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Dec 9-11, Charlottesville, VA

Lower cost air measurement technology – what is on the market, what is coming, and is it good enough?

Gayle Hagler, PhD
EPA Office of Research and Development

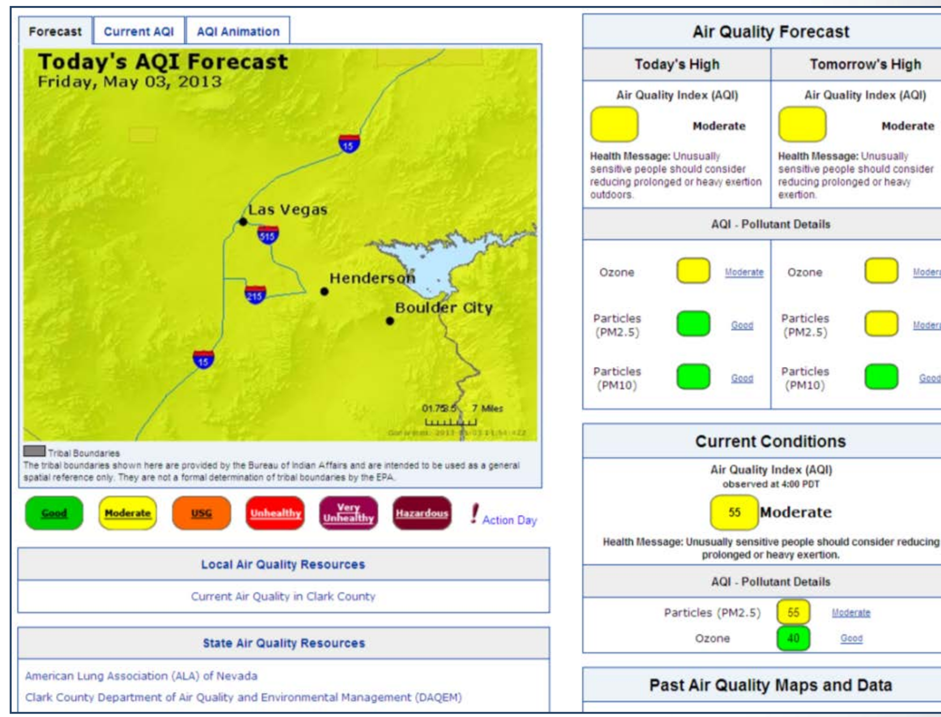
Goals of this talk

- Provide our perspective on the ongoing evolution of lower cost air measurement technologies
- Provide information on recent and upcoming EPA activities

Many hands at EPA contributing to this work!

Traditional paradigm

Government-provided data via traditional instrumented shelters; Air Quality Index calculated on broad time and spatial scales.



- Expensive instruments
- Specialized training required
- Large physical footprint
- Large power draw

Motivation for new approaches

High interest by public for more information

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

Measuring air pollution is an evolving technology landscape

Higher cost systems

Desirable direction

Lower cost systems

Lower spatial resolution

Desirable direction

Higher spatial resolution

New mid-tier cost systems

AQ Mesh

Measures:
Ozone, nitrogen dioxide, nitrogen oxide, sulfur dioxide, carbon monoxide, temperature, RH

What is inside?:

- Multiple low-cost <u>electrochemical sensors</u>
- Integrated battery power
- Integrated communications
- Proprietary manufacturer algorithms to estimate concentrations from the suite of sensors.

New mid-tier cost systems

elm

Older generation: CanairIT

Measures:
Nitrogen dioxide, nitrogen oxide, ozone, VOCs, particles, noise, RH

What is inside?:

- Low-cost electrochemical and metal oxide sensors for gases
- Light-scattering based sensor for particles
- Integrated battery power
- Integrated communications
- Proprietary manufacturer algorithms to estimate concentrations from the suite of sensors.

New mid-tier cost systems

CAIRSENSE sensor pod

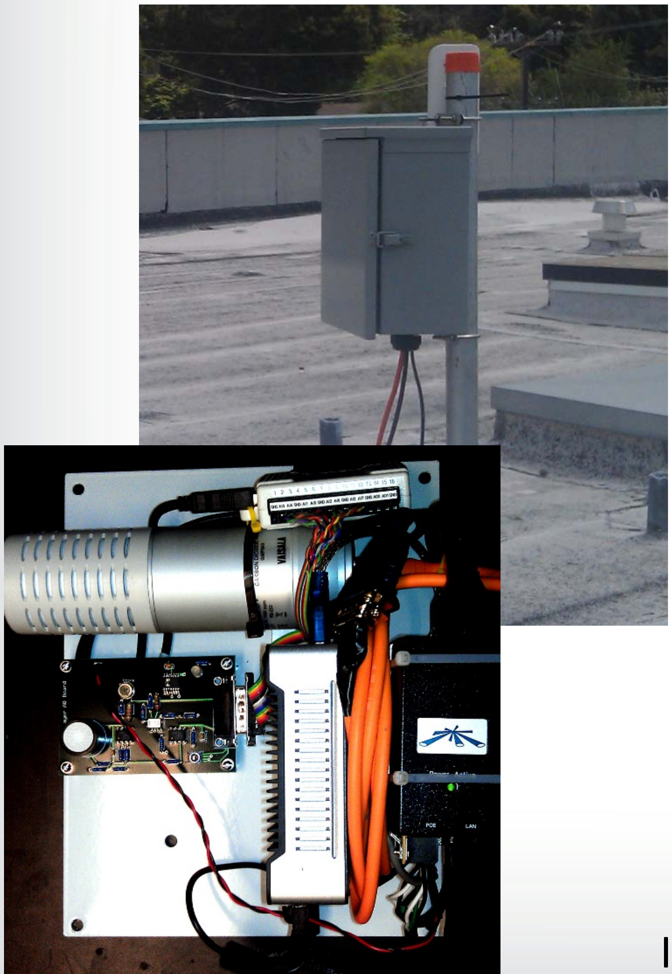
Measures:
Nitrogen dioxide, ozone, particles, temperature, relative humidity

What is inside?:

- Low-cost electrochemical and semiconductor sensors for gases
- Light-scattering based sensor for particles
- Integrated battery power
- Integrated communications
- Using "sensor devices" with direct concentration readout

New mid-tier cost systems

BEACON sensor pod



Measures:
Carbon dioxide, nitrogen dioxide, carbon monoxide, ozone, temperature, pressure, humidity

What is inside?:

- Mid-cost instrument for CO_2 (Vaisala)
- Low cost metal oxide sensors for other gases
- Ethernet communications - relies on local access
- No internal power – relies on landpower

Information from: http://beacon.berkeley.edu/Overview.aspx

New mid-tier cost systems

Village Green Project

Measures:
$PM_{2.5}$, ozone, wind speed/direction, temperature, humidity

What is inside?:

- Mid-cost instruments for $PM_{2.5}$ (pDR-1500, Thermo Scientific) and ozone (OEM-106, 2B Technologies)
- Cellular based communications
- Solar panels plus battery (wind turbine option in-development)
- Automated data quality checks on server

