2017 Air Quality Sensor Conference, Diamond Bar, CA
September 27, 2017

Real-world evaluation and application of emerging air sensing technologies

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Foreword

- 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.

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

CAIRSENSE-Denver Overview

- **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 O_3 Monitor
- Teledyne 200EU NO_2 Analyzer
- GRIMM EDM 180 Dust Monitor

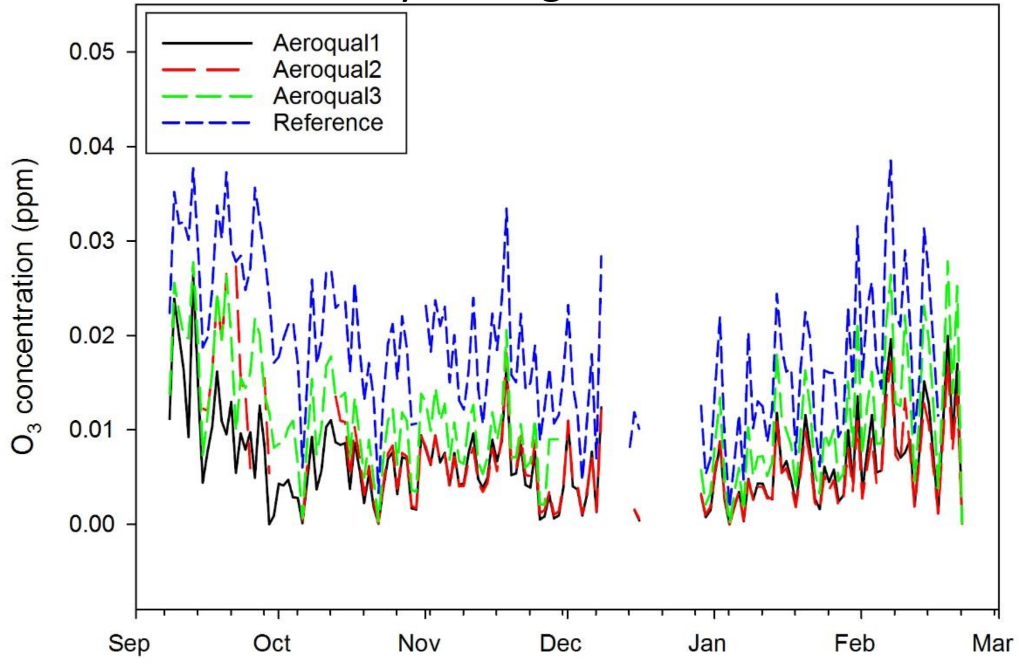
Sensor Deployment: Housing

Evaluation Challenges

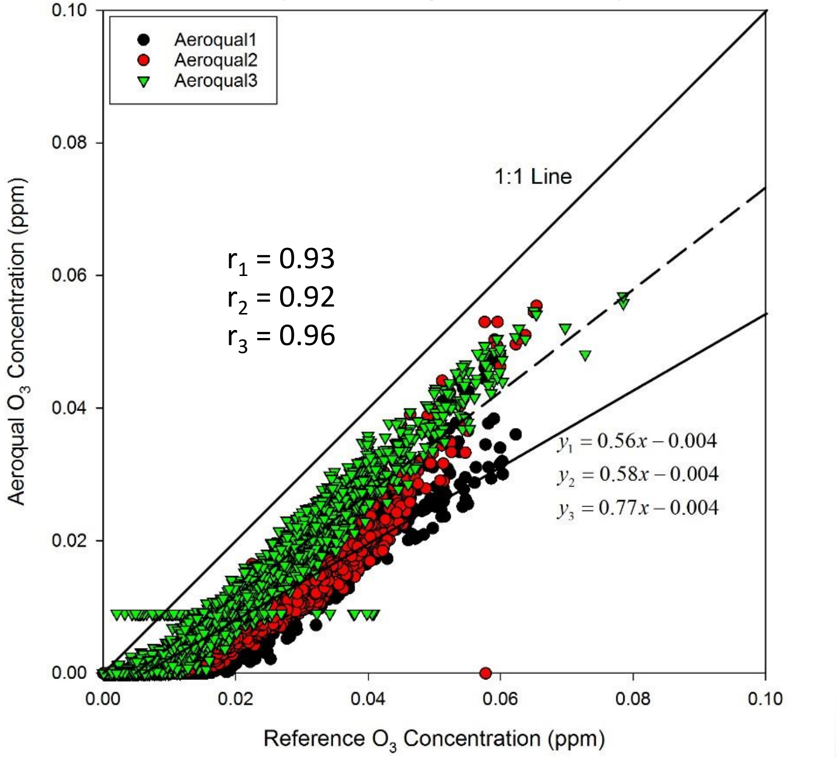
- **Data logging**
  - Many sensors had no internal data logging – required connection to EPA built data loggers or laptops
  - Some sensors had cloud based data storage, but this capability was removed for data security
- **Data processing**
  - Multiple different data output formats
  - Different time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

