Sensor Environmental Test Chamber-2 (SEnTeC-2):

Advancing Today's Sensor Testing To Meet Tomorrow's Sensor Needs

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AQ-SPEC
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Background

- The Air Quality Sensor Performance Evaluation Center (AQ-SPEC) program of the South Coast Air Quality Management District (South Coast AQMD) has evaluated the performance of over 160 low-cost sensors (LCS) measuring air pollutants both in the field and a controlled test chamber (AQ-SPEC Chamber system #1 or SEnTEc-1).
- A second larger Sensor Environmental Test Chamber (SEnTeC-2) has been developed capable of performing more comprehensive test procedures using the knowledge and experience gained from SEnTEc-1 and expands the testing capabilities of AQ-SPEC.
- This updated chamber system can generate complex aerosol and gas mixtures and specific/predetermined test sequences such as the ASTM designation for the approved standard D8405-21: Standard Test Method for PM2.5 Sensors or Sensor Units Used in Indoor Air Applications and that in the EPA's Performance Testing Protocol for Fine Particulate Matter and Ozone Air Sensors.
- The development and execution of highly specialized testing scenarios (i.e., vibration, wind speed, and altitude tests) can provided additional validation into the use of LCS in extreme environments.

SEnTeC-2: Overview

i) A professional grade environmental test chamber fabricated from SilicoNert™-coated stainless steel
ii) A “zero-air” system
iii) A liquid and dust particle generator for coarse/fine/ultrafine particulate matter (PM)
iv) A dynamic dilution calibrator with a low flow mass flow controller
v) A custom 8-channel electronic gas sampling manifold
vi) An ozone generator
vii) Altitude sampling equipment
viii) Windspeed/Vibration system control
ix) An array of FEM/FRM/BAT reference instruments
x) Custom computer software with data logging/visualization

AQ-SPEC Chamber Test Systems

Characteristic	SEnTeC-1	SEnTeC-2
Test Volume	~1.1 m^3	~1.6 m^3
Temperature Range	-32 °C to +177 °C	-70 °C to +180 °C
Humidity Range	10% to 95%	5% to 98%
Maximum Sensor Testing Capability	3-9 sensors	20+ sensors
Specialty Tests (wind, vibration, altitude)	No	Yes
Simultaneous Pollutant Testing	No	Yes
Automatic Pollutant Stabilization	No	Yes
FRM/FEM Instrument Cert.	All criteria pollutant gases and $PM_{2.5}$	All criteria pollutant gases and $PM_{2.5}$ + PM_{10}

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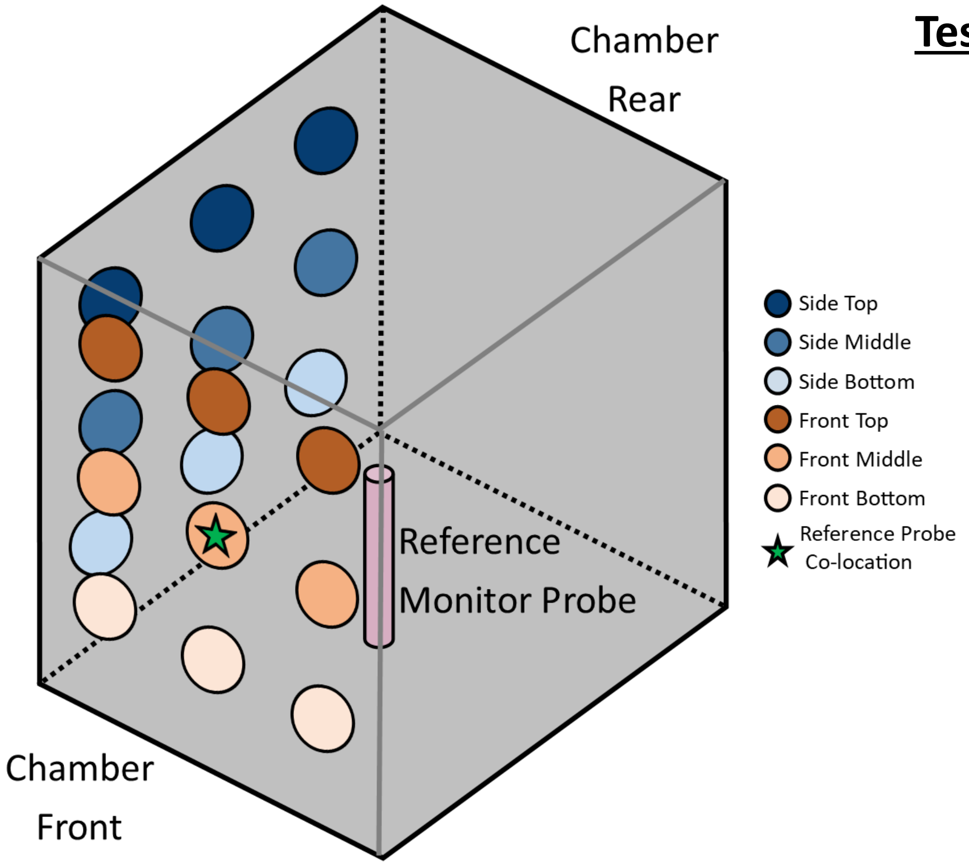
Spatial Homogeneity

