Laboratory Evaluation

Kunak Air A10 - PM

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South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **Kunak Air A10** (Hereinafter **Kunak**) sensors (units IDs: 0000, 0001 and 0002) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (04/28/2019 to 07/11/2019) under ambient environmental conditions and have now been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity. The same three Kunak units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

- ***Kunak*** *(3 units tested)*:
  - **Particle sensor: AlphaSense OPC N3 (optical; non-FEM)**
  - Gas sensors: AlphaSense B4 series (electrochemical; non-FEM)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)[1], Ozone (ppb), CO (ppb), NO, NO_2, NO_x (ppb), temperature (°C), RH (%), pressure, [2]Wind Speed (km/h), [2]Wind Direction (degree)
  - [3]Unit cost: ~$7,900 (PM + Gas); $3,000 (PM only) and $5,000 (4 gases, temp/RH, anemometer and solar panel)
  - Time resolution: 5-min
  - Units IDs: 0000, 0001, 0002

Note: all results presented here are 5-min averages due to the 5-min time resolution of the Kunak sensors

[1]Parameters tested in this laboratory evaluation
[2]Only available in Unit 0002
[3]4G LTE, 9w solar panel, includes 1-yr cell connectivity, tech support, cloud data access for configuration, calibration, firmware upgrade, alarms, data validation, reporting, advanced analytics, APIrest.

GRIMM (*reference method*):

- Optical particle counter
- FEM $PM_{2.5}$
- Uses proprietary algorithms to calculate total PM, $PM_{2.5}$, and PM_1 mass conc. from particle number measurements
- Cost: ~$25,000
- Time resolution: 1-min

TSI APS 3321 (*reference 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

- Kunak Air A10 vs GRIMM $PM_{1.0}$ mass concentration
- Kunak Air A10 vs FEM GRIMM $PM_{2.5}$ mass concentration
- Kunak Air A10 vs GRIMM vs APS PM_{10} mass concentration

Kunak Air A10

TSI APS 3321

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Evaluation results for $PM_{1.0}$ mass concentration

Kunak vs GRIMM

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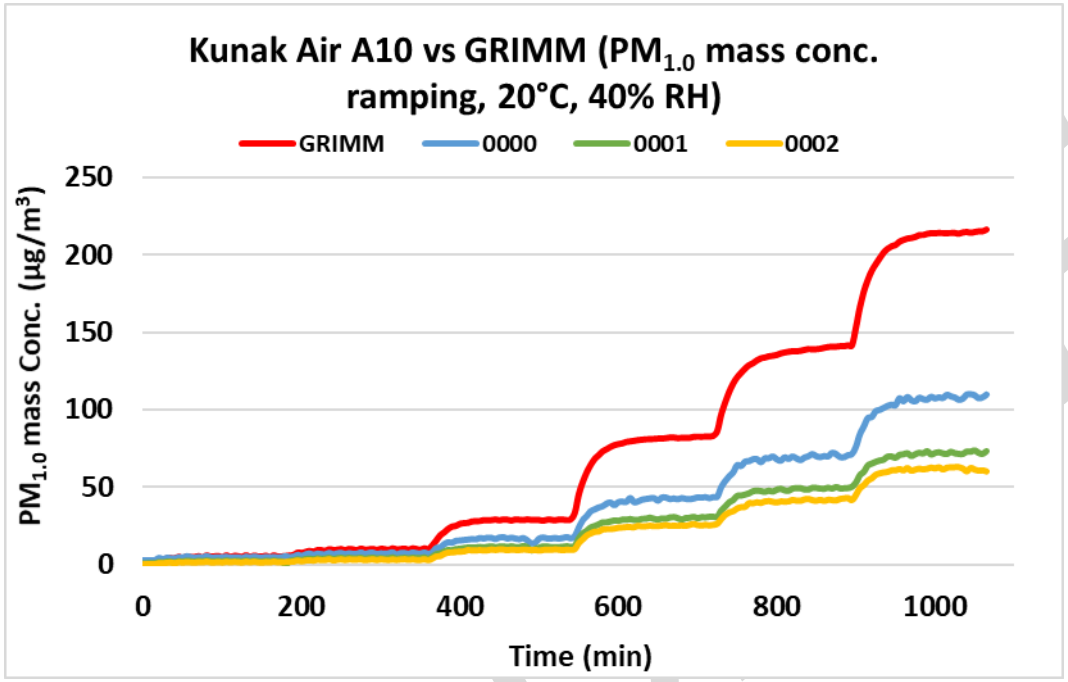
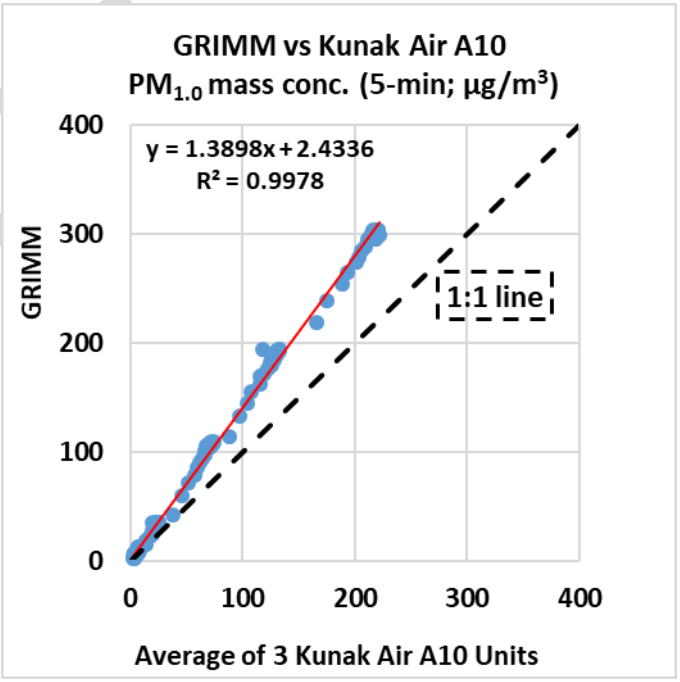
Kunak vs GRIMM ($PM_{1.0}$ mass conc.)