Daily Average Time Series



Hourly Average Scatterplot



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

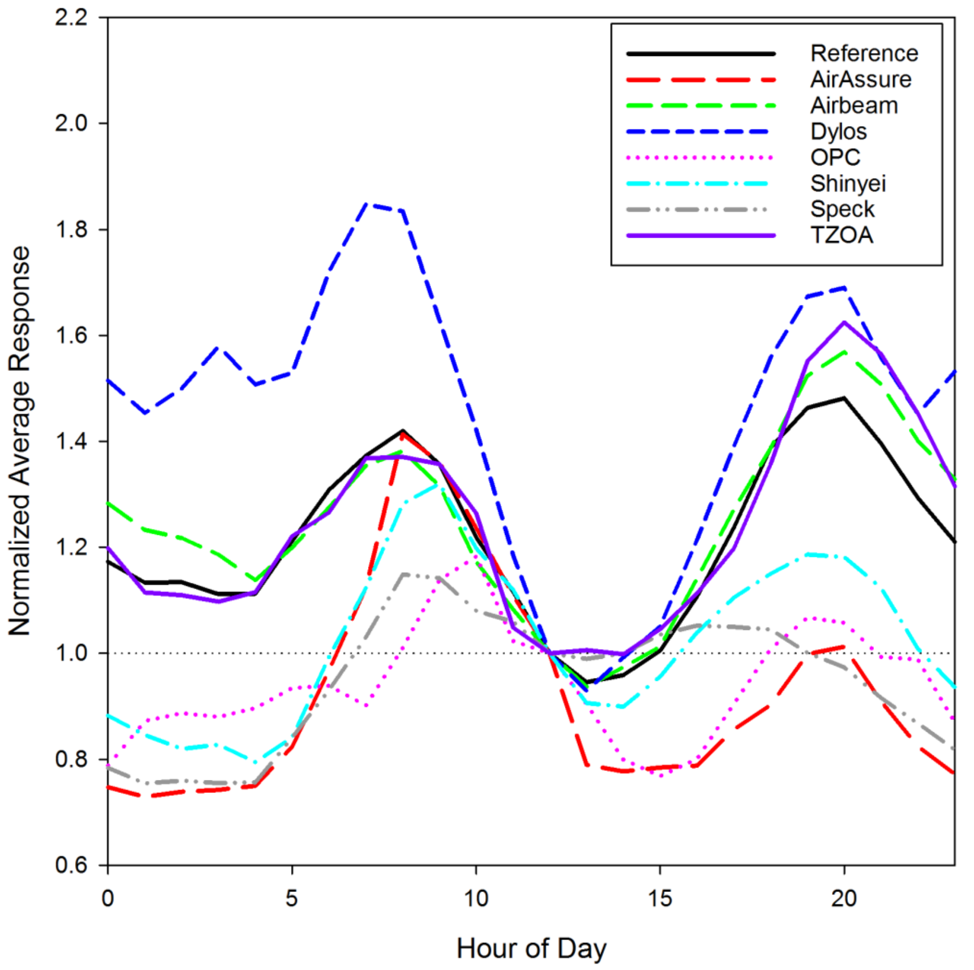
Hourly Average PM Correlations

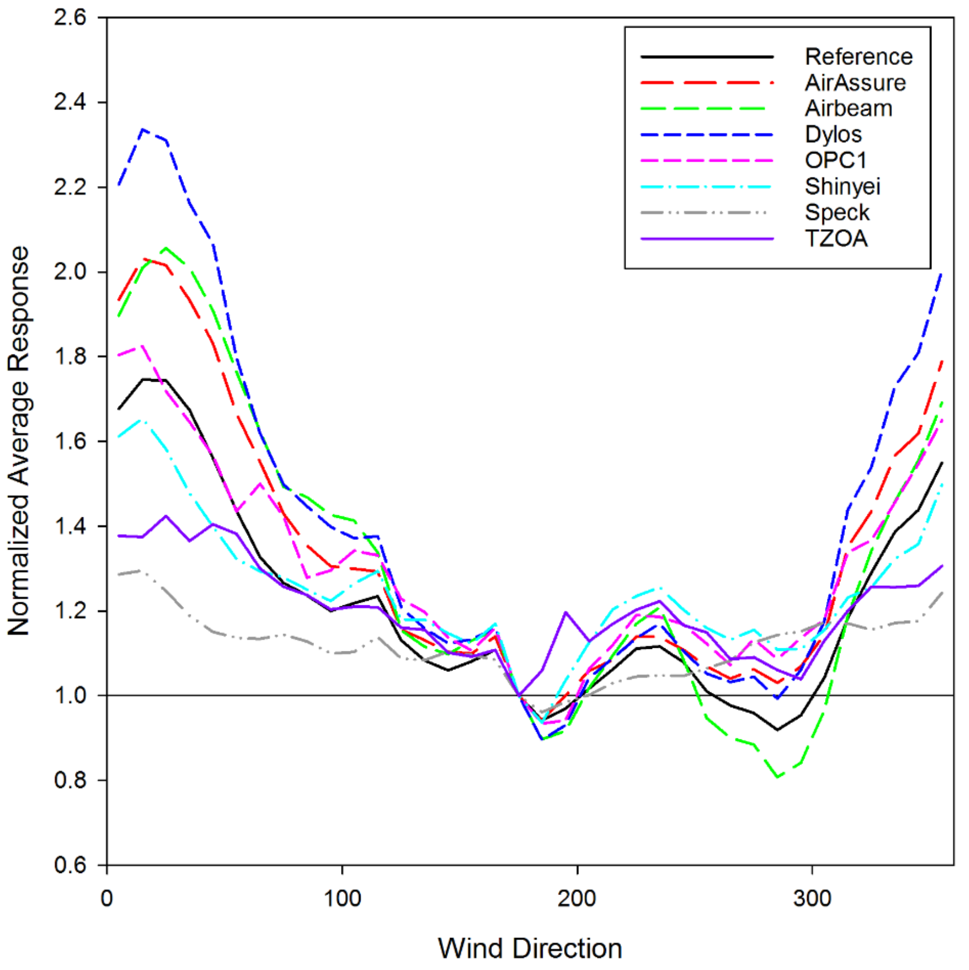
	AirAssure1	AirAssure2	AirAssure3	Airbeam1	Airbeam2	Airbeam3	DylosF1	DylosF2	DylosF3	OPCF1	OPCF2	OPCF3	Speck1	Speck2	Speck3	Shinyei1	Shinyei2	Shinyei3	TZOA1	TZOA2	TZOA3	Regulatory
AirAssure1	100																					
AirAssure2	98	100																				
AirAssure3	98	98	100																			
Airbeam1	91	90	91	100																		
Airbeam2	90	89	90	100	100																	
Airbeam3	90	88	89	100	100	100																
DylosF1	83	81	82	78	83	82	100															
DylosF2	88	84	85	92	96	96	85	100														
DylosF3	87	84	84	94	95	96	84	99	100													
