Field Evaluation
Kunak Air A10
From 04/28/2019 to 07/11/2019, three Kunak Air A10 (hereinafter Kunak) 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.

**Kunak (3 units tested):**
- Particle sensor: AS OPC N3 (optical; non-FEM)
- Gas sensors: AS B4 series (electrochemical; non-FEM)
- Each unit reports: PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ ($\mu$g/m$^3$), Ozone (ppb), CO (ppb), NO, NO$_2$, NO$_x$ (ppb), temperature ($^\circ$C), RH (%), pressure, Wind Speed (km/h), Wind Direction (degree)
- 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

**South Coast AQMD Reference instruments:**
- MetOne BAM (FEM PM$_{2.5}$ & PM$_{10}$), cost: ~$20,000
  - Time resolution: 1-hr
- Teledyne T640 (FEM PM$_{2.5}$), cost: ~$21,000
  - Time resolution: 1-min
- CO instrument; FRM, cost: ~$10,000
  - Time resolution: 1-min
- NO$_x$ instrument; FRM, cost: ~$11,000
  - Time resolution: 1-min
- O$_3$ instrument; FEM, cost: ~$7,000
  - Time resolution: 1-min
- Met station (T, RH, P, WS, WD), cost: ~$5,000
  - Time resolution: 1-min

1 Only available in Unit 0002
2 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, API rest.
Ozone \((O_3)\) in Kunak
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 units 0000, 0001, 0002 was ~ 98% for ozone measurements

Kunak; intra-model variability

- Absolute intra-model variability was ~ 0.32 ppb (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 0.94% (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
Kunak vs FEM (Ozone; 5-min mean)

- Kunak sensors showed strong correlations with the corresponding FEM ozone data ($R^2 \approx 0.87$)
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument
Kunak vs FEM (Ozone; 1-hr mean)

- Kunak sensors showed strong correlations with the corresponding FEM ozone data ($R^2 \sim 0.88$).
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument.
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument.

![Graph showing Kunak vs FEM Ozone](image)

- $y = 0.912x + 6.5133$  
  $R^2 = 0.8694$

- $y = 1.0596x + 1.1113$  
  $R^2 = 0.8881$

- $y = 1.0569x + 0.8975$  
  $R^2 = 0.8784$
Kunak vs FEM (Ozone; 8-hr mean)

- Kunak sensors showed very strong correlations with the corresponding FEM ozone data ($R^2 \sim 0.93$)
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument
Carbon Monoxide (CO) in Kunak
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 units 0000, 0001, 0002 was ~100% for CO measurements

Kunak; intra-model variability

- Absolute intra-model variability was ~ 0.002 ppm (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 0.66% (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

![Graph showing carbon monoxide levels for different units](image-url)
Kunak vs FRM (CO; 5-min mean)

- Kunak sensors showed moderate correlations with the corresponding FRM CO data ($R^2 \sim 0.58$)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument
- Kunak sensors showed moderate correlations with the corresponding FRM CO data ($R^2 \sim 0.59$)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument
Kunak vs FRM (CO; 24-hr mean)

- Kunak sensors showed moderate correlations with the corresponding FRM CO data ($R^2 \sim 0.68$)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument

Note: The FRM instrument was down between 6/7/19-6/11/19, both FRM and sensor CO data were excluded from the data set during this period.
Nitrogen Oxides in Kunak
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).
- Average Data recovery from all units was 94%, 96% and 92% for NO, NO$_2$ and NO$_x$ measurements, respectively.

Kunak; intra-model variability

- Absolute intra-model variability was $\sim$ 0.15, 0.33 and 0.47 ppb for NO, NO$_2$ and NO$_x$, respectively (calculated as the standard deviation of the three sensor means).
- Relative intra-model variability was $\sim$ 11.4%, 2.9% and 3.7% for NO, NO$_2$ and NO$_x$, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means).

