My Air Quality: Using Sensors to Know What’s in Your Air

AGENDA

Northern California (N)
Wednesday, November 19, 2014
Elihu M. Harris State Building
1515 Clay Street
Oakland, California 94612

9:00 Welcome & Introductions

9:10 Understanding What Is In the Air
- Major air pollution sources
- Particle and gaseous pollutants
- Spatial and temporal variations (regional v. local)
- Health impacts associated with air quality

9:30 Measuring Air Pollution: Monitoring & Sensor Technology
- Monitoring objectives
  - Types of objectives (NAAQS, emission point, localized impacts)
  - Technology used
- Low-cost sensor technology
  - Pros & cons
  - State of the science
  - Technical issues
  - Next Generation Air and Compliance Monitoring

Southern California (S)
Friday, November 21, 2014
South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, California 91765

N: Jack Broadbent, Bay Area Air Quality Management District (BAAQMD)
S: Barry Wallerstein, South Coast Air Quality Management District (SCAQMD)

9:00 Welcome & Introductions

9:10 Understanding What Is In the Air
N: Phil Martien, BAAQMD
S: Philip Fine, SCAQMD & Rob McConnell, Univ. of Southern California

9:30 Measuring Air Pollution: Monitoring & Sensor Technology
N: Eric Stevenson, BAAQMD
S: Dan Johnson, Great Basin Unified Air Pollution Control District

10:00 “Low-cost” Sensor Performance and Data Quality
- Evaluating performance
  - Building a testing center
  - Addressing sensor reliability
  - Communicating results
- Getting good data
  - Issues affecting data quality

N & S: Laki Tisopulos and Andrea Polidori, SCAQMD
My Air Quality: Using Sensors to Know What’s in Your Air

- Developing QA/QC procedures and documentation

10:30 Break

10:45 Meaning of Sensor Data
  - Context
    - What levels are of concern?
  - Data limitations
    - Data interpretation & reporting
    - How can these data be used?
  
  N & S: John Vandenberg, U.S. EPA, Office of Research and Development at Research Triangle Park
  N & S: Dena Vallano, U.S. EPA, Region IX

11:15 Sensors Deployment and Applications
  - Community monitoring
    - Available technology
    - Development of air quality maps
    - Case studies
  - Monitoring in high concentration environments
    - Near-field exposure
    - Indoor cook stove
    - Transportation corridors
  - Sensor networks
    - Building a “high density” sensor network
    - BEACON project

  N & S: Michael Heimbinder, HabitatMap
  N & S: David Holstius, BAAQMD
  N & S: Ron Cohen, Univ. of California, Berkeley

12:00 Lunch

1:15 Focused Discussions/Q&A
  - Community projects using sensors
  - Compliance & industrial applications for sensors
  - Developing good sensors
  - Sensors as educational tools

  N: BAAQMD staff and Denny Larson, Global Community Monitor
  S: SCAQMD staff and Luis Olmedo Velez, Comite Civicco Del Valle
  
  N: BAAQMD staff and Janet Whittick, California Council for Environmental and Economic Balance (CCEEB)
  S: SCAQMD staff and Janet Whittick, CCEEB

  N: BAAQMD staff and Clinton MacDonald, Sonoma Technologies, Inc. (STI)
  S: SCAQMD staff and Clinton MacDonald, STI

  N: BAAQMD staff and Ron Cohen, Univ. of California, Berkeley
  S: SCAQMD staff and Ron Cohen, Univ. of California, Berkeley
2:45  Break

3:00  Sensor Technology Demonstration & Poster Exhibit

Participating organizations/developers/manufacturers will include:
Sonoma Technology Inc. (STI), Perkin Elmer, Valencell, T&B Systems,
Acrobotic, Dylos, Metone, Aeroqual, Horiba, Landtec

4:00  Next Steps Together on the Path to Sensor Technology

Moderator N: Barbara Lee, Northern Sonoma County Air Pollution
Moderator S: Philip Fine, SCAQMD
Panel: Sector representatives from the Focused Discussions, plus
N: Jack Broadbent or Eric Stevenson, BAAQMD
    Michael Benjamin, California Air Resources Board (CARB)
    Meredith Kurpius, U.S. EPA, Region IX
S: Barry Wallerstein or Philip Fine or Laki Tisopulos, SCAQMD
    Michael Benjamin, CARB
    Meredith Kurpius, U.S. EPA, Region IX

- A facilitated discussion on sensor issues confronting agencies
  - Engaging/educating the public
  - Communication with communities & developers
  - Consistent agency strategy & message
  - Avoid duplication of work
  - Provide/promote clear & consistent information on sensors,
    data quality, and expectations
  - Funding for sensor projects
Understanding What Is In the Air

Philip M. Fine, Ph.D.
Assistant Deputy Executive Officer
Planning, Rule Development & Area Sources
South Coast Air Quality Management District

Workshop on Air Quality Sensor Technologies
November 21, 2014
Why Does Southern California have some of the Worst Air Quality in the Nation?
Key Air Pollutants

- Carbon Monoxide
- Nitrogen Dioxide
- Sulfur Dioxide
- Lead
- Ozone
- Particulate Matter (PM10, PM2.5)
- Air Toxics (Diesel Particulate Matter, benzene, lead, etc.)
- Climate Forcers (CO2, methane, black carbon, etc.)
Main Southern California Air Pollution Concerns

- Ozone
- Particulate Matter
- Air Toxics
- Diesel Particulate Matter
- VOCs, Metals

Particulate Matter

- Diameter of human hair (for scale): 60 µm
- PM10 (≤10µm)
- PM2.5 (≤2.5µm)
- PM0.1 (≤0.1µm)

Coarse: 2.5–10µm
Fine: ≤2.5µm
Ultrafine: ≤0.1µm
Regional Pollution

NOx, NH3, VOC, SOx, Direct PM

Ozone, PM2.5

Wind

Hours/Days, Miles

Wind

Map of Southern California with various pollution sources and effects.
Los Angeles Region
Ground-Level Ozone

July 4, 2008
8:00 am PDT
Localized Pollution

Air Toxics
Lead, CO

Usually less than one mile
Air Toxics

Diesel Particulate Matter

Toxic Chemicals
- VOC (i.e. Benzene)
- Metals (i.e. Nickel)
  etc.
Air Quality Has Improved Significantly

Ozone

Days Exceeding Federal Ozone Standard (0.075 ppm)

Maximum 8-Hour Ozone Concentration (ppm)

Federal Standard
Air Quality Has Improved Significantly
MATES IV (2012) Modeled Air Toxics Risk
Key Air Quality Challenges

