Field Evaluation
PM Monitor – iMonPM

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center
From 03/17/2022 to 05/17/2022, three PM Monitor – iMonPM (hereinafter iMonPM) 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.

**iMonPM (3 units tested):**
- Particle sensor: optical; non-FEM (Wuhan Cubic PM3006S)
- Each unit reports: PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ ($\mu$g/m$^3$), T ($^\circ$C), RH (%)
- Unit cost: $1,595
- Time resolution: 1-min
- Units IDs: 0028, 0029, 0030

**GRIMM EDM180 (reference instrument):**
- Optical particle counter (FEM PM$_{2.5}$)
- Measures PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ ($\mu$g/m$^3$)
- Cost: ~$25,000 and up
- Time resolution: 1-min

**Teledyne API T640 (reference instrument):**
- Optical particle counter (FEM PM$_{2.5}$)
- Measures PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ ($\mu$g/m$^3$)
- Cost: ~$21,000
- Time resolution: 1-min

**Met Station (T, RH, P, WS, WD):**
- 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 Unit 0028, Unit 0029 and Unit 0030 was ~97.5%, respectively for all PM measurements

**iMonPM; intra-model variability**

- Absolute intra-model variability was ~0.53, ~0.55 and ~0.27 µg/m$^3$ for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~4.5%, ~3.2% and ~1.2% for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

![Graphs showing 5-minute mean mass concentration for PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ across Units 0028, 0029, and 0030.](image-url)
Data recovery for PM$_{1.0}$ from GRIMM and T640 was ~100%.

Strong correlations between the reference instruments for PM$_{1.0}$ measurements ($R^2$ ~0.89) were observed.
Data recovery for PM$_{2.5}$ from FEM GRIMM and FEM T640 was $\sim$100%.

Strong correlations between the reference instruments for PM$_{2.5}$ measurements ($R^2 \sim 0.82$) were observed.
Reference Instruments: PM$_{10}$
GRIMM and T640

- Data recovery for PM$_{10}$ from GRIMM and T640 was ~100%.
- Strong correlations between the reference instruments for PM$_{10}$ measurements ($R^2$ ~0.85) were observed.
The iMonPM sensors showed strong correlations with the corresponding GRIMM data ($0.71 < R^2 < 0.73$).

Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.

The iMonPM sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The iMonPM sensors showed moderate correlations with the corresponding FEM GRIMM data ($0.65 < R^2 < 0.66$).

Overall, the iMonPM sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM.

The iMonPM sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM.
The iMonPM sensors showed weak correlations with the corresponding GRIMM data ($0.44 < R^2 < 0.50$).

Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM.

The iMonPM sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by GRIMM.
iMonPM vs GRIMM (PM$_{1.0}$; 1-hr mean)

- The iMonPM sensors showed strong correlations with the corresponding GRIMM data ($0.71 < R^2 < 0.73$).
- Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.
- The iMonPM sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The iMonPM sensors showed moderate correlations with the corresponding FEM GRIMM data (0.65 < R² < 0.67).

Overall, the iMonPM sensors overestimated the PM₂.₅ mass concentrations as measured by FEM GRIMM.

The iMonPM sensors seemed to track the PM₂.₅ diurnal variations as recorded by FEM GRIMM.
iMonPM vs GRIMM (PM$_{10}$; 1-hr mean)

- The iMonPM sensors showed weak to moderate correlations with the corresponding GRIMM data ($0.45 < R^2 < 0.52$)
- Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM
- The iMonPM sensors sometimes seemed to track the PM$_{10}$ diurnal variations as recorded by GRIMM
iMonPM vs GRIMM (PM$_{1.0}$; 24-hr mean)

- The iMonPM sensors showed strong to very strong correlations with the corresponding GRIMM data (0.89 < $R^2$ < 0.91)
- Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM
- The iMonPM sensors seemed to track the PM$_{1.0}$ daily variations as recorded by GRIMM
The iMonPM sensors showed strong correlations with the corresponding FEM GRIMM data ($0.82 < R^2 < 0.84$).

Overall, the iMonPM sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM.

The iMonPM sensors seemed to track the PM$_{2.5}$ daily variations as recorded by FEM GRIMM.

\[ y = 0.6982x + 2.7397 \quad R^2 = 0.8246 \]

\[ y = 0.7664x + 2.4968 \quad R^2 = 0.8365 \]

\[ y = 0.735x + 2.2292 \quad R^2 = 0.8355 \]
- The iMonPM sensors showed weak to moderate correlations with the corresponding GRIMM data ($0.48 < R^2 < 0.57$)
- Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM
- The iMonPM sensors sometimes seemed to track the PM$_{10}$ daily variations as recorded by GRIMM
The iMonPM sensors showed strong correlations with the corresponding T640 data (0.87 < $R^2$ < 0.90)

Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by T640

The iMonPM sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640
The iMonPM sensors showed strong correlations with the corresponding FEM T640 data ($0.88 < R^2 < 0.89$).

- Overall, the iMonPM sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

- The iMonPM sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640.
The iMonPM sensors showed moderate correlations with the corresponding T640 data ($0.57 < R^2 < 0.62$).

Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by T640.

The iMonPM sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640.
iMonPM vs T640 (PM$_{1.0}$; 1-hr mean)

- The iMonPM sensors showed strong to very strong correlations with the corresponding T640 data (0.88 < $R^2$ < 0.91)
- Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by T640
- The iMonPM sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640
iMonPM vs FEM T640 (PM$_{2.5}$; 1-hr mean)

- The iMonPM sensors showed strong correlations with the corresponding FEM T640 data (0.89 < R$^2$ < 0.90)
- Overall, the iMonPM sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640
- The iMonPM sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
The iMonPM sensors showed moderate correlations with the corresponding T640 data ($0.61 < R^2 < 0.66$).

Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by T640.

The iMonPM sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640.
The iMonPM sensors showed very strong correlations with the corresponding T640 data (0.96 < $R^2$ < 0.98).

Overall, the iMonPM sensors overestimated the PM$_{1.0}$ mass concentrations as measured by T640.

The iMonPM sensors seemed to track the PM$_{1.0}$ daily variations as recorded by T640.
iMonPM vs FEM T640 (PM$_{2.5}$; 24-hr mean)

- The iMonPM sensors showed very strong correlations with the corresponding FEM T640 data ($0.97 < R^2 < 0.99$)

- Overall, the iMonPM sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640

- The iMonPM sensors seemed to track the PM$_{2.5}$ daily variations as recorded by FEM T640
**iMonPM vs T640 (PM$_{10}$; 24-hr mean)**

- The iMonPM sensors showed moderate to strong correlations with the corresponding T640 data ($0.64 < R^2 < 0.74$)
- Overall, the iMonPM sensors underestimated the PM$_{10}$ mass concentrations as measured by T640
- The iMonPM sensors seemed to track the PM$_{10}$ daily variations as recorded by T640
• The iMonPM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (0.93 < $R^2$ < 0.95)

• Overall, the iMonPM sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station

• The iMonPM sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station
The iMonPM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (0.96 < $R^2 < 0.97$).

Overall, the iMonPM sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station.

The iMonPM sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station.
### Summary

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM&lt;sub&gt;1.0&lt;/sub&gt;</th>
<th>iMonPM vs GRIMM &amp; T640, PM&lt;sub&gt;1.0&lt;/sub&gt;</th>
<th>GRIMM &amp; T640 (PM&lt;sub&gt;1.0&lt;/sub&gt;, µg/m&lt;sup&gt;3&lt;/sup&gt;)</th>
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<td>Average (µg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>SD (µg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
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<td>5-min</td>
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<td>1-hour</td>
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<td>24-hour</td>
<td>11.6</td>
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<th>Average of 3 Sensors, PM&lt;sub&gt;2.5&lt;/sub&gt;</th>
<th>iMonPM vs FEM GRIMM &amp; FEM T640, PM&lt;sub&gt;2.5&lt;/sub&gt;</th>
<th>FEM GRIMM &amp; FEM T640 (PM&lt;sub&gt;2.5&lt;/sub&gt;, µg/m&lt;sup&gt;3&lt;/sup&gt;)</th>
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<th>Average of 3 Sensors, PM&lt;sub&gt;10&lt;/sub&gt;</th>
<th>iMonPM vs GRIMM &amp; T640, PM&lt;sub&gt;10&lt;/sub&gt;</th>
<th>GRIMM &amp; T640 (PM&lt;sub&gt;10&lt;/sub&gt;, µg/m&lt;sup&gt;3&lt;/sup&gt;)</th>
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<td>24-hour</td>
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<td>9.7</td>
<td>0.49 to 0.74</td>
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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.
Discussion

- The three iMonPM sensors’ data recovery from Unit 0028, Unit 0029 and Unit 0030 was ~ 97.5% for all PM measurements
- The absolute intra-model variability was ~ 0.53, ~0.55 and ~0.27 μg/m³ for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$, respectively
- Regulatory-grade instruments: Strong correlations between GRIMM and T640 for PM$_{1.0}$ ($R^2$ ~ 0.89, 1-hr mean); strong correlations between FEM GRIMM and FEM T640 for PM$_{2.5}$ ($R^2$ ~ 0.82, 1-hr mean) and strong correlations between GRIMM and T640 for PM$_{10}$ ($R^2$ ~ 0.85, 1-hr mean) mass concentration measurements
- PM$_{1.0}$ mass concentrations measured by the iMonPM sensors showed strong to very strong correlations with the corresponding GRIMM and T640 data ($0.71 < R^2 < 0.91$, 1-hr mean). The sensors overestimated PM$_{1.0}$ mass concentrations as measured by GRIMM and T640
- PM$_{2.5}$ mass concentrations measured by the iMonPM sensors showed moderate to strong correlations with the corresponding FEM GRIMM and FEM T640 data ($0.65 < R^2 < 0.90$, 1-hr mean). The sensors overestimated PM$_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640
- PM$_{10}$ mass concentrations measured by the iMonPM sensors showed weak to moderate correlations with the corresponding GRIMM and T640 data ($0.45 < R^2 < 0.66$; 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