2014 National Ambient Air Monitoring Conference

Overview of Emerging Air Sensors

Gayle Hagler, PhD

U.S. EPA Office of Research and Development

Overview of the overview

Why is there a demand for new air monitoring methods?

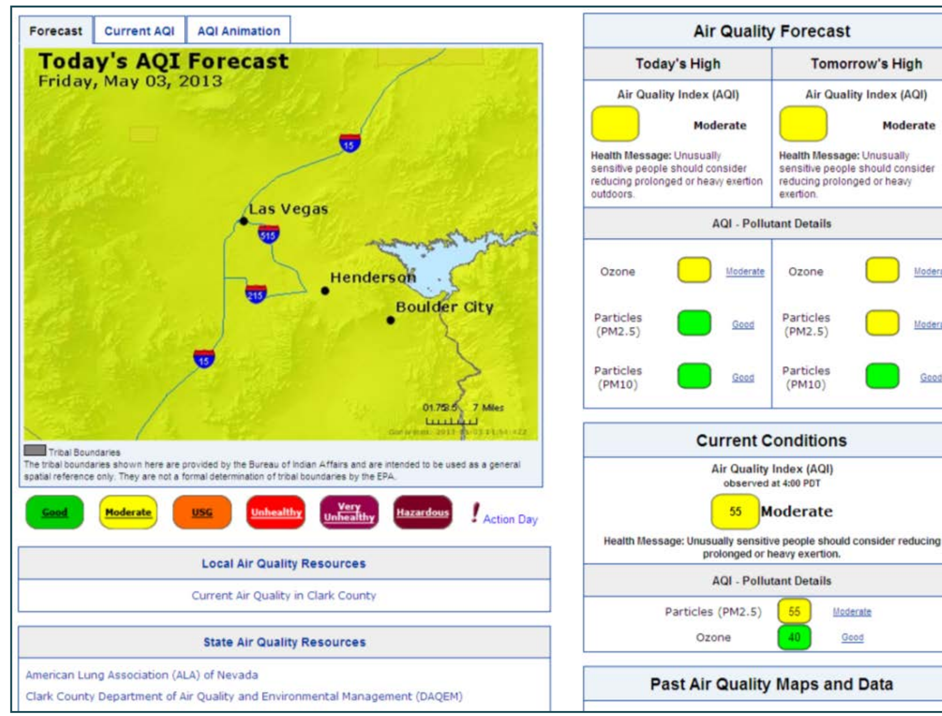
What are these new technologies?

What is the future forecast?

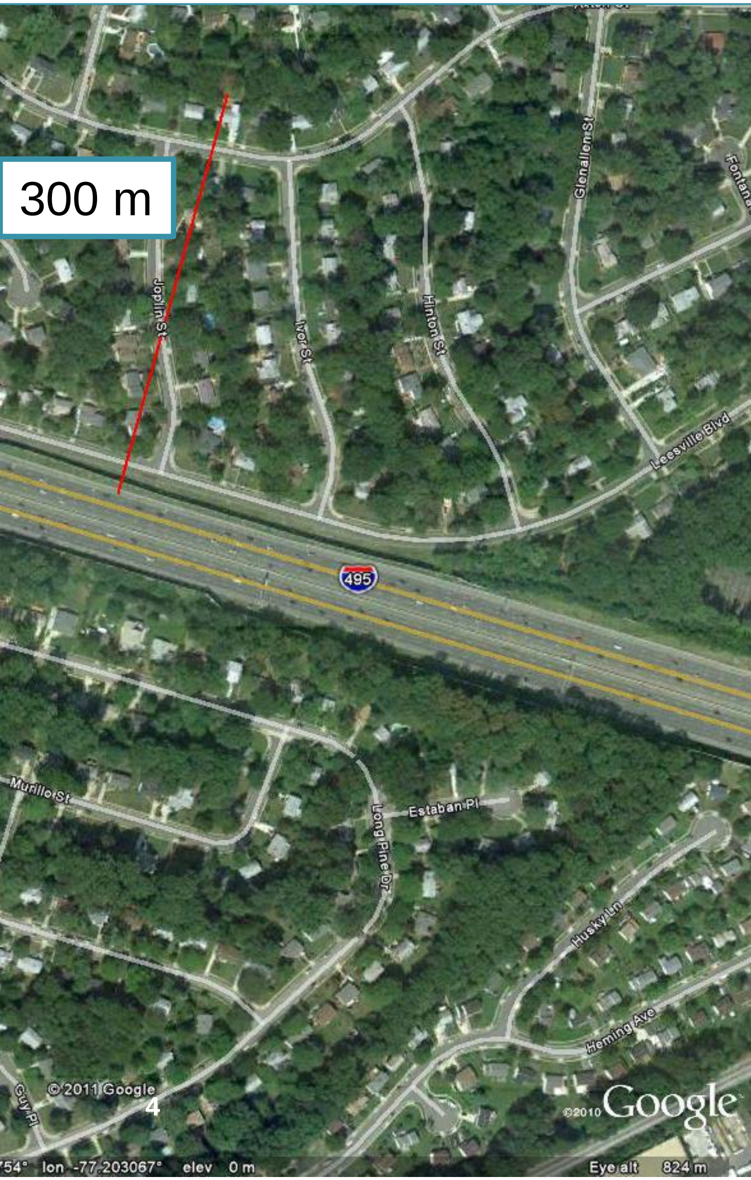
Traditional air monitoring paradigm

Government-provided data, Air Quality Index provided on broad time and spatial scales.

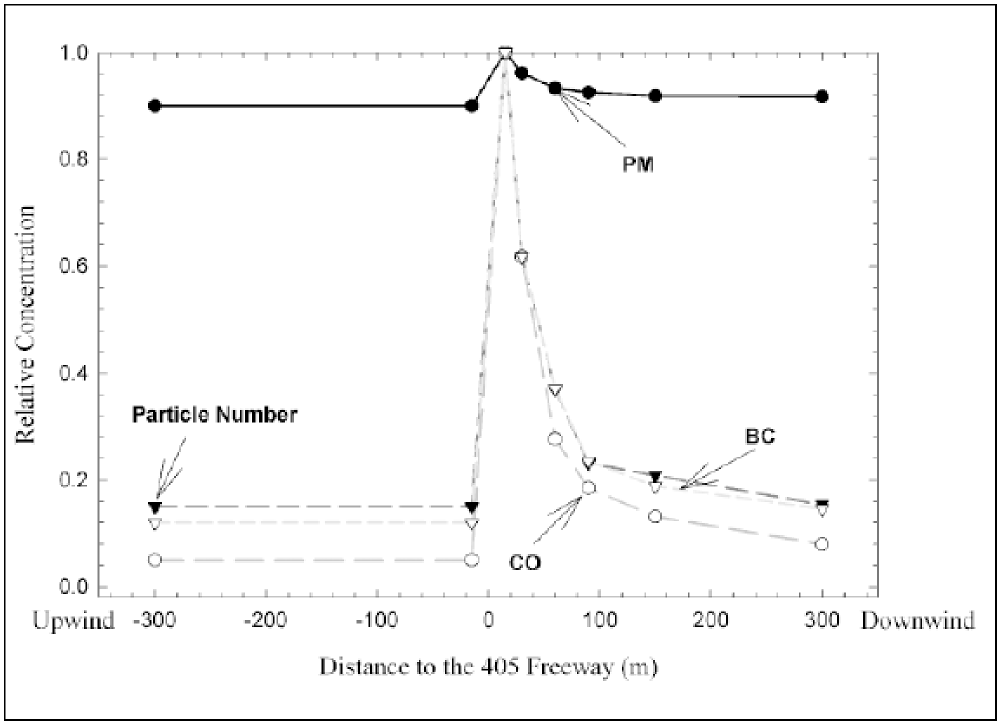
Expensive instruments
Specialized training required
Large physical footprint
Large power draw



However, research shows that air pollution can vary over small spatial increments



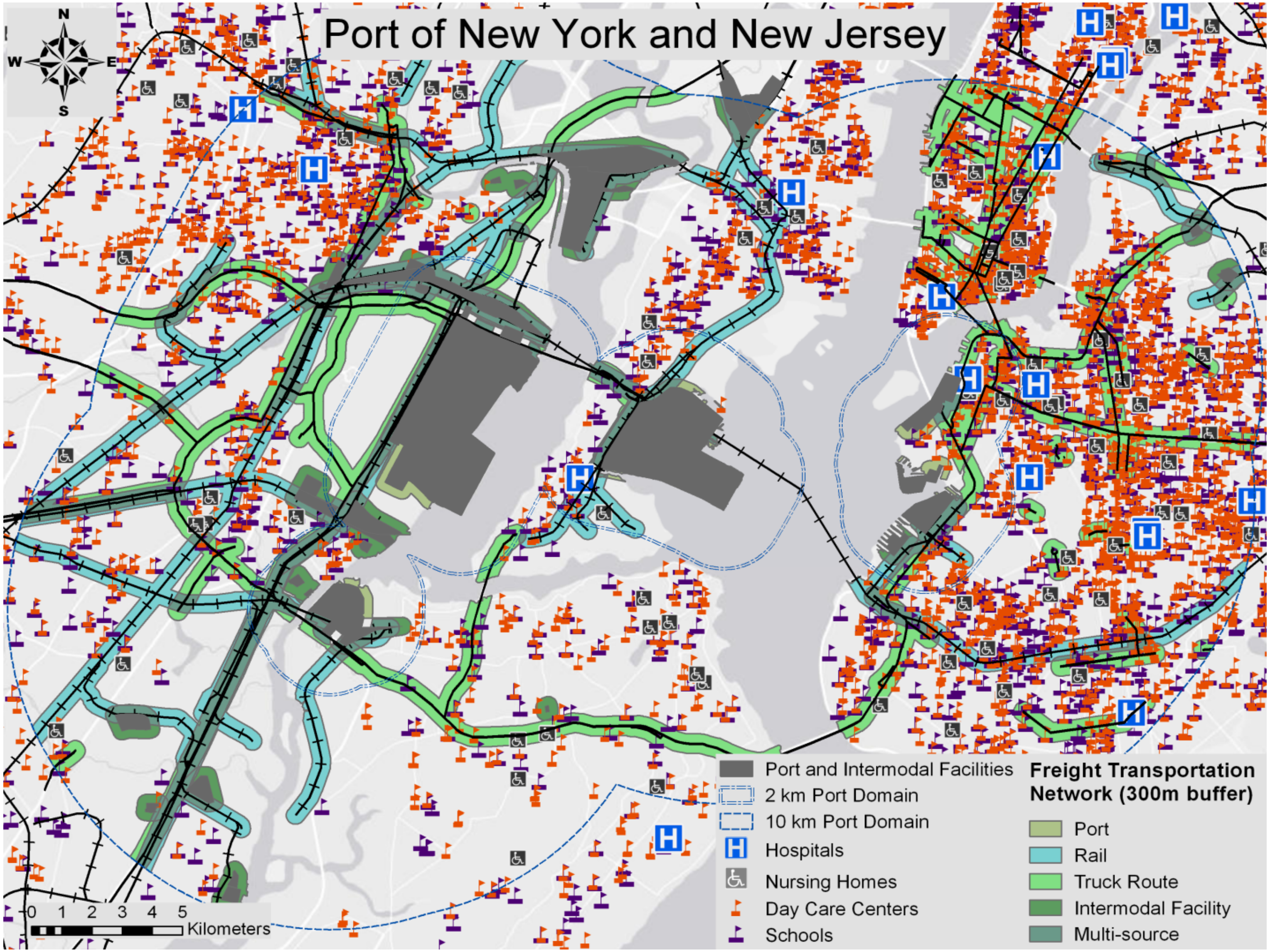
e.g., Over 45 million people in the United States live within 100 meters of a major transportation system.



