Laboratory Evaluation

PurpleAir PA-I PM Sensor

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South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **PurpleAir PA-I PM Sensors** that were previously evaluated for their performance in the field (deployment period: 02/19/2016 to 04/19/2016) under ambient environmental conditions, have now been evaluated in the SCAQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity.

PurpleAir PMS1003 (*3 units tested*):

- Particle sensors (optical; non-FEM)
- Each unit measures: $PM_{1.0}$, $PM_{2.5}$, PM_{10} mass concentration (µg/m^3) and the numbers of particles with diameters larger than 0.3, 0.5, 1.0, 2.5, 5.0, and 10.0 µm in 0.1 L of air (count concentration in #/dl)
- Unit cost: ~$150
- Time resolution: 20-sec
- Units IDs: 22d0, 2336, b610

GRIMM (*ref. $PM_{2.5}$ mass*):

- Optical particle counter
- FEM $PM_{2.5}$
- Uses proprietary algorithms to calculate total PM, $PM_{2.5}$, and $PM_{1.0}$ mass conc. from particle number measurements
- Cost: ~$25,000

TSI APS 3321 (AQ-SPEC *ref. method for PM_{10} mass*):

- Aerodynamic particle sizer
- Measures particles from 0.5 to 20 µm
- Uses a patented, double-crest optical system for unmatched sizing accuracy
- Cost: ~$50,000

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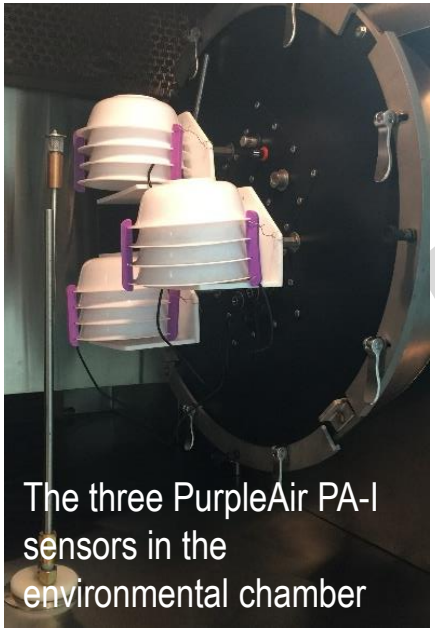
Evaluation results guideline

- PurpleAir *vs* GRIMM $PM_{1.0}$ mass concentration
- PurpleAir *vs* GRIMM $PM_{2.5}$ mass concentration
- PurpleAir *vs* APS *vs* GRIMM PM_{10} mass concentration


The three PurpleAir PA-I sensors in the environmental chamber

GRIMM

TSI APS 3321

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Evaluation results for PurpleAir $PM_{1.0}$ mass

GRIMM *vs* PurpleAir PA-I

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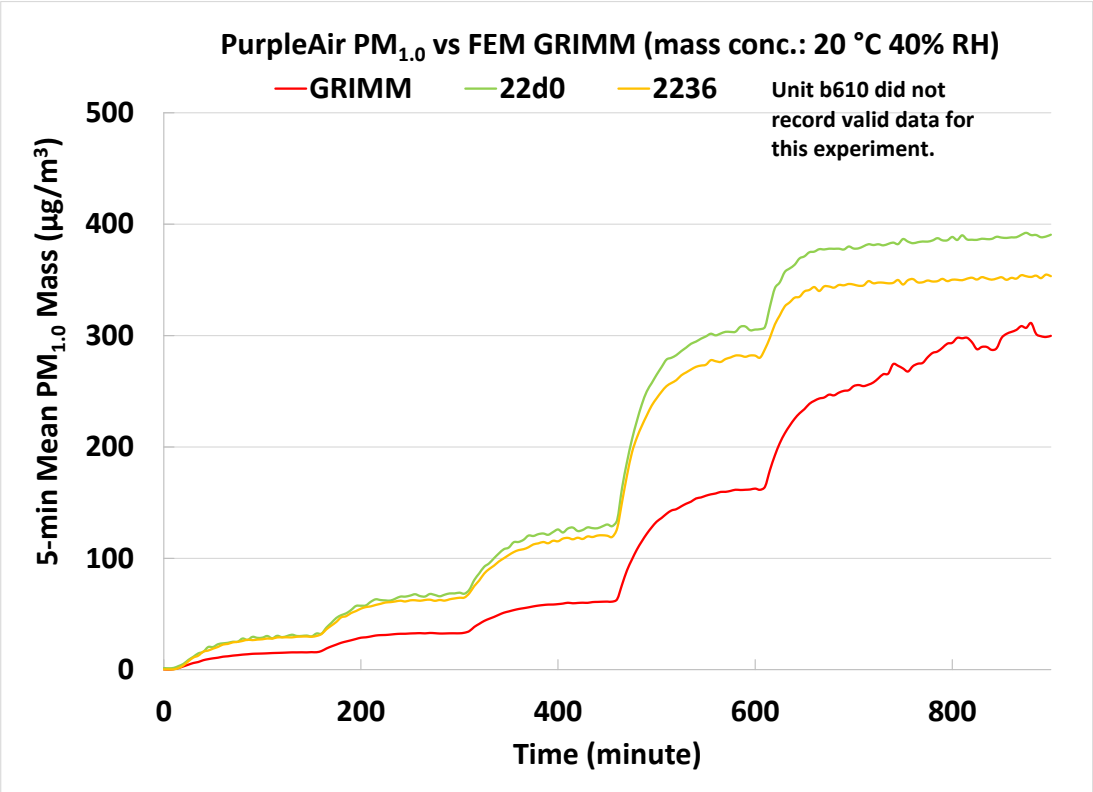
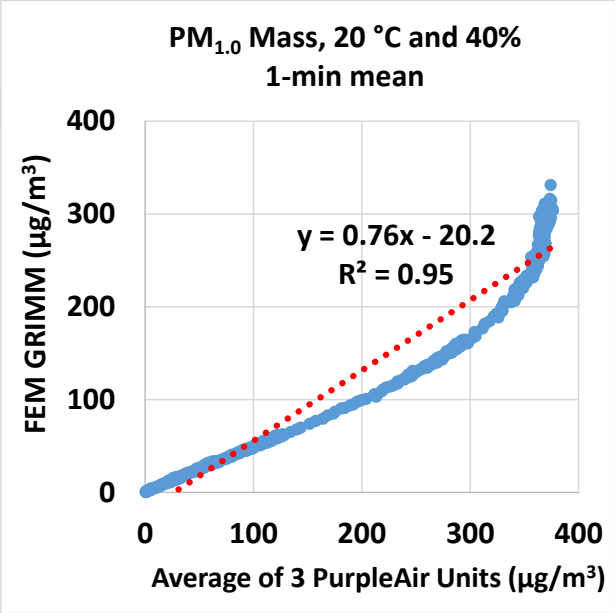
Coefficient of Determination: PA-I vs GRIMM $PM_{1.0}$



