Field Evaluation
PurpleAir PA-II-FLEX
Background

- From 03/17/2022 to 05/24/2022, three PurpleAir PA-II-FLEX (hereinafter PA-II-FLEX) sensors were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) instruments measuring the same pollutants.

**PA-II-FLEX (3 units tested):**
- Particle sensor: optical; non-FEM (dual Plantower PMS6003)
- Each unit reports: PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ (μg/m$^3$)
- Also measures: internal temperature (°F) and internal relative humidity (%)
- Unit cost: $299
- Time resolution: 1-min
- Units IDs: Unit #1 (7fd9, 7fd9-b); Unit #2 (7f6d, 7f6d-b); Unit #3 (2bf1, 2bf1-b)

*Note: each unit has two PM sensors and reports two PM values (Channel A and Channel B. Sensors are named Unit ID and Unit ID-b for Channel A and Channel B values, respectively.)*

**South Coast AQMD Reference Instruments:**
- **GR IMM EDM 180 (hereinafter FEM GR IMM for PM$_{2.5}$, GR IMM otherwise):**
  - Optical particle counter (FEM PM$_{2.5}$)
  - Measures PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ (μg/m$^3$)
  - Cost: ~$25,000 and up
  - Time resolution: 1-min
- **Teledyne API T640 (hereinafter FEM T640 for PM$_{2.5}$, T640 otherwise):**
  - Optical particle counter (FEM PM$_{2.5}$)
  - Measures PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ (μg/m$^3$)
  - Unit cost: ~$21,000
  - Time resolution: 1-min
- **Met Station (T, RH, P, WS, WD)**
  - Unit cost: ~$5,000
  - Time resolution: 1-min
Data validation & recovery

• Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)

• Data recovery from all units was ~94% for all PM measurements

PA-II-FLEX; intra-model variability

• Absolute intra-model variability was ~0.18, ~0.38 and ~1.64 µg/m³ for PM₁₀, PM₂·₅ and PM₁₀, respectively (calculated as the standard deviation of the three sensor means)

• Relative intra-model variability was ~2.3%, ~3.0% and ~8.9% for PM₁₀, PM₂·₅ and PM₁₀, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
Reference Instruments: PM$_{1.0}$
GRIMM and T640

- Data recovery for PM$_{1.0}$ from GRIMM and T640 was ~98% and ~93%, respectively.
- Very strong correlations between the reference instruments for PM$_{1.0}$ measurements ($R^2 \sim 0.95$) were observed.
Reference Instruments: PM$_{2.5}$
FEM GRIMM and FEM T640

- Data recovery for PM$_{2.5}$ from FEM GRIMM and FEM T640 was ~ 98% and ~ 93%, respectively.
- Very strong correlations between the reference instruments for PM$_{2.5}$ measurements ($R^2$ ~0.95) were observed.

![Graph showing data recovery and correlation between FEM GRIMM and FEM T640 for PM$_{2.5}$ measurements.](image-url)
Reference Instruments: PM$_{10}$ GRIMM and T640

- Data recovery for PM$_{10}$ from GRIMM and T640 was ~98% and ~93%, respectively.
- Very strong correlations between the reference instruments for PM$_{10}$ measurements ($R^2$ ~0.91) were observed.

![Graph showing data recovery and correlation between PM$_{10}$ measurements from GRIMM and T640.](image)
The PA-II-FLEX sensors showed very strong correlations with the corresponding GRIMM data (0.90 < $R^2$ < 0.92).
Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.

The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The PA-II-FLEX sensors showed strong correlations with the corresponding FEM GRIMM data (0.77 < $R^2$ < 0.81).
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM.
The PA-II-FLEX sensors showed very weak correlations with the corresponding GRIMM data (0.21 < $R^2$ < 0.25).
• Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM
• The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by GRIMM
The PA-II-FLEX sensors showed very strong correlations with the corresponding GRIMM data ($0.90 < R^2 < 0.93$).
PA-II-FLEX vs GRIMM (PM$_{1.0}$; 1-hr mean)

- Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.
- The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The PA-II-FLEX sensors showed strong correlations with the corresponding FEM GRIMM data (0.78 < $R^2$ < 0.82).
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM.
The PA-II-FLEX sensors showed very weak correlations with the corresponding GRIMM data (0.22 < R² < 0.26).
Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM.