Coefficient of Determination



- The Kunak sensors tracked well with the $PM_{1.0}$ concentration variation as recorded by the GRIMM in the concentration range of 0 - ~200 µg/m^3.
- The Kunak sensors showed very strong correlations with the GRIMM $PM_{1.0}$ mass conc. ($R^2 > 0.99$).

Kunak vs GRIMM $PM_{1.0}$: Accuracy

- Accuracy (20 °C and 40% RH)

Steady state #	Sensor Mean (µg/m³)	GRIMM (µg/m³)	Accuracy (%)
1	2.9	5.5	52.7
2	5.0	10.0	50.1
3	13.0	29.9	43.4
4	33.3	83.4	39.9
5	54.1	141.1	38.3
6	80.8	215.0	37.6

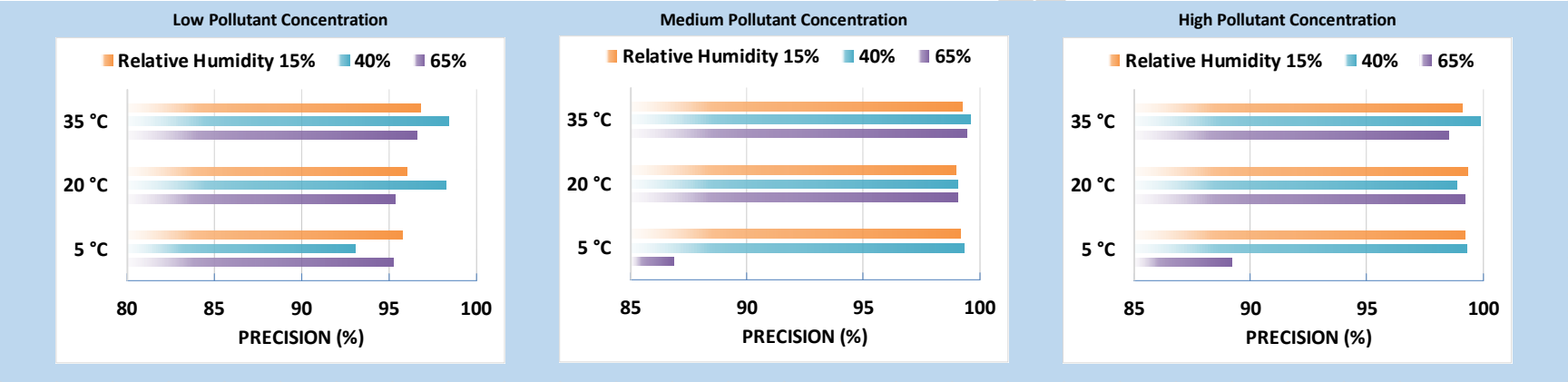
- The Kunak sensors underestimated GRIMM $PM_{1.0}$ mass concentration. The accuracy of the Kunak sensors decreased as $PM_{1.0}$ mass concentrations increased.