Linearity of unit response



- Over the full $PM_{1.0}$ concentration range tested (0-300 µg/m^3), PurpleAir units 22d0 and 2336 tracked well the diurnal variations as recorded by the FEM GRIMM.
- For this experiment, Unit b610 did not record valid measurements, probably due to the miscommunication with WiFi. Later, Unit b610 resumed normal data logging by itself.

- Three PurpleAir units showed good correlation with FEM GRIMM $PM_{1.0}$ measurement data (R^2 = 0.95) between 0-300 µg/m^3.
- The PurpleAir units overestimated the FEM GRIMM $PM_{1.0}$ concentration.

PurpleAir PA-I Accuracy

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (µg/m³)	FEM (µg/m³)	Accuracy (%)
1	30.3	15.7	7.2
2	65.8	32.8	-0.8
3	124.3	60.9	-4.1
4	293.8	161.9	18.5
5	365.7	269.9	64.5
6	371.7	302.6	77.2

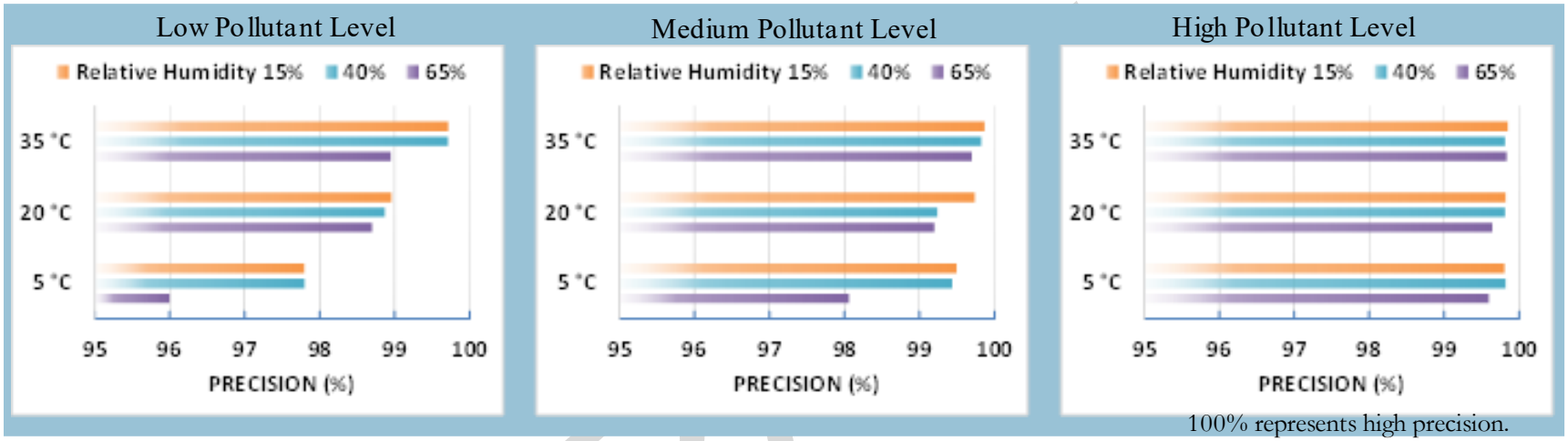
- The three PurpleAir units showed low accuracy compared to GRIMM $PM_{1.0}$ over the concentration range of 0-160 µg/m³. At higher $PM_{1.0}$ concentration (200-300 µg/m³), PurpleAir sensors' accuracy increased to up to 77%. In general, PurpleAir sensors overestimated the $PM_{1.0}$ mass measured by FEM GRIMM.