<table>
<thead>
<tr>
<th></th>
<th>Unit 0000</th>
<th>Unit 0001</th>
<th>Unit 0002</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>
Kunak vs Reference (NO; 5-min mean)

- Kunak sensors showed strong correlations with the corresponding reference NO data ($R^2 \sim 0.87$)
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument
Kunak vs FRM (NO$_2$; 5-min mean)

- Kunak sensors showed very weak correlations with the corresponding FRM NO$_2$ data ($R^2 \approx 0.29$)
- Overall, the Kunak sensors overestimated the NO$_2$ concentrations as measured by the FRM instrument
- The Kunak sensors did not seem to track the NO$_2$ diurnal variations as recorded by the FRM instrument

\[
y = 0.2971x + 5.3515 \\
R^2 = 0.3102
\]

\[
y = 0.3318x + 4.8799 \\
R^2 = 0.3226
\]

\[
y = 0.265x + 5.557 \\
R^2 = 0.2407
\]
Kunak vs Reference (NO\textsubscript{x}; 5-min mean)

- Kunak sensors showed moderate correlations with the corresponding reference NO\textsubscript{x} data (R\textsuperscript{2} ~ 0.54)
- Overall, the Kunak sensors overestimated the NO\textsubscript{x} concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO\textsubscript{x} diurnal variations as recorded by the reference instrument

\begin{align*}
\text{Reference} & \quad \text{Unit 000} & \quad \text{Unit 0001} & \quad \text{Unit 0002} \\
y = 0.6525x + 3.0539 & \quad y = 0.7545x + 1.5495 & \quad y = 0.6487x + 2.5872 \\
R^2 = 0.5542 & \quad R^2 = 0.5427 & \quad R^2 = 0.5207
\end{align*}
Kunak vs Reference (NO; 1-hr mean)

- Kunak sensors showed strong correlations with the corresponding reference NO data ($R^2 \approx 0.88$).
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument.
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument.

**Kunak vs Reference NO**

- **Reference NO**
- **Unit 0000**
- **Unit 0001**
- **Unit 0002**

**NO (1-hr mean, ppb)**

- **Unit 0000**
  - $y = 1.2259x + 0.5931$
  - $R^2 = 0.9192$

- **Unit 0001**
  - $y = 1.3243x + 0.4244$
  - $R^2 = 0.7863$

- **Unit 0002**
  - $y = 1.194x + 0.25$
  - $R^2 = 0.9406$
Kunak vs FRM (NO₂; 1-hr mean)

- Kunak sensors showed weak correlations with the corresponding FRM NO₂ data (R^2 ~ 0.33)
- Overall, the Kunak sensors overestimated the NO₂ concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the NO₂ diurnal variations as recorded by the FRM instrument

\[
y = 0.3148x + 5.0787 \\
R^2 = 0.3435
\]

\[
y = 0.3562x + 4.5547 \\
R^2 = 0.3611
\]

\[
y = 0.2911x + 5.237 \\
R^2 = 0.2791
\]
Kunak vs Reference (NO$_x$; 1-hr mean)

- Kunak sensors showed moderate correlations with the corresponding reference NO$_x$ data ($R^2 \sim 0.55$)
- Overall, the Kunak sensors overestimated the NO$_x$ concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO$_x$ diurnal variations as recorded by the reference instrument
Kunak vs Reference (NO; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding reference NO data ($R^2 \sim 0.86$)
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument

\begin{align*}
y &= 1.3998x + 0.5612 \\
R^2 &= 0.8329
\end{align*}

\begin{align*}
y &= 1.8371x - 0.1725 \\
R^2 &= 0.8316
\end{align*}

\begin{align*}
y &= 1.3818x + 0.1598 \\
R^2 &= 0.9257
\end{align*}
Kunak vs FRM (NO$_2$; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding FRM NO$_2$ data ($R^2 \approx 0.79$)
- Overall, the Kunak sensors overestimated the NO$_2$ concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the NO$_2$ diurnal variations as recorded by the FRM instrument
Kunak vs Reference (NO$_x$; 24-hr mean)

- Kunak sensors showed moderate correlations with the corresponding reference NO$_x$ data ($R^2 \sim 0.82$)
- Overall, the Kunak sensors overestimated the NO$_x$ concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO$_x$ diurnal variations as recorded by the reference instrument

![Graph showing Kunak vs Reference NO$_x$ concentrations over time.]

![Scatter plots showing the relationship between Kunak and reference NO$_x$ concentrations for Unit 0000, Unit 0001, and Unit 0002.]