OPCF1	65	65	66	62	50	48	64	52	46	100												
OPCF2	57	58	59	48	55	53	84	57	58	62	100											
OPCF3	32	37	38	39	-2	-2	9	13	0	39	10	100										
Speck1	22	29	32	21	28	25	20	4	2	26	17	27	100									
Speck2	29	35	39	22	21	18	25	4	3	31	21	30	77	100								
Speck3	24	32	36	20	18	16	20	-2	-4	27	21	33	84	92	100							
Shinyei1	86	88	91	84	81	80	76	68	68	74	62	56	43	54	52	100						
Shinyei2	76	80	83	70	71	69	77	57	56	67	68	20	57	67	68	93	100					
Shinyei3	13	13	12	14	80	82	13	11	12	11	9	10	12	7	11	19	18	100				
TZOA1	10	12	12	27	8	8	2	4	-5	18	22	28	3	-16	6	7	-3	-3	100			
TZOA2	58	59	60	69	92	91	67	66	76	21	30	23	17	23	25	57	62	9	8	100		
TZOA3	65	65	66	71	93	92	69	71	80	21	25	18	16	22	20	54	60	3	4	93	100	
Regulatory	80	78	81	82	84	82	86	78	73	45	34	11	24	40	35	71	72	1	12	66	72	100