Website: http://villagegreen.epa.gov

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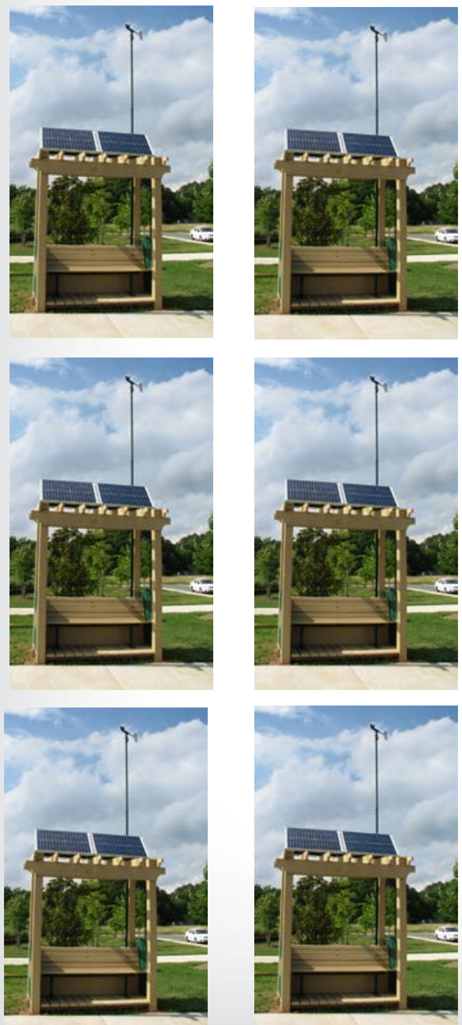
New mid-tier cost systems

"Village Green 2"



- Five locations selected from 22 state/local agency proposals to receive a Village Green station in a pilot expansion

- Several of the new stations will have an added 2' diameter wind turbine for supplemental power.

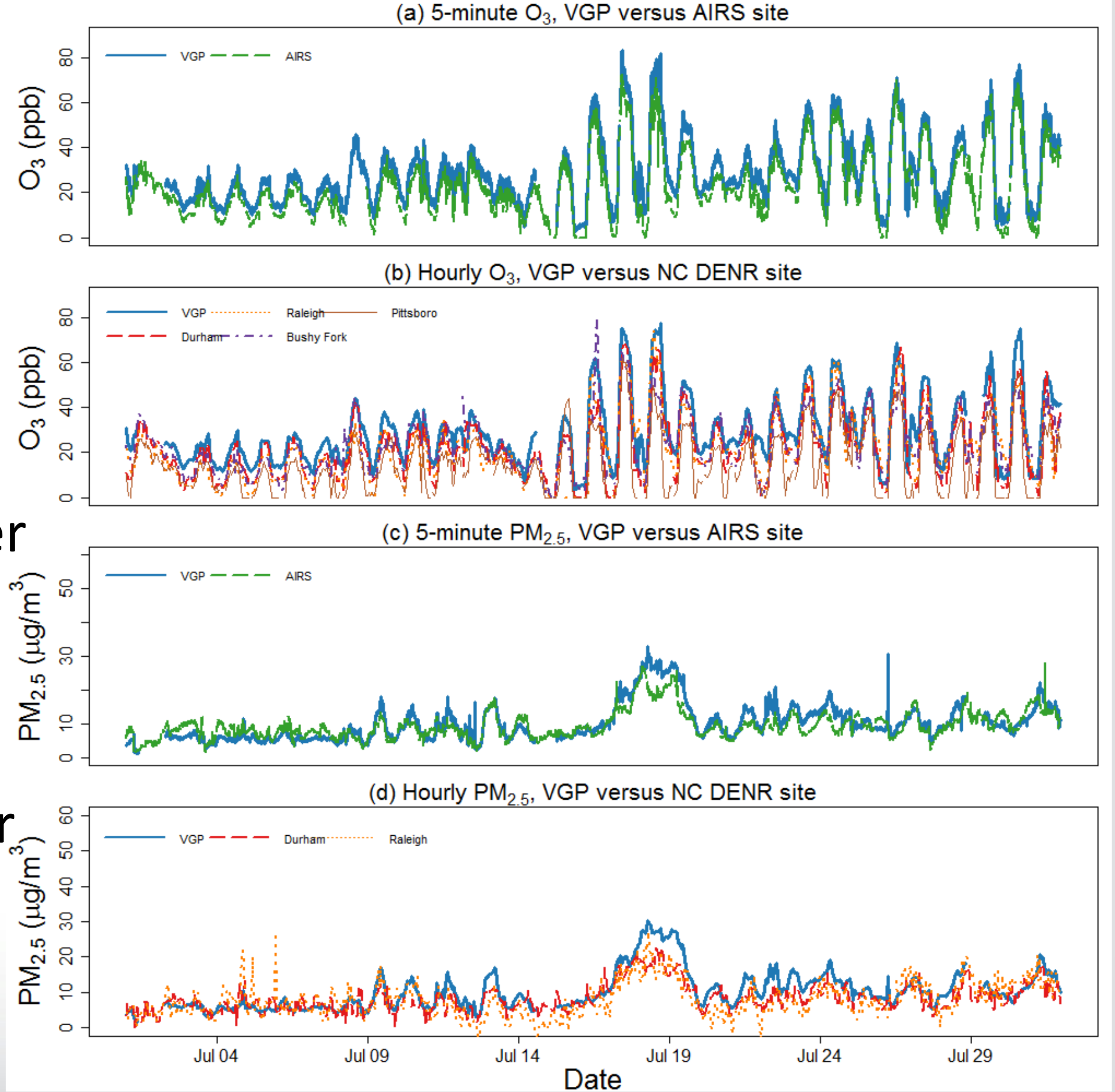
- Cold weather capacity developed – automated instrument shutdown and low power heater with low temperature trigger

- Expanded data-handling capacity through migrating data system to AirNow

New mid-tier cost systems

"Village Green 2"

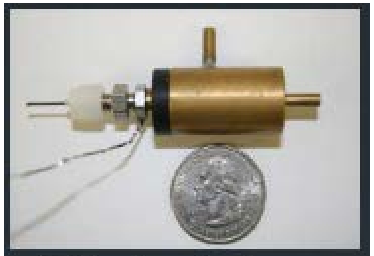
- Overall, very good agreement on area-wide trends
- Solar power system provided adequate power for operation 95% of the time in North Carolina.
- Other sporadic causes for interruption were communications, instrument maintenance



What is missing on the mid-tier measurement list?

Particles:

- **True "mass" measurement…work is in progress**
- **All specific species missing (ions, elements, carbon fractions)**
- **Ultrafine sensors – work in progress**



Unipolar min-charger

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"

- **Black carbon is close, but still not there for long-term, continuous monitoring**

- Palm-sized black carbon instrument (cost >5K)
- Requires ~daily internal filter change, manually
- Data logged internally and requires manual download

What is missing on the mid-tier measurement list?

