

2014 National Ambient Air Monitoring Conference

***Performance Evaluation of a
Lower-Cost, Real-Time Community Air
Monitoring Station***

**Wan Jiao¹, Gayle Hagler², Ron Williams²,
Bobby Sharpe³, Lewis Weinstock⁴, Joann Rice⁴**

¹Student Services Contractor, U.S. EPA Office of Research and Development

²U.S. EPA Office of Research and Development

³ARCADIS U.S., Inc.

⁴U.S. EPA Office of Air Quality Planning and Standards

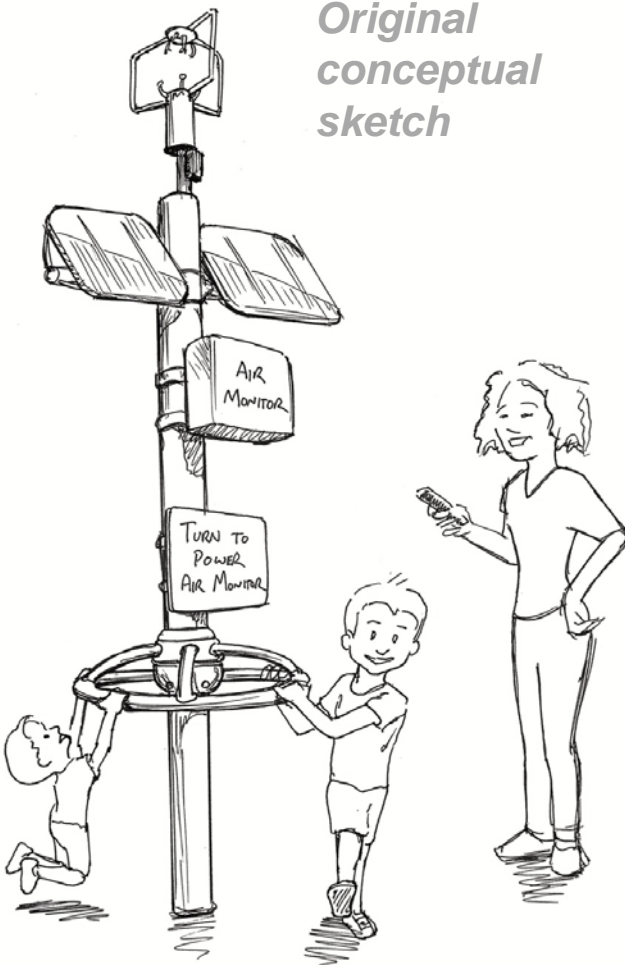


Introduction

- A need for technologies that provide information to engage the community for local air quality
- Limitation in traditional air monitoring due to cost and logistical issues
- EPA's Village Green Project (VGP) seeks to address the technology gap by designing a proof-of-concept air monitor prototype

Village Green Project (VGP): Vision and design

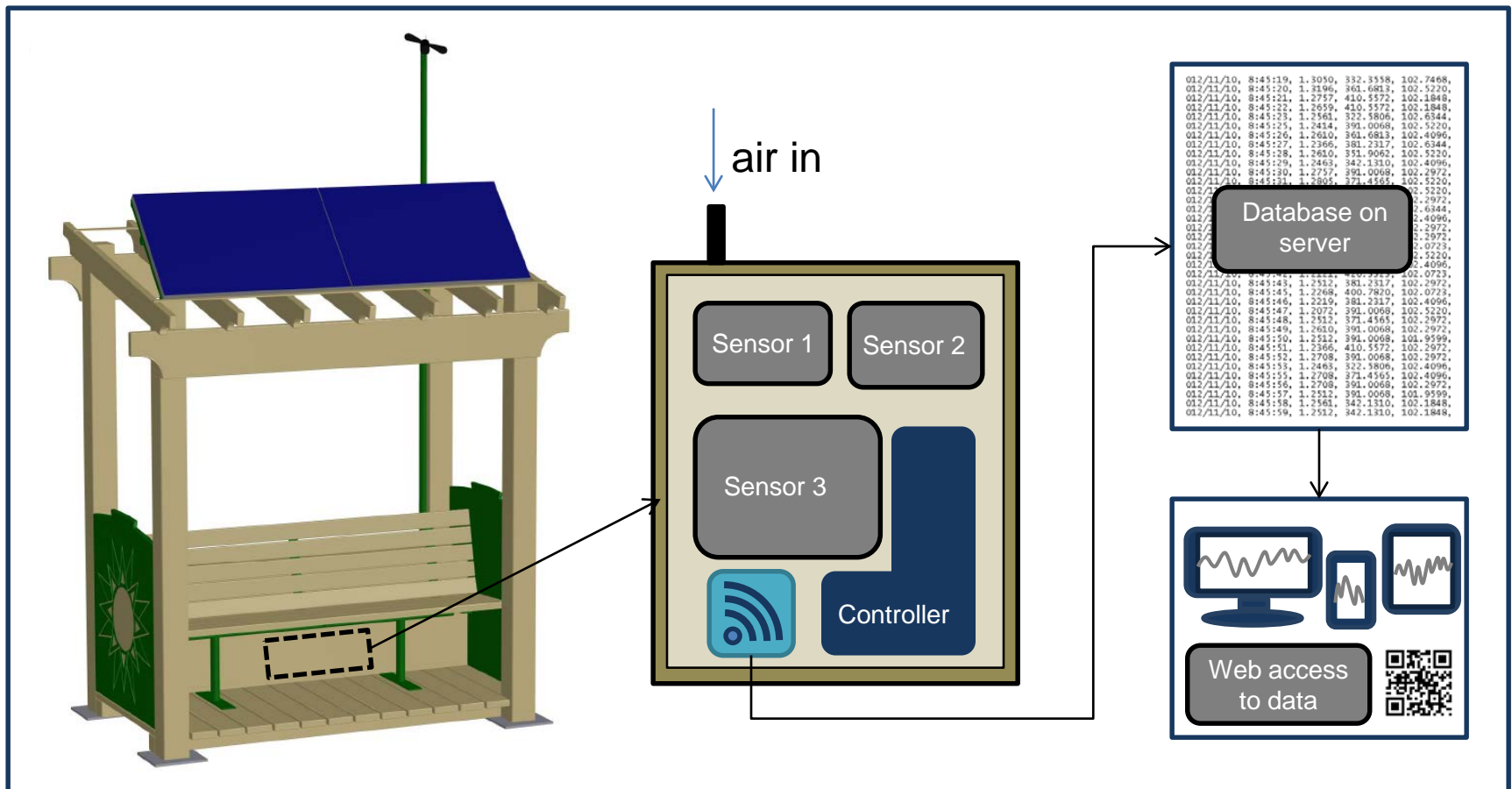
*Original
conceptual
sketch*



- Lower cost to install and run: sustainable, self-powered, minimum maintenance
- Provides real-time data: one minute data rate, automated quality checks
- Engages the community: in a community environment
- Accessible data and information: publically available on a website

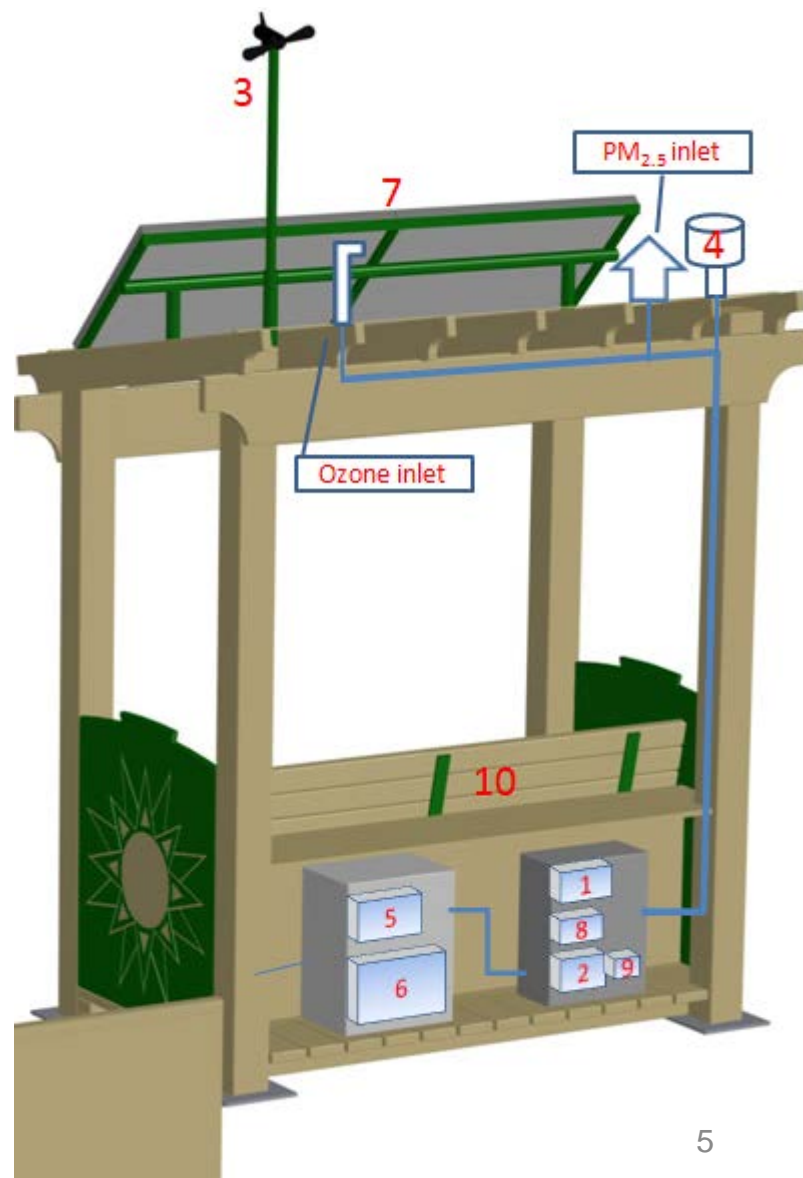
VGP Schematic

Key constraints: physical footprint, power, instrumentation that can withstand no heating or A/C, minimize cost to the extent possible



System components

No.	Component (model)	Manufacturer
1	PM monitor (pDR-1500)	Thermo Scientific
2	Ozone monitor (OEM-106)	2B Technologies
3	Wind sensor (09101)	RM Young
4	Humidity and temperature sensor (HMP60)	Vaisala
5	Power controller (Sunsaver SS-10L-12V)	Morningstar
6	AGM battery (WKDC12-80P, 12V, 80Ah)	Werker
7	Solar panel (SLP085-12MKCT, 85W, 12 VDC)	Solarland
8	Microprocessor (Arduino Mega 2560)	Arduino
9	Cellular router (Airlink Raven XE)	Sierra Wireless
10	Bench structure	Safeplay Systems

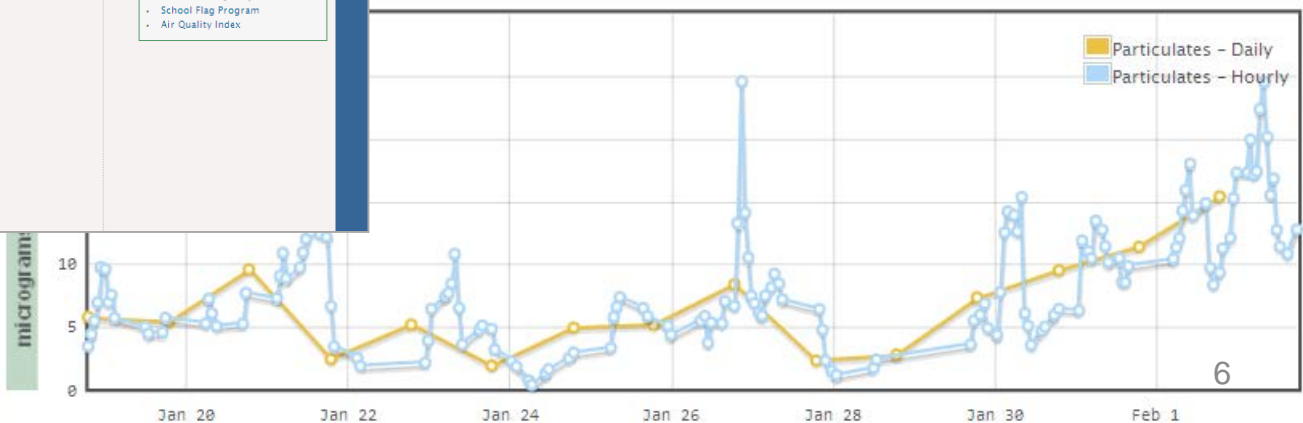
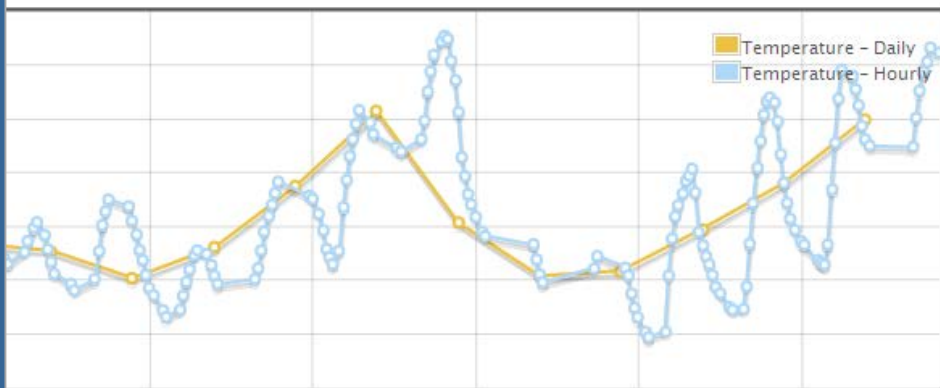