- Unit 0000: 
  \[ y = 0.9605x - 1.3111 \]
  \[ R^2 = 0.7979 \]

- Unit 0001: 
  \[ y = 1.0158x - 2.4366 \]
  \[ R^2 = 0.8559 \]

- Unit 0002: 
  \[ y = 0.9147x - 1.4926 \]
  \[ R^2 = 0.8069 \]
Discussion

- The three Kunak sensors’ data recovery from all units was ~ 98%, ~ 96% and ~ 100% for ozone, NO₂ and CO measurements, respectively.

- The three sensors showed an absolute intra-model variability of 0.32 ppb, 0.33 ppb and 0.002 ppm for ozone, NO₂ and CO measurements, respectively.

- During the field deployment testing period:
  - Ozone sensors showed strong correlations ($R^2 \sim 0.87$, 5-min mean) with the FEM instrument and underestimated the corresponding FEM Ozone measurements.
  - Nitric Oxide (NO) sensors showed strong correlations ($R^2 \sim 0.87$, 5-min mean) with the reference instrument.
  - Nitrogen Dioxide (NO₂) sensors showed weak correlations ($R^2 \sim 0.29$, 5-min mean) with the reference instrument and overestimated the corresponding FRM NO₂ data.
  - Nitrogen Oxides (NOₓ) sensors showed moderate correlations ($R^2 \sim 0.54$, 5-min mean) with the reference instrument.
  - CO sensors showed moderate correlations ($R^2 \sim 0.58$, 5-min mean) with the FRM instrument and underestimated the corresponding FRM CO data.

- No sensor calibration was performed by South Coast AQMD Staff prior to the beginning of this test.

- 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.
PM in Kunak
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 units 0000, 0001, 0002 was ~100% for all PM measurements

Kunak; intra-model variability

• Absolute intra-model variability was ~ 1.02 and 1.73 µg/m³ for PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the standard deviation of the three sensor means)
• Relative intra-model variability was ~ 13 and 10 % for PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
Data recovery for PM$_{2.5}$ from FEM BAM and FEM T640 was 98 % and 99.7%, respectively.

Strong correlations between the reference instruments for PM$_{2.5}$ measurements ($R^2 \sim 0.88$) were observed.
Data recovery for PM$_{10}$ from FEM BAM and T640 was 98.9% and 99.7%, respectively.

Strong correlations between the reference instruments for PM$_{10}$ measurements ($R^2 \approx 0.85$) were observed.
Kunak vs FEM BAM (PM$_{2.5}$; 1-hr mean)

- Kunak sensors showed moderate correlations with the corresponding FEM BAM data ($R^2 \approx 0.63$)
- Overall, the Kunak sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM
Kunak vs FEM BAM (PM$_{10}$; 1-hr mean)

- Kunak sensors showed moderate correlations with the corresponding FEM BAM data ($R^2 \sim 0.63$)
- Overall, the Kunak sensors underestimated the PM$_{10}$ mass concentrations measured by FEM BAM
- The Kunak sensors seemed to track the PM$_{10}$ diurnal variations as recorded by FEM BAM
Kunak vs FEM BAM (PM$_{2.5}$; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding FEM BAM data ($R^2 \approx 0.73$)
- Overall, the Kunak sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM
Kunak vs FEM BAM (PM$_{10}$; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding FEM BAM data ($R^2 \sim 0.82$)
- Overall, the Kunak sensors underestimated the PM$_{10}$ mass concentrations measured by FEM BAM
- The Kunak sensors seemed to track the PM$_{10}$ diurnal variations as recorded by FEM BAM

\[
y = 1.7845x + 6.2023 \\
R^2 = 0.8367
\]

\[
y = 2.3153x + 2.8671 \\
R^2 = 0.7952
\]

\[
y = 1.9481x + 1.9936 \\
R^2 = 0.8315
\]
Kunak vs FEM T640 (PM$_{2.5}$; 5-min mean)

- Kunak sensors showed strong correlations with the corresponding FEM T640 data ($R^2 \sim 0.73$)
- Overall, the Kunak sensors underestimated the PM$_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640

$$y = 1.3202x + 5.2555$$

$$R^2 = 0.7419$$

$$y = 1.609x + 5.3219$$

$$R^2 = 0.6853$$

$$y = 1.431x + 3.7719$$

$$R^2 = 0.7532$$
Kunak vs T640 (PM$_{10}$; 5-min mean)

