Duke Wireless Intelligent Sensor Network Workshop
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Rapid evolution of air sensor technologies

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Foreword

- The goal of this presentation is to give information on the following topics:
  - Technical perspective on next-generation air monitoring technologies
  - Potential application of sensors
  - Sensor data communication (and concern)

  This presentation is to the public and would be useful for a technical or non-technical individual wanting to understand the state of science on air sensor technologies.

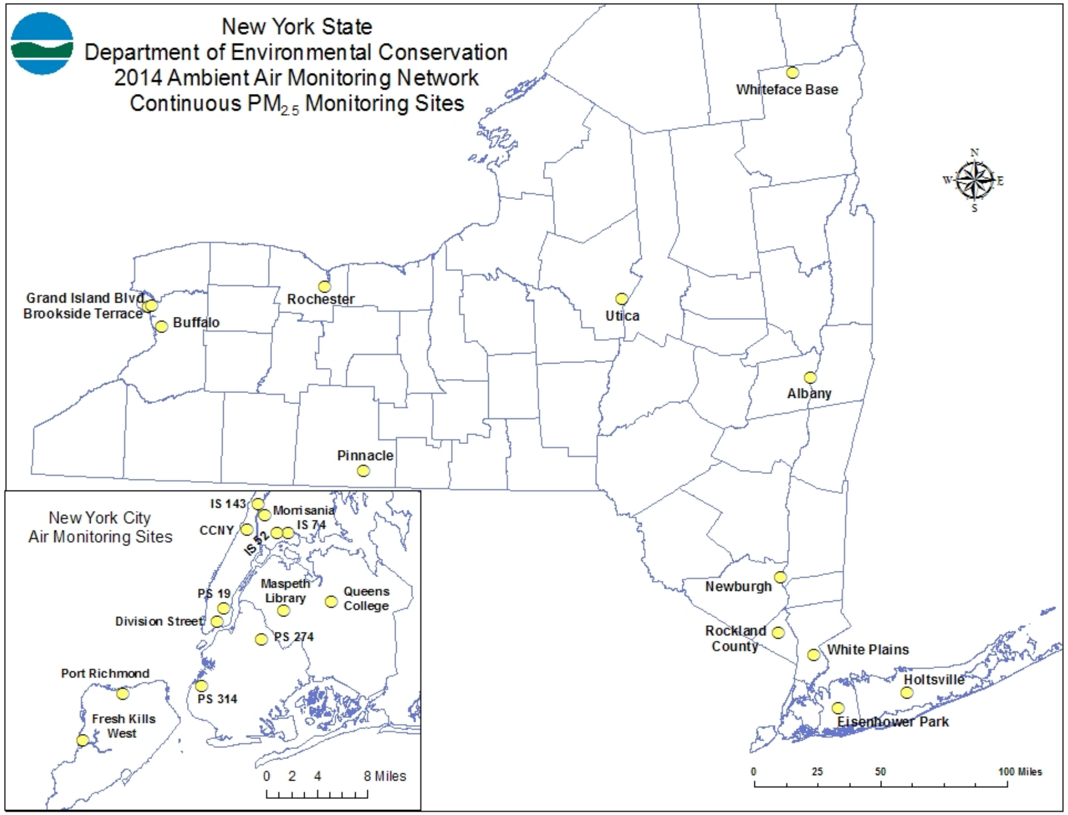
Measuring the air

In the United States, traditional paradigm for air quality monitoring:

Rigorous protocols and methods for regulatory applications

- Expensive instruments (>$10K)
- Specialized training required
- Large physical footprint
- Large power draw