Data transmission

Public website updated minute-by-minute

<https://villagegreen.epa.gov/>





Data transmission

Behind the scenes – admin viewing page, real-time QA checks of instruments, raw data for download

Ozone data

diagnostic data

PM data

diagnostic data

Met data

diagnostic data

MeasurementDate	WindSpeed	O3_PPBB	O3_Temp	O3_Flow	O3_Diode	O3_CellP	PDR_Conc	DR_Temp	PDR_RH	PDR_Pres	ARD_T	ARD_RH	ARD_STAT	IsValid	AmbRH	AmbTemp	WindDirection	ComponentStatus
6/22/2013 0:00	1.1	38.1	37.5	871	1.139	725.2	5.88	39	17	763	38.76	20.26	4	TRUE	57.5	26.5	196	27
6/22/2013 0:01	0.8	38.5	37.5	905	1.139	725.4	5.3	39	17	763	38.77	20.19	4	TRUE	57.8	26.6	207	27
6/22/2013 0:02	0	37.3	37.5	898	1.138	725.2	5.35	39	17	763	38.75	20.26	4	TRUE	58	26.6	165	27
6/22/2013 0:03	0.3	35.6	37.4	896	1.138	725.3	4.98	39	17	763	38.7	20.33	4	TRUE	58	26.6	206	27
6/22/2013 0:04	0	36.6	37.4	889	1.138	725.1	5.47	39	17	763	38.68	20.44	4	TRUE	57.9	26.6	192	27
6/22/2013 0:05	0	37.3	37.4	893	1.138	725	4.84	39	17	763	38.67	20.55	4	TRUE	58.2	26.7	208	27
6/22/2013 0:06	0	35.8	37.4	882	1.137	725	5.39	38.9	18	763	38.64	20.65	4	TRUE	58.5	26.6	318	27
6/22/2013 0:07	0	36.4	37.4	892	1.137	725	5.4	39	17	763	38.64	20.69	4	TRUE	58.1	26.6	90	27
6/22/2013 0:08	0.7	36	37.4	868	1.137	725.1	5.3	38.9	17	763	38.6	20.76	4	TRUE	57.8	26.6	224	27
6/22/2013 0:09	1	37.2	37.4	897	1.137	725.1	5.22	38.9	17	763	38.58	20.83	4	TRUE	57.8	26.7	172	27
6/22/2013 0:10	0.4	34.8	37.3	933	1.136	725.2	5.59	38.9	17	763	38.58	20.83	4	TRUE	58.9	26.5	193	27
6/22/2013 0:11	0	36.4	37.3	894	1.136	725.1	4.92	38.9	18	763	38.59	20.83	4	TRUE	59.2	26.4	193	27
6/22/2013 0:12	0	36.1	37.3	881	1.136	725.1	5.86	38.9	18	763	38.56	20.94	4	TRUE	59.1	26.3	193	27
6/22/2013 0:13	0.4	37.8	37.3	862	1.135	725.1	5.14	38.8	17	763	38.55	20.94	4	TRUE	58.5	26.4	214	27
6/22/2013 0:14	0	36	37.3	870	1.135	725.1	5.28	38.9	18	763	38.53	20.97	4	TRUE	59	26.4	214	27
6/22/2013 0:15	0.5	34	37.3	901	1.135	725.1	5.39	38.8	18	763	38.54	20.97	4	TRUE	59.8	26.3	159	27
6/22/2013 0:16	0.7	34.7	37.3	872	1.135	725.1	5.44	38.8	18	763	38.52	21.08	4	TRUE	59.2	26.3	174	27
6/22/2013 0:17	0	32.2	37.2	880	1.135	725.1	5.15	38.8	18	763	38.48	21.12	4	TRUE	59.8	26.2	155	27
6/22/2013 0:18	0.3	30.7	37.2	867	1.134	725.1	5.45	38.8	18	763	38.48	21.12	4	TRUE	61.3	26.1	180	27
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6/22/2013 0:20	0.6	36.1	37.2	903	1.134	725.1	5.6	388	18	76	38.45	21.19	4	TRUE	60	26	189	27
6/22/2013 0:21	0.4	34.3	37.2	893	1.134	725.1	5.7	38.8	18	763	38.44	21.19	4	TRUE	60.2	26	141	27
6/22/2013 0:22	0	31	37.2	873	1.133	725.1	5.87	38.8	18	763	38.44	21.19	4	TRUE	60.9	26	138	27
6/22/2013 0:23	0	32.4	37.2	868	1.133	725.1	5.35	38.8	18	763	38.43	21.26	4	TRUE	61.1	25.9	138	27
6/22/2013 0:24	0	31.4	37.2	887	1.133	725.1	5.16	38.8	18	763	38.41	21.33	4	TRUE	61.4	25.9	251	27
6/22/2013 0:25	0.6	34	37.1	888	1.133	725.1	5.69	38.7	18	763	38.38	21.36	4	TRUE	60.9	25.9	213	27
6/22/2013 0:26	0.1	34.4	37.1	894	1.133	725.1	5.5	38.7	18	763	38.37	21.4	4	TRUE	60.7	25.8	180	27
6/22/2013 0:27	0	32.1	37.1	895	1.132	725	5.61	38.7	18	763	38.33	21.47	4	TRUE	60.6	25.9	208	27
6/22/2013 0:28	0.1	33.3	37.1	896	1.132	725	5.93	38.7	18	763	38.32	21.54	4	TRUE	61.8	25.7	232	27
6/22/2013 0:29	0	31	37.1	912	1.132	725	5.88	38.7	18	763	38.29	21.54	4	TRUE	61.5	25.6	90	27
6/22/2013 0:30	0	31.5	37.1	903	1.132	725	5.82	38.6	18	763	38.28	21.65	4	TRUE	62.1	25.7	227	27
6/22/2013 0:31	0	31.7	37.1	899	1.131	725	5.93	38.6	18	763	38.28	21.69	4	TRUE	62.4	25.5	226	27
6/22/2013 0:32	0	29	37	892	1.131	725.1	5.92	38.6	18	763	38.27	21.68	4	TRUE	63	25.4	227	27
6/22/2013 0:33	0	28.8	37	939	1.131	725	5.32	38.6	19	763	38.25	21.72	4	TRUE	63.9	25.5	179	27
6/22/2013 0:34	0	27.2	37	884	1.131	725	5.47	38.6	18	763	38.23	21.83	4	TRUE	63.4	25.3	234	27



System installation at local library in Durham, NC

EPA and Durham County signed Memorandum of Understanding supporting station placement and educational outreach



System installation in June 2013





System installation at local library in Durham, NC

Sign next to station with information on the air monitoring project, explanation of the Air Quality Index, QR code for smartphones to easily connect to website





System installation at local library in Durham, NC

Ribbon-cutting ceremony in June, 2013

Library also participating in School Flag Program





System installation at local library in Durham, NC

Outreach events at the library:





Review of system performance (June 2013-March 2014)

Goals:

- (1) Evaluate the long-term operability of the VGP system
- (2) Compare the pollutant concentrations measured by the VGP system with nearby ambient monitoring stations
- (3) Assess the potential for measurement artifacts due to meteorological conditions



System performance

- Power system provided sufficient power for ~95% operation over 10 months of data analyzed thus far (June 2013 through March 2014)
- Other causes of data collection interruption:
 - Communications – resolved initial challenges with Arduino to EPA server data transmission
 - Instrument maintenance or calibration – PM pump replacement approximately every 6 months, ozone instrument cleaning at 6 months mark

System performance

Month	Missing data (%) per month due to...				Overall completeness ^a (%)			
	Quality checks or maintenance		Low solar power	Comm. interruptions				
	Ozone	PM _{2.5}			Ozone	PM _{2.5}	Wind	Temp/RH
2013/06	0	0	0	4	96	96	96	96
2013/07	0	0	0	7	93	93	93	93
2013/08	0	0	0	0	100	100	100	100
2013/09	0	1	0	0	100	99	100	100
2013/10	0	59 ^b	17	0	83	24	83	83
2013/11	0	1	3	31	66	65	66	66
2013/12	43 ^b	1	11	10	36	79	79	79
2014/01	28 ^b	2	1	2	70	96	97	97
2014/02	9	8	9	0	82	83	91	91
2014/03	8	4	3	6	83	87	91	91

Solar panels provided sufficient power to operate ~94.5% of the time

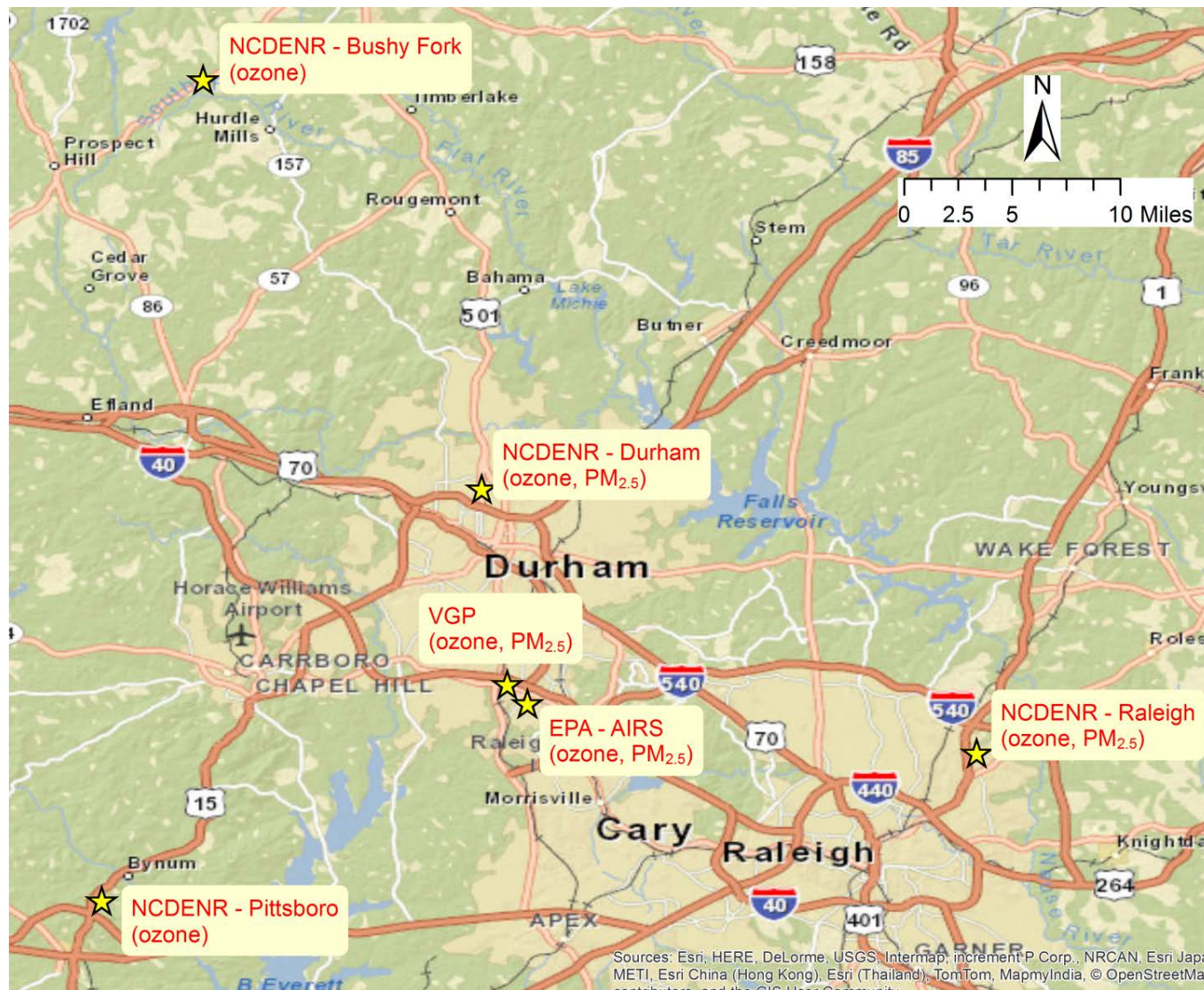
Data comparison with surrounding federal equivalent method (FEM) instrumentation



