Field Evaluation
Oizom – Polludrone Smart
From 07/31/2021 to 09/29/2021, three Oizom Polludrone Smart (hereinafter Polludrone Smart) multi-sensor pods were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) and Federal Reference Method (FRM) instruments measuring the same pollutants.

Polludrone Smart (3 units tested):
- Sensors: CO – Electrochemical (Alphasense B4, non-FEM)
  - O$_3$ – Electrochemical (Alphasense B4, non-FEM)
  - NO – Electrochemical (Alphasense B4, non-FEM)
  - NO$_2$ – Electrochemical (Alphasense B4, non-FEM)
- PM Sensors – Optical Particle Counter (Wuhan Cubic PM3006S)
- Each unit measures: CO (ppm), O$_3$ (ppb), NO and NO$_2$ (ppb), PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ (μg/m$^3$), T (°C), RH (%)
- Unit cost: $8,000 (PM + Gas sensors)
- Time resolution: 1-min
- Units IDs: 0001, 0002, 0003

South Coast AQMD Reference instruments:
- CO instrument (FRM); cost: ~$7,000
- Time resolution: 1-min
- O$_3$ instrument (FEM); cost: ~$7,000
- Time resolution: 1-min
- NO$_X$ instrument (FRM NO$_2$); cost: ~$13,000
- Time resolution: 1-min
- Met station (T, RH, P, WS, WD); cost: ~$5,000
- Time resolution: 1-min
Carbon Monoxide (CO) in Polludrone Smart
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 for CO from Unit 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

Polludrone Smart; Intra-model variability

• Absolute intra-model variability was ~ 0.01 ppm for the CO measurements (calculated as the standard deviation of the three sensor means)
• Relative intra-model variability was ~ 3.4% for the CO measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
The Polludrone Smart sensors showed moderate to strong correlations with the corresponding FRM CO data ($0.63 < R^2 < 0.72$).

Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument.

The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument.

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis.
Polludrone Smart vs FRM (CO; 1-hr mean)

- The Polludrone Smart sensors showed moderate to strong correlations with the corresponding FRM CO data ($0.63 < R^2 < 0.71$).
- Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument.
- The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument.

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis.
The Polludrone Smart sensors showed moderate correlations with the corresponding FRM CO data (0.58 < R² < 0.70).

Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument.

The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument.

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis.
## Summary: CO

<table>
<thead>
<tr>
<th></th>
<th>Polludrone Smart vs FRM, CO</th>
<th>FRM CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of 3 Sensors, CO</td>
<td></td>
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<tr>
<td></td>
<td>Polludrone Smart vs FRM, CO</td>
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<tr>
<td></td>
<td>FRM CO (ppm)</td>
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<td>Average (ppm)</td>
<td>FRM Average</td>
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<td></td>
<td>SD (ppm)</td>
<td>FRM SD</td>
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<td></td>
<td>R²</td>
<td>Range during the field evaluation</td>
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<tr>
<td></td>
<td>Slope</td>
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<td></td>
<td>Intercept</td>
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<td></td>
<td>MBE¹ (ppm)</td>
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<td></td>
<td>MAE² (ppm)</td>
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<td></td>
<td>RMSE³ (ppm)</td>
<td></td>
</tr>
<tr>
<td>5-min</td>
<td>0.31</td>
<td>0.32</td>
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<tr>
<td></td>
<td>0.15</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>0.64 to 0.71 0.84 to 1.02</td>
<td>0.10 to 2.33</td>
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<tr>
<td></td>
<td>0.02 to 0.05</td>
<td>0.02 to 0.03</td>
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<tr>
<td></td>
<td>-0.02 to 0.003</td>
<td>0.076 to 0.081</td>
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<tr>
<td></td>
<td>0.076 to 0.081</td>
<td>0.093 to 0.098</td>
</tr>
<tr>
<td>1-hr</td>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>0.64 to 0.71 0.85 to 1.04</td>
<td>0.12 to 2.10</td>
</tr>
<tr>
<td></td>
<td>0.02 to 0.05</td>
<td>-0.03 to -0.001</td>
</tr>
<tr>
<td></td>
<td>-0.03 to -0.001</td>
<td>0.075 to 0.080</td>
</tr>
<tr>
<td></td>
<td>0.075 to 0.080</td>
<td>0.090 to 0.097</td>
</tr>
<tr>
<td>24-hr</td>
<td>0.31</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>0.59 to 0.70 0.70 to 0.87</td>
<td>0.16 to 0.65</td>
</tr>
<tr>
<td></td>
<td>0.06 to 0.09</td>
<td>0.02 to 0.003</td>
</tr>
<tr>
<td></td>
<td>0.06 to 0.09</td>
<td>0.051 to 0.054</td>
</tr>
<tr>
<td></td>
<td>0.051 to 0.054</td>
<td>0.058 to 0.064</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.
Ozone ($O_3$) in Polludrone Smart
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 for ozone from Unit 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