Gases:

- **Speciated VOCs and air toxics**
- **Sulfur dioxide sensor or instrument with adequate sensitivity for low ambient concentrations (e.g., <10 ppb)**
- **Capability to assess data quality in real-time for the low cost gas (and some particle) sensors which output only a single value (e.g., voltage) – work in progress**

Emergence of low cost sensors

Particle-phase

Larger particles (>0.1 µm)

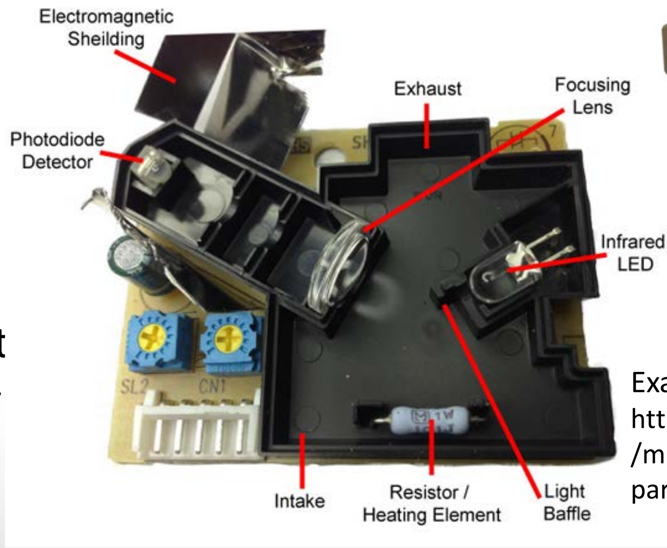
<u>Sensor detection</u>:

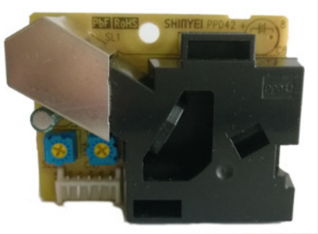
- Most emerging particle sensors operate using a **light-scattering measurement** principle.
- Most **do not have a physical size cut** (cyclone, impactor).
- Some use a passive means to move air through sensing region; others have a fan.

<u>Possible sensor measurement issues</u>:

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

Emerging sensors (examples):



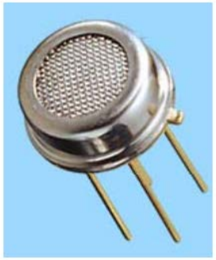


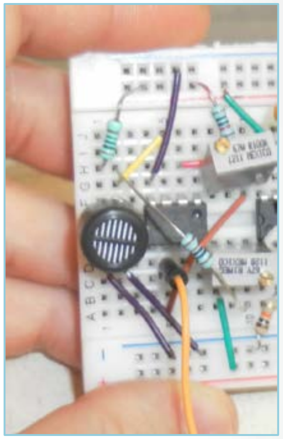
Example diagram (from: http://www.takingspace.org/make-your-own-aircasting-particle-monitor/)

Emergence of low cost sensors

Gas-phase

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

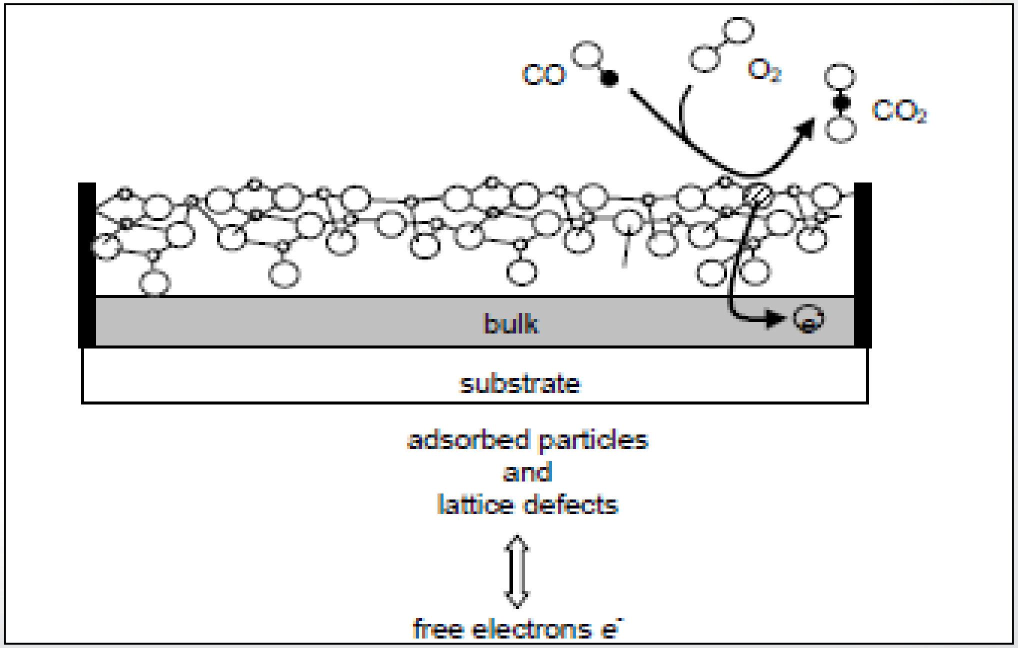




<u>Metal oxide sensors:</u>
Operate by contact of gas with semiconductor material; free electrons in reaction reduces resistance by increasing the flow of electrons.

<u>Possible sensor measurement issues</u>:

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



Emergence of low cost sensors

Gas-phase

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

__Electrochemical sensors__:
Operates by oxidation reaction at sensing electrode and then reduction reaction at counter electrode

<u>Possible sensor measurement issues</u>:

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

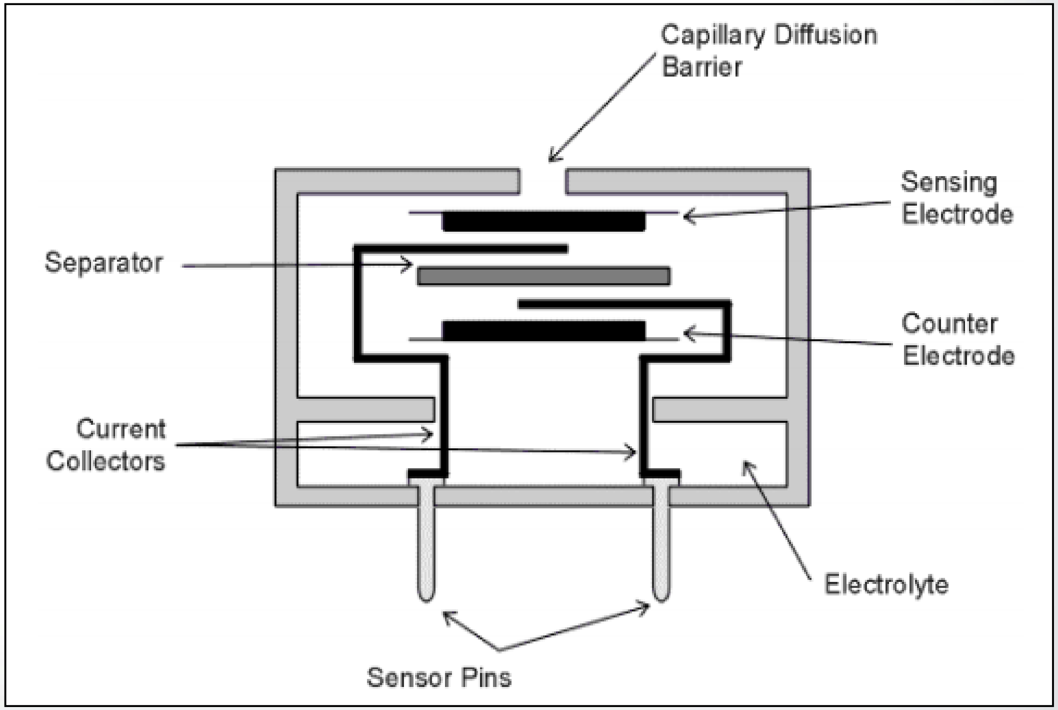


Figure. Electrochemical sensor (e2v, 2007)

Emergence of low cost sensors

Gas-phase

e.g., VOCs

<u>Photoionization sensors</u>:
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)

