Real Time Monitoring

Things to Know Before You Take the Plunge

Ron Williams

EPA Office of Research and Development

Environmental Protection Agency, Research Triangle Park, NC

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Key Take Home Training Topics

- Features of continuous monitoring study designs
- An examination of use of continuous monitors and their application
- Examples of continuous monitors, especially low cost sensors
- Data quality features one must consider
- Critical findings in low cost sensors with respect to their ongoing laboratory and/or field evaluations
- Sharing of resources available to you as you work through your own decision making

Your Instructor-Ron Williams

- 35 year veteran of academic, private institution, and government-based environmental or associated research programs
- Currently, the Program Lead for EPA-ORD's Air, Climate, and Energy Emerging Technology research area
- Has designed and executed studies involving the collection in excess of 10K participant days of environmental measures involving both continuous and time integrated monitoring (personal, indoor, outdoor, ambient)

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Disclaimer

- Mention of trade names or commercial products does not constitute endorsement or recommendation for use and are provided here solely for informational purposes as to some of the market survey information being gathered

Be Careful of What You Ask For….

Anyone who has ever conducted extensive continuous monitoring and then had to deal with making sense out of it

Value of Continuous Measures

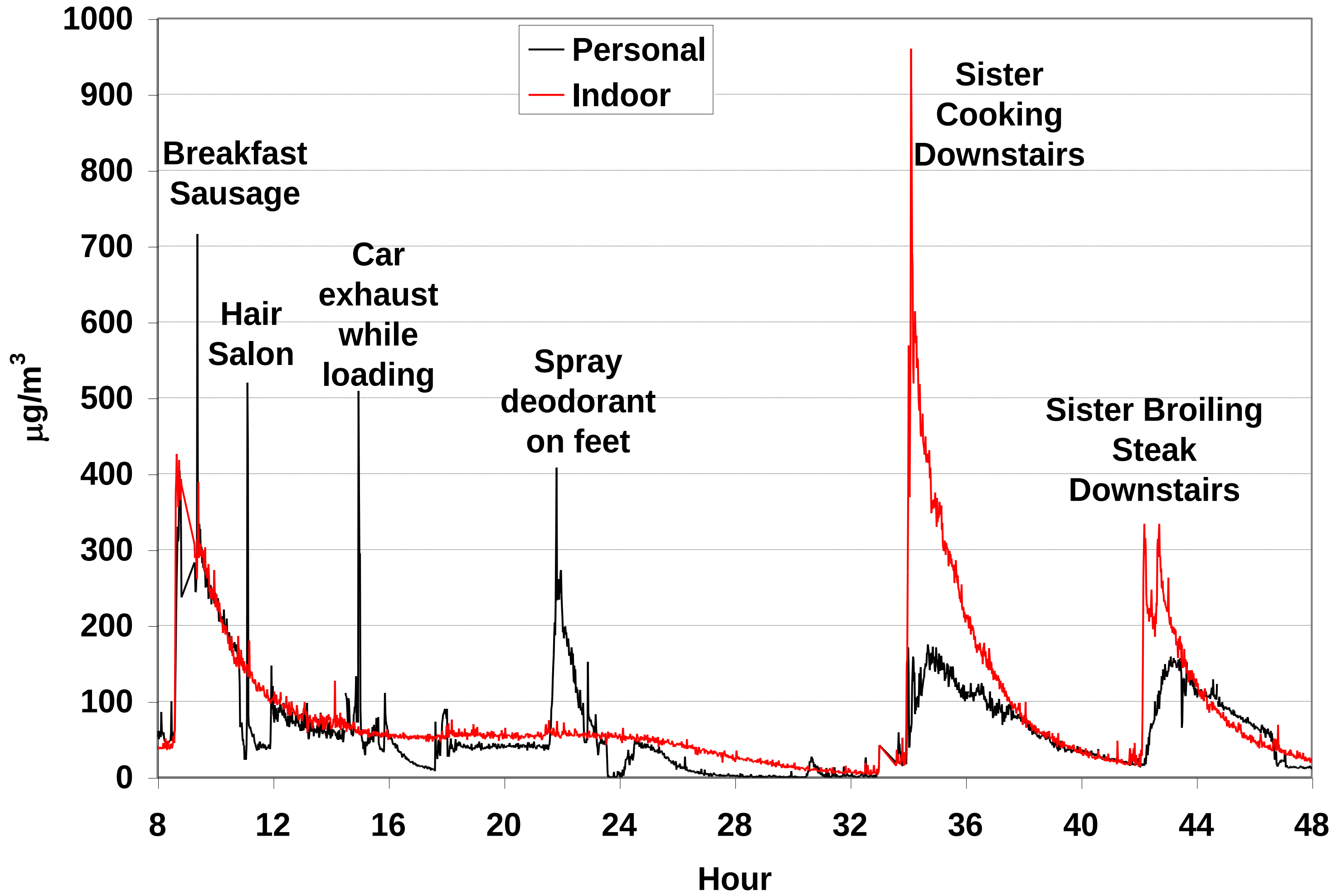
- Provides greater understanding of temporal changes of environmental conditions
- Has potential of establishing variability due to spatiality
- Depending on the frequency of data collection, has the potential of providing discreet linkages to environmental events and human activity factors impacting exposure potential
- Has the potential of defining critical episodic events that would otherwise not be discerned when using a time integrated data collection method

Features of Continuous Monitoring

Features of Continuous Monitoring

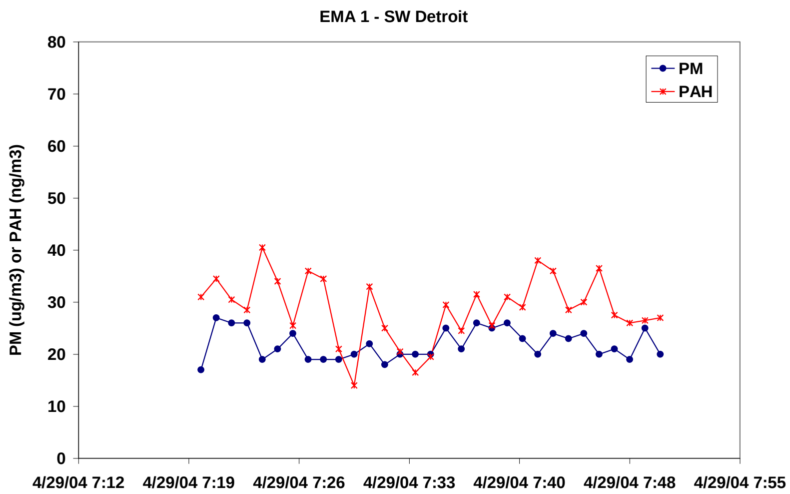
- Provides for high definition of temporal resolution
- Provides means for discerning primary exposure events
- Provides means for critically examining data quality rather than just an average point
- Applicable to any measure of interest (air quality, time activity, location, event) if a suitable method is available

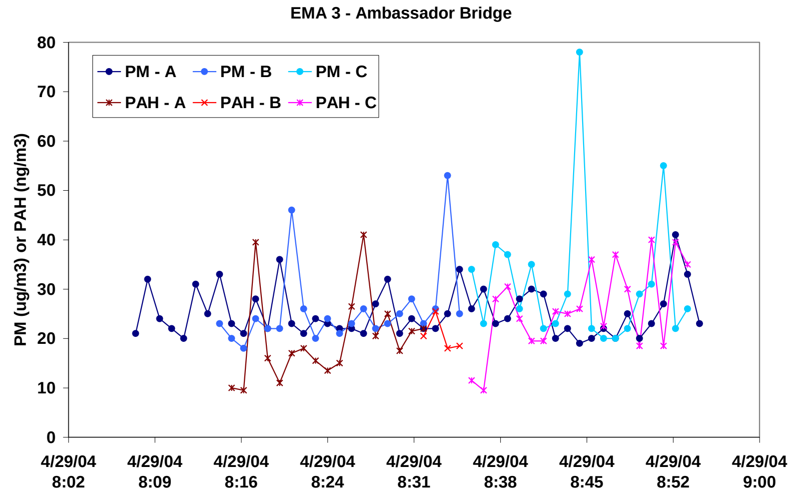
Continuous $PM_{2.5}$ Monitoring

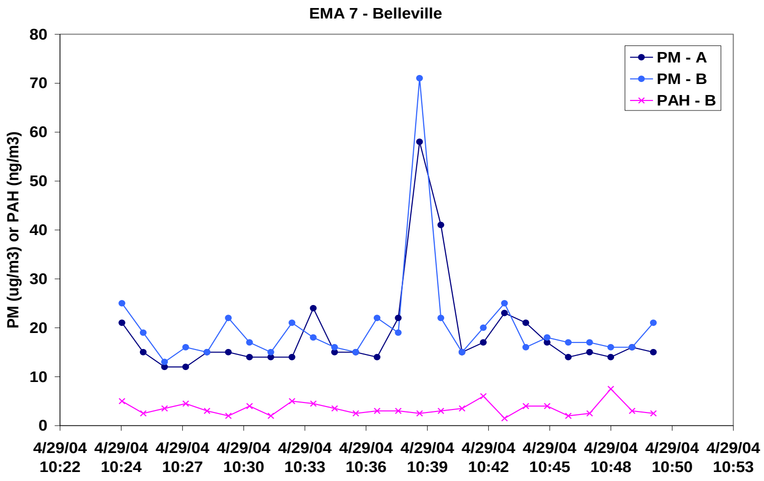


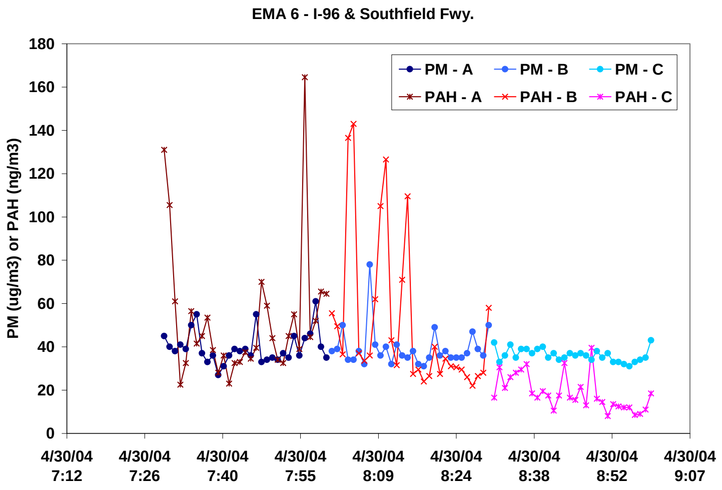
Indoor versus Personal $PM_{2.5}$ Concentrations

