Supplement of

Stationary and portable multipollutant monitors for high-spatiotemporal-resolution air quality studies including online calibration

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**S1 Concentration Conversion Methodology and Example**

First, raw voltages are collected and converted to concentrations based on a laboratory derived calibration curve for each box. For the electrochemical sensors, we use the differential voltage, which is the working electrode minus the auxiliary electrode.

\[ \text{Volt}_{\text{diff}} = \text{Volt}_{\text{WE}} - \text{Volt}_{\text{AE}}, \]  
(S1)

In the case below for this particular monitor there is a linear relationship between the differential voltage and the known concentration of reference gas (see Fig. S1). The fit follows the form of:

\[ C_{\text{raw}} = a_{\text{cal}} \text{Volt}_{\text{diff}} + b_{\text{cal}}, \]  
(S2)

where \( C_{\text{raw}} \) represents the non-RH/T corrected concentration value. This fit works well for the Alphasense electrochemical sensors. See notes at the end for CO\(_2\) sensor fits. The limit of detection values shown in Table 1 are calculated by taking three times the standard deviation of the sensor output in zero air and dividing by the slope (\( a_{\text{cal}} \)).

![Figure S1](image)

**Figure S1**: (a) Laboratory linear calibration of one CO sensor under a range of known gas concentrations and (b) zoom in on one point to show minimal standard deviation in differential signal for a several minute period under constant laboratory RH/T setting.

For this study we implement RH/T correction factors from co-location evaluations rather than from lab calibrations. Using a training period, we apply the following equations to reach a final concentration:

\[ C_T = \frac{C_{\text{raw}}}{a_T T^2 + b_T T + c_T}, \]  
(S3)

\[ C_{RH/T} = \frac{C_T}{a_{RH} RH^2 + b_{RH} RH + c_{RH}}. \]  
(S4)

First the ratio of the monitor value over the reference is plotted against temperature. We apply a best-fit linear and quadratic regression to determine the relationship (see Fig. S2). Then we examine the \( r^2 \) value for each and choose the fit with the strongest correlation. Here, the best temperature relationship is determined to be quadratic (apply fit to Eqn. S2 to extract temperature corrected concentration). Then the temperature corrected concentration relative to reference is plotted against
relative humidity. Here, the best relative humidity relationship is linear (apply fit to Eqn. S3 to extract the final concentration data). With these two relationships we can apply the RH/T correction factors to the rest of the data.

**Figure S2:** Training period example for the NO$_2$ sensor after a one-week co-location. The left shows the ratio of the multipollutant monitor concentration relative to the reference monitor against T. The right shows the ratio of the temperature corrected multipollutant monitor concentration relative to the reference against RH. These plots are used to generate the coefficients for the denominators of Eqn S3 and Eqn S4.

Notes for CO$_2$: The CO$_2$ calibrations follows Alphasense technical documentation rather than the above methodology (Alphasense Ltd., 2014). No RH adjustment is made for the CO$_2$ sensor, only the Alphasense-specified T correction. In addition, when aggregating the data to evaluate the CO$_2$ sensor relative to a reference, we implement a rolling geometric mean rather than arithmetic for averaging and smoothing sensor response. All other sensors use an arithmetic mean for calculations.

**S2 Comparison with Literature**

In a systematic review of the literature, Karagulian et al. (2019) compiled the $r^2$ and slope values of numerous field and laboratory co-locations for low cost monitors. They then determined a “best selection region” for monitors from the union of high correlation ($r^2>0.75$) and minimal over or under estimation ($0.5<m<1.5$). Three out of our five co-located pollutants (O$_3$, CO, PM$_{2.5}$) discussed in detail lie inside of the best selection region, with one additional pollutant (NO$_2$) along the edge (Fig. S12). Two pollutants do not fall near this region (CO$_2$ and NO) for reasons previously discussed in the main text.

**References:**


Table S1: Physical and electronic technical information on the stationary and portable monitors.