Sensor applications

Stationary mode – source fence-line, community measurements

Conceptual application

"S-Pod": Drop-in-place VOC sensor + 3D wind measurement

Sensor applications

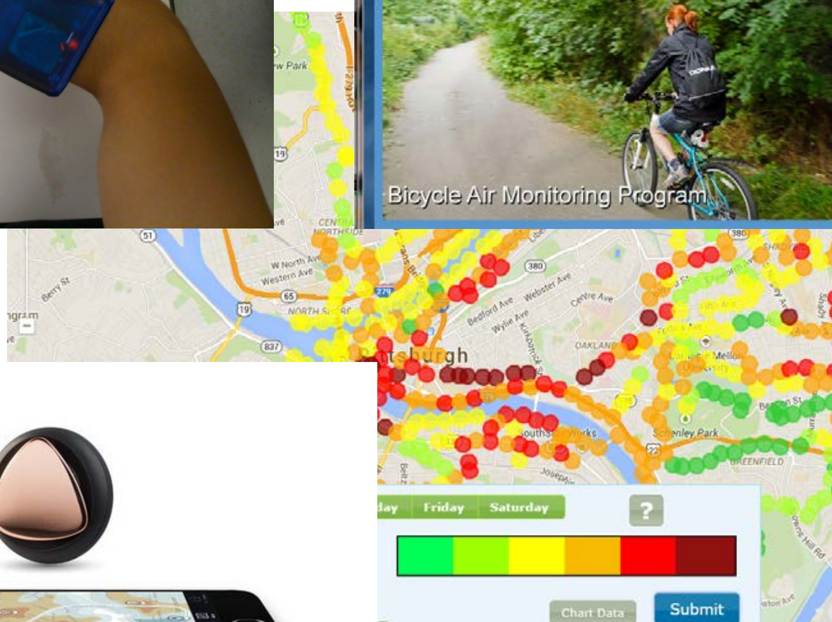
Stationary mode – source fence-line, community measurements

e.g., multipollutant sensor stations in near-road community setting

Sensor applications

Mobile mode:

- Personal monitoring
- Community group monitoring
- Mapping spatial trends



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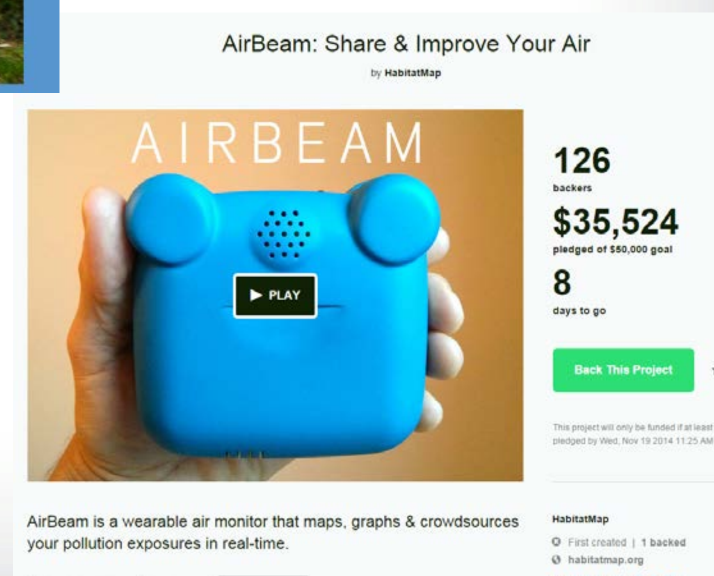


Sensor applications

Education/outreach

EPA ORD’s particle sensor kit

Instrumented kites measuring VOCs

http://f-l-o-a-t.com/

Hacking fiber optic flowers to light up based on CO_2 sensor readings (EPA ORD)

The big question

Would a "low cost" sensor device meet my monitoring need?

Which naturally leads to additional questions:

- *Are the sensors any good / "good enough" for my application?*
- *Are they easy to operate?*
- *How does the performance vary with environmental conditions?*
- *What do I need to do to process and interpret the data?*

Are any sensors "good enough"?

Testing environments:

- Controlled laboratory setting – challenge against interfering species, temperature/humidity effects, etc.
- Co-locate with reference instruments in a field setting

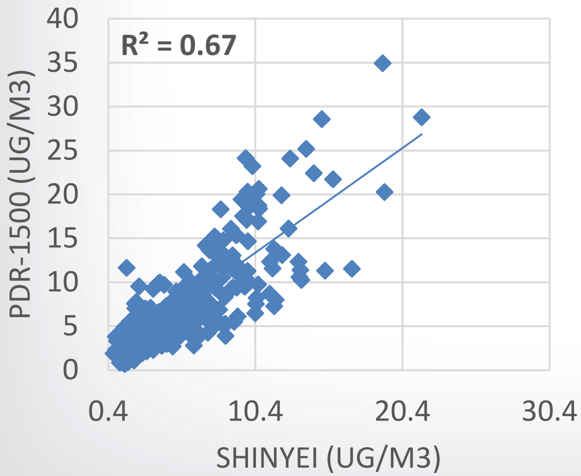
<u>Ongoing side-by-side evaluation:</u>

e.g., sensor testing in triplicate next to reference instruments

Are any sensors "good enough"?

Example short-term field test comparison of particle sensors (EPA RTP) – *preliminary observations (~1 week of data)*

SHINYEI



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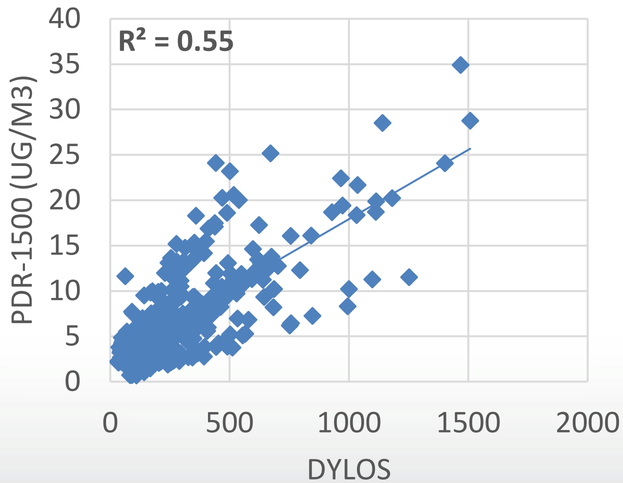
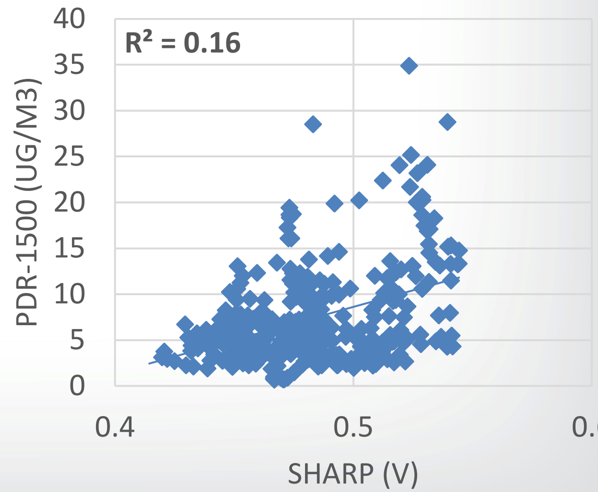