• Meeting federal standards by the CAA deadlines
• Further reducing toxic exposure and risk
• Addressing emerging issues such as ultrafine particles
• Development of new air monitoring methods
  • More refined exposure information
    *Risk assessment, health studies*
  • Lower cost
    *Enabling wider and denser networks*
  • Performance and data quality
    *Appropriate for the monitoring objectives*
  • Real-time
    *Faster response, better information for the public*
• Fence-line
  • *Remote sensing, fugitive and upset emissions monitoring*
OPPORTUNITIES FOR APPLICATION OF BETTER EXPOSURE ASSESSMENT TOOLS IN LARGE COHORT STUDIES OF CHRONIC DISEASE

Rob McConnell
Department of Preventive Medicine
Keck School of Medicine
University of Southern California

My Air Quality
(SCAQMD, November 21, 2014)
OVERVIEW

• Health Effects
  – Regional pollutants
  – Near-roadway pollutant mixture

• How we know about health effects

• Why better sensors could advance understanding of health effects
  – Some examples from the Southern California Children’s Health Study
DISTINCT AIR POLLUTION MIXTURES

Regulated

Largely Unregulated
Regulated Regional Pollutants

- Particulate matter mass less than 10 micrograms in aerodynamic diameter (PM10)
- PM2.5
- Ozone
- Nitrogen dioxide
- Sulfur dioxide
- Lead
Particulate Matter

- Various studies of adults show:
  - **INCREASED DEATH FROM HEART ATTACKS AND STROKE** when levels of particle pollution rise
    - (Pope CA, 3rd, Dockery DW. Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manag Assoc* 2006;56(6):709-42)
  - **HIGHER CARDIOVASCULAR AND RESPIRATORY MORTALITY** in cities with higher particle pollution
  - **THICKER ARTERIES** in southern Californians living in areas with higher particle pollution
  - **MORE LUNG CANCER** in areas with more particle pollution and in workers exposed to diesel exhaust
    - (Pope, et. al. JAMA 2002;287(9):1132-41)
Ozone

  - Asthma exacerbation
    - Symptoms, medications, emergency department, hospitalization
  - New onset asthma
  - Respiratory symptoms, hospitalization, school absence
  - Cardiovascular morbidity, hospitalization, mortality
  - Respiratory mortality
Summary Nearby Traffic Effects

- **Studies in U.S. and in Europe show that**
  - LIVING NEAR BUSY ROADS AND FREEWAYS – ESPECIALLY WITH LOTS OF TRUCK TRAFFIC – HAS BEEN LINKED TO:
    - **Asthma**
    - **Heart attack (and other heart disease)**

- **AND OTHER CONDITIONS:**

- **Decreased lung function**
- **Lung cancer**
- **Low birth weight and preterm birth**
- **Cardiopulmonary mortality (deaths related to the heart or lungs) – shortened life expectancy**
- ?neurodevelopment including childhood IQ, autism; obesity2
How Health Effects are Identified

Regional Pollution
Traffic Proximity
Tobacco Smoke

Personal Exposure

Dose

Genetics
Epigenetics Marks
CIMT
Lung Function

Stress, Diet, Endotoxin, Allergens

Physical Activity and Location

eNO

Asthma
Later Life Disease
PM2.5

Annual Arithmetic Mean, μg/m³
(Federal Standard = 15 μg/m³)
Number of Days Exceeding the U.S. Ozone Standard
(8-hour average ozone > 0.08 ppm)
18-year-olds in Polluted Communities are 4-5 Times More Likely to Have Low Lung Function

Increases risk for:
Emphysema?
Heart disease?
Mortality?

Air Quality is Worse Near a Freeway

Other pollutants are also high near freeway (e.g. NO2, benzene, …)

(Zhu et al., 2002, 2006)
Prevalent Asthma And Residential Distance To A Major Road

Regional Pollution
Traffic Proximity
Tobacco Smoke

Regional Pollution
Traffic Proximity
Tobacco Smoke

Pathways Tell us More

Mechanism
Causality
True size of effect
Where we might intervene
Overview of Some Challenges

- Exposures vary diurnally and seasonally
- Near-roadway exposures have small area variation
- Exposures are complex mixtures with many toxic pollutants
- Exercise and location increases exposure
Some Criteria for Ideal Sensor (for epidemiologists)

- **Key**
  - Cheap ($10s or $100s/unit)
  - Time resolved

- **Desirable**
  - Accurate
  - Rugged
  - Wearable
  - Biologically relevant
What Personal (or Distributed Microenvironmental) Markers to Measure?

- Traffic markers/occupational exposures, eg VOC’s, BTEX, CO
- New refinements
  - Eg criteria pollutants such as PM2.5 by nephelometry, NO2
  - Black carbon by aethelometry (available commercially)
  - CO2
What Markers to Measure?

• Wishful thinking?
  – Ozone
  – Toxic air contaminants, eg aldehydes, quinones?
  – Identify source, eg fresh and aged diesel, gasoline?
  – Class of action, eg redox activity?
  – Biological activity?
Physical Activity and Location Neglected

Mechanism
Causality
True size of effect
Where we might intervene
### Regional Ozone, Exercise and New Onset Asthma

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<td>0.79 (0.38-1.63)</td>
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Essentially all O3 exposure occurs outside and summer cannot be ignored.

Diurnal Pattern of Outdoor Activity and Ozone
Children Ages 9-11 and 1993 Ozone at Upland

- Outdoors on Weekends
- Outdoors on Weekdays
- Ozone
**Extreme Gradient in Potential Dose of Traffic-Related Pollutant Exposure**

- Time-location 50m from freeway
  - 5-fold freeway proximity (c/w 500 m)
  - 2-fold indoor/outdoor gradient (particle size mode of 0.03 µm at 50m)
  - 3-fold morning rush hour Long Beach compared with Santa Barbara

- PA
  - 6-fold increase in minute ventilation associated with moderate and vigorous physical activity

- Total 180-fold

- Plus distributional shift within lung?