Example: Measuring fine particles in New York



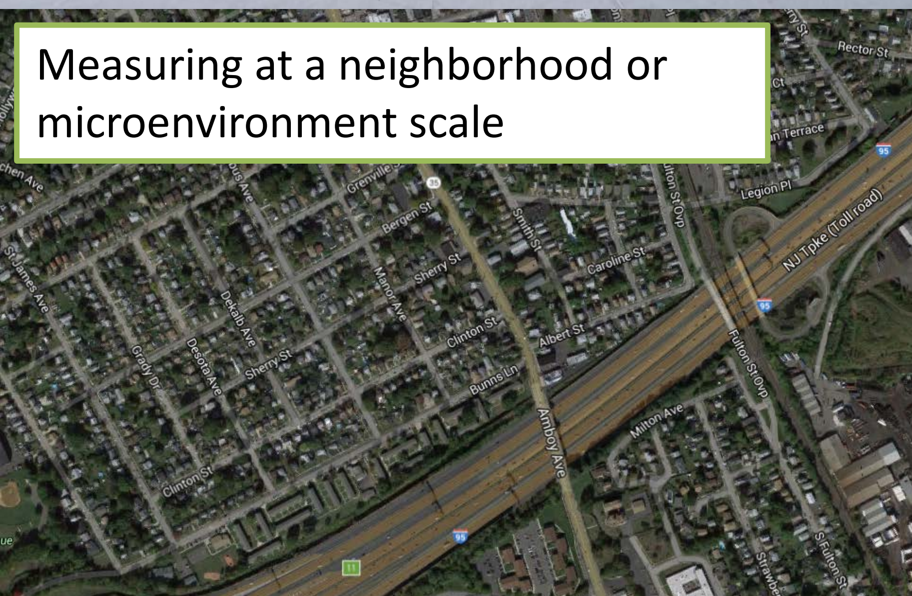
Map from: dec.ny.gov

Challenge areas for the specialists

Measuring in areas with limited infrastructure

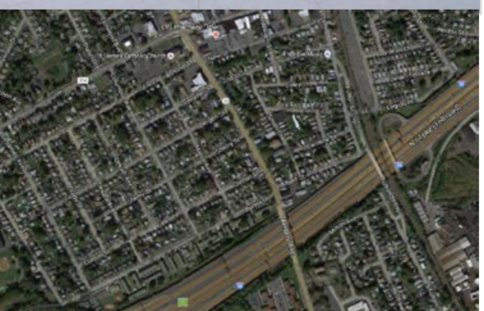
Measuring fugitive emissions over large areas

Measuring at a neighborhood or microenvironment scale



Personal exposure & Indoors

Challenge areas for the specialists

Cross-cutting needs:
- Increased time-resolution
- Miniaturized
- Rugged
- Low power requirements
- Low cost

Unique needs:
- Pollutant types
- Detection ranges
- Data management

Plus, needs of the unknown non-specialist population

<u>Needs (??)</u>:

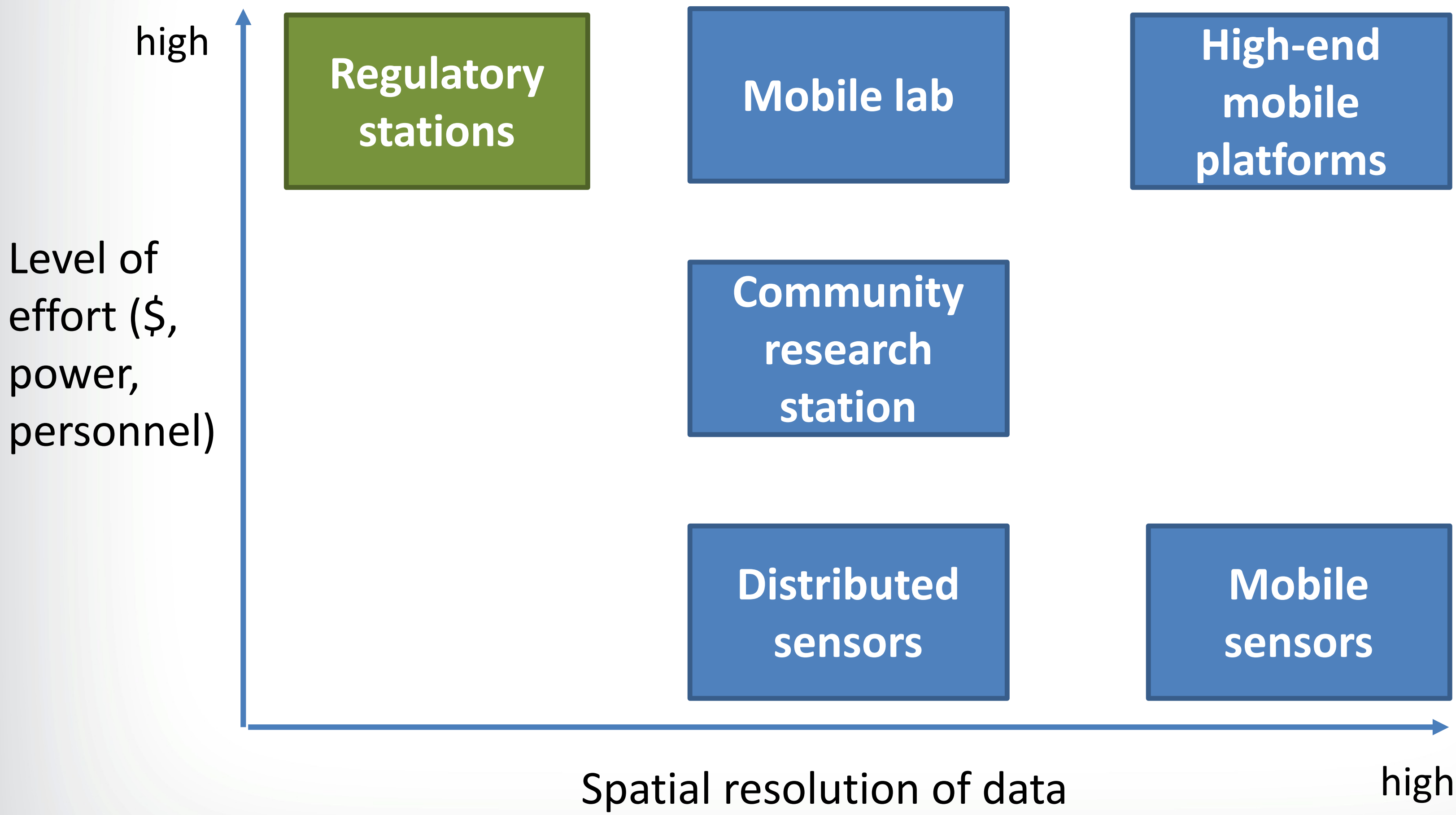
- What we *think* people want to know:
  - What is my exposure to air pollution?
  - What is my child's exposure?
  - What is the air quality like in my neighborhood?
  - What actions should I take to reduce my exposure?
  - How can I demand change?

What do we mean by "next-generation air measurement technologies?"

Generally, traits of:

- Greater spatial coverage (mobile, distributed sensors)
- Greater temporal coverage (real-time measurement)
- Cost-effective

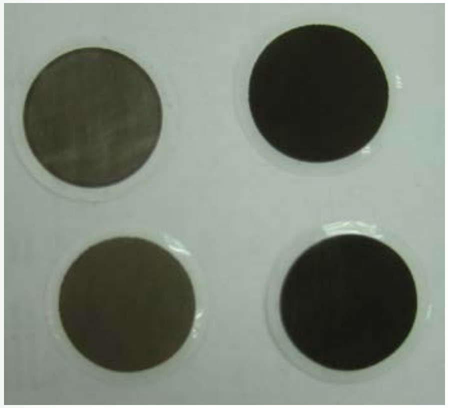
Emerging technologies to measure the air



Particulate matter (PM)

Detecting particles: well-established methods

Particle filter samples



Regulatory

Mass (gravimetric)

