# Laboratory Evaluation

# Atmotube Pro

South Coast AQMD

**AQ-SPEC**
Air Quality Sensor Performance Evaluation Center

# Background

Three **Atmotube Pro** sensors (units IDs: E7E0, 05AB and 6C77) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (01/07/2020 to 03/11/2020) under ambient environmental conditions and have been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity. The same three Atmotube Pro units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

- **_Atmotube Pro_** (_3 units tested_):
  - Particle sensor: optical; non-FEM (model SPS30, Sensirion)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$ (µg/m$^3$), temperature (°C), RH (%), pressure (mm Hg), VOC (ppm)
  - Unit cost: $189
  - Time resolution: 1-min
  - Units IDs: E7E0, 05AB, 6C77

**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
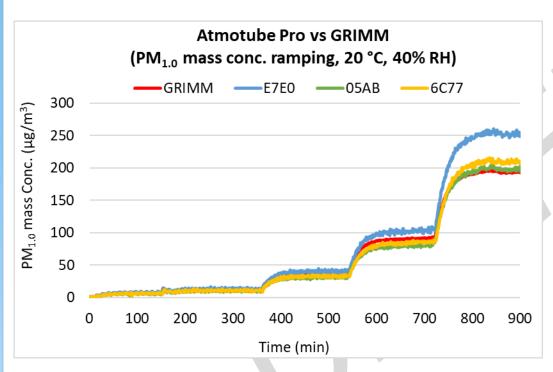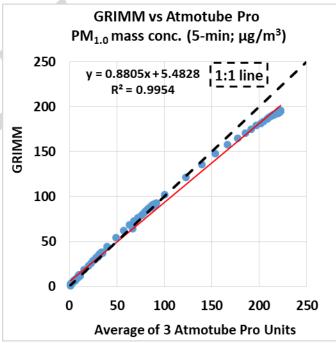  - Cost: ~$25,000
  - Time resolution: 1-min



FEM GRIMM

# Evaluation results for PM$_{1.0}$ mass concentration

## Atmotube Pro vs GRIMM

# Atmotube Pro vs GRIMM (PM$_{1.0}$ mass conc.)

Coefficient of Determination



Atmotube Pro vs GRIMM
(PM$_{1.0}$ mass conc. ramping, 20 °C, 40% RH)

— GRIMM — E7E0 — 05AB — 6C77



GRIMM vs Atmotube Pro
PM$_{1.0}$ mass conc. (5-min; µg/m$^3$)

$y = 0.8805x + 5.4828$
$R^2 = 0.9954$

1:1 line

- The Atmotube Pro 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 Atmotube Pro sensors showed very strong correlations with the GRIMM PM$_{1.0}$ mass conc. ($R^2$ > 0.99.

# Atmotube Pro vs GRIMM $PM_{1.0}$ Accuracy

- Accuracy[*] (20 °C and 40% RH)

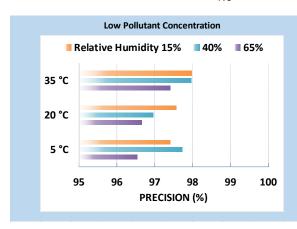| Steady state # | Sensor Mean ($\mu g/m^3$) | GRIMM ($\mu g/m^3$) | Accuracy (%) |
|:---:|:---:|:---:|:---:|
| 1 | 6.1 | 7.2 | 84.3 |
| 2 | 10.7 | 12.0 | 89.4 |
| 3 | 34.5 | 37.8 | 91.3 |
| 4 | 90.7 | 92.1 | 98.4 |
| 5 | 219.9 | 193.5 | 86.3 |

- Overall, the Atmotube Pro sensors overestimated GRIMM $PM_{1.0}$ measurements when $PM_{1.0}$ mass concentrations were > 100 $\mu g/m^3$. The accuracy of the Atmotube Pro sensors fairly constant (84% to 98%) over the range of $PM_{1.0}$ mass concentration tested.
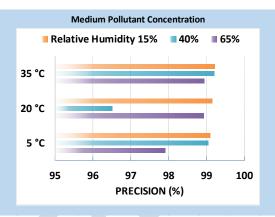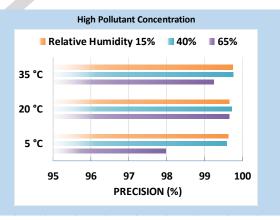
# Atmotube Pro: Data Recovery and Intra-model Variability