Changing Ambient Conditions and Site Comparisons

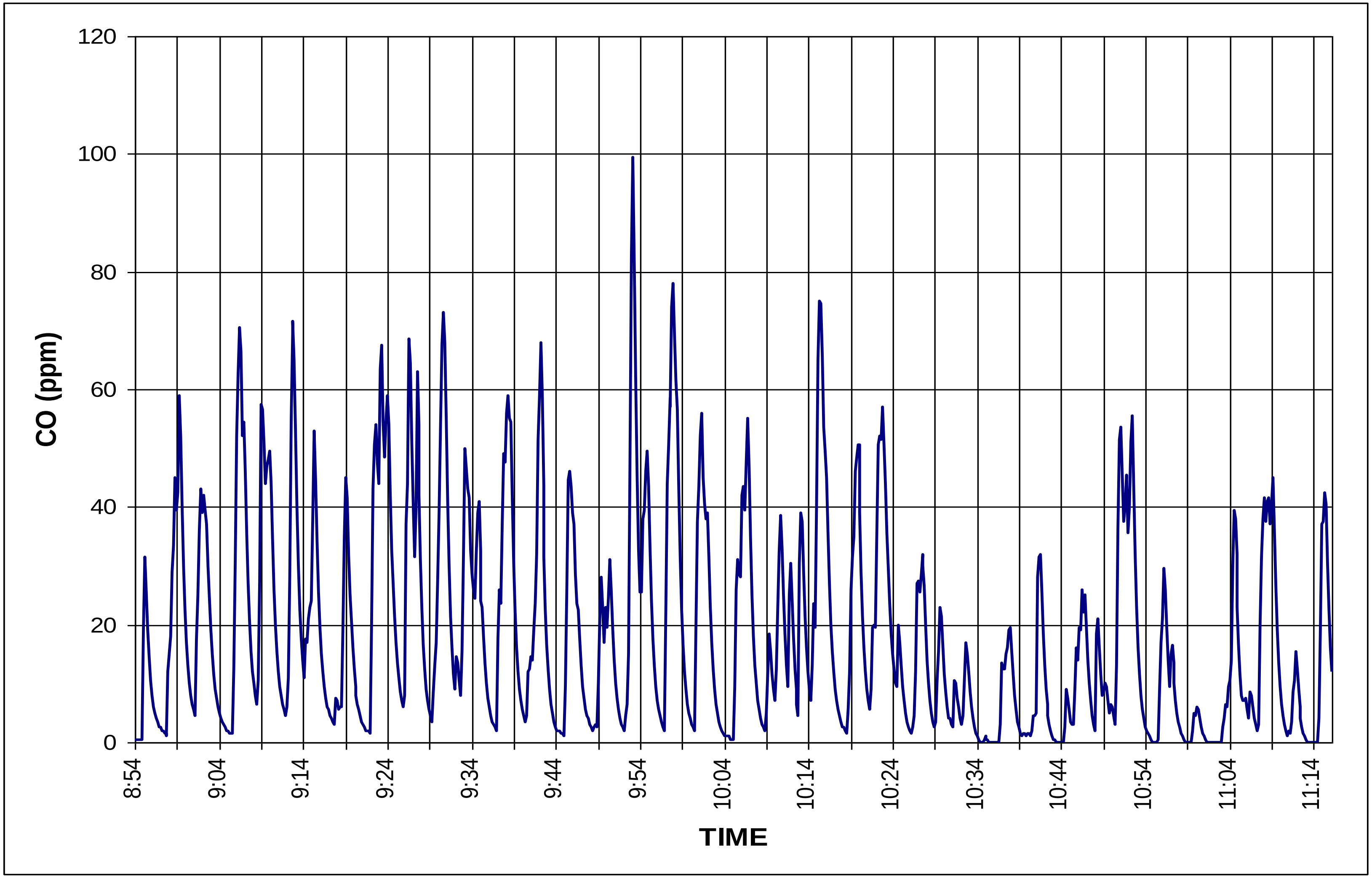




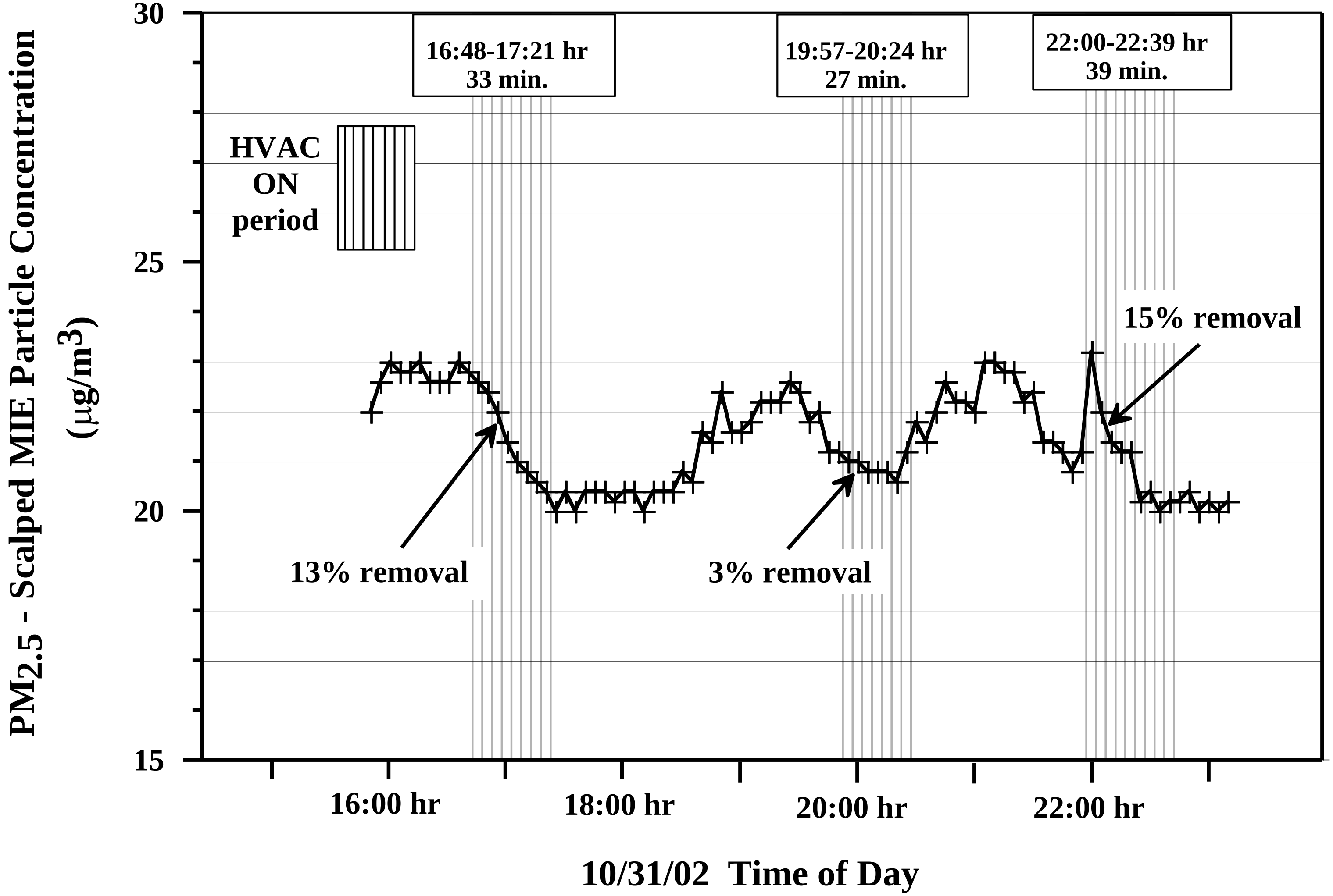




Personal CO Exposure and Small Engine Operation

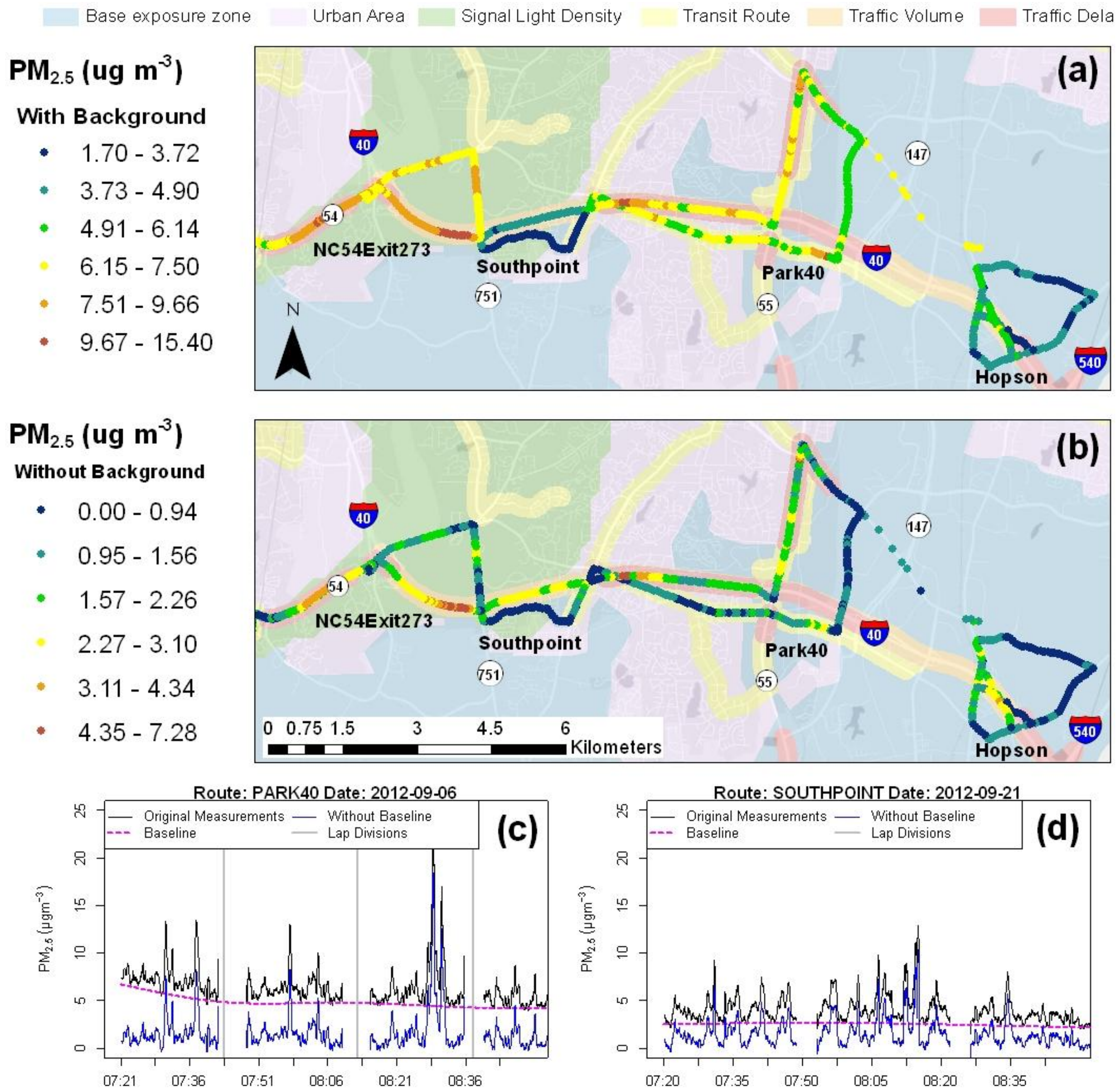


Environmental Exposure Factor Monitoring- HVAC Operation



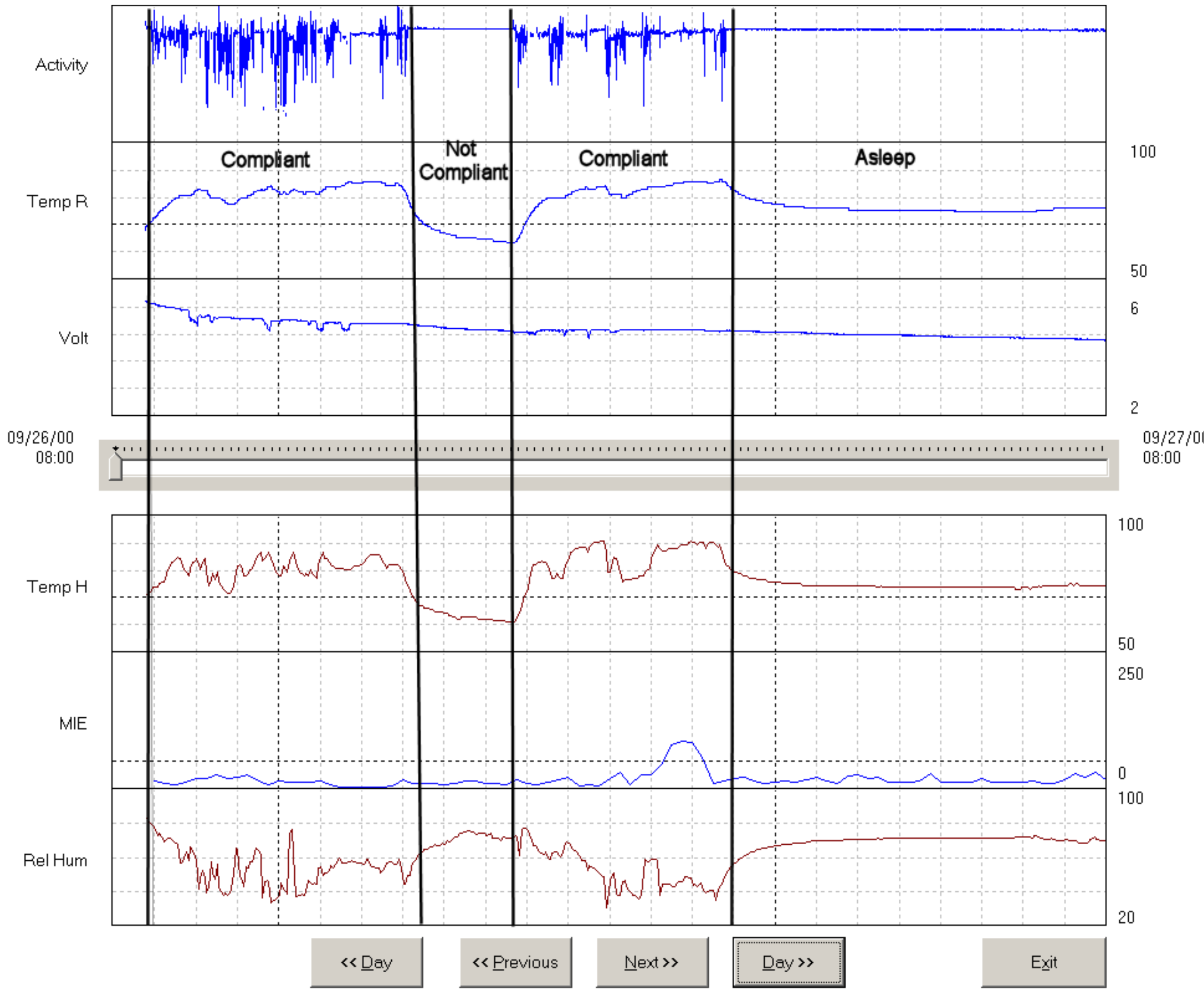
Thornburg et al., Atmos Environ, 38 (2004)

Continuous Mobile Monitoring- Spatial and Temporal Change Combined



Brantley et al., AMT 2104 (in press)

Human Activity Monitoring



Lawless et al., JESEE, 22: 2012

Key Negative Considerations

- The amount of data being produced can become staggering. As an example:
  - A single monitor operating 24 hrs/day @ 1 second time resolution for 1 week would produce >600K one second data points!
- Need for more sophisticated data recovery and manipulation software. Excel normally does not meet this need. Math Lab, R., SAS, S-Plus, Python, etc often required to reduce labor intensity and make sense of the data
- Monitors are not without bias and noise. Some pre-determined plan should exist for reducing this effect (either during or following data collections). The basic bias and noise features of the monitor must be known before sampling is initiated

Examination of Continuous Monitoring Applications

A Typical Regulatory Monitor

- Produces data of known value and highly reliable
- Stationary- cannot be easily relocated
- Instruments are often large and require a building to support their operation
- Expensive to purchase and operate (typically > $20K each)
- Requires frequent visits by highly trained staff to check on their operation
- Often operate for 10+ years before needing to be replaced

A Typical Low Cost Monitor

- Inexpensive ($100 to $5000) to purchase
- Highly portable and easy to operate (often mobile)
- Requires little or no training to start collecting data
- Inexpensive to operate (replace or recharge batteries)
- Lifetime of service not expected to exceed 1-2 years

High interest by public for more information

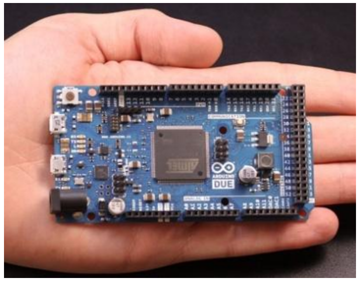
Public demand for more personalized information – what about *my* exposure, *my* neighborhood, my family

What are some of these new technologies?