- Common gradients are 5-fold
Complementary Challenges

• Dose
  – Physical activity
    • Accelerometry
    • …or time resolved step counts
  – Location
    • Personal GPS
    • …or exploit structured pattern of activity

• Pair with modest sensor improvements
  – Good enough for microenvironmental assessment
  – Proxies for biological relevance (eg. BC, NOx)
Indoor Infiltration is a Knotty Problem

- Depends on ventilation and size of particle
- Air exchange rate costly to measure
- Some markers have been used because they have few indoor sources
  - Eg. sulfur
  - Elemental (or black) carbon a marker for traffic

- HOW TO DETERMINE INDOOR/OUTDOOR TIME?
What to Consider When Developing a Monitoring Strategy

Eric Stevenson, BAAQMD
Daniel Johnson, GBUAPCD
Before We Start…

Collect AQ Data

- Why?
- Where?
- When?
- What?
- Who?
- How?
Types of Monitoring Objectives

- Ambient Air Quality Standards (regulatory)
- Emission point (source contribution)
- Exposure
- Research
- Localized impacts from pollution sources (gradients)
Agency Ambient Monitoring Design Objectives

- Provide air pollution information to the general public
- Determine compliance with air quality standards
- Support air pollution research studies
Determining Data Requirements

- Representative compounds of interest
- Spatial and temporal representativeness
- Data quality (accuracy, precision, bias, etc.)
  - Data quality needed to take action
  - Measurement timeframes appropriate for risks of exposure
  - Uniformity of measurements
- Locations chosen need to be representative based on monitoring goal
Location Requirements

- Locations that are representative of appropriate scale
- Locations that can represent populations/sources
- Data that represents actual concentrations over time (meteorology and topography)
- Documentation that demonstrates uniform and appropriate data quality
Monitoring Design Site Types

- Highest concentration
- Typical concentrations in areas of high population density
- Source impacts
- Background
- Transport
- Visibility and other welfare impacts
- Validation/relationship to other measurements
Scales of Representativeness

- Micro – 100 meters or less
- Middle – 100 meters to 0.5 km
- Neighborhood – 0.5 km to 4 km
Micro Scale Site
Usually Source Oriented

Up to 100 m
Middle Scale Site –
High Concentration/Source Impacts

100 m to 0.5 km
Neighborhood Scale Site – Most common as it balances impacts and area.
Additional Scales of Representativeness

- Urban – 4 to 50 km (Usually population oriented sites)
- Regional – 10 to 100s of km (Usually transport sites) - PAMS
- National and Global - >100s of km (Usually background sites)
Other Considerations

- Consistent procedures and equipment used for project
- Consistent data management and appropriate chain of custody
- Overall considerations of data defensibility and appropriate amount of data to meet desired conclusions of monitoring goal
Instrumentation Considerations

- Measurement error
- Stability
- Calibration / QC / QA
- Data reporting capabilities
- Power / Security / Safety
- Interferences
- Ease of operation
- Reliability
- Cost / Resource needs
Instrumentation Selection

- **Regulatory Monitors**
  - Federal Reference Method
    - Operation and performance defined in CFR
  - Federal Equivalent Method
    - Meets performance criteria in CFR vs. FRM
  - Approved Regional Method
    - With EPA approval

- **Screening & Research Monitors**
  - Lower precision & accuracy
  - Confidence improved by colocation

- **Personal & Industrial Monitors**
  - Portable; lower cost
Collect AQ Data

Why?

Where?

When?

What?

Who?

How?

Keep asking these questions to define your monitoring objectives and maximize your data quality!

Eric Stevenson, BAAQMD
Daniel Johnson, GBUAPCD
Workshop: “My Air Quality: Using Sensors to Know What's in Your Air”

Low cost air sensor technology

Gayle Hagler and Carlos Nunez
EPA Office of Research and Development
Goals of this talk

• Provide our perspective on the ongoing evolution of air sensors
• Provide information on EPA activities related to low cost sensors
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 the air is an evolving technology landscape.

- Higher cost systems
  - Traditional air monitoring shelter

- Lower cost systems
  - Moveable mobile laboratory
  - Autonomous measurement systems
  - Wearable sensors
  - Vehicle air pollution mapping systems
  - Lofted sensor platforms
  - Moveable mobile laboratory
  - Traditional air monitoring shelter

Desirable direction

Lower spatial resolution

Desirable direction

Higher spatial resolution
Emergence of low cost 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/)
Emergence of low cost sensors

**Gas-phase**

**Metal oxide sensors:**
Operate 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

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

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

*Figure.* Electrochemical sensor (e2v, 2007)
Gas-phase  e.g., VOCs

**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)
Sensor applications

Stationary mode – source fence-line, community measurements

Conceptual application

Drop-in-place in SPod ($$) using inverse source algorithms

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

Source: Microsoft Bing Maps (© Microsoft Corporation Pictometry Bird’s Eye © 2010 Pictometry International Corp)
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
Sensor applications

Education/outreach

EPA ORD’s particle sensor kit

Instrumented kites measuring VOCs

Hacking fiber optic flowers to light up based on CO₂ sensor readings (EPA ORD)

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

Ongoing side-by-side evaluation:
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**: $R^2 = 0.67$
- **DYLOS**: $R^2 = 0.55$
- **SHARP**: $R^2 = 0.16$
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
EPA activities in a nutshell

FY12
- ASAP workshop
- Mobile system development and application
- Sensors Evaluation and Collaboration

We are looking forwards to keeping in touch!

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-Pods
- 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: CAIRSENSE Project
- Data visualization support: RETIGO
- Mobile

Next-generation air monitoring research at EPA
Resources available

• Air Sensors Guidebook: Defines what sensor users need to understand if they are to collect meaningful air quality data

• Ongoing posting of reports, research studies, etc.

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

www.epa.gov/heasd/airsensortoolbox
Take home thoughts

- Ongoing assessment of sensor performance in controlled settings and real-world conditions is a major area of need.
- Sensors are easily available and already in use by the public, and new versions are arriving on the market at fast pace.
- Utility of sensors is a function of the sensor device performance and data post-processing/interpretation capability.
- This area is a high priority for EPA and we are eager to keep in touch.
Acknowledgements

Air Quality Sensor Performance Evaluation Center (AQ-SPEC)

Laki Tisopulos, Ph.D.
Assistant Deputy Executive Officer
South Coast AQMD

Air Quality Sensors Workshop
November 21, 2014
Traditional Air Monitoring

- Permanent, large, fixed sites
- Address NAAQS
- Comply with all CFR specs
- Sophisticated and highly accurate
- Expensive
- Limited spatial resolution
Community-Based Air Monitoring

- Local concerns and issues
  - Resident complaints
  - Perceived health impacts
  - Requests from other agencies, elected officials, etc.