Additional useful measurements

Ions

Metals

Organic and elemental (aka “black”) carbon

Trace organics

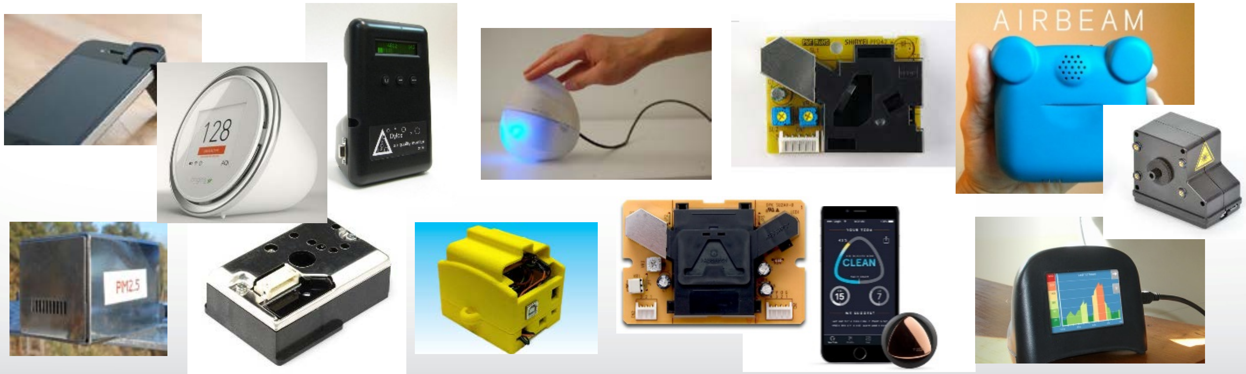
Light absorption (transmissometry)

Real-time or near-real time detection of components – most fairly costly (>>10K), require specialized knowledge

Exception (<10K)

Emerging air sensor technologies

Existing, commercially-available PM methods in the mid- ($2-10K) to low-cost (<$2K), and ultra-low cost (<$500) range

	"Estimated, total PM"	"Particle component" Black carbon
MID-COST	   	
LOW-COST	  	<N/A>
ULTRA LOW-COST		<N/A>

Emerging air sensor technologies

OEM sensors and ancillary equipment for custom devices

Shinyei

Raspberry Pi

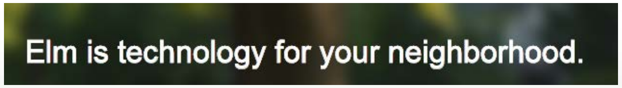
Arduino

Alphasense

Turn-key instruments for field / indoor use

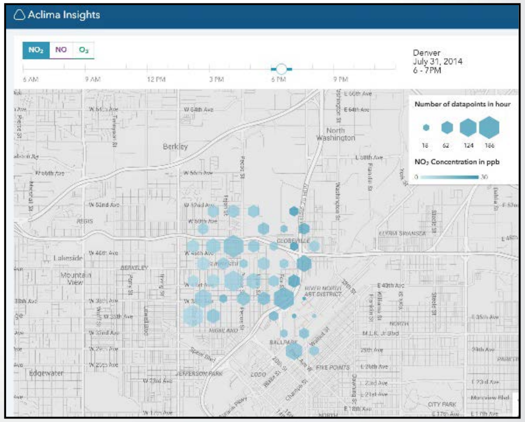
AQMesh

MetOne



Sensor deployment and data services:

Google & Aclima



*OEM: original equipment manufacturer

What is the difference?

What is the difference between regulatory instrument, traditional research instruments, and emerging sensors?

Trait	Federal equivalent method	Mid-tier cost research instrument	Low-cost, emerging air sensor
Cost	~10-20K	~5-10K	~0.02K (or ~$20)
Isolates particles under 2.5 microns?	Yes – cyclone removes PM greater than 2.5	Yes – cyclone removes PM greater than 2.5	**No**
Active air flow?	Yes	Yes	**No**
True mass measurement?	Yes – e.g., beta-attenuation	**No – light-scattering**	**No – light scattering**
On-board humidity artifact correction?	Not needed	Yes	**No**
Data time resolution	**Hourly (or longer)**	Seconds to minutes	Seconds

Getting to "good enough"

A new philosophy on measurement performance

Our established method

My instrument:
Initial calibration
Use
Calibration checks
Analyze data

"…**a separate model was selected for each sensor**….**Fifth order polynomial models** that included relative humidity (RH %) and temperature (C) was found to best convert PUWP signals into $PM_{2.5}$…"