- Three-point calibration curve derived by co-locating a triplicate of LCS next to the inlet of the reference monitor
- LCS then positioned at 6 different locations within the chamber
- Sensor PM values corrected according to the calibration curve and performance in each location compared to data acquired from the reference monitor



Test Pollutant: 50 µg/m³ of ammonium sulfate for one hour at each position

Orientation	Measured $PM_{2.5}$ (µg/m³)			Percent Deviation from Ref. Mean		
	Sens 1	Sens 2	Sens 3	Sens 1	Sens 2	Sens 3
Front Top	52.31	52.26	54.16	0.89	0.79	4.46
Front Middle	51.41	53.16	53.61	-0.84	2.53	3.41
Front Bottom	49.22	49.54	50.96	-5.08	-4.45	-1.71
Side Top	48.06	48.13	51.28	1.80	1.94	8.63
Side Middle	46.83	46.14	46.34	-0.80	-2.26	-1.84
Side Bottom	45.30	44.85	47.95	-4.04	-5.00	1.57

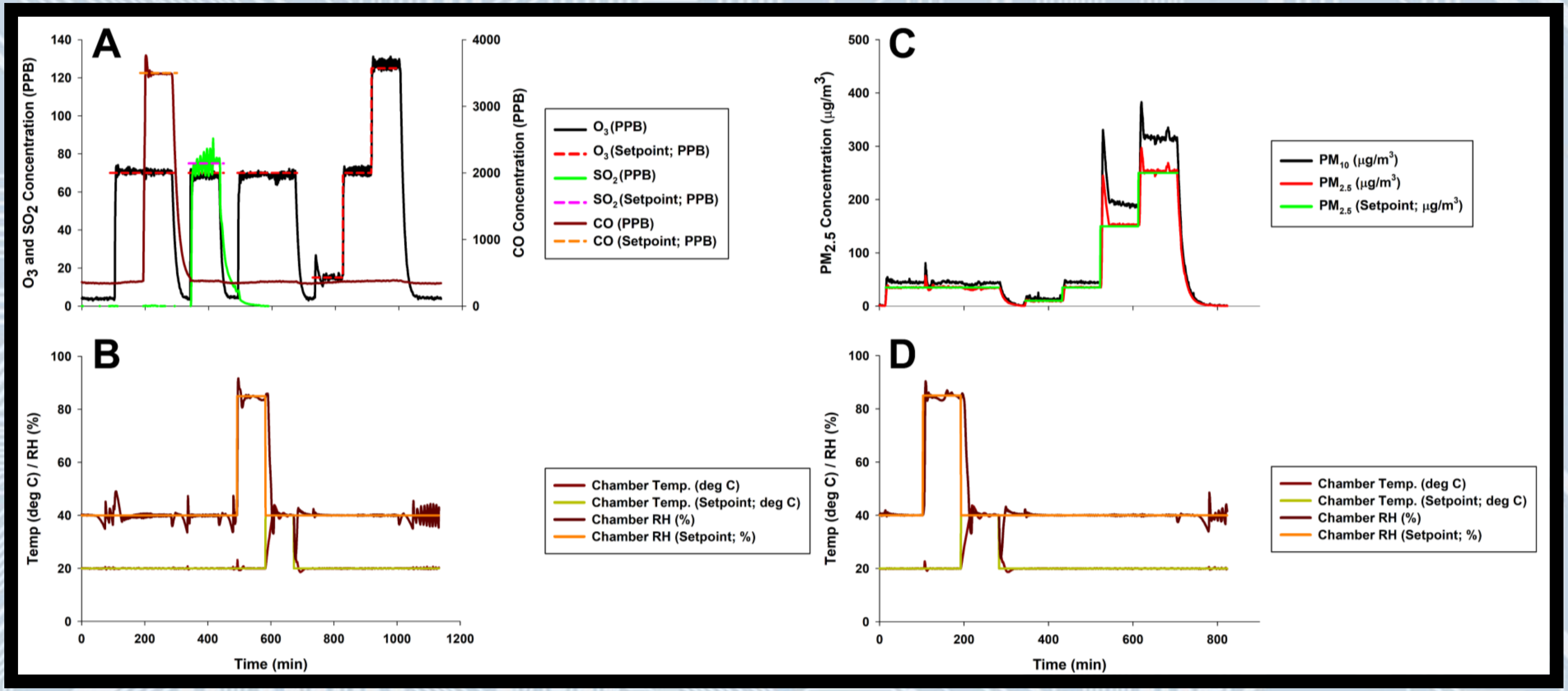
- Sensors positioned in the middle row exhibited the smallest percent deviations than sensors located in the top and bottom rows.