Zhu et al (2002)

Many near-source zones potentially of interest for more finer-grained monitoring

e.g., near-source areas around trucking routes, rail lines, and intermodal facilities



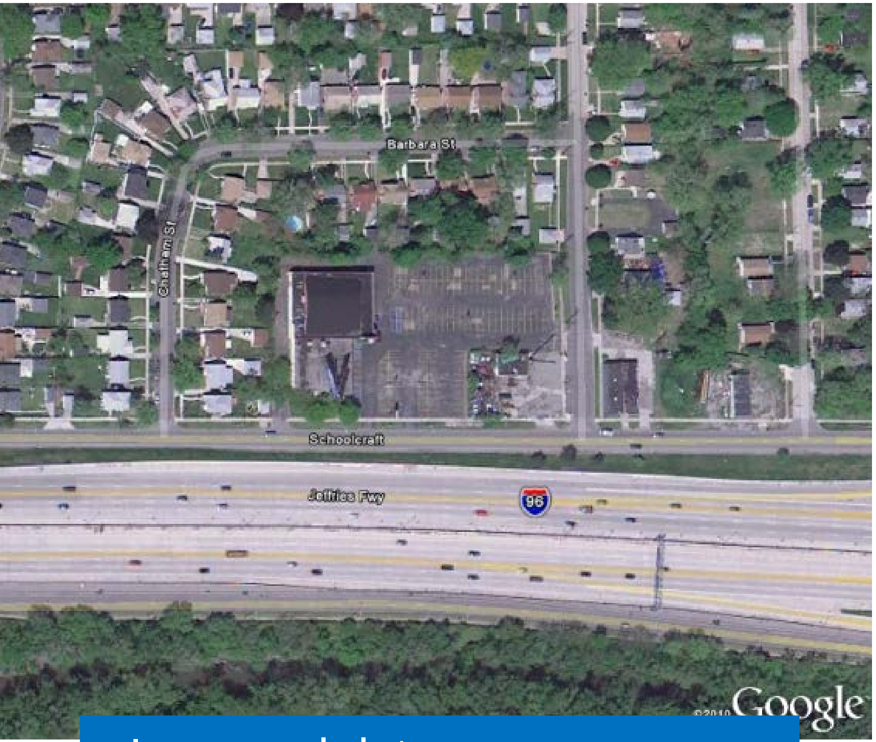
(Brantley et al., in review)

High interest by public for more information

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

Example environments for NGAM application

Near-road assessment:



- Improved data on exposure
- Mitigation assessment
- Urban planning
- Personal health decisions

Industry fence line

- Increase emissions understanding
- Improve worker safety
- Reduced product loss
- Benefit local air quality
- Provide transparency
- Improve public relations

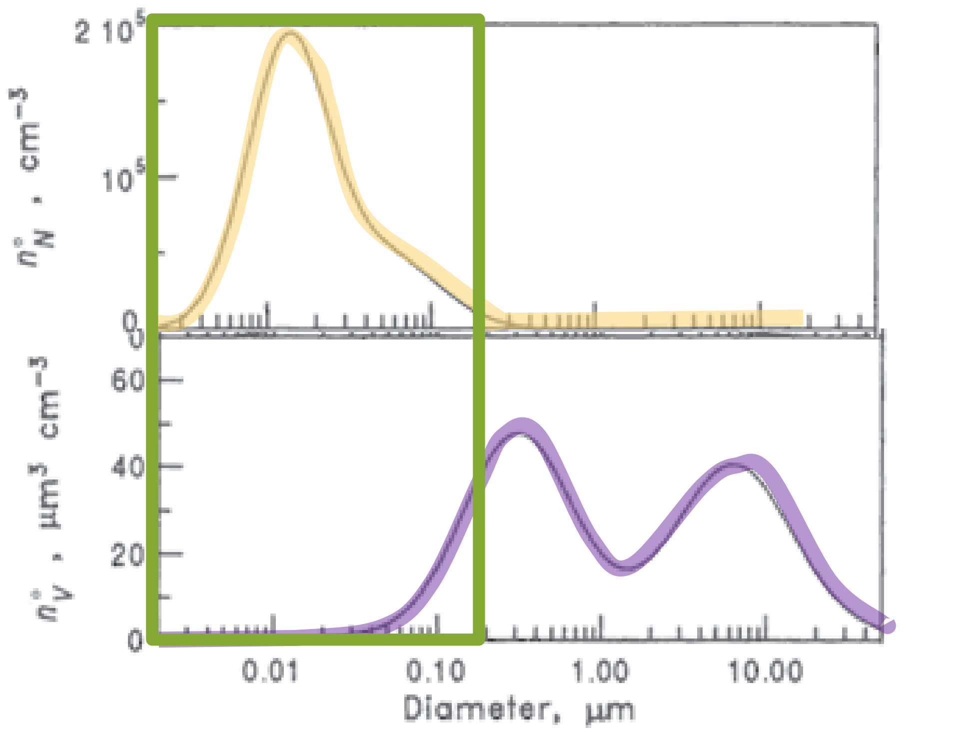
What are some of these new air sensors?

Particle-phase

Ultrafine particles (<0.1 μm)

Active detection principle:
<u>Size (if detected):</u> Classifies particles by size according to motion of charged particle

<u>Count:</u>
Option A: Electrometer-based detection
Option B: Grow particles (condensational growth) and then count by light scattering



Particle distributions in a typical urban aerosol (adopted and modified from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

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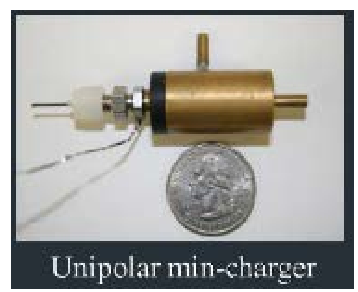
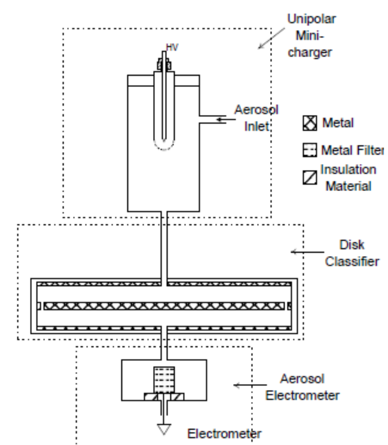
<u>Possible measurement challenges for sensors:</u>
Very small sample volume, dynamic pollutant
Detection limit (lower) with electrometers

Recent EPA grant recipient:
Da-Ren Chen (Virginia Commonwealth University)
“Development of Cost-effective, Compact Electrical Ultrafine Particle (eUFP) Sizers and Wireless eUFP Sensor Network”

Existing methods

Emerging sensor (example): miniaturized particle count sensor





What are some of these new air sensors?

Particle-phase

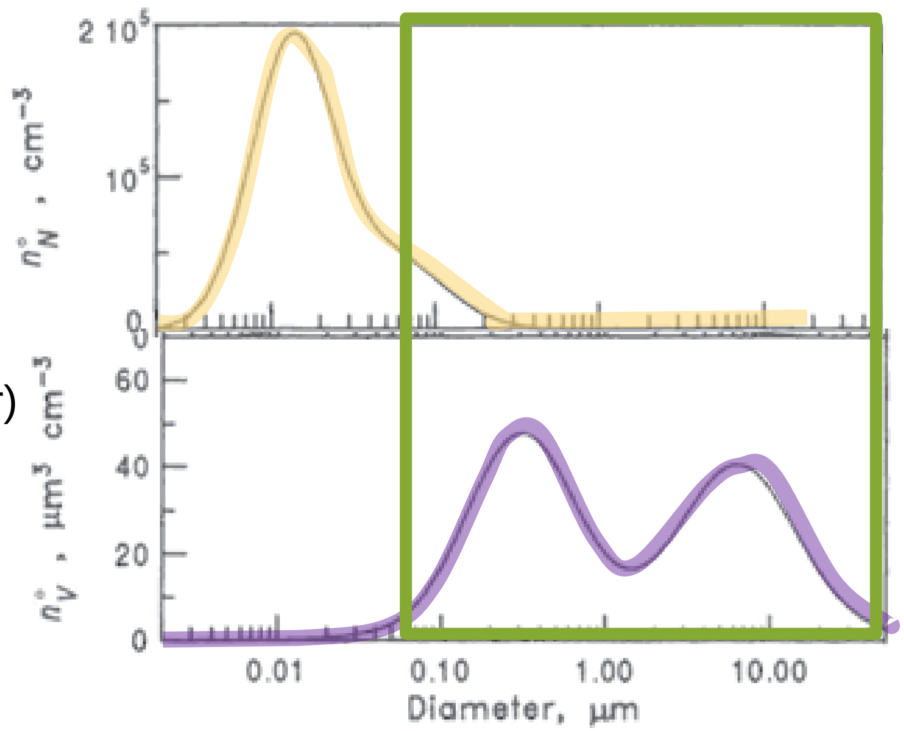
Larger particles (>0.1 µm)

