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

AGENDA

Northern California (N)	Southern California (S)
Wednesday, November 19, 2014	**Friday, November 21, 2014**
Elihu M. Harris State Building	**South Coast Air Quality Management District**
1515 Clay Street	**21865 Copley Drive**
Oakland, California 94612	**Diamond Bar, California 91765**

9:00 Welcome & Introductions

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

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

N: Phil Martien, BAAQMD
S: Philip Fine, SCAQMD & Rob McConnell, Univ. of Southern California

9:30 Measuring Air Pollution: Monitoring & Sensor Technology

- Monitoring objectives
  - Types of objectives (NAAQS, emission point, localized impacts)
  - Technology used

N: Eric Stevenson, BAAQMD
S: Dan Johnson, Great Basin Unified Air Pollution Control District

- Low-cost sensor technology
  - Pros & cons
  - State of the science
  - Technical issues
  - Next Generation Air and Compliance Monitoring

N: Carlos Nunez, U.S. EPA, Office of Research and Development at Research Triangle Park
S: Gayle Hagler, U.S. EPA, Office of Research and Development at Research Triangle Park

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)

- Developing QA/QC procedures and documentation

10:30 Break

10:45 Meaning of Sensor Data

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

11:15 Sensors Deployment and Applications

• Community monitoring	N & S: Michael Heimbinder, HabitatMap
○ Available technology	
○ Development of air quality maps	
○ Case studies	
• Monitoring in high concentration environments	N & S: David Holstius, BAAQMD
○ Near-field exposure	
○ Indoor cook stove	
○ Transportation corridors	
• Sensor networks	N & S: Ron Cohen, Univ. of California, Berkeley
○ Building a "high density" sensor network	
○ BEACON project	

12:00 Lunch

1:15 Focused Discussions/Q&A

• Community projects using sensors	N: BAAQMD staff and Denny Larson, Global Community Monitor
	S: SCAQMD staff and Luis Olmedo Velez, Comite Civico Del Valle
• Compliance & industrial applications for sensors	N: BAAQMD staff and Janet Whittick, California Council for Environmental and Economic Balance (CCEEB)
	S: SCAQMD staff and Janet Whittick, CCEEB
• Developing good sensors	N: BAAQMD staff and Clinton MacDonald, Sonoma Technologies, Inc. (STI)
	S: SCAQMD staff and Clinton MacDonald, STI
• Sensors as educational tools	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

- 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

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

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

South Coast AQMD

Workshop on Air Quality Sensor Technologies
November 21, 2014

Why Does Southern California have some of the Worst Air Quality in the Nation?

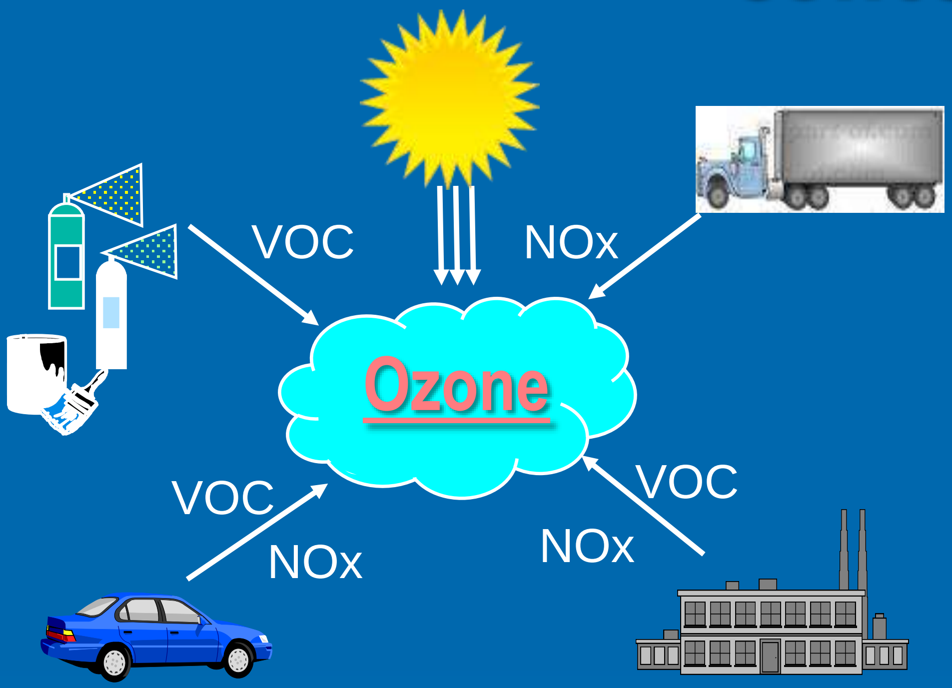
Key Air Pollutants

- ☑ Carbon Monoxide
- ☑ Nitrogen Dioxide
- ☑ Sulfur Dioxide
- Lead
- Ozone
- Particulate Matter (PM10, PM2.5)

