Array of Things: Characterizing low-cost air quality sensors for a city-wide instrument

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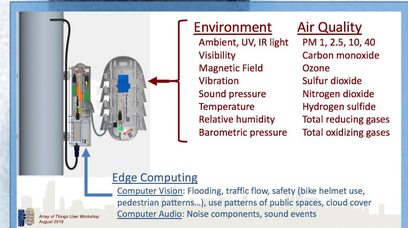
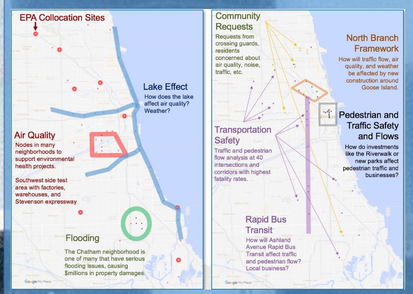
Abstract

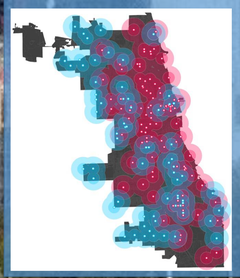
The Array of Things (AoT) is a collaborative effort among leading scientists, universities, local government and communities in Chicago to collect real-time data on the city's environment, infrastructure, and activity for research and public use. The AoT is composed of nodes that will measure and sense the urban environment of Chicago and provide openly accessible data in near real time. One component of each node is the ChemSense board, which uses chemical sensors to measure five gas-phase species: ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide and hydrogen sulfide. In addition, the ChemSense board provides information on total reducing gases and total oxidizing gases. The nodes also include meteorological information and cameras that will provide pedestrian and traffic counts using computer vision algorithms. Because the ChemSense boards rely on low-cost sensors, characterizing the sensor responses is critical to understanding the applicability of the AoT for urban air quality issues. As a first step, a node with the ChemSense board was installed at an EPA air quality monitoring site within the City of Chicago, which is run by the Cook County Department of Environment and Sustainability. The EPA site has Federal Reference Method monitors for ozone, nitrogen dioxide and sulfur dioxide. After collecting collocation data for seven months, the results are promising for ozone, but much less so for sulfur dioxide. For nitrogen dioxide, unexplained spikes not observed in the EPA data drive a poor fit. Results from the collocation project will be used to consider larger issues for characterizing the air quality component of the AoT.



Cutaway view of current AoT node configuration showing sensors. Sensor pod is expandable to accommodate new experiments; deployment in groups of 100 supports rapid evolution of sensor complement and edge computing hardware.



Initial 105 AoT node locations, showing that locations are selected in groups as part of specific science investigations.



Current (red) and 60 of 100 additional planned (blue) AoT nodes. Both 1km and 2km buffers are shown, illustrating that even with 200 nodes over 95% of Chicago's residents will live within 2km of a node and over 75% will live within 1km. (GIS map created by A. Laha, Center for Spatial Data Science, University of Chicago)

Long-term goal

Calibrate the entire AoT instrument

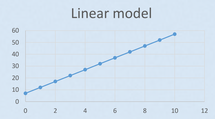
- Focus on the spatial aspect of the data
- Key: how to separate real events from noisy sensors
- One person's noise is another person's data!

Methodology

Short-term goal

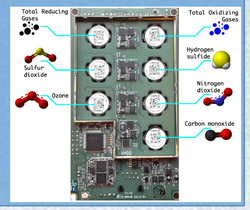
Characterize the individual boards

- Assume response is linear:
  - Zero (temperature dependent)
  - Span
- Cross sensitivities
  - NO2 and ozone, for example

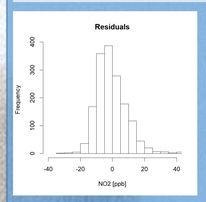


Chemsense board installed on AoT nodes

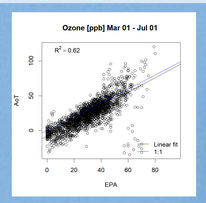
- Nitrogen dioxide
- Ozone
- Carbon monoxide
- Sulfur dioxide
- Hydrogen sulfide
- Respiratory irritants
- Indoor Air Quality



Need to consider and characterize different types of error

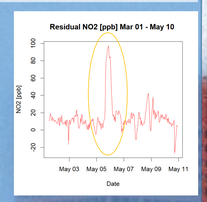


Random error
Accept will be larger than reference instruments



Systematic error

- Zero and span
- Trends

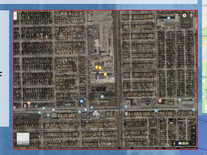


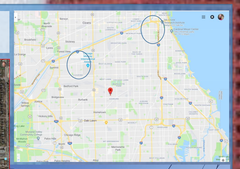
Spikes
Attribution?