Smartphone / Tablet in widespread use

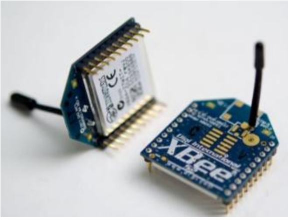
e.g., fitbit activity tracker

Miniaturized environmental sensors



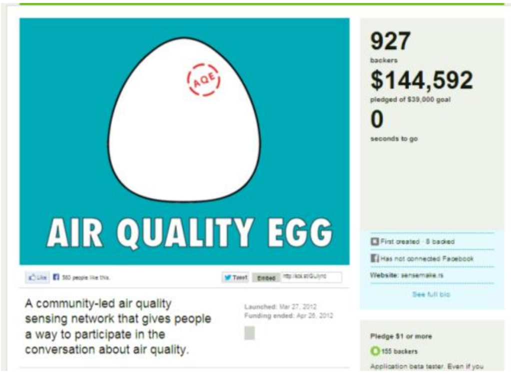
Introduction of low cost controls and communications

e.g., Arduino microprocessor



Crowd-funding supporting do-it-yourself (DIY) innovation

e.g., Kickstarter



Web-based portals are being developed

Emerging data-viewing/communication apps

airalliancehouston.org

londonair.org.uk/
iphone

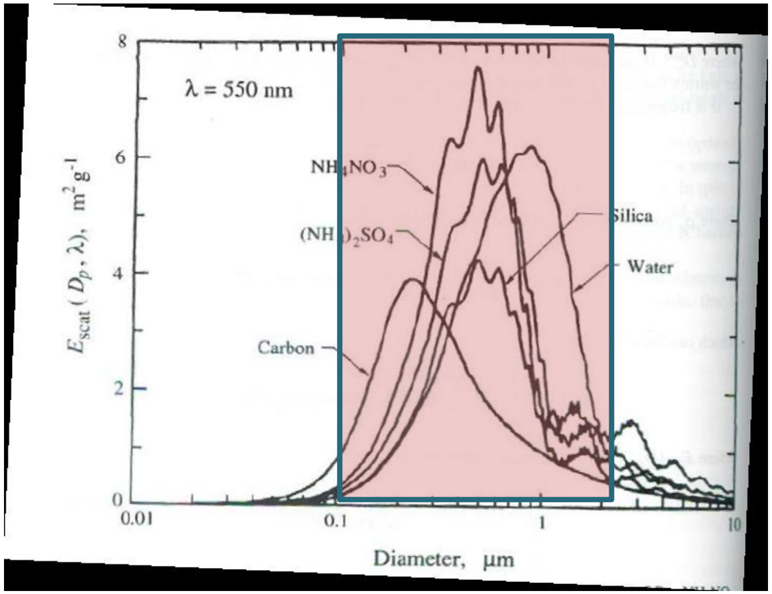
airqualityegg.com

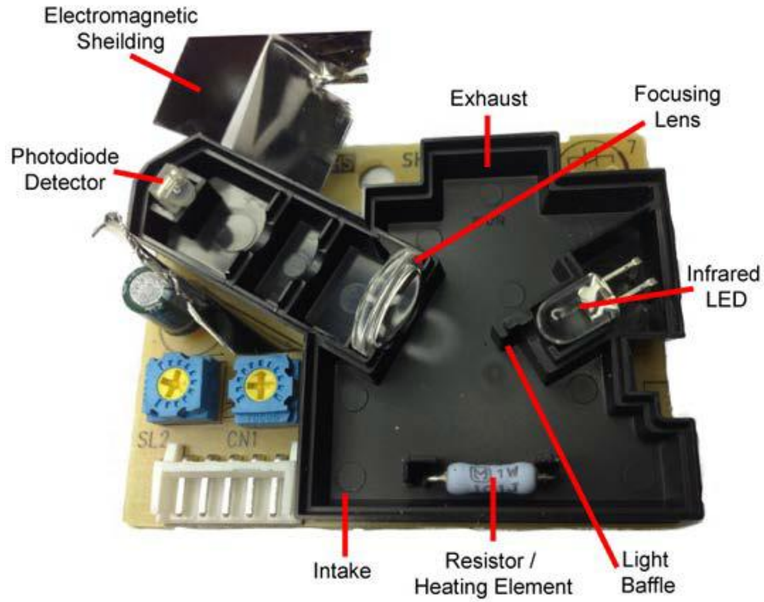
AirCasting App

aircasting.org

AirCasting Air Monitor

A Typical Light Scattering Device





At 550 nm light, strongest scattering signal for Dp~0.1-2 μm

http://www.takingspace.org/make-your-own-aircasting-particle-monitor/

Metal Oxide (MOS) and Electrochemical Sensors

- The most widely available of all sensor types
- Inexpensive ($15-$300)
- Available in a wide array of pollutants
- Often not specific to any one pollutant
- Co-factors often influence their output
- Response relational to some given parameter

Photo credit:http://www.alpha-sense.com/

Descriptions of potential uses for low cost air sensors.

Application	Description	Example
Research	Scientific studies aimed at discovering new information about air pollution.	A network of air sensors is used to measure particulate matter variation across a city.
Personal Exposure Monitoring	Monitoring the air quality that a single individual is exposed to while doing normal activities.	An individual having a clinical condition increasing sensitivity to air pollution wears a sensor to identify when and where he or she is exposed to pollutants potentially impacting their health.
Supplementing Existing Monitoring Data	Placing sensors within an existing state/local regulatory monitoring area to fill in coverage.	A sensor is placed in an area between regulatory monitors to better characterize the concentration gradient between the different locations.
Source Identification and Characterization	Establishing possible emission sources by monitoring near the suspected source.	A sensor is placed downwind of an industrial facility to monitor variations in air pollutant concentrations over time.
Education	Using sensors in educational settings for science, technology, engineering, and math lessons.	Sensors are provided to students to monitor and understand air quality issues.
Information/Awareness	Using sensors for informal air quality awareness.	A sensor is used to compare air quality at people's home or work, in their car, or at their child's school.

Typical Pollutants of Interest

Air Pollutant of Interest	Type	Source Example	Useful Detection Limits	Range to Expect	Level
Ozone (O_3)	Secondary	Formed via UV (sunlight) and pressure of other key pollutants	10 ppb	0-150 ppb	75 ppb (8 hr)
Carbon monoxide (CO)	Primary	Fuel combustion – mobile sources, industrial processes	0.1 ppm	0-0.3 ppm	9 ppm (8 hr) 35 ppm (1 hr)
Sulfur dioxide (SO_2)	Primary	Fuel combustion – electric utilities, industrial processes	10 ppb	0-100 ppb	75 ppb (1 hr) 0.5 ppm (3 hr)
Nitrogen dioxide (NO_2)	Primary and Secondary	Fuel combustion – mobile sources, electric utilities, off-road equipment	10 ppb	0-50 ppb	100 ppb (1 hr) 53 ppb (1 yr)
Carbon dioxide (CO_2)	Primary	Fuel combustion – electric utilities, mobile sources	100 ppm	350-600 ppm	None
Volatile organic compounds (VOCs)	Primary and Secondary	Fuel combustion (mobile sources, industries) gasoline evaporation; solvents	1 µg/m^3	5-100 µg/m^3 (total VOCs)	None
Benzene (an example of a VOC and air toxic)	Primary	Gasoline, evaporative losses from above ground storage tanks	0.01 – 10 µg/m^3	0-3 µg/m^3	None
Fine particulate matter ($PM_{2.5}$)	Primary and Secondary	Fuel combustion (mobile sources, electric utilities, industrial processes), dust, agriculture, fires	5 µg/m^3 (24-hr)	0-40 µg/m^3 (24-hr)	35 µg/m^3 (24 hr) 12 µg/m^3 (1 yr)
Particulate matter (PM_{10})	Primary and Secondary	Dust, fuel combustion (mobile sources, industrial processes), agriculture, fires	10 µg/m^3 (24-hr)	0-100 µg/m^3 (24-hr)	150 µg/m^3 (24 hr)
Black carbon (BC)	Primary	Biomass burning, diesel engines	0.05 µg/m^3	0-15 µg/m^3	None

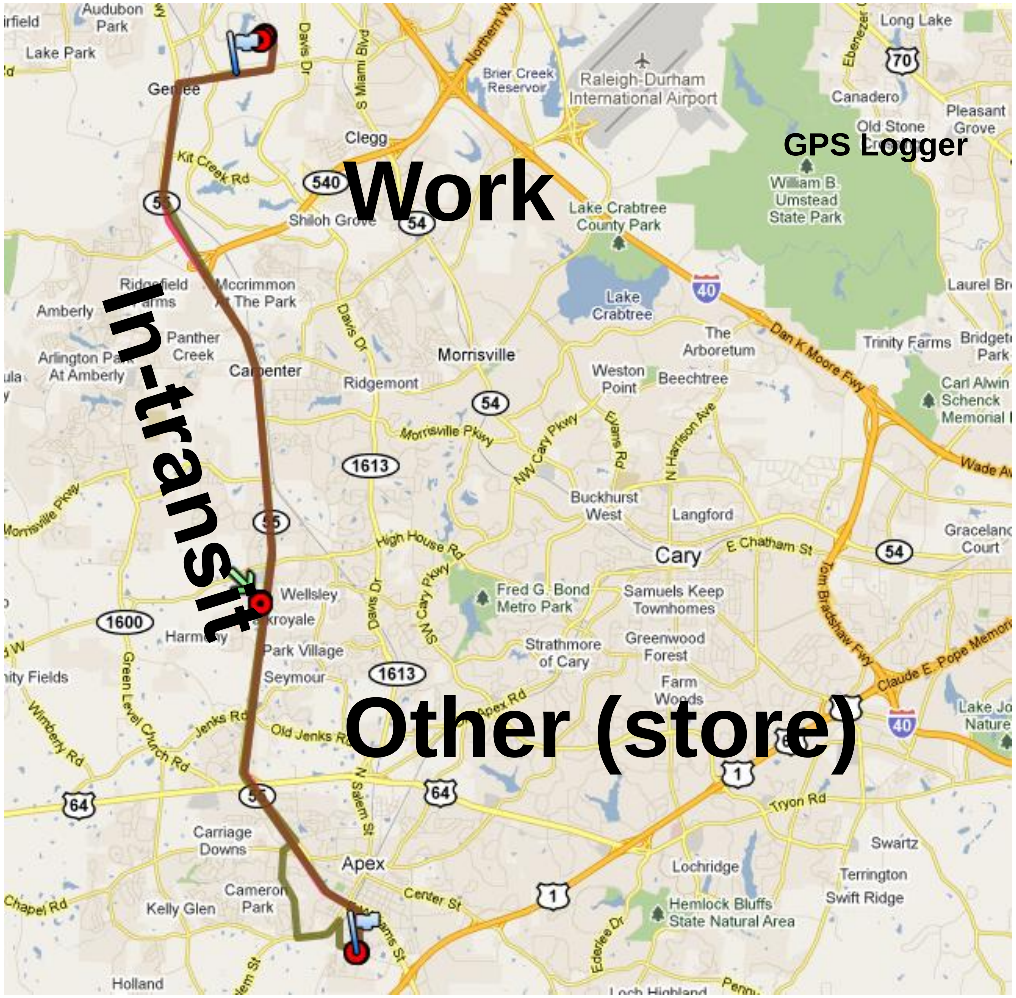
EPA/600/R-14/159 (June 2014)

Possible Sensor Tiers

Tier	Application Area	Pollutants	Precision and Bias Error	Data Completeness*	Rationale (Tier I-IV)
I	Education and Information	All	<50%	≥ 50%	Measurement error is not as important as simply demonstrating that the pollutant exists in some wide range of concentration.
II	Hotspot Identification and Characterization	All	<30%	≥ 75%	Higher data quality is needed here to ensure that not only does the pollutant of interest exist in the local atmosphere, but also at a concentration that is close to its true value.
III	Supplemental Monitoring	Criteria pollutants, Air Toxics (incl. VOCs)	<20%	≥ 80%	Supplemental monitoring might have value in potentially providing additional air quality data to complement existing monitors. To be useful in providing such complementary data, it must be of sufficient quality to ensure that the additional information is helping to “fill in” monitoring gaps rather than making the situation less understood.
IV	Personal Exposure	All	<30%	≥ 80%	Many factors can influence personal exposures to air pollutants. Precision and bias errors suggested here are representative of those reported in the scientific literature under a variety of circumstances. Error rates higher than these make it difficult to understand how, when, and why personal exposures have occurred.

EPA/600/R-14/159 (June 2014)

MicroTrac Pilot Study



Home

- **Collected GPS data for 24 hr workday (5 sec sampling time)**
- **Created diaries by marking “waypoints” with GPS loggers when changing microenvironments**
- **Evaluated MicroTrac estimates with diaries**

Kindly provided by M. Breen

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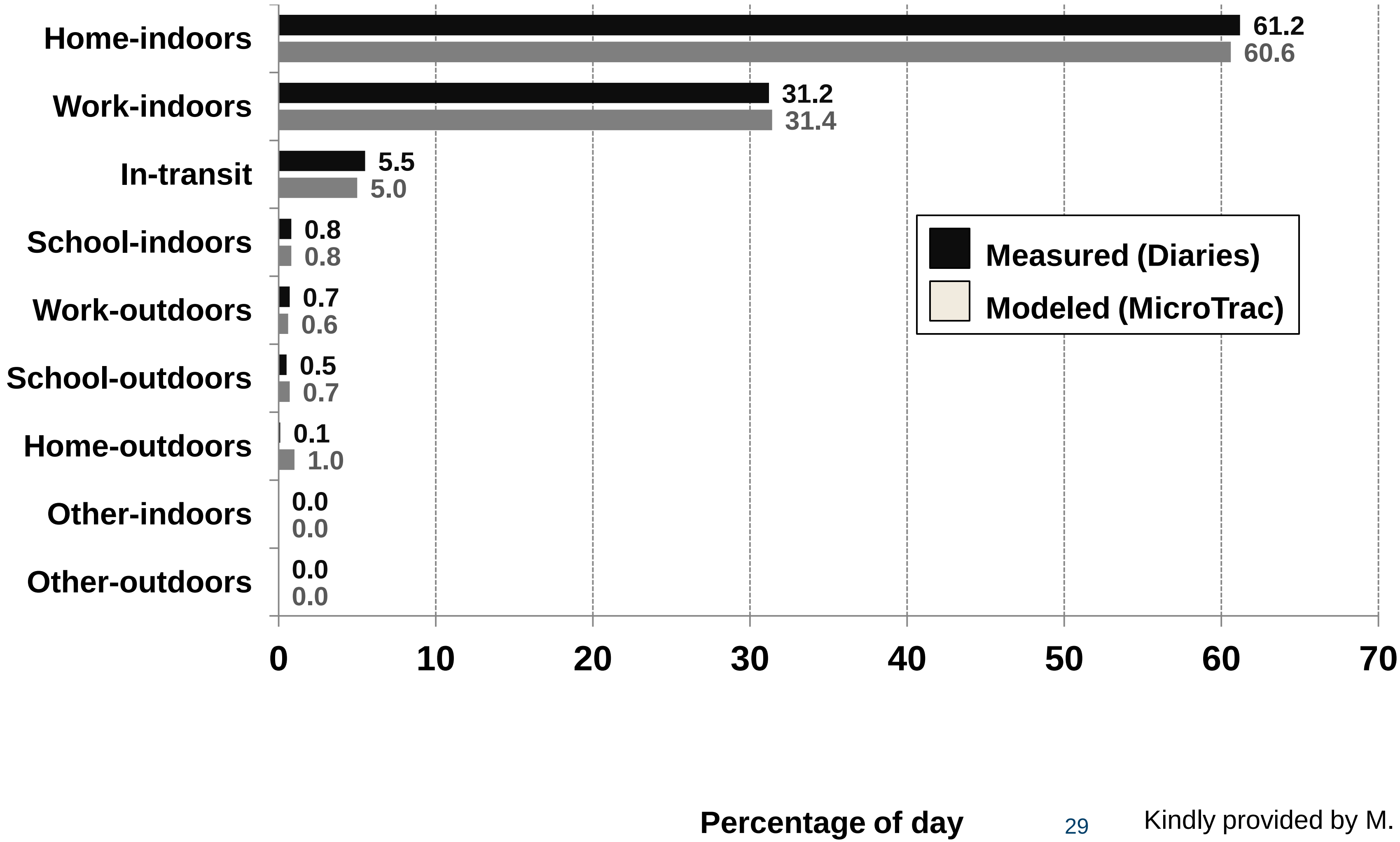
MicroTrac Evaluation for Participant 1