PA-I Data Recovery & Intra-model Variability

- Data recovery for $PM_{1.0}$ mass concentration from 22d0, 2336, and b610 was 100%, 100%, and 74.5%, respectively.
- Low $PM_{1.0}$ measurement variations were observed between the 22d0 and 2336. Unit b610 did not record valid data during the intra-model variability test.

PA-I Precision

- Precision (%, Effect of $PM_{1.0}$ conc.,Temperature and Relative Humidity)



- Overall, the three PurpleAir units showed high precision for all combinations of low, medium and high $PM_{1.0}$ conc., T, and RH.
- FEM GRIMM's precision was also high across all conditions.

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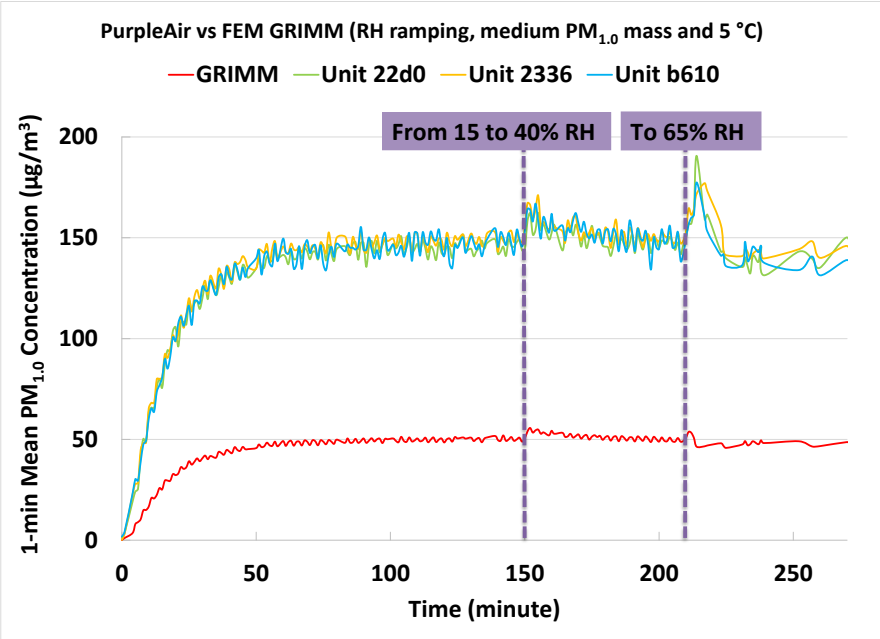
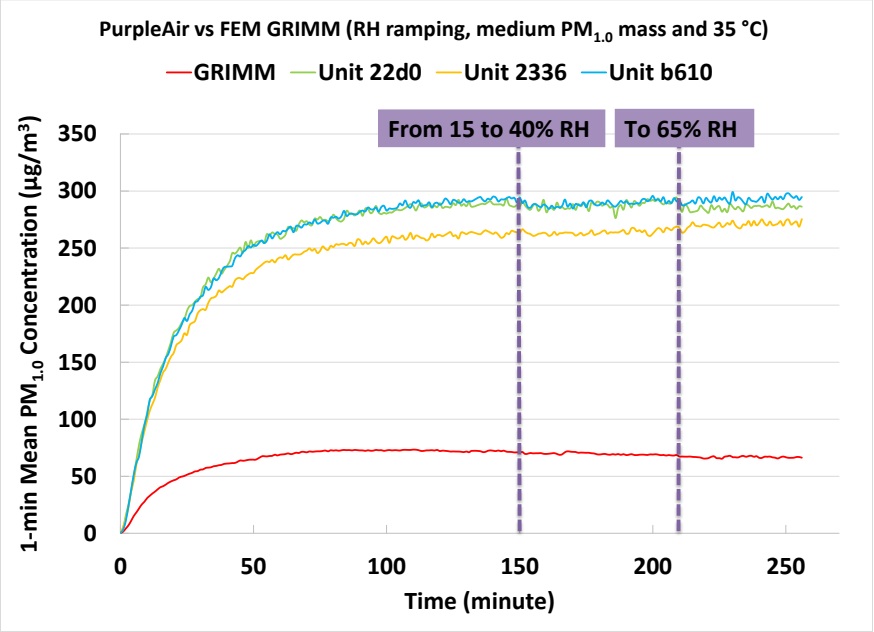
PA-I Climate Susceptibility



Low Temp – RH ramping
(medium conc.)



High Temp – RH ramping
(medium conc.)