Active detection principle:

Size (if detected):
Option A: Create cut point by how particle moves around an obstacle (cyclone, impactor)
Option B: Photodetection – small particles generate small pulses of light, large particles generate larger pulses (optical particle counter)
Option C: Accelerated air flow / inertial separation (Aerodynamic particle sizer)

Mass:
Options:
Mass – beta-attenuation, tapered element oscillating microbalance (TEOM)

Mass estimate – optical particle counter + assumptions, nephelometry + assumptions (main assumption: particles in environment = calibration aerosol)



Particle distributions in a typical urban aerosol (adopted and modified from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)

What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 µm)

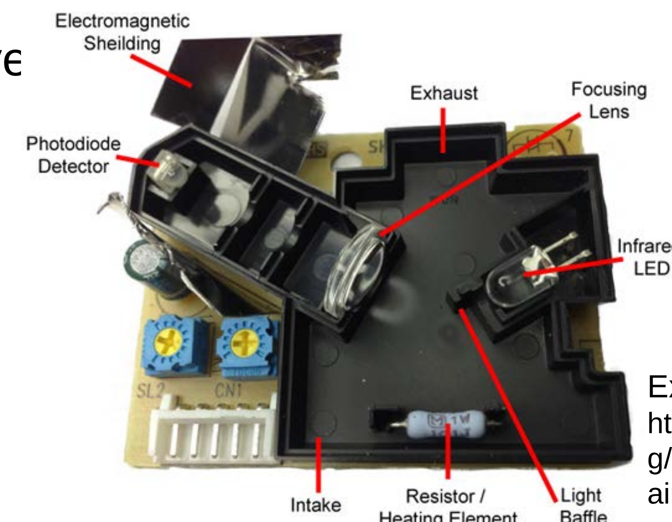
Sensor detection:

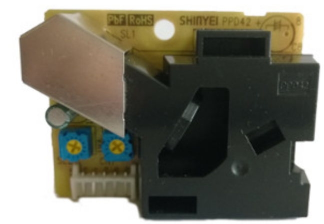
- Most emerging particle sensors operate using a light-scattering measurement principle.
- Most do not have a physical size cut (cyclone, impactor)
- Some use a passive means to move air through sensing region; others have a fan

Possible sensor measurement issues:

- Particle detection capability – transport of particles to sensor, sensor sensitivity
- Signal translation to concentration estimate

Emerging sensors (examples):





Example diagram (from: http://www.takingspace.org/make-your-own-aircasting-particle-monitor/)

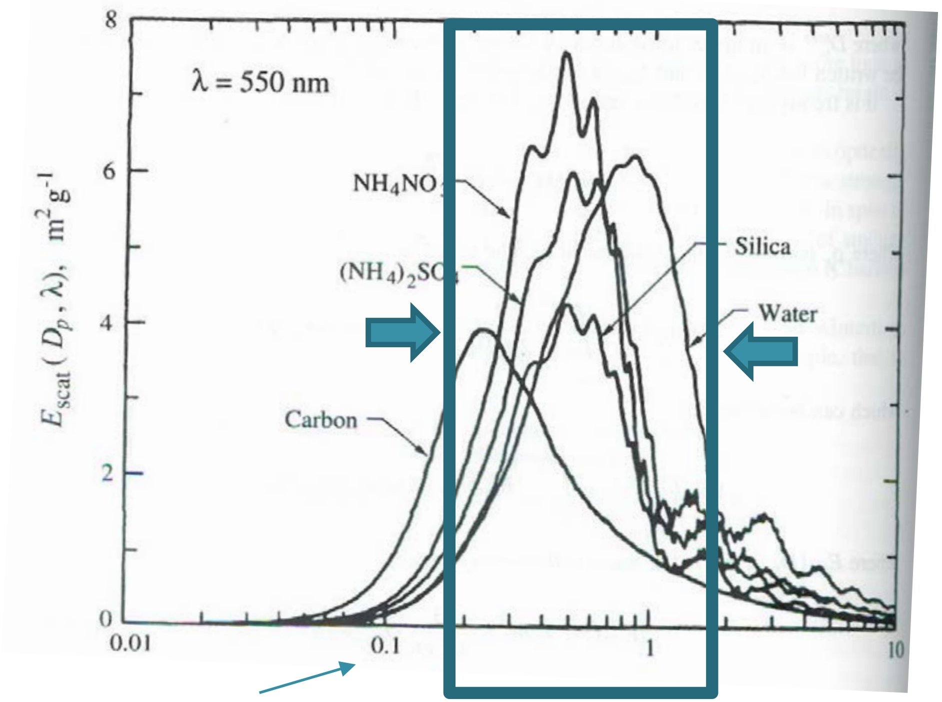
What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 µm)

Light scattering detection: what is actually being detected?

At 550 nm light, strongest scattering signal <u>per unit mass</u> for Dp ~0.2-2 µm



Increasing scattering signal with diameter, <u>per particle</u>

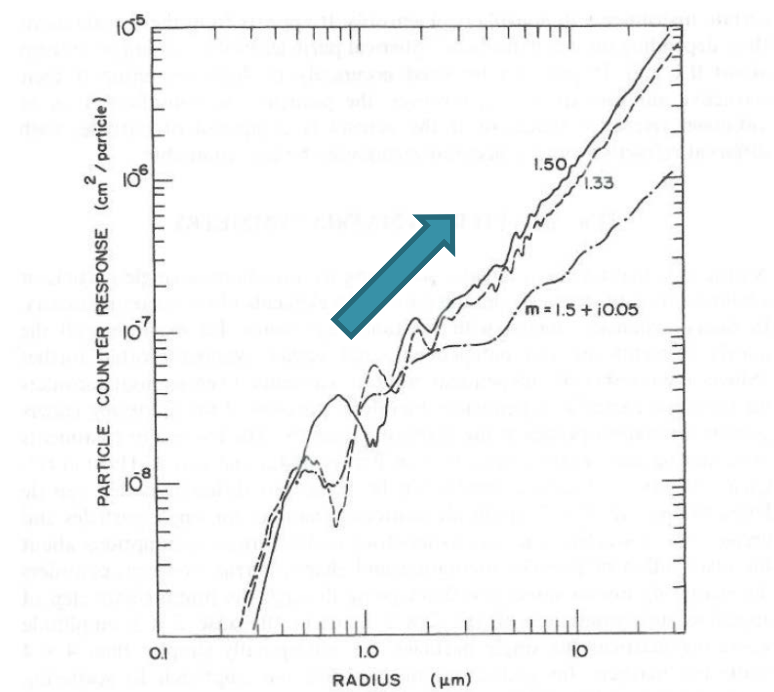


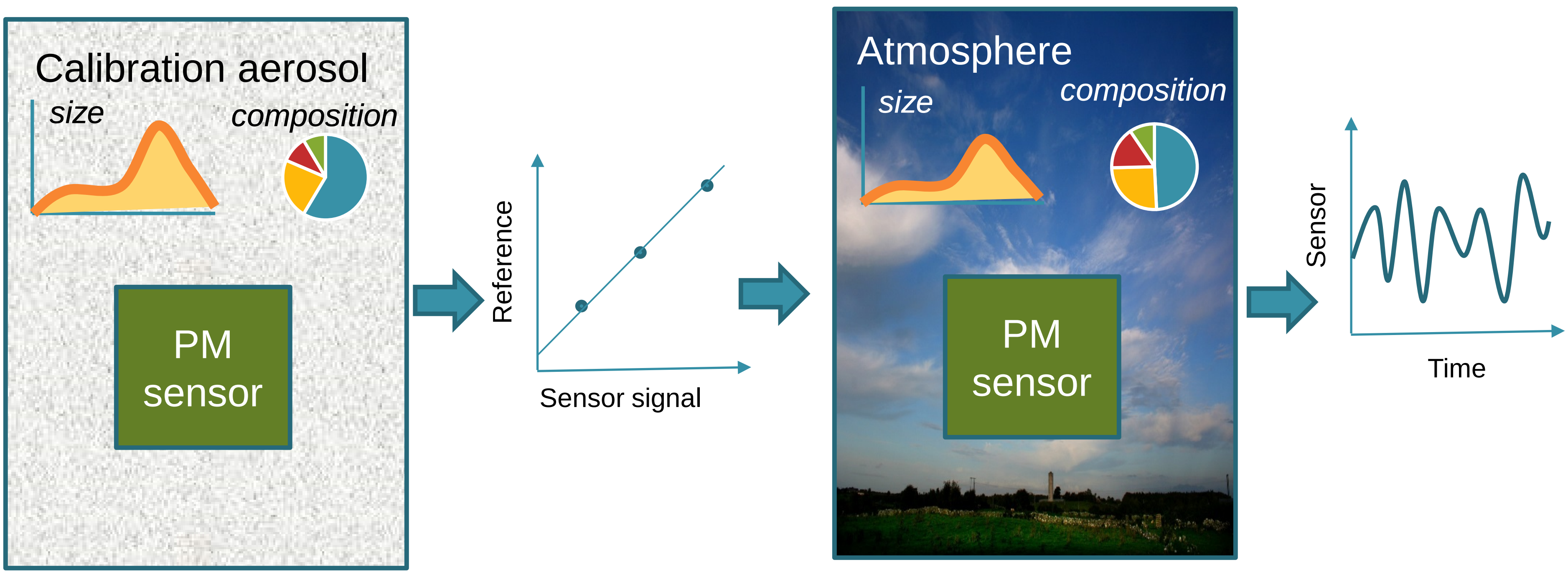
Figure 13.10 Response calculations for a particle counter that collects He–Ne laser light scattered between 4 and 22°. Reprinted with permission from R. G. Pinnick and J. J. Auvermann, *J. Aerosol Sci.*, **10** (1979), 55–74; copyright 1979, Pergamon Press, Ltd.

