

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

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Abstract

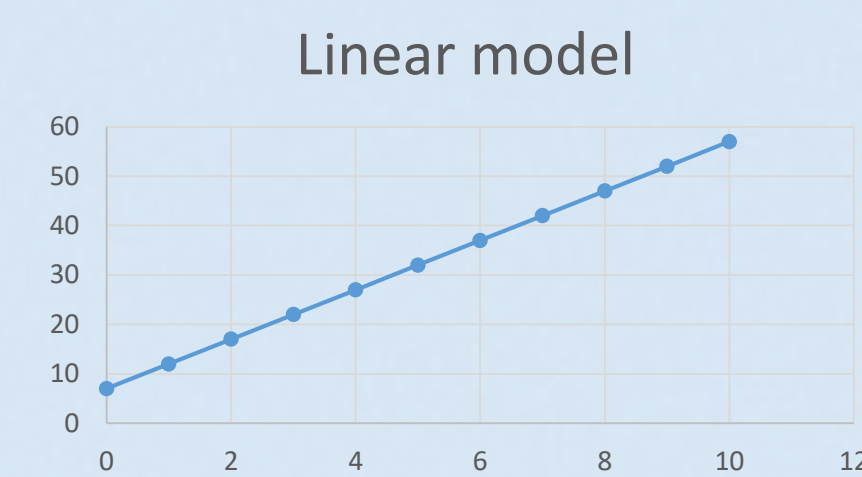
The Array of Things (AoT) is a collaborative effort among leading scientists, universities, local government and communities in Chicago to collect real-time data on the city's environment, infrastructure, and activity for research and public use. The AoT is composed of nodes that will measure and sense 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.

Methodology

Short-term goal

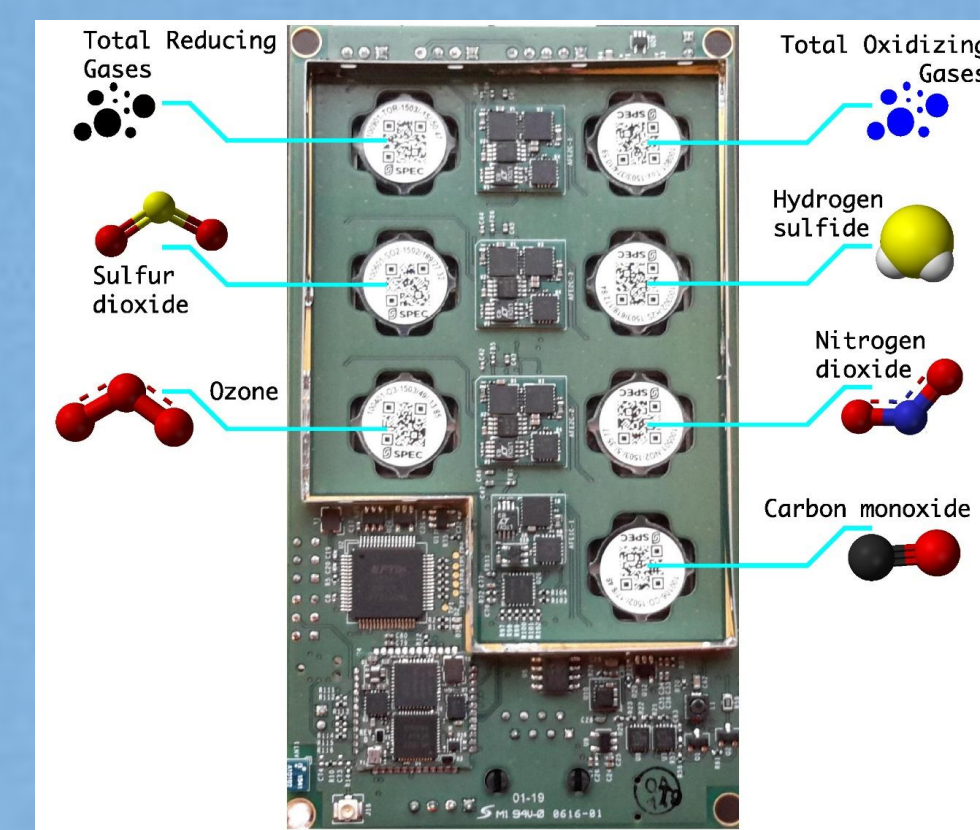
Characterize the individual boards

- 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



NO₂ Results

Consider first, because of cross sensitivity to ozone

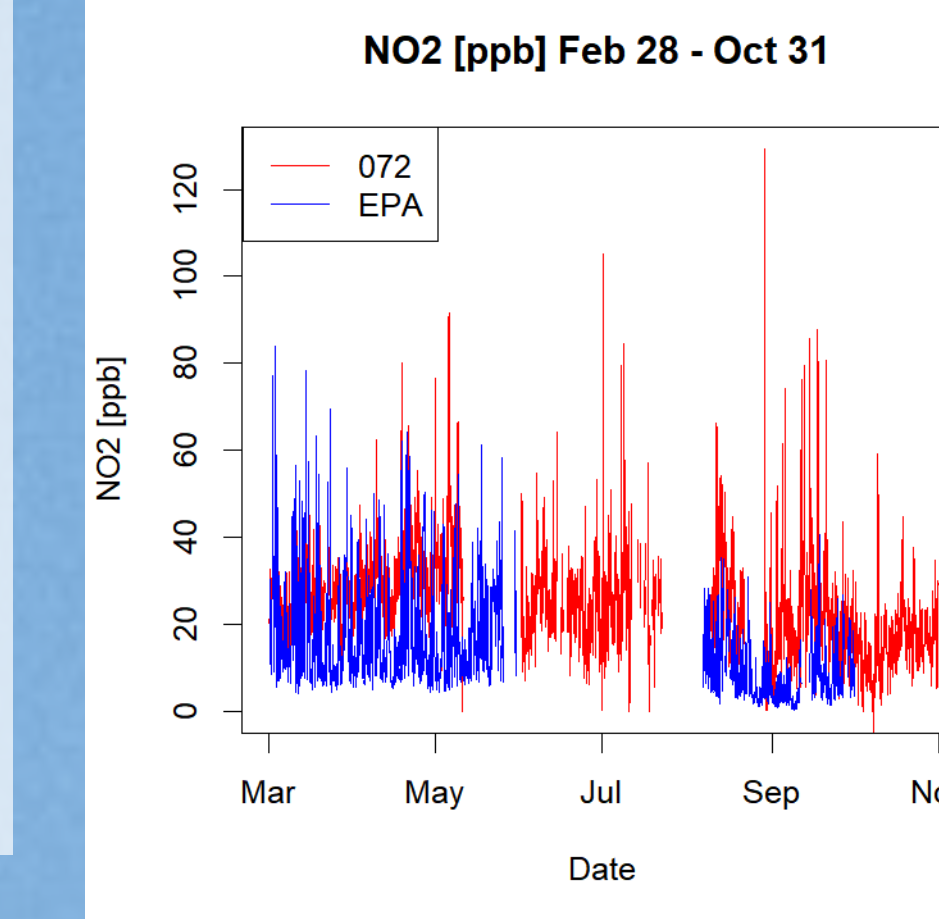
- $O3_{current} = f(O3, NO2)$
- $NO2_{current} = f(NO2)$