Kunak : Data Recovery and Intra-model Variability

- Data recovery for $PM_{1.0}$ mass concentration from all units was 100%
- High $PM_{1.0}$ measurement variations were observed between the Kunak sensors

Kunak $PM_{1.0}$: Precision

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



- Overall, the Kunak sensors showed high precision for all of the combinations of low, medium and high $PM_{1.0}$ conc., T and RH except at medium and high $PM_{1.0}$ conc. under 5 °C/65% RH.

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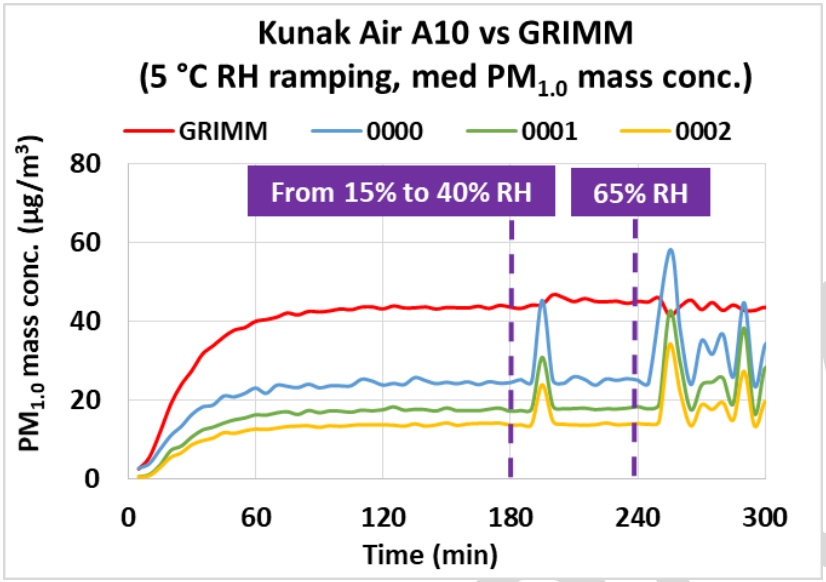
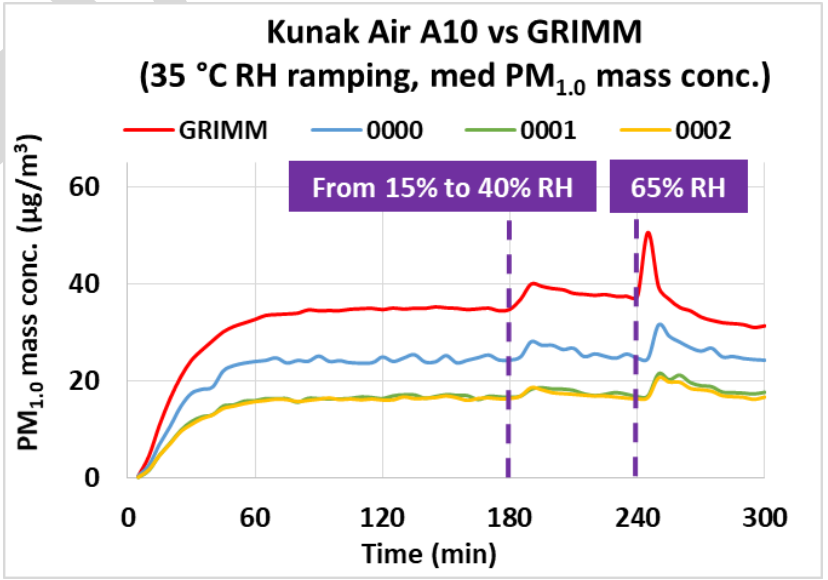
Kunak $PM_{1.0}$: Climate Susceptibility



Low Temp – RH ramping (medium conc.)

High Temp – RH ramping (medium conc.)



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Evaluation results for $PM_{2.5}$ mass concentration