Take Home: LCS had comparable measurements to the reference in many tested locations within the chamber

Pollutant Generation

<u>EPA Performance Testing Protocol</u>

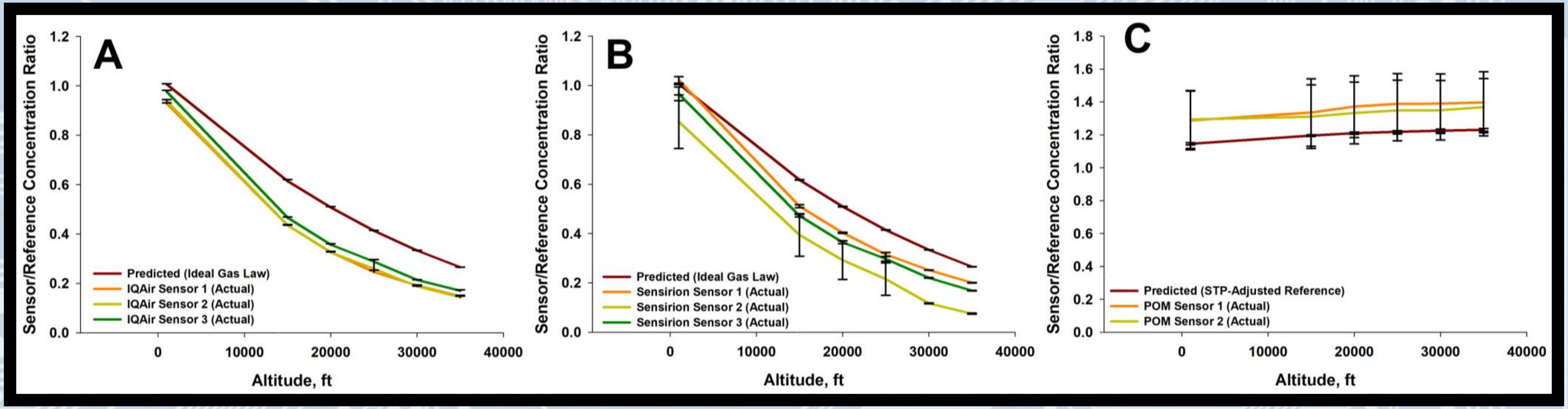
Challenges O_3 and PM sensors to temp/RH, interferent, accuracy, and drift effects



- Ozone and $PM_{2.5}$ stable throughout experiment regardless of temp/RH differences or interferents
- Sequence was pre-programmed and can be reliably repeated
- Can simultaneously produce a wide range of pollutant/environmental conditions
  - Liquid aerosol + dust aerosol + ozone + gasses
- The system can be adapted to perform other testing protocols and novel scenarios (i.e., regional pollutant mixtures)

Take Home: Enhanced testing gaseous and PM protocols can be reliably performed on the SEnTeC-2 System

Altitude Testing



A and B)