Essentially

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

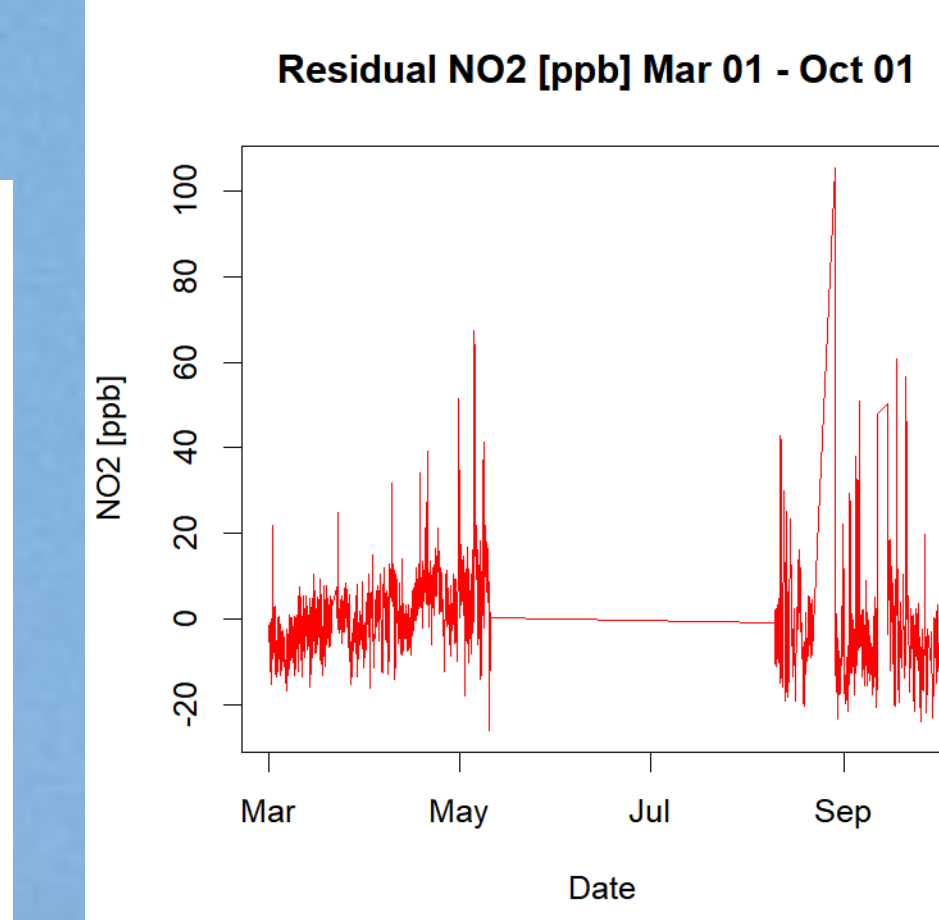
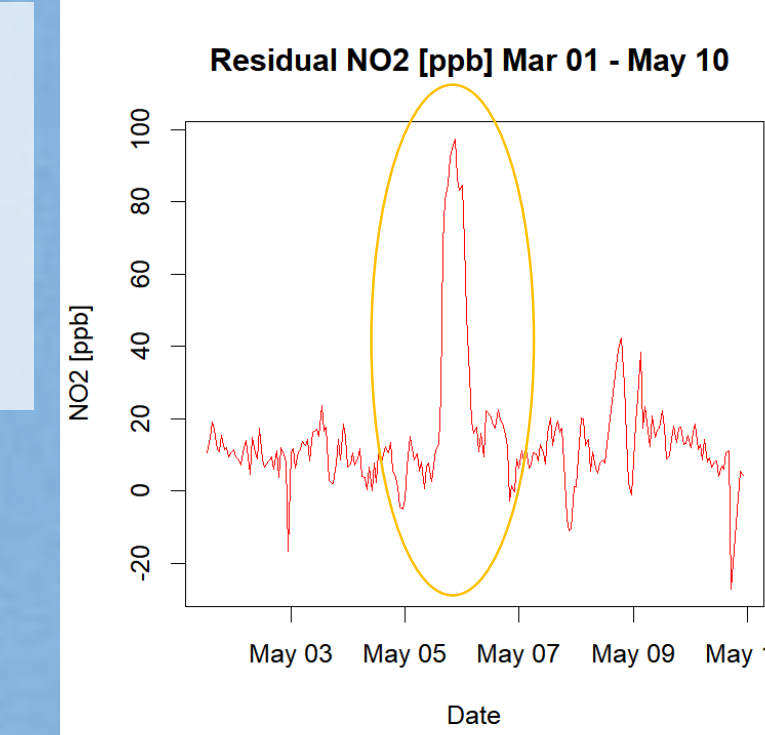
Gaps in EPA NO₂ data

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



Residuals: NO₂ (AoT – EPA FRM)