- Kunak sensors showed moderate correlations with the corresponding T640 data ($R^2 \sim 0.64$)
- Overall, the Kunak sensors underestimated the PM$_{10}$ mass concentrations measured by T640
- The Kunak sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640
- Kunak sensors showed strong correlations with the corresponding FEM T640 data ($R^2 \sim 0.73$)
- Overall, the Kunak sensors underestimated the PM$_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
Kunak vs T640 (PM\textsubscript{10}; 1-hr mean)

- Kunak sensors showed strong correlations with the corresponding T640 data ($R^2 \sim 0.73$)
- Overall, the Kunak sensors underestimated the PM\textsubscript{10} mass concentrations measured by T640
- The Kunak sensors seemed to track the PM\textsubscript{10} diurnal variations as recorded by T640
Kunak vs FEM T640 (PM$_{2.5}$; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding FEM T640 data ($R^2 \sim 0.80$)
- Overall, the Kunak sensors underestimated the PM$_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
Kunak vs T640 (PM$_{10}$; 24-hr mean)

- Kunak sensors showed strong correlations with the corresponding T640 data ($R^2 \approx 0.83$)
- Overall, the Kunak sensors underestimated the PM$_{10}$ mass concentrations measured by T640
- The Kunak sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640

\[ y = 1.6627x + 7.5652 \]
\[ R^2 = 0.8069 \]

\[ y = 2.2363x + 3.2803 \]
\[ R^2 = 0.8241 \]

\[ y = 1.8751x + 2.5553 \]
\[ R^2 = 0.8557 \]
Meteorological data in Kunak
Kunak vs South Coast AQMD Met Station (Temp; 5-min mean)

- Kunak temperature measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.98$)
- Overall, the Kunak temperature measurements overestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the temperature diurnal variations as recorded by South Coast AQMD Met Station
Kunak vs South Coast AQMD Met Station (RH; 5-min mean)

- Kunak RH measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.99$)
- Overall, the Kunak RH measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the RH diurnal variations as recorded by South Coast AQMD Met Station
Kunak vs South Coast AQMD Met Station (WS; 5-min mean)

- Kunak wind speed (WS) measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.94$)
- Overall, the Kunak WS measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the WS diurnal variations as recorded by South Coast AQMD Met Station

Note: Only Unit 0002 reports wind speed (WS).
Kunak vs South Coast AQMD Met Station (WD; 5-min mean)

- Kunak wind direction (WD) measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \approx 0.91$)
- Overall, the Kunak WD measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track the WD diurnal variations as recorded by South Coast AQMD Met Station

Note: Only Unit 0002 reports wind direction (WD). Only valid wind direction data were included (at wind speed higher than 0.5 m/s). To avoid confusion in WD comparison, values lower than 15 degrees and higher than 345 degrees have been omitted from the data set.
Discussion

• The three Kunak sensors’ data recovery from all units was ~ 100% for all PM measurements
• The absolute intra-model variability was ~ 1.02 and 1.73 µg/m$^3$ for PM$_{2.5}$ and PM$_{10}$, respectively
• The reference instruments (BAM and T640) showed strong correlations with each other for both PM$_{2.5}$ ($R^2$ ~ 0.88) and PM$_{10}$ ($R^2$ ~ 0.85) mass concentration measurements (1-hr mean)
• PM$_{2.5}$ mass concentration measurements measured by Kunak sensors showed moderate to strong correlations with the corresponding FEM BAM and FEM T640 data ($R^2$ ~ 0.63 and 0.73, respectively; 1-hr mean). The sensors underestimated PM$_{2.5}$ mass concentrations measured by FEM BAM and FEM T640
• PM$_{10}$ mass concentration measurements measured by Kunak sensors showed moderate to strong correlations with the corresponding FEM BAM and T640 data ($R^2$ ~ 0.63 and 0.73, respectively; 1-hr mean) and underestimated PM$_{10}$ mass concentrations measured by FEM BAM and T640
• No sensor calibration was performed by South Coast AQMD Staff prior to the beginning of this test
• 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