EPA-RTP AIRS site (~1 mile away)



Data comparison with surrounding federal equivalent method (FEM) instrumentation



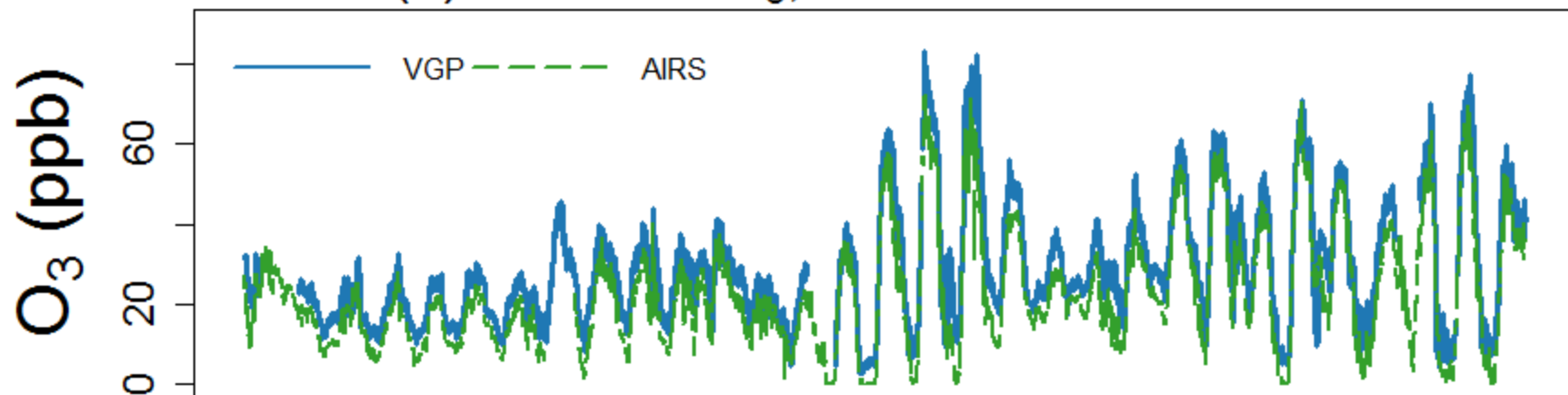


VGP and Other Nearby Instrumentation

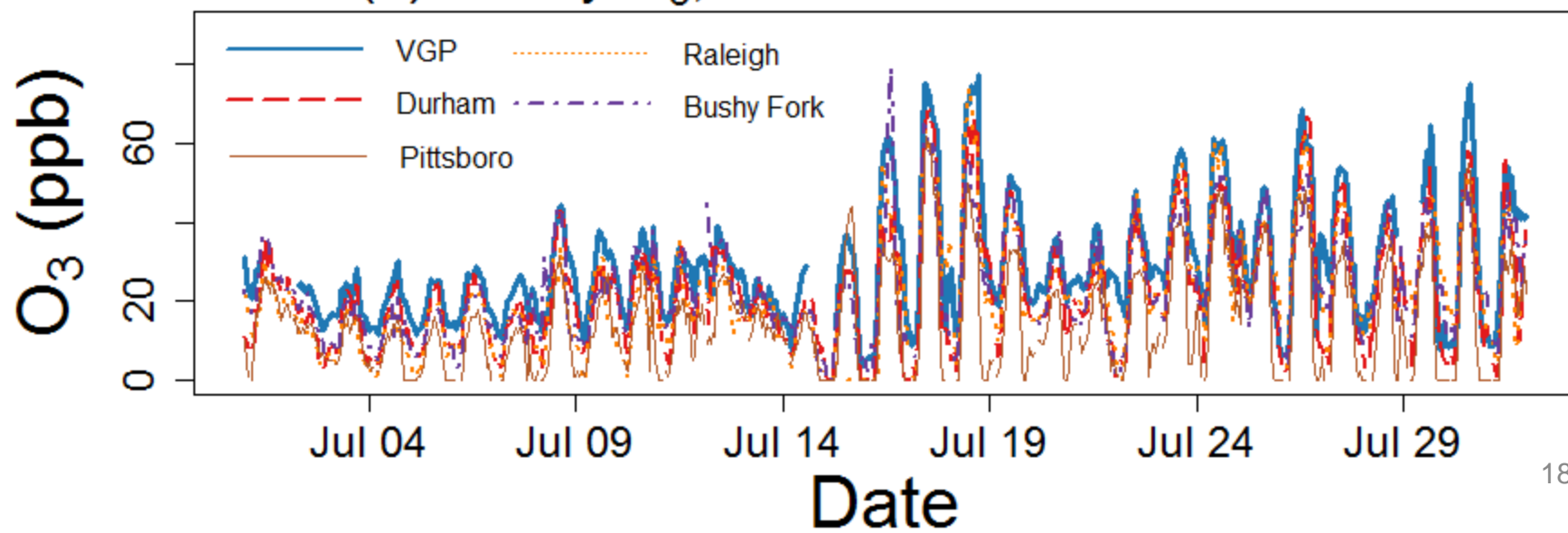
Location (Data owner)	Measurement	Instrument(s)
Village Green Project (VGP)	Ozone	2B Technologies, OEM-106
	PM _{2.5}	Thermo Scientific, MIE pDR-1500
EPA-RTP campus (OAQPS)	Ozone	Teledyne T265
	PM _{2.5}	GRIMM180
Millbrook (NC DENR)	Ozone	Thermo Environmental 49C
	PM _{2.5}	MetOne BAM 1020
Durham (NC DENR)	Ozone	Thermo Environmental 49C
	PM _{2.5}	R&P TEOM 1400AB
Pittsboro (NC DENR)	Ozone	Thermo Environmental 49C
Bushy Fork (NC DENR)	Ozone	Thermo Environmental 49C

