Low-cost, high-density sensor network for urban air quality monitoring: BEACO$_2$N

Jinsol Kim, Alexis A. Shusterman, Kaitlyn J. Lieschke, Catherine Newman, Ronald C. Cohen*

Berkeley UNIVERSITY OF CALIFORNIA

University of California, Berkeley, CA, USA

***Contact Information: rccohen@berkeley.edu**

Introduction

- **BEACO$_2$N** is a low-cost, high-density air quality monitoring network in San Francisco Bay Area that consists of approximately 50 nodes distributed at 2km horizontal spacing, measuring CO_2, CO, NO, NO_2, O_3 and particulate matter.
- Here, we describe an in-field calibration procedure for CO, NO, NO_2, and O_3 that are consistent with the low-cost specification.

Berkeley Atmospheric CO$_2$ Observation Network (BEACO$_2$N)

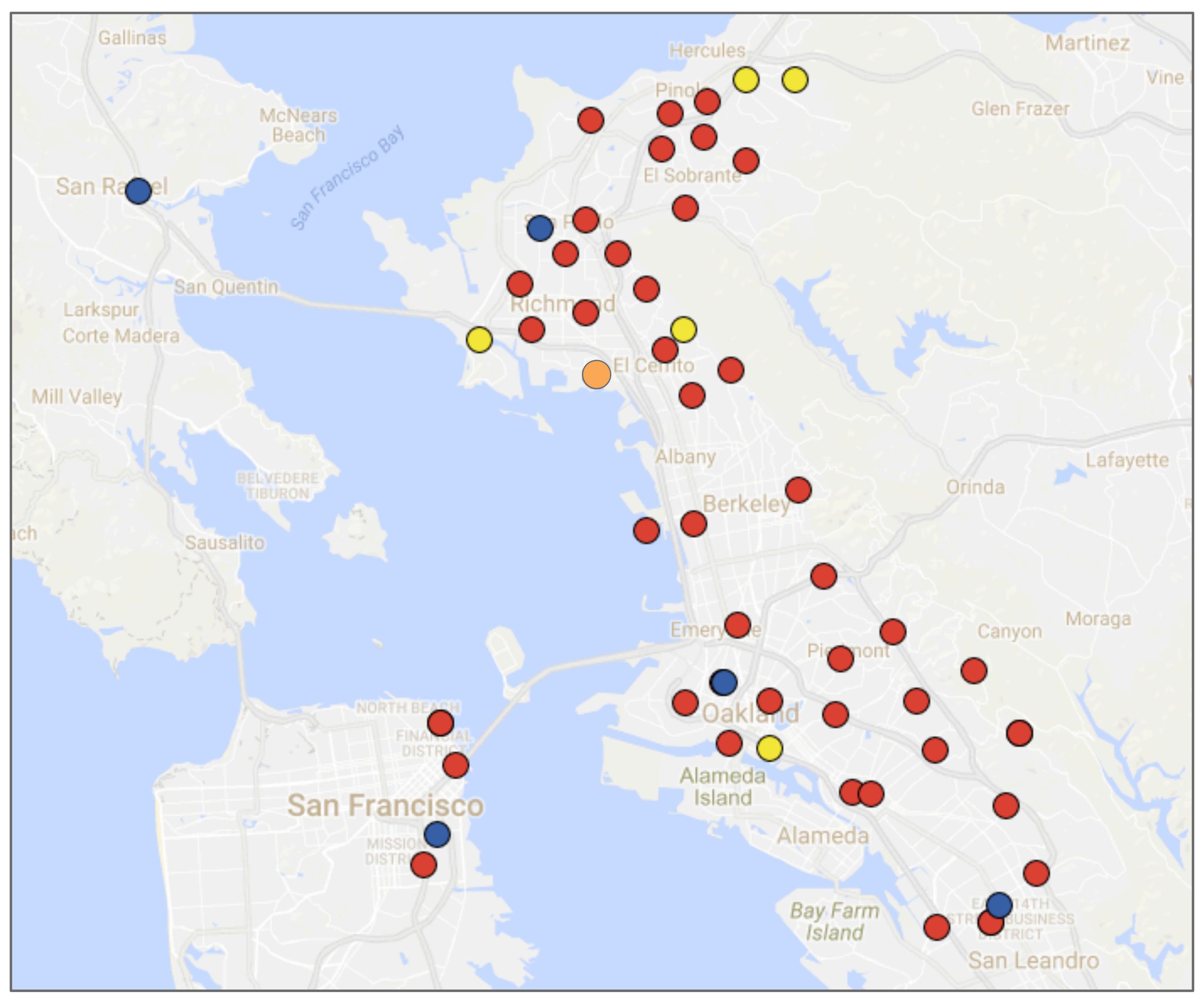

Figure 1. Map of current BEACO$_2$N nodes (red) and BAAQMD sites measuring O_3 (blue). The sites shown for examples are marked in yellow and supersite is marked in orange.

Node Design of BEACO$_2$N

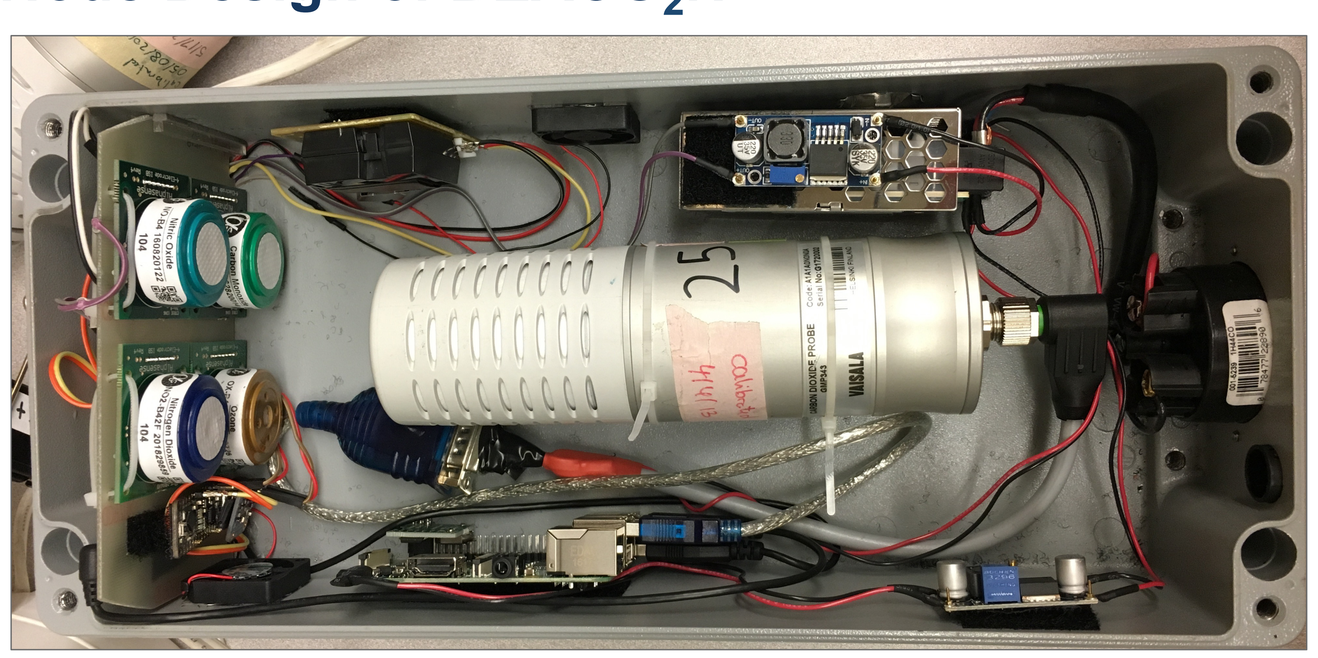

Figure 2. Current BEACO$_2$N node design.