AirAssure Airbeam Dylos OPC Speck Shinyei TZOA

- 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

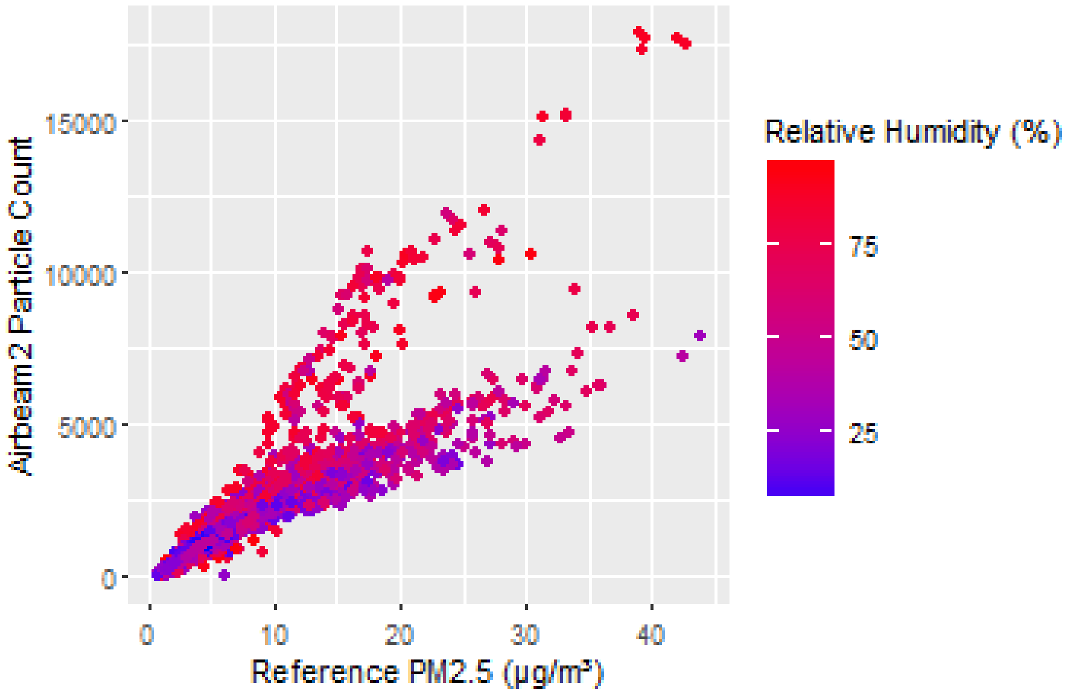
Diel and Wind Directional Trends



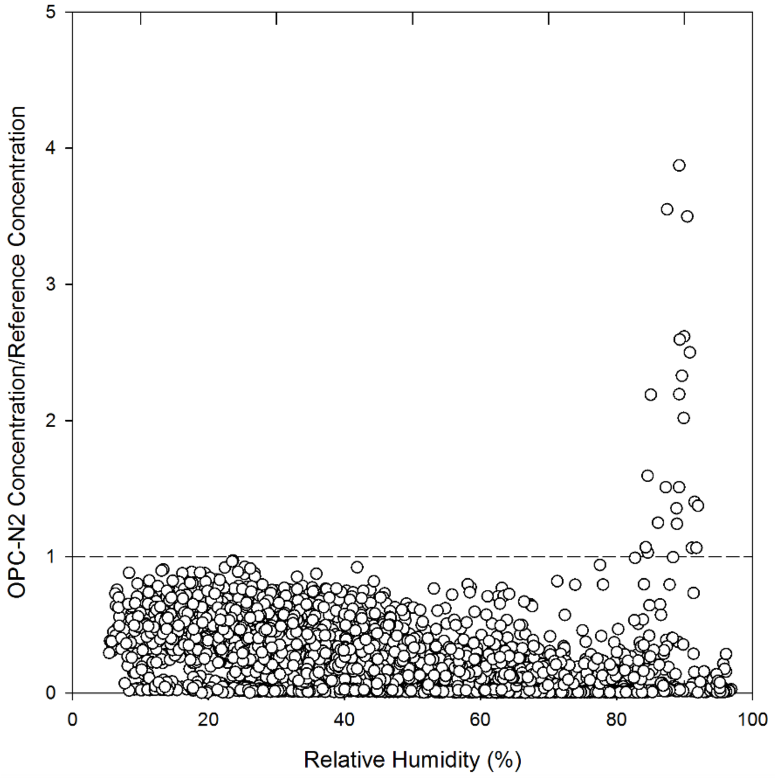


Humidity Effects

