± 5	20 ± 1	10 ± 10%		
		Measured Value					

60-Day Mid Concentration Drift

			Average RH (%)	Average T (°C)	Average FEM monitor $PM_{2.5}$ concentration of test aerosol (µg m^{-3})	Average sensor $PM_{2.5}$ concentration (µg m^{-3})	Sensor drift after 60 days (µg m^{-3})
60-Day Mid Concentration Drift	Day 1 Date	Setpoint	40 ± 5	20 ± 1	35 ± 5%		
		Measured Value					
	Day 60 Date	Setpoint	40 ± 5	20 ± 1	35 ± 5%		
		Measured Value					

Accuracy at high concentrations test



Testing Report – $PM_{2.5}$ Enhanced Testing
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Accuracy at High Concentrations

		Average RH (%)	Average T (°C)	Average FEM monitor $PM_{2.5}$ concentration of test aerosol (µg m^{-3})	Average sensor $PM_{2.5}$ concentration (µg m^{-3})	Test averaged difference between sensor and FEM $PM_{2.5}$ concentrations (µg m^{-3})
Accuracy at High Concentrations	Setpoint	40 ± 5	20 ± 1	150 ± 5%		
	Measured Value					
	Setpoint	40 ± 5	20 ± 1	250 ± 5%		
	Measured Value					

Recommended Target Values

- **Target values only recommended for Base Testing (*Field Deployment*)**

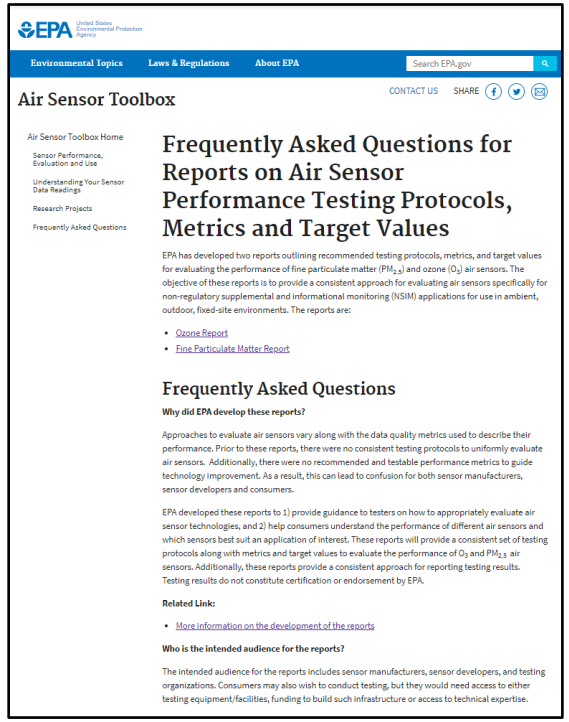
Performance Metric		O_3 Target Value	$PM_{2.5}$ Target Value
Precision	Standard Deviation (SD) **OR**	≤ 5 ppbv	≤ 5 μg/m^3
	Coefficient of Variation (CV)	≤ 30%	≤ 30%
Bias	Slope	1.0 ± 0.2	1.0 ± 0.35
	Intercept (b)	-5 ≤ b ≤ 5 ppbv	-5 ≤ b ≤ 5 μg/m^3
Linearity	Coefficient of Determination (R^2)	≥ 0.80	≥ 0.70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

NRMSE = normalized root mean square error

- Target values considered **reasonably achievable (at this time)** and **adequate for many NSIM applications** (based on literature)
- 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

Important Reminders and Notes

- Reports provide **recommendations for evaluating sensor performance**
- Conducting the testing protocols is **entirely voluntary**
- Conducting the testing protocols **does not** constitute certification or endorsement by the US EPA
- **EPA does not provide funding** to conduct the testing protocols
- EPA recommends that **testers share results on their respective websites**