Ozone Concentration Comparison

(a) 5-minute O_3 , VGP versus AIRS site

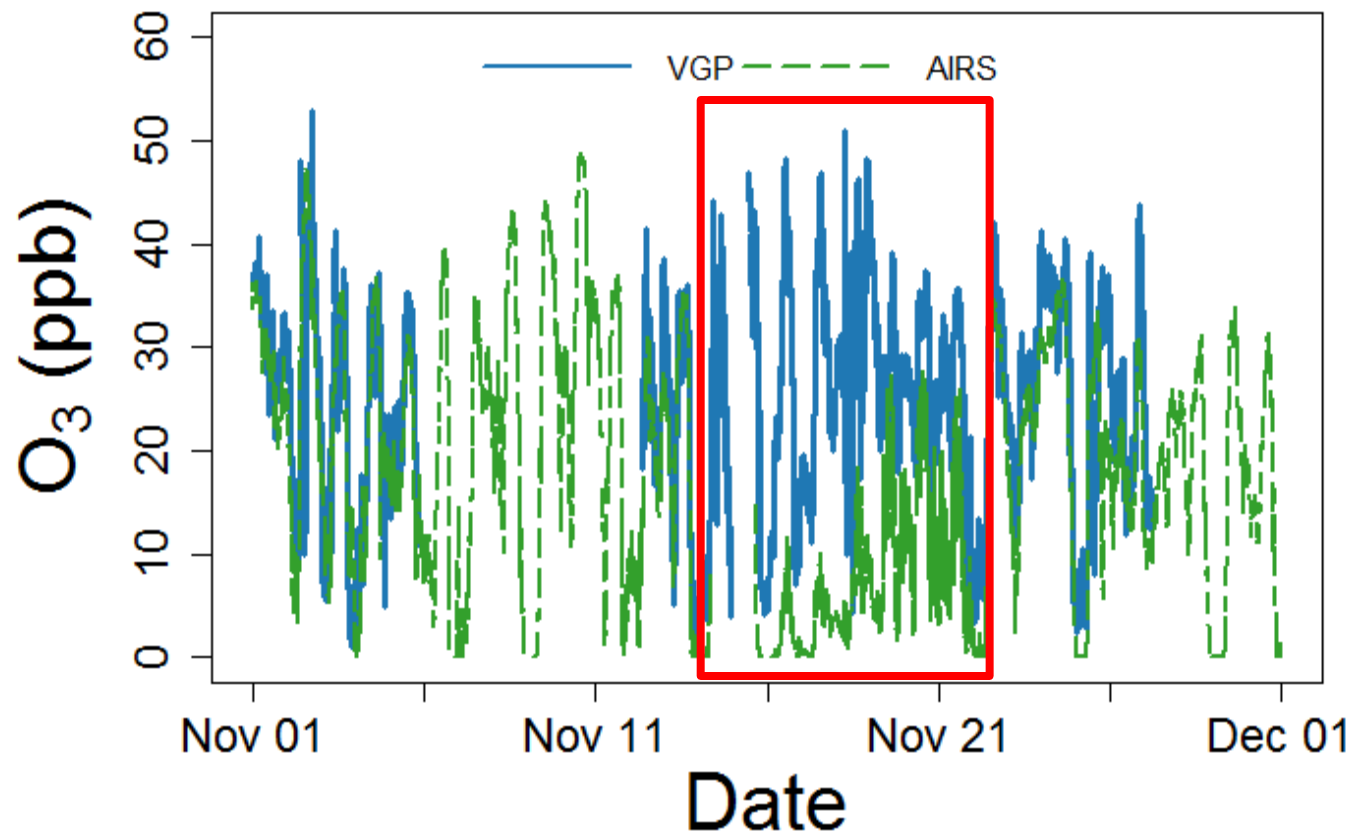


(b) Hourly O_3 , VGP versus NC DENR site



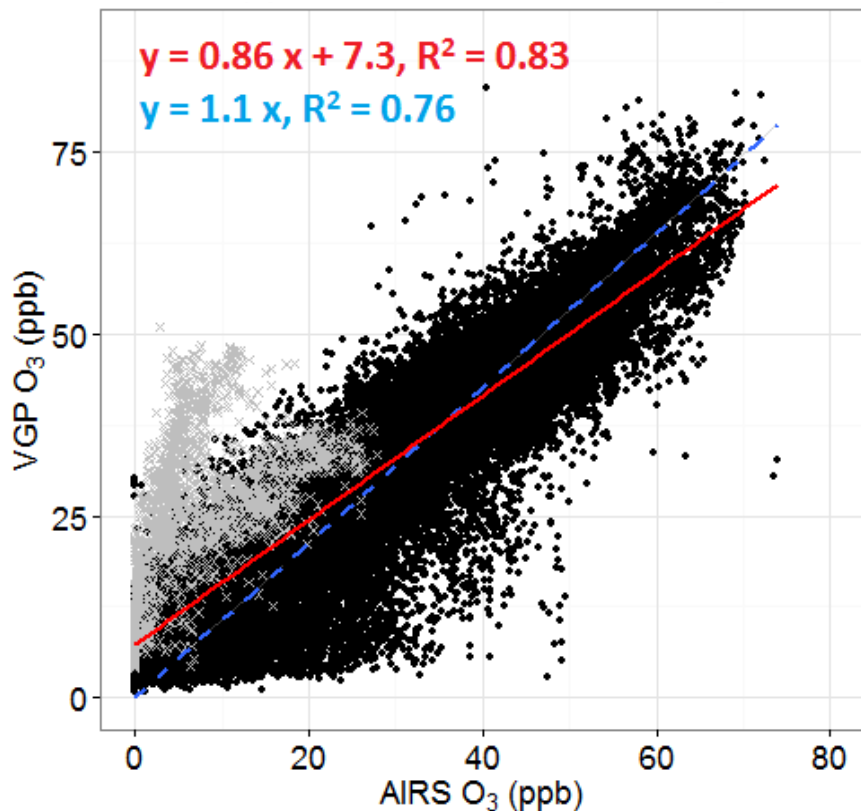


Deviation of 5-minute Average Ozone Concentration

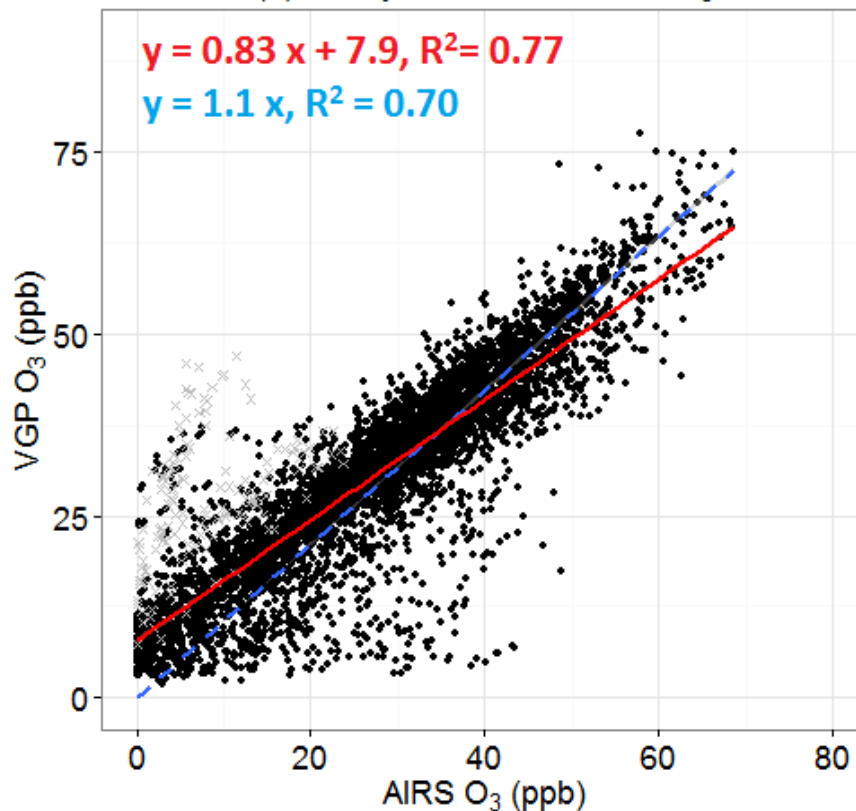


Ozone Concentration Correlation

(a) 5-minute VGP versus AIRS, O₃



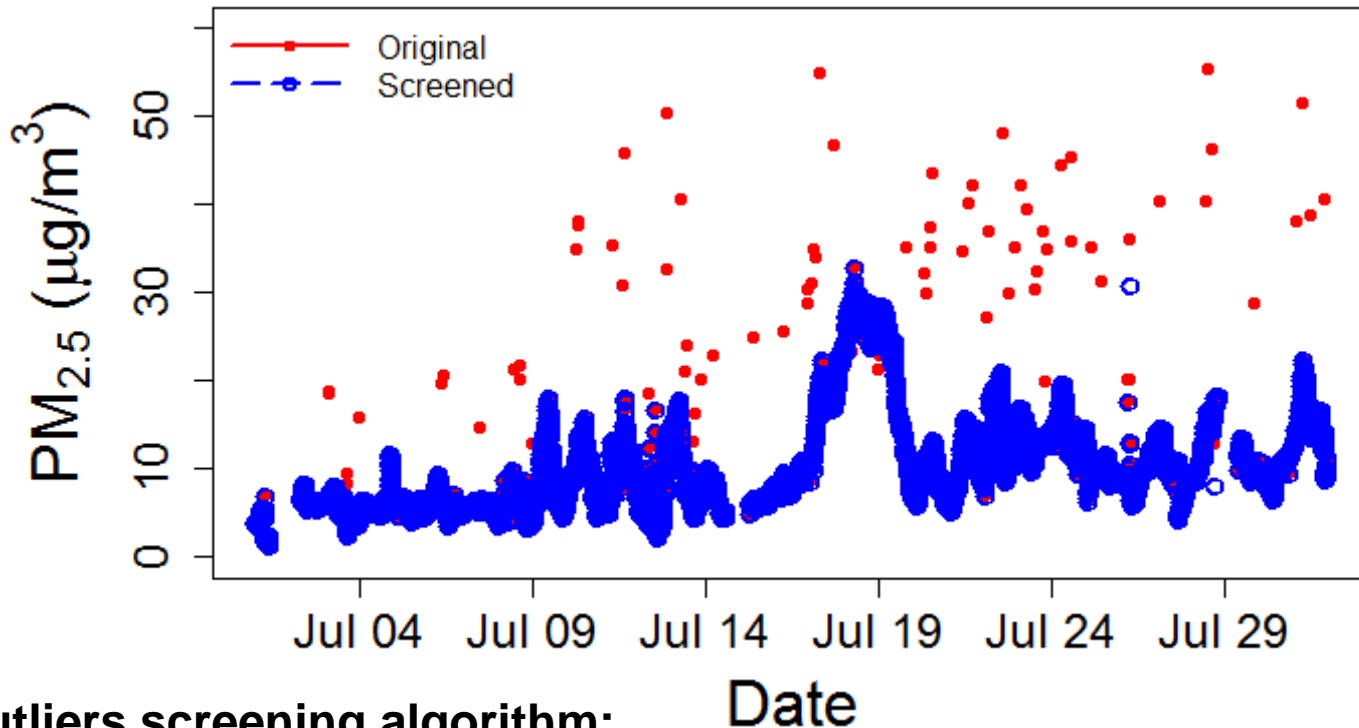
(b) Hourly VGP versus AIRS, O₃



When the one period of apparent deviation (~7 total days over November) were isolated from analysis (grey x marks), the R² increases to 0.86 and 0.81 at 5-minute and hourly intervals, respectively.



PM_{2.5} comparison – local exhaust flagged for removal



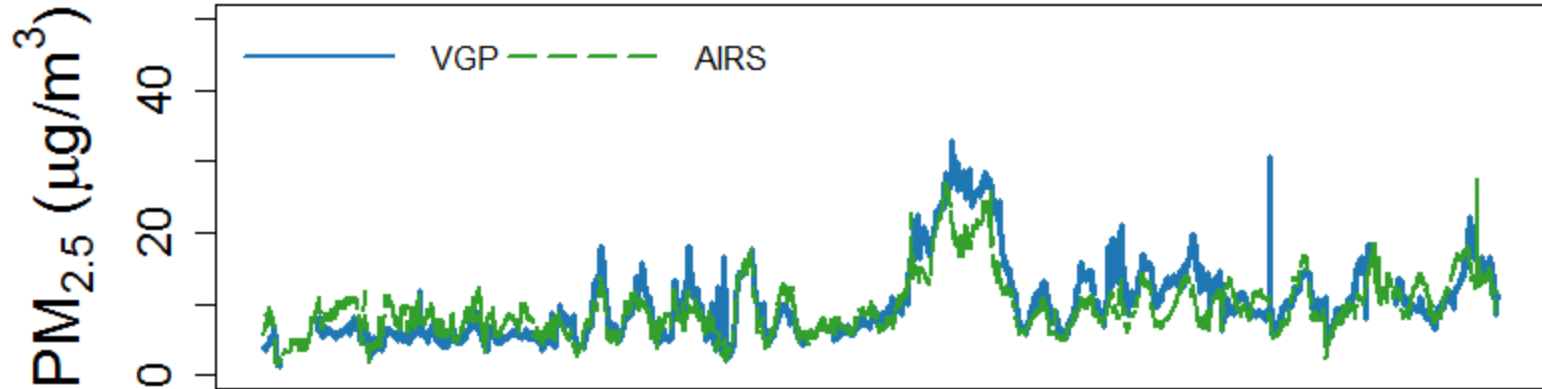
PM_{2.5} outliers screening algorithm:

```
for (i in 2:length(PM)){  
  if (PM[i] - PM[i-1] >= abs(15)){  
    PM[i] <- "Flagged"  
  }  
}
```

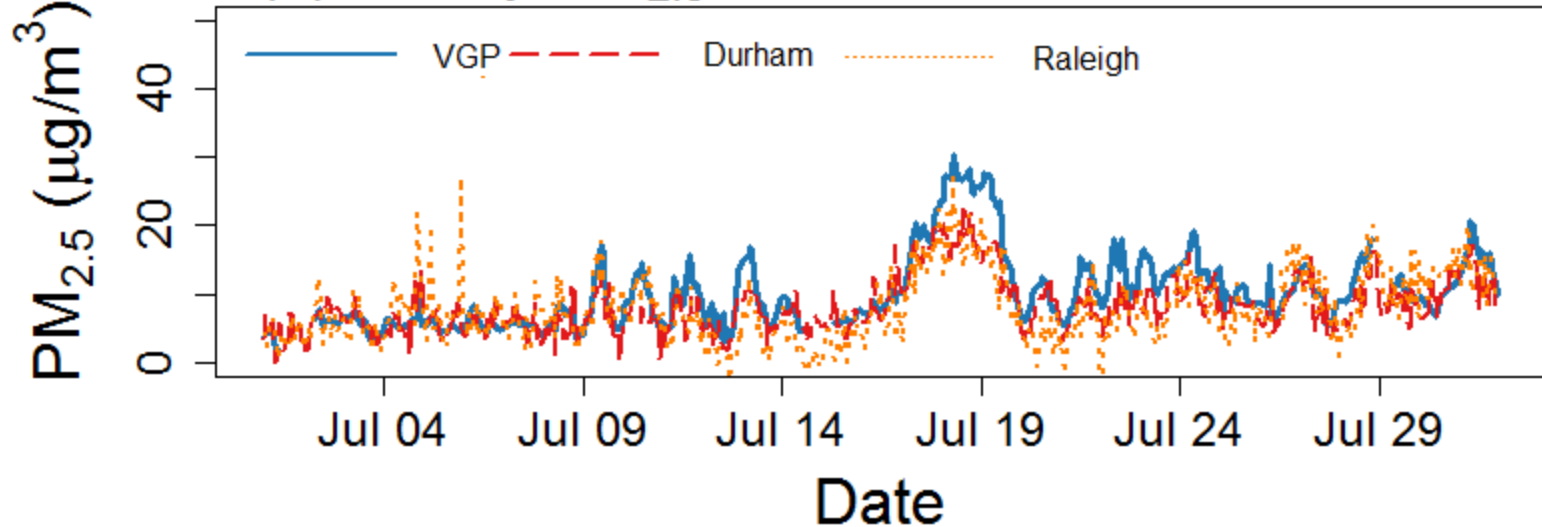
**Total removed minute
PM_{2.5} data: 0.32%**

PM_{2.5} Concentration Comparison

(a) 5-minute PM_{2.5}, VGP versus AIRS site

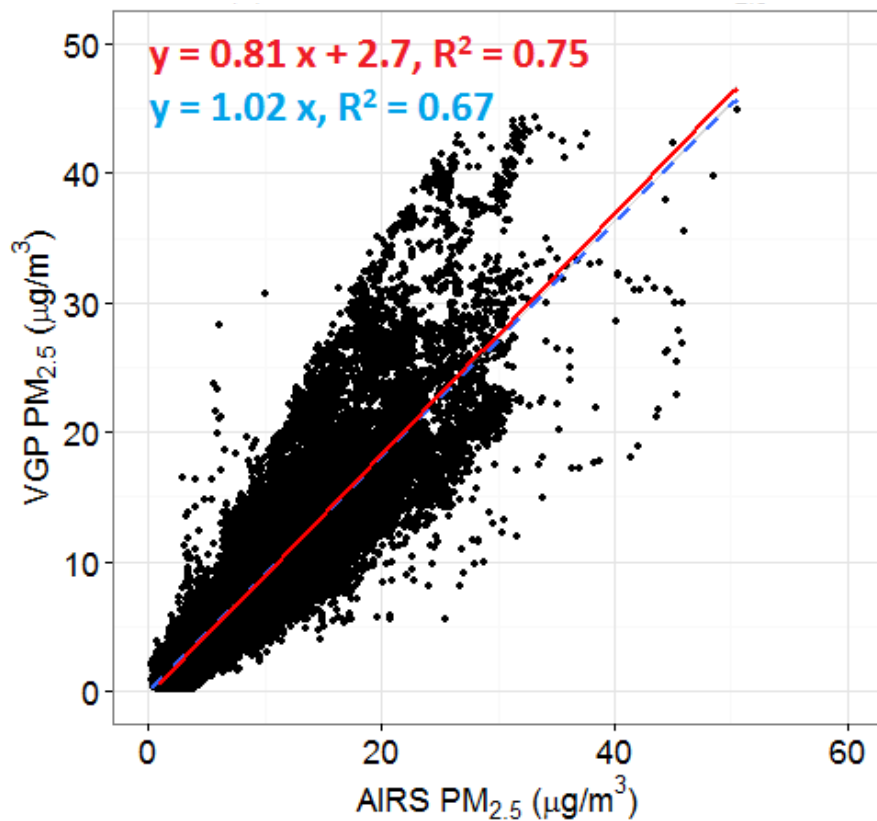


(b) Hourly PM_{2.5}, VGP versus NC DENR site

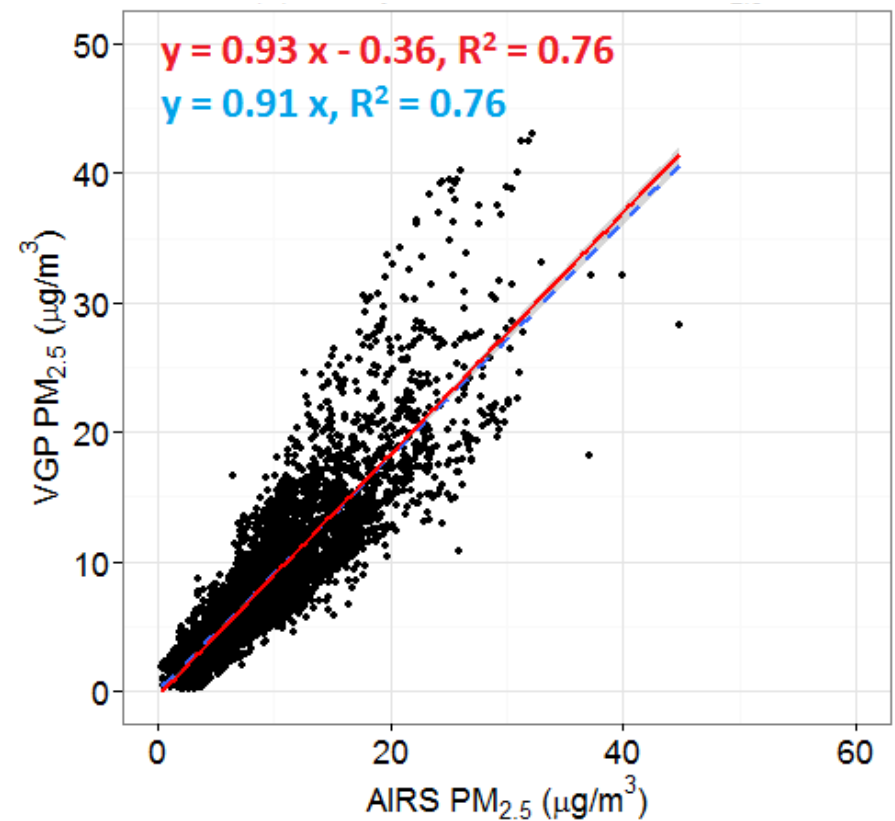


PM_{2.5} Concentration Correlation

(a) 5-minute VGP versus AIRS, PM_{2.5}



(b) Hourly VGP versus AIRS, PM_{2.5}





Effects of temperature (T) and relative humidity (RH)