<table>
<thead>
<tr>
<th></th>
<th>Stationary</th>
<th>Portable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (cm)</td>
<td>28 x 18 x 14</td>
<td>15 x 6.5 x 5 (^1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23 x 12 x 6.5 (^2)</td>
</tr>
<tr>
<td>Power</td>
<td>Wall Outlet</td>
<td>Tenergy #31800 Rechargable Li-ion Battery (11.1 V 10.4 Ah, 115.45 Wh)</td>
</tr>
<tr>
<td>Data Storage</td>
<td>Onboard 16 GB SanDisk Edge MicroSD</td>
<td></td>
</tr>
<tr>
<td>Data Transmission</td>
<td>Cellular communication to InfluxDB via Telit LE910C1-NS module at 10s interval</td>
<td>N/A</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>Cypress 68 pin PSoC 5lp</td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>PSoC Creator 4.1</td>
<td></td>
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<tr>
<td>Cell Antenna</td>
<td>LTE + Cellular flexiiANT Mitis SRFL026</td>
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<tr>
<td>GPS Antenna</td>
<td>N/A</td>
<td>Octaband LTE Cellular Embedded antenna (FPC) 1002292</td>
</tr>
<tr>
<td>Operational Duration</td>
<td>Indefinitely</td>
<td>~3 days per single charge</td>
</tr>
</tbody>
</table>

\(^1\)Dimensions for shoulder mountable sensor manifold and enclosure  
\(^2\)Dimensions for motherboard enclosure and battery

Figure S3: Photo of the (a) non-cylinder and (b) cylinder version of the stationary multipollutant monitor.
**Figure S4:** Calibration system flow diagram in the overall system schematic for Yale multipollutant monitor. This system includes calibration approaches for both the gas-phase sensors and particulate matter sensor. The pump operates during all sampling modes except when the standard gas cylinder is used.
Figure S5: Data management and visualization software to see real time measurements. Grafana (a) is an open source data visualization platform allowing us to interface directly with our data management software InfluxDB (b) which is accessed through the secure shell PuTTY.
**Figure S6**: Demonstration of linearity of electrochemical sensor calibration. Error bars represent standard deviation of signal over several minutes of exposure to the target gas at a given concentration. Note that this is for the calibration of one sensor and there is variation in slopes among sensors.

**Figure S7**: Calibration data for the Figaro TGS 2600 CH₄ sensor. A linear response is observed in typical ambient or urban background levels both with and without an activated carbon cloth filter to remove cross-sensitivity to VOCs.
Figure S8: PM sensor intercomparison (raw data) for 5 co-located monitors over 2.5 weeks in New Haven, CT (accompanies data shown in Fig. 2b).

Figure S9: CO comparisons to reference instrument for low (<18 °C, left) and high (>18 °C, right) temperature readings. This accompanies Fig. 4 in the main text.
**Figure S10:** Additional examples of field data with fast monitor response times to concentration changes demonstrated roadside with motor vehicle spikes in PM$_1$ and raw CO differential signal at 10-s resolution.

**Figure S11:** NO sensor regression (a) and probability density (b) from a two-week field deployment in New Haven, CT. The reference instrument comes from the near-road DEEP Criscuolo Park site (1.6 km away from sampling location in downtown New Haven). Given the generally low NO levels during the sampling period the probability density is shown as the MBE rather than the ratio of sensor to reference as in main text figures. Nearly 60% of data points fall within ±5 ppb of the reference at a 1 h resolution. Accompanies the data shown in Fig. 7.
**Figure S12:** Performance of the zero trap for O\textsubscript{3} removal via steel wool and activated carbon shown as raw O\textsubscript{3} sensor resistances. Two tests during a mid-July afternoon in Baltimore, MD show a rapid decrease in sensor response through the zero trap (orange) relative to normal sampling and other calibration steps. Note: data are shown on a logarithmic scale due exponential response to concentration.

**Figure S13:** Raw PM\textsubscript{2.5} (black) and PM\textsubscript{10} (red) sensor zero near food-cooking carts in New Haven, CT. After the valve switch, a short lag occurs (i.e. to purge inlet) before the sensor is zeroed for two minutes.
Figure S14: Sensor $r^2$ and slope values for collocation data. Blue shaded triangle represents the “best selection region” from Karagulian et al. (2019). Three of our measurements lie within this region (O$_3$, CO, and PM$_{2.5}$), with one along the edge (NO$_2$). Two pollutants (CO$_2$ and NO) did not fall into the region partially due to not having a true co-location comparison (reference sites were 2.7 and 1.6 km away from sampling location, respectively).