For these and other Frequently Asked Questions on the reports visit: https://www.epa.gov/air-sensor-toolbox/frequently-asked-questions-reports-air-sensor-performance-testing-protocols

Anticipated Outcomes

- Reports will provide a **consistent approach** for
  - Evaluating air sensor performance for NSIM applications
  - Reporting performance evaluation results
- Help all consumers (*from the public to decision makers*) **better understand sensor performance and data quality**
- Help consumers make **informed decisions on choosing appropriate air sensors** for their intended NSIM application
- **Encourage innovation** and **product improvement** in the marketplace

Consumers include state/local/tribal agencies, federal government agencies, community groups, citizen scientists, academia, and others.

Take Home Messages

- **Reports developed provide much needed guidelines** for evaluating $PM_{2.5}$ and O_3 air sensor performance
- Performance **target values have been recommended** that can
  - Provide a benchmark for sensor performance
  - Encourage improvements in sensor technology
- Testing **results will help consumers**
  - Have more confidence in sensor data quality
  - Make informed decisions on choosing sensors that best suit an application of interest

Reports and reporting templates can be found here:
https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols

Future Plans

- As more knowledge is gained and sensor technology improves, **we anticipate re-evaluating the recommended testing protocols, metrics, and target values** for $PM_{2.5}$ and O_3
- **Similar reports** with same application focus (*ambient, outdoor, fixed site NSIM applications*) **for sensors measuring additional pollutants are currently being developed**
  - Additional pollutants include
    - Particles with diameters of 10 microns or less (PM_{10})
    - Nitrogen dioxide (NO_2)
    - Carbon monoxide (CO)
    - Sulfur dioxide (SO_2)
  - Reports will be informed by
    - 2019 Deliberating Performance Targets for Air Sensors Workshop
    - First and second literature reviews (*EPA sponsored*)
    - Other available literature and evaluations

Journal article summarizing the 2019 workshop findings

Atmospheric Environment 246 (2021) 118099

Contents lists available at ScienceDirect

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journal homepage: http://www.elsevier.com/locate/atmosenv

Deliberating Performance Targets: Follow-on workshop discussing PM_{10}, NO_2, CO, and SO_2 air sensor targets

R.M. Duvall, G.S.W. Hagler, A.L. Clements, K. Benedict, K. Barkjohn, V. Kilaru, T. Hanley, N. Watkins, A. Kaufman, A. Kamal, S. Reece, P. Fransioli, M. Gerboles, G. Gillerman, R. Habre, M. Hannigan, Z. Ning, V. Papapostolou, R. Pope, P.J. E. Quintana, J. Lam Snyder

HIGHLIGHTS

- Performance targets would assist in selecting sensors appropriate for a given use.
- Varying sensor performance metrics are currently reported in literature.
- Transparency and consistency in performance metrics is recommended.
- Documenting sensor calibration and processing algorithms is recommended.