Gao et al., 2015, A distributed network of low-cost continuous reading sensors to measure spatiotemporal variations of $PM_{2.5}$ in Xi'an China. Environmental Pollution

An evolving new strategy for sensors with artifacts/drift

My Sensor:
(More complex) Initial calibration
Use
"Virtual calibration"
Analyze data

"….**we presumed that between 01:00 and 04:00 am** the WDSN nodes…and the AQM station (deployed ~600–800 m away…) **report similar concentrations**. A sensor-specific linear regression was developed…."

Moltchanov et al., 2015, On the feasibility of measuring urban air pollution by wireless distributed sensor networks. Science of the Total Environment.

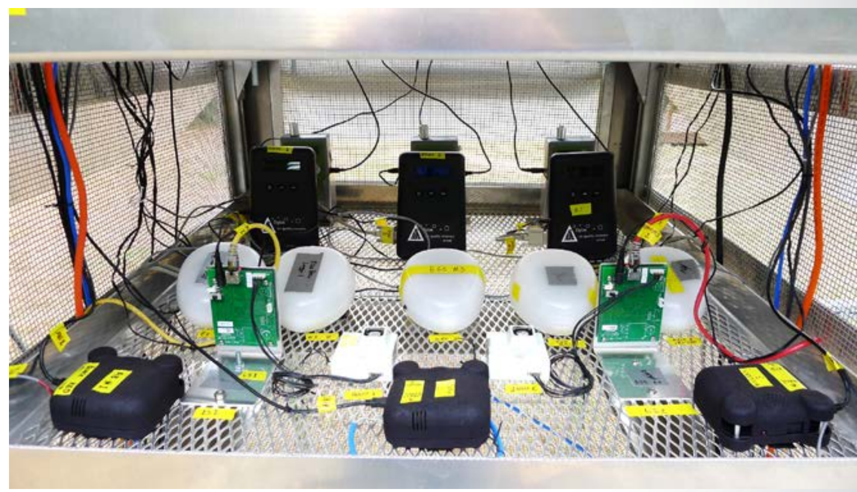
* PUWP: Portable University of Washington Particle monitors; WDSN: Wireless Distributed Sensor Network; AQM: Air Quality Monitoring station

EPA activities

1. Testing air sensor performance in laboratory and field settings

- Atlanta, GA (2014-2015)
- Denver, CO (2015-2016)
- Research Triangle Park, NC (2014 – 2016)

- Emphasis on turn-key devices that are commercially available, measure regulated air pollutants (e.g., ozone, particulate matter), and <2K



- Sensor performance has varied widely – from very strong (r>0.9) to very poor performance (r=0)

EPA activities

2. Exploratory research studies

- High-concentration environments near sources
  - Example: balloon-lofted sensors within wildfire emissions plume
  - Example: drop-in-place solar-powered volatile organic compounds (VOC) sensor near a source fenceline

- Urban-ambient environments
  - Development of single- or multi-pollutant systems supporting citizen science
  - Development of long-term, resilient community monitoring systems

Example project: CAIRSENSE

Project / Year	Regional Partner(s)	Measurements	Location
CAIRSENSE (FY15)	Region 1 Region 4 Region 5 Region 7 Region 8	PM, ozone, nitrogen dioxide – four sensor nodes	Atlanta, GA