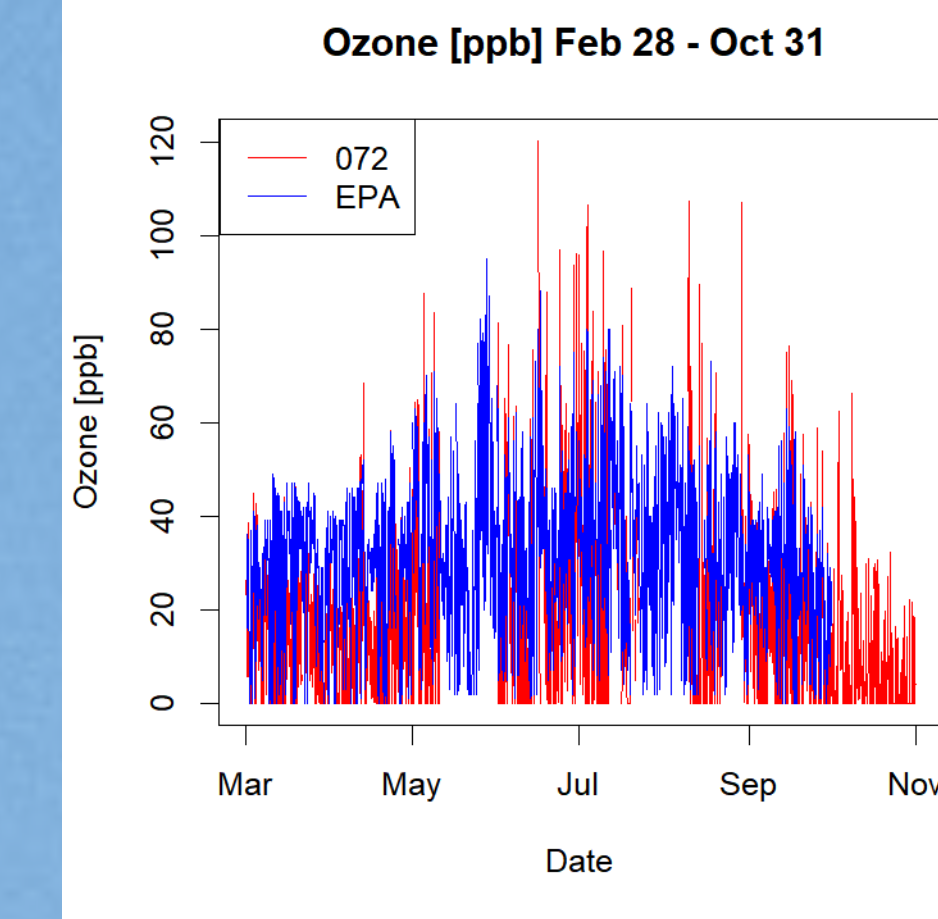
- Trend in baseline in spring, but does not continue into the fall
- See spikes



O₃ Results

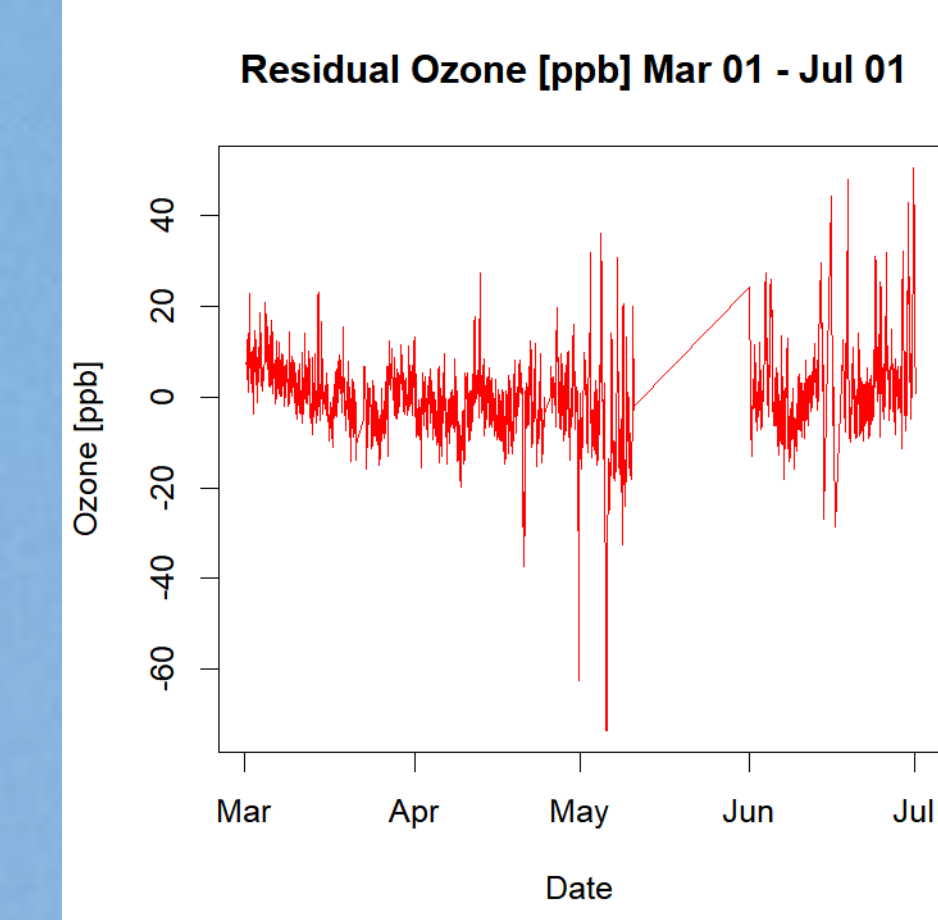
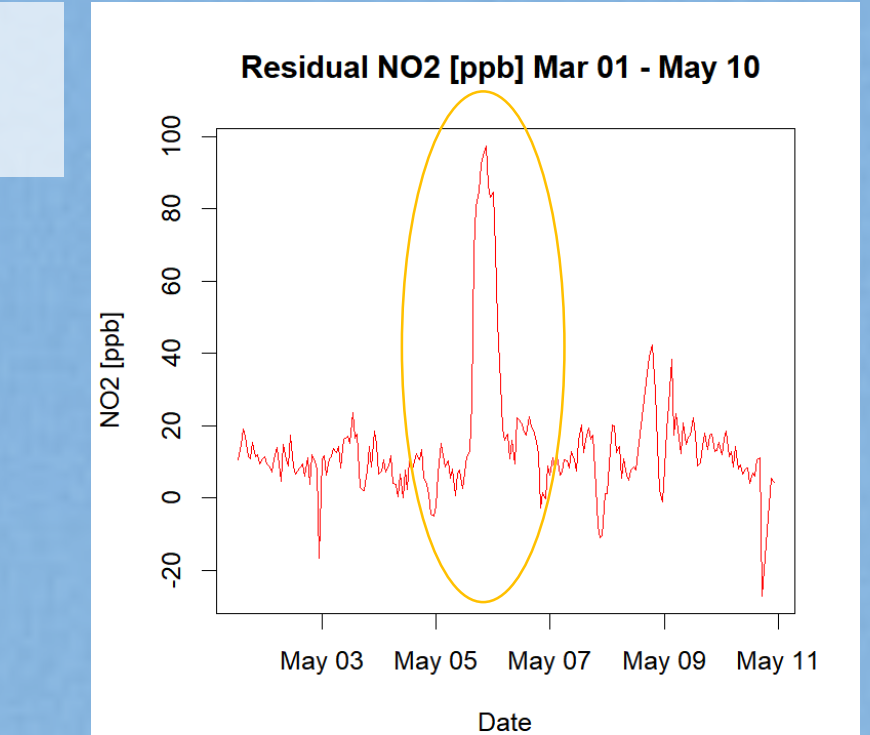
Consider second, because of cross sensitivity to NO₂