- Vaisala CarboCap GMP343 NDIR sensor for CO_2
- Alphasense B4 electrochemical sensors for CO, NO, NO_2 and O_3
- Shinyei PPD42NS nephelometric PM sensor
- Bosch Sensortec BME280 sensor for pressure, temperature and humidity inside the node
- Communication by wifi or cellular

Physical model of air quality sensors

The sensors' response to target gases is linear (Eqn. 1-4). Additional terms in Eqn. 3 and 4 indicate observed cross-sensitivity of the NO_2 and O_3 sensors. Zero offset, sensitivity and cross-sensitivity terms are temperature dependent.

$$CO_{ambient} = (V_{CO} - zero_{CO})/k_{CO} \quad (1)$$

$$NO_{ambient} = (V_{NO} - zero_{NO})/k_{NO} \quad (2)$$

$$NO2_{ambient} = (V_{NO2} - zero_{NO2})/k_{NO2} - r_{NO-NO2} \times NO_{ambient} \quad (3)$$

$$O3_{ambient} = (V_{O3} - zero_{O3})/k_{O3} - r_{NO2-O3} \times NO2_{ambient} \quad (4)$$

In-field Calibration

Ten calibration parameters have to be constrained simultaneously. The first constraint fixes O_3 cross-sensitivity to NO_2 at unity.

1. Use of chemical conservation equations near emissions (5 constraints)

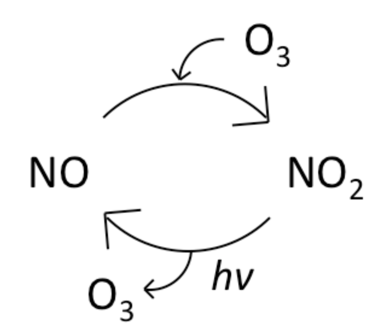

Figure 3. Schematic of NO$_x$ cycle.

$$\frac{\Delta NO_{ambient}}{\Delta NO2_{ambient}} = \frac{\Delta NO2_{ambient}}{\Delta O3_{ambient}} = -\frac{\Delta O3_{ambient}}{\Delta NO_{ambient}} = -1 \quad (5)$$

At night, NO➔0 (in the absence of emissions)
O_3 ➔0 (near strong emissions) (6)

During the day, $j_{NO2}[NO_2] = k_{NO-O3}[NO][O_3]$ (7)

2. Regional ozone uniformity (3 constraints)

From Eqn. 2-4 we drive Eqn. 8:

$$O3_{ambient} = \frac{V_{O3}}{k_{O3}} - \frac{V_{NO2}}{k_{NO2}} + \frac{V_{NO}}{k_{NO}/r_{NO-NO2}} - offset \quad (8)$$

We use regulatory ozone data for $O3_{ambient}$ and implement multiple linear regression.

3. Use of co-emitted gases in plumes (1 constraint)

$$EF_{CO} = \frac{\Delta CO_{ambient}}{\Delta CO2_{ambient}} \quad (9)$$

CO emission factors reported in Dallmann et al. (2013) are used.

4. Use of global background (1 constraint)

$$[CO]_{node} = [CO]_{background} + [CO]_{local} + offset \quad (10)$$

We assume that the monthly minimum concentration measured at a given site represents $[CO]_{background}$ and the daily minimum concentration has a constant deviation from the background signal. The background signal is compared to measurements at a "supersite" of reference instruments located within the network domain.

- **Temperature dependence and temporal drift**

Each calibration parameter is calculated in temperature increments of 1°C and this calibration protocol is repeated every month or so with 3-month running window to account for drift in sensors' sensitivity and zero offset.