- Often source-specific
  - Special monitoring studies
  - Different approaches for different situations

- Non-regulatory

- Technologies deployed
  - Monitoring trailers
  - Deposition plates
  - Portable monitors
  - Grab samples

- Enlist the help of residents

- Risk communication
Monitoring By Community Groups / Others

• Current efforts in South Coast
  ➢ Community based health studies
  ➢ Measurements conducted by
    o University researchers
    o Local agencies
    o Consultants
    o Single Individuals (DIYers)
    o A combination of the above

• Technology used
  ➢ Portable monitors
    o Non-FRM/FEM but quite reliable
  ➢ “Low-cost” air quality sensors
    o Non-FRM/FEM; unknown performance
    o Uncertain data quality
Low Cost Sensor Technology

- Only a few
- Single pollutant measurements
- Non-FRM/FEM

SENSOR PERFORMANCE

- Many (and more to come)
- Single and multi-pollutant measurements

Decent
Moderate cost ($8K – 10K)

Unknown
Lower cost ($0.5K – 10K)
Low Cost Sensor Technology

• Air monitoring sensor information and data already available on the web

http://www.smartcitizen.me/
http://airqualityegg.com
http://elm.perkinelmer.com/map/
Low Cost Sensor Technology

Potential concerns
- Rapid proliferation
- Data quality not on par with that of FRM and FEM instruments
- Potential “overload” in the amount of non-agency air monitoring data
- Technical Issues
  - Calibration, accuracy, interferences, time averaging, longevity, expertise of user
- Data interpretation
  - Which pollutant?
  - What levels?
  - False positives: unwarranted alarm
  - False negatives: false sense of security
- Confusion

Opportunities
- Low cost
- Relatively small size
- Ease of operation
- Broader community participation and awareness
- Wider spatial and temporal distribution
  - More refined control strategy
  - Early warning/community alert system
- Data available on web, smart-phones, etc.
Low Cost Sensor Technology

• European and US EPA efforts to gather information, encourage use, and engage the public but...

• ...there is no State/Federal program to systematically evaluate sensor performance
Path Forward

• Engagement, Education and Communication are essential
   Example: EPA STAR Grant "Air Pollution Monitoring for Communities"

• CAPCOA Conferences:
   Example: “My Air Quality: Using Sensors to Know What’s in Your Air”
    o Northern California (BAAQMD): November 19, 2014
    o Southern California (SCAQMD): November 21, 2014

• Latest SCAQMD Initiative
   Establish Sensor Testing Center: AQ-SPEC
    (approved by Governing Board on July 11, 2014)
   Utilize SCAQMD staff experience and expertise
AQ-SPEC Overview

• Main Goals & Objectives
  ➢ Provide guidance & clarity for ever-evolving sensor technology & data interpretation
  ➢ Catalyze the successful evolution / use of sensor technology
  ➢ Minimize confusion

• Sensor Selection Criteria
  ➢ Potential near-term use
  ➢ Real- or near-real time
  ➢ Criteria pollutants & air toxics
  ➢ Turnkey products first
  ➢ Price range:
    o < ~$2,000 (purchase)
    o > ~$2,000 (lease/borrow)
FIELD TESTING
(Side-by-side comparison w/ FRMs)

LAB TESTING
(Controlled conditions)

RESULTS
(Categorize sensors based on performance)

RH = 30%  T = 25C
Conc = 10 ppb
AQ-SPEC Overview

RESULTS

SCAQMD Website / Clearinghouse

Vendor

AQ Officials

Community

Vendors
AQ-SPEC Field Testing

- Started on 09/12/2014
  - Sensor tested in triplicates
  - Two month deployment
  - Locations:
    - Rubidoux station
      - Inland site
      - Fully instrumented
    - I-710 station
      - Near-roadway site
      - Fully instrumented

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<th>PM</th>
<th>CO</th>
<th>NO2</th>
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<td>Cairclip (NO2/O3)^</td>
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<td>X</td>
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<td>AeroQual Ozone card^</td>
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<td>X</td>
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<tr>
<td>Cairclip VOC^</td>
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<td>ELM*</td>
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<tr>
<td>SmartCitizen^</td>
<td>X</td>
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</tbody>
</table>

^Purchased; *Loaned
AQ-SPEC Lab Testing

### Dynamic dilution calibrator
- CO, SO2, NOx, O3

### Zero Air

### Particle generation system

### Sensor
- #1
- #2
- #3

### Teflon fan

### Teflon coated Stainless Steel

### Teflon Gloves

### Vent

### Design considerations:
- Dimensions, material
- T and RH controlled: T (0-50 °C; +/- 5 °C); RH (5-95%; +/- 5%)

*Central data logger to collect all data
*Insulated
*PM filter port needed?
*Individual ports could be used instead
Looking Forward

- Gather and disseminate knowledge necessary to help select, use, and maintain sensors and correctly interpret data
- Explore new and more effective ways to interact with local communities
- Provide manufacturers with valuable feedback for improving available sensors and designing the next generation sensor technology
- Create a “sensor library” to make “low-cost” sensors available to communities, schools, and individuals across California
- Catalyze the successful evolution / use of sensor technology
Sensor Performance, Data Quality, and Novel Applications

My Air Quality: Using Sensors to Know What’s in Your Air

Diamond Bar, CA
November 21, 2014
Andrea Polidori, Ph.D.
QA Manager; South Coast AQMD

(apolidori@aqmd.gov)
Background

- Technology trend: smaller, faster, cheaper
  - Example: PCs have evolved into tablets, and cell-phones have become small PCs.

- Most traditional air monitoring instruments are following the same trend

- Safe to assume that the performance of “low-cost” sensors will soon match that of FRM/FEM instruments.....but when?
Many deciding factors, including:
- Advancements in sensor technology
- Performance & cost of microprocessors
- Growing public interest
- Large tech-company involvement

“Researchers turn Google Glass into health sensor”
—wired (Sept. 2014)

How can governmental agencies help?
- Engage, educate, and empower the public
- Work with sensor manufacturers & developers
- Characterize sensors performance & data quality
• Evaluation (not certification) program
• Field and chamber testing
• Determine parameters affecting sensor performance and data quality:
  - Detection range
  - Linearity
  - Detection limit
  - Accuracy
  - Precision
  - Response time
  - Intra-model variability
  - Co-pollutant interference
  - RH and T influences
  - Durability
Categorize sensors based on performance

Several novel applications

- Characterize spatial variations
  - Wide area coverage
- Improve network design
  - Identify high concentration areas
- Permitting
  - Monitor before and after construction
- Fence-line monitoring
  - Large refineries and emission sources
- Community concerns
  - Local impact of freeways, airports, refineries, etc.
- Aerial measurements
  - Stack sampling, plume profiling, and much more

EPA’s “DRAFT Roadmap for Next Generation Air Monitoring”
Novel Applications (example): Characterize Spatial Variations

- **iSPEX**
  - < $4 add-on for smart-phone cameras to measure Aerosol Optical Thickness to estimate atmospheric aerosols!!!
  - Spectropolarimetric method
  - Daytime, cloud-free measurements only
  - Project led by Frans Snik, Leiden University (Netherlands)

- Thousands of (free) iSPEX used for three days in 2013
- Results comparable to ground-based, network, and satellite measurements

http://ispex.nl/en/
Novel Applications (example): Aerial Measurements

• Unmanned Aerial Vehicles
  - Provide stable X-Y-Z platform for sample collection
  - Sensors can be mounted to provide integrated and real-time data (e.g., GPS, meteorological, gaseous, and particulate)
  - FAA Restrictions (commercial vs. recreational) and flight time limitations
  - Many potential uses: stack sampling, plume profiling, fence-line monitoring, gradient studies, previously unreachable locations

NASA’s Global Hawk UAV (not properly “low-cost”)
T&B systems quadcopter (affordable!)
(...don’t call me DRONE!)