The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by GRIMM.
The PA-II-FLEX sensors showed very strong correlations with the corresponding GRIMM data ($0.92 < R^2 < 0.94$).
Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.

The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ daily variations as recorded by GRIMM.
- The PA-II-FLEX sensors showed strong correlations with the corresponding FEM GRIMM data ($0.81 < R^2 < 0.84$).
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ daily variations as recorded by FEM GRIMM.
• The PA-II-FLEX sensors showed very weak correlations with the corresponding GRIMM data (0.19 < R² < 0.23)
Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM.

The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ daily variations as recorded by GRIMM.
The PA-II-FLEX sensors showed very strong correlations with the corresponding T640 data ($0.92 < R^2 < 0.94$).
PA-II-FLEX vs T640 (PM$_{1.0}$; 5-min mean)

- Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640.
- The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640.
PA-II-FLEX vs FEM T640 (PM$_{2.5}$; 5-min mean)

- The PA-II-FLEX sensors showed strong correlations with the corresponding FEM T640 data ($0.86 < R^2 < 0.89$)
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640.
PA-II-FLEX vs T640 (PM$_{10}$; 5-min mean)

- PA-II-FLEX sensors showed weak correlations with the corresponding T640 data (0.35 < $R^2$ < 0.39)
Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by T640.

The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by T640.
The PA-II-FLEX sensors showed very strong correlations with the corresponding T640 data ($0.93 < R^2 < 0.95$).
Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640.
The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640.
PA-II-FLEX vs FEM T640 (PM$_{2.5}$; 1-hr mean)

The PA-II-FLEX sensors showed strong correlations with the corresponding FEM T640 data ($0.87 < R^2 < 0.90$)

- PM$_{2.5}$ (1-hr mean, μg/m$^3$)
  
  **Unit 7fd9**
  
  $y = 0.6626x + 5.3368$
  $R^2 = 0.8784$

  **Unit 7fd9-b**
  
  $y = 0.6629x + 5.0627$
  $R^2 = 0.8903$

  **Unit 7f6d**
  
  $y = 0.6268x + 5.3086$
  $R^2 = 0.8713$

  **Unit 7f6d-b**
  
  $y = 0.6421x + 5.3288$
  $R^2 = 0.8736$

  **Unit 2bf1**
  
  $y = 0.6268x + 5.3086$
  $R^2 = 0.8713$

  **Unit 2bf1-b**
  
  $y = 0.6421x + 5.3288$
  $R^2 = 0.8736$

- PM$_{10}$ (1-hr mean, μg/m$^3$)
  
  **Unit 7fd9**
  
  $y = 0.6626x + 5.3368$
  $R^2 = 0.8784$

  **Unit 7fd9-b**
  
  $y = 0.6629x + 5.0627$
  $R^2 = 0.8903$

  **Unit 7f6d**
  
  $y = 0.6268x + 5.3086$
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  **Unit 7f6d-b**
  
  $y = 0.6421x + 5.3288$
  $R^2 = 0.8736$

  **Unit 2bf1**
  
  $y = 0.6268x + 5.3086$
  $R^2 = 0.8713$

  **Unit 2bf1-b**
  
  $y = 0.6421x + 5.3288$
  $R^2 = 0.8736$
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640.
PA-II-FLEX vs T640 (PM$_{10}$; 1-hr mean)

- The PA-II-FLEX sensors showed weak correlations with the corresponding T640 data (0.38 < $R^2$ < 0.43)
Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by T640.

The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by T640.
The PA-II-FLEX sensors showed very strong correlations with the corresponding T640 data (0.95 < $R^2$ < 0.97).
Overall, the PA-II-FLEX sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640.