Polludrone Smart; Intra-model variability

- Absolute intra-model variability was ~ 3.3 ppb for the ozone measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 15.7% for the ozone measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
The Polludrone Smart sensors showed very weak correlations with the corresponding FEM ozone data ($0.14 < R^2 < 0.23$).

Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument.

The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument.

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis.
The Polludrone Smart sensors showed very weak correlations with the corresponding FEM ozone data ($0.15 < R^2 < 0.23$)

Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument.

The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument.

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis.
The Polludrone Smart sensors showed very weak to weak correlations with the corresponding FEM ozone data (0.10 < $R^2$ < 0.31).

Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument.

The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument.

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis.
# Summary: Ozone

## Average of 3 Sensors, Ozone

<table>
<thead>
<tr>
<th>Polludrone Smart vs FEM, Ozone</th>
<th>FEM Ozone (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong> (ppb)</td>
<td><strong>SD</strong> (ppb)</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>5-min</td>
<td>29.4</td>
</tr>
<tr>
<td>1-hr</td>
<td>29.9</td>
</tr>
<tr>
<td>8-hr</td>
<td>31.3</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.
Nitric Oxide (NO) in Polludrone Smart
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 for NO from Unit 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

Polludrone Smart; Intra-model variability

• Absolute intra-model variability was ~ 0.3 ppb for the NO measurements (calculated as the standard deviation of the three sensor means)
• Relative intra-model variability was ~ 1.8% for the NO measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
The Polludrone Smart sensors showed very weak to weak correlations with the corresponding reference NO data ($0.10 < R^2 < 0.36$). Overall, the Polludrone Smart sensors overestimated the NO concentrations as measured by the reference instrument. The Polludrone Smart sensors did not seem to track the diurnal NO variations as recorded by the reference instrument.

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis. 24-hr data not shown as a result of lack of data from the sensors due to values below LOD being removed.
Polludrone Smart vs Reference (NO; 1-hr mean)

- The Polludrone Smart sensors showed very weak to weak correlations with the corresponding reference NO data ($0.11 < R^2 < 0.36$)
- Overall, the Polludrone Smart sensors overestimated the NO concentrations as measured by the reference instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO variations as recorded by the reference instrument

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis. 24-hr data not shown as a result of lack of data from the sensors due to values below LOD being removed.
## Summary: NO

<table>
<thead>
<tr>
<th>Average of 3 Sensors, NO</th>
<th>Polludrone Smart vs Reference, NO</th>
<th>Reference NO (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (ppb)</td>
<td>SD (ppb)</td>
</tr>
<tr>
<td>5-min</td>
<td>28.3</td>
<td>18.6</td>
</tr>
<tr>
<td>1-hr</td>
<td>28.7</td>
<td>17.1</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.
Nitrogen Dioxide (NO$_2$) in Polludrone Smart
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 for NO$_2$ from Unit 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

Polludrone Smart; Intra-model variability

• Absolute intra-model variability was ~ 3.3 ppb for the NO$_2$ measurements (calculated as the standard deviation of the three sensor means)
• Relative intra-model variability was ~ 11.2% for the NO$_2$ measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
Polludrone Smart vs FRM (NO₂; 5-min mean)

- The Polludrone Smart sensors did not correlate with the corresponding FRM NO₂ data (0.001 < \( R^2 \) < 0.04)
- Overall, the Polludrone Smart sensors overestimated the NO₂ concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO₂ variations as recorded by the FRM instrument