- Data recovery for $PM_{1.0}$ mass concentration from all units was 100%

- Moderate $PM_{1.0}$ measurement variations were observed between the Atmotube Pro sensors

# Atmotube Pro PM$_{1.0}$: Precision

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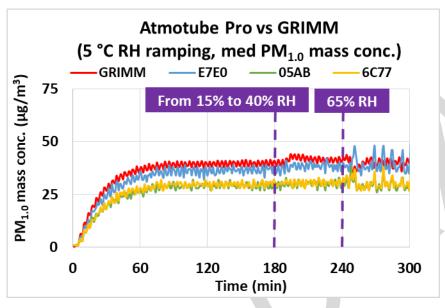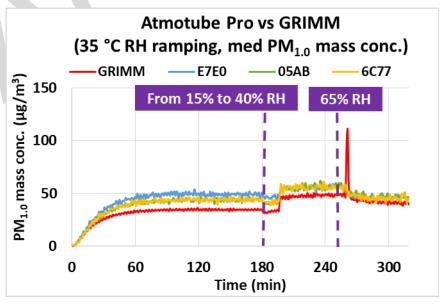


- Overall, the Atmotube Pro sensors showed high precision for all of the combinations of low, medium and high PM$_{1.0}$ conc., T, and RH.
- Precision was relatively higher at higher PM$_{1.0}$ mass concentrations.

# Atmotube Pro PM$_{1.0}$: Climate Susceptibility
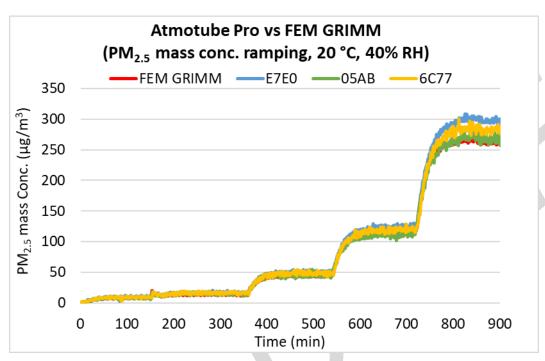


**Low Temp – RH ramping (medium conc.)**

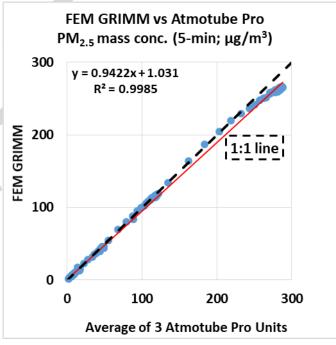**High Temp – RH ramping (medium conc.)**

# Evaluation results for PM$_{2.5}$ mass concentration

## Atmotube Pro vs FEM GRIMM

# Atmotube Pro vs FEM GRIMM (PM$_{2.5}$ mass conc.)

Coefficient of Determination



**Atmotube Pro vs FEM GRIMM**
**(PM$_{2.5}$ mass conc. ramping, 20 °C, 40% RH)**

— FEM GRIMM — E7E0 — 05AB — 6C77



**FEM GRIMM vs Atmotube Pro**
**PM$_{2.5}$ mass conc. (5-min; μg/m$^3$)**

$y = 0.9422x + 1.031$
$R^2 = 0.9985$

1:1 line

- The Atmotube Pro sensors tracked well with the concentration variation as recorded by the FEM GRIMM in the concentration range of 0 - ~250 μg/m$^3$.

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

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# Atmotube Pro vs FEM GRIMM PM$_{2.5}$ Accuracy

- Accuracy[*] (20 °C and 40% RH)

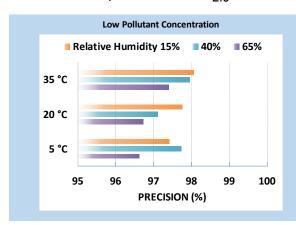| Steady state # | Sensor Mean (µg/m³) | FEM GRIMM (µg/m³) | Accuracy (%) |
|---|---|---|---|
| 1 | 9.0 | 8.4 | 93.3 |
| 2 | 15.6 | 13.7 | 86.1 |
| 3 | 47.8 | 45.3 | 94.3 |
| 4 | 120.1 | 117.7 | 98.0 |
| 5 | 282.8 | 261.5 | 91.9 |

