Low cost Air Quality Monitoring Tools: What Are They Good For?

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What can you do with a $500 monitor?
I. Sensor options

II. How good are they?

III. Case studies
   - Indoor air quality and air exchange rate
   - Neighborhood scale ambient spatial variability of $O_3$
   - Outdoor concentrations of $CH_4$ in oil and gas development regions
   - Education and outreach

IV. What’s next?
What sensors are out there?

- **VOCs** – general combustible gas monitors mostly PIDs
  - Mostly constant mixture of VOCs, comparisons
- **Methane** – IR sensors, MOx sensors
  - Mostly constant mixture of VOCs, up to 1 month
- **CO** – electrochemical, MOx
- **Ozone** – UV sensors, MOx sensors
  - Up to 1 month
- **Particulate Matter** – light scattering
  - Mostly constant mixture of PM chemistry and size
- **NO$_x$** – electrochemical, chemiluminescence, MOx
  - Near sources
- **CO$_2$** – NDIR

Accurate quantification is a challenge for all these – possible but not yet simple.
Sensor Options

**CO sensors**
- metal oxide sensor (MOS)
  - T and RH also impact resistance
  - $d_l \sim 100 \text{ ppb}$
  - $\$5 \text{ ea}$
- electrochemical sensor
  - $d_l \sim 500 \text{ ppb}$
  - $\$50 \text{ ea}$

**VOC sensors**
- metal oxide sensor (MOS)
  - T and RH also impact resistance
  - $d_l \sim 10 \text{ ppb}$
  - $\$5 \text{ ea}$
- Photoionization detector (PID)
  - $d_l \sim 10 \text{ ppb}$
  - $\$250 \text{ ea}$
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IV. What’s next?
It depends …

- What question you are asking
- How you design your measurement campaign
- How you calibrate

BTW, don’t trust the manufacturer’s calibration!
Think before you measure

• Different pollutants cause different impacts on different temporal and spatial scales.
• Frame your concern/problem/interest in terms of question that has a comparison built in.
• Use that comparison to develop your measurement plan.

Practice what we teach
What does a calibration look like?

\[
\frac{R}{R_0} = p_1 T \exp(p_2 C) + p_3 H \exp(p_4 C) + p_5 \exp(p_6 C)
\]

Each type of sensor is different

$$V = p_1 + p_2 C + p_3 (T - p_4)^2$$

$R^2 = 0.97$ Standard error of 11.7 ppm
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Our 1st System Design (MAQS)

Few MAQS Results

CU campus CO₂ measurements by students

CO₂ measurements by Haskell College students
Research of Emissions, Air Quality, Climate, and Cooking Technologies in Northern Ghana
Personal Measurements

Carbon monoxide (CO)

- Real-time CO loggers worn by participants
  - Around necks or in “child-proof” pockets
- Lascar EL-USB (electrolytic)
  - 1-minute logging interval
  - Range: 0-300 ppm
  - 0.5 ppm resolution

- Battery operated
- Calibrated weekly at NHRC
Example CO personal exposure
Why aren’t we seeing differences in CO exposure?

- No difference
- Which stove is actually being used
- Other CO sources driving dose
Improve link between CO exposure and stove use
– Personal monitoring with iBeacons
Apportioning CO exposure
Exposure by distance range

Exposures within distance thresholds

- CO dose (ppm*hours)
  - 700
  - 600
  - 500
  - 400
  - 300
  - 200
  - 100

- Ratio of exposure within distance thresholds
  - 1.0
  - 0.9
  - 0.8
  - 0.7
  - 0.6
  - 0.5
  - 0.4
  - 0.3
  - 0.2
  - 0.1
  - 0.0

Distance thresholds:
- 15m
- 30m
- 50m
- 100m
Research Contributions and Goals of this Work:

1. Improve low-cost and quiet gas measurement techniques for indoor air quality monitoring applications

2. Inform air quality in homes using different fuels for home heating on the Navajo Nation, and to examine the relative importance of driving factors
UPOD CO Indoor Collocation

CO Calibration

Model: Sensor = p(1) + p(2)*Reference + p(3)*T + p(4)*absHum  
RMSE = 0.048  
adjR² = 0.97