- 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



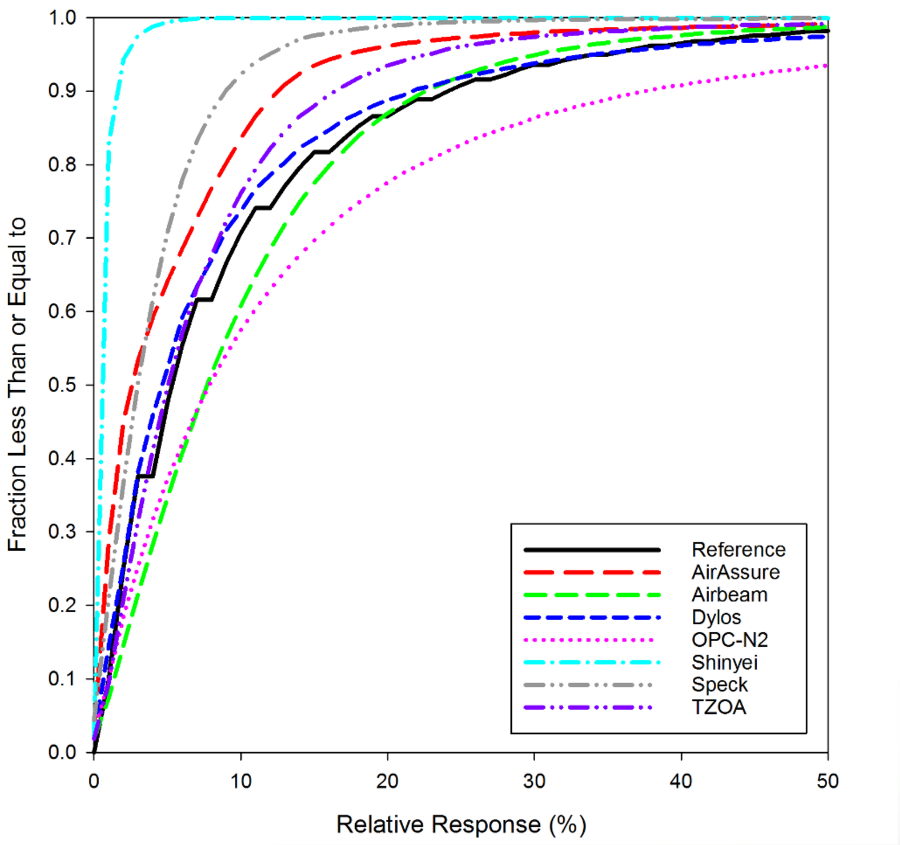
High Humidity Artifacts



- RH appears to impact other PM sensors as well
- The OPC-N2 (shown here) exhibits positive artifacts for PM at high RH