Linear regress model:

$$C_{VGP} = \beta_1 + \beta_2 C_{AIRS} + \beta_3 T + \beta_4 RH$$

Explanatory variables	5-minute average VGP concentration			
	Ozone ^a		PM _{2.5} ^b	
	Estimate	Standard error	Estimate	Standard error
AIRS concentration	0.81	0.0022	0.91	0.0021
Temperature	0.20	0.0027	0.14	0.0011
Relative humidity	- 0.011	0.0015	- 0.0049	0.00053
Intercept	6.0	0.14	- 1.9	0.039

a. $R^2 = 0.84$, all p -values are significant at 0.001 level.

b. $R^2 = 0.81$, all p -values are significant at 0.001 level.



Air Quality Index (AQI)

*Air Quality Index (AQI)
calculation:*

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}$$

Where I_p = the index for pollutant p

C_p = the rounded concentration of pollutant p

BP_{Hi} = the breakpoint that is greater than or equal to C_p

BP_{Lo} = the breakpoint that is less than or equal to C_p

BP_{Hi} = the breakpoint that is greater than or equal to C_p

I_{Hi} = the AQI value corresponding to BP_{Hi}

I_{Lo} = the AQI value corresponding to BP_{Lo}

Breakpoint...		AQI	Category
O ₃ (ppm) 8-hr	PM _{2.5} (µg/m ³) daily		
0.000 – 0.059	0.0 – 12.0	0 – 50	Good
0.060 – 0.075	12.1 – 35.4	51 – 100	Moderate
0.076 – 0.095	35.5 – 55.4	101 – 150	Unhealthy for Sensitive Groups
0.096 – 0.115	55.5 – 150.4	151 – 200	Unhealthy

AQI Level Comparison

AQI Level	Ozone		PM _{2.5}	
	AIRS (days)	VGP (days)	AIRS (days)	VGP (days)
Good	242	237	172	161
Moderate	5	3	52	36
Percent of identical level (%)	97		88	



Performance Assessment Summary

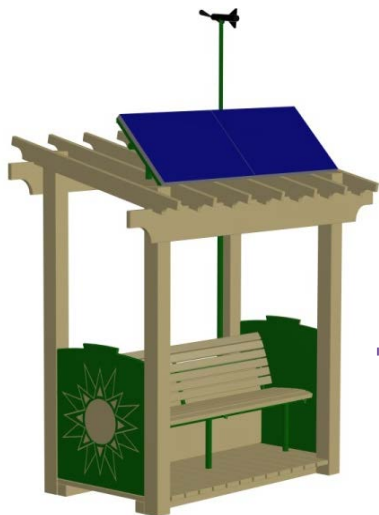
- The VGP design was useful and promising for near-source community air quality monitoring.
- Comparison to nearby regulatory ambient air monitoring stations revealed good agreement in general for ozone and $\text{PM}_{2.5}$ over a range of environmental conditions across multiple seasons.



Future steps: advancing beyond prototype

Starting place:

- Proof of concept prototype: Single system installed in Durham, NC
- Power system designed for NC solar conditions
- Website supporting one data stream



Wireless data transmission





Village Green Project II

Point of contact:
Esteban Herrera
Herrera.Esteban@epa.gov

VGP II Goals:

- Expand on prototype for increased system capability and additional sensors
- Partner with states and communities
- Increase transparency through public access to real time data from multiple data sets
- Utilize AirNow and share IT services with increased data capacity
- Flexibility for long term expansion – platform design with capability to supplement and flexible to allow for interchangeable parts





Village Green Project II

- Multiple stations installed with state partnerships
- Enhanced design options – cold weather durability and upgraded power (solar plus small wind turbine) for northern climates
- Evaluation of potential added measurements beyond ozone and $\text{PM}_{2.5}$: NO_2
- Design package to support technology availability
- New back-end support by AirNow, with development underway to support high time-resolution data
- Website re-design to support real-time data viewings for multiple locations



Acknowledgements

Many many individuals supporting and contributing to the Village Green Project!

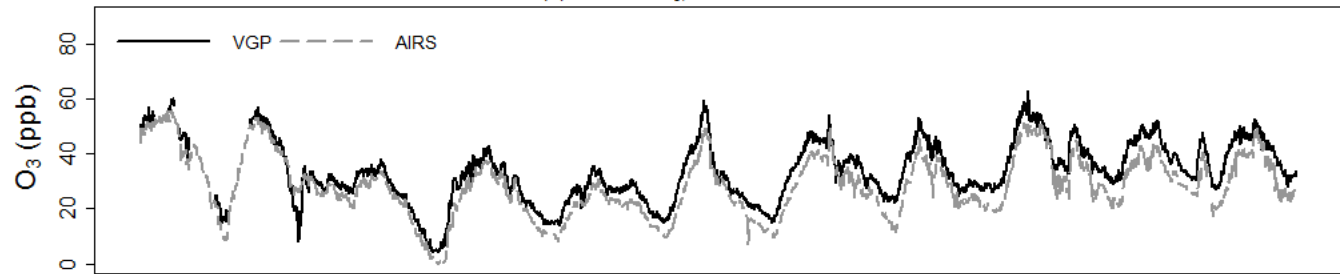
- MOU, communications, technical support, quality assurance, lab/ACE support for station: Kelly Leovic, Bill Mitchell, Dana Buchbinder, Ann Brown, Eben Thoma, Renee Marshall, John Masters, Rachel Clark, Robert Wright, Paul Groff, Richard Shores, Doug McKinney, Frank Princiotta, Tim Watkins, Dan Costa, Lindsay Stanek, Carlos Nunez, Jewel Morris, Jacques Kapuscinski, Solomon Ricks
- ARCADIS: Drew Knott, Aaron DeBlois
- CGI: Mike Tumbarello, David Crawford, Stephen Jackson
- Durham County: T. Che Anderson, Tammy Baggett, Sandra Lovely, Jennifer Brannen, Kathleen Hays
- Potential new efforts to expand VGP: Esteban Herrera, Phil Dickerson, John White, Ron Evans, Lewis Weinstock, Stacey Katz, Gail Robarge, Peter Preuss
- NC DENR for providing the comparison regulatory data: Wayne Cornelius, Vitaly Karpusenko



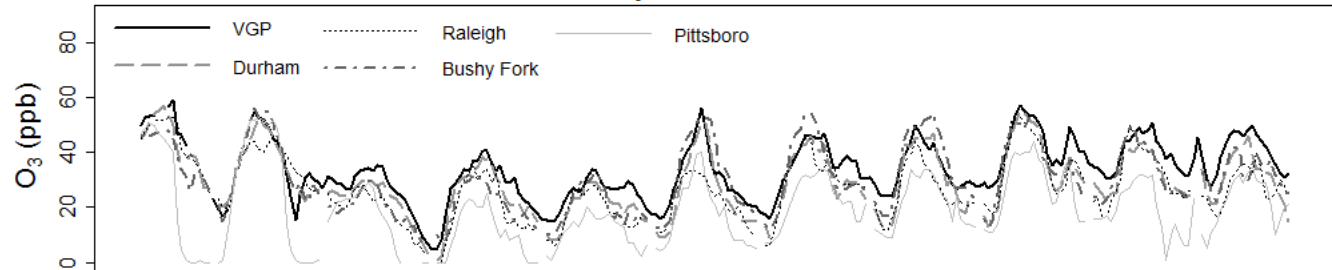
Appendix

Jun, 2013

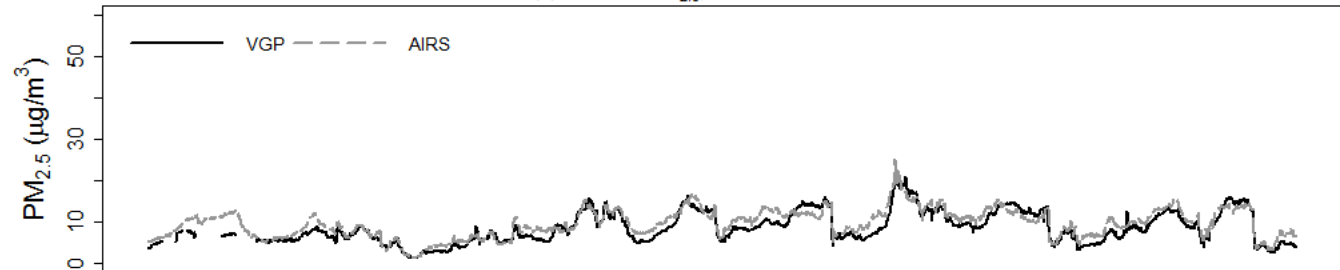
(a) 5-minute O_3 , VGP versus AIRS site



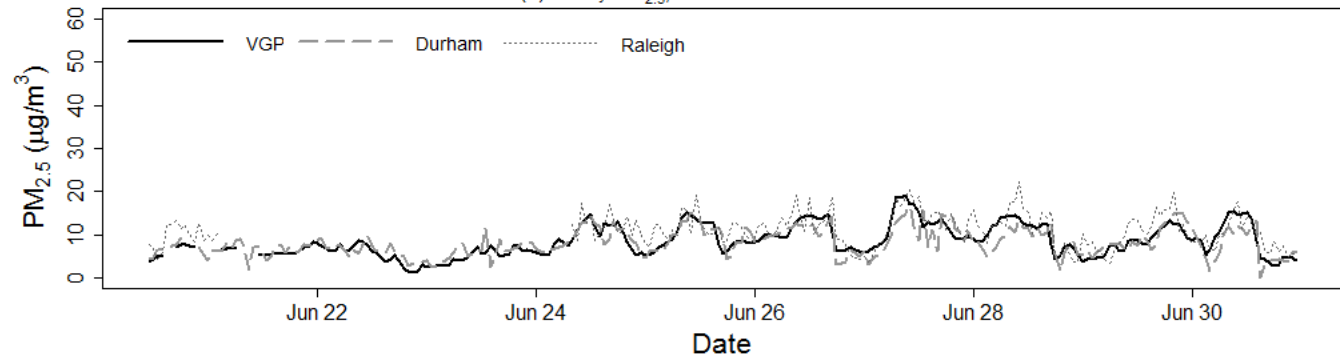
(b) Hourly O_3 , VGP versus NC DENR site