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Evaluation results for PurpleAir $PM_{2.5}$ mass

GRIMM *vs* PurpleAir PA-I

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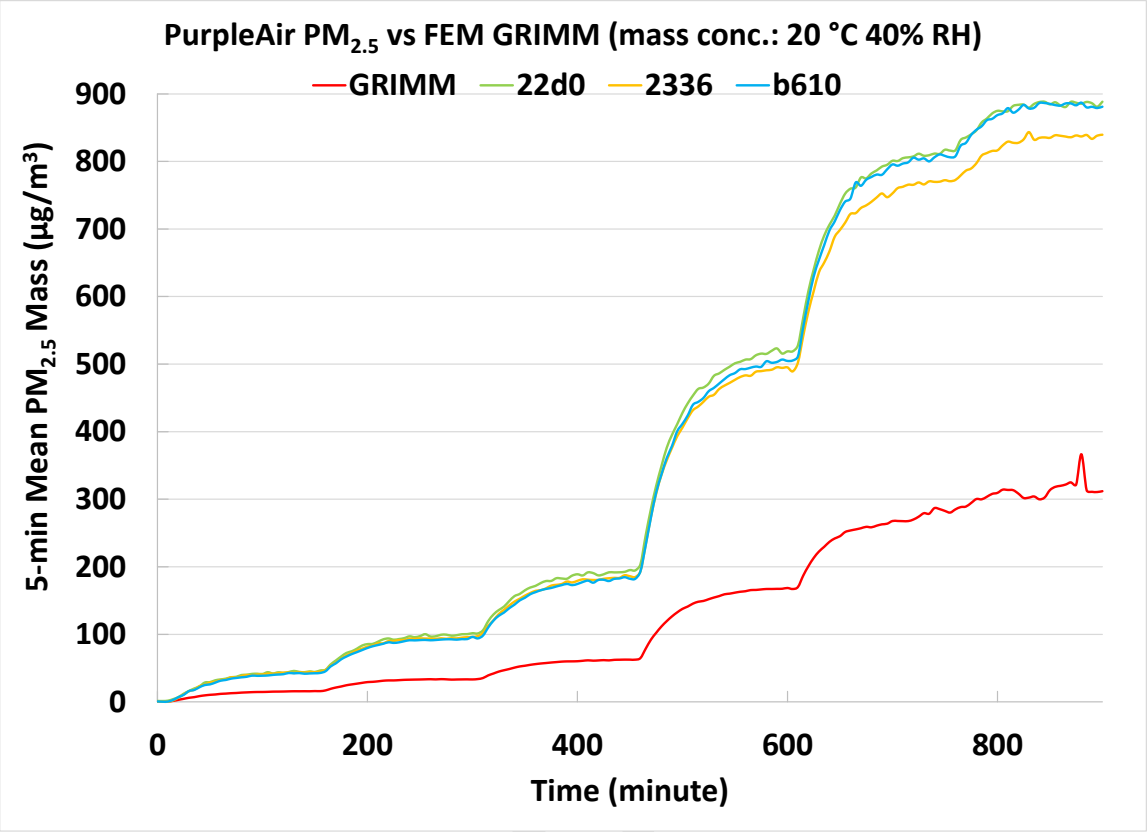
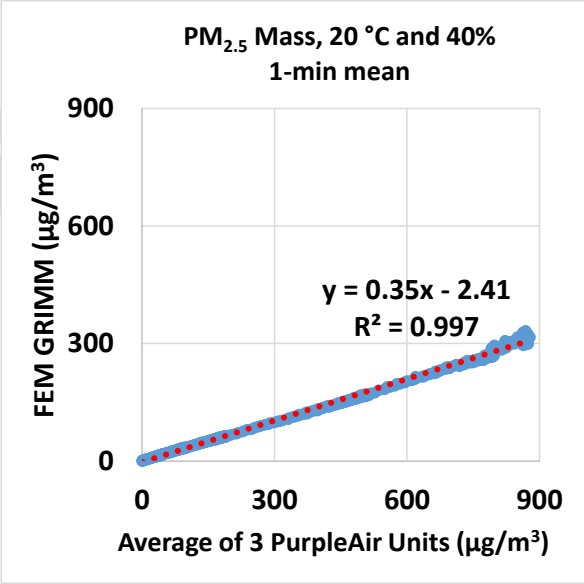
Coefficient of Determination: PA-I vs FEM GRIMM $PM_{2.5}$





- Over the full $PM_{2.5}$ concentration range tested (0-300 µg/m^3), the PurpleAir units tracked well the diurnal variations as recorded by the FEM GRIMM.

- Three PurpleAir units showed good correlation with FEM GRIMM $PM_{2.5}$ measurement data ($R^2 > 0.99$) between 0-300 µg/m^3.

- The PurpleAir units overestimated the FEM GRIMM $PM_{2.5}$ concentration.

PurpleAir PA-I Accuracy

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (µg/m³)	FEM (µg/m³)	Accuracy (%)
1	43.8	15.9	-74.8
2	96.5	33.4	-88.6
3	187.0	62.4	-99.7
4	505.4	167.6	-101.6
5	796.2	282.6	-81.7
6	866.9	322.1	-69.1

- The three PurpleAir units showed low accuracy compared to GRIMM $PM_{2.5}$ over the concentration range test (0-300µg/m³). At all steady-states, the sensors overestimated the FEM GRIMM by more than 100%, therefore, the calculated accuracy reported negative values at all concentration levels.

PA-I Data Recovery & Intra-model Variability

- Data recovery for $PM_{2.5}$ mass concentration from all three units was 100%.
- Low $PM_{2.5}$ measurement variations were observed between the three units.