Sensor 1-minute Response

- **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.**



Analysis of Village Green Sensor Data from Kansas City

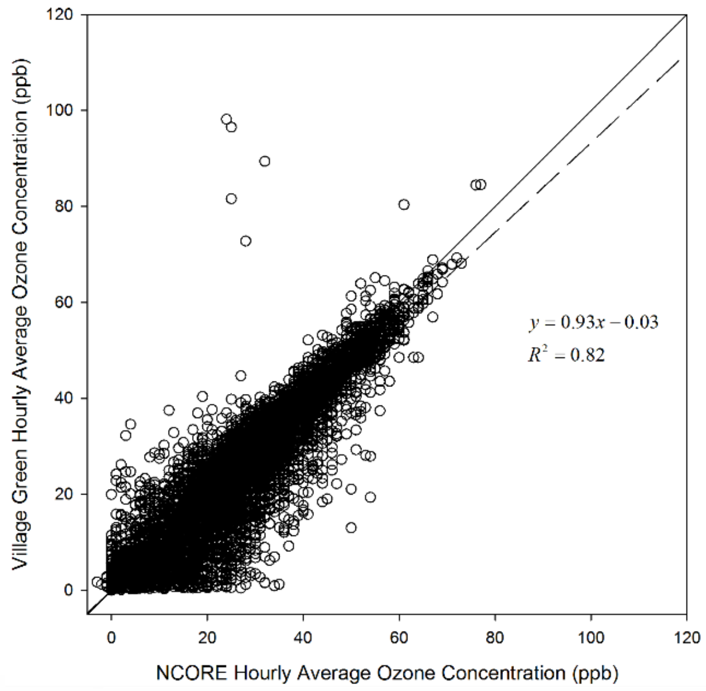
- The Village Green Project is a park bench that has been fitted with a solar-powered air-monitoring system.
- The bench monitor provides real-time air quality data to community members and data is saved in an online database.
- The bench measures, particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and ambient meteorological conditions.
- The Village Green bench is also near an NCore measurement site, approximately 5 km to the northeast.