Kunak vs FEM GRIMM

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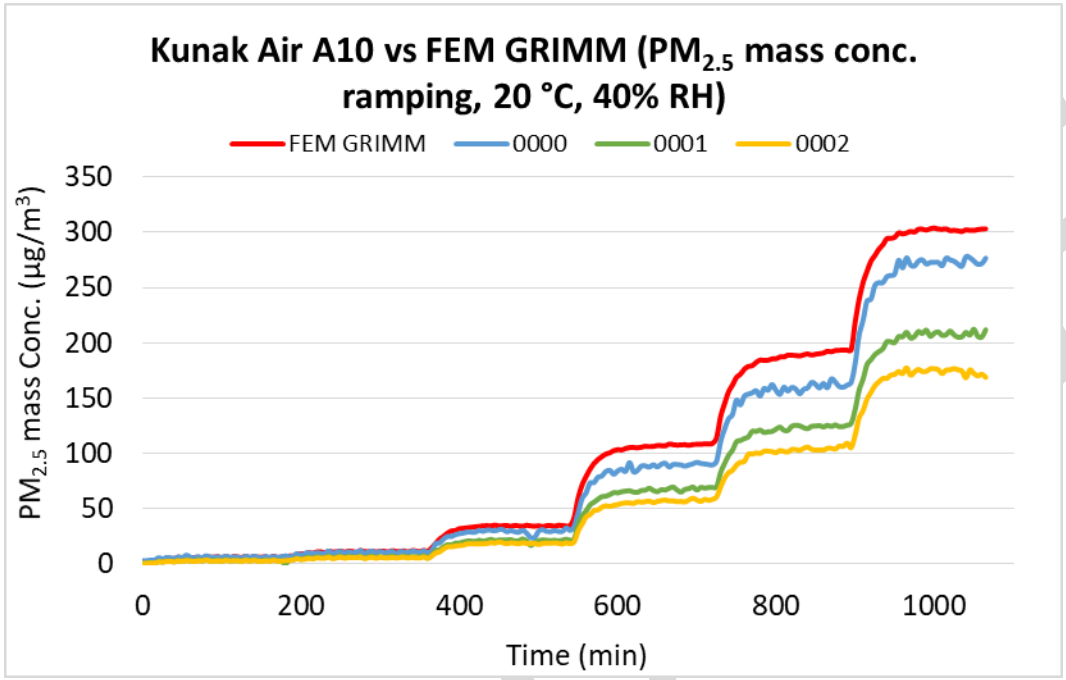
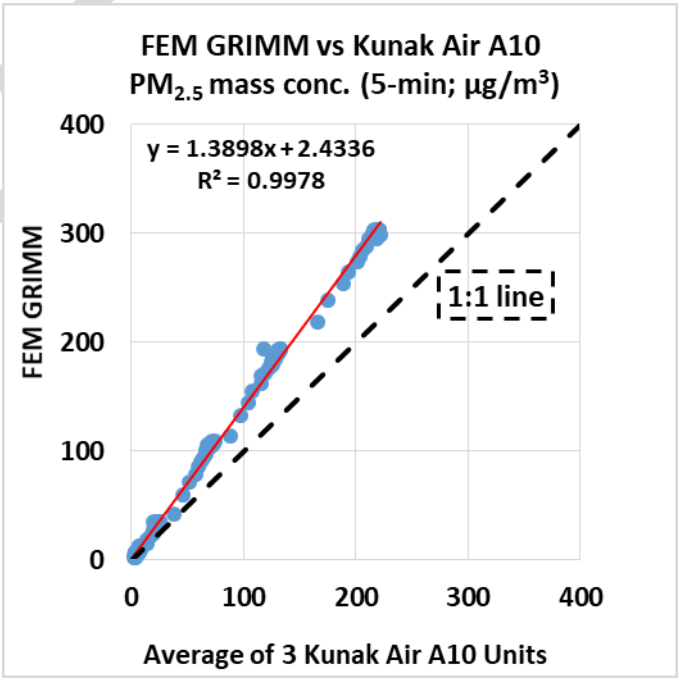
Kunak vs FEM GRIMM ($PM_{2.5}$ mass conc.)



Coefficient of Determination



- The Kunak sensors tracked well with the concentration variation as recorded by the FEM GRIMM in the concentration range of 0 - ~300 µg/m³.

- The Kunak sensors showed very strong correlations with the FEM GRIMM $PM_{2.5}$ mass conc. (R^2 > 0.99)

Kunak vs FEM GRIMM $PM_{2.5}$ Accuracy

- Accuracy (20 °C and 40% RH)

Steady state #	Sensor Mean (µg/m³)	FEM GRIMM (µg/m³)	Accuracy (%)
1	4.4	6.6	66.7
2	7.7	11.5	66.6
3	24.0	36.3	66.2
4	72.9	109.8	66.3
5	131.4	193.4	67.9
6	218.2	301.7	72.3