(Casey et al. In Prep)
CO By Deployment

(Casey et al. In Prep)
Summary of Observed Carbon Monoxide

Rolling Hour-Averaged CO By Fuel Type

(Casey et al. In Prep)
Estimation of Air Exchange Rate

\[
ACH = \frac{Q_{\text{leak}}}{V} = \frac{\ln([CO]_{\text{in\_final}} - [CO]_{\text{out}})}{t_{\text{final}} - t_{\text{initial}}} - \ln([CO]_{\text{in\_initial}} - [CO]_{\text{out}})
\]

Air Exchange Rate = 0.3 ACH

(Casey et al. In Prep)
Estimation of CO Emission Rate

\[ \frac{E_{\text{combustion}}}{V} = ACH([CO]_{out} - [CO]_{in}) + \frac{d[CO]_{in}}{dt} \]

CO Emission Rate Per Volume
= 15.05 mg/m^3/hr

(Casey et al. In Prep)
A study of 509 homes in Texas, California, and New Jersey and found a similar median air exchange rate of 0.71 ACH (Yamamoto et al. 2010)

(Casey et al. In
Median emission rate = 8.67 mg/m³/hr

If V = 75 m³: 648 mg/hr and a range of 37.4 – 17,939 mg/hr

Emissions from gas stoves:
750 mg/hr (Caceres et al. 1983)
563 – 2328 mg/hr (Relwani et al. 1986)

Emissions from carefully operated of EPA certified woodstove: 8 – 7 mg/hr (Nabinger et al. 1995)

(Casey et al. In Prep)
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IV. What’s next?
Summer 2015, Ozone Fun

Project led by Kira Sadighi and Evan Coffey
Back in Boulder

Project led by Lauren Deanes and Lucy Cheadle
Co-location and then deploy

South Coast AQMD station in Riverside

South Boulder Creek & CU campus
Sample Calibration
Do we observe spatial variability?
How do we explore this variability?

Riverside, CA measurements
Difference in $O_3$ concentration in Riverside, CA

(a) Deployment and calibration differences for Ozone

(b) Median of Absolute Differences for ozone for deployment
Back in Boulder, So Boulder Creek
Why do we see differences?
Trail Map

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Objectives:
*To determine how well we can inform spatial variability of $O_3$, $CH_4$, $CO$, and $CO_2$ with low-cost sensors in a basin that produces both gas and oil.
*Seasons patterns in gas abundance and distribution as well as sensor performance under these changing conditions
Correlation Matrices for UPOD CH₄: Collocated
Correlation Matrices for UPOD CH$_4$: Distributed
Why do we see differences?

![Graph showing correlation between number of producing wells and median CH$_4$ concentration. The linear fit has an R$^2$ value of 0.49.](image)
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Air Quality in the Classroom (PBL Curriculum)

- Air quality monitoring and education/outreach in the North Fork Valley (Western Slope CO) ~ PILOT PROJECT

- *Initial goal:* collect baseline data for a community faced with potential land use changes and work with students as citizen scientists

- *Fall/winter 2014:* set up stationary monitors throughout the valley & began working with local high schools

Ashley Collier, Katya Hafich, Daniel Knight, Lucy Cheadle, CU Outreach
Energy Development in the North Fork Valley …

Current

Future
Let’s team with local teachers …

Ben Graves helps us think about and try on Project Based Learning (PBL) Curriculum
Student Projects

Students monitoring plane emissions, pilot idled the plane and adjusted the air/fuel ratio resulting in dynamic combustion data.
Year 2 of Project Based Learning …

An Introduction to Air Quality

Our atmosphere differs on the surface of the earth and vertically

What are the primary causes of air pollution?

- Combustion
- Chemicals
  - Some compounds volatilize (enter the gas phase)
- Mechanically generated
  - (e.g., dust)

Meteorological conditions and atmospheric dynamics can then impact whether or not emissions disperse
- "the solution to pollution is dilution"
What did we learn?

- Rural schools vs Front Range schools
- College kids can be role models, so
- This year and last …
  - Teaching a service learning course in CU ME
  - 8 engineering students/yr
  - 18 high school classes
  - 700 students used Pods
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Big Data

- Monitors (lots between $50 and $1000)
- Databases (OpenAQ, AirNOW, EDF effort)
- Analysis tools
- Educational material (AQ-IQ)

Vision: monitor check-out with open source databases and analysis tools that include some data quality assessment AND recipes or expert guidance on “what to do”
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