24 hr dataset (17,280 samples): processing time = 36 sec



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Kindly provided by M. Breen

Intensive Literature and Market Surveys

EPA/600/R-14/051

RESEARCH AND DEVELOPMENT HIGHLIGHTS:

MOBILE SENSORS AND APPLICATIONS FOR AIR POLLUTANTS

Prepared by

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Research Triangle Park, NC

31 October 2013

http://www.epa.gov/research/airscience/next-generation-air-measuring.htm

Example-Sensaris

Sensor gathers data and send it to the phone via Bluetooth

Real time data displayed on phone and broadcast data to the web

Get charts, track data and manage sensors from one web interface

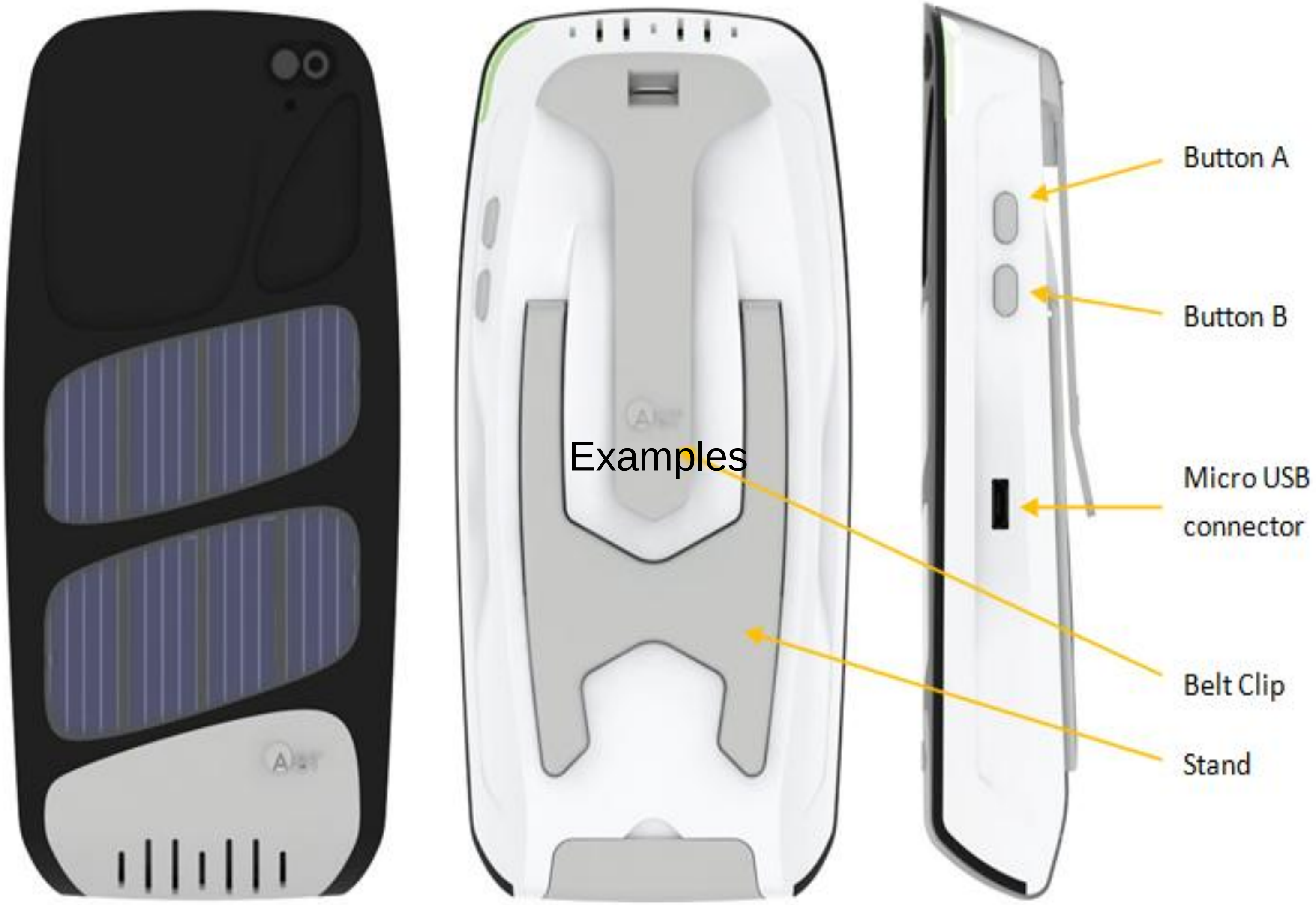
Example-Sensaris PM

Example-AirCasting

AirCasting App

AirCasting Air Monitor

Example-AGT



Examples
Button A
Button B
Micro USB
connector
Belt Clip
Stand

Example-CanAiriT (PE ELM)

Example-Cairpol PM

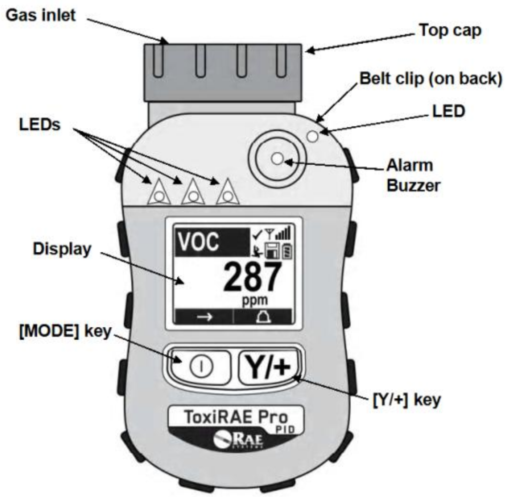
Example-Carnegie Mellon (Speck)

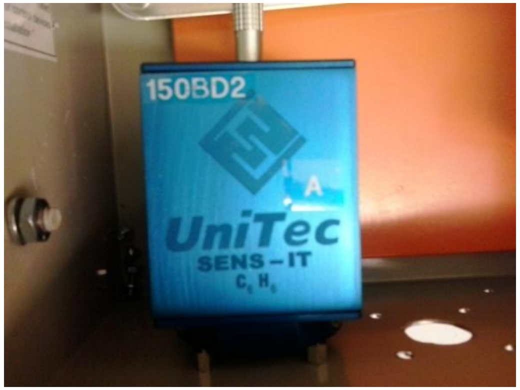
Example-Dylos

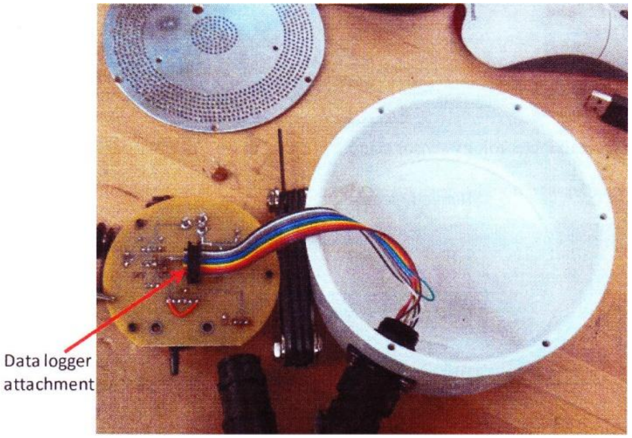
Example-Met One

Example-Cairpol (VOC,NO_2,O_3)

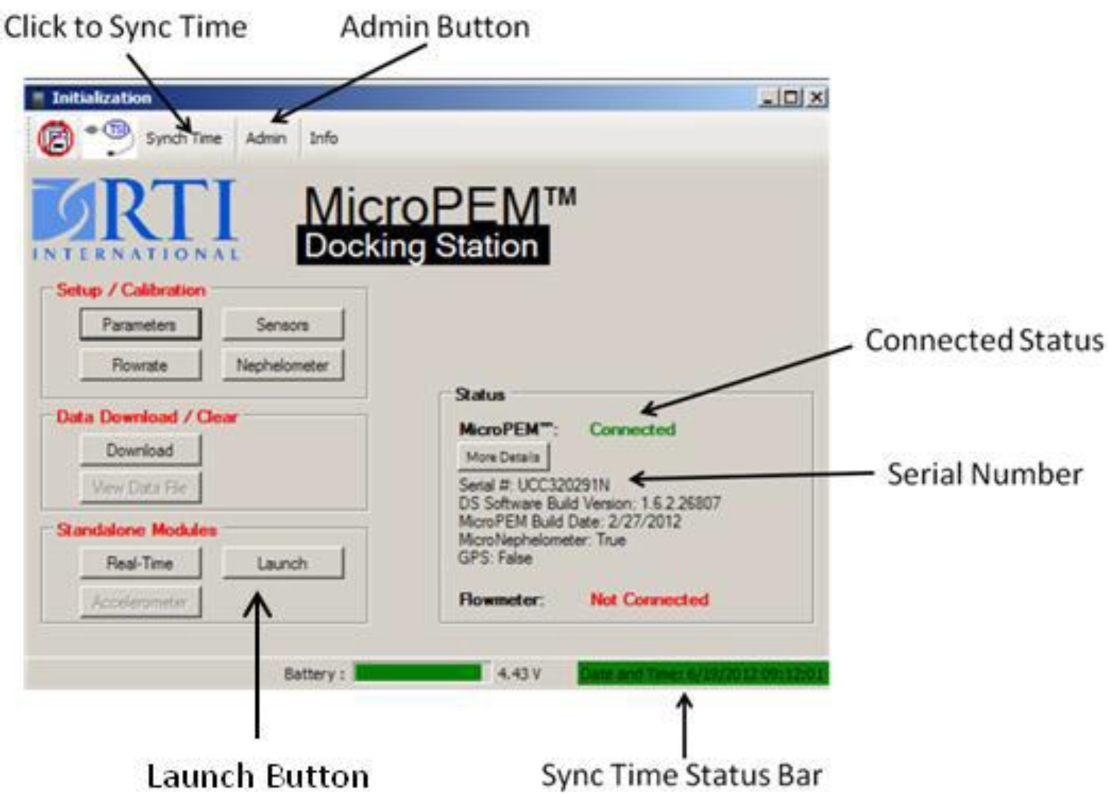
Example-UniTec, ToxRae, EPA VOC sensors



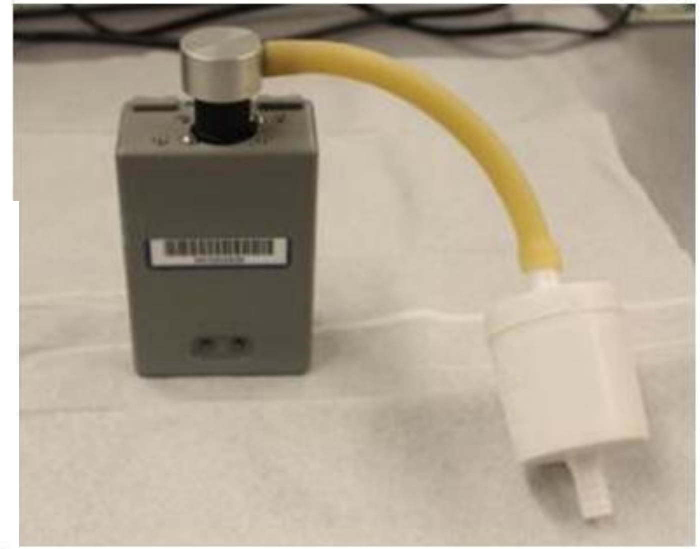




Example-RTI MicroPEM



Zero Cap on MicroPEM



Example- Cairpol /Aeroqual

Cairpol NO_2/O_3 sensor: electrochemical sensor

Prior lab-testing determined strong performance when challenged against gas standard.

A key issue for this sensor is the single data output that represents the addition of NO_2 + O_3.

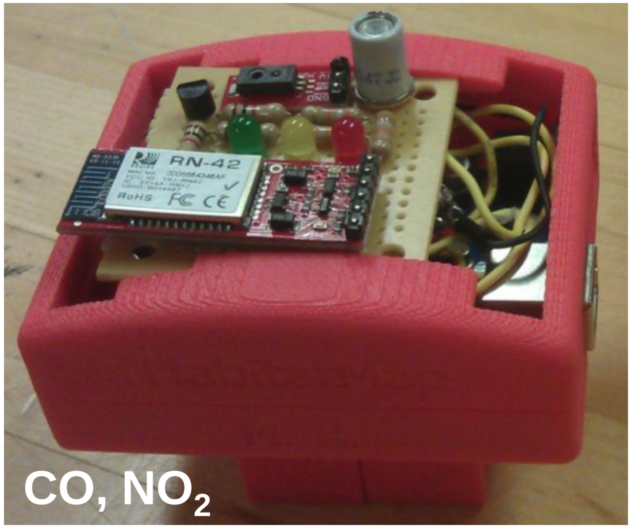
To differentiate between the two, a second ozone-only sensor added

Aeroqual SM50 O_3 sensor: gas-sensitive semiconductor (GSS)

Recent publication by University of Colorado-Boulder researchers noted good performance of this sensor.

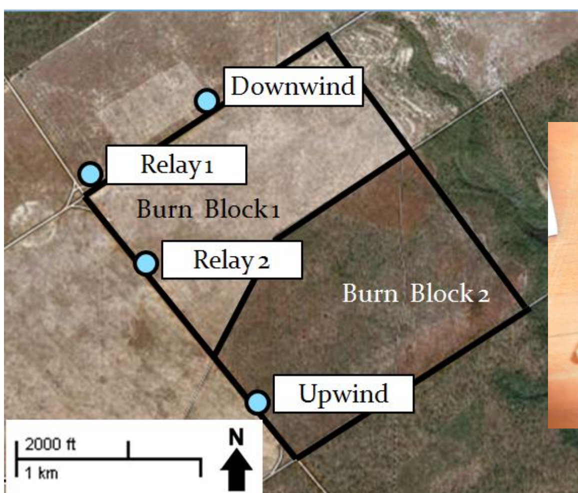
Issue with this sensor is higher power draw.