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



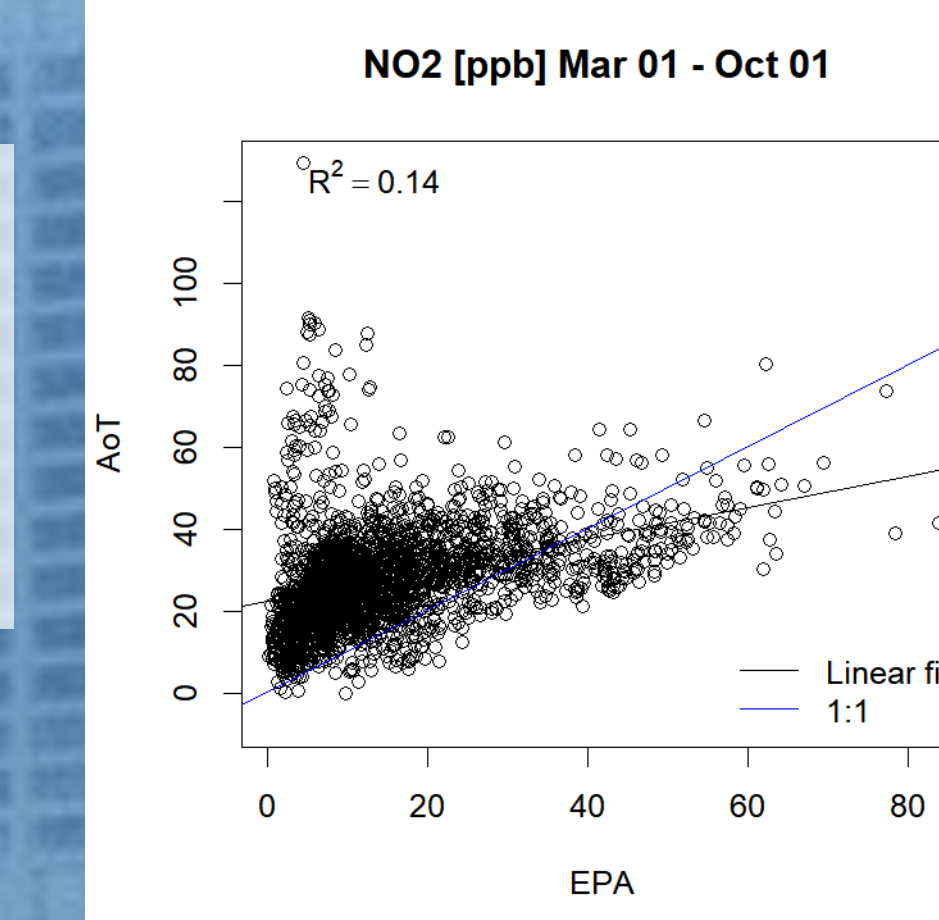
Residuals: O₃ (AoT – EPA FRM)