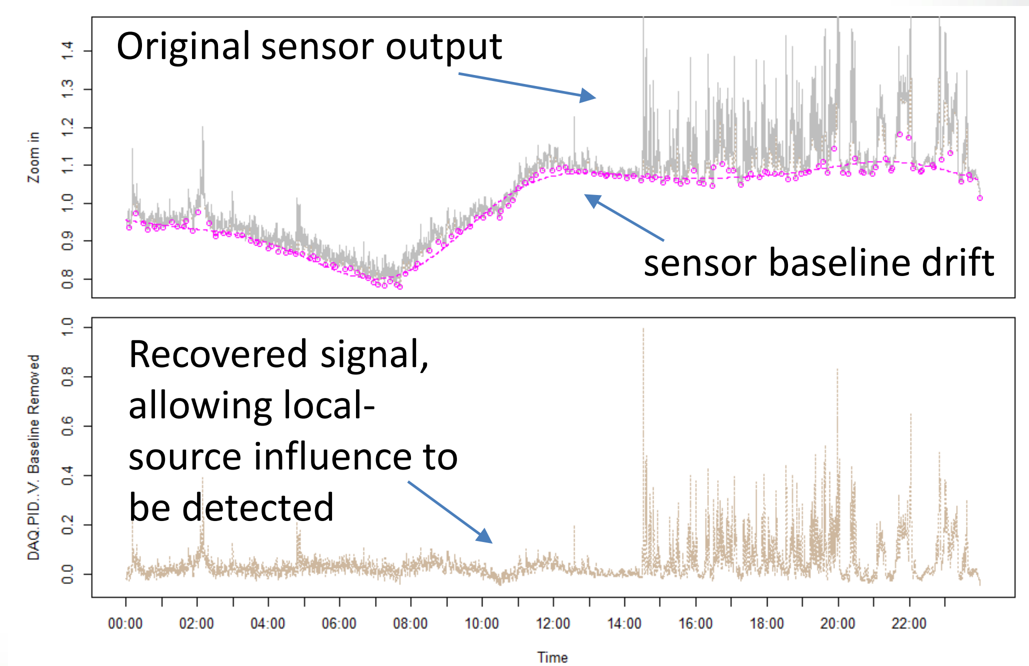
Goal: Test feasibility of using low-cost sensor network in suburban setting

- Solar-powered
- Daisy-chained data communication via ZigBee communication
- PM sensor: Shinyei PM sensor
- NO_2 sensor: Cairclip NO_2/O_3 sensor
- O_3 sensor: Aeroqual SM50

Point of contact: Ron Williams, Gayle Hagler

Example projects: SPOD

Project / Year	Regional Partner(s)	Measurements	Location
SPOD (FY15)	Region 3	Total VOCs	Philadelphia, PA



Point of contact: Eben Thoma

Example projects: CSAM

Project / Year	Regional Partner(s)	Measurements	Location
CSAM (FY15)	Region 2	PM, NO_2, temperature, humidity – portable stations	Ironbound community, NJ

Goal: Support community group in using low-cost sensors to explore their air quality

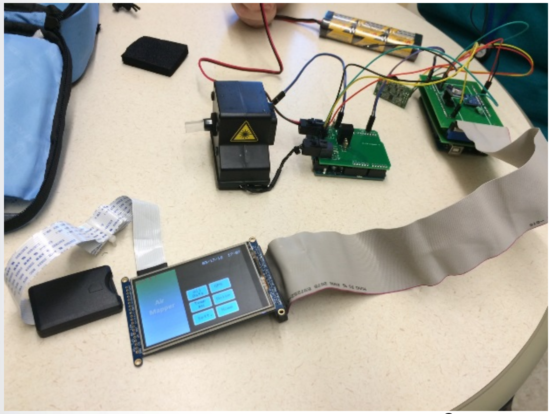
- Designed for temporary use by citizens in multiple locations (on tripod)
- Battery-powered
- Local data storage
- PM sensor: personal DataRAM nephelometer
- NO_2 sensor: Cairclip NO_2
- Citizens operated sophisticated ease of use sensors for 5 months

Point of contact: Ron Williams

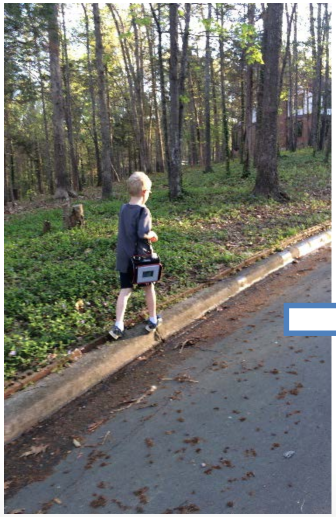
Example project: AirMapper

Project / Year	Regional Partner(s)	Measurements	Location
AirMapper (FY16)	*Region 5 Region 10*	*PM, noise, temperature, humidity*	*Chicago, IL Portland, OR*