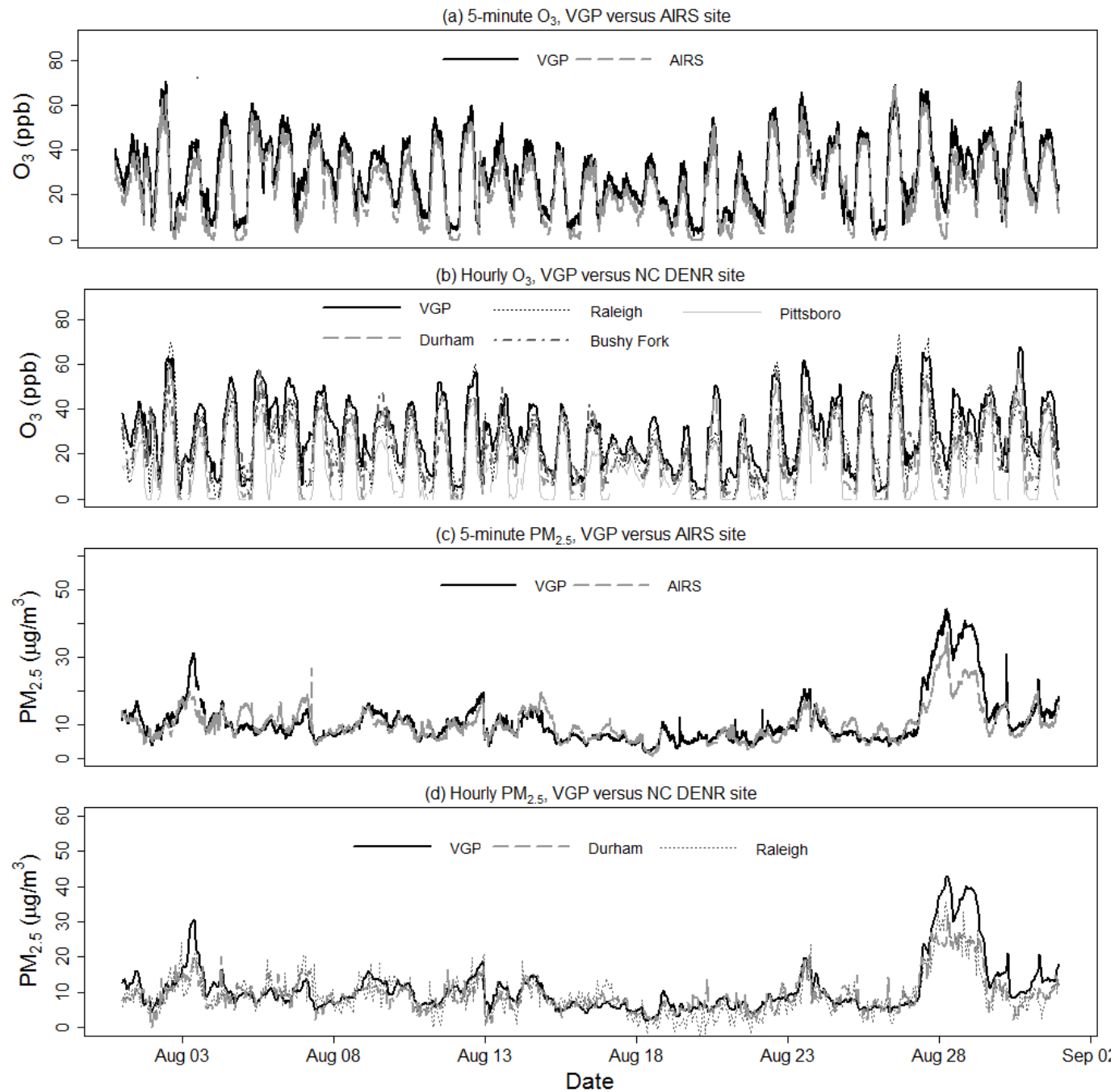
(c) 5-minute $PM_{2.5}$, VGP versus AIRS site



(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

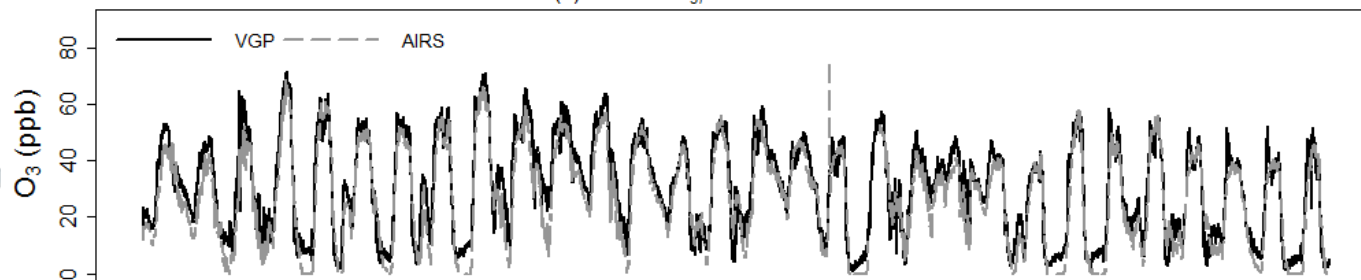


Aug, 2013

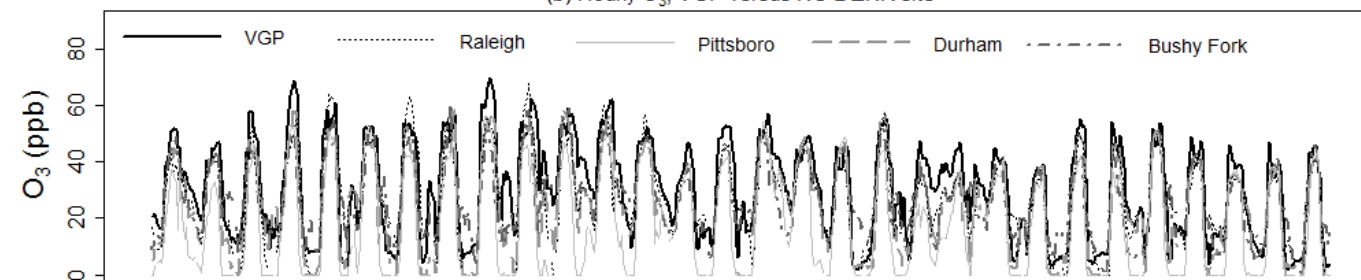


Sep, 2013

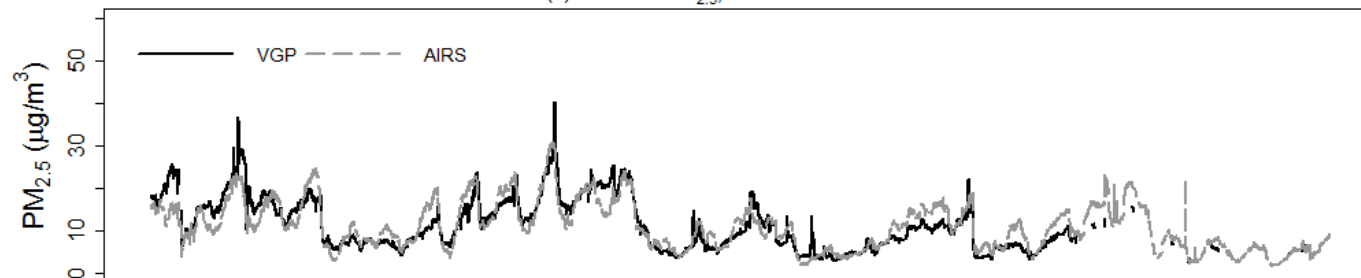
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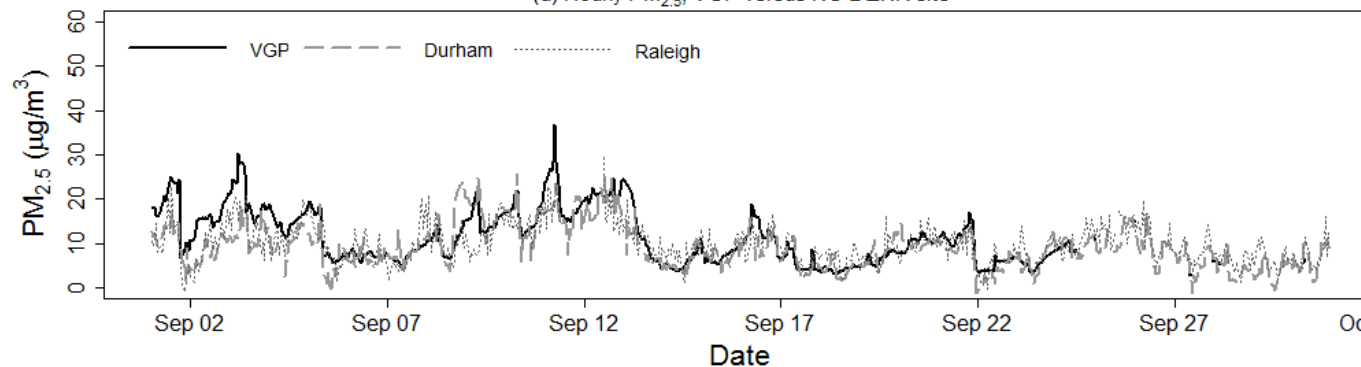
(b) Hourly O_3 , VGP versus NC DENR site



(c) 5-minute $PM_{2.5}$, VGP versus AIRS site

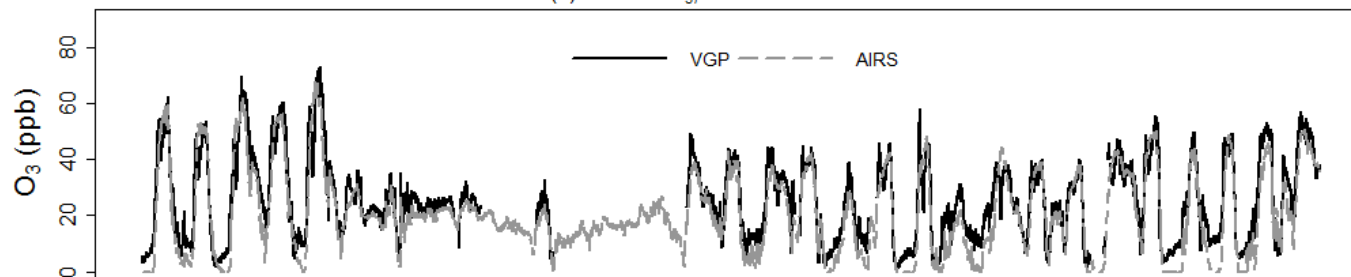


(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

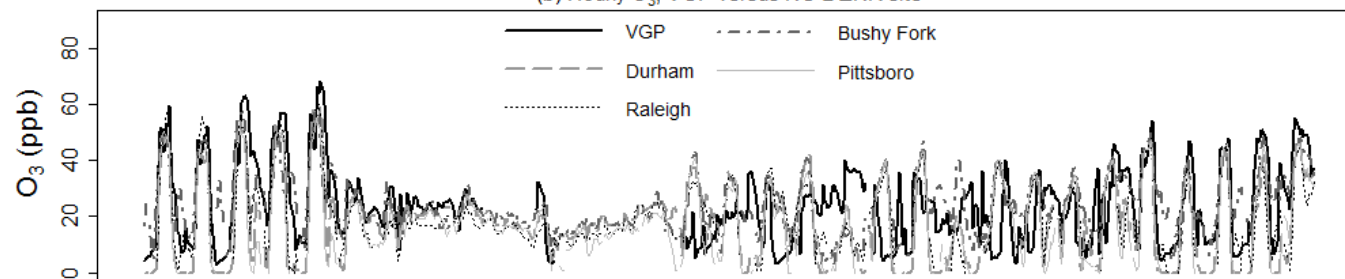


Oct, 2013

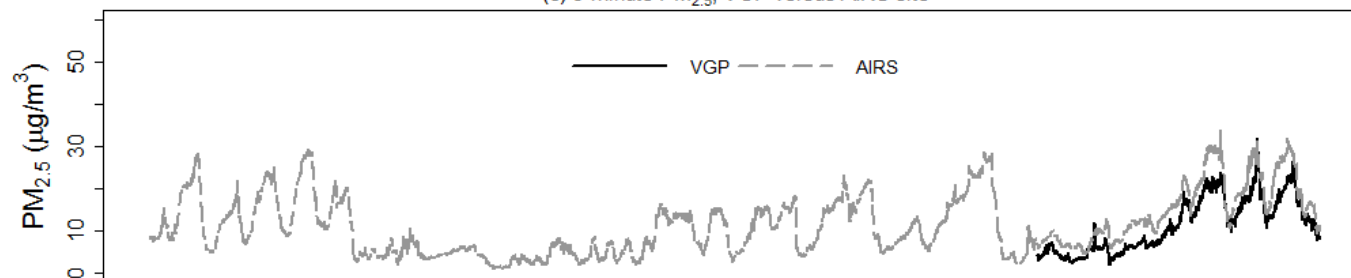
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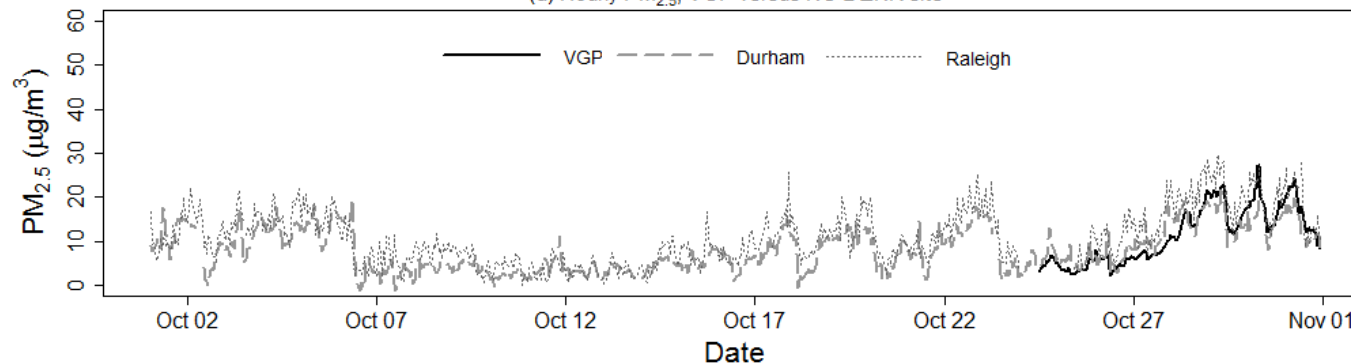
(b) Hourly O_3 , VGP versus NC DENR site