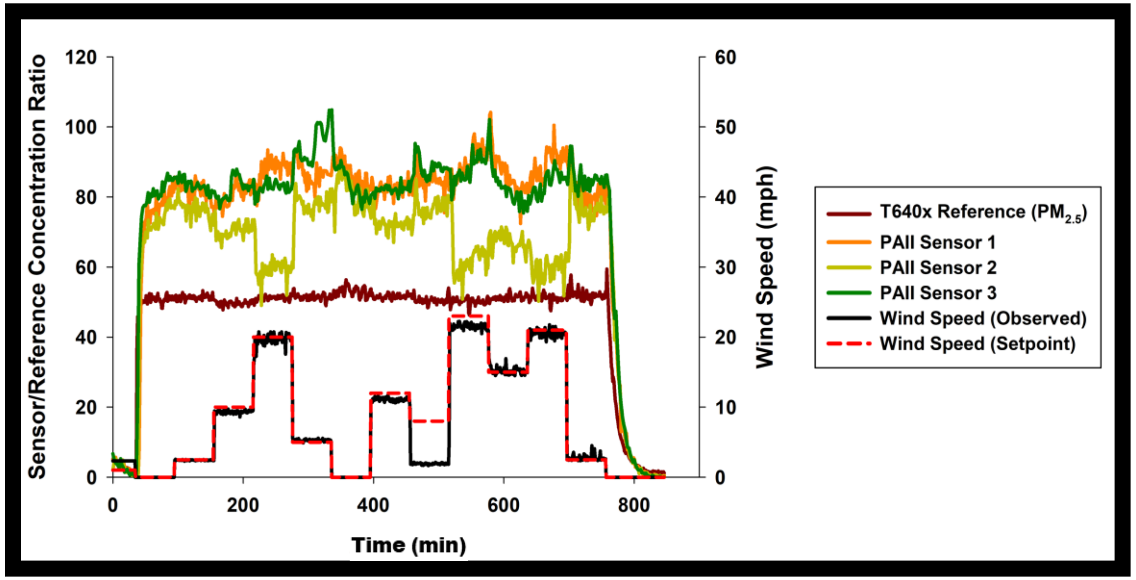
- Low-cost CO_2 sensors tested **did not** perform internal pressure/altitude correction. Data reported from the low-cost
- CO_2 sensors inside chamber observed decreasing CO_2 concentrations as altitude increased, compared to CO_2 reference monitor outside chamber
- Using Ideal Gas Law to predict CO_2 concentration inside chamber as altitude increased showed improved agreement between sensors and reference monitor

C)

- Low-cost O_3 sensor tested **did** perform internal pressure/altitude correction and reported relatively constant O_3 concentrations as altitude increased.

Take Home: Correction algorithms can be employed to predict LCS responses to gases at different altitudes