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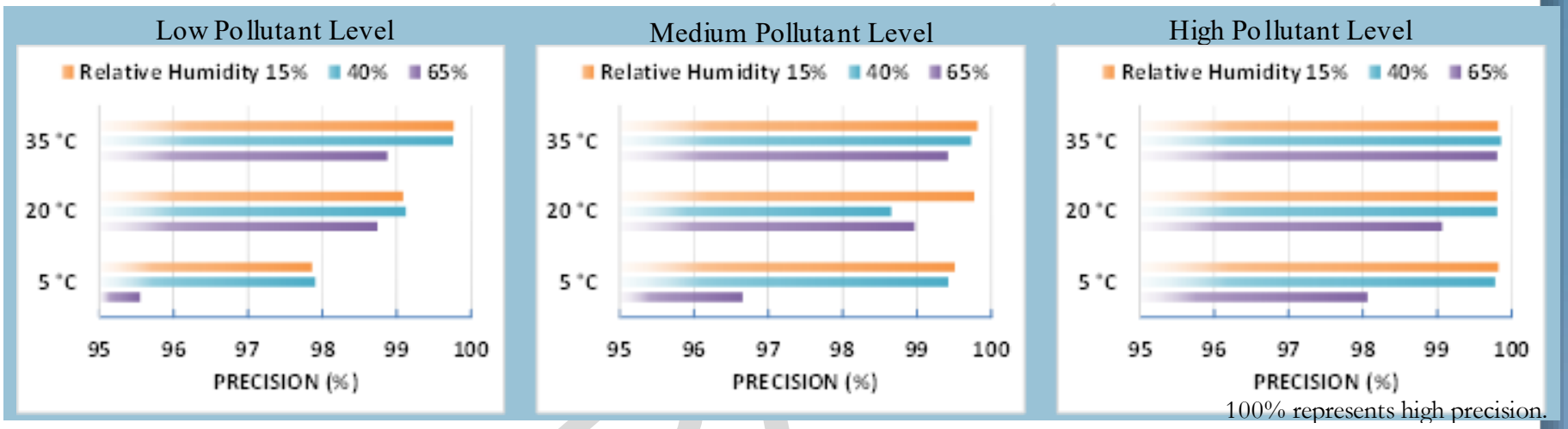
PA-I Precision

- Precision (Effect of $PM_{2.5}$ conc.,Temperature and Relative Humidity)



100% represents high precision.

- Overall, the three PurpleAir units showed high precision for all combinations of low, medium and high $PM_{2.5}$ conc., T, and RH. At 5 °C and 65% RH, the precision was slightly lower than that for other conditions.
- FEM GRIMM's precision was also high across all conditions.

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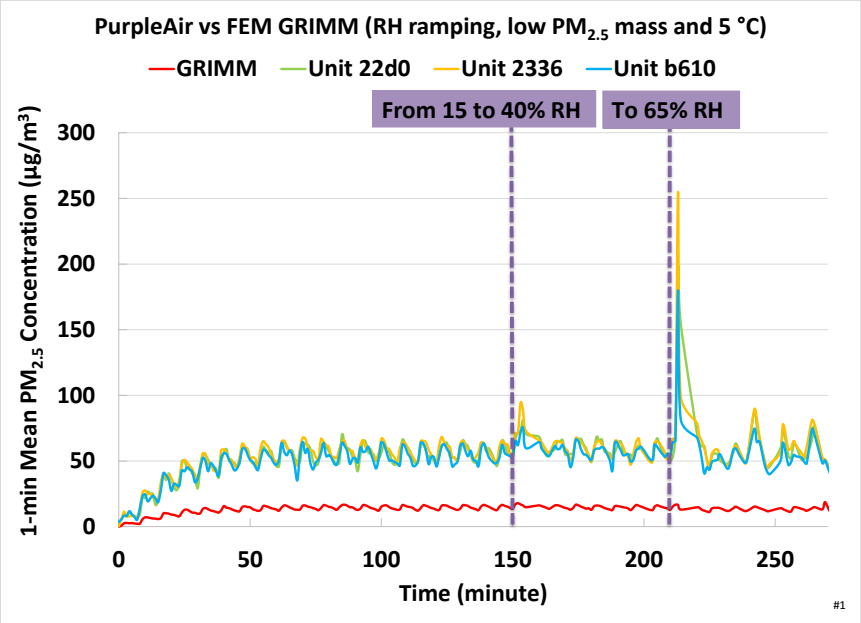
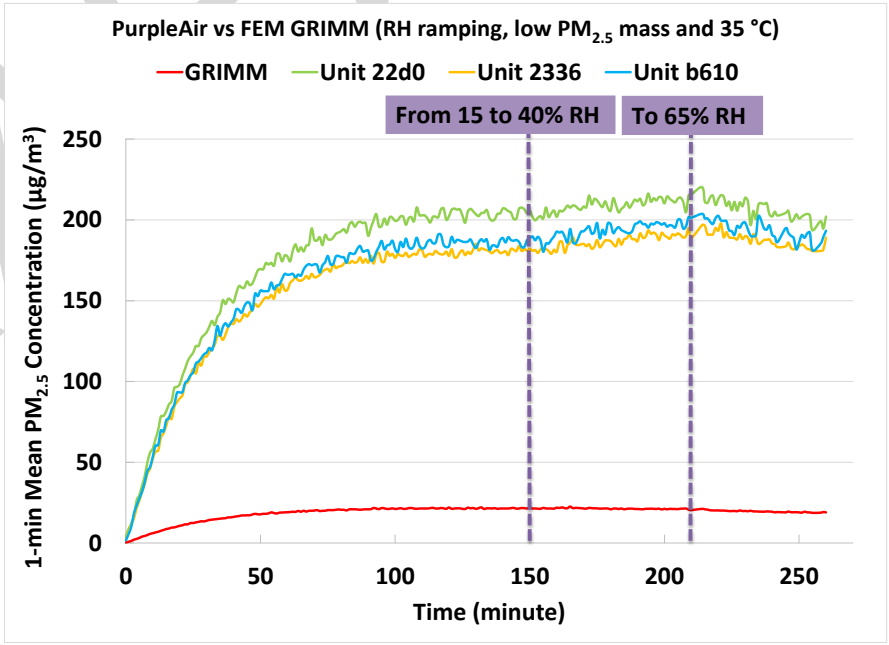
PA-I Climate Susceptibility