- See spikes from NO₂ in O₃ record



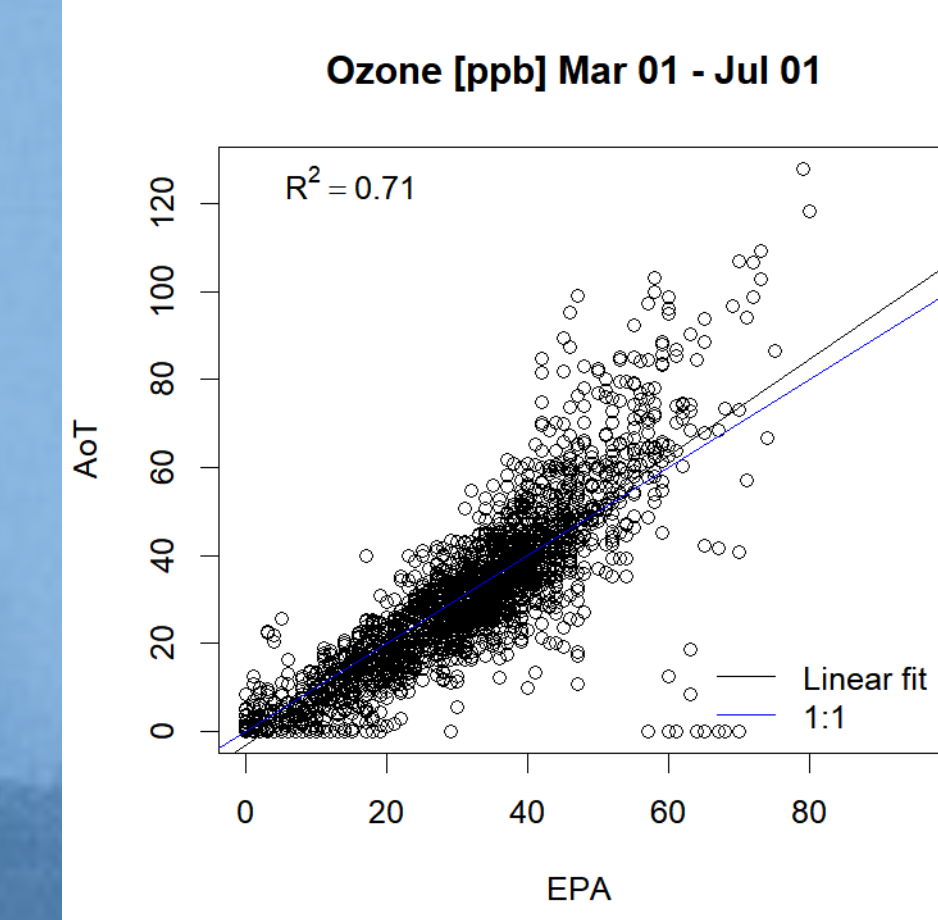
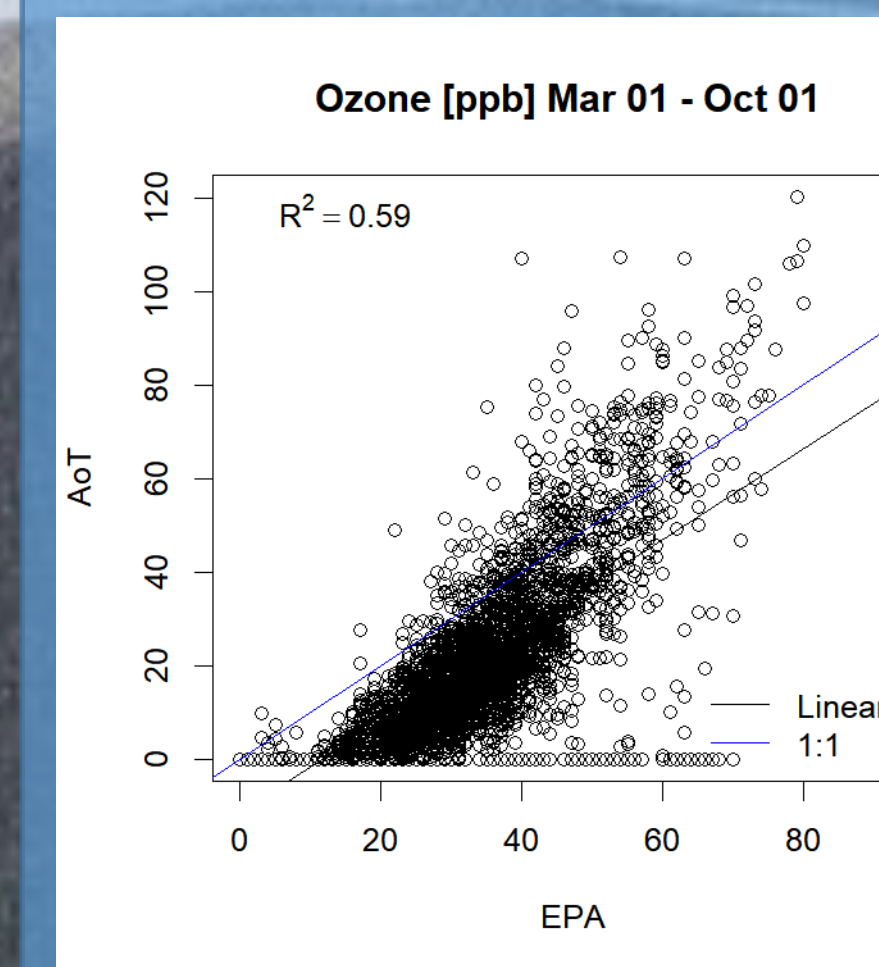
NO₂ overall fit

- Spikes are killing r²
- Residuals and spikes have no obvious correlation to:
 - Temperature
 - Humidity (absolute, relative)
 - Spikes do occur mostly during the day