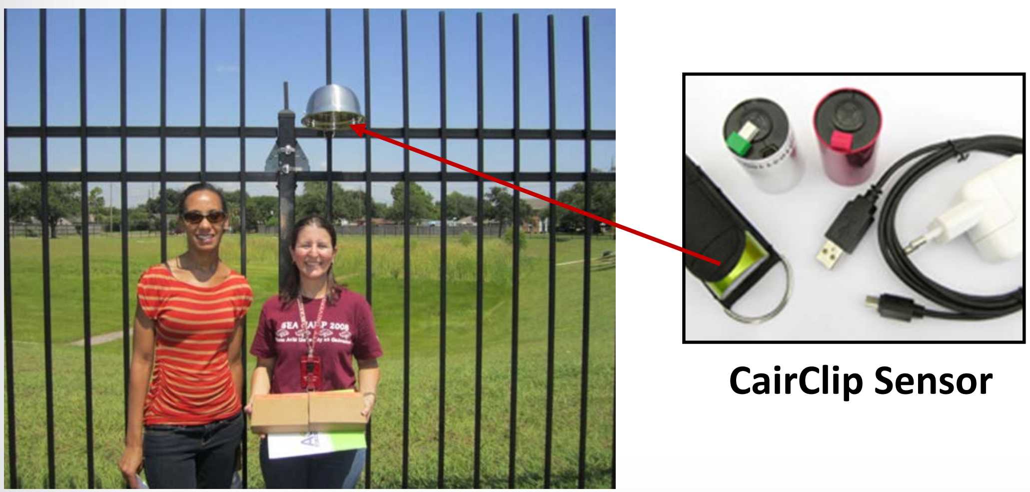
SHARP



Are any sensors "good enough"?

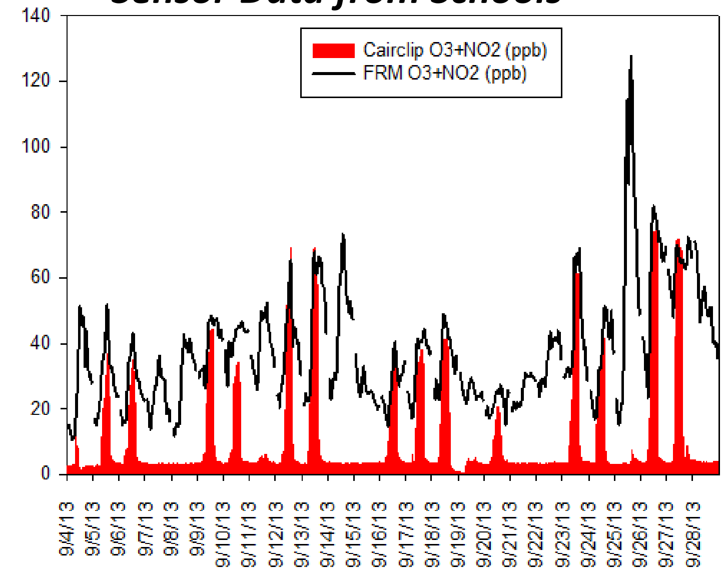
DISCOVER-AQ Study Houston, TX (Sept. 2013)

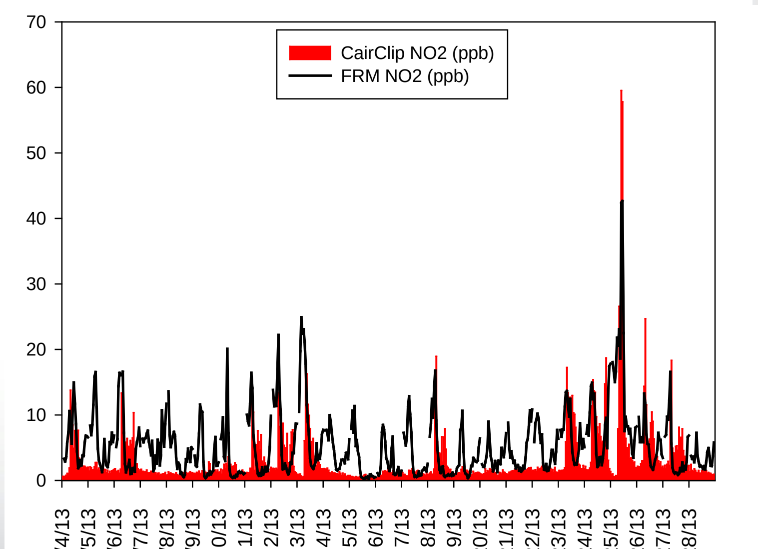
- Citizen science: small NO_2/O_3 and NO_2 sensors deployed at 7 schools
- Sensor data compared to reference analyzer data
- Low-cost sensors performed well