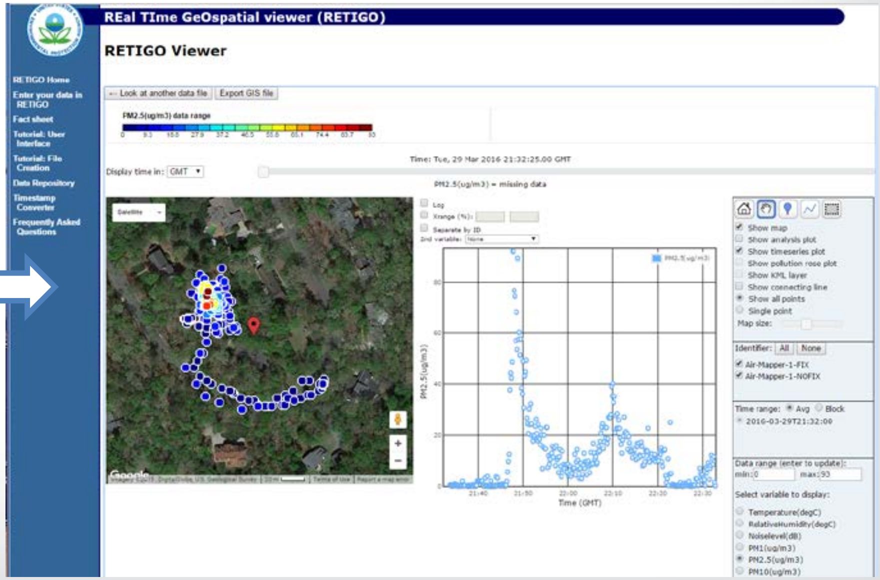
Goal: Develop portable monitoring system to measure geospatial patterns of PM, that is user-friendly for students and adults.



- Measurements at rate of 1-10 s
- Target parameters: PM, noise, temperature, humidity, location