Examples- Air Casting/UPOD



Michael Heimbinder, Habitat Map, Brooklyn NY

Mike Hannigan – Univ. of Colorado



Sensor networks for source emissions, EPA/ORD

Example Mid-cost Systems

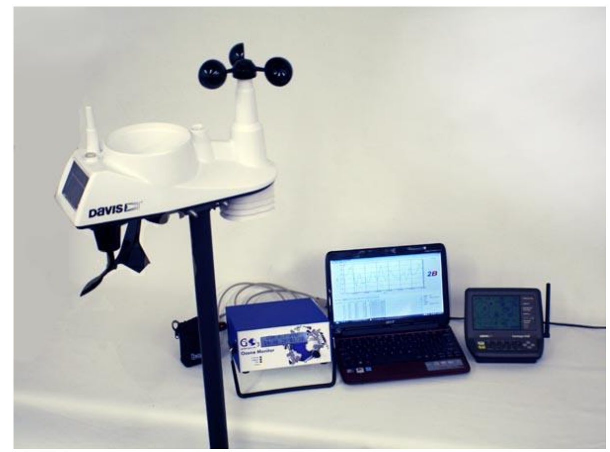
Aqmesh.com: AQ electrochemical sensors

skcinc.com: “Haz-Scanner EPAS”

Aeroqual.com

Global Ozone Project

Students around the world measure ground level ozone at their schools and share their data on Google Earth. Students at 80 schools in 25 countries have contributed nearly two million ozone measurements in the past two years. Ground level ozone is damaging to human health, crops, and ecosystems and is an important greenhouse gas.



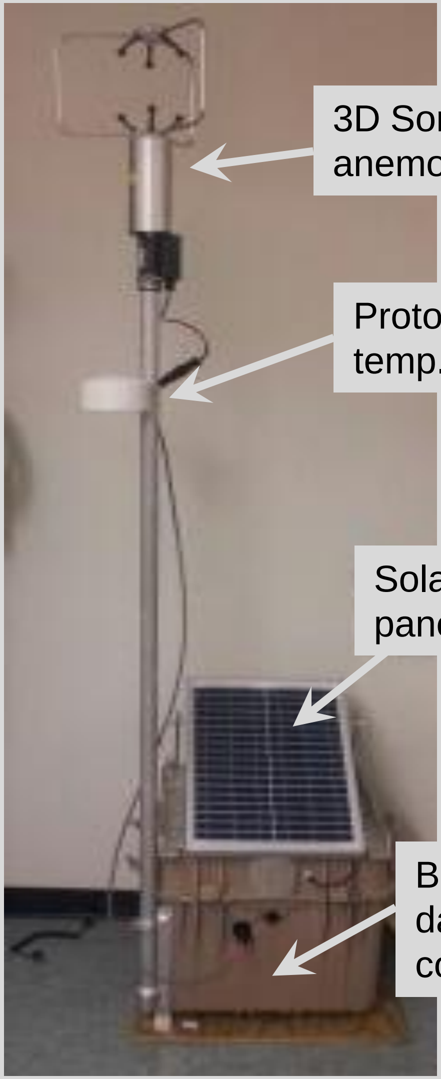
GO3project.com

EPA Village Green Project

Sensor systems: Build your own types

Drop-in-place Sensor Pod (SPod)

7 ft



3D Sonic anemometer

Prototype sensor package (pres. temp. RH. PID VOC)

Solar panel

Battery backup and data logger, communications

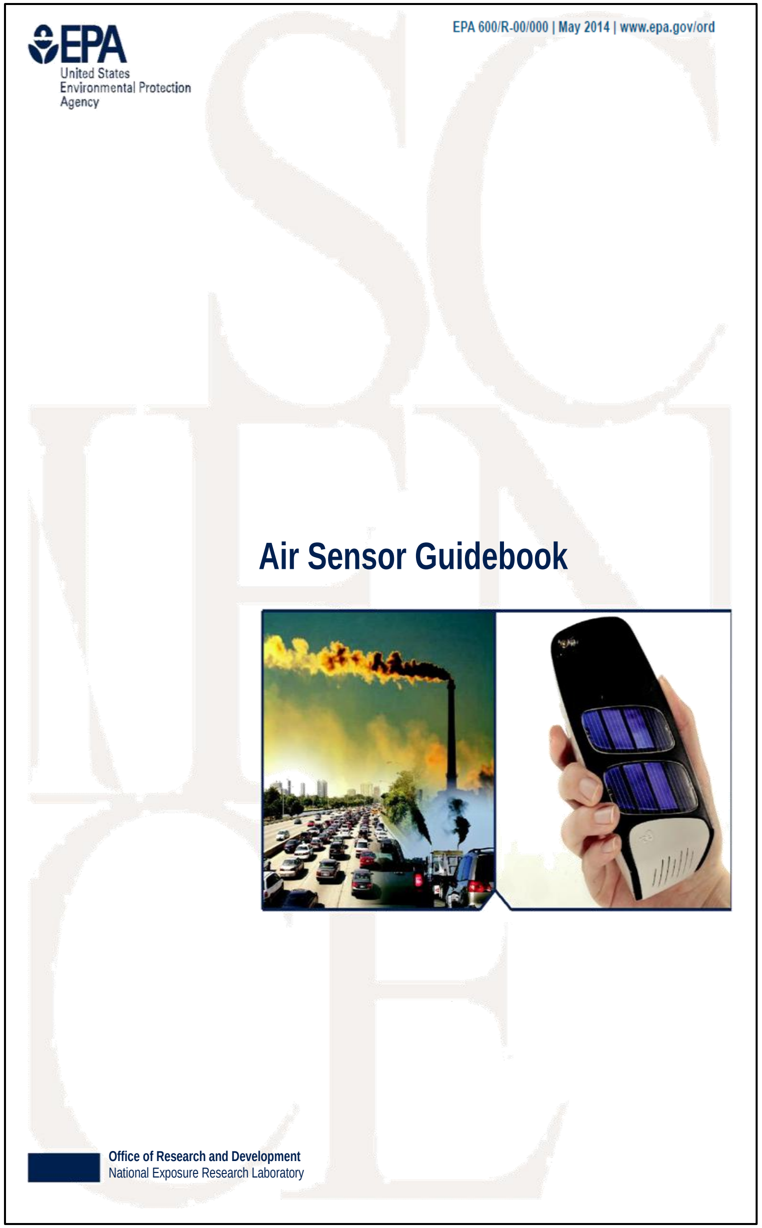
Inside of battery box

Courtesy Eben Thoma- US EPA

Critical Peer Reviewed Articles Defining Emerging Sensor Technology

Development of the Air Sensors Guidebook

Defines what sensor users need to understand if they are to collect meaningful air quality data



http://www.epa.gov/research/airscience/next-generation-air-measuring.htm

Providing Researchers A Direct Means of Sensor Data Comparison

Sensor Evaluation API

Log Out

- Home
- Web Services

AirNow Sensor Evaluation API - Web Services

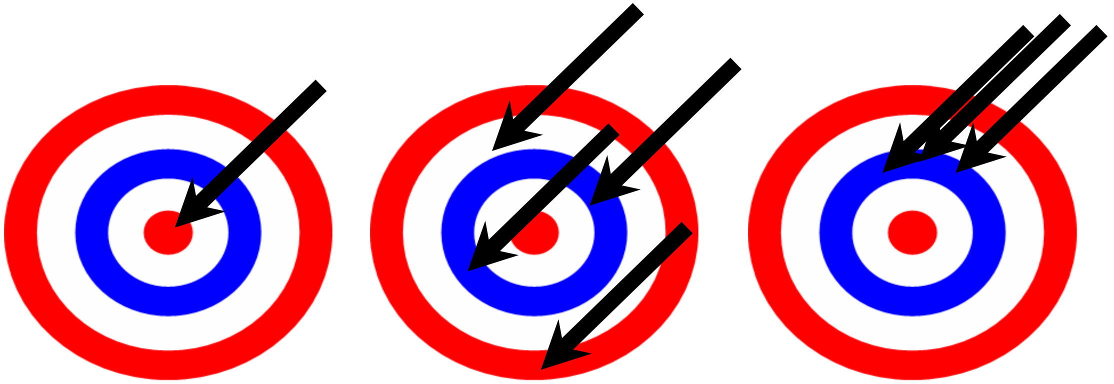
By Site Documentation Query Tool

This web service provides access to high-time-resolution air quality data collected by U.S. state and local air quality agencies. This web service takes various input parameters (site, parameter, duration, parameter occurrence code, date ranges, and output format) specified in the URL and returns data in CSV, JSON, or XML format.

http://smallsensors.sonomatechdata.com/webservices

Data Quality Considerations

Key Data Quality Features You Must Identify



Accuracy= how close to "true" concentration

Precision= being able to consistently predict the same concentration

Bias= a systematic (common) error of reporting a value higher or lower than the true value

EPA/600/R-14/159 (June 2014)

Select Quality Assurance Parameters Involving Continuous Monitoring

- Bias-is it routinely high or low with respect to the true value
- Precision- how repeatable is the measurement
- Calibration- does it respond in a systematic fashion as conc changes
- Detection limit -how low and high will it measure successfully
- Response time -how fast does the response vary with conc change
- Linearity of sensor response -what is the linear or multilinear range
- Measurement duration -how much data do you need to collect
- Measurement frequency -how many collection periods are needed
- Data aggregation -value in aggregating data (1 sec, 1 min, 1 hr, etc)
- Selectivity/specificity -does it respond to anything else
- Interferences -how does heat, cold, effect response
- Sensor poisoning and expiration -how long will the sensor be useful
- Concentration range -will the device cover expected highs and lows
- Drift -how stable is the response
- Accuracy of timestamp - what response output relates to the event
- Climate susceptibility - does RH, temp, direct sun, etc impact data
- Data completeness -what is the uptime of the sensor
- Response to loss of power - what happens when it shuts down

EPA/600/R-14/159 (June 2014)

Critical Findings in Sensor Evaluations

Sensor Evaluation MCRADAs

www.epa.gov/airscience

AIR CLIMATE & ENERGY RESEARCH PROGRAM
BUILDING A SCIENTIFIC FOUNDATION FOR SOUND ENVIRONMENTAL DECISIONS

Sensor and Apps Evaluation Opportunity

WHAT: EPA offers technology developers the opportunity to send in your sensor for evaluation in a controlled laboratory setting.

WHEN: Nominate your device by June 30, 2012
Testing to occur July – September, 2012

HOW: Device developers should submit a statement of interest to EPA by June 30, 2012 providing basic information about their device. Due to capacity constraints, EPA will accept a limited number (~10) devices for evaluation over a range of pollutant concentrations and environmental conditions (e.g. humidity and potential interferences). Participants will be invited to visit the EPA lab in early July to discuss their instruments, the evaluation protocol, and receive a tour of the facility. Following the completion of the evaluation each participant will receive information on the performance of their device under known environmental conditions.

QUESTIONS or Point of Contact: Ron Williams, 919-541-2957, williams.ronald@epa.gov

SELECTION CRITERIA: Devices receiving the highest consideration:

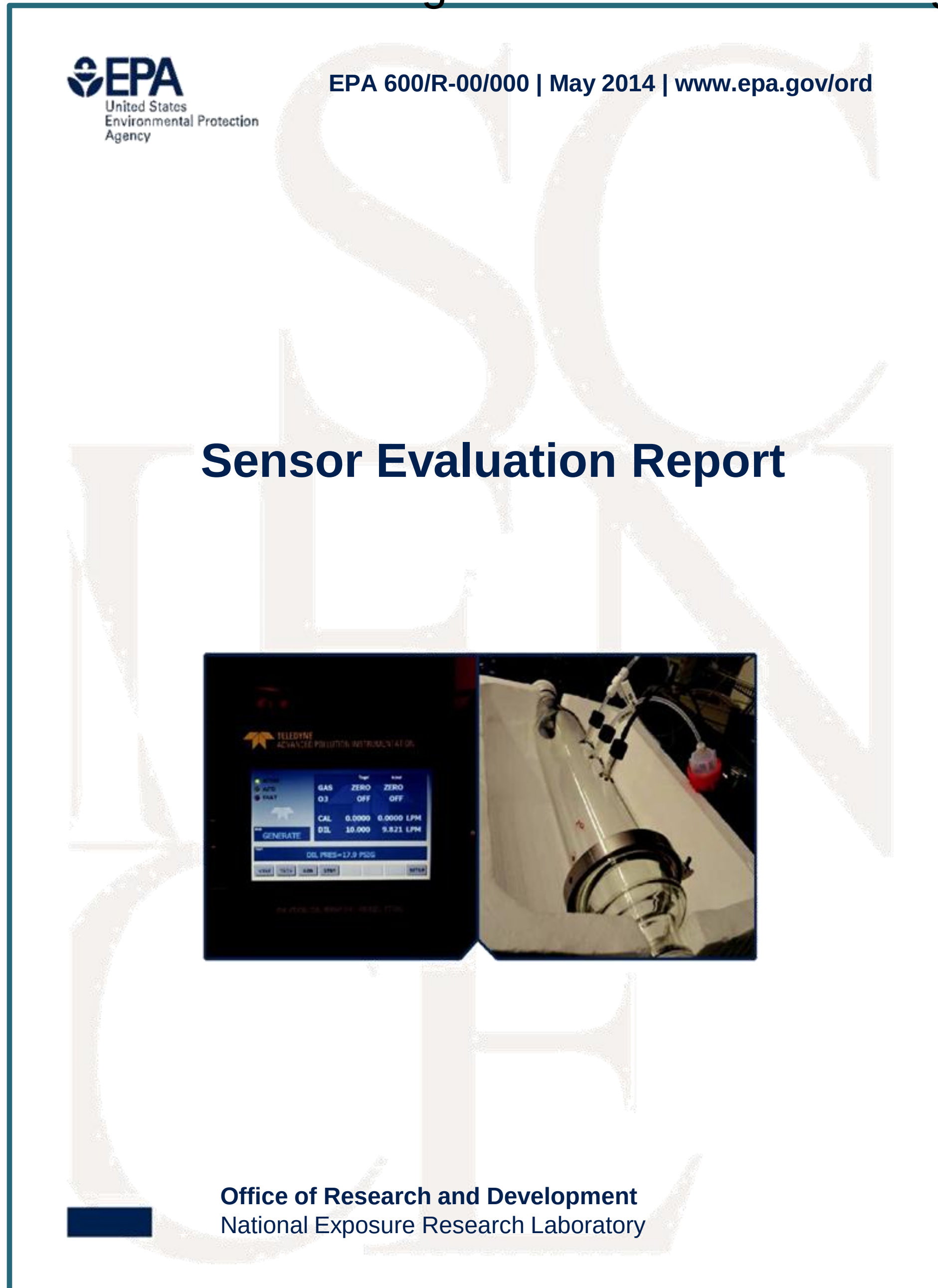
- have the technical feasibility to measure NO_2 and/or O_3 at environmentally relevant concentrations,
- have some preliminary data on expected performance characteristics,
- have not previously undergone standardized evaluations under known challenge test conditions by any party, and
- represent highly portable sensor and smart phone type applications featuring continuous measurement capabilities.