What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 µm)

Light scattering detection: what is actually being detected?



What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 µm)

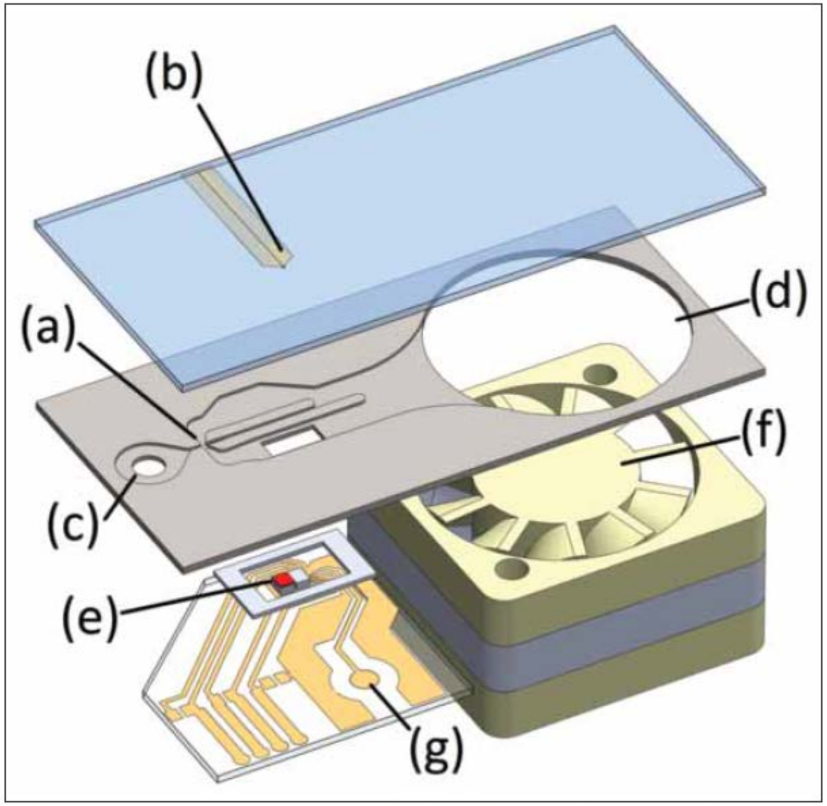
Particle mass detection:
e.g., miniature particle mass sensor with virtual impactor and mass-sensing oscillator

Reference: White, R.M. et al., Sensors and “Apps” for Community-Based Atmospheric Monitoring; *EM* May **2012**, 36-40.

Microfabricated Portable PM Monitor

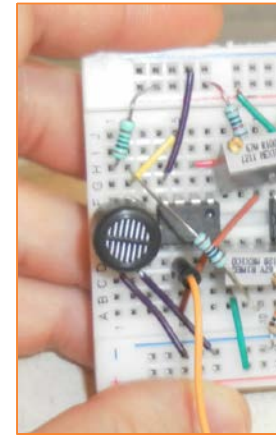
Figure 1 shows a microfabricated portable air quality PM mass monitor designed to link with a cellphone for data collection, processing, and transmission.[4] Microfabrication techniques, such as photolithography, evaporation, and etching form the structures,

Figure 1. Expanded view of the MEMS PM monitor.



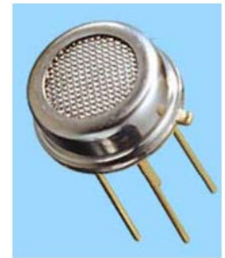
Notes: The labeled elements are (a) microfabricated virtual impactor, (b) a resistive thermophoretic heater, (c) air inlet, (d) air outlet, (e) exposed FBAR die, (f) air sampling fan, and (g) oscillator output port.

What are some of these new air sensors?



Gas-phase

e.g., Nitrogen dioxide, ozone, carbon monoxide



"Real-time" detection principle:

<u>Metal oxide sensors:</u>

Operates by contact of gas with semiconductor material, free electrons in reaction reduces resistance by increasing the flow of electrons.

Possible sensor measurement issues:

- Interfering gases in mixture
- Measurement artifact due to temperature and humidity
- Eventual failure of sensor

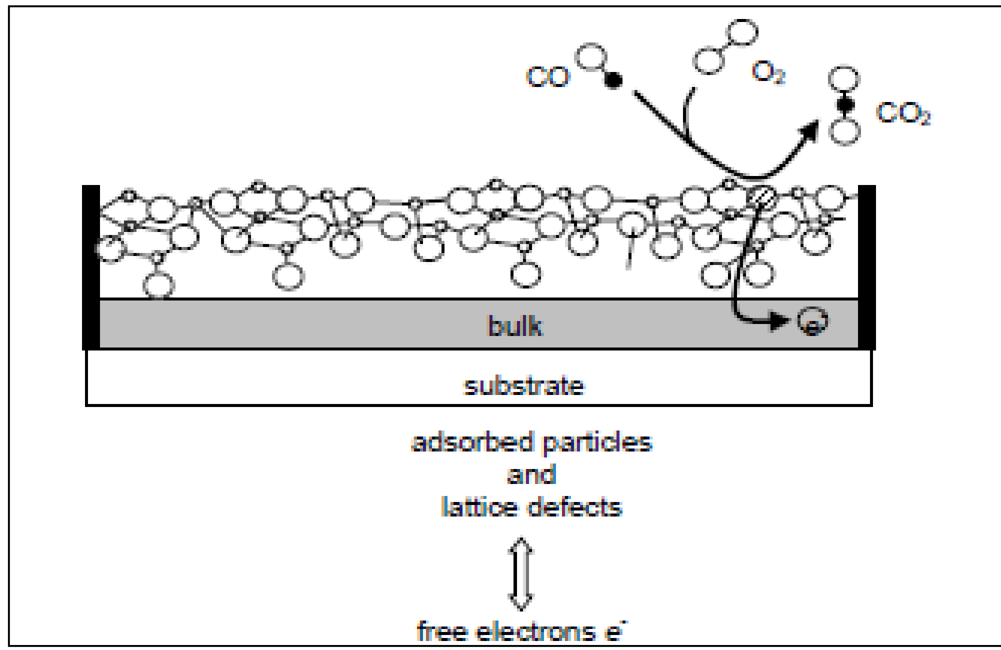


Figure. CO reaction with CO metal oxide sensor MiCS-5525 (e2v, 2009)

What are some of these new air sensors?

Gas-phase

e.g., Nitrogen dioxide, ozone, carbon monoxide

"Real-time" detection principle:

Electrochemical sensors:

Operates by oxidation reaction at sensing electrode and then reduction reaction at counter electrode

Possible sensor measurement issues:

- Interfering gases in mixture
- Measurement artifact due to temperature and humidity
- Eventual failure of sensor

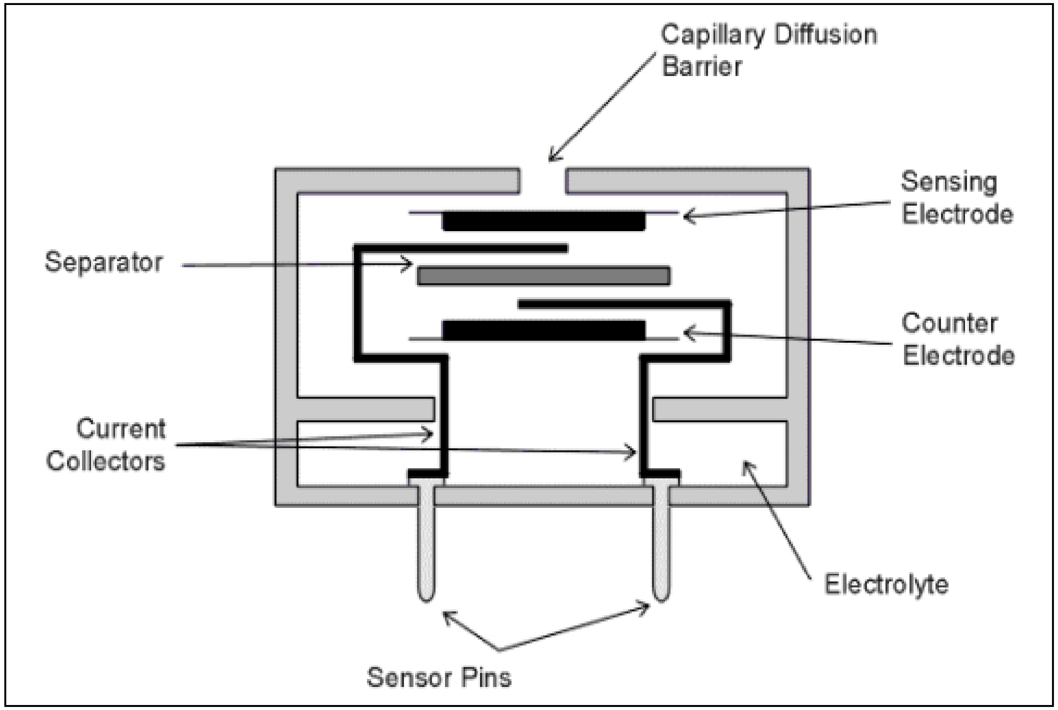


Figure. Electrochemical sensor (e2v, 2007)

What are some of these new air sensors?

Gas-phase

e.g., VOCs

"Real-time" detection principle:

Photoionization sensors:

Operates by exposing sample gas to ultraviolet light, which ionizes the sample, detector outputs voltage signal corresponding to concentration.

Possible sensor measurement issues:

- Baseline drift
- Eventual failure of sensor based on lamp lifetime.