The PA-II-FLEX sensors seemed to track the PM$_{1.0}$ daily variations as recorded by T640.
The PA-II-FLEX sensors showed strong to very strong correlations with the corresponding FEM T640 data (0.88 < R² < 0.91).

- **Unit 7fd9**
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.686x + 5.0424
    - R² = 0.8958
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6451x + 5.0636
    - R² = 0.8883
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6809x + 5.3991
    - R² = 0.893

- **Unit 7fd6**
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.649x + 5.2773
    - R² = 0.9
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6676x + 4.9969
    - R² = 0.8908
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6862x + 4.7555
    - R² = 0.9081

- **Unit 2bf1**
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.686x + 5.0424
    - R² = 0.8958
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6451x + 5.0636
    - R² = 0.8883
  - PM₂.₅ (24-hr mean, μg/m³)
    - y = 0.6862x + 4.7555
    - R² = 0.9081
Overall, the PA-II-FLEX sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

The PA-II-FLEX sensors seemed to track the PM$_{2.5}$ daily variations as recorded by FEM T640.
• The PA-II-FLEX sensors showed weak to moderate correlations with the corresponding T640 data (0.47 < R² < 0.51)
Overall, the PA-II-FLEX sensors underestimated the PM$_{10}$ mass concentrations as measured by T640.

The PA-II-FLEX sensors sometimes seemed to track the PM$_{10}$ daily variations as recorded by T640.
## Summary: Channel A

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM$_{1.0}$</th>
<th>PA-II-FLEX vs GRIMM &amp; T640, PM$_{1.0}$</th>
<th>GRIMM &amp; T640 (PM$_{1.0}$, $\mu$g/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average ($\mu$g/m$^3$)</td>
<td>SD ($\mu$g/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>7.8</td>
<td>6.4</td>
<td>0.91 to 0.94</td>
</tr>
<tr>
<td>1-hr</td>
<td>7.8</td>
<td>6.4</td>
<td>0.91 to 0.95</td>
</tr>
<tr>
<td>24-hr</td>
<td>7.8</td>
<td>5.1</td>
<td>0.92 to 0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Average of 3 Sensors, PM$_{2.5}$</th>
<th>PA-II-FLEX vs FEM GRIMM &amp; FEM T640, PM$_{2.5}$</th>
<th>FEM GRIMM &amp; FEM T640 (PM$_{2.5}$, $\mu$g/m$^3$)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Average ($\mu$g/m$^3$)</td>
<td>SD ($\mu$g/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>13.0</td>
<td>10.3</td>
<td>0.78 to 0.87</td>
</tr>
<tr>
<td>1-hr</td>
<td>13.0</td>
<td>10.2</td>
<td>0.79 to 0.88</td>
</tr>
<tr>
<td>24-hr</td>
<td>13.1</td>
<td>8.1</td>
<td>0.81 to 0.90</td>
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<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM$_{10}$</th>
<th>PA-II-FLEX vs GRIMM &amp; T640, PM$_{10}$</th>
<th>GRIMM &amp; T640 (PM$_{10}$, $\mu$g/m$^3$)</th>
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<td></td>
<td>Average ($\mu$g/m$^3$)</td>
<td>SD ($\mu$g/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>19.0</td>
<td>14.6</td>
<td>0.21 to 0.38</td>
</tr>
<tr>
<td>1-hr</td>
<td>19.0</td>
<td>14.4</td>
<td>0.22 to 0.42</td>
</tr>
<tr>
<td>24-hr</td>
<td>19.2</td>
<td>11.5</td>
<td>0.20 to 0.50</td>
</tr>
</tbody>
</table>