CairClip Sensor

Sensor Data from Schools

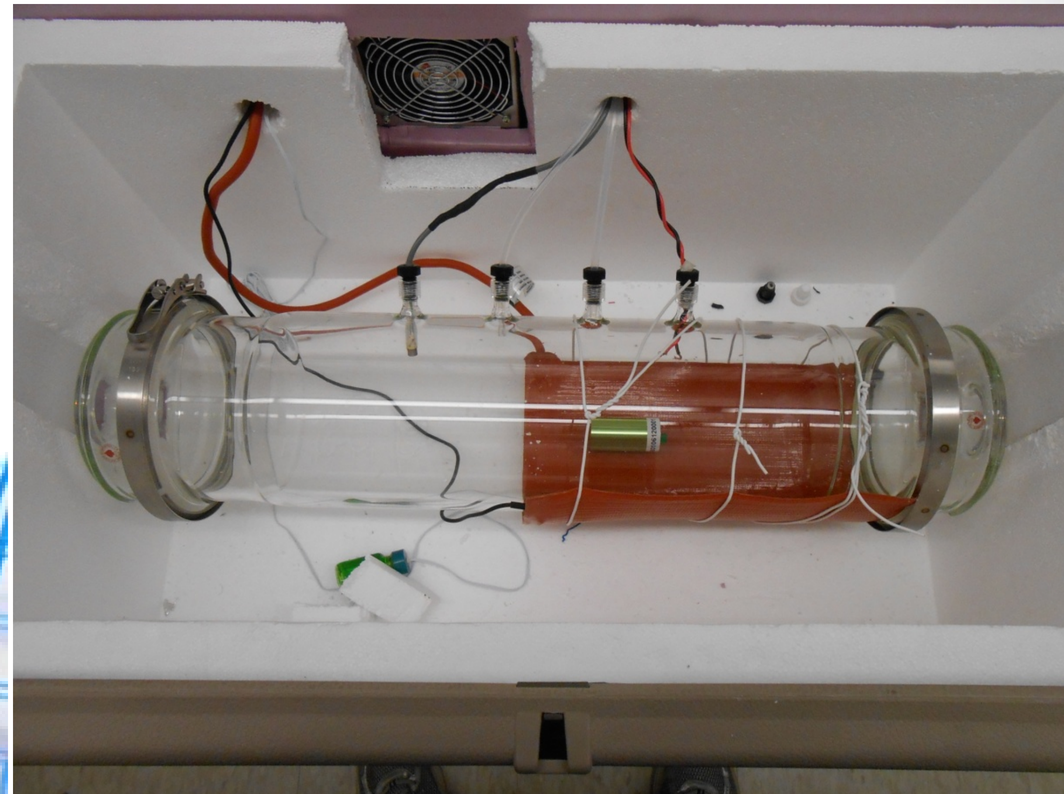




Point of Contact: Russell Long, Rachelle Duvall

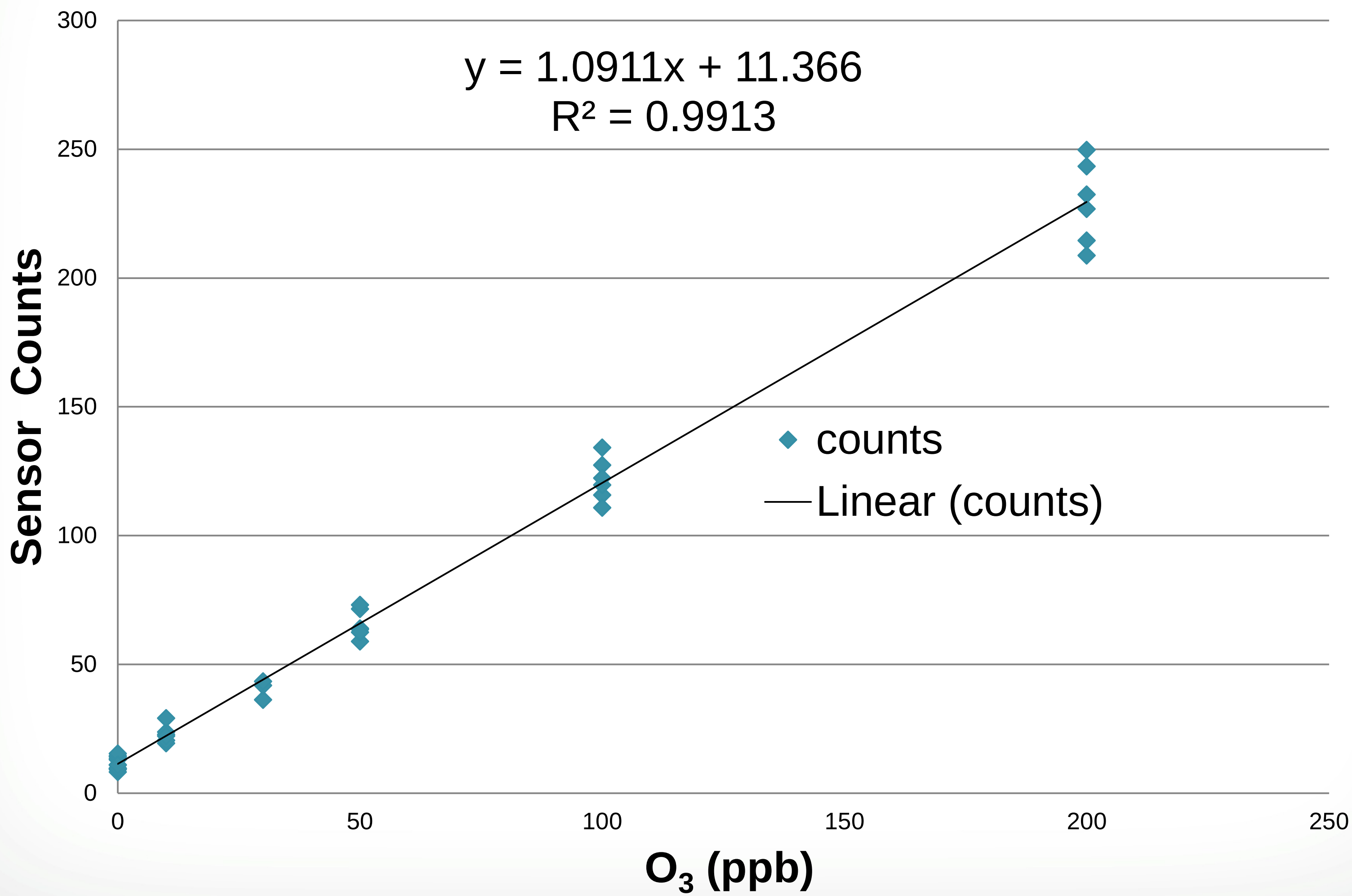
Are any sensors "good enough"?

Example: Cairpol sensor for NO_2/O_3



Point of contact: Ron Williams

Are any sensors "good enough"?



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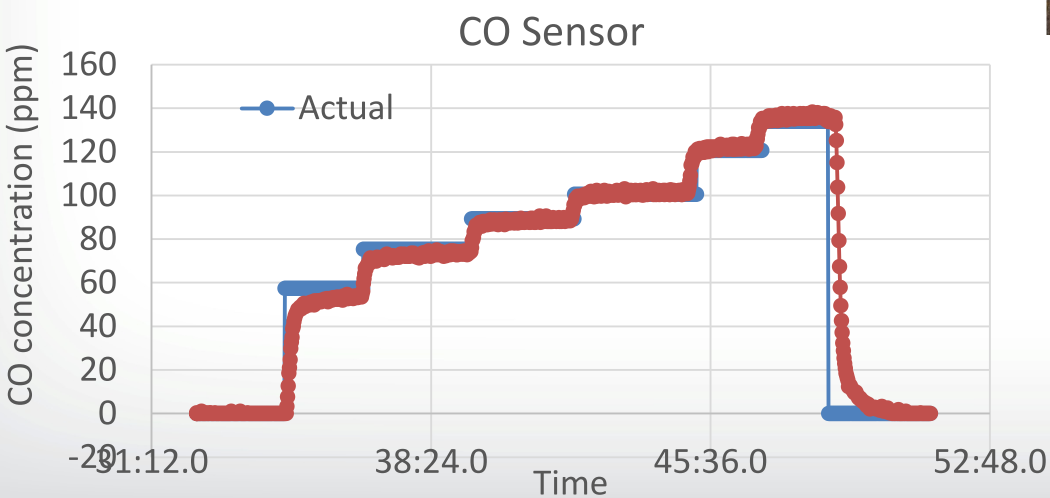
Are any sensors "good enough"?