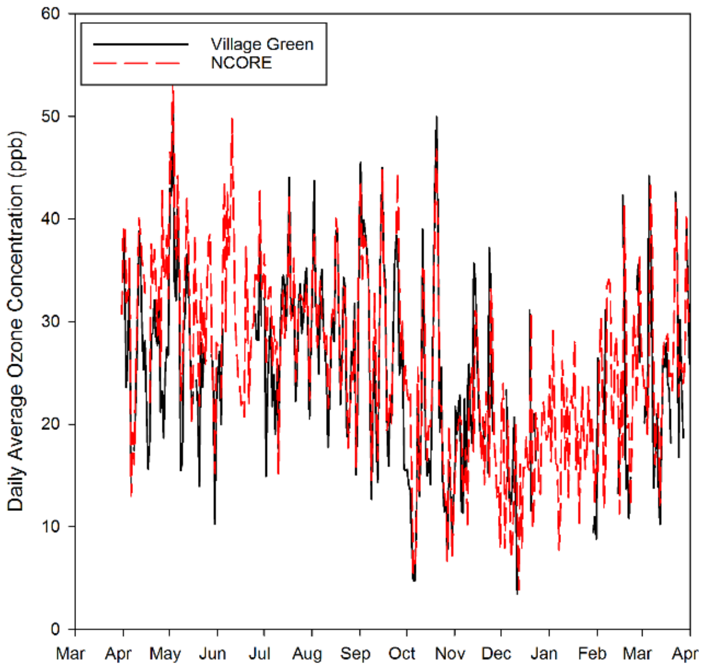
Village Green Data

- 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

Village Green and NCORE: Ozone

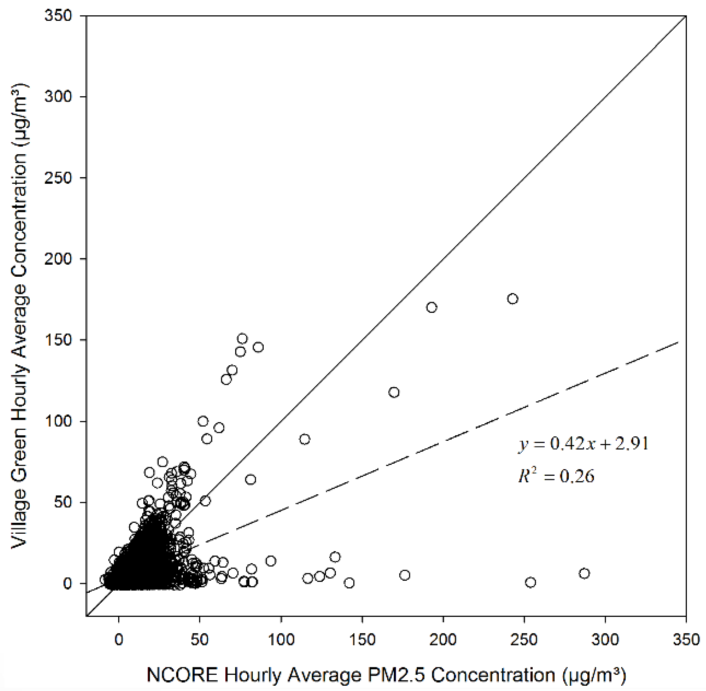
- O_3 measured by the Village Green Bench showed strong correlations for hourly averages
- Village Green O_3 time series matches well with NCORE site

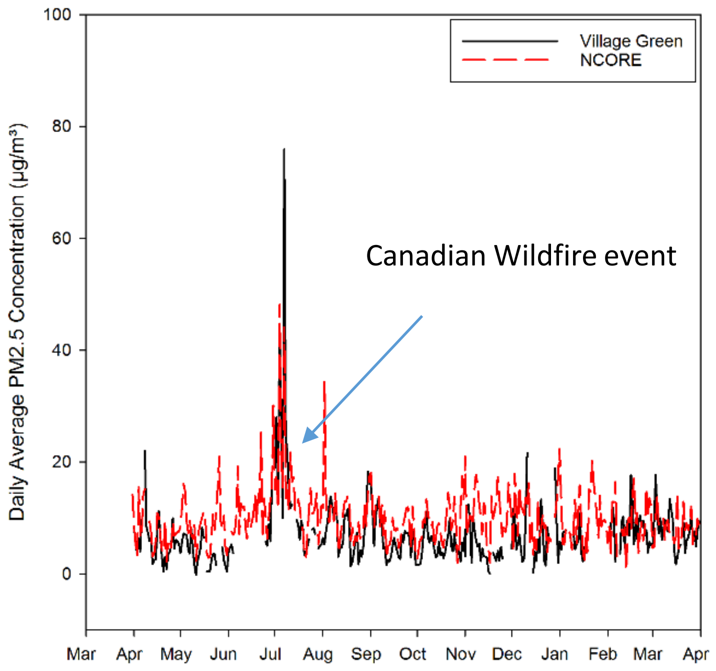




Village Green and NCORE: $PM_{2.5}$

- $PM_{2.5}$ correlations not as strong as O_3, but captures regional events
- $PM_{2.5}$ differences are expected at 5 km distances due to varying local impacts