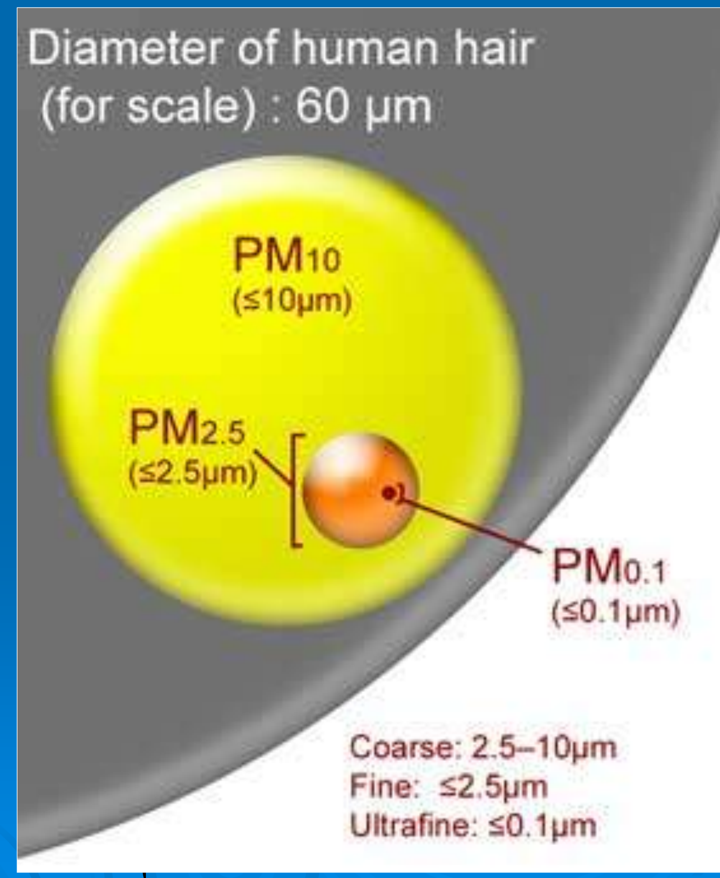
U.S. EPA Criteria Pollutants

- Air Toxics (Diesel Particulate Matter, benzene, lead, etc.)
- Climate Forcers (CO2, methane, black carbon, etc.)