Air sensor system development to characterize emission plumes

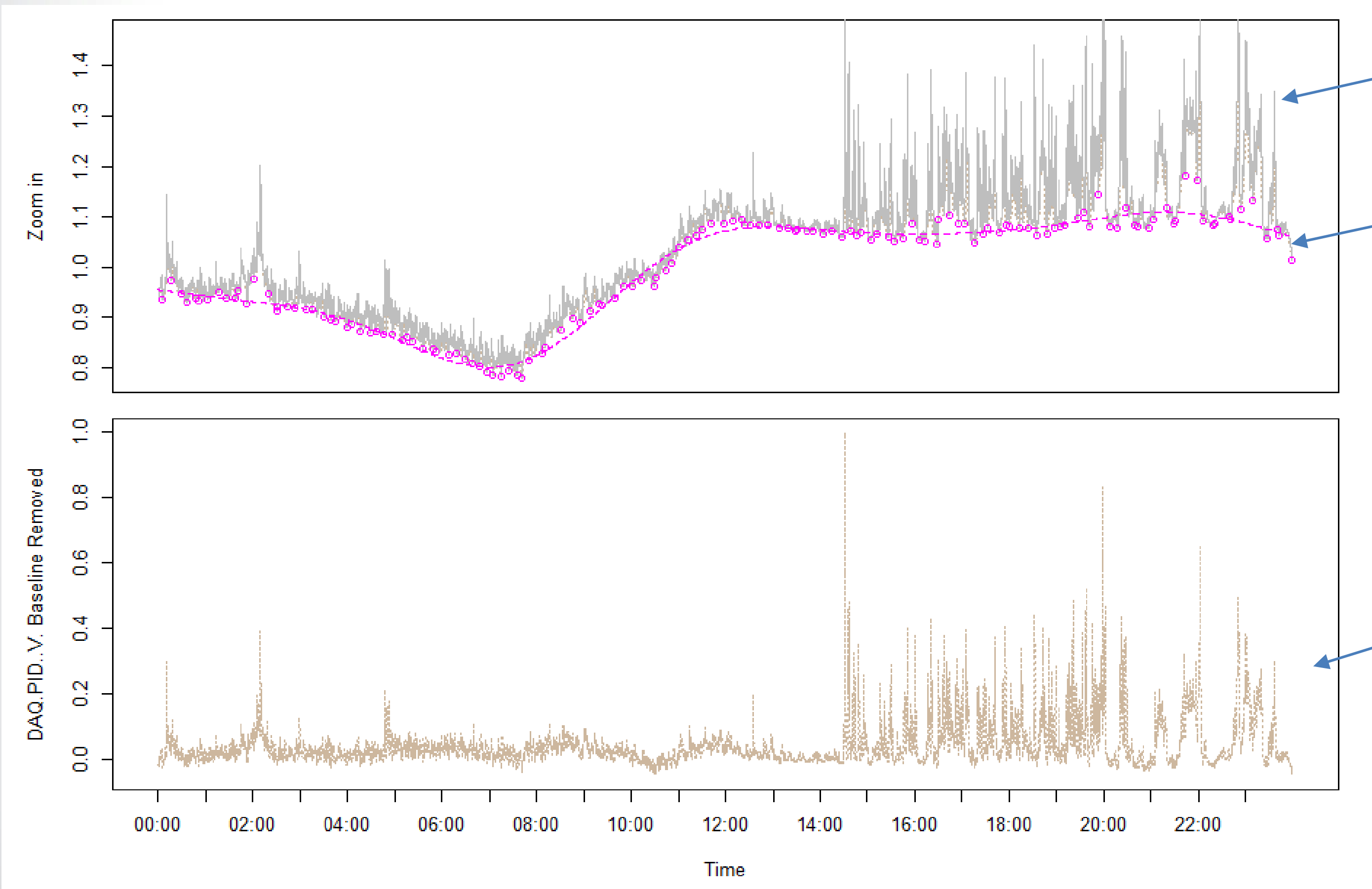


Very small sensors undergoing laboratory testing in advance of field tests of source emissions

Are any sensors "good enough"?

Considering context – what is your top priority?

A sensor may have baseline drift making it not useful for ambient concentration estimates, but "spikes" could characterize emissions events



Original PID sensor output (in Volts)

Estimation of sensor baseline drift

Recovered signal, allowing local-source influence to be detected

Are any sensors “good enough”?

Additional factors:

Reliability of the manufacturing - many are produced in batches

Data communications

Ease of operation

Power draw

Lifetime of sensor – some likely to fail within 1 year

Are any sensors "good enough"?

Bottom line:

YES – for specific applications

Some sensors already exist that perform very well in ambient-level lab and field challenge tests – including *some* sensors for PM, ozone, NO_2

Some sensors that do not perform well at ambient levels appear to do well at higher concentrations (e.g., source plumes) – including *some* sensors for total VOCs, CO

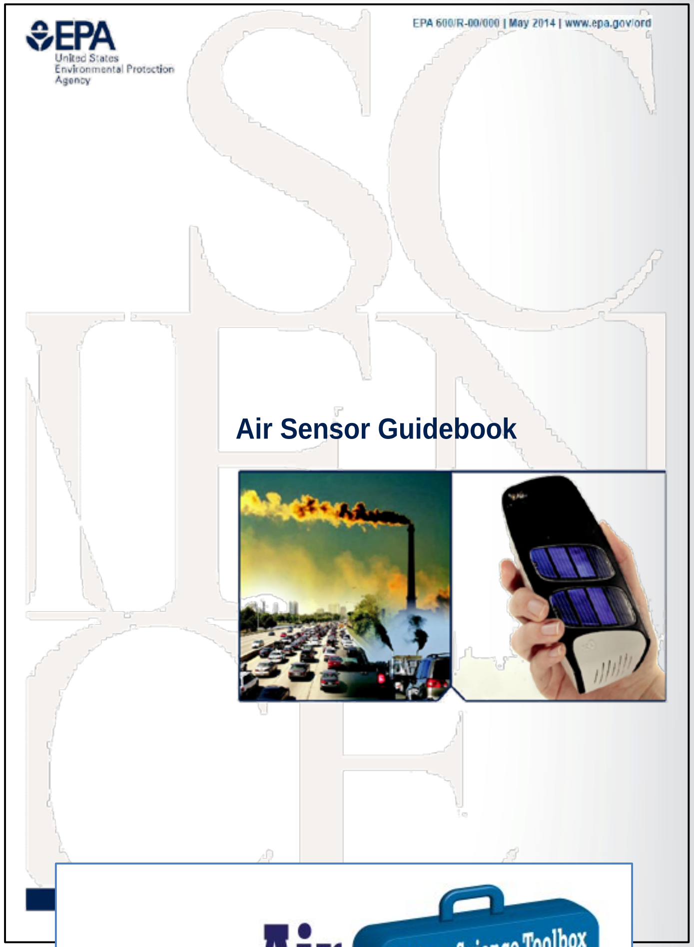
Many sensors are ready for educational activities – e.g., build-it-yourself kits

Resources available

- Air Sensors Guidebook: Defines what sensor users need to understand if they are to collect meaningful air quality data
- Citizen Science ToolBox
- Ongoing posting of reports, research studies, etc.