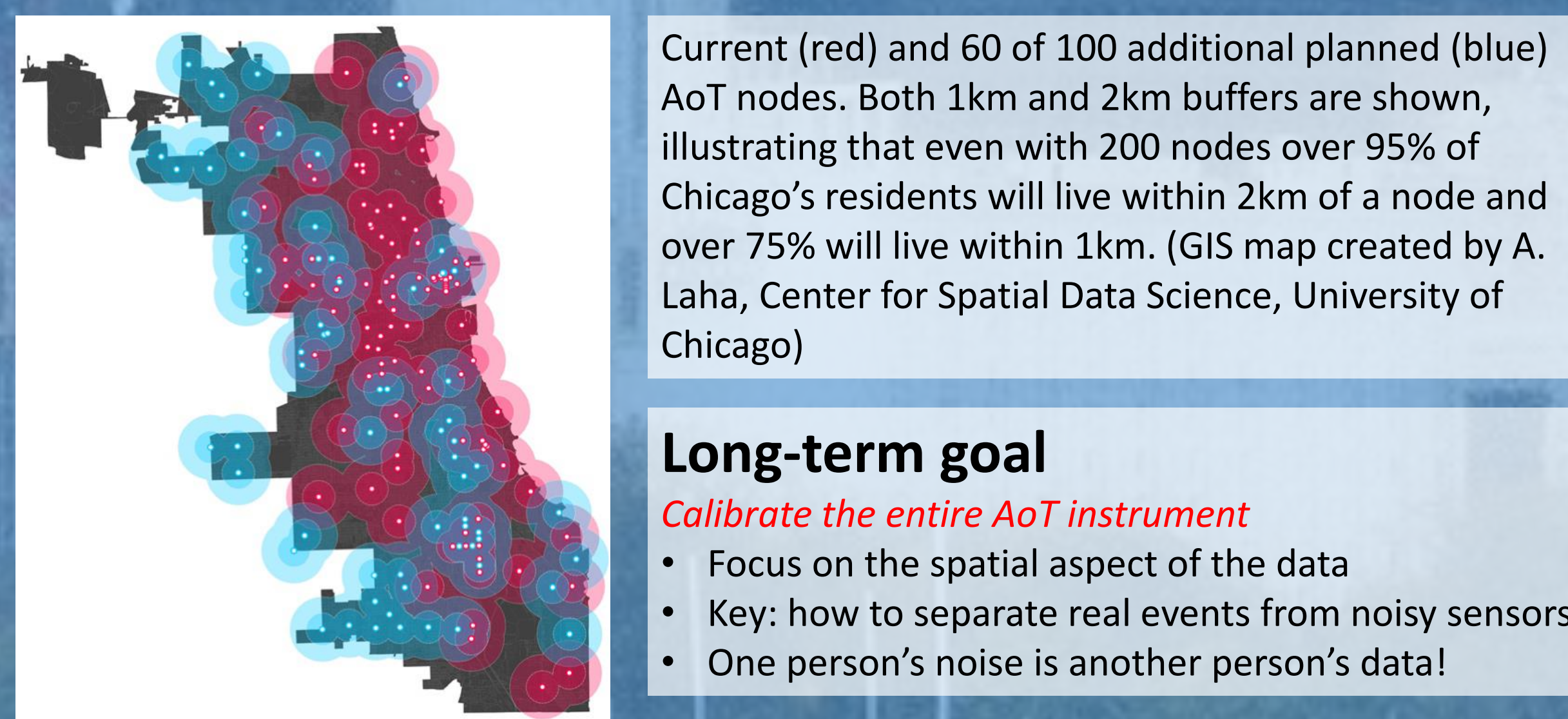
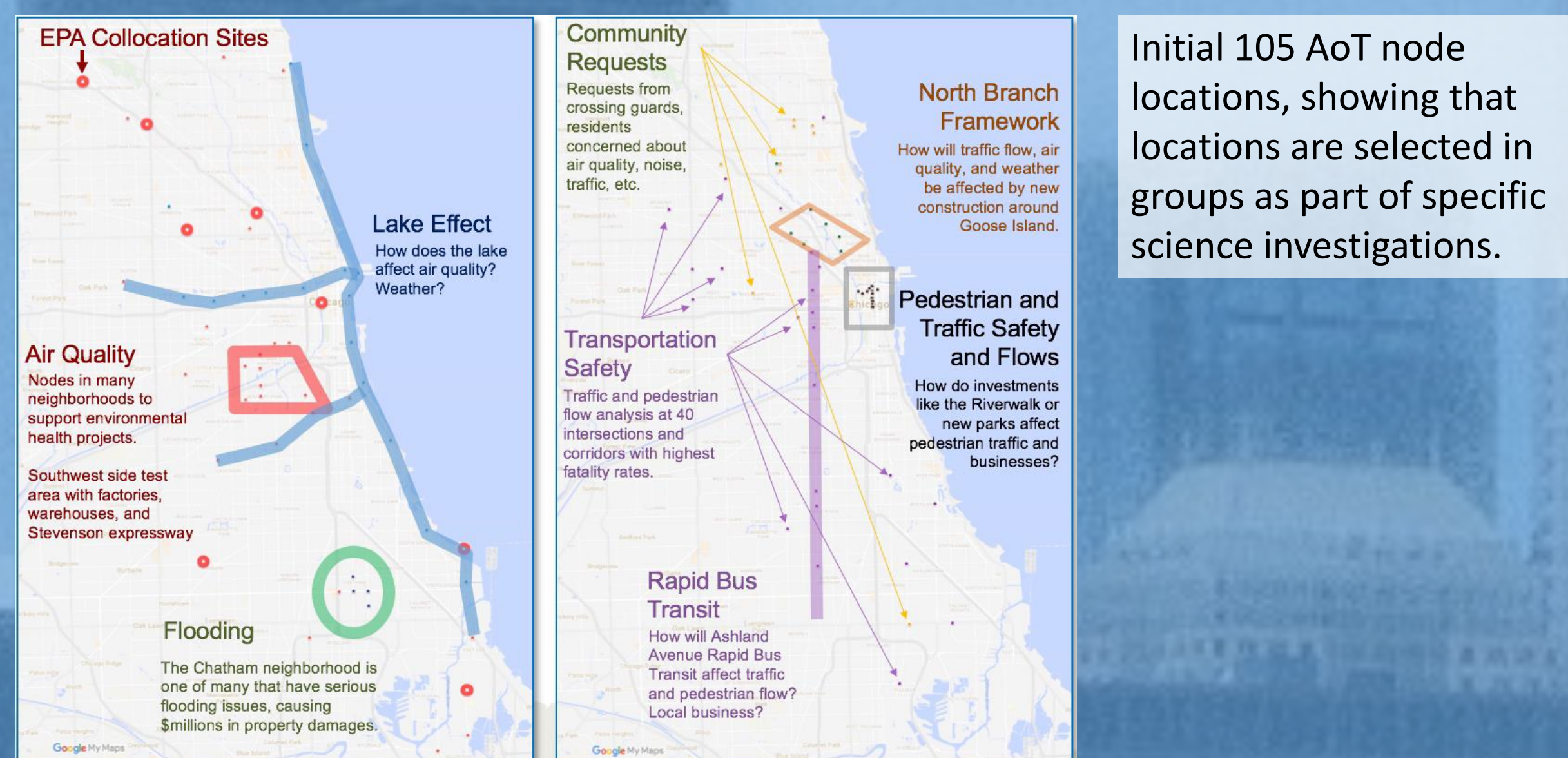
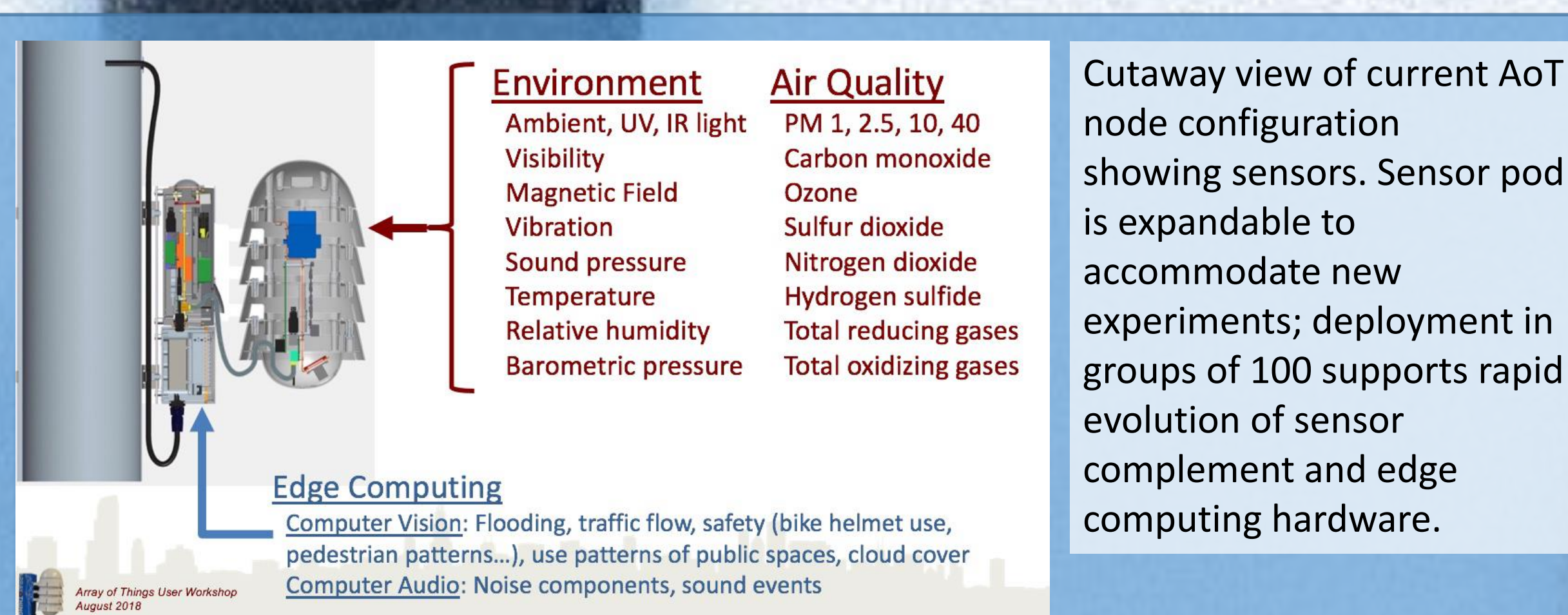