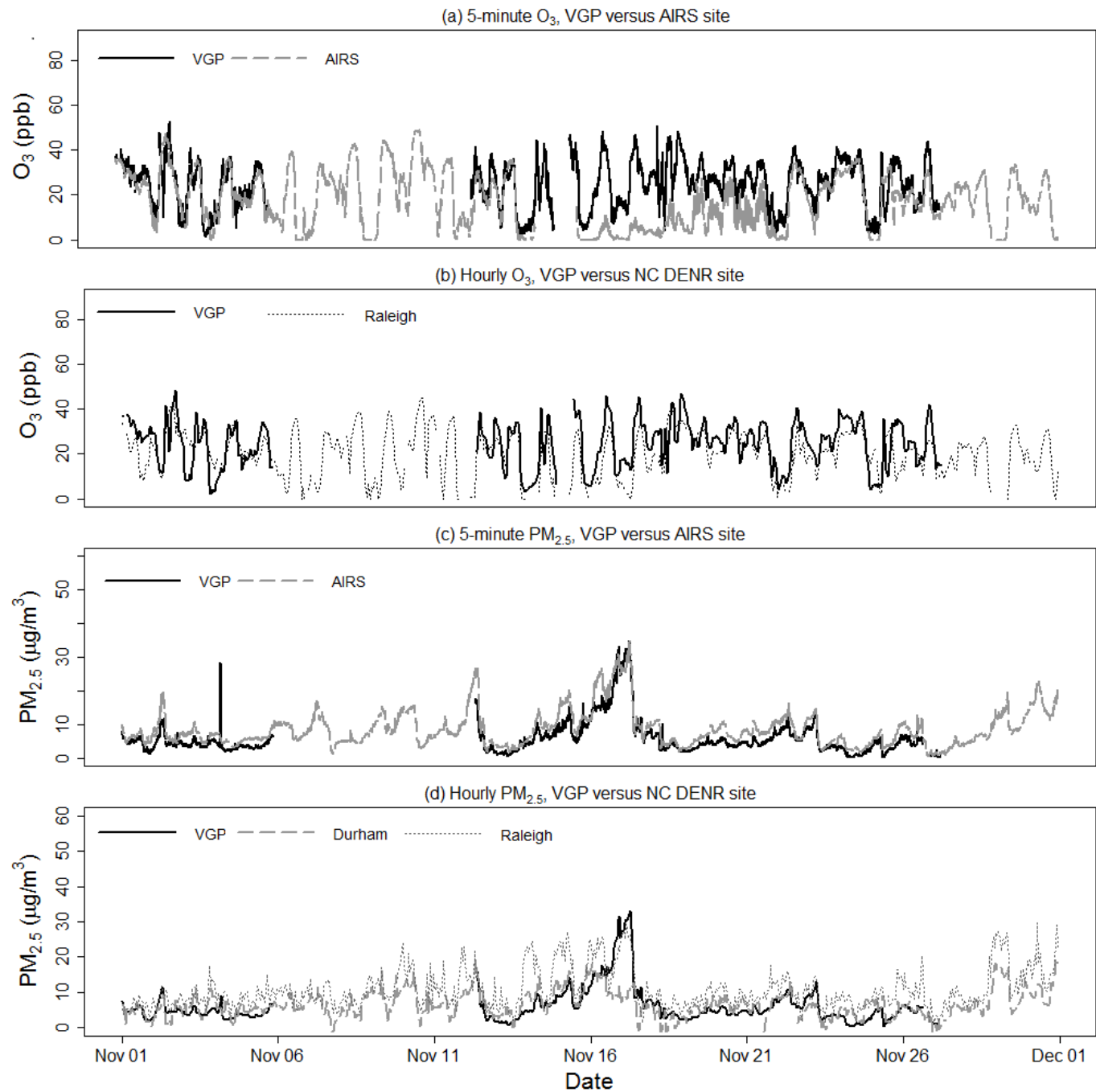
(c) 5-minute $PM_{2.5}$, VGP versus AIRS site



(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

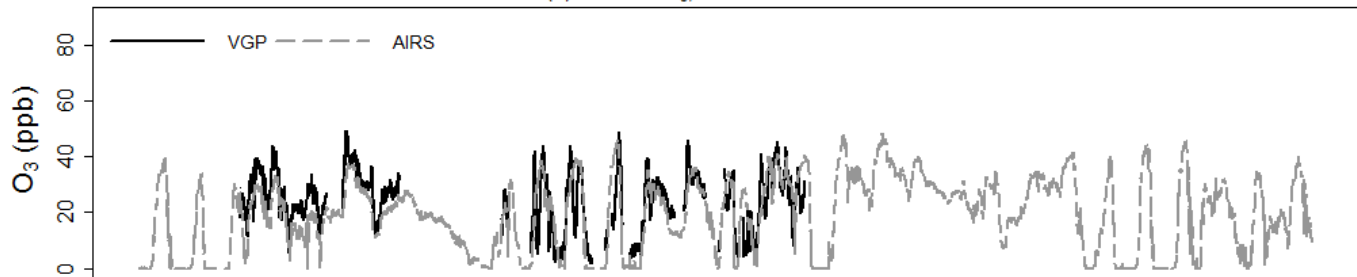


Nov, 2013

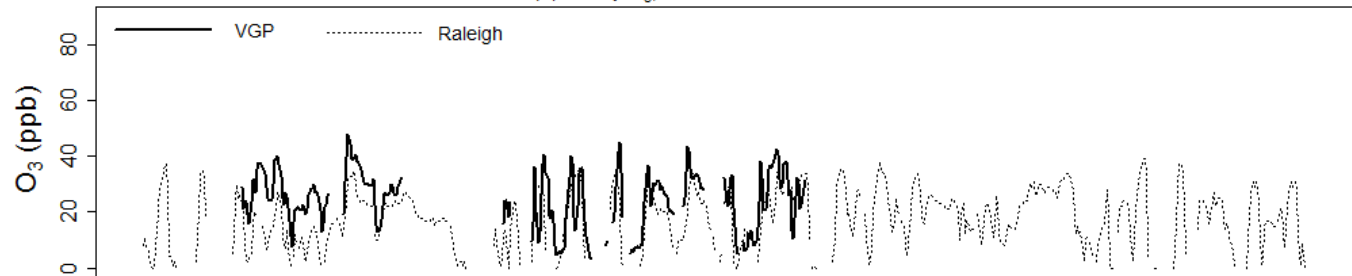


Dec, 2013

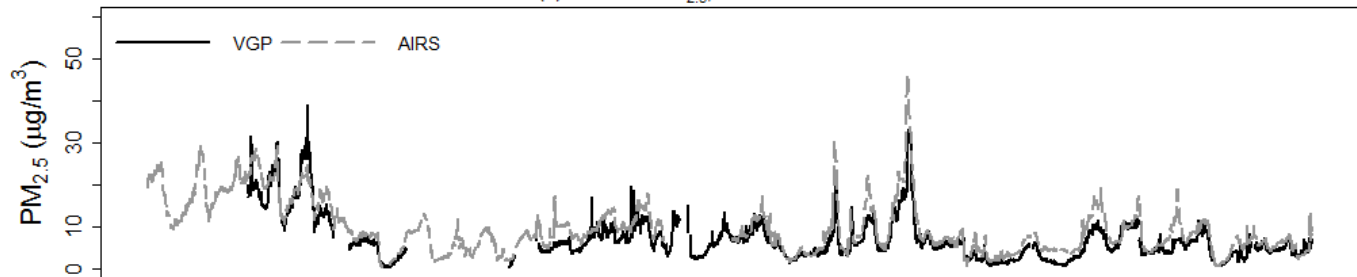
(a) 5-minute O_3 , VGP versus AIRS site



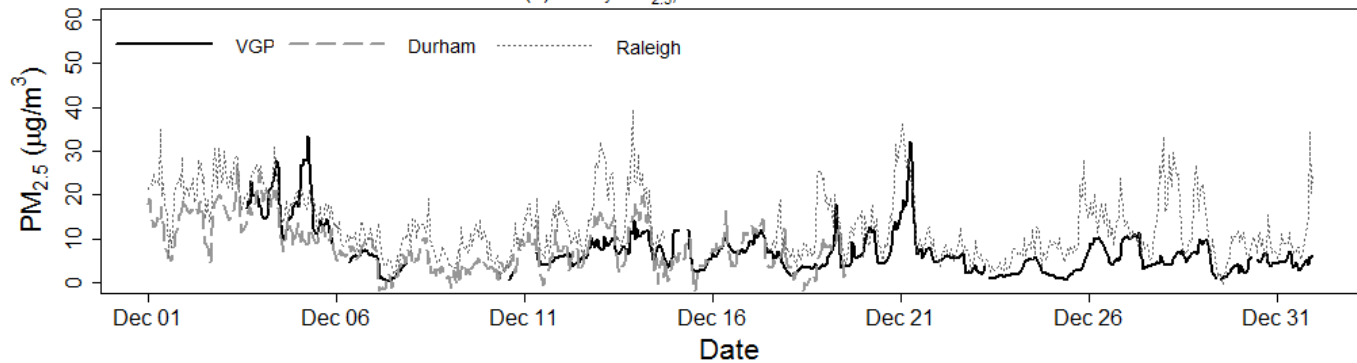
(b) Hourly O_3 , VGP versus NC DENR site