Main Southern California Air Pollution Concerns

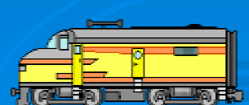


Particulate Matter

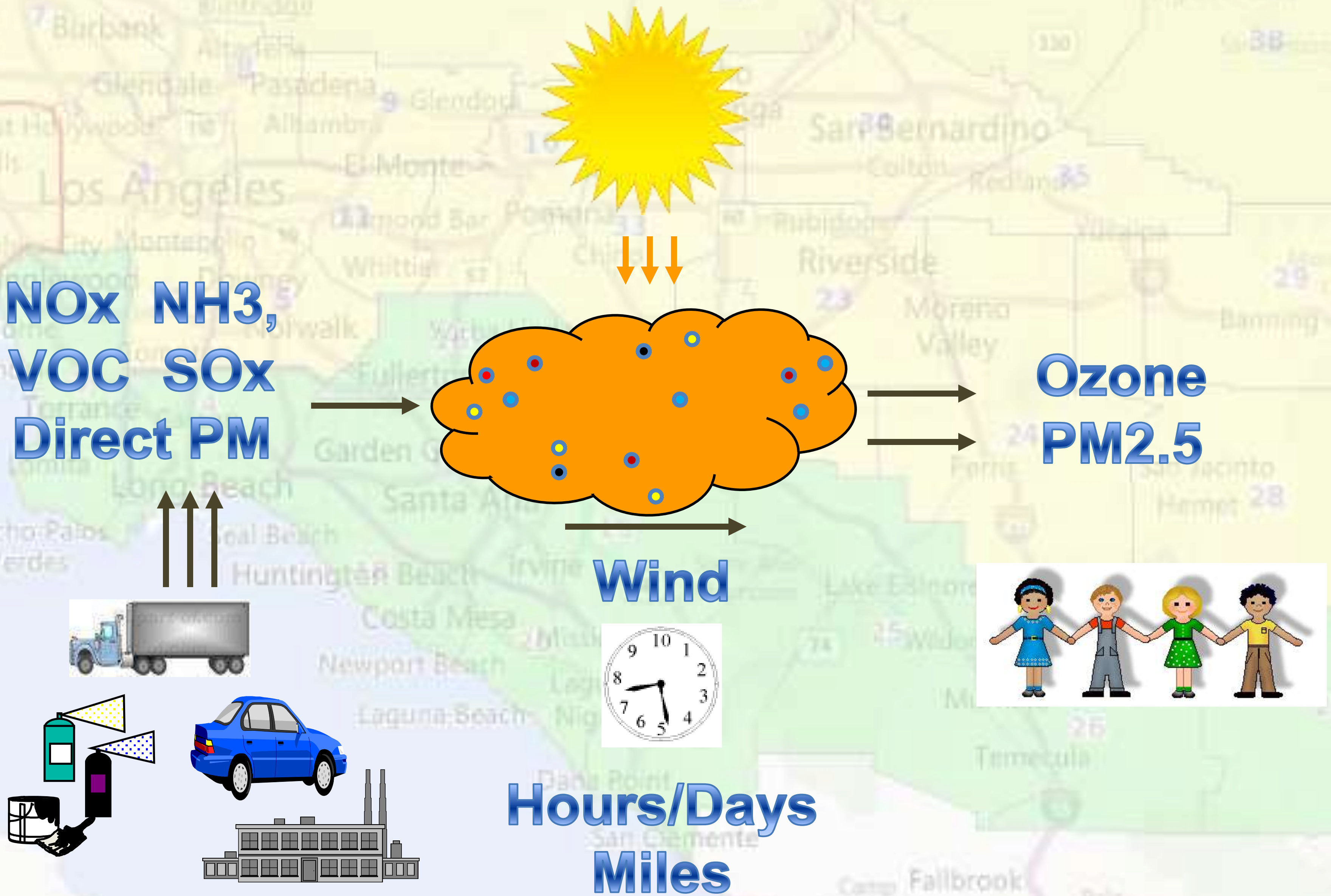


Air Toxics

Diesel Particulate Matter
VOCs, Metals

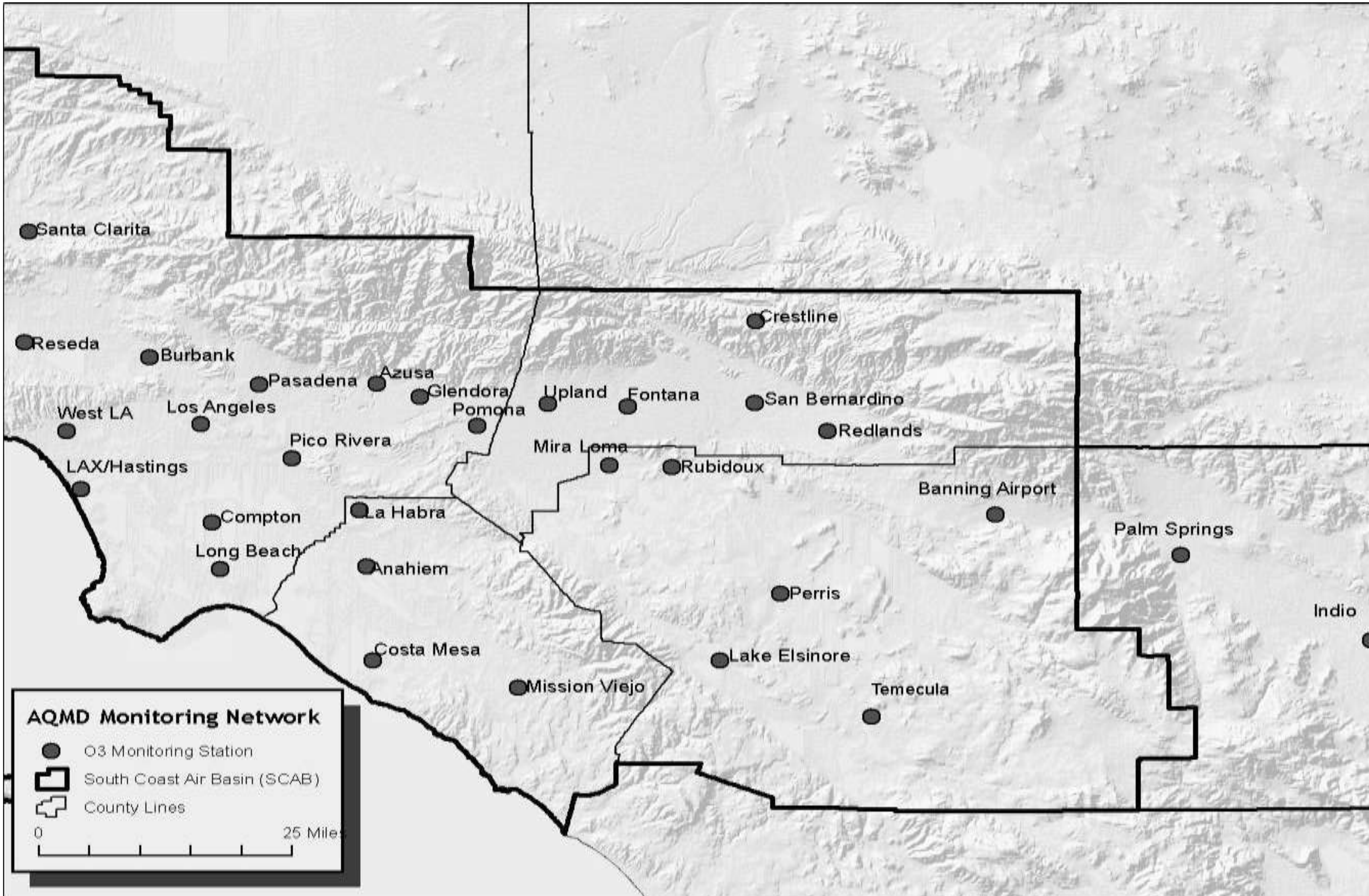


Regional Pollution

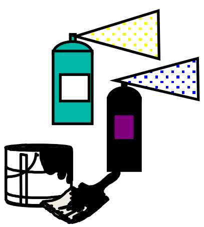


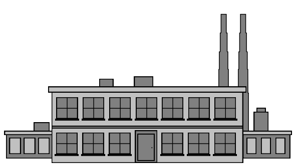

Los Angeles Region
Ground-Level Ozone
July 4, 2008
8:00 am PDT
Santa Clarita
14
San Fernando
118
Simi Valley
Pasadena
210
San Dimas
15