Courtesy of...
Conclusions

• More comprehensive field and laboratory testing needed to:
  ➢ Address sensor data quality issues
  ➢ Correctly interpret sensor data
  ➢ Appropriately select sensors for specific applications
  ➢ Promote a more responsible sensor use
  ➢ Improve performance of available sensors
  ➢ Design the next generation sensor technology

• Available sensors are not as accurate and reliable as FRM/FEM (yet), but they can be used for many useful applications

• Many short- and long-term challenges, including:
  ➢ Incorrect use of sensors and sensor data
  ➢ Rapid proliferation
  ➢ Dealing with “Big data”
Parameters affecting sensor performance and data quality

- **Detection range**: nominal minimum and maximum concentrations that a method is capable of measuring
- **Linearity**: correlation ($R^2$) between collocated sensor and FRM/FEM concentration measurements
- **Detection limit**: lowest pollutant concentration that a sensor can reliably detect
- **Accuracy**: degree of closeness of sensor concentration measurements to the actual (true) concentration value measured using FRM/FEM instruments
- **Precision**: variation about the mean of repeated measurements of the same pollutant concentration
- **Response time**: time interval between a step change in input concentration and the first observable corresponding change in measurement response
- **Intra-model variability**: variability in the measurements provided by different units of the same model
- **Co-pollutant interference**: positive or negative measurement response caused by a substance other than the one being measured
- **RH and T influences**: positive or negative measurement response caused by variations in RH and T
- **Durability**: ability to withstand wear, pressure, or damage and to provide reliable data over an extended period of time
Challenges to Interpretation of New Air Sensor Data: What Does it Mean?

John Vandenberg, PhD
National Program Director
Human Health Risk Assessment Program
National Center for Environmental Assessment
U.S. Environmental Protection Agency

My Air Quality: Using Sensors to Know What’s in Your Air
Diamond Bar, CA
November 21, 2014

Disclaimer: This presentation does not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.
Challenges to Interpretation of New Air Sensor Data: What Does it Mean?

Data itself is not “information”: Interpretation required

• For an individual:
  • What does a reading mean for me, my family?
  • Is my home safe? Where should I exercise?

• For a community:
  • What neighborhoods are impacted the most?

• For State and Local officials:
  • How do I respond to citizen inquiries?
Air Sensors Health Group (ASHG) formed to support data interpretation

• Includes EPA Program offices and Regional representatives
  • Office of Research and Development (several programs)
  • Office of Air and Radiation
  • EPA Regional Offices

• Includes other Federal Agencies:
  • National Institute for Environmental Health Sciences
  • National Institute for Occupational Safety and Health
  • Centers for Disease Control
  • National Library of Medicine
ASHG Goals

• To help the state/local agencies and regions on the front lines of answering phone calls from concerned citizens

• To help consumers understand how to interpret the readings from their sensors

• To help guide sensor developers to produce instruments with meaningful information or translation
Initial ASHG Approaches

• Consider available reference values
• Consider what is “normal” air quality
Understanding Reference Values

Values vary due to assumptions that depend on target population and intended exposure scenario

Occupational values:
- 8-hour work shift TWA or 15-minute STEL
- Healthy workers
- 40-year exposure duration
- Safety factors

Emergency response values:
- Degrees of severity – all include some level of effect
- Aid in evacuation/Take-shelter decisions
- Assume “once in a lifetime” exposure scenario, not routine excursions

Extrapolation factors may not account for general population, sensitive subpopulations, or dosimetry
Air Reference Value Evaluation

Graphical Arrays of Chemical-Specific Health Effect Reference Values for Inhalation Exposures
Acrolein: Comparison of Reference Values

* Indicates an occupational value; expert judgment necessary prior to applying these values to the general public.

Figure 2.1. Comparison of Available Health Effect Reference Values for Inhalation Exposure to Acrolein
<table>
<thead>
<tr>
<th></th>
<th>Emergency Response</th>
<th>Occupational</th>
<th>General Public</th>
<th>WHO Air Quality Guideline</th>
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<td></td>
<td>AEGL</td>
<td>ERPG</td>
<td>TEEL</td>
<td>IDLH</td>
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<tr>
<td>Acrolein</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ammonia</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Arsine (SA)*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Chlorine*</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Chromium VI</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Cyanogen Chloride*</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Ethylene Glycol Methyl Ether</td>
<td>X</td>
<td></td>
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<td>Ethylene Oxide</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Formaldehyde</td>
<td>X</td>
<td>X</td>
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<td>Soman (GD) + Cyclosarin (GF)*</td>
<td>X</td>
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<tr>
<td>Hydrogen Fluoride</td>
<td>X</td>
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<td>Hydrogen Sulfide</td>
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<td>Lewisite (L)*</td>
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<td>Mercury</td>
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<td>Sulfur Mustard (HD)*</td>
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<td>Tabun (GA)*</td>
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<tr>
<td>VX*</td>
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* indicates a chemical warfare agent
Reference Values?

• Consider available reference values
• Consider what is “normal” air quality

• National Ambient Air Quality Standards: 4 components
  • Indicator (e.g., ozone)
  • Level (e.g., 75 ppb)
  • Averaging time (8 hour daily maximum) **
  • Form (4th highest average across 3 years) **

** = short-term exposure data (minutes, hour) does not match up with standard
e.g., a one minute reading of 85 ppb does not mean the standard has been exceeded
What is “Normal” Air Quality?

• Examine one year of data (2013) at two contrasting sites near San Francisco, California (“higher concentration” vs. “lower concentration”)
  • Results should not be generalized. Relationships and patterns likely vary for other geographic locations, monitoring equipment, etc.
  • 1-minute data provided by Mark Stoelting, Bay Area Air Quality Management District
Santa Rosa
(lower concentration)

Livermore
(higher concentration)

Daily Max 8-hour Ozone Concentrations from 01/01/13 to 12/31/13
Parameter: Ozone (Applicable standard is 0.075 ppm)
CBSA: San Francisco-Oakland-Fremont, CA
County: Alameda
State: California
AQS Site ID: 06-001-0007, poc 1

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Generated: April 8, 2014
May 2: 1-minute value > 75 ppb but the daily max 8-hour is not
An Advantage to the initial ASGH focus on gaseous criteria pollutants is the large network of monitors.