Description:
- Open call for potential collaboration
- O_3 and NO_2 focus
- A total of 9 research groups nominated devices for evaluation
- Variety of devices
- Formal cooperative agreements established
- Not FRM/FEM Evaluations

Feedback Provided to Sensor Developers:
- General performance of the device
- Observations on operation
- Validated non-summarized data
- EPA's intent was not to compare one specific device with another
- EPA recognized the confidential nature of the technologies being evaluated

http://www.epa.gov/research/airscience/next-generation-air-measuring.htm

MCRADA Evaluation of NO_2 and O_3 Sensor


EPA United States Environmental Protection Agency

EPA 600/R-00/000 | May 2014 | www.epa.gov/ord

Sensor Evaluation Report

Office of Research and Development
National Exposure Research Laboratory

A similar effort has been Reported by the EU Joint Research Center

Technical Aspects – FRM/FEM Performance Parameters

40 CFR Part 53 Table B-1: Performance Limit Specifications for Automated Methods

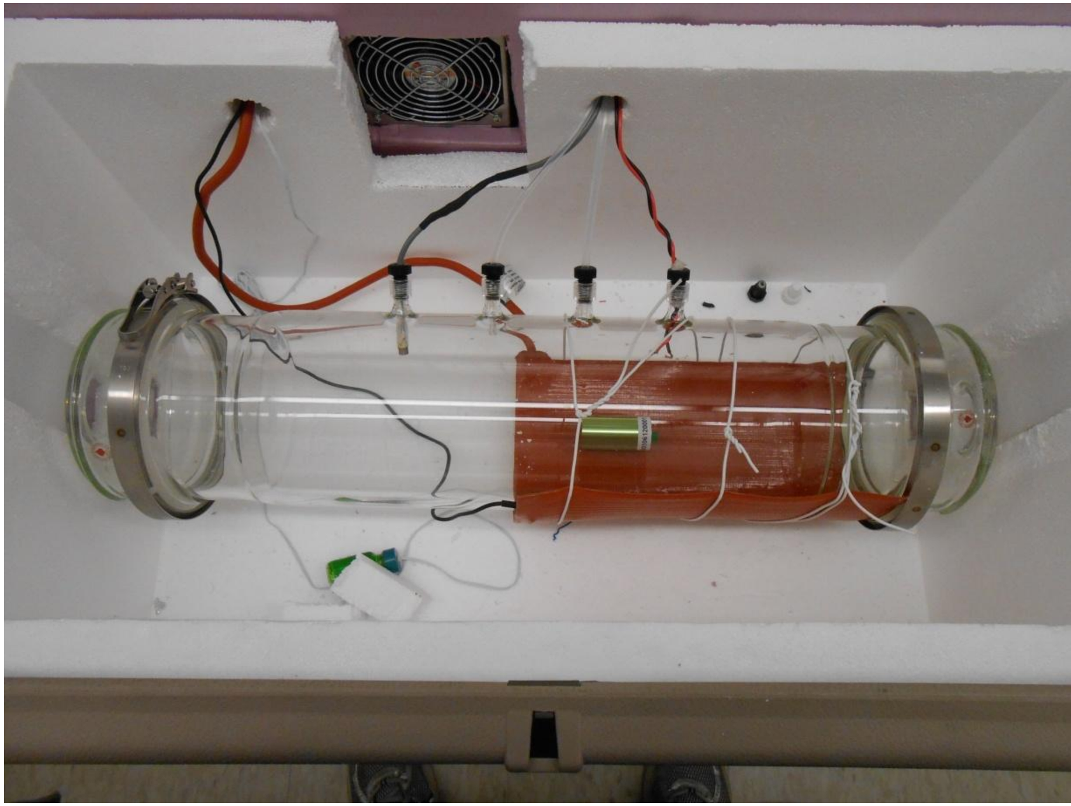
Performance parameter	Units[1]	SO_2 Std. range[3]	SO_2 Lower range[2,3]	O_3 (Std. range)	NO_2 (Std. range)
1. Range	ppm	0-0.5	<0.5	0-0.5	0-0.5
2. Noise	ppm	0.001	0.0005	0.005	0.005
3. Lower detectable limit	ppm	0.002	0.001	0.010	0.010
4. Interference equivalent Each interferent Total, all interferents	 ppm ppm	 ±0.005 ---	 [4]±0.005 ---	 ±0.02 0.06	 ±0.02 0.04
5. Zero drift, 12 and 24 hour	ppm	±0.004	±0.002	±0.02	±0.02
6. Span drift, 24 hour 20% of upper range limit 80% of upper range limit	 Percent Percent	 --- ±3.0	 --- ±3.0	 ±20.0 ±5.0	 ±20.0 ±5.0
7. Lag time	Minutes	2	2	20	20
8. Rise time	Minutes	2	2	15	15
9. Fall time	Minutes	2	2	15	15
10. Precision 20 % of upper range limit 80 % of upper range limit	 ppm Percent ppm Percent	 --- 2 --- 2	 --- 2 --- 2	 0.010 --- 0.010 ---	 0.020 --- 0.030 ---

Evaluation Aspects – Performance Traits

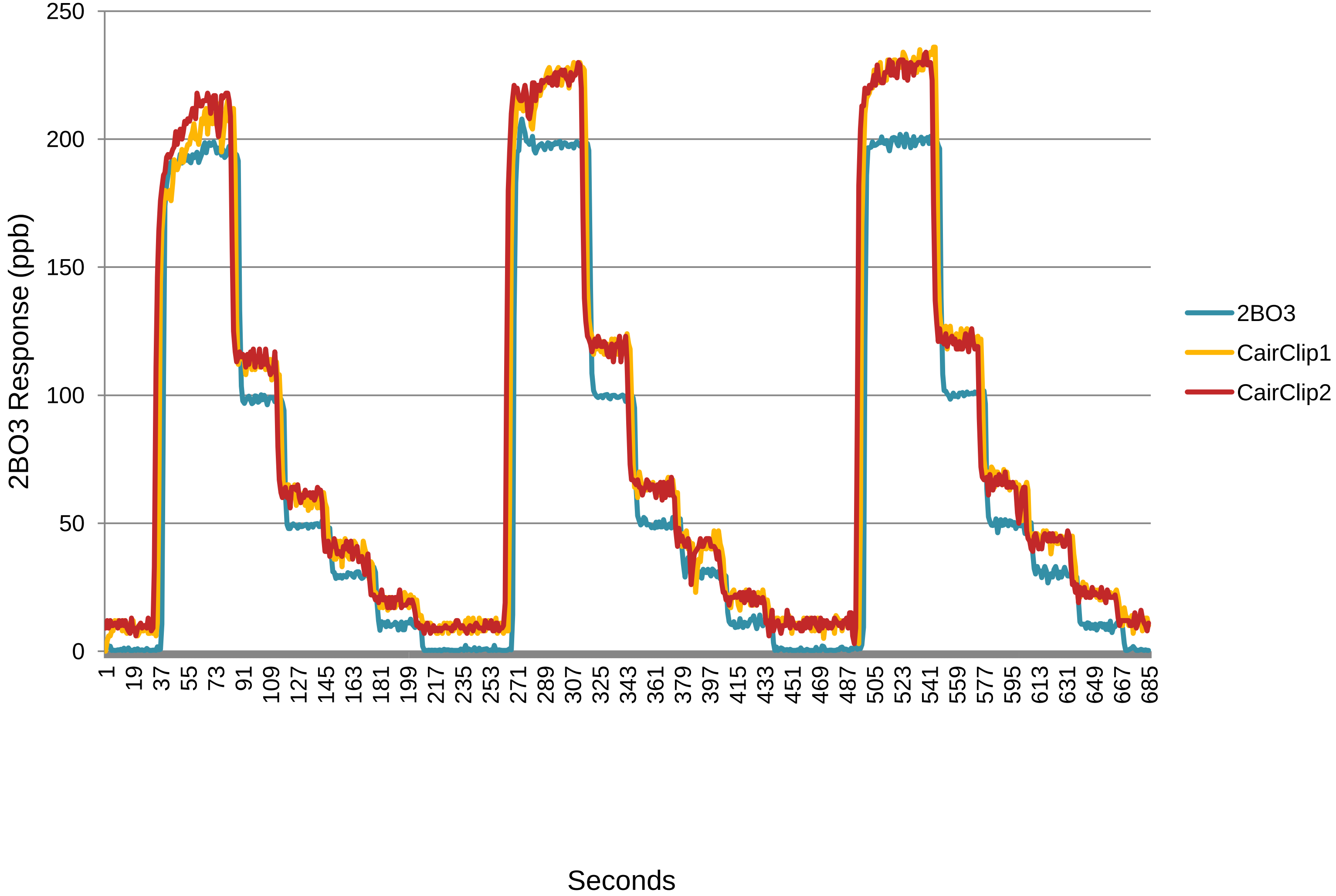
1. Linearity (range)
2. Precision of measurements
3. Lower detectable limit
4. Resolution (noise)
5. Response time (lag and rise time)
6. RH and temperature influence
7. Interference equivalent

Sensor performance evaluation: lab investigations

Example: Cairpol sensor for NO_2/O_3



Example of Basic Performance Characteristics



Typical O_3 and NO_2 Sensor Performance Characteristics

	Conditions	Response	Linearity	Precision	LDL	IDL	Res low	Res High	Lag Time	Rise Time	SO2 int	O3 Int	NO2 Int
		kOhm/ppb	R^2	ppb	ppb	ppb	ppb	ppb	minutes	minutes	ppb	ppb	ppb
O3	Normal	0.4186	0.9824	10.3	15.6	11.8	8.3	14.1	1	5	7.5	NA	32.2
	Hot	0.2492	0.9933	13.6	12.4	18.1	6.8	37.7	1	6	Widely Variable		
	Humid	0.3383	0.9774	2.6	12.4	16	5.9	4	1	4			
	Cold	0.5484	0.9772	7.2	9.8	11.3	2.6	6.1	1	3			
NO2	Normal	0.6362	0.9972	1.2	15	9.5	1.8	2.3	1	5	19.5	off scale	NA
	Hot	0.0995	0.9919	6.4	13.6	24	5.7	8.1	1	20	Widely Variable		
	Humid	0.4526	0.9937	7.4	17.7	22.8	2.7	5.2	1	7			
	Cold	3.4208	0.9917	7.5	10.2	5.2	0.8	6.8	1	6			
CFR O3	NA	NA	NA	10	10	10	5	5	20	15	20	20	20
CFR NO2	NA	NA	NA	10	10	10	5	5	20	15	20	20	20

Sensor and Data Quality-Considerations

- Weather. Many devices are temperature and relative humidity (RH) sensitive
  - Sensors often function poorly in high humidity
  - Sensors often respond differently when it is either very hot or very cold (may under or over-report true pollutant concentrations or even stop working)
  - The impact on data quality for temperature and RH effects for many low cost sensors have not been established

Unique Qualities

- Battery life. It is apparent that a wide range of battery options are being used. Operating periods from 3 hrs to 24 hrs have been observed
- Recharge issues. Very specific recharge requirements (USB to use of transformed outlet voltage) and recharge times
- Orientation. Some devices had to have a very specific orientation in the exposure chamber

Unique Qualities

- Sensor Interface. Some of the sensors required a discreet movement of air flow over the surface of the sensor. (Goldilocks requirement= not too much, not too little). Interface stagnation versus physical influence (cooling of sensor influences resistance and therefore output had to be considered individually for each sensor.
- Test range. There appears to be a wide range in sensor sensitivities

Communication Protocols

- WiFi, Bluetooth, hard line (direct interface with laptop, tablet or other device), flash drive download, on-screen
- Communication protocols were often less than foolproof and work around solutions had to be developed. Internal wireless security issues, cell-based signal strength and other factors had to be resolved (all were resolved)

Data Recovery/Processing

- Raw data processing (even reporting in some cases) often required interface with proprietary software data management programs. Such links prevented direct access to raw data and represented another communications linkage that had to be resolved
- Difficultly in some situations to get to raw data as the raw signal was processed via developer's software prior to being "reported" back to user

Field Evaluations

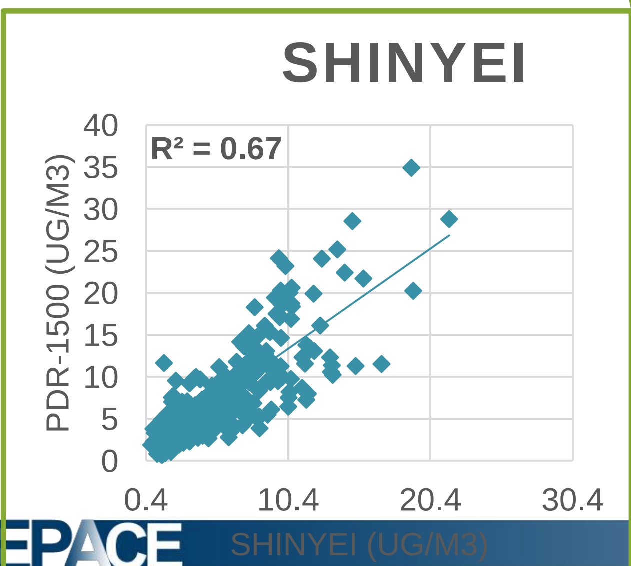
- **PM and VOC Sensors (Research Triangle Park)**
- **DISCOVER AQ (Houston)**
- **Village Green Project**

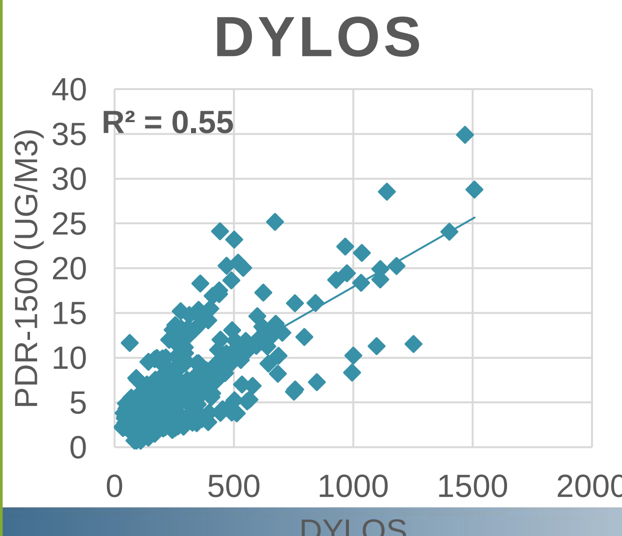
Wireless sensor network: sensor selection

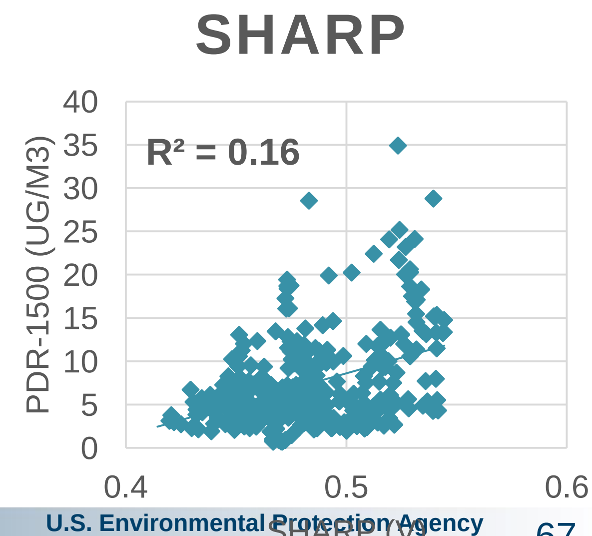
Shinyei PM sensor: light scattering-based detection principle

Week-long field test in Durham, NC determined that the Shinyei PM sensor had promising response, compared to a pDR-1500 (Thermo Scientific)

Also met criteria of being small, low powered, and easy to integrate with other sensors into wireless data stream.