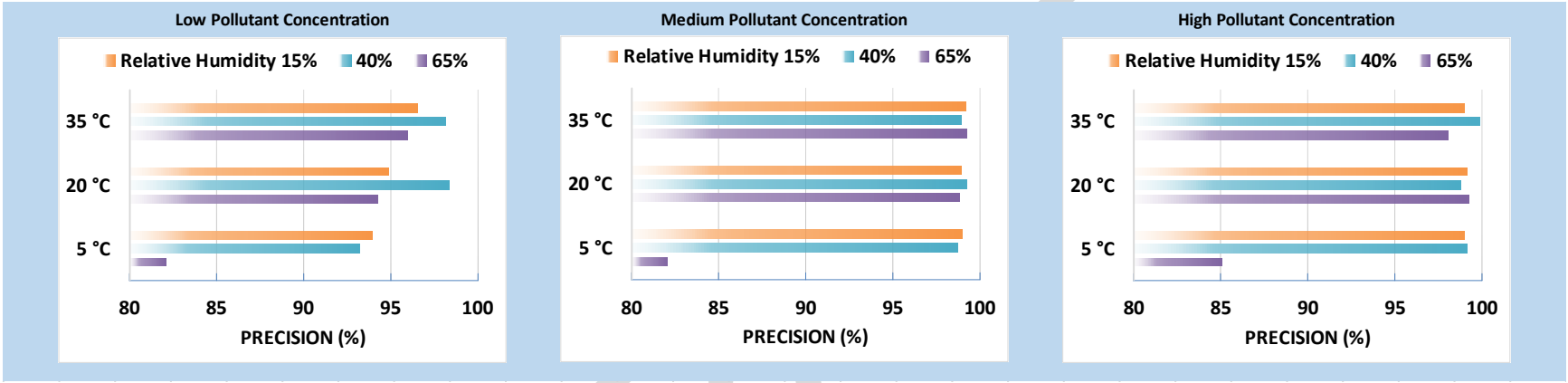
- The Kunak sensors underestimated FEM GRIMM $PM_{2.5}$ mass concentration at 20 °C and 40% RH. The accuracy of the Kunak sensors was fairly constant (66% to 72%) for the $PM_{2.5}$ mass concentration range tested.

Kunak : Data Recovery and Intra-model Variability

- Data recovery for $PM_{2.5}$ mass concentration from all units was 100%
- High $PM_{2.5}$ measurement variations were observed between the Kunak sensors

Kunak $PM_{2.5}$: Precision

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



- Overall, the Kunak sensors showed high precision for all of the combinations of low, medium and high $PM_{2.5}$ conc., T and RH except at 5 °C/65% RH for all $PM_{2.5}$ levels

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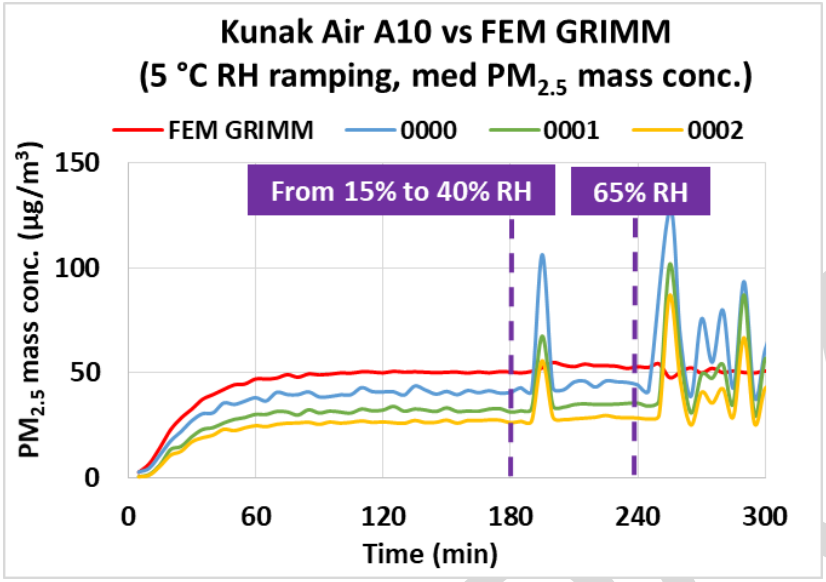
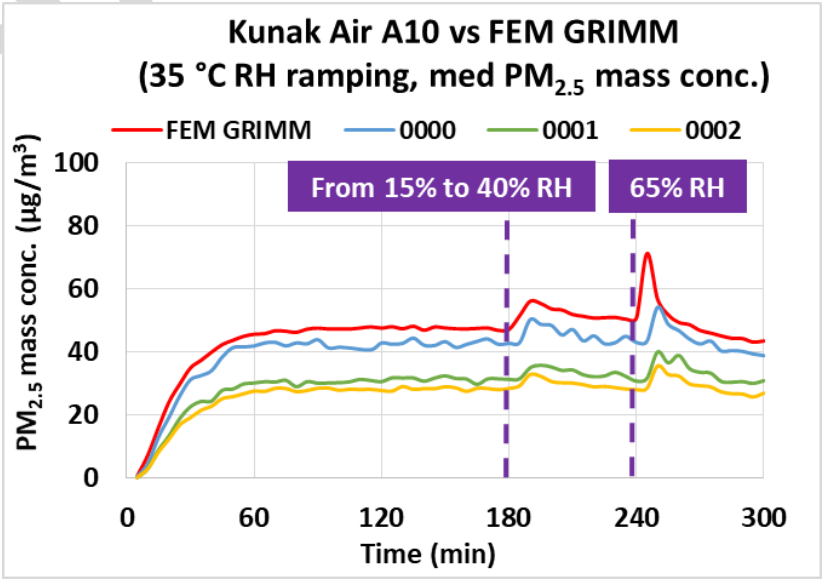
Kunak $PM_{2.5}$: Climate Susceptibility