ARTICLE INFO

ABSTRACT

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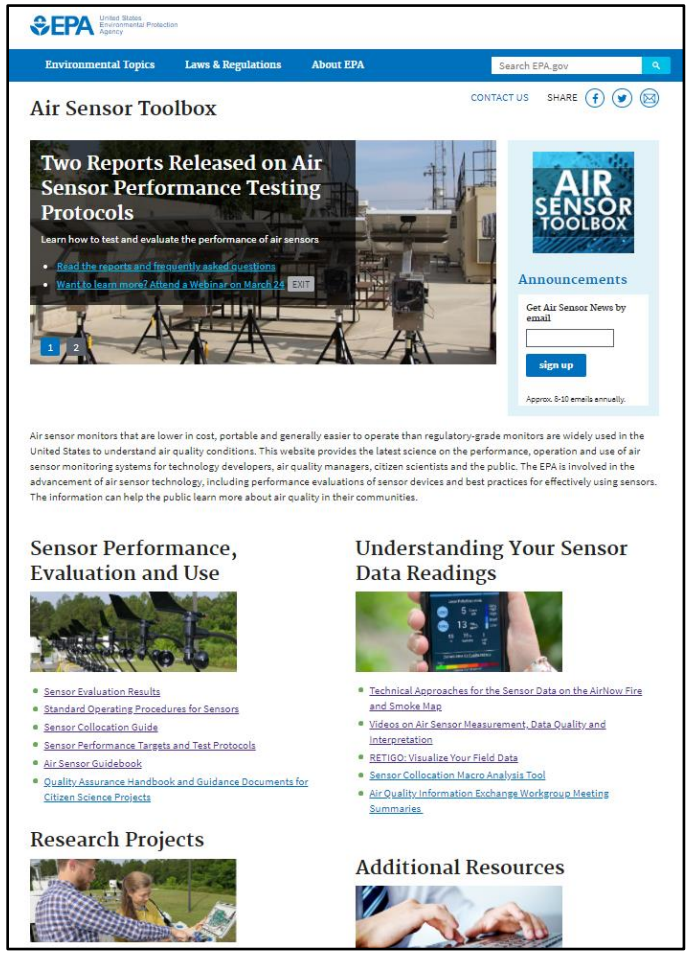
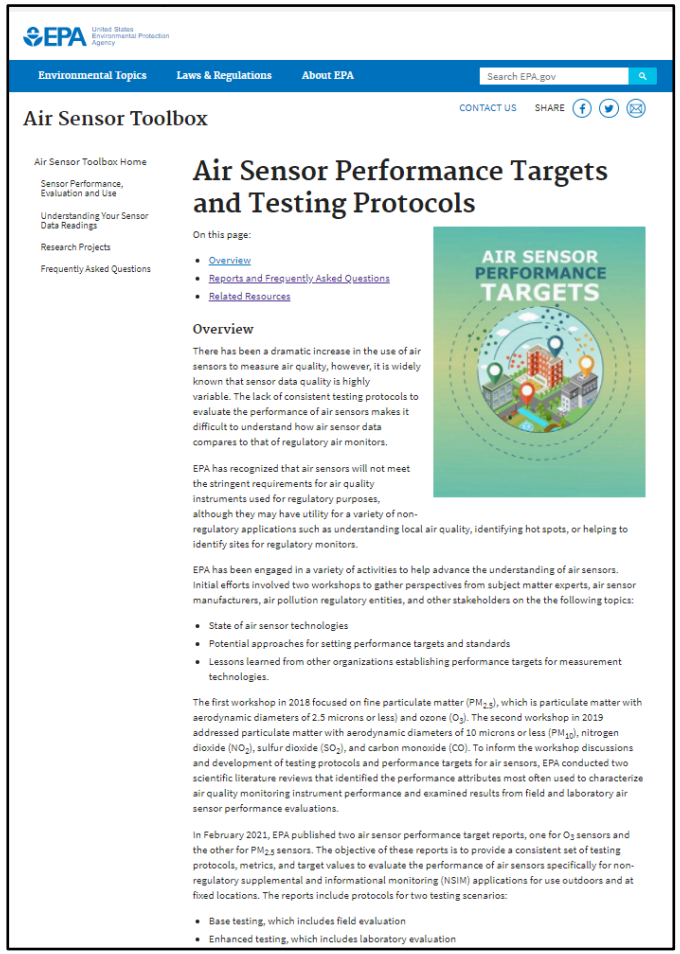
Resources

- Updates on air sensor performance testing protocols, metrics, and targets will be posted to the **Air Sensor Toolbox website**



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



https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols

Contacts

Rachelle Duvall, Ph.D.
Environmental Engineer
Center for Environmental Measurement and Modeling
US EPA Office of Research and Development
duvall.rachelle@epa.gov
919-541-4462

Andrea Clements, Ph.D.
Research Physical Scientist
Center for Environmental Measurement and Modeling
US EPA Office of Research and Development
clements.andrea@epa.gov
919-541-1363

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