Low Temp – RH ramping (medium conc.)



High Temp – RH ramping (medium conc.)

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Discussion

- **Accuracy**: Overall, the three PurpleAir units have low accuracy, compared to the FEM GRIMM $PM_{1.0}$ and $PM_{2.5}$ in the range 0.0 to 300 µg/m^3. The three PurpleAir units overestimated the $PM_{1.0}$ and $PM_{2.5}$ mass measured by FEM GRIMM. (refer to slide 6 and 11).
- **Precision**: PurpleAir units have high precision for almost all test combinations (PM concentrations, T and RH). (refer to slide 7 and 12)
- **Intra-model variability**: Low intra-model variability was observed among the PurpleAir units (slide 6, 11). Unit b610 had miscommunication with WiFi for a period of time.
- **Data Recovery:** Data recovery for $PM_{2.5}$ from all three sensors was 100%. For PurpleAir and all WiFi enabled devices, the data logging happens in the background and there is no alert/notification on the device(s) when they stop logging.
- **Linearity of sensor response**: PurpleAir units showed good correlation/linear response with the corresponding GRIMM $PM_{1.0}$ and $PM_{2.5}$ measurement data (R^2 = 0.95 and 0.99, respectively) for mass concentration range between 0 and 300 µg/m^3 (refer to slides 5 and 10)
- **Climate susceptibility**: From the laboratory studies, temperature and relative humidity had minimal effect on the PurpleAir units' precision. At low temperature (5 °C) and the set-points of RH changes, units reported spiked changes in concentrations.

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Evaluation report for PM_{10} mass