Low Temp – RH ramping (medium conc.)

High Temp – RH ramping (medium conc.)



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Discussion ($PM_{1.0}$ and $PM_{2.5}$)

- **Accuracy**: Overall, the accuracy of the Kunak decreased as $PM_{1.0}$ mass concentrations increased and was fairly constant (66% to 72%) for the $PM_{2.5}$ mass concentration range tested. The Kunak sensors underestimated $PM_{1.0}$ and $PM_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.
- **Precision**: The Kunak sensors showed high precision for all test combinations (PM concentrations, T and RH) for both $PM_{1.0}$ and $PM_{2.5}$ mass concentrations except at 5 °C/65% RH.
- **Intra-model variability**: high intra-model variability was observed among the Kunak sensors.
- **Data Recovery:** Data recovery for $PM_{1.0}$ and $PM_{2.5}$ mass concentration from all units was 100%.
- **Coefficient of Determination**: The Kunak sensors showed very strong correlation/linear response with the corresponding GRIMM $PM_{1.0}$ and FEM GRIMM $PM_{2.5}$ measurement data ($R^2 > 0.99$).
- **Climate susceptibility**: For most of the temperature and relative humidity combination, the climate condition had minimal effect on the Kunak's precision. The Kunak sensors showed some small spikes at the RH set-points and showed significant variation in concentration at 5 °C/65% RH; this could be due to the RH transient effect produced when abrupt change in RH occurs (e.g. RH change exceeding ±10% RH per hour), as explained in the Kunak Manual.

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Evaluation results for PM_{10} mass concentration