Windspeed Testing

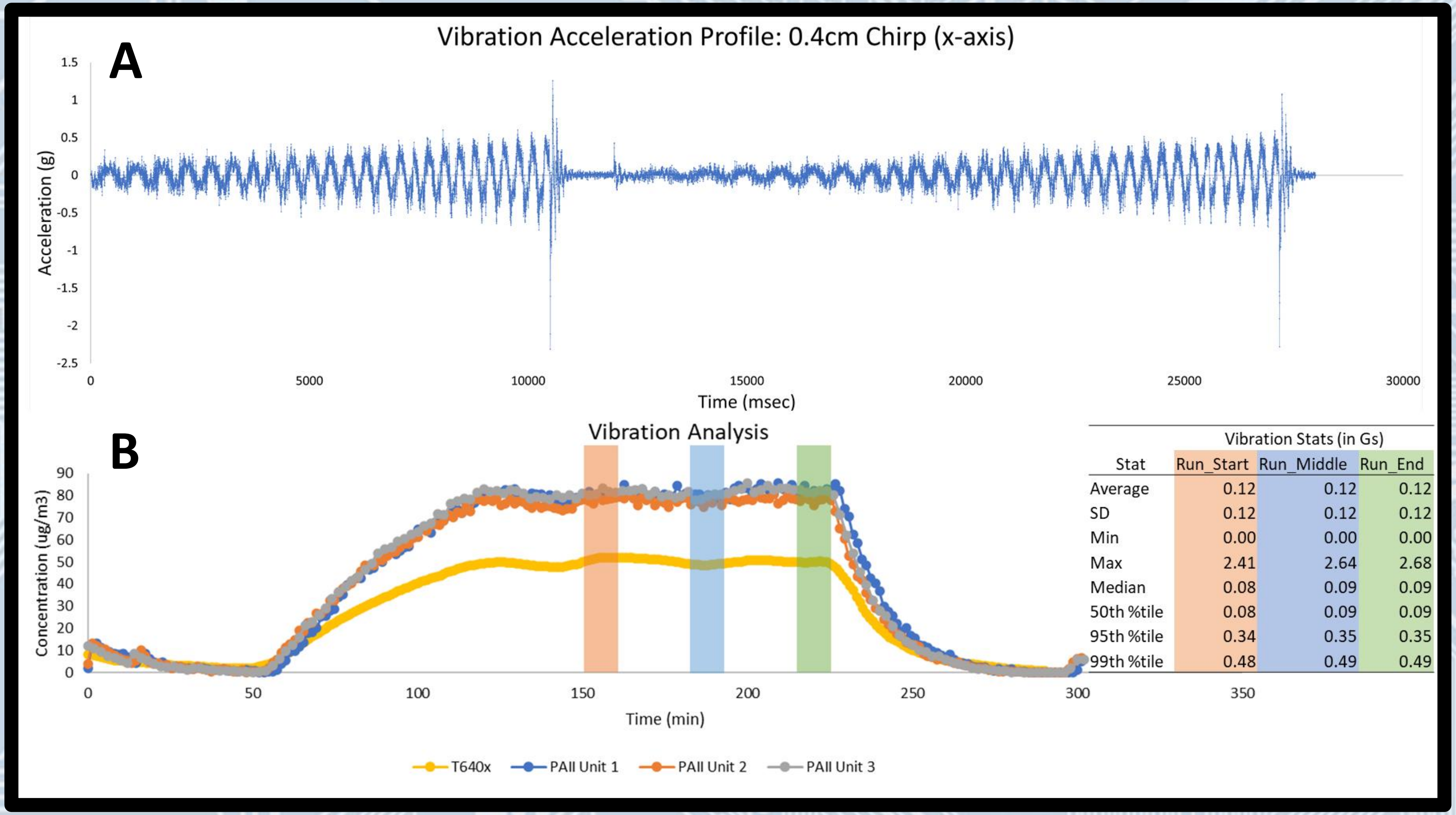


Step	Wind Speed		TSI T640x	PurpleAir II
#	SP_MPH	Actual_MPH (Avg ± SD)	PM2.5_ug/m3 (Avg ± SD)	PM2.5_ug/m3 (Avg ± SD)
1	2.50	2.57 ± 0.33	**51.76 ± 1.21**	78.38 ± 6.87
2	10.00	9.21 ± 0.92	**49.70 ± 0.64**	77.56 ± 5.72
3	20.00	19.61 ± 0.89	**51.17 ± 0.64**	76.76 ± 12.99
4	5.00	5.25 ± 0.14	**51.44 ± 0.87**	84.93 ± 6.67
5	0.00	0.60 ± 1.01	**50.75 ± 1.37**	69.70 ± 6.56
6	12.00	11.10 ± 0.25	**51.60 ± 0.69**	78.74 ± 5.17
7	8.00	2.05 ± 1.02	**50.60 ± 1.01**	82.31 ± 6.57
8	23.00	21.27 ± 2.16	**50.23 ± 1.11**	80.42 ± 13.75
9	15.00	15.21 ± 0.54	**51.24 ± 0.81**	78.97 ± 10.61
10	21.00	20.50 ± 0.51	**51.26 ± 1.07**	78.58 ± 12.97

- Graph
  - Three LCS tested over a variety of wind speeds (0-23 MPH)
- Table
  - Average windspeed and PM data at each windspeed set point
  - Windspeed maintained by control system with feedback from anemometer
  - T640 reference monitor was stable at 50 ug/m^3 throughout the test
  - LCS were more variable
    - One sensor (Purpleair PA-II) influenced more at higher windspeeds
    - Can test sensors in different orientations to assess overall wind effects

Take Home: Windspeed testing can help verify sensor performance prior to deployment in mobile applications

Vibration Testing



A. Vibration profile for standard test scenario provides repeated G-forces found to occur during normal driving conditions

B. Example vibration test using three LCS
   - Vibration was steady throughout experiment (colored columns, inlay stats)
   - LCS units performed normally regardless of vibration status

PAII Experiment Statistics	
Intra model average	80.16 µg/m³
Intra model SD	2.38 µg/m³
Intra model RSD	2.97 µg/m³
Intra model accuracy	41.07 %
Intra model precision	97.03 %

Take Home: Vibration testing can help verify sensor performance prior to deployment in mobile applications

Wrap-up: Advancing Today's Sensor Testing To Meet Tomorrow's Sensor Needs

- The SEnTeC-2 system is a new tool that has been designed to reliably and repeatedly test particulate and gas LCS under a wide range of environmental conditions
- The LCS had comparable measurements to the reference monitor in many tested locations within the chamber validating spatial homogeneity within the test space
- Advanced gaseous and PM testing protocols (i.e., the ASTM designation for the approved standard D8405-21: Standard Test Method for PM2.5 Sensors or Sensor Units Used in Indoor Air Applications and the EPA's Performance Testing Protocol for Fine Particulate Matter and Ozone Air Sensors) can be reliably performed on the system
- LCS response to altitude can be compared to the Ideal Gas Law
- Wind speed and vibration testing can help verify sensor performance prior to mobile applications
- The system can be adapted to perform other testing protocols and novel scenarios (i.e., regional pollutant mixtures)

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Thank You!

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