Examples of node performance

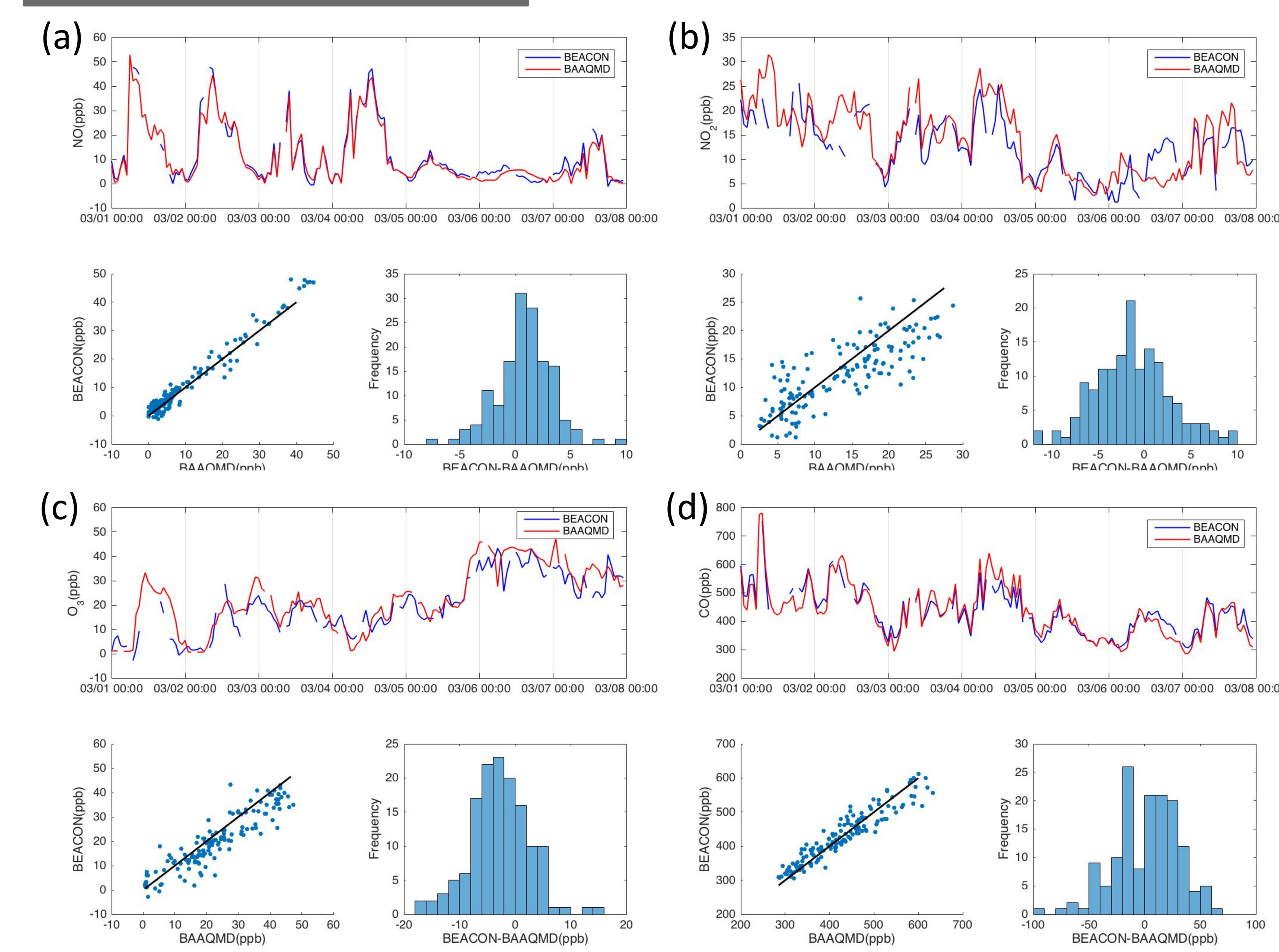

Figure 4. Calibrated data of Laney College site for (a) NO, (b) NO$_2$, (c) O$_3$, and (d) CO compared to standard regulatory measurements.