(c) 5-minute $PM_{2.5}$, VGP versus AIRS site

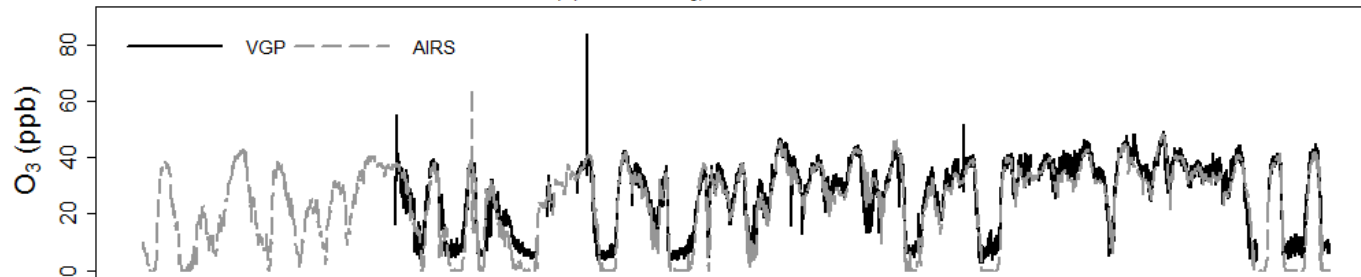


(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

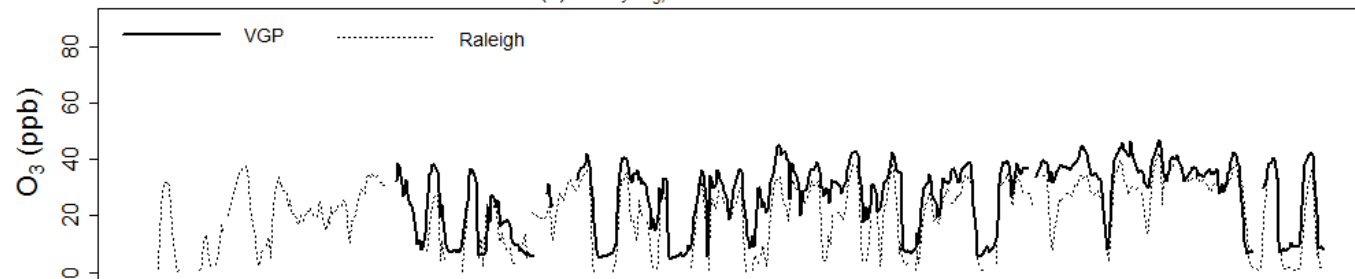


Jan, 2014

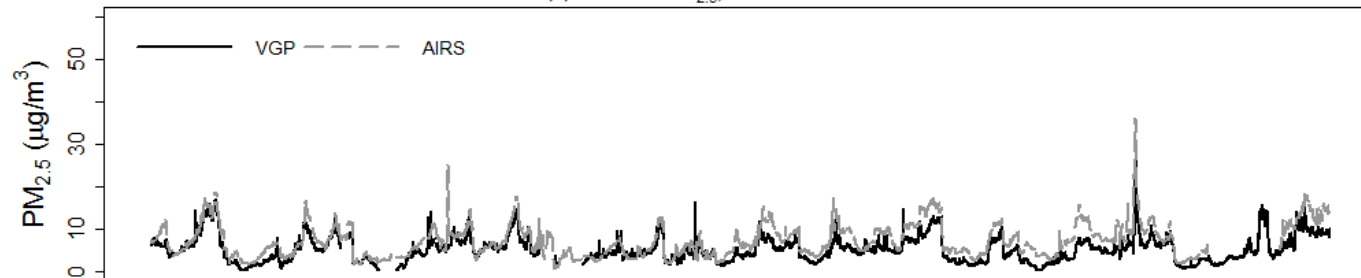
(a) 5-minute O_3 , VGP versus AIRS site



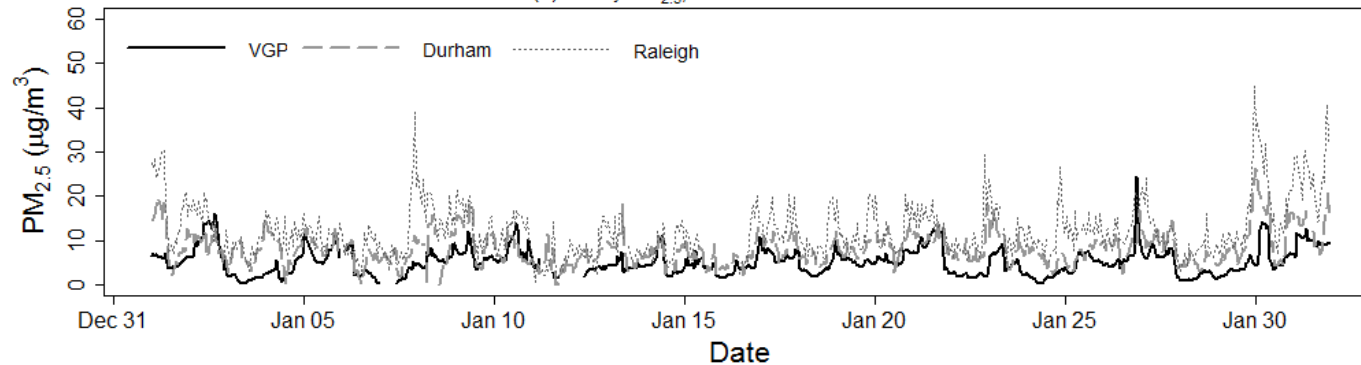
(b) Hourly O_3 , VGP versus NC DENR site



(c) 5-minute $PM_{2.5}$, VGP versus AIRS site

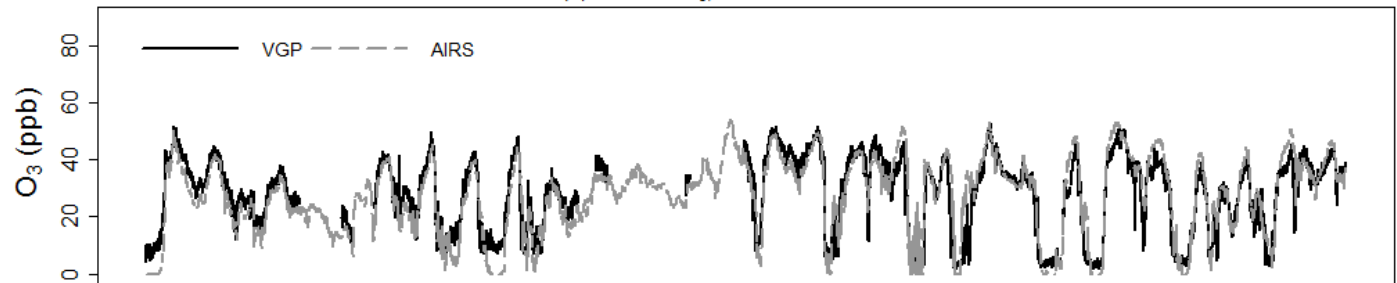


(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

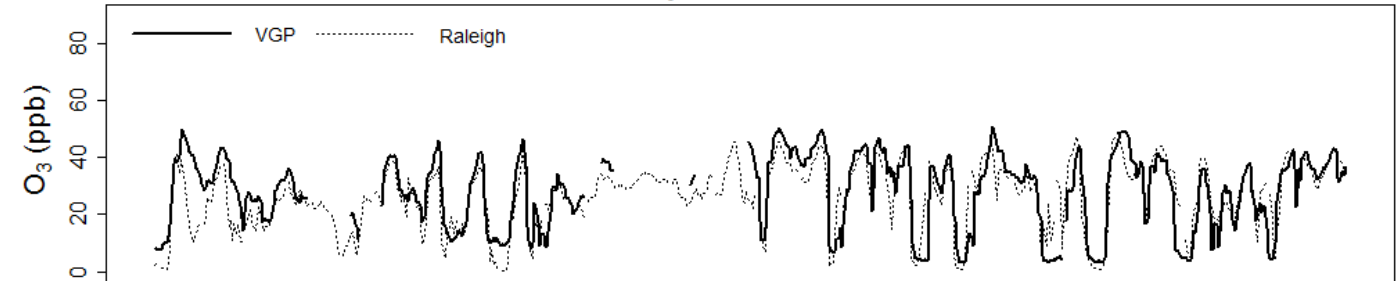


Feb, 2014

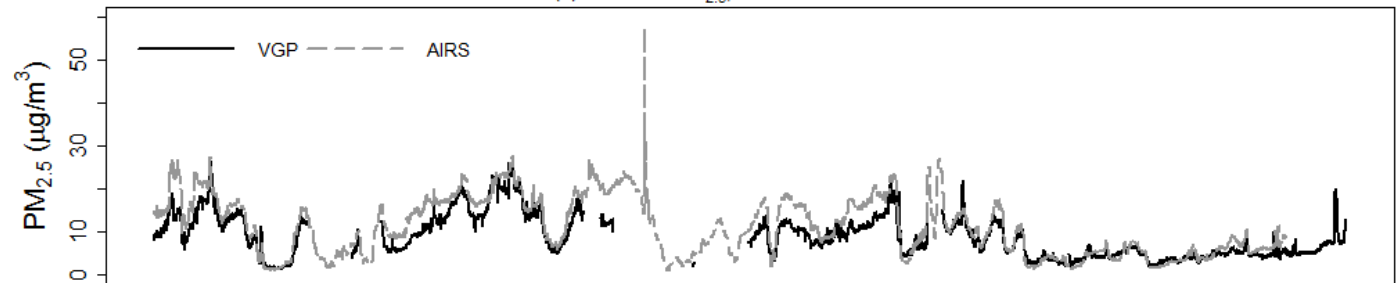
(a) 5-minute O_3 , VGP versus AIRS site



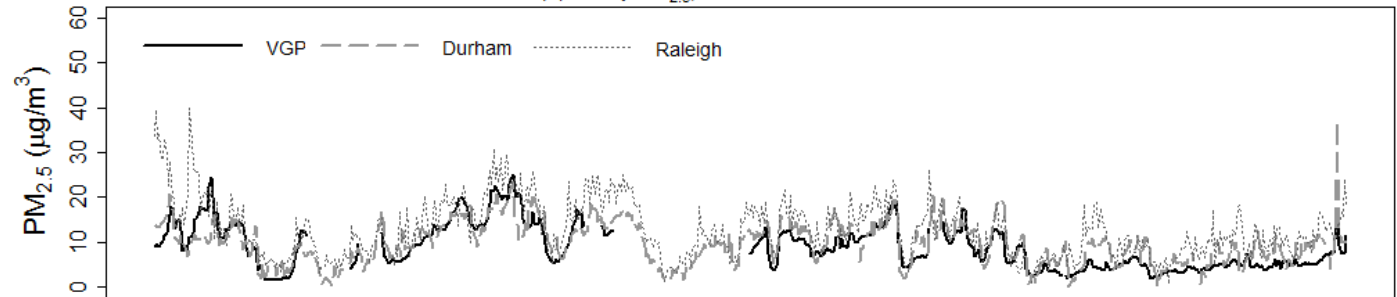
(b) Hourly O_3 , VGP versus NC DENR site



(c) 5-minute $PM_{2.5}$, VGP versus AIRS site



(d) Hourly $PM_{2.5}$, VGP versus NC DENR site



Feb 04

Feb 09

Feb 14

Feb 19

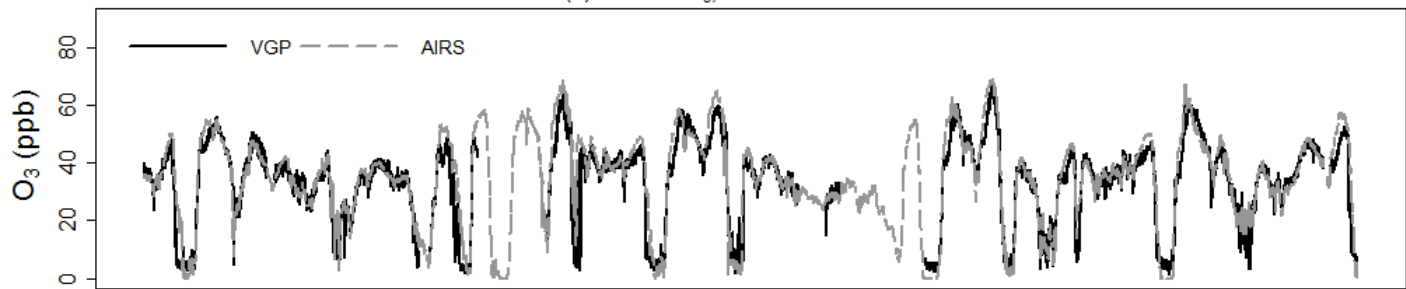
Feb 24

Mar 01

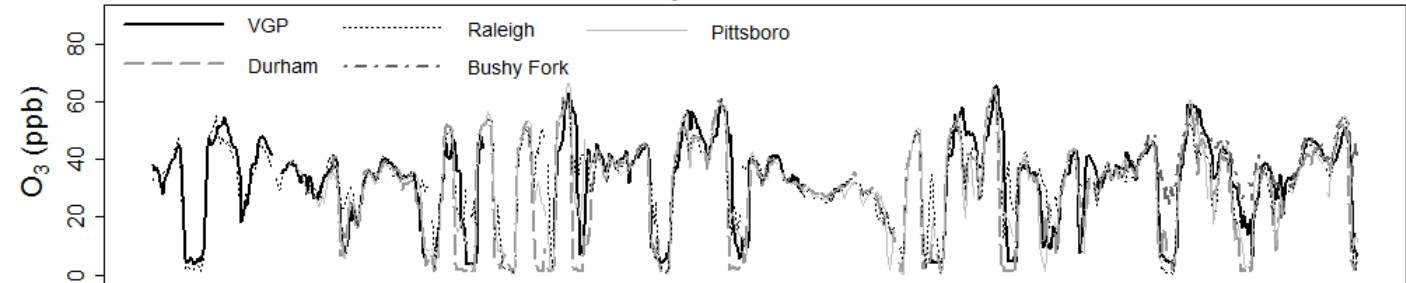
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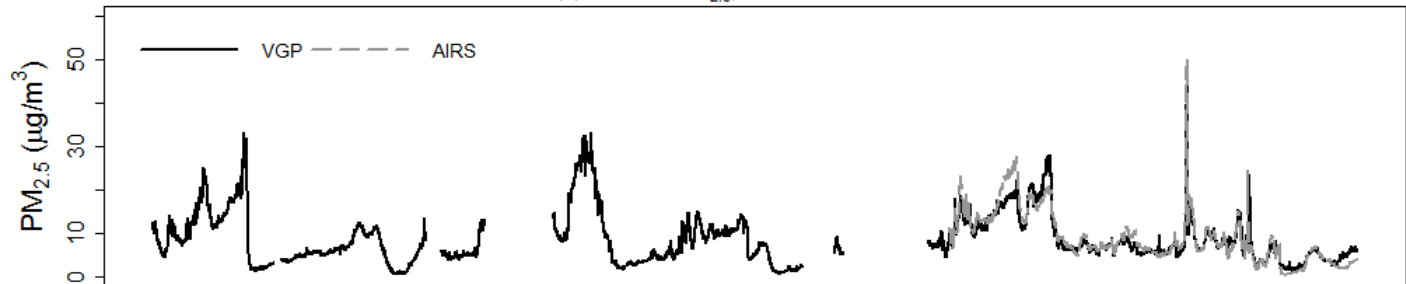
(a) 5-minute O_3 , VGP versus AIRS site



(b) Hourly O_3 , VGP versus NC DENR site



(c) 5-minute $PM_{2.5}$, VGP versus AIRS site



(d) Hourly $PM_{2.5}$, VGP versus NC DENR site