APS *vs* PurpleAir PA-I

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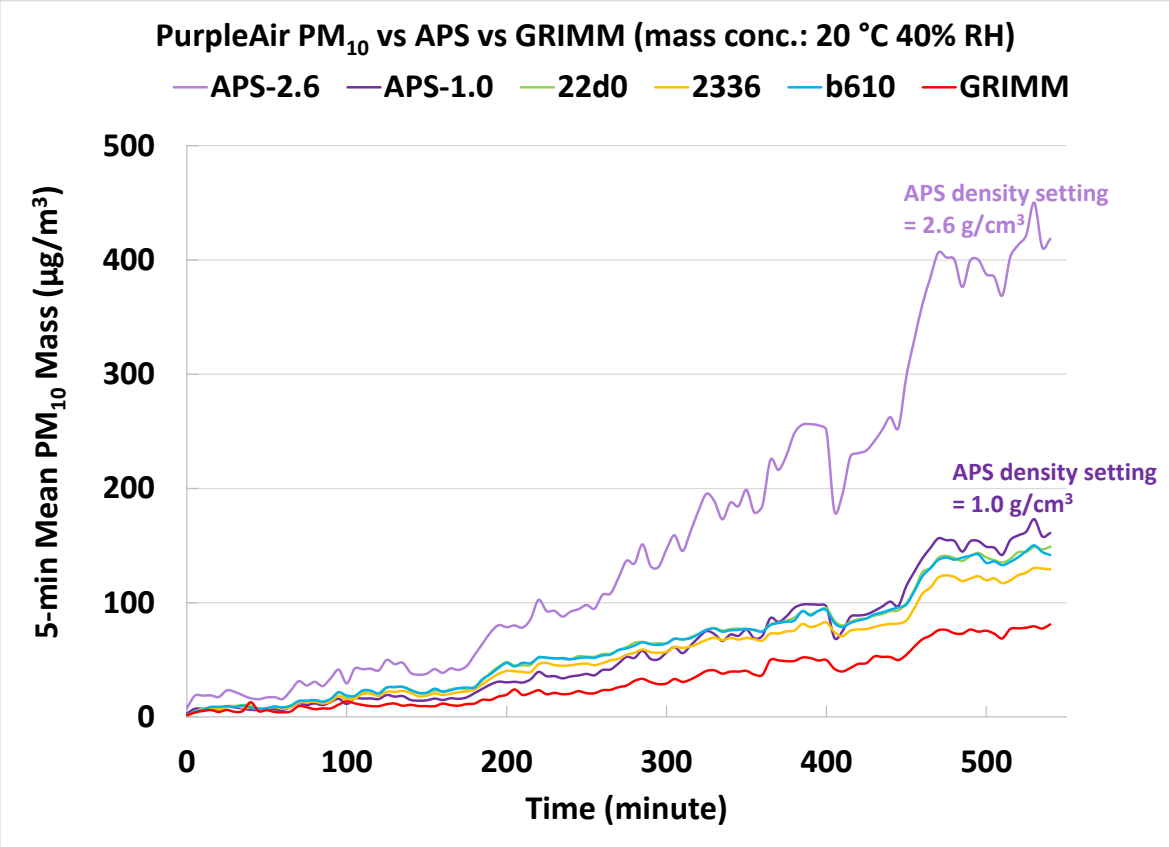
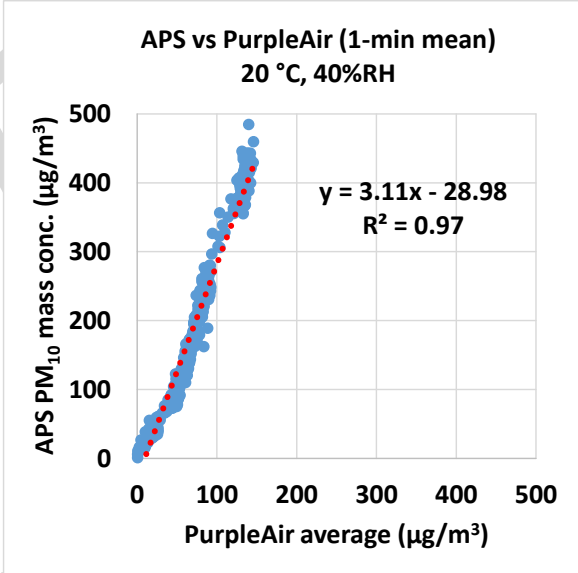
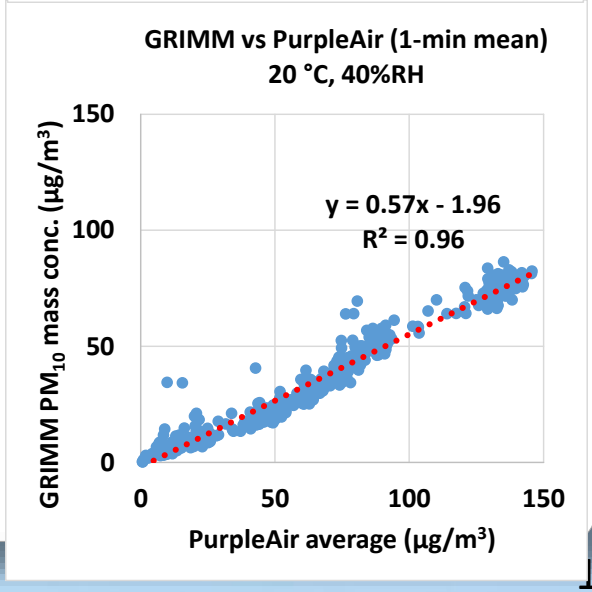
Coefficient of Determination: PA-I vs GRIMM vs APS



Linearity of unit response





- Over the full PM_{10} concentration range tested (0-450 µg/m^3 as measured by APS using 2.6 g/cm^3), the three PurpleAir units tracked well the diurnal variations as recorded by the APS and GRIMM.

PurpleAir PA-I Accuracy

- Accuracy (20 °C and 40% RH)

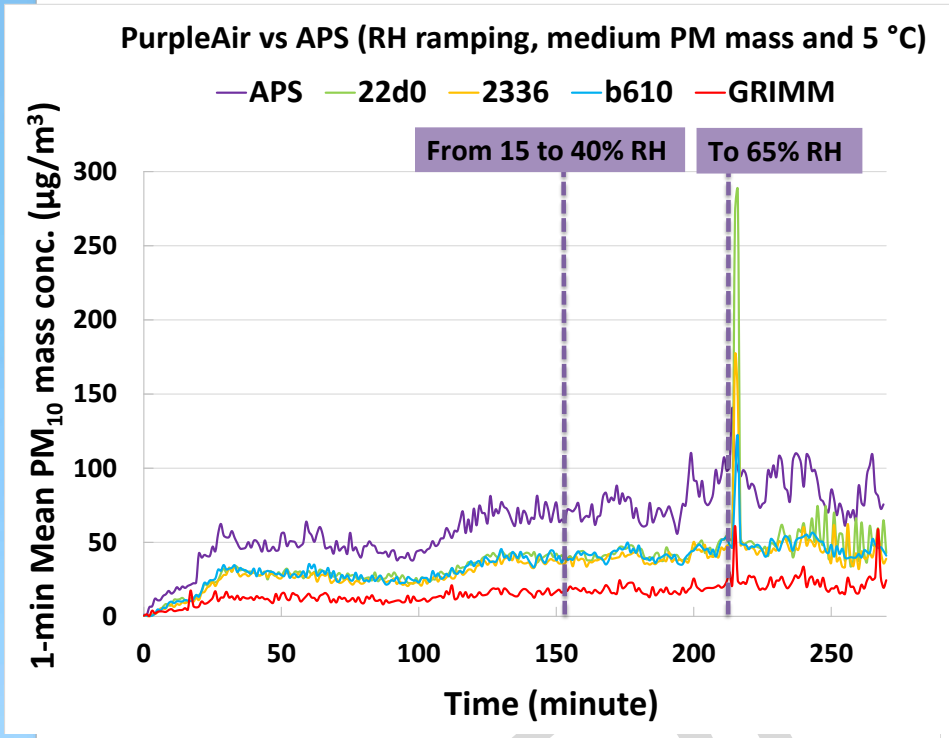
Steady State (#)	Sensor mean (μg/m^3)	APS-2.6 (μg/m^3)	Accuracy (%)
1	14.9	33.9	43.9
2	25.4	54.3	46.8
3	56.0	121.8	46.0
4	72.2	184.9	39.0
5	94.2	297.9	31.6
6	140.0	418.5	33.4