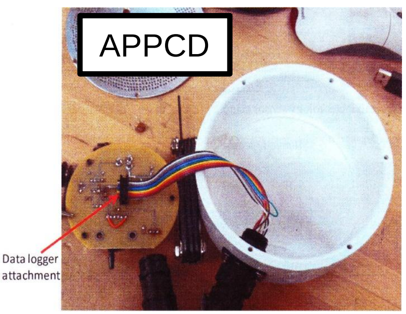


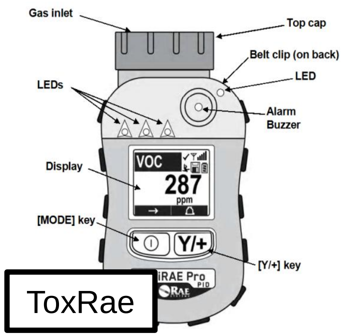


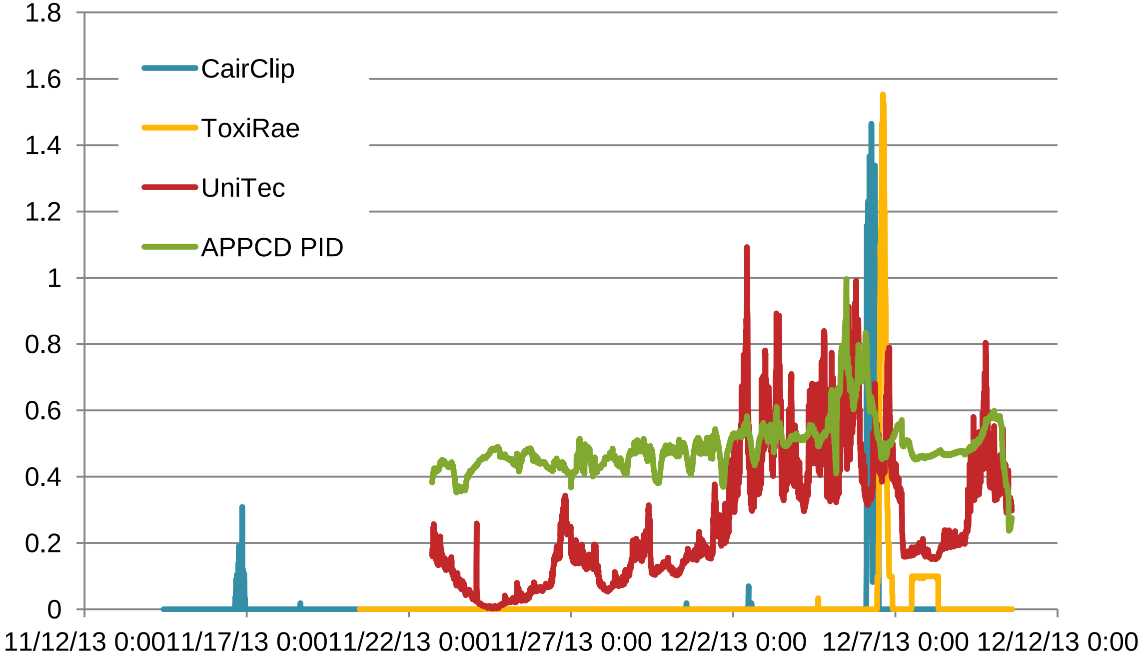
Low Cost VOC Sensor Characterization at Near Road Site

VOC sensors

- It is obvious the sensors have a wide range of sensitivities.
- Specificity is currently being determined on select models.







Preliminary Performance Characteristics of VOC Sensors

Sensor	R^2 Temp Linearity (°C)	R^2 RH Linearity	Time Resolution (s)
AirBase CanarIT (ppb)	0.4942	0.4087	20
APPCD PID (V)	0.0811	0.2191	1
CairClip (ppb)	0.0038	0.0307	60
Sensotran Benzene (V)	NA	NA	600
ToxiRAE Pro PID (ppm)	0.0088	0.3597	20
UniTec Sens-It (V)	0.0327	0.0079	60

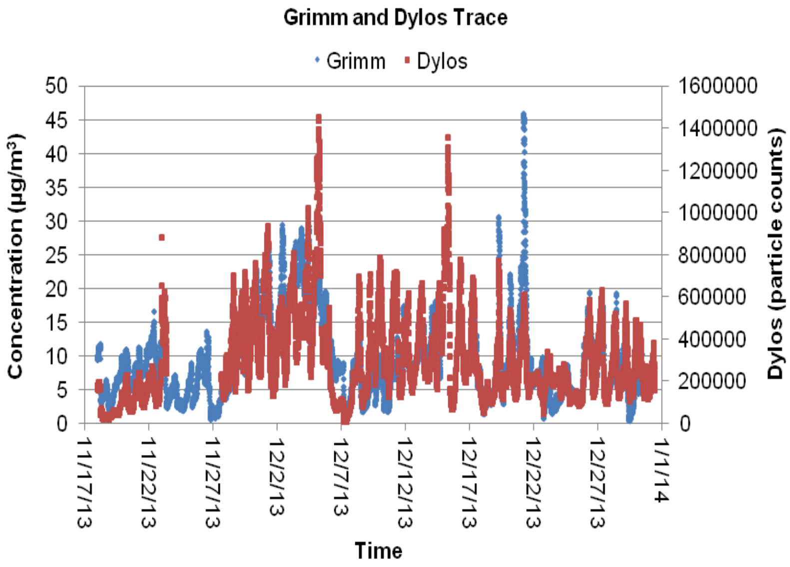
Direct Collocation with FEMs

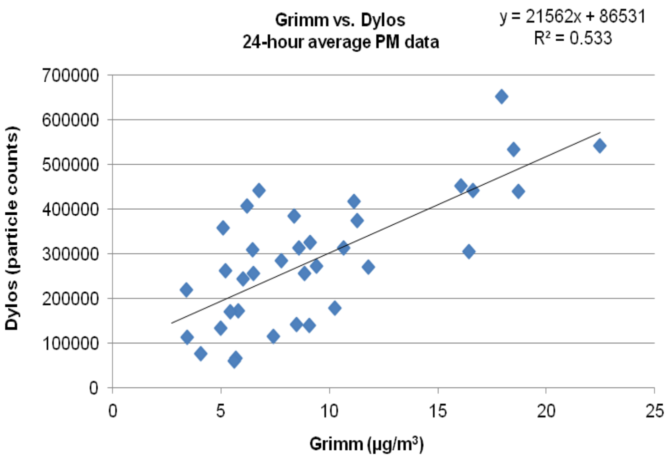
Sensor performance evaluation: lab and field

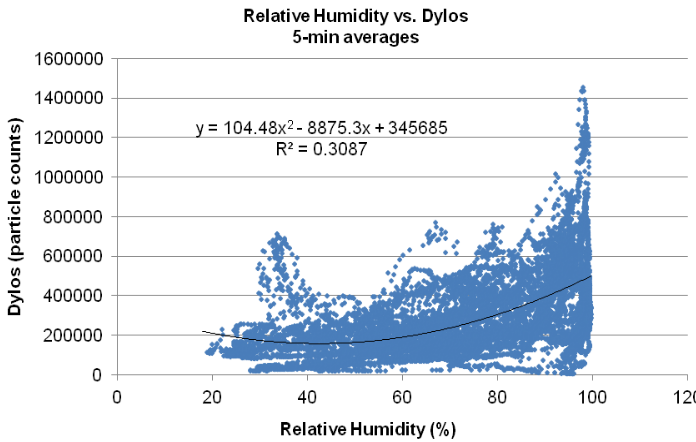
PM short-term tests – ambient, field conditions

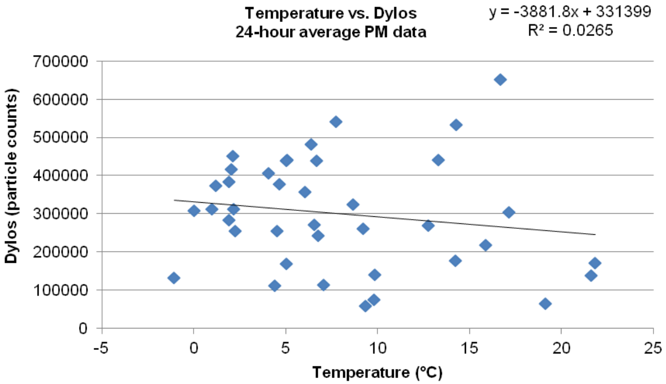
- Most low cost PM sensors provide on **modest agreement with FEM** in direct collocation challenge (CODs between 0.1 to 0.5).
- **Temperature and RH being observed as influencing factors**. Some (Cairpol) suffering from very poor sensitivity. The Dylos appears to be one of the more agreeable units even though it only provides particle counts (not mass).
- We have no information on intra/inter-variability of these sensors.

An Example of In-Depth PM Sensor Evaluation









Low Cost PM Sensor Evaluations

Sensor	FEM R^2 Linearity	RH Limit	Temp R^2 Linearity	Time Resolution
AirBase CanarIT (µg/m³)	0.004	100%	None	20 s
CairClip PM (µg/m³)	0.064	95%	0.657	1 min
Carnegie Mellon Speck (particle counts)	0.000	90%	None	1 s
Dylos DC1100 (particle counts)	0.548	95%	None	1 min
Met One 831 (µg/m³)	0.773	90%	None	1 min
RTI MicroPEM (µg/m³)	--	--	>0.8*	10 s
Sensaris Eco PM (µg/m³)	0.315	100%	0.313	Unknown

* Manufacturer has developed new programming to account for this effect

Sensor Evaluation in Collaboration with NASA (Houston, TX Sept 2013)

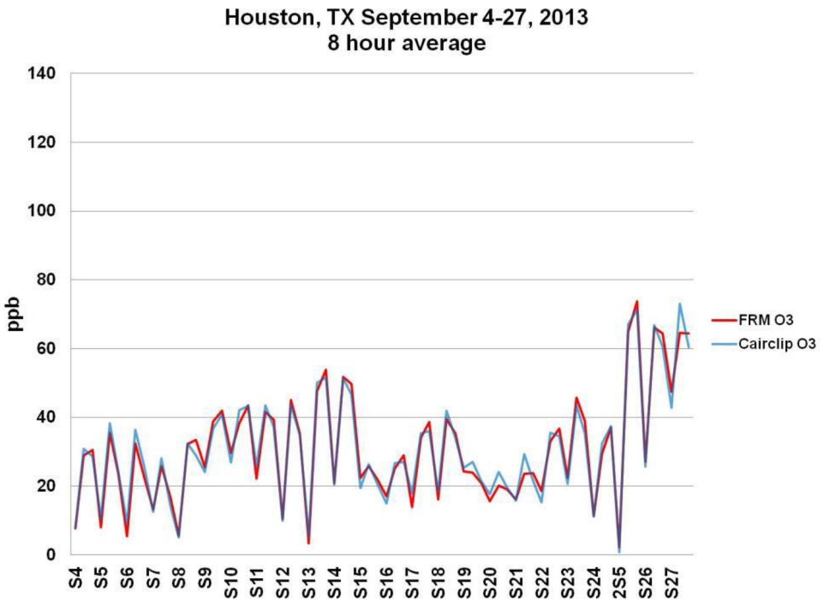
- EPA deploying sensor technology (CairClip) for NO2 and O3 that performed well during the EPA Sensor Evaluation Open House.
- NASA deploying sensor technology (Geotech AQMesh-5) to measure O_3, NO, NO_2, CO, SO_2.
- Sampling with sensors used to evaluate air craft and remote measurements as well as air quality models.
- Provides EPA with additional insights and experience with the use of sensor technologies in the field for future applications.