RETIGO data viewer: www.epa.gov/retigo



Point of contact: Gayle Hagler, Sue Kimbrough

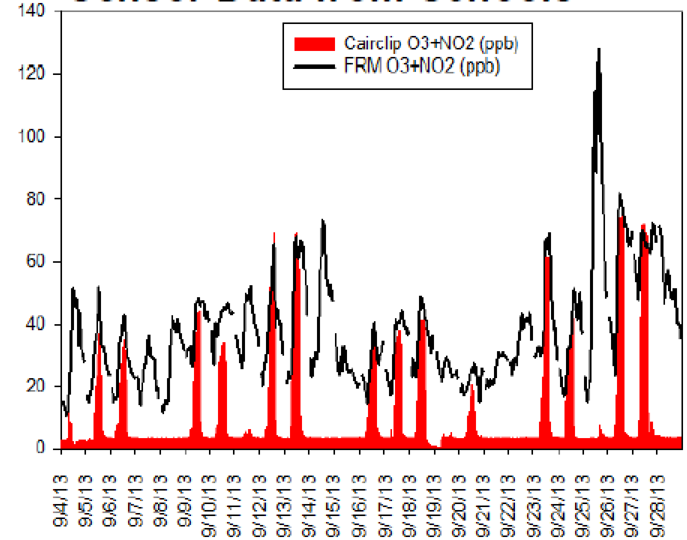
Example project: DISCOVER-AQ

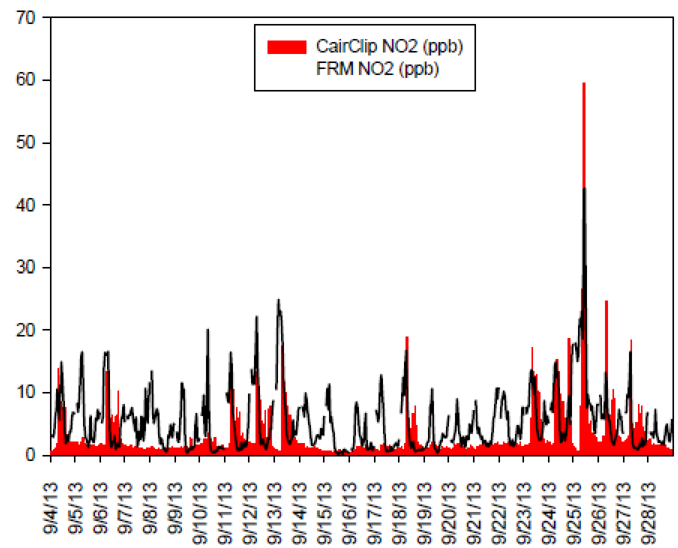
DISCOVER-AQ Study Houston, TX (Sept. 2013)

- Citizen science: small NO_2/O_3 and NO_2 sensors deployed at 7 schools
- Sensor data compared to reference analyzer data
- Low-cost sensors performed well

CairClip Sensor

Sensor Data from Schools

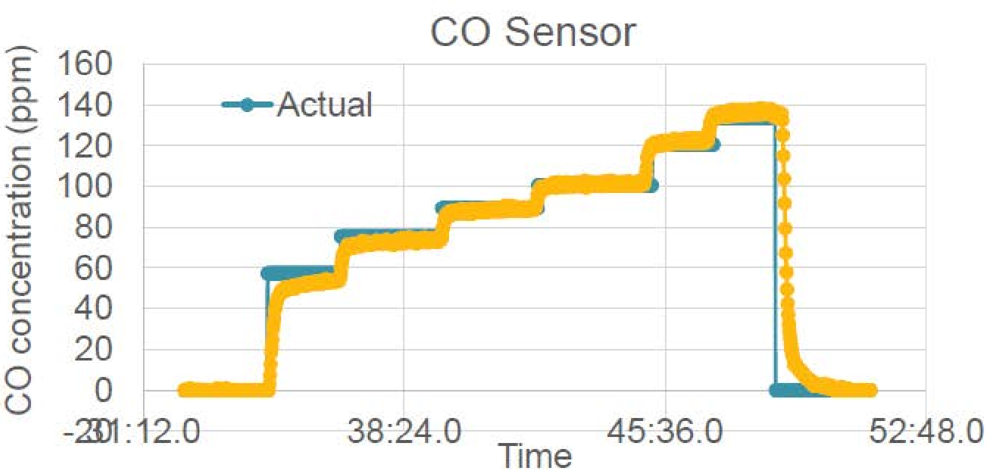




Point of Contact: Russell Long, Rachelle Duvall

Example project: AEROSTAT

Air sensor system development to characterize emission plumes



Very small sensors undergoing laboratory testing in advance of field tests of source emissions

Point of contact: Brian Gullett

Sensor applications

- Very high bar to reach for regulatory application
  - Must be officially certified as a method, siting criteria applied, etc.
  - e.g., a federal-equivalent monitor for ozone is used on the Village Project System, *however,* not operated according to regulations (siting criteria, QA, temperature range)

- However, other important applications are envisioned:
  - Research studies
  - Screening – siting a monitoring station
  - Community monitoring
  - Individual monitoring
  - Educational purposes

- A major concern for EPA – public data communication practices

Where is this going?

(communitysensing.org)

<u>Changing the paradigm: from sensors to satellites</u>:

- Data of mixed quality, temporal/spatial coverage: sensors, regulatory monitors, wearables
- Satellite remote sensing
- Model – data fusion

<u>Opportunities:</u>

- Unprecedented data on air quality
- New participants in air monitoirng

<u>Challenges:</u>

- Data quality
- Data interpretation and public messaging
- “Big data” analysis
- Support for do-it-yourself/citizen science

Thank you for your attention!

Any questions?

Keep in touch! We are just down the road and always interested in exploring research collaborations.