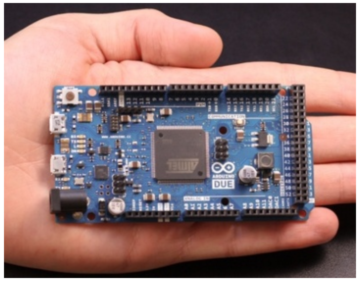
Figure. PID sensor (baseline-mocon.com)

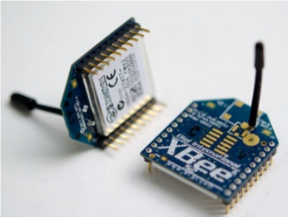
Other developments supporting new sensing technology

Smartphones / Tablets in wide use

e.g., fitbit activity tracker

Miniaturization of sensors

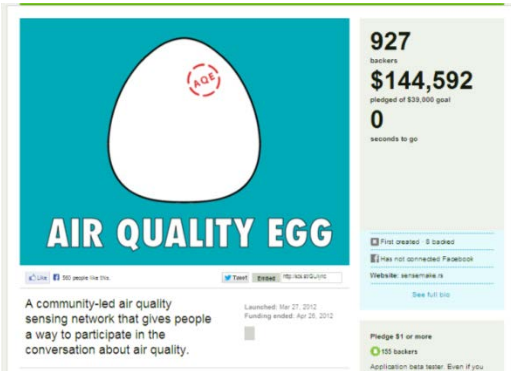




Low cost controls and communications

e.g., Arduino microprocessor

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



e.g., Kickstarter

Other developments supporting new sensing technology

Emerging data-viewing/communication apps

airalliancehouston.org

londonair.org.uk/iphone

aircasting.org

AirCasting App

AirCasting Air Monitor

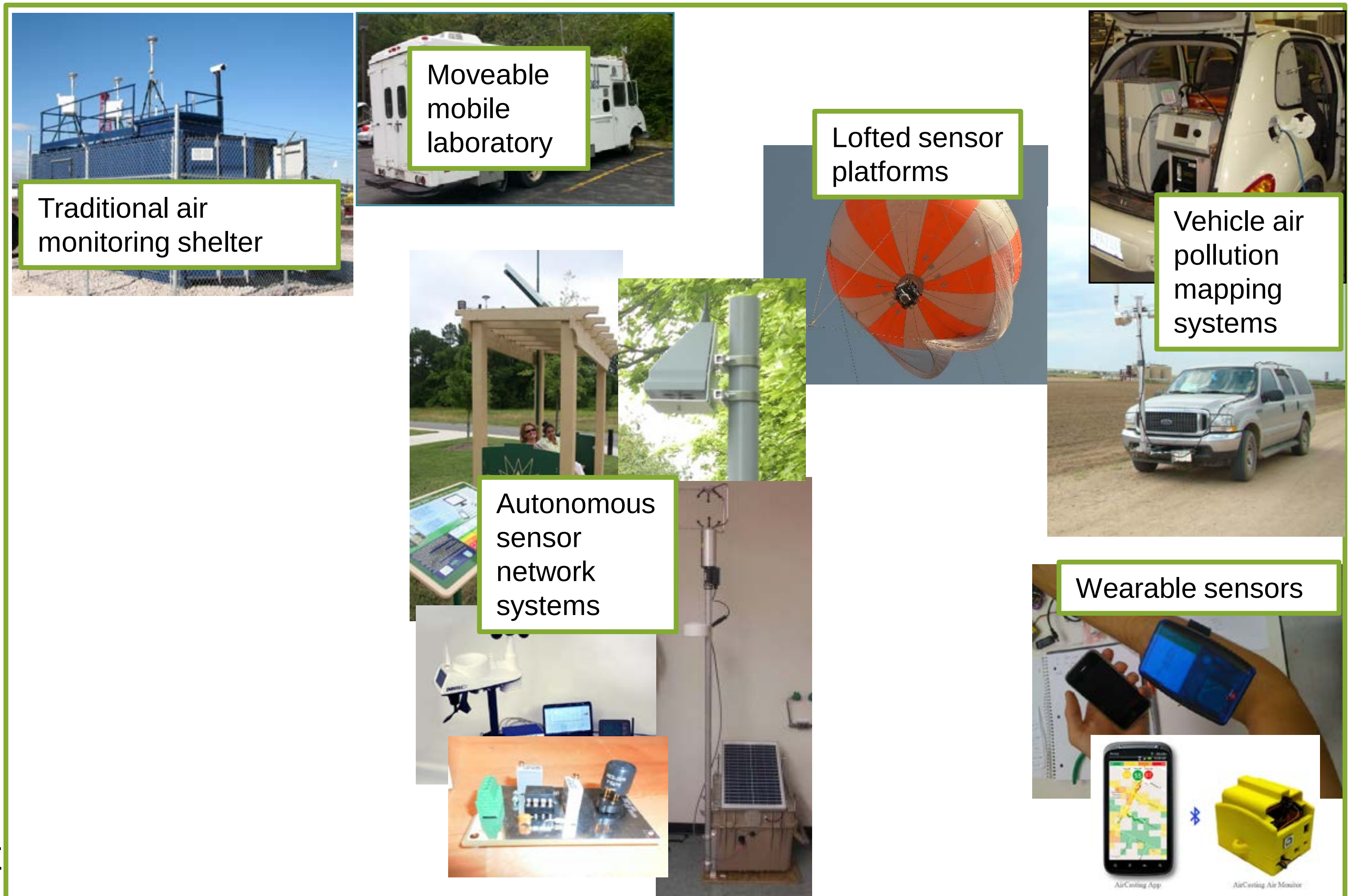
airqualityegg.com

Air sensors in full spectrum of monitoring

Higher cost systems

Desirable direction

Lower cost systems



Lower spatial resolution

Desirable direction

Higher spatial resolution

Other factors: sensor reliability, data quality, sampling rate

Next-generation air monitoring R&D has been a rapidly moving area

FY12

- ASAP workshop
- Mobile system development and application
- Sensors Evaluation and Collaboration

FY13

- Regions workshop
- Short-term sensor field tests (DISCOVER-AQ, AIRS, roadside, wildfire, fenceline)
- Data visualization support: RETIGO
- Designing/building autonomous systems: Village Green Project, S-Pod
- Mobile system development and application

FY14

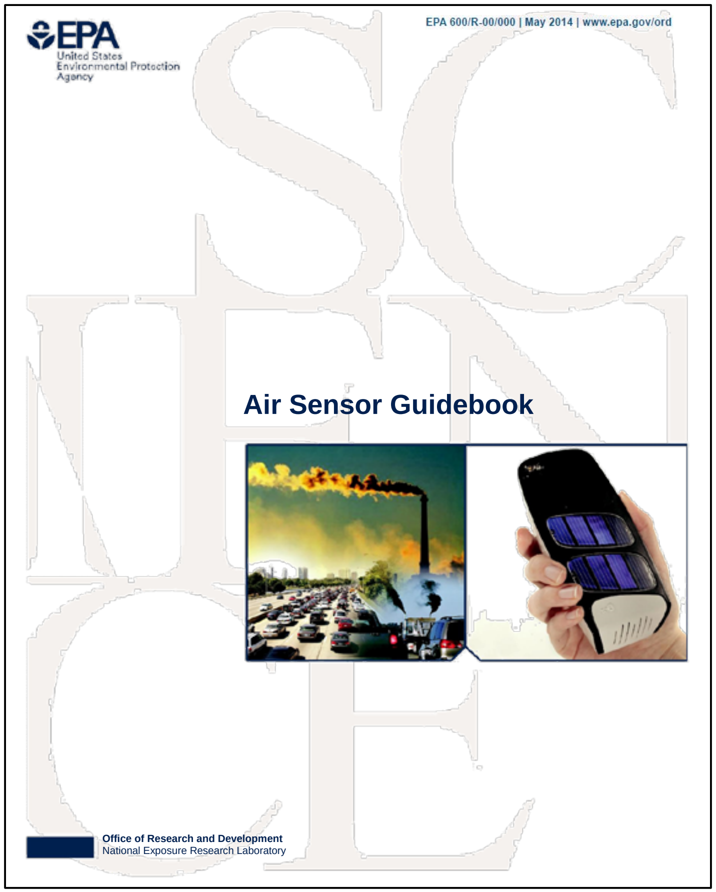
- Air sensors workshop
- Citizen Science Toolkit
- Short-term sensor field tests (DISCOVER-AQ, AIRS, roadside, wildfire, fenceline)
- Sensor network intelligent emissions locator tool (SENTINEL)
- Designing/building autonomous systems: Village Green Project II, S-Pods
- Long-term testing of sensors: Regional Methods Project
- Data visualization support: RETIGO
- Mobile

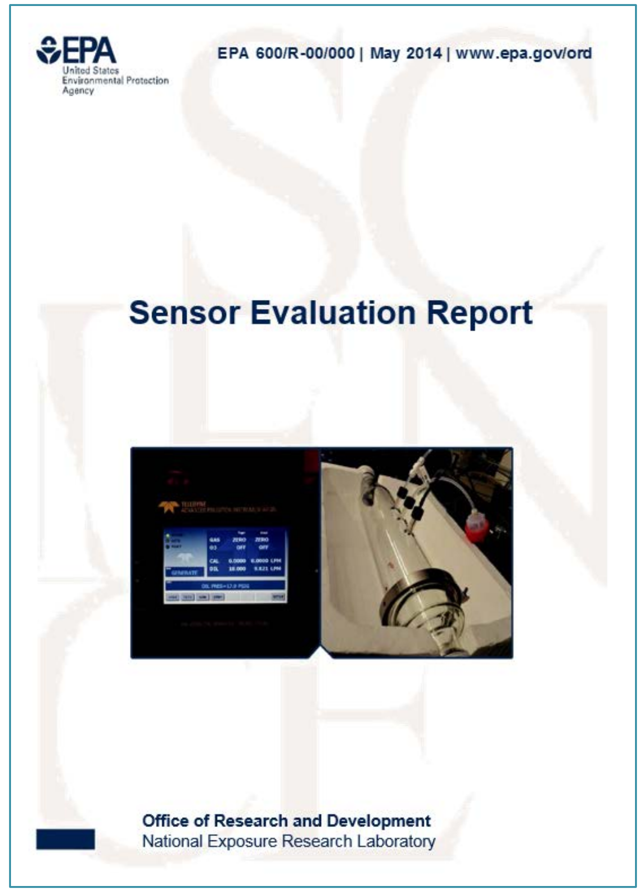
Legend:

- Workshops
- Performance testing
- Sensor system build
- Sensor data tools
- Mobile monitoring systems

Next-generation air monitoring R&D has been a rapidly moving area

Recent relevant publications and other resources:
http://www.epa.gov/research/airscience/next-generation-air-measuring.htm





Sensor performance evaluation: lab and field

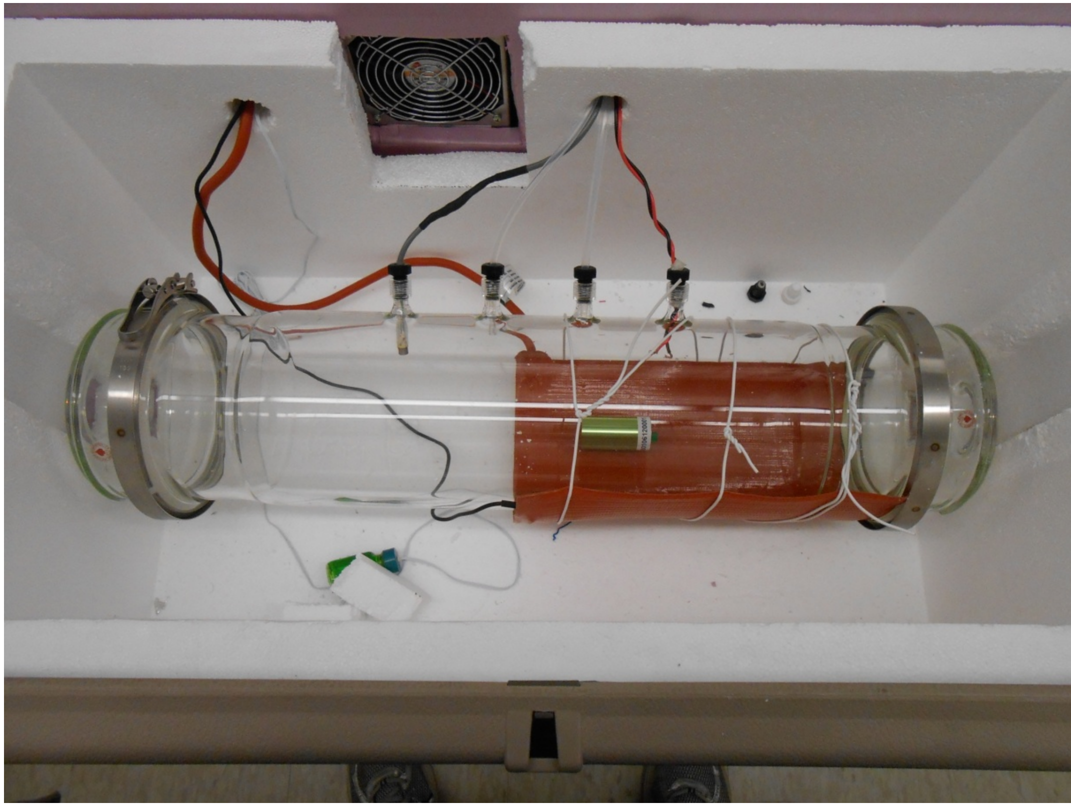
Pollutant	Laboratory controlled test	Short-term field test	Long-term field test
PM	n/a	Near-road, ambient (2013-2014)	CAIRSENSE (2014-2016)
Ozone	Completed (2013)	DISCOVER-AQ (2013-2014)	CAIRSENSE (2014-2015)
Nitrogen dioxide	Completed (2013)	DISCOVER-AQ (2013-2014)	CAIRSENSE (2014-2015)
VOCs	Ongoing	Near-road, ambient (2013-2014)	CAIRSENSE (2014-2015)
Carbon monoxide	Ongoing	DISCOVER-AQ (2014) Forest fire study (2014)	CAIRSENSE (2014-2015)
Sulfur dioxide		DISCOVER-AQ (2014)	CAIRSENSE (2014-2015)

- Report on laboratory evaluation of ozone and nitrogen dioxide sensors to be released in 2014

Points of contact: Ron Williams, Russell Long, Gayle Hagler

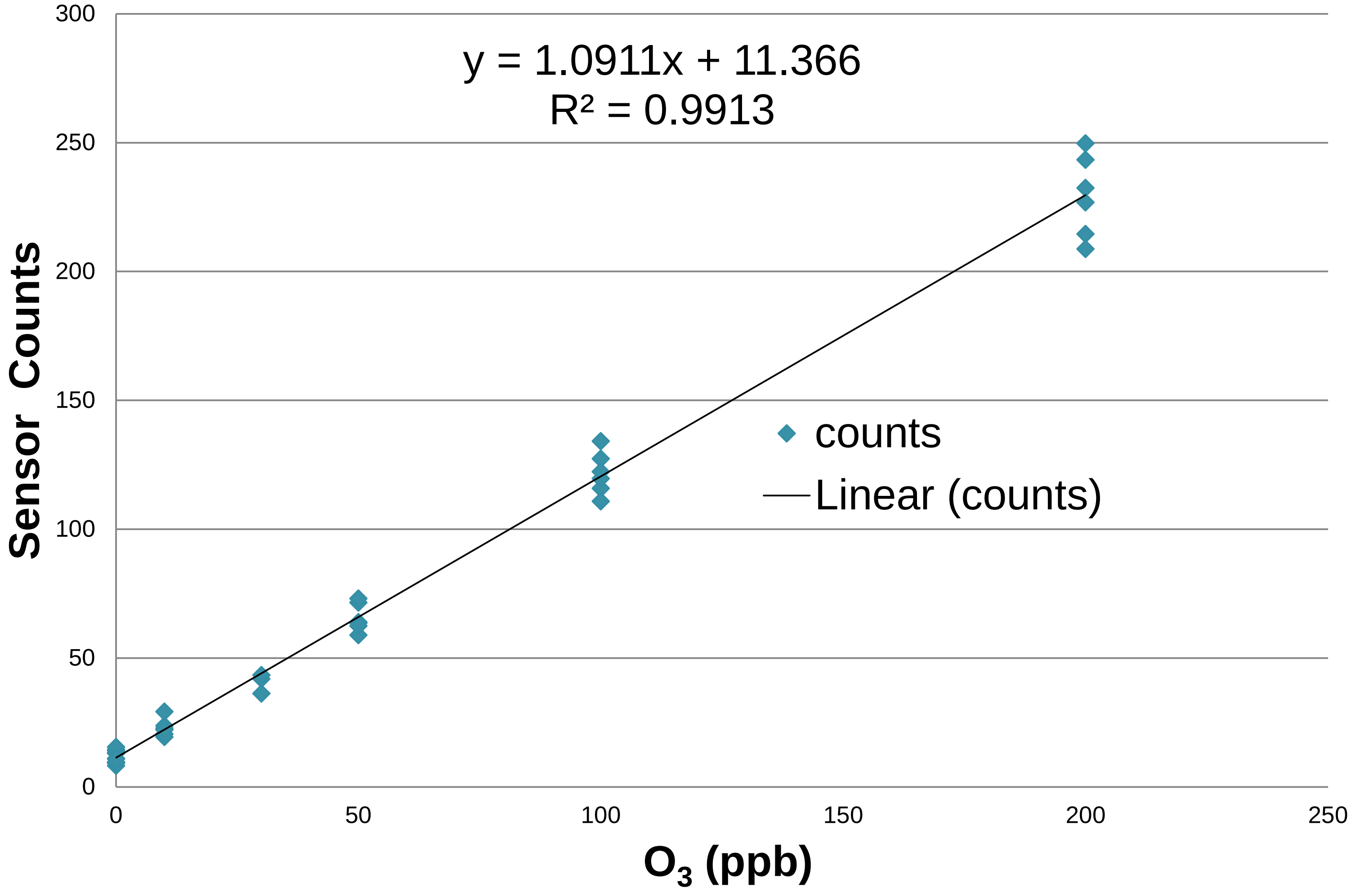
Sensor performance evaluation: lab and field

Example: Cairpol sensor for NO_2/O_3



Point of contact: Ron Williams

Sensor performance evaluation: lab and field

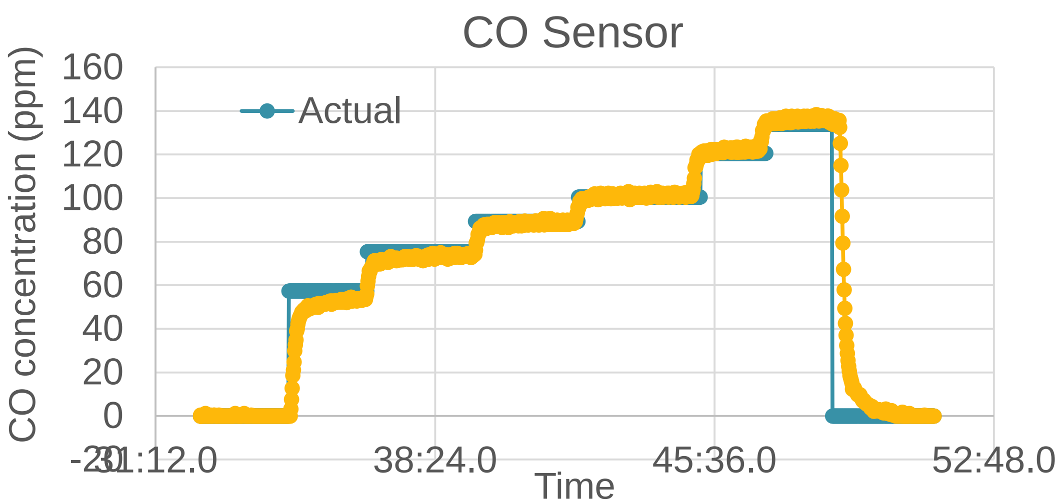


(slide courtesy of Ron Williams)