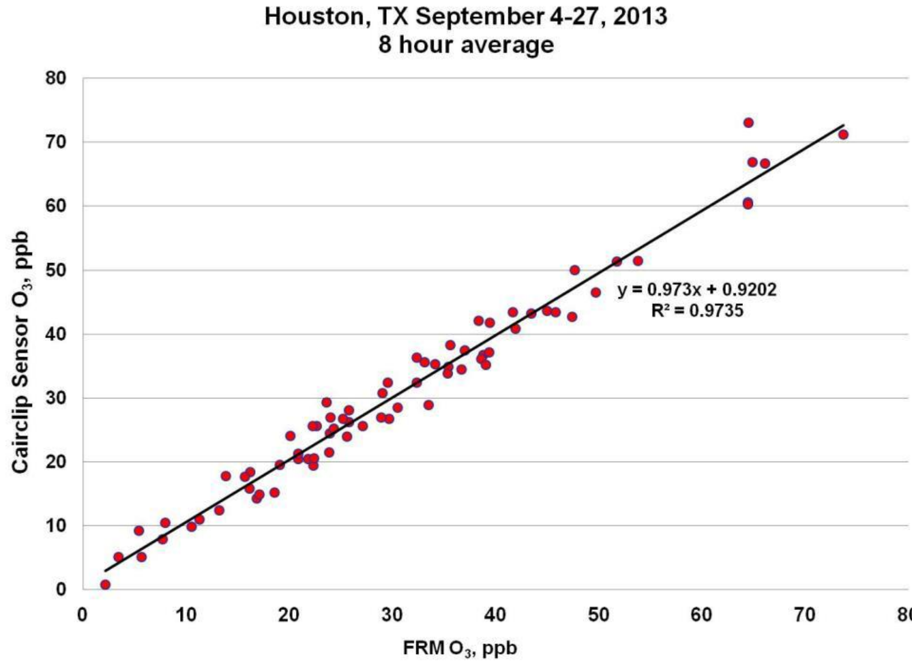
CairClip

DISCOVER-AQ Sensor Network

- Sensor network installed on August 19-20, 2013 at 8 schools
- Elementary, junior high, and high school science teachers trained on operation of sensors
- Outreach opportunities/scientist visits requested by <u>all</u> participating schools
- Teachers/students collected data with their sensor devices and incorporated sensor measurements into their lesson plans
- ORD scientists visited schools and conducted educational outreach activities

DISCOVER AQ Low Cost Sensor Comparison





- Cairclip sensor data corrected by subtracting NO_2 data (as measured by NO_2 FRM) to obtain sensor O_3 results
- Sensor and FRM O_3 results averaged to 8 hours (starting at midnight) for comparison to 8 hour O_3 NAAQS
- Excellent agreement between sensor and FRM results for O_3

The Village Green Project

Solar-powered, air and meteorology monitoring bench:

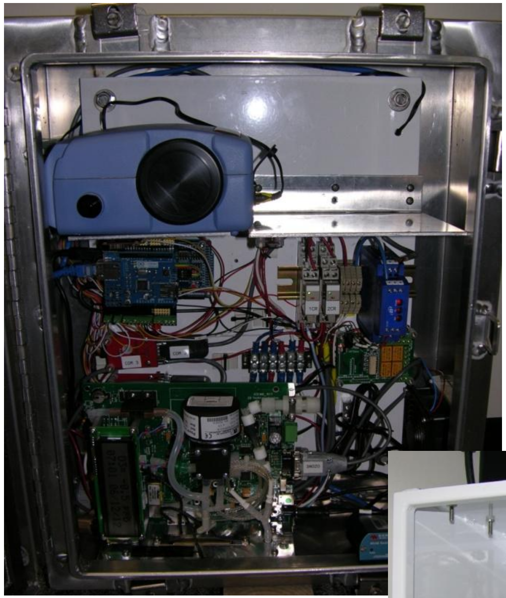
- Sustainable materials: manufactured from recycled milk jugs

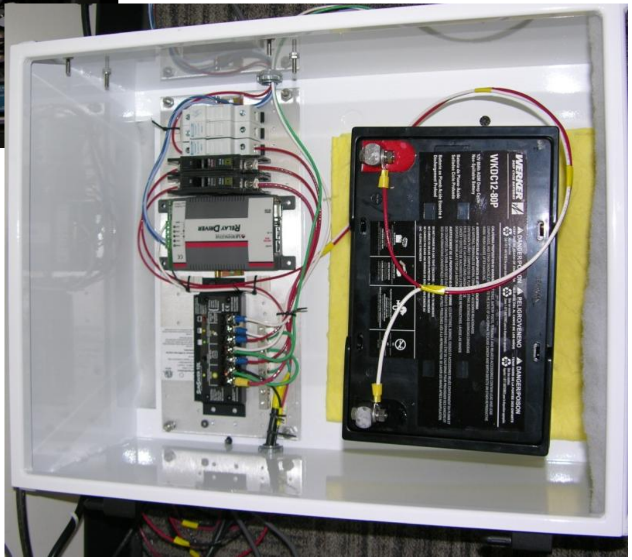
- Tamper-proof: Instruments secured in bench or base of play structure

-Designed to add value to public environments (bench)

-Formal agreement with Durham County on collaboration

Village Green Project





Air instruments (PM, ozone), power system and communications components stored securely behind bench

Cost of instruments, power, structure, sign ~30K

Public website updated minute-by-minute

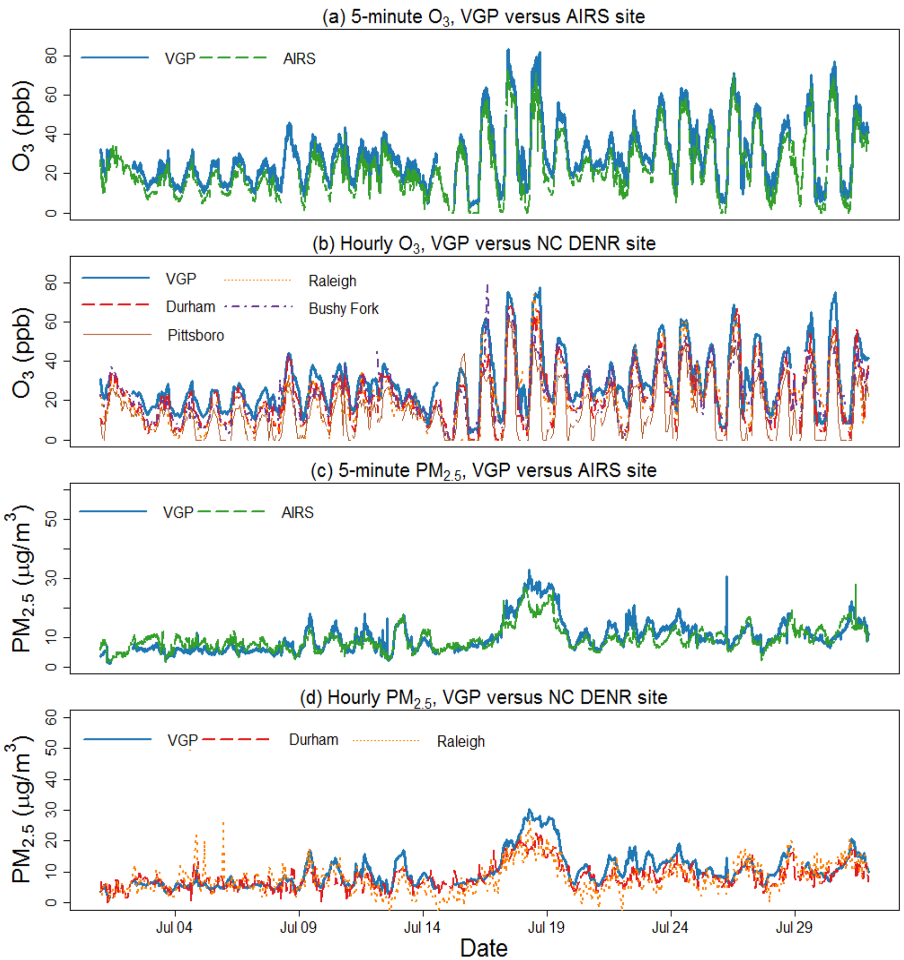
System performance

- Power system provided sufficient power for 95% operation over 10 months of data analyzed thus far (June 2013 through March 2014)

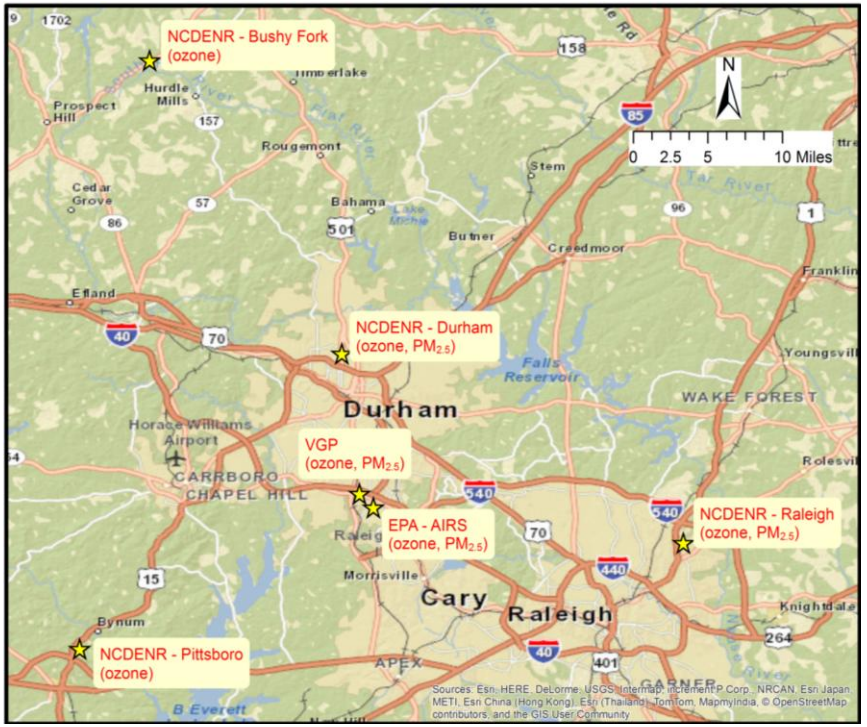
- Other causes of data collection interruption:
  - Communications – resolved initial challenges with Arduino to EPA server data transmission
  - Instrument maintenance or calibration – PM pump replacement approximately every 6 months, ozone instrument cleaning at 6 month mark

- Example typical operation for months without any instruments pulled out for cleaning or maintenance
  - During the “Arctic blast” NC winter: February completeness was 83-91% for all measured variables.
  - During hot and sunny NC summer: August completeness was 100% for all measured variables.

Comparison with nearby federal equivalent methods (FEMs)



Comparison with other sites operating FEMs in the area revealed strong agreement

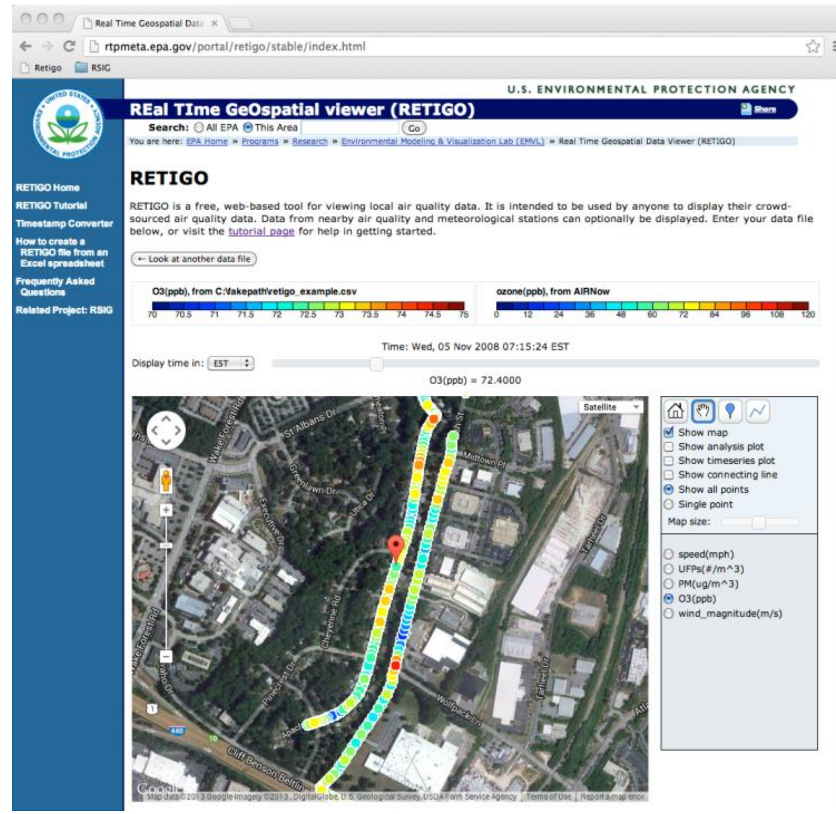


Jiao et al., in preparation

Data visualization support: RETIGO

Point of contact:
ORD: Gayle Hagler

<u>Objective</u>: reduce barriers to participating in mobile air monitoring data analysis



Mobile air monitoring data:
- A function of time, location, and pollutant
- Often collected at a high time resolution (large time series)
- Variable format, location, instruments

Mobile air monitoring data analysis and exploration:
- Analysis often limited to those individuals with advanced training and access to specific software tools (e.g., MATLAB, GIS, etc.)

We are building RETIGO to support mobile air monitoring individuals and teams, reducing the technical barriers to visualize the complex data and complement advanced data analysis techniques.

Resources for Decision Making

Continuous Measurement Decision Tree

- Define the pollutant or exposure variable(s) of interest
- What is the hypothesis that needs to be tested
- Are continuous measurements truly needed. Are simple time integrated options (e.g., y/n) as valuable
- What parameters need to be co-measured to facilitate the testing
- Do they all lend themselves to continuous monitoring or only some of them. Does it matter
- What analytical methods are available to collect the raw data

Continuous Measurement Decision Tree

- Are these methods readily available.
- Are they within your financial budget and timeline relative to acquisition (number of sensors). Would you need to make the devices “field worthy”
- Based on power calculations or other relevant statistical tests, what population size of data need be collected. What assumptions are you having to make to develop those statistical tests? How far do you use guesstimation rather than historical values in developing those calculations?
- Can you successfully execute a study design once you have defined the data size population (with respect to study resources)

Continuous Measurement Decision Tree

- What do you need to do to “validate” or prepare the continuous monitor before its use. Is this feasible with your resources and expertise. Are there others who could do this for you if you lack the expertise
- Do you have software that will reduce the labor of recovering big data for the purpose at hand. If not, can you handle the labor to more laboriously recover/organize/validate data
- Data validation is paramount to your success. Will you be able to use collocation or other QA schemes to ensure data is and peer acceptable

Continuous Measurement Decision Tree

- Aggregation is sometimes valuable and rarely is 1 second data amenable for hypothesis testing. What is the shortest duration of measurement that is feasible, reasonable, and logical with respect to the study design and hypothesis. Do you collect "it all" and then decide if aggregation is profitable as part of your post-processing effort
- How do you plan to handle monitor refurbishment, calibration, repair and upkeep as part of the day to day operation of the equipment. Are there any "off days" where such work can occur with no impact on the data collection schedule.

Continuous Monitoring-Last Words

- Can be highly profitable, not always needed
- To be most useful, ancillary data must be of a similar nature and time duration
- Must ensure data quality using instruments often of a non-proven stature. There is definitely a price range of poor/good/excellent in continuous monitors. You get what you pay for is often a valid description
- Statistical and mathematical efforts are key to mining the data. Often, it is not obvious how this needs to be performed

Thank You

- If interested, you can join a monthly EPA and other interested parties webinar series on low cost sensor applications
- A great resource for you is the following website

(www.epa.gov/heasd/airsensortoolbox)