Kunak vs GRIMM vs APS

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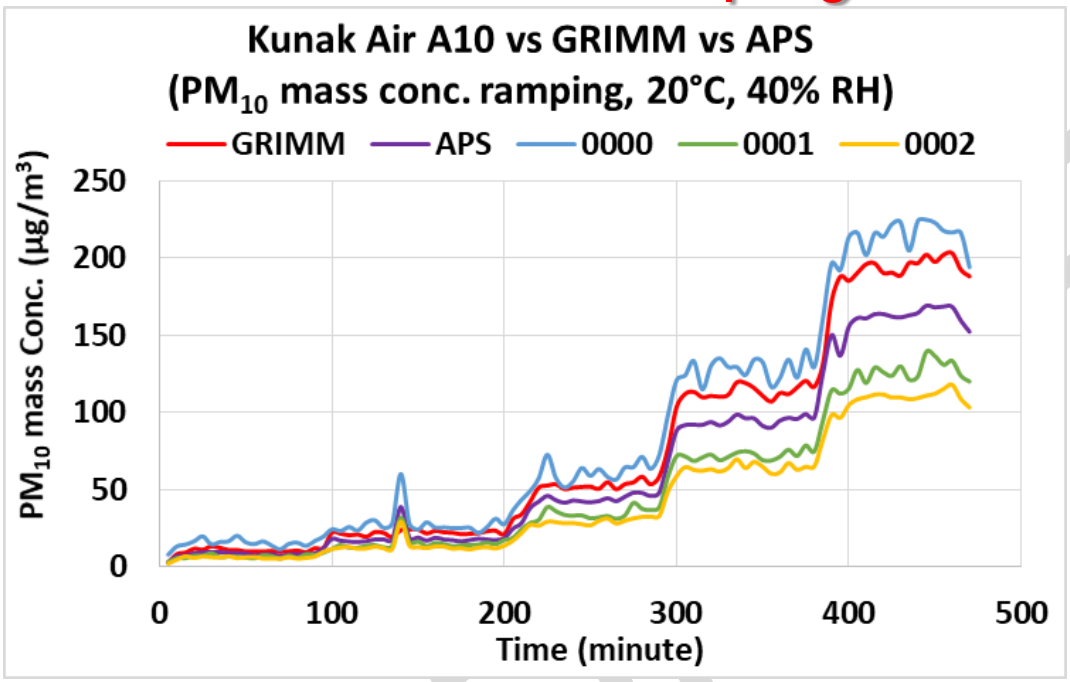
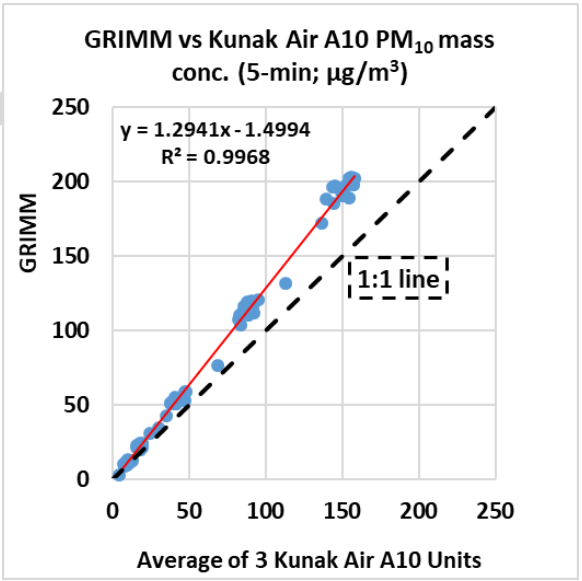
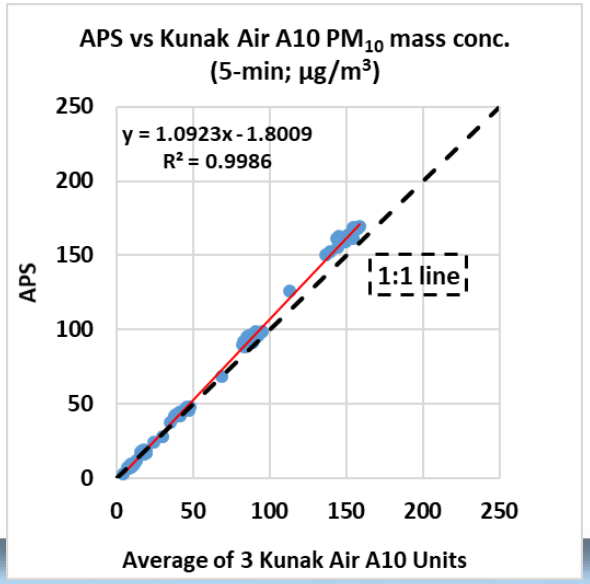
Kunak vs GRIMM vs APS (PM_{10} mass conc.) Concentration Ramping at 20 °C and 40% RH







- The Kunak sensors tracked well with the concentration variation as recorded by the APS and GRIMM in the concentration range of 0 - ~200 µg/m^3.
- The Kunak sensors showed very strong correlations with the corresponding GRIMM and APS PM_{10} mass conc. (R^2 > 0.99).

Kunak vs GRIMM vs APS PM_{10} Accuracy

- Accuracy (20 °C and 40% RH)

Steady state #	Sensor Mean (µg/m³)	GRIMM (µg/m³)	Accuracy (%)	Steady state #	Sensor Mean (µg/m³)	APS (µg/m³)	Accuracy (%)
1	9.0	10.1	88.8	1	9.0	8.0	87.3
2	17.2	22.1	77.9	2	17.2	17.6	97.7
3	39.8	51.9	76.7	3	39.8	42.8	93.0
4	89.6	115.4	77.7	4	89.6	95.5	93.9
5	153.5	199.1	77.1	5	153.5	166.5	92.2

- The Kunak sensors underestimated GRIMM and APS PM_{10} mass concentration at 20 °C and 40% RH. The accuracy of the Kunak sensors was fairly constant (77% to 88% for GRIMM and 87% to 98% for APS) over the PM_{10} mass concentration range tested. The accuracy is higher when compared to APS than to GRIMM.