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis
Polludrone Smart vs FRM (NO$_2$; 1-hr mean)

- The Polludrone Smart sensors did not correlate with the corresponding FRM NO$_2$ data ($0.003 < R^2 < 0.04$)
- Overall, the Polludrone Smart sensors overestimated the NO$_2$ concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO$_2$ variations as recorded by the FRM instrument

Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis
**Polludrone Smart vs FRM (NO$_2$; 24-hr mean)**

- The Polludrone Smart sensors showed no to very weak correlations with the corresponding FRM NO$_2$ data ($0.005 < R^2 < 0.11$)
- Overall, the Polludrone Smart sensors overestimated the NO$_2$ concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO$_2$ variations as recorded by the FRM instrument

*Note: Values that were below the manufacturer’s stated Limit of Detection (LOD) were removed and not included in this analysis*
# Summary: NO₂

<table>
<thead>
<tr>
<th>Average of 3 Sensors, NO₂</th>
<th>Polludrone Smart vs FRM, NO₂</th>
<th>FRM NO₂ (ppb)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>FRM Average</td>
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<td>FRM SD</td>
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<td></td>
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<td>Range during the field evaluation</td>
</tr>
<tr>
<td><strong>Average</strong> (ppb)</td>
<td><strong>SD</strong> (ppb)</td>
<td><strong>R²</strong></td>
</tr>
<tr>
<td>5-min</td>
<td>35.5</td>
<td>34.4</td>
</tr>
<tr>
<td>1-hr</td>
<td>35.6</td>
<td>29.4</td>
</tr>
<tr>
<td>24-hr</td>
<td>35.7</td>
<td>10.9</td>
</tr>
</tbody>
</table>

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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.
Oizom Polludrone Smart vs South Coast AQMD Met Station (Temp; 5-min mean)

- The Polludrone Smart sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.97$)
- Overall, the Polludrone Smart temperature measurements overestimated the corresponding South Coast AQMD Met Station data
- The Polludrone Smart sensors seemed to track the temperature diurnal variations as recorded by South Coast AQMD Met Station

![Graph showing temperature data and regression lines for South Coast AQMD Met Station and Polludrone Smart sensors.](image-url)
Oizom Polludrone Smart vs South Coast AQMD Met Station (RH; 5-min mean)

- The Polludrone Smart sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.98$)
- Overall, the Polludrone Smart RH measurements overestimated the corresponding South Coast AQMD Met Station data
- The Polludrone Smart sensors seemed to track the RH diurnal variations as recorded by South Coast AQMD Met Station

\[ y = 1.0011x - 2.8256 \quad R^2 = 0.9808 \]

\[ y = 1.0067x - 3.4801 \quad R^2 = 0.9799 \]

\[ y = 1.0072x - 2.8584 \quad R^2 = 0.9784 \]
The average data recovery of three **Polludrone Smart** sensors for CO, ozone, NO, and NO$_2$ was ~98%.

The absolute intra-model variability for CO, ozone, NO, and NO$_2$ was ~ 0.01 ppm, 3.3 ppb, 0.3 ppb, and 3.3 ppb, respectively.

During the entire field deployment testing period:

- CO sensors showed moderate to strong correlations with the FRM instrument ($0.63 < R^2 < 0.72$, 5-min mean) and underestimated the corresponding FRM data.
- Ozone sensors showed very weak correlations with the FEM instrument ($0.14 < R^2 < 0.23$, 5-min mean) and underestimated the corresponding FEM data.
- Nitric Oxide (NO) sensors showed very weak to weak correlations with the reference instrument ($0.10 < R^2 < 0.36$, 5-min mean) and overestimated the corresponding reference data.
- NO$_2$ sensors did not correlate with the FRM instrument ($0.001 < R^2 < 0.04$, 5-min mean) and overestimated the corresponding FRM data.
- Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station data (T: $R^2 \sim 0.97$ and RH: $R^2 \sim 0.98$) and overestimated T and RH data as recorded by the South Coast AQMD Met Station.

No sensor calibration was performed by AQ-SPEC prior to the beginning of this field testing.

Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under controlled T and RH conditions, and known target and interferent pollutants concentrations.

These results are still preliminary.