O₃ overall fit

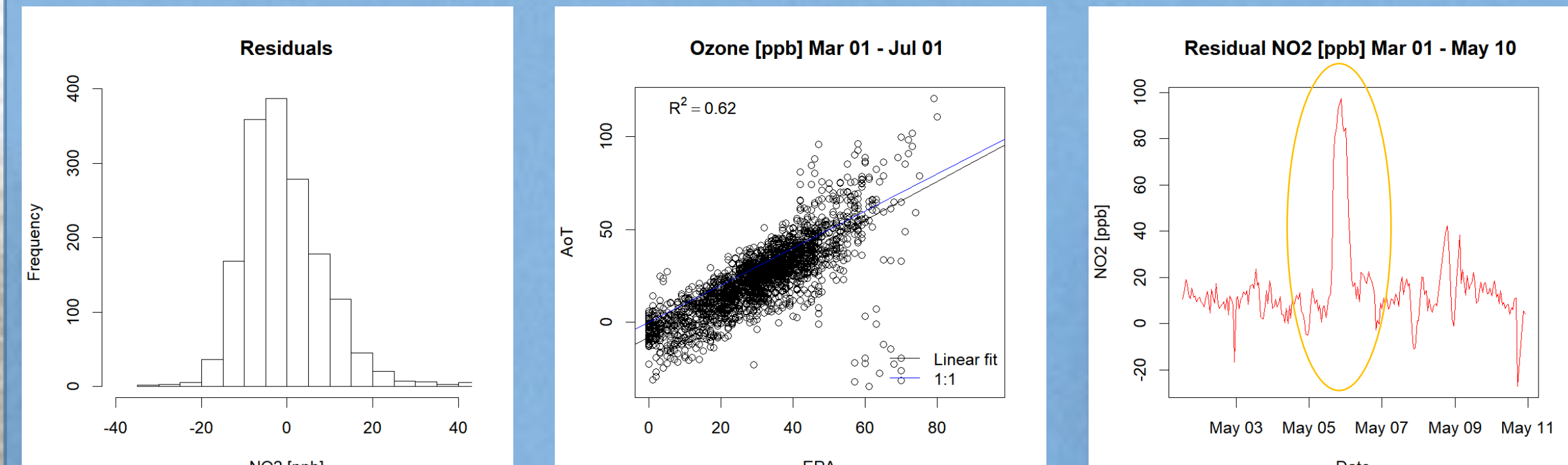
- Spikes are still lowering r², but can be removed
- During shorter comparison without NO₂ spikes, r² approaches 0.80



- Fit over entire record, using a filter to remove negative spikes, approaches r² = 0.6