Kunak : Data Recovery and intra-model variability

- Data recovery for PM_{10} mass concentration from all units was 100%
- High PM_{10} measurement variations were observed between the Kunak sensors

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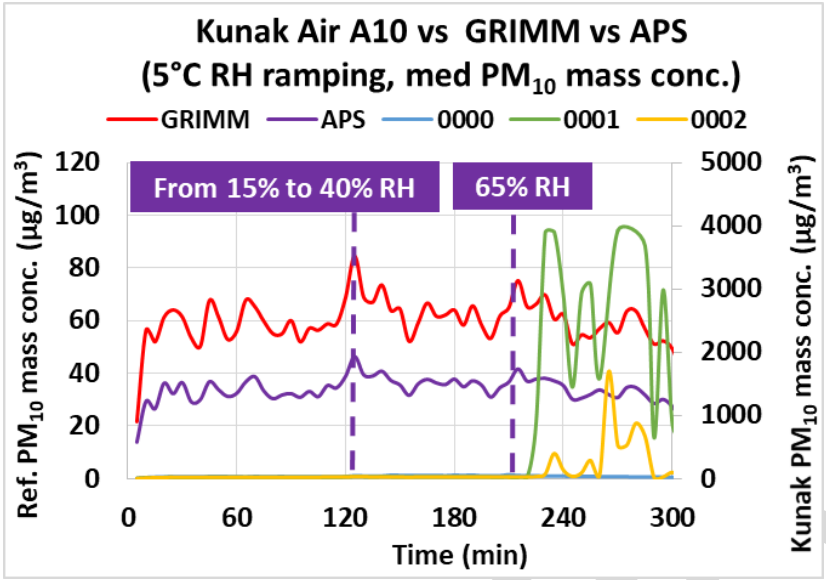
Kunak PM_{10}: Climate Susceptibility



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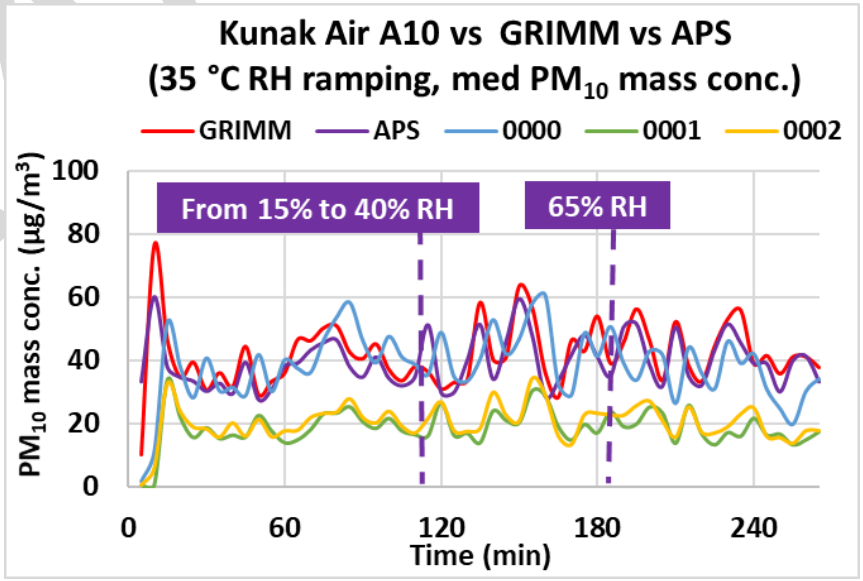
High Temp – RH ramping (medium conc.)



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Discussion (PM_{10})

- **Accuracy**: Overall, the accuracy of the of the Kunak sensors was fairly constant (77% to 88% for GRIMM and 87% to 98% for APS) over the entire range of PM_{10} mass concentrations tested. The accuracy is higher when compared to APS than to GRIMM. The Kunak sensors underestimated PM_{10} mass concentrations as measured by GRIMM and APS in the laboratory experiments at 20 °C and 40% RH.
- **Precision**: Due to the nature of Arizona test dust, the aerosol concentration showed some variability, therefore, the precision cannot be fairly estimated.
- **Intra-model variability**: High intra-model variability was observed among the Kunak sensors.
- **Data Recovery:** Data recovery for PM_{10} mass concentration from all units was 100%.
- **Coefficient of Determination**: The Kunak sensors showed very strong correlation/linear response with the corresponding GRIMM PM_{10} and APS PM_{10} ($R^2 > 0.99$).
- **Climate susceptibility**: For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the Kunak sensors. The Kunak sensors recorded out-of-range PM_{10} mass concentrations at 5 °C/65% RH; this could be due to the RH transient effect produced when abrupt change in RH occurs (e.g. RH change exceeding ±10% RH per hour), as explained in the Kunak Manual.

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