- The Atmotube Pro sensors overestimated FEM GRIMM PM$_{2.5}$ mass concentration at 20 °C and 40% RH. The accuracy of the Atmotube Pro sensors was fairly constant (86% to 98%) for the PM$_{2.5}$ mass concentration range tested.
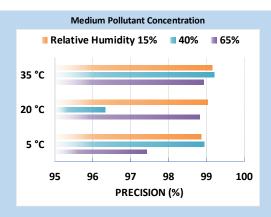
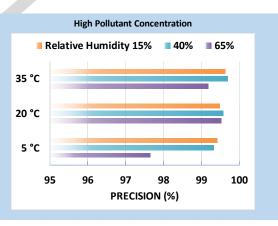# Atmotube Pro: Data Recovery and Intra-model Variability

- Data recovery for PM$_{2.5}$ mass concentration from all units was 100%
- Low PM$_{2.5}$ measurement variations were observed between the Atmotube Pro sensors

# Atmotube Pro PM$_{2.5}$: Precision

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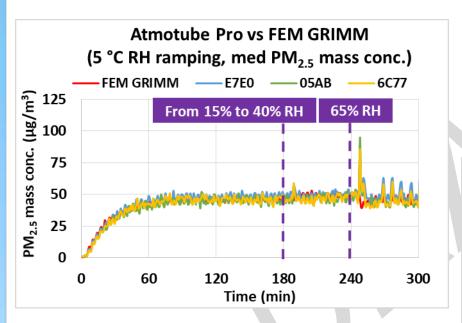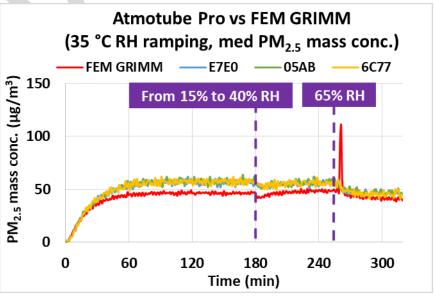


- Overall, the Atmotube Pro sensors showed high precision for all of the combinations of low, medium and high PM$_{2.5}$ conc., T, and RH.

- Precision was relatively higher at higher PM$_{2.5}$ mass concentrations.

# Atmotube Pro PM$_{2.5}$: Climate Susceptibility



**Atmotube Pro vs FEM GRIMM
(5 °C RH ramping, med PM$_{2.5}$ mass conc.)**

FEM GRIMM — E7E0 — 05AB — 6C77

From 15% to 40% RH    65% RH

PM$_{2.5}$ mass conc. (µg/m³)

Time (min)

**Low Temp – RH ramping
(medium conc.)**

**High Temp – RH ramping
(medium conc.)**



**Atmotube Pro vs FEM GRIMM
(35 °C RH ramping, med PM$_{2.5}$ mass conc.)**

FEM GRIMM — E7E0 — 05AB — 6C77

From 15% to 40% RH    65% RH

PM$_{2.5}$ mass conc. (µg/m³)

Time (min)

# Discussion

➢ **Accuracy**: Overall, the accuracy of the Atmotube Pro sensors fairly constant (84% to 98% and 86% to 98%) over the range of $PM_{1.0}$ and $PM_{2.5}$ mass concentration tested, respectively. Overall, the Atmotube Pro sensors overestimated GRIMM $PM_{1.0}$ measurements when $PM_{1.0}$ mass concentrations were > 100 µg/m$^3$ and overestimated $PM_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.

➢ **Precision**: The Atmotube Pro sensors showed high precision for all test combinations (PM concentrations, T and RH) for both $PM_{1.0}$ and $PM_{2.5}$ mass concentrations.

➢ **Intra-model variability**: moderate to low intra-model variability was observed among the Atmotube Pro sensors for $PM_{1.0}$ and $PM_{2.5}$ mass concentrations, respectively.

➢ **Data Recovery:** Data recovery for $PM_{1.0}$ and $PM_{2.5}$ mass concentration from all units was 100%.

➢ **Coefficient of Determination**: The Atmotube Pro 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 Atmotube Pro's precision. At the set-points of RH changes, the Atmotube Pro sensors reported spiked concentration changes for all PM levels at 5 °C and significant variation in concentrations for all PM levels at 5 °C/65% RH.