Messaging for PM$_{2.5}$ is also under development.
Monitoring data is limited for most Hazardous Air Pollutants, i.e. what is “normal” more difficult to evaluate
Conclusions

• Lack of short-term health reference values for general population exposure
• Lack of short-term health effects studies
• Short-term new sensor data does NOT compare to National Ambient Air Quality Standards
• Short-term (minute-by-minute) air monitoring available for some criteria air pollutants, which can be used to communicate what is “normal”
• Major challenge is effective and appropriate communication
• ASHG is working to develop information to support interpretation of new air sensor data
Sensor Data Limitations: Interpretation, Messaging, and Uses

Dena Vallano, PhD, ORISE Fellow, Air Division
U.S. Environmental Protection Agency, Region 9
“I’ll pause for a moment so you can let this information sink in.”
Data Interpretation: What does it mean?

- Me: How does air pollution affect my health? What is my least polluted commute route?

- Communities: Is my neighborhood air quality ok? Are our kids playing in a safe environment?

- Local governments and planning agencies: How well are we balancing growth, development, and public health?

- Governmental air agencies: How to effectively address community concerns and apply sensor results?
Data Interpretation: Challenges

• Good data interpretation starts with identifying specific objectives, careful study design, QA, and measurement uncertainty
  – Guidance is needed for users on choosing which sensors/projects best meet their needs and understanding results to make better use of measurements

• Sensors present several unique challenges related to analysis and interpretation:
  – Availability of sensors (affordability)
  – Mobility of the sensors
  – Results in large data sets (“Big Data”) with high temporal and spatial resolution (sampling intervals of seconds to minutes)
  – Local influences

• Real-time air pollution monitor measurements should be validated prior to their analysis and interpretation
Making Sense of Big Data

- Personal sensors do not equate to regulatory data
  - NAAQS are set with long-term datasets
  - Regulatory monitors have very rigorous quality requirements and oversight

- Interpretation of high resolution data in the context of regulatory standards
  - Consideration of spatial and temporal representativeness

- Example: Sensor Ozone Measurements
  - 8-hr ozone standard is 75 parts per billion (ppb), but how should the public interpret the health implications of shorter-term averages if they exceed the standard?
    - Is it safe for ozone levels to be at 100 ppb for only one hour or one minute?

- EPA recognizes that accurate messaging is needed for short-term personal air quality measurements that guide exposure mitigation and behavior change
Data Reporting

• Privacy issues, including a general apprehension of users to share sensitive data

• Training users to understand technical information and gain confidence in their data-collecting skills is critical for active engagement
  – Identification of objective
  – Data-collection and methods
  – Tracking and sharing of metadata
  – Handling data quality issues post-collection (averaging, quality assurance)
  – Data interpretation
  – Data fusion with model and regulatory observations
  – Data visualization and presentation (i.e. conveying uncertainty)
Data Uses: Education

• Using sensors in educational settings for STEM (science, technology, engineering, and math) curricula and promotion

• Example: Sensors are provided to students to monitor and understand air quality issues – and they have a blast doing it

Wright Brothers Institute Student Project 2012
Data Uses: Information/Awareness

• Using sensors for informal air quality awareness

• Example: A sensor is used to compare air quality at people’s home, work, in their car, local park, or at their child’s school.
Data Uses: Personal Exposure Monitoring

- Monitoring the air quality that a single individual is exposed to while doing normal activities

- Example: 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
Data Uses: Research

• Scientific studies aimed at discovering new information about air pollution

• Example: A network of air sensors is used to measure particulate matter variation across a city, a neighborhood, a few blocks, etc.
Data Uses: Supplemental Monitoring

- Placing sensors within an existing state/local regulatory monitoring area to fill in coverage and assess network adequacy

- Example: A sensor is placed in an area between regulatory monitors to better characterize the concentration gradient between the different locations
Data Uses: Source Identification and Characterization

- Investigate possible emission sources by monitoring near the suspected source.

- Example: A sensor is placed downwind of an industrial facility or near a busy intersection to monitor variations in air pollutant concentrations over time.
Data Uses: Policy Implications

...an EPA perspective

- Sensor data is currently not used to determine whether an area is in compliance with the NAAQS

- Non-regulatory (i.e. secondary) data has informed boundaries for nonattainment areas and to support additional monitoring in areas of concern

- EPA does not expect personal sensors to be used for regulatory decisions
  - Guidance would help clarify appropriate uses of secondary data from sensors
“Huge volumes of data may be compelling at first glance, but without an interpretive structure they are meaningless.”

— Tom Boellstorff, Ethnography and Virtual Worlds: A Handbook of Method
Thanks!

Contact information: Dena Vallano
(vallano.dena@epa.gov)

Disclaimer: Mention of commercial products does not constitute endorsement or recommendation for use and are provided here solely for informational purposes.
THE AIRCASTING PLATFORM

**HOW IT WORKS**

![Image of a bear with a sensor]

Your air quality sensor

**AIRBEAM**

- Your air quality recordings and location map
- Community perspective and awareness

**AIRCASTING MOBILE APP** + **AIRCASTING WEBSITE**

Your optional public air quality indicator

**LED WEARABLES**

Individual, community and government change
Component Parts:
1. Main fastener hook
2. Main fastener sleeve
3. Size adjustment slider
4. Internal Breathing Rate Sensor
5. ECG sensors
6. Care label with Size, Serial # & Wash symbols
7. Brand label
8. Strap main body
9. Device receptacle
10. Electrical contacts
11. Shoulder strap (detachable, not visible)
12. Shoulder strap adjuster buckle (not visible)
13. Tension indicator loop
14. Strap (rear)
AIRBEAM
AirGo
Carbon Monoxide
Particulate Matter
Temperature
Relative Humidity

BioHarness
Heart Rate Variability
Heart Rate
Breathing Rate
Activity Level
Peak Acceleration
R to R
Core Temperature

Phone
Sound Levels
AirCasting Greenpoint

Citizen Science for Clean Air

A Community based participatory research project that will:

1) Equip Greenpoint residents with wearable sensors and smartphones for recording, mapping, and sharing air quality measurements; and