1 Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

2 Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

3 Root Mean Square Error (RMSE): another metric to calculate measurement errors.
### Summary: Channel B

#### Mean Bias Error (MBE)
- **MBE**: the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

#### Mean Absolute Error (MAE)
- **MAE**: the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

#### Root Mean Square Error (RMSE)
- **RMSE**: another metric to calculate measurement errors.

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM$_{1,0}$</th>
<th>PA-II-FLEX vs GRIMM &amp; T640, PM$_{1,0}$</th>
<th>GRIMM &amp; T640 (PM$_{1,0}$, μg/m$^3$)</th>
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<tr>
<td></td>
<td>Average (μg/m$^3$)</td>
<td>SD (μg/m$^3$)</td>
<td>R$^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>7.7</td>
<td>6.4</td>
<td>0.91 to 0.94</td>
</tr>
<tr>
<td>1-hr</td>
<td>7.7</td>
<td>6.3</td>
<td>0.91 to 0.94</td>
</tr>
<tr>
<td>24-hr</td>
<td>7.8</td>
<td>5.0</td>
<td>0.92 to 0.96</td>
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<th>Average of 3 Sensors, PM$_{2.5}$</th>
<th>PA-II-FLEX vs FEM GRIMM &amp; FEM T640, PM$_{2.5}$</th>
<th>FEM GRIMM &amp; FEM T640 (PM$_{2.5}$, μg/m$^3$)</th>
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<tr>
<td></td>
<td>Average (μg/m$^3$)</td>
<td>SD (μg/m$^3$)</td>
<td>R$^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>12.7</td>
<td>10.1</td>
<td>0.79 to 0.88</td>
</tr>
<tr>
<td>1-hr</td>
<td>12.7</td>
<td>9.9</td>
<td>0.80 to 0.89</td>
</tr>
<tr>
<td>24-hr</td>
<td>12.9</td>
<td>7.9</td>
<td>0.82 to 0.91</td>
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<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM$_{10}$</th>
<th>PA-II-FLEX vs GRIMM &amp; T640, PM$_{10}$</th>
<th>GRIMM &amp; T640 (PM$_{10}$, μg/m$^3$)</th>
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<tr>
<td></td>
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<td>R$^2$</td>
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<tr>
<td>5-min</td>
<td>18.1</td>
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<td>0.22 to 0.39</td>
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<td>1-hr</td>
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<td>13.6</td>
<td>0.23 to 0.42</td>
</tr>
<tr>
<td>24-hr</td>
<td>18.2</td>
<td>10.8</td>
<td>0.20 to 0.50</td>
</tr>
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1 Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
2 Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
3 Root Mean Square Error (RMSE): another metric to calculate measurement errors.
The PA-II-FLEX sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.94$).

Overall, the PA-II-FLEX sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station.

The PA-II-FLEX sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station.
The PA-II-FLEX sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.97$).

Overall, the PA-II-FLEX sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station.

The PA-II-FLEX sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station.
Discussion

- The three PA-II-FLEX sensors' data recovery from all units was ~94% for all PM measurements.
- The absolute intra-model variability for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ was ~0.18, ~0.38 and ~1.64 µg/m$^3$, respectively.
- Reference instruments: Very strong correlations between GRIMM and T640 for PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ ($R^2$ ~0.95, $R^2$ ~0.95, and $R^2$ ~0.91, respectively, 1-hr mean).
- PM$_{1.0}$ mass concentrations measured by PA-II-FLEX sensors showed very strong correlations with the corresponding GRIMM and T640 data (0.90 < $R^2$ < 0.95, 1-hr mean). The sensors underestimated PM$_{1.0}$ mass concentrations as measured by GRIMM and T640.
- PM$_{2.5}$ mass concentrations measured by PA-II-FLEX sensors showed strong correlations with the corresponding FEM GRIMM and FEM T640 data (0.78 < $R^2$ < 0.90, 1-hr mean). The sensors underestimated PM$_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640.
- PM$_{10}$ mass concentrations measured by PA-II-FLEX sensors showed very weak to weak correlations with the corresponding GRIMM and T640 (0.22 < $R^2$ < 0.43; 1-hr mean). The sensors underestimated PM$_{10}$ mass concentrations as measured by GRIMM and T640.
- No sensor calibration was performed by South Coast AQMD staff for this evaluation.
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions.
- All results are still preliminary.