Collocation site

EPA air quality site run by Cook County

- About 2 miles SW of Midway airport
- Mostly residential
- Most complete suite of measurements within the city





EPA Federal Reference Method (FRM) site

- Gas-phase species
- Ozone, NO2, SO2
- Also particulate matter
- Data available from EPA
- https://aqs.epa.gov/api

Collocation approach

- Close (< 4 m) to EPA inlet
- Begin with calibration from manufacturer
  - Background current (zero)
  - Span value (slope)
- Zero depends on temperature (manufacturer's algorithm)

NO_2 Results

Consider first, because of cross sensitivity to ozone

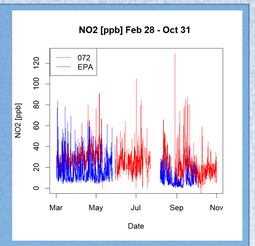
- $O3_{current}$ = f(O3, NO2)
- $NO2_{current}$ = f(NO2)

Essentially

- $[O3] = O3_{current} - NO2_{current}$

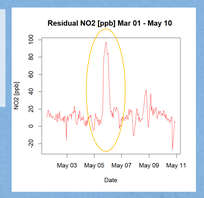
Gaps in EPA NO2 data

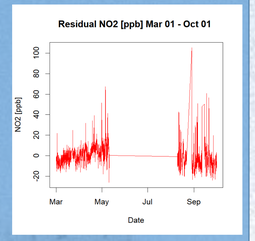
- Instrument issue during June and July
- Currently, data only available until end of September



Residuals: NO2 (AoT – EPA FRM)

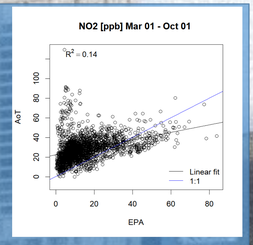
- Trend in baseline in spring, but does not continue into the fall
- See spikes

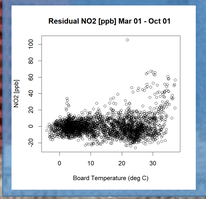


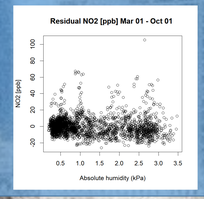


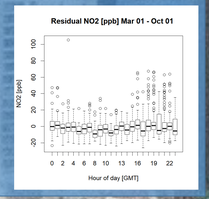
NO2 overall fit

- Spikes are killing r^2
- Residuals and spikes have no obvious correlation to:
  - Temperature
  - Humidity (absolute, relative)
  - Spikes do occur mostly during the day



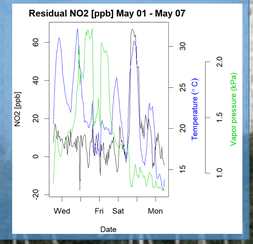






NO2 spikes

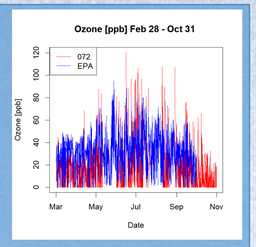
- Occur on warm days, but other warm days do not have spikes
- Spikes do occur mostly during the day



O_3 Results

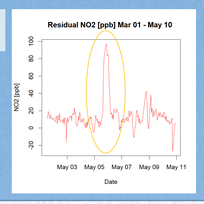
Consider second, because of cross sensitivity to NO2

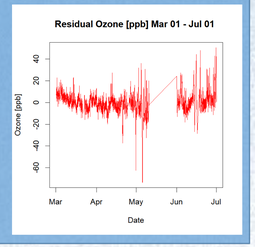
- Recall that Ozone depends on NO2
- More data available for comparison (July)



Residuals: O3 (AoT – EPA FRM)

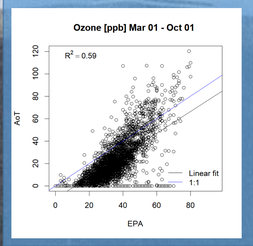
- See spikes from NO2 in O3 record

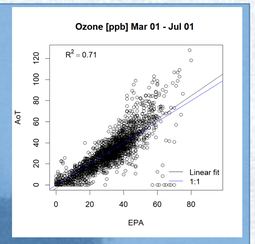




O3 overall fit

- Spikes are still lowering r^2, but can be removed
- During shorter comparison without NO2 spikes, r^2 approaches 0.80





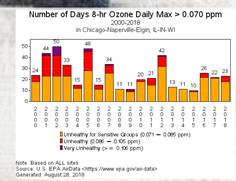
- Fit over entire record, using a filter to remove negative spikes, approaches r^2 = 0.6

Conclusions

- Results for ozone are very promising
- For periods without NO2 spikes, very good fit
- Good enough to evaluate spatial issues
- Lake effect breeze

Back to the big picture

- Understand that sensors won't be perfect
- Our goal is to characterize the individual sensors
- Use the spatial power of AoT to do unique science
- If we know the error of individual sensors, can use spatial data analysis techniques to compensate
- Key is evaluating if data spikes are real or spurious



Manufacturer information

SPEC Sensors/KWJ Engineering, engineering contact David Peaslee
https://www.spec-sensors.com/

Acknowledgements

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