Need to consider and characterize different types of error



Random error

Accept will be larger than reference instruments

Systematic error

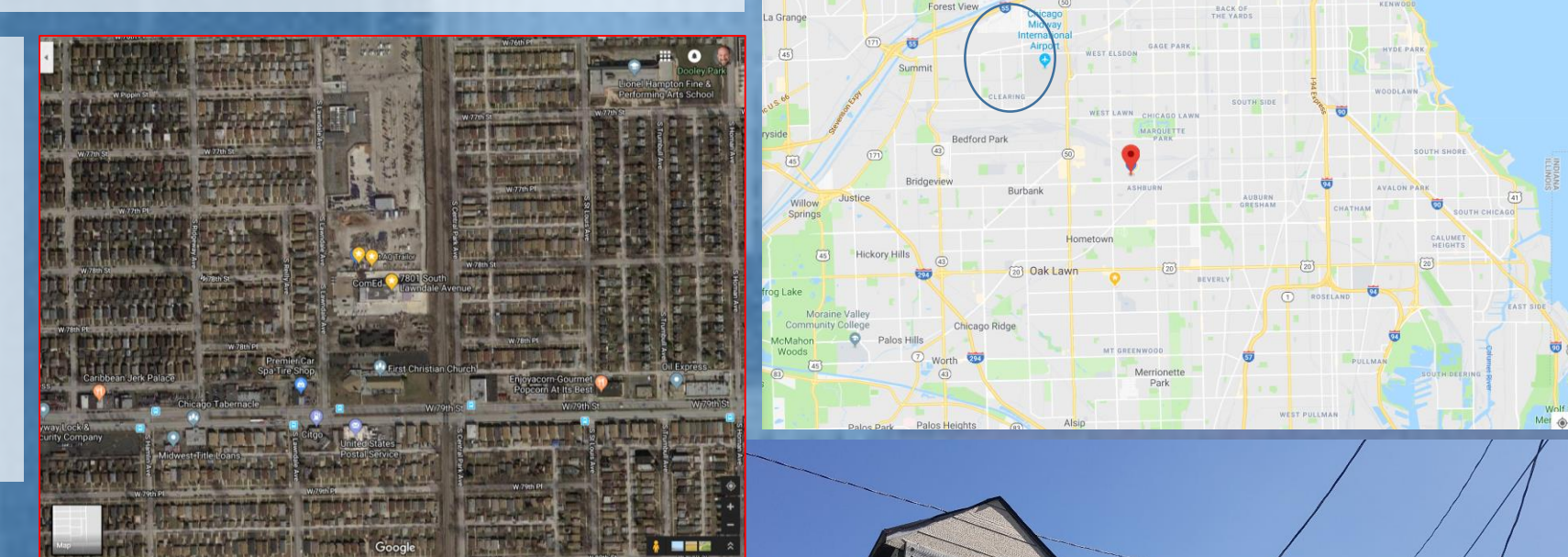
- Zero and span
- Trends

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>

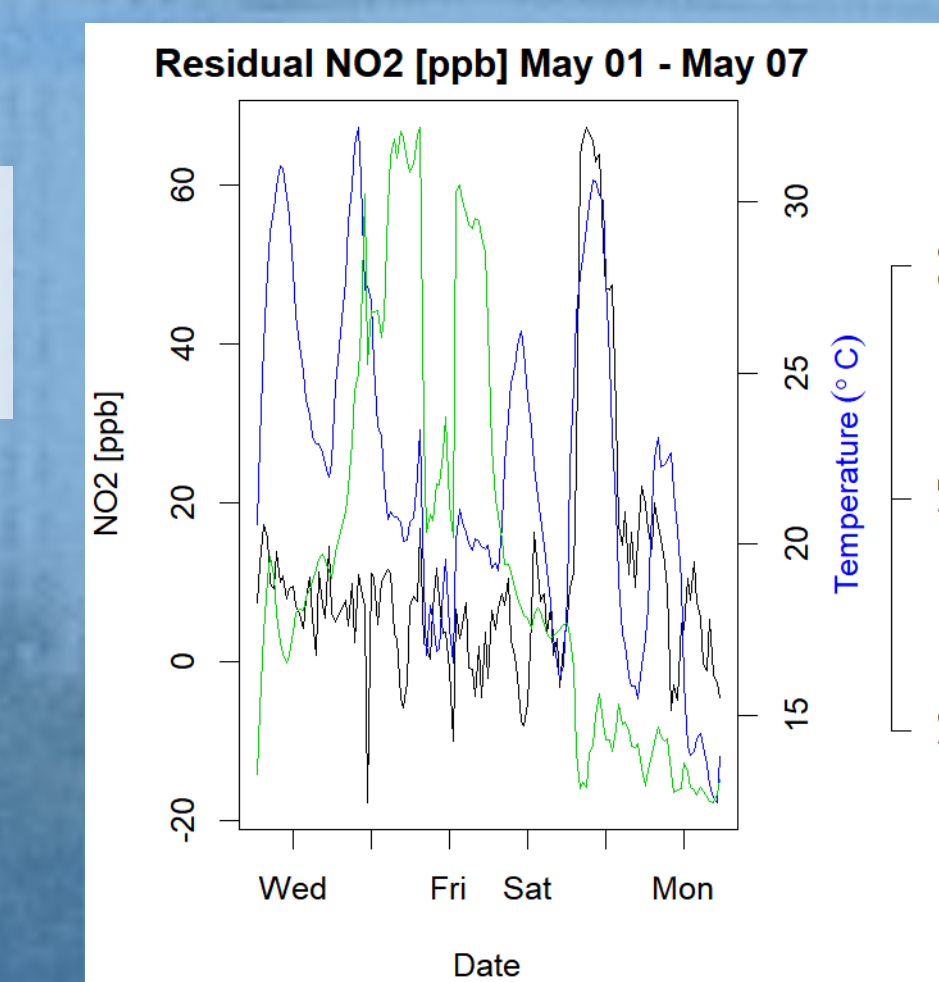
Collocation approach

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



NO₂ spikes

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



Acknowledgements

Array of Things (AoT) is funded through a Major Research Instrumentation grant from the U.S. National Science Foundation (NSF #1532133; supported by NSF CISE, ENG, and OIA). AoT cost-sharing partners include the City of Chicago, the University of Chicago, AT&T, Cisco, Intel, Microsoft, Motorola Solutions, and Schneider Electric. AoT technology partners include JCDcaux, Sidewalk Labs, Astronics, and Surya Electronics. The AoT project would not be possible without the extensive support from Argonne's Director, Office of the Director, and Associate Director for Computing, Environment, and Life Sciences; the City of Chicago Department of Innovation and Technology, Department of Transportation, and City of Chicago Mayor and Office of the Mayor.

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