2) Provide the Greenpoint community with innovative ways to visualize and make sense of the collected data to reduce air pollution exposures and address community concerns related to air pollution, health, and quality of life.
Why Greenpoint?
info@habitatmap.org

habitatmap.org

aircasting.org

takingspace.org

twitter.com/habitatmap
Monitoring Localized Elevations of PM

David Holstius, Ph.D.
Senior Advanced Projects Advisor
Bay Area AQMD

November 2014
Acknowledgments

Workshop organizers and participants

- CAPCOA and SCAQMD
- Andrea Polidori, Eric Stevenson, Barbara Lee, Annie Boyd, …
- Presenters and attendees

Research sponsors and advisors

- Bay Area AQMD
- Phil Martien, Virginia Lau, Henry Hilken, …
- Prof Ron Cohen and the UC Berkeley BEACON project
- Profs Kirk Smith and Edmund Seto
Motivation and background
Motivation and background

Knowledge deficits in air pollution epidemiology

- Lack of support in “mid range” of IER models
- Approx 50 – 5,000 $\mu g \cdot m^{-3}$ PM$_{2.5}$

Exposure burdens co-incident with substantial person-time

- Global: indoor cookstoves, …
- California: transportation corridors, …

Uncertainties inhibiting planning and policymaking

- Faster, cheaper, more agile evaluations needed
Motivation and background

Figure 1: Burnett et al (2014) *Environ Health Persp*
Motivation and background

Figure 2: Chulha stove and traffic congestion. [Wikimedia]
Study 1
Study 1: commodity hardware

Figure 3: Prototype incorporating PPD42NS sensor.
Study 1: colocation at Oakland BAAQMD site

Figure 4: Holstius D, Pillarisetti A, Smith KR, Seto E. Field calibrations of a low-cost aerosol sensor at a regulatory monitoring site in California. *Atmos Meas Tech* 7, 1121–1131, 2014.
Study 1: $R^2 = 0.72$ vs. 24 h FEM PM$_{2.5}$

Figure 5: Holstius D, Pillarisetti A, Smith KR, Seto E. Field calibrations of a low-cost aerosol sensor at a regulatory monitoring site in California. *Atmos Meas Tech* 7, 1121–1131, 2014.
Study 2
Study 2: larger-scale evaluation \((n = 48)\)

Figure 6: Holstius D. *Monitoring PM w/Commodity Hardware*, 2014.
Study 2: exchange near-road ↔ background sites

Figure 7: Holstius D. Monitoring PM w/Commodity Hardware, 2014.
Study 2: single-parameter calibrations

Figure 8: Holstius D. *Monitoring PM w/Commodity Hardware*, 2014.
Study 2: near-road site

Figure 9: Laney College site, looking southeast along I-880
Study 2: localized elevations at < 1 h scale

Figure 10: Sensor data, 30 min scale (near-road, background, background). Black steps = 1 h PM$_{2.5}$-FEM (reference).
Study 2: localized elevations at < 1 h scale

Figure 11: Sensor data, 10 min scale (near-road, background, background). Black steps = 1 h PM$_{2.5}$-FEM (reference).
Study 2: localized elevations at < 1 h scale

Figure 12: Sensor data, 3 min scale (near-road, background, background). Black steps = 1 h PM$_{2.5}$-FEM (reference).
Study 2: localized elevations at < 1 h scale

Figure 13: Sensor data, 1 min scale (near-road, background, background). Black steps = 1 h PM$_{2.5}$-FEM (reference).
Study 2: localized elevations at < 1 h scale

Figure 14: Sensor data, 1 min scale (near-road, background, background). Black steps = 1 h PM$_{2.5}$-FEM (reference).
Study 2: “remote” calibration

1. Assume one reference group \((m = 12)\) operated by AQMD.
2. For the other three, just cross-calibrate gains within groups.
3. Expect group-level \(\hat{\beta}_1\)s to converge for “big enough” \(m\).

- Costs & limitations
  - \pm 10\% error in \(\beta_1\) for \(m = 12\)
  - usual threats to validity (extrapolation)

- Benefits to good-faith collaborations
  - faster than colocation if \(\tau < 1\ h\)
  - no need to travel to regulatory sites
Summary and conclusion
Summary of findings

**Reliability.** In our field studies, PPD42NS optical aerosol sensors have exhibited acceptable performance:

- No failures of \( n = 48 \) sensors in 10+ weeks
- Very good precision (inter-sensor agreement)

**Fidelity.** Good agreement with FEM reference (BAM-1020). Measurand is not is exactly PM\(_{2.5}\)!

- 24 h scale: \( R^2 = 0.72 \)
- 1 h scale: \( R^2 \approx 0.6 \)
  - comparable to GRIMM, DustTrak, or 2\(^{nd}\) BAM
  - \( \sigma \) for BAM is 2 – 2.4 \( \mu g \cdot m^{-3} \) at 1 h scale
Summary of findings

**Utility.** Simple model has reasonable fit:

- $\beta_0$ very close to zero
- modest variation in $\beta_1$
- 10% error in $\beta_1$ if “remotely” calibrated

**Relevance.** Can observe localized PM elevations:

- consistently, with multiple PPD42NS sensors
- can resolve structure at timescales < 1 h

*Further assessments under varying conditions are warranted. Independent replications are needed to substantiate or refute these findings.*
Conclusion

Contributes to prospects for monitoring localized PM elevations

▶ Good-enough assessments in absense of viable alternatives
▶ Supplement/complement to established monitoring
▶ Meeting the challenges of new geographies

Large $n$ can support more than just increased density/coverage

▶ Calibrate remotely with good-faith partners
▶ Degrade, don’t fail: triplicate sensors per device
Future directions

Figure 15: Sharp DN7C3JA001 with impactor, claimed to attenuate 98% of response to $d_p = 5.0 \mu m$ (vs GP2Y1010AU0F).


