Real-world evaluation and application of emerging air sensing technologies

Stephen Feinberg, PhD
Oak Ridge Institute for Science and Education (ORISE) research appointment at
EPA Office of Research and Development
Coauthors

• Ron Williams¹, Gayle Hagler¹, Joshua Rickard², Ryan Brown³, Daniel Garver³, Greg Harshfield⁴, Phillip Stauffer⁴, Erick Mattson⁴, Robert Judge⁵, Rollins Sachs⁶, Erik Wolf⁶, Doug Watson⁷, Jayson Prentice⁷

• 1. U.S. Environmental Protection Agency (EPA), Office of Research and Development, Research Triangle Park, NC 27711,
• 2. U.S. EPA Region 8, Denver, CO 80202,
• 3. U.S. EPA Region 4, Atlanta, GA 30303,
• 4. State of Colorado Department of Public Health and Environment (CDPHE),
• 5. U.S. EPA Region 1, Boston, MA 02109,
• 6. Unified Government of Wyandotte County, KS,
• 7. Kansas Department of Health and Environment (KDHE)
The goal of this presentation is to give information on the following topics:

- Performance evaluation of low-cost sensors
- Challenges in performing sensor evaluation
- Application and analysis of Village Green Project data

This presentation is targeted to the public and would be useful for a technical individuals wanting to use sensors for research or for interpreting sensor data.

Disclaimer: This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official U.S. Environmental Protection Agency (EPA) approval, endorsement, or recommendation.
EPA Sensor Evaluation

- **Colocation With Reference Measurements**
  - Sensors Deployed in Triplicate
  - Multiple Locations
    - Denver, CO
    - Atlanta, GA
    - RTP, NC

- **Field Deployments**
  - Village Green – Multiple Locations
  - CitySpace – Memphis, TN
  - Ironbound – Newark, NJ
Objectives:

1. Evaluate long term performance and comparability of nine different low-cost sensors against regulatory monitors
2. Evaluate sensor performance in high altitude, low humidity, and low temperature

Low cost sensors (<$2500) are a rapidly developing industry with limited real world evaluation and accompanying results

Data collected from September 2015 to February 2016

Follow-up to a similar study in Atlanta, GA
PM Sensors – Light Scattering

- TSI AirAssure ($1000)
- AirCasting AirBeam ($250)
- AirViz Speck ($150)
- Shinyei PMS-SYS-1 ($1000)
PM Sensors – Laser Particle Counters

Alphasense OPC-N2 ($500)

TZOA PM Research Sensor ($600)

Dylos DC-1100/DC-1100 Pro ($200-260)
Denver Monitoring Site

Regulatory Monitors:
- Teledyne 400E O₃ Monitor
- Teledyne 200EU NO₂ Analyzer
- GRIMM EDM 180 Dust Monitor
Sensor Deployment: Housing
Evaluation Challenges

- **Data logging**
  - Many sensors had no internal data logging – required connection to EPA built data loggers or laptops
  - Some sensors had cloud based data storage, but this capability was removed for data security

- **Data processing**
  - Multiple different data output formats
  - Different time series formats (daylight, standard, elapsed time)
  - Large amounts of 1-minute data to be processed (used, 5 minute, 1 and 12 hour, and daily averages for comparison)

- **Weather events**
  - Snow intrusion
Aeroqual – $O_3$

- Initial lab audit had 1:1 ratio
- Underreports regulatory monitor $O_3$
- Consistent across seasons
- Strong correlation to regulatory monitor

$\text{Daily Average Time Series}$

$\text{Hourly Average Scatterplot}$

$r_1 = 0.93$
$r_2 = 0.92$
$r_3 = 0.96$
• Most sensors exhibit strong correlation within model types
• Correlations with regulatory monitors range from weak to very strong (characterized by R values)
• Hourly average values had strongest correlations
Humidity Effects

- Fork with lower particle count has a range of humidities
- Fork with higher particle count also has higher relative humidity
- Similar effect seen in Dylos units 2 and 3
High Humidity Artifacts

• RH appears to impact other PM sensors as well
• The OPC-N2 (shown here) exhibits positive artifacts for PM at high RH
• Sensors were evaluated for the range in their 1-minute concentration differences

• Lines to the left/above the reference (black line) indicate slower responses

• Lines to the right/below the reference could indicate high noise levels.
The Village Green Project is a park bench that has been fitted with a solar-powered air-monitoring system.

The bench monitor provides real-time air quality data to community members and data is saved in an online database.

The bench measures, particulate matter (PM), ozone (O₃), nitrogen dioxide (NO₂) and ambient meteorological conditions.

The Village Green bench is also near an NCore measurement site, approximately 5 km to the northeast.
The Village Green Project collects pollutant concentration and meteorology measurements at 1-minute intervals.

One year of Village Green data, beginning April 2015, was compared to the nearby reference site.

To evaluate the Village Green measured concentrations in context of nearby NCore measurements, the following screening criteria were applied:

- Screened data for short term changes in concentration (potential local plumes such as engine exhaust)
  - 1-minute $O_3$ differences > 20 ppb
  - 1-minute $PM_{2.5}$ differences > 15 µg/m³

- Removed Outlier/Artifact Data
  - $O_3$ less than -2 ppb and greater than 125 ppb
  - $PM_{2.5}$ when RH is less than -1% and greater than 95%
  - $O_3$ monitor temperature less than 0 C and greater than 50 C (to remove $O_3$ artifact)
  - Also $O_3$ monitor cell potential, flow rate, etc

- Hourly averages included only hours with at least 45 minutes of valid, unscreened data
- O₃ measured by the Village Green Bench showed strong correlations for hourly averages.
- Village Green O₃ time series matches well with NCORE site.
Village Green and NCORE: $\text{PM}_{2.5}$

- $\text{PM}_{2.5}$ correlations not as strong as $\text{O}_3$, but captures regional events
- $\text{PM}_{2.5}$ differences are expected at 5 km distances due to varying local impacts
The 1-minute data collected by the Village Green allows for advanced data analysis techniques.

One such technique is called Non-parametric Trajectory Analysis (NTA; Henry, R. C.; Vette, A.; Norris, G., *Environ. Sci. Technol.*, 2011, 45 (24), 10471-10476.).

NTA calculates local wind back trajectories (in this case, 50 minute trajectories) with associated measured concentrations.

The analysis then performs weighted averaging to calculate the statistically expected concentration at the monitoring site when the wind passes over a given point before reaching the monitor.

Additionally, the high-time resolution data allowed for an estimate of the excess or local contributions by subtracting an estimated background value.
NTA Results Using Village Green Data

Total PM$_{2.5}$

Excess PM$_{2.5}$