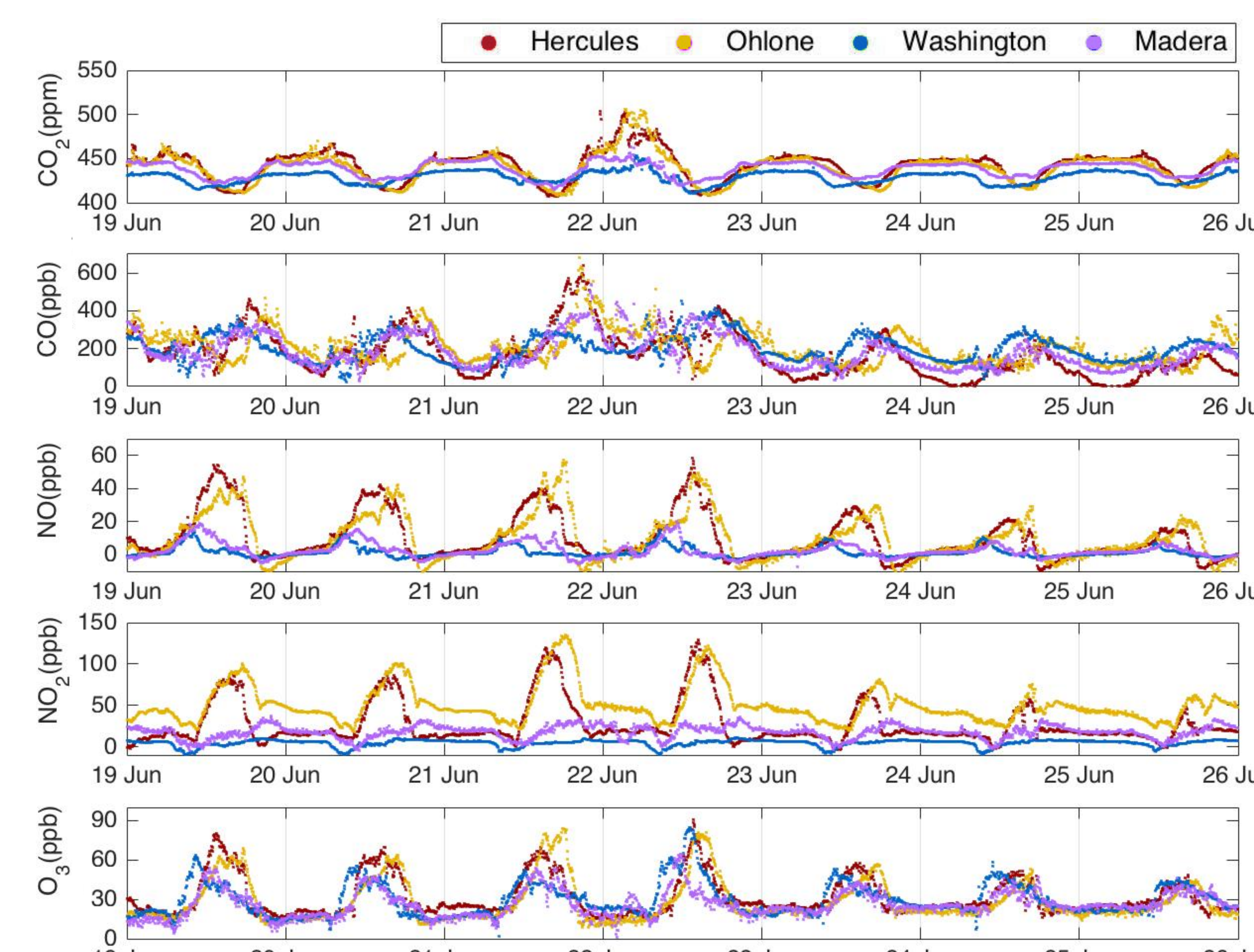

Figure 5. Time series of calibrated BEACO2N data from a representative week at 4 Ricmond sites.

References

[1] Shusterman et al., *Atmospheric Chemistry & Physics*, 16, 13449-13463, 2016

[2] Kim et al., *Atmospheric Measurement Techniques*, submitted

[3] Dallmann et al., *Environmental Science & Technology*, 47, 13873-13881, 2013

- BEACO$_2$N website: http://beacon.berkeley.edu/Sites.aspx