Additional slides
Study 1: colocation

West Oakland, 15 – 23 Apr 2013

R² = 0.55
R² = 0.60
R² = 0.56

Figure 16: PPD42NS vs BAM at 1 h scale. (R² ≈ 0.6)
Study 1: colocation

Vallejo, 7 – 30 Apr 2013

Figure 17: BAM vs BAM at 1 h scale. ($R^2 \approx 0.6$)
BEACO$_2$N: Dense networks for air quality and climate research

Ronald C. Cohen
Professor of Chemistry
Professor of Earth and Planetary Science
UC Berkeley

$NSF$, BAAQMD, HEI, UC Berkeley
Climate

Illustration by John Heinly

Air Quality

[Image of a highway with heavy traffic]
Particulate Matter
(co-emitted with CO$_2$, NO$_x$, CO, ...)

from Choi et al. 2014
Shinyei Grove Particulate Sensor

Vaisala GMP343 NDIR CO₂ Sensor
Electrochemical O$_3$, NO, NO$_2$ & CO Sensors

Shinyei Grove Particulate Sensor

Vaisala GMP343 NDIR CO$_2$ Sensor
BErkeley
Atmospheric
CO$_2$
Observation
Network

2km
<table>
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<th>Performance</th>
<th>Picarro G2301</th>
<th>Vaisala GMP343</th>
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</thead>
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<td>Accuracy</td>
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<td>± 7 ppm</td>
</tr>
<tr>
<td>Precision</td>
<td>± &lt; 0.2 ppm (5s)</td>
<td>± 3 ppm (2s)</td>
</tr>
<tr>
<td>Drift</td>
<td>± 6 ppm/yr</td>
<td>± 8 ppm/yr</td>
</tr>
<tr>
<td>Weight</td>
<td>58 lbs</td>
<td>0.8 lbs</td>
</tr>
<tr>
<td>Price</td>
<td>$50,000-100,000</td>
<td>$3,000</td>
</tr>
</tbody>
</table>
BEACO$_2$N CO$_2$ 2013

Sites:
- Burckhalter
- Kaiser
- CollegePrep
- Korematsu
- ODowd
- HeadRoyce
- ElCerrito
- StLiz
- NOakland
Downwind of Port of Oakland

Downwind of Bay Bridge
Bay Bridge

→ Day of week effect?
→ Lower signal during low bridge traffic?
Bay Bridge Aug/Sept Diurnal Cycle

CO2 (ppm)

weekdays (M-F)
weekends (Sat/Sun)
Port of Oakland

→ Affected by shipping? Or just traffic?
Port Aug/Sept Diurnal Cycle

weekdays (M-F)
weekends (Sat/Sun)
Port Diurnal Cycle by Ship Movement

- Ships stationary
- Ships in motion

CO2 (ppm)

Hour

5 AM  10 AM  3 PM  8 PM
☑ Sensitivity
☑ Spatial Resolution
☑ Temporal Resolution
Interpreting the observations
WRF-STILT

\[ Kx + \varepsilon = y \]

- \( y = \) concentrations (BEACO\(_2\)N observations)
- \( x = \) emissions
- \( K = \) “footprint” mapping from \( x \) to \( y \)
- \( \varepsilon = \) error
WRF-STILT

\[ Kx + \varepsilon = y \]

forward \hspace{2cm} inverse

\( y = \) concentrations (BEACO\(_2\)N observations)
\( x = \) emissions
\( K = \) “footprint” mapping from \( x \) to \( y \)
\( \varepsilon = \) error
WRF-STILT for day bridge was closed
- Sensitivity
- Spatial Resolution
- Temporal Resolution
- Multi-Node Analysis
1999-2000 Emissions Factors

- **Light-duty passenger vehicles**
- **Heavy-duty diesel**

Harley et al. 2005
- Sensitivity
- Spatial Resolution
- Temporal Resolution
- Multi-Node Analysis
- Chemical Speciation
Thank you!
Thank you!
Using Data from Small Sensors to Address Air Quality Issues

Clinton P. MacDonald, Timothy S. Dye, Briana J. Gordon, Hilary R. Hafner
Sonoma Technology, Inc., Petaluma, California

About Small Sensors
Small sensors have a wide range of applications but there are several key issues to consider when using and interpreting their data:

- Small sensors are available for many pollutants
- Sensor cost is decreasing, but it is important to consider costs for associated equipment
- Sensor accuracy is improving, but there are limited evaluations, especially in the real world
- Sensor data pose challenges with processing, quality control, and display

Applications
Small sensors can be used in a variety of ways:

- Applied science
- Regulatory
- Education
- Community action
- Personal health information

This poster provides three examples of small sensor applications: understanding residential wood burning behavior, evaluating the representativeness of regulatory monitors, and educating students about air quality in their neighborhoods.

Key Issues
Sensor accuracy in the ambient environment, especially interferences
- Appropriate use of the data, given data quality
- Quality control of data
- Managing large amounts of data
- Use of data collected by the public

Applied Science
Santa Rosa, CA, Wood Smoke Study

Funding: Bay Area Air Quality Management District (BAAQMD)
Goal: Understand neighborhood-scale gradients in wintertime PM2.5
Method: Mobile monitoring in several neighborhoods using a PDR 1500
Key Findings
- Sensor performed very well; data were compared to data from a BAM 1020
- Large neighborhood-scale gradients in PM2.5 due to wood burning behavior
- Observations imply that burning occurred on burn-ban days
Conclusion: Mobile measurements can be used to characterize burning behavior and assess effectiveness of wood-burning curtailment programs

Regulatory
Representativeness of Federal Reference Method Ozone Monitors in Arvin, CA

Funding: San Joaquin Valley Air Pollution Control District (SJVAPCD)
Goal: Determine whether the location of a key regulatory ozone monitor that was moved to a new site still represented peak ozone concentrations in the area
Method: Deployed 23 low-cost Aeroqual ozone sensors for six weeks
Key Findings
- Ozone sensor precision and accuracy were good
- Sensor drift occurred; collocation of all sensors with the federal reference method (FRM) was critical at the beginning and end of the study, and with selected sensors during the study
- While modest ozone gradients were observed, we determined that the new location for the regulatory monitor met siting objectives
- Spatial data were used to develop equations that can now be used to predict ozone spatially using less-dense permanent FRM monitors
Conclusion: Deployment of low-cost sensors can be an effective method to evaluate monitoring networks

Education
Kids Making Sense Program

Funding: Knight News Foundation, U.S. Environmental Protection Agency (EPA), EPA Taiwan, Sonoma Technology, Inc.
Goal: Teach students air quality science and empower them to take action to improve the air they breathe
Method: Taught high school students in San Francisco, Brooklyn, Los Angeles, and Taiwan how to take measurements using AirBeam PM sensors and analyze the data they collected

Key Findings
- Teachers and students were very engaged
- Students quickly understood the relationship between local sources and air quality
- There is interest in implementing the program in other areas in the U.S. and abroad
Conclusion: Hands-on measurement and data analysis teach students about science and build awareness about air quality in their communities

Big-Picture Thoughts
- Quality low-cost sensors are available
- Anticipated large increase in the number of small sensors and users in the next few years
- It will be a challenge to quality control and handle large amounts of data
- Application of sensors will ultimately help improve the environment

Tell us what you think
707.665.9900 | sonomatech.com
Poster presented by Clinton MacDonald (clint@sonomatech.com) at the My Air Quality Conference in Oakland, California, on November 19, 2014, and Diamond Bar, California, on November 21, 2014 (STI-6122).