Sensor system development

Point of contact: Brian Gullett

Air sensor system development to characterize emission plumes



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

Sensor system development

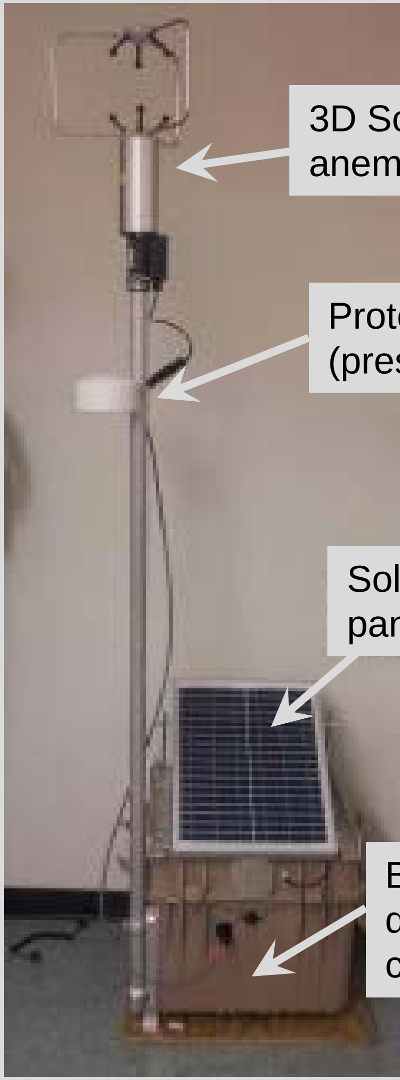
Points of contact: Gayle Hagler, Ron Williams

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

Sensor system development

Point of contact: Eben Thoma

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

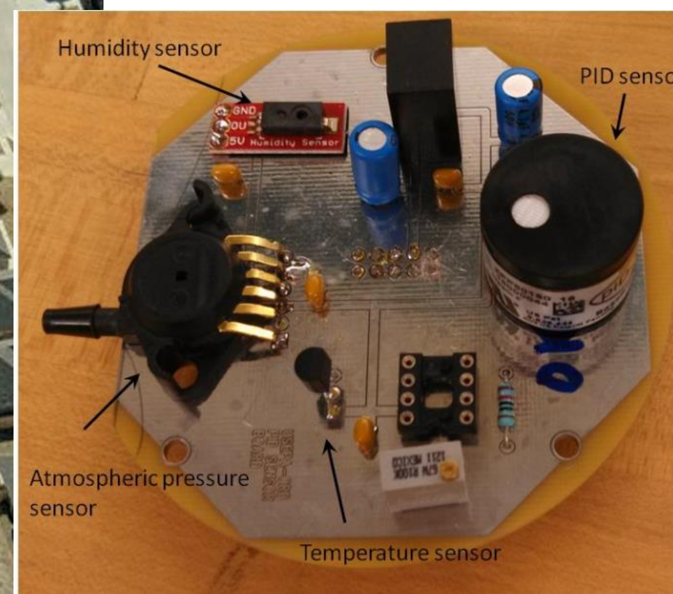
Point of contact: Eben Thoma

Sensor system development

Conceptual application

EPA PID sensor board

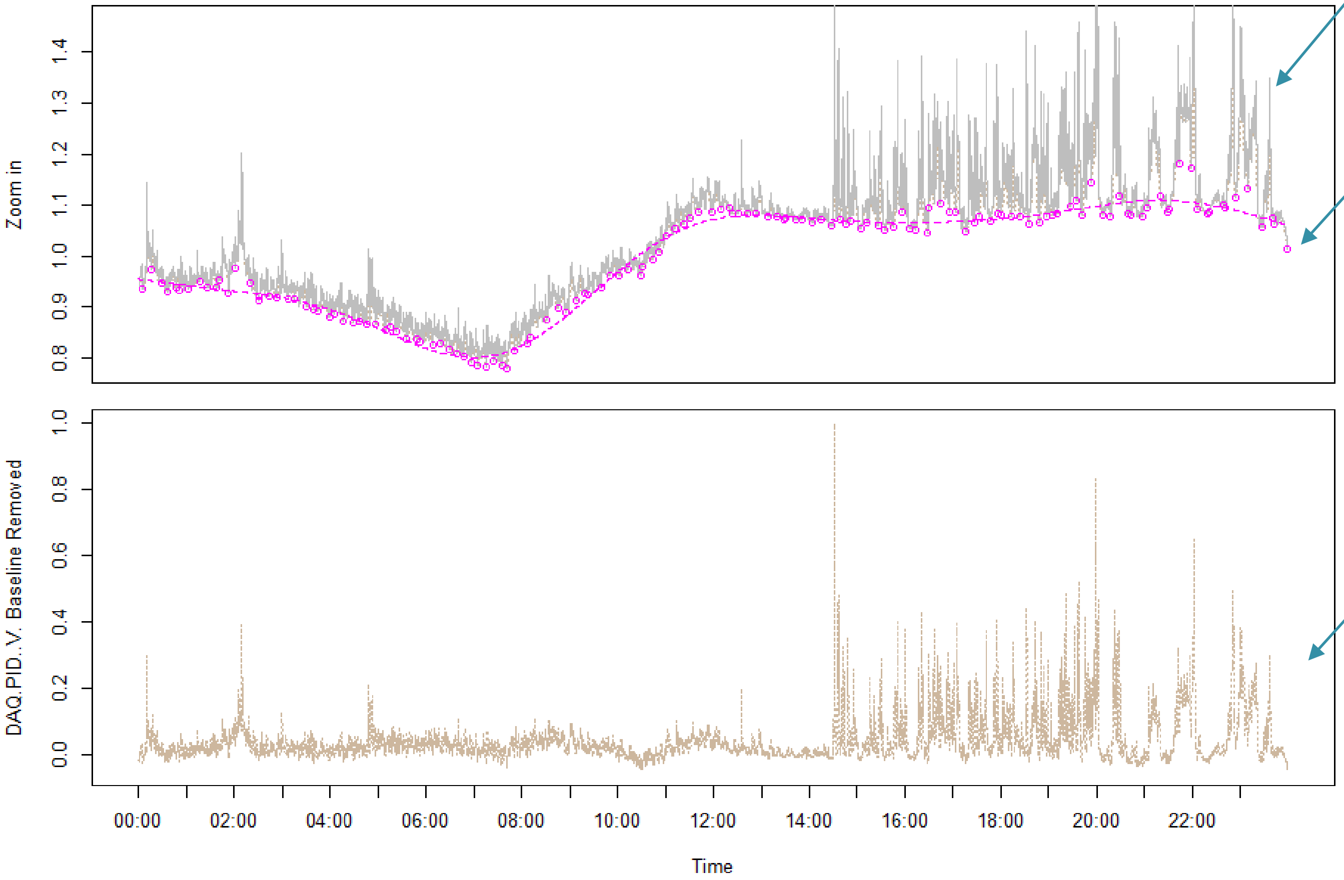
(PID from Baseline Mocon Inc.)



Sensor system development

Point of contact: Eben Thoma

Data processing exploration to maximize sensor utility:



Original PID sensor output (in Volts)

Estimation of sensor baseline drift

Recovered signal, allowing local-source influence to be detected

Sensor system development

Region 2 / ORD RARE Project – Citizen Science Toolkit and the Ironbound Community Corporation

Citizen Science Tool Box:

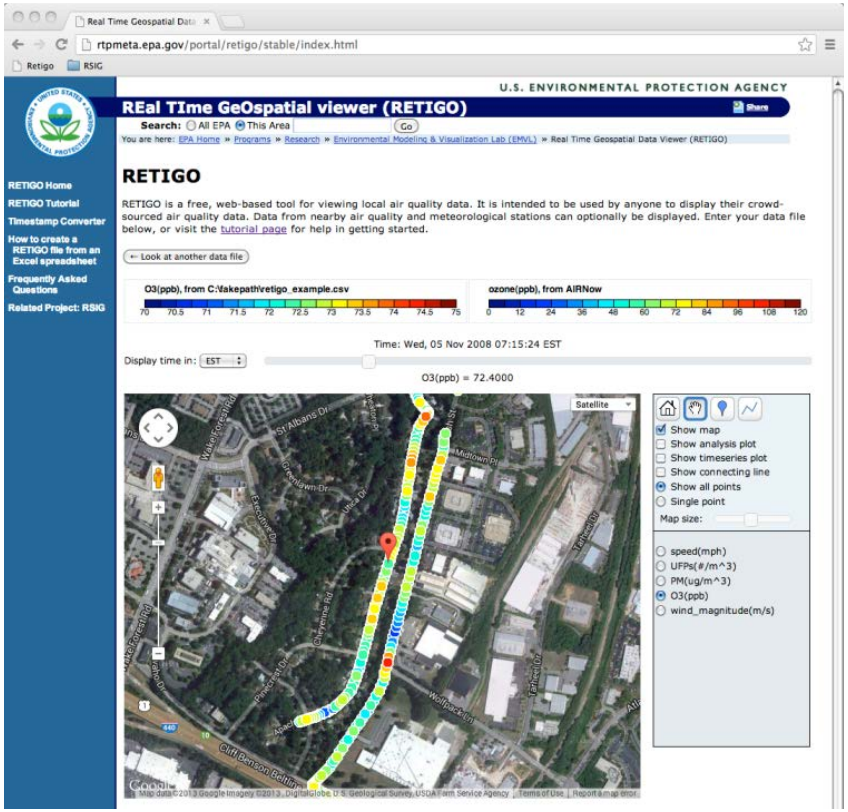
1. Basic SOP for hand-held sensors
2. One-page, quick-start guide
3. Training materials on sensor use
4. Guidance and deployment based on pollutants and sources
5. Basic ideas for data analysis, interpretation, and communication

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

Data visualization support: RETIGO

Point of contact: 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:

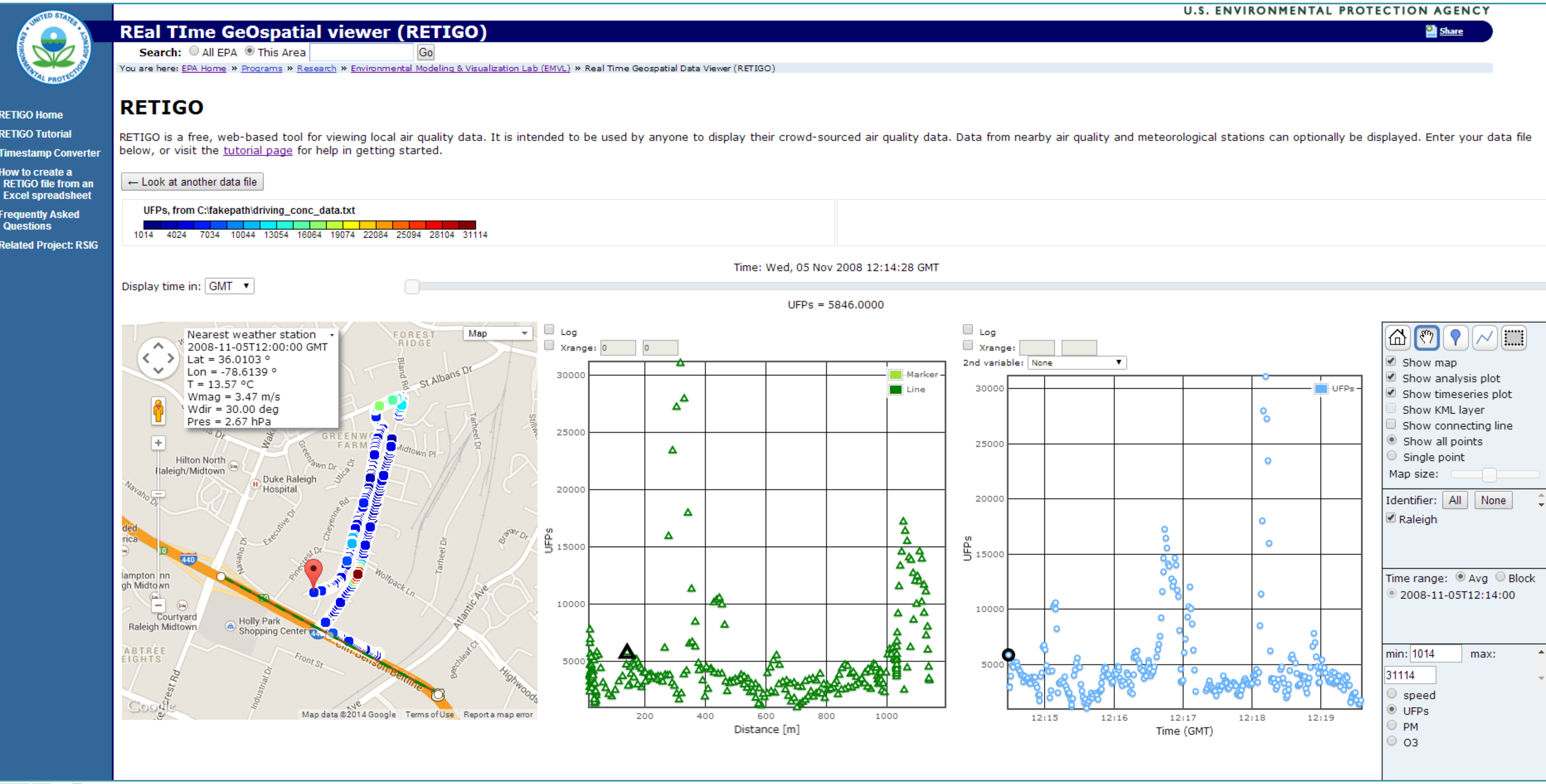
- Analysis often limited to those individuals with advanced training and access to specific software tools (e.g., MATLAB, GIS, etc.)

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.

Data visualization support: RETIGO

Point of contact: Gayle Hagler

- Allows exploration of data over time and space
- Supports plotting concentration as a function of distance from a hypothesized line or point source

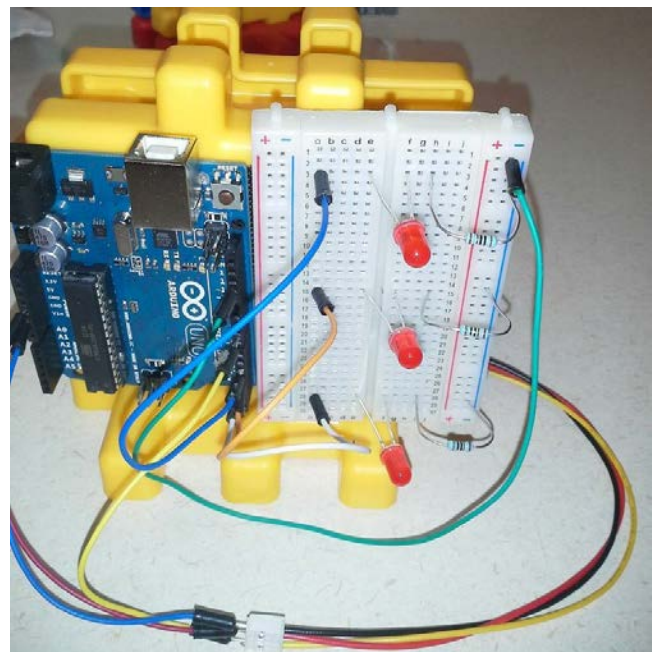


What else is out there? : Education focus

- Supporting project-based learning and STEM (science, technology, engineering, and mathematics) education

<u>Components</u>

- Low cost particle sensor
- Arduino microprocessor
- Breadboard, LEDs, wires



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Hacking a fiber-optic flower centerpiece to change colors with CO_2 levels

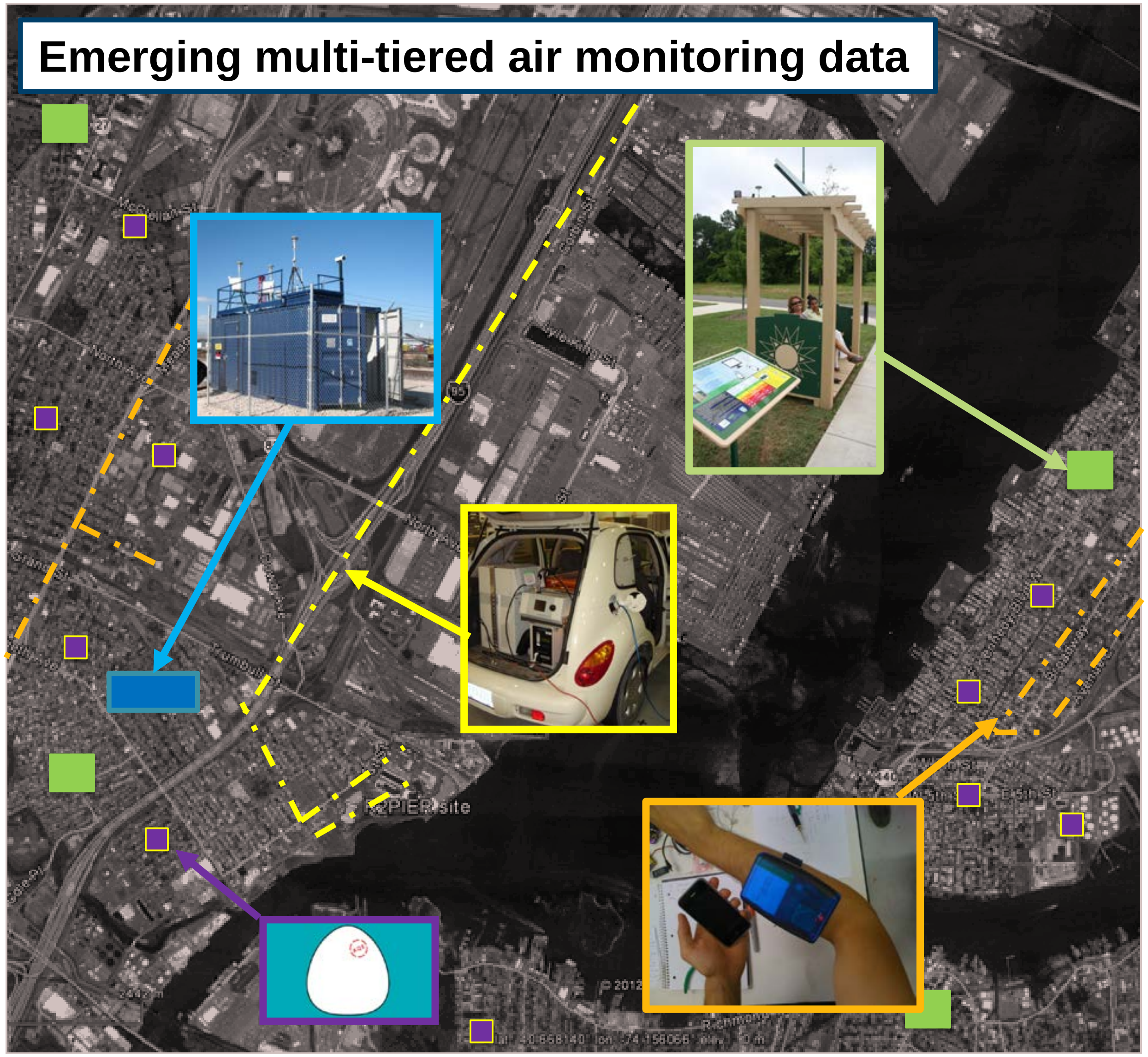
CO_2 NDIR sensor

Fiber optic flower demo

What does this all mean?

	Current Approach		New Paradigm
How data are collected?		Sensor Technology →	
Who collects the data?	Limited Mostly to Governments, Industry, and Researchers		Expanded Use by Communities and Individuals
Why data are collected?	Compliance Monitoring, Enforcement, Trends, Research		New and Enhanced Applications
How data are accessed?	Government Websites, Permit Records, Research Databases		Increased Data Availability and Access

Challenges and opportunities



Opportunities:

- Unprecedented access to data on neighborhood-scale air quality
- Lower cost strategies to achieve air monitoring goals
- Engagement with communities, schools, industry

Challenges:

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

Ongoing work at EPA

- Field and laboratory research to characterize performance of new sensors
- Development of tools for managing and visualizing sensor data
- Ongoing dialogue on policy implications and public health messenging

Acknowledgements

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