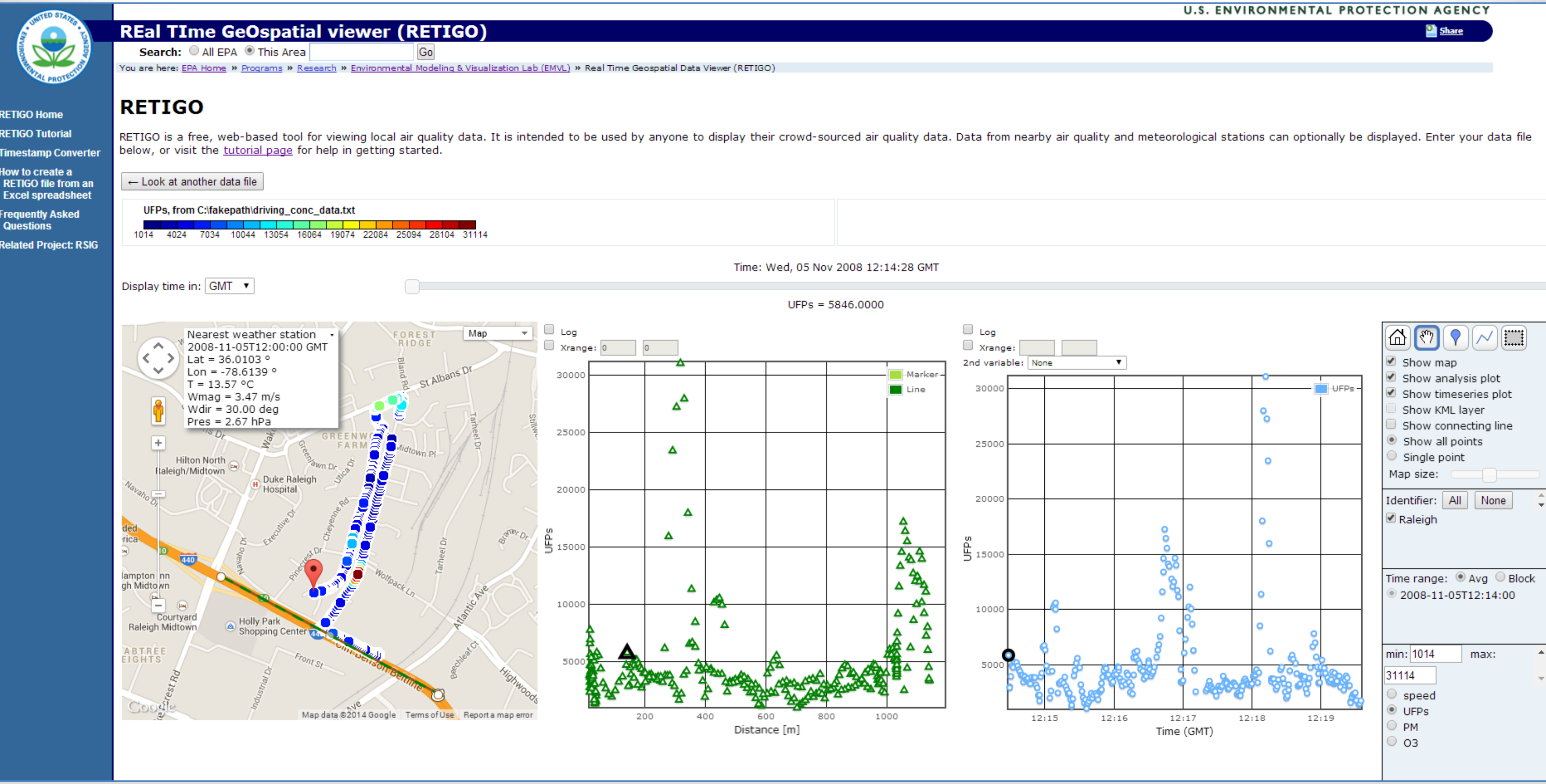
➡ www.epa.gov/research/airscience/next-generation-air-measuring.htm

➡ www.epa.gov/heasd/airsensortoolbox



One useful new tool

- RETIGO: web-based tool for a quick upload and exploration of air monitoring data.
- **To try it out and see tutorials: http://epa.gov/retigo**



Take-home thoughts on sensors

- Ongoing assessment of sensor performance in controlled settings and real-world conditions is a major area of need.
  – EPA ongoing research conducting lab and field characterization (www.epa.gov/heasd/airsensortoolbox)
  – South Coast Air Quality District planning to initiate AQ-SPEC – a sensor evaluation initiative that will include laboratory and field testing
- Sensors are easily available and already in use by the public, and new versions are arriving on the market at fast pace.
- Utility of these new technologies depends upon not only measurement performance, **but also** data post-processing/interpretation capability.

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What does all of this mean?

Current Approach

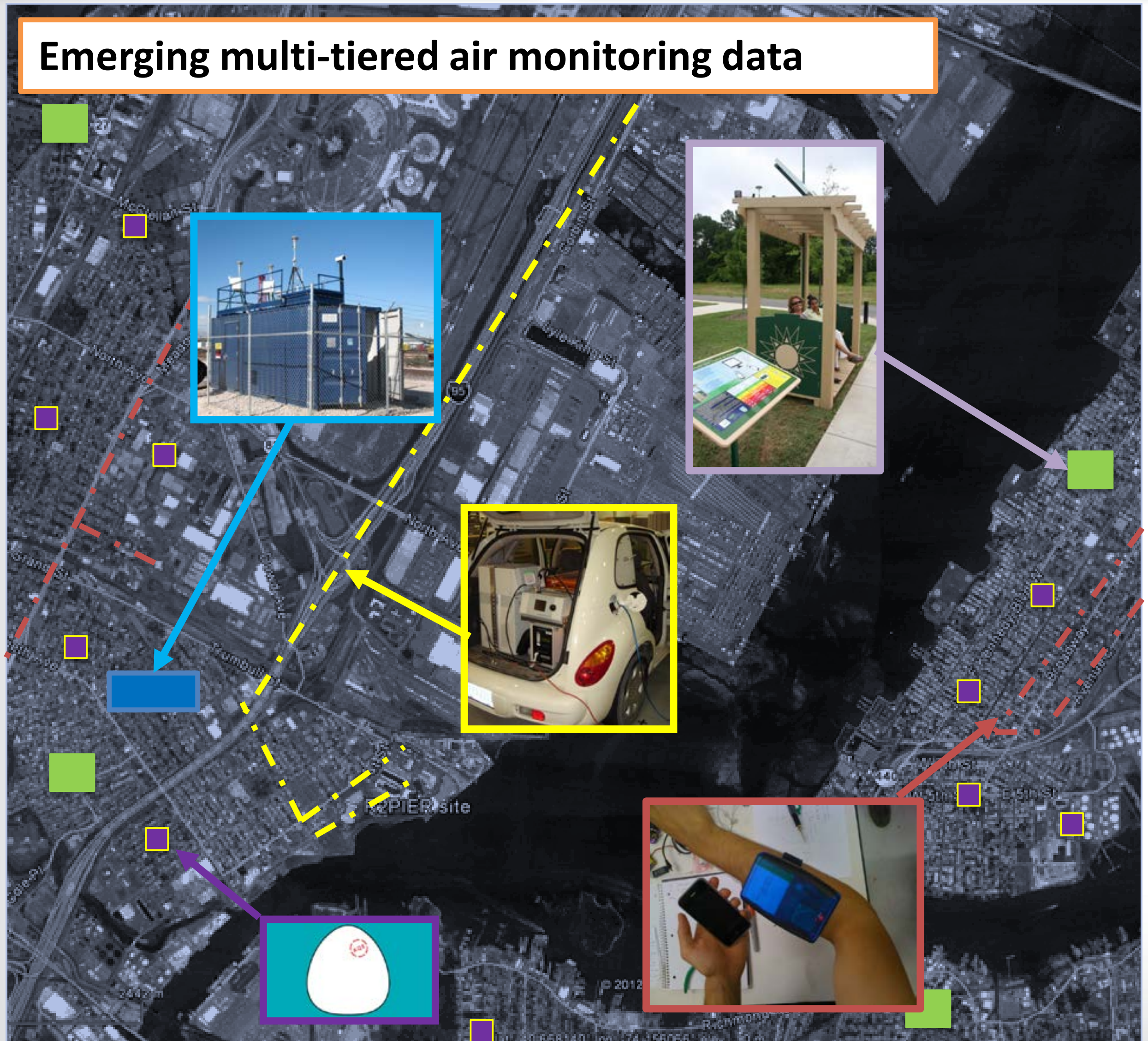
New Paradigm

Sensor Technology

How data are collected?

	Current Approach	New Paradigm
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

What does all of this mean?



<u>Opportunities:</u>

•Unprecedented access to data on neighborhood-scale air quality

•Lower cost strategies to achieve air monitoring goals

• Engagement with communities, schools, industry

<u>Challenges:</u>

• Data interpretation and public messaging

•“Big data” analysis

• Support for do-it-yourself/citizen science

Acknowledgements

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- OAR: Kristen Benedict, Ron Evans, Lewis Weinstock