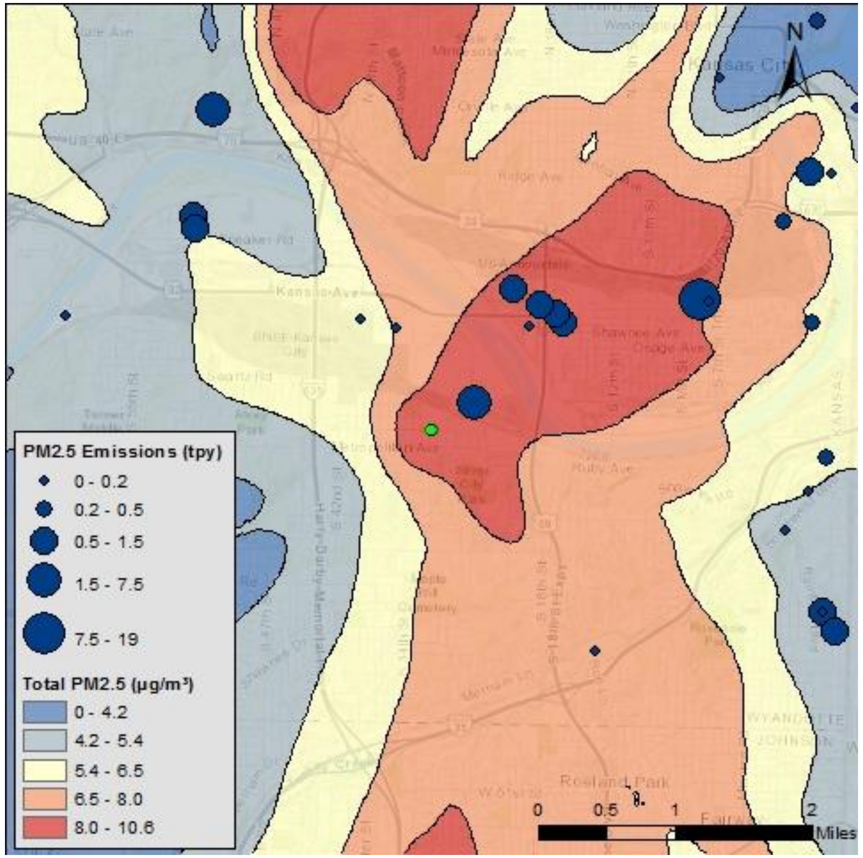




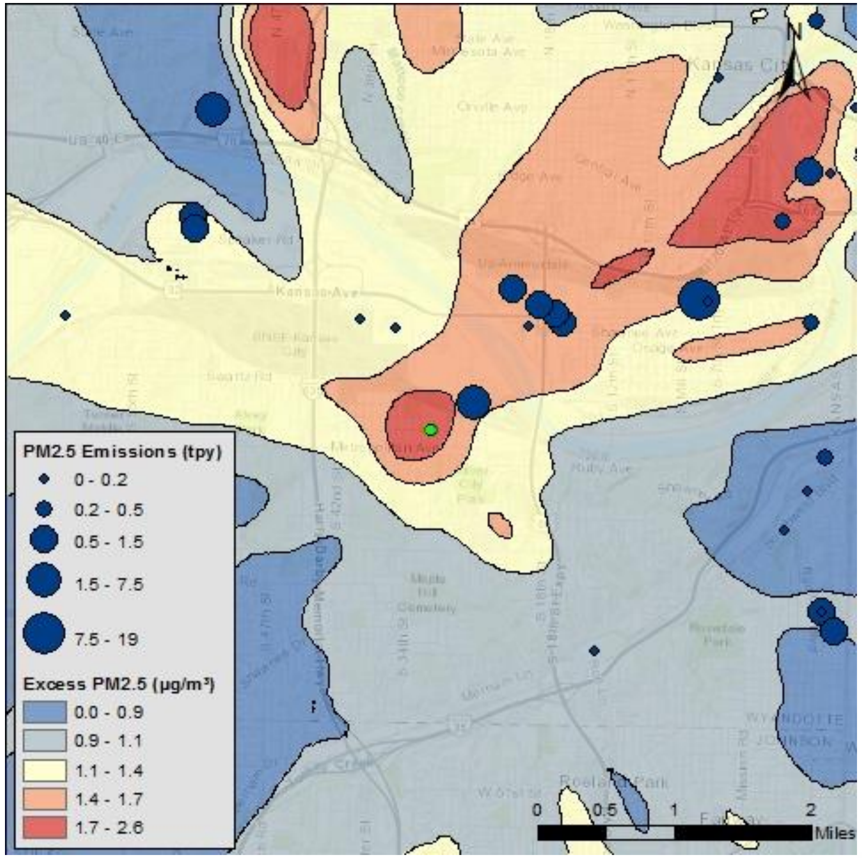
Nonparametric Trajectory Analysis

- 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 $PM_{2.5}$