- When compared against APS using 2.6 g/cm^3 as particle density (for potassium chloride), the PurpleAir units have accuracy between 31.6 and 46.8%.

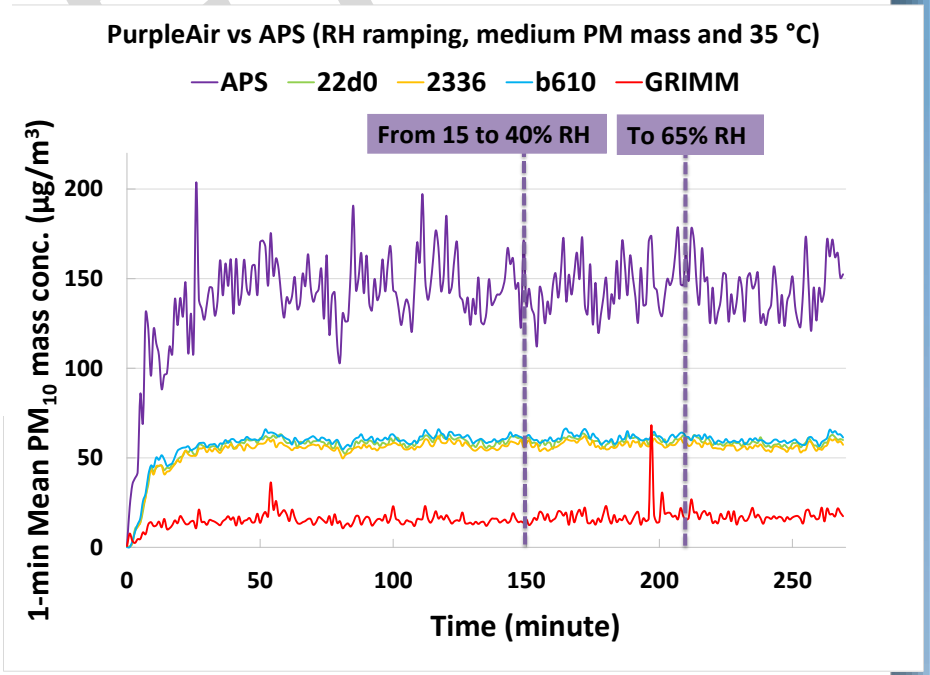
PA-I Data Recovery & Intra-model Variability

- Data recovery for PM_{10} mass concentration from 22d0, 2336, and b610 were 100%, 66.0%, and 100%.
- Low $PM_{2.5}$ measurement variations were observed between the three units.

PA-I Climate Susceptibility



Low Temp – RH ramping (medium conc.)



High Temp – RH ramping (medium conc.)

Discussion (PM_{10} mass)

- **Accuracy**: When compared against APS using particle density of 2.6 g/cm^3, the PurpleAir units have accuracy of 31.6 to 46.8%. The three PurpleAir units reported PM_{10} mass concentration closer to APS using particle density of 1.0 g/cm^3 than using 2.6 g/cm^3 and accuracy ranges from 82.2 to 98.5%. (slide 17)
- **Precision**: Due to the nature of Arizona test dust, the aerosol concentration showed about 20% variability in the chamber, therefore, the precision cannot be fairly estimated. As observed in the climate susceptibility experiments, APS showed higher sensitivity to the aerosol concentration changes than the three PurpleAir units did (refer to slide 18).
- **Intra-model variability**: Low intra-model variability was observed among the PurpleAir units (slide 17).
- **Data Recovery:** Data recovery for PM_{10} mass concentration from 22d0, 2336, and b610 were 100%, 66.0%, and 100%. Unit 2336 was not logging data for a period of time, and was resumed logging after restart. The PurpleAir WiFi enabled devices do not have the capability of notifying the user when WiFi connection is lost and data logging has either stopped or has been interrupted.
- **Linearity of sensor response**: PurpleAir units showed good correlation/linear response with the corresponding APS PM_{10} ($R^2 > 0.97$) and GRIMM PM_{10} ($R^2 > 0.96$). (refer to slides 16)
- **Climate susceptibility**: From the laboratory studies, temperature and relative humidity had minimal effect on the PurpleAir units' precision. At low temperature (5 °C) the set-points of RH changes, units reported spiked changes in concentrations.

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