San Bernardino
Agoura Hills
Hollywood
Los Angeles
Alhambra
Ontario
Fontana
405
Malibu
La Puente
10
Santa Monica
Culver City
60
Chino
Whittier
710
Riverside
Banning
El Segundo
Compton
57
Anaheim
Corona
Palos Verdes
Long Beach
Santa Ana
Perris
15
Huntington Beach
215
Irvine
Lake Elsinore
El Toro
Newport Beach
5
San Juan Capistrano
Temecula
Santa Catalina Island
San Diego County

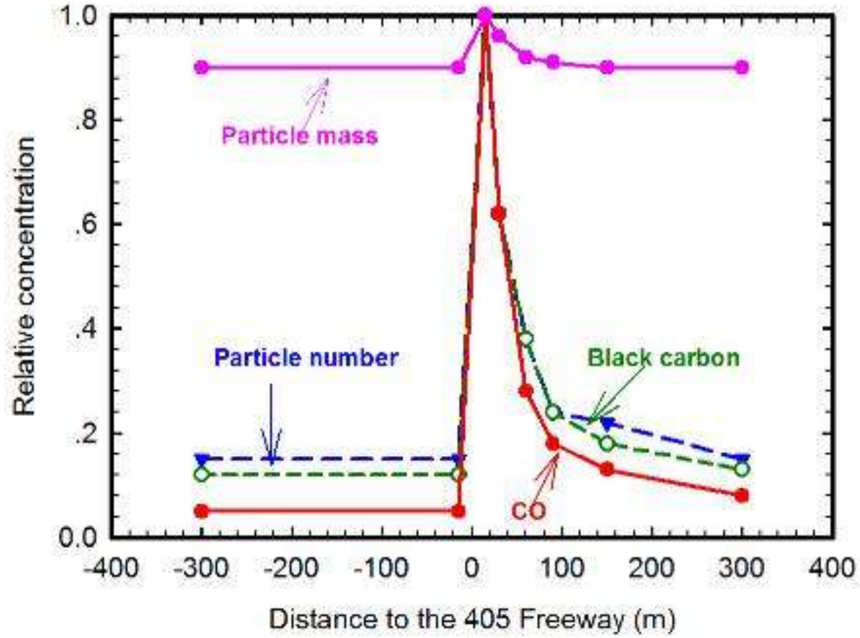
AQMD Permanent Air Monitoring Network
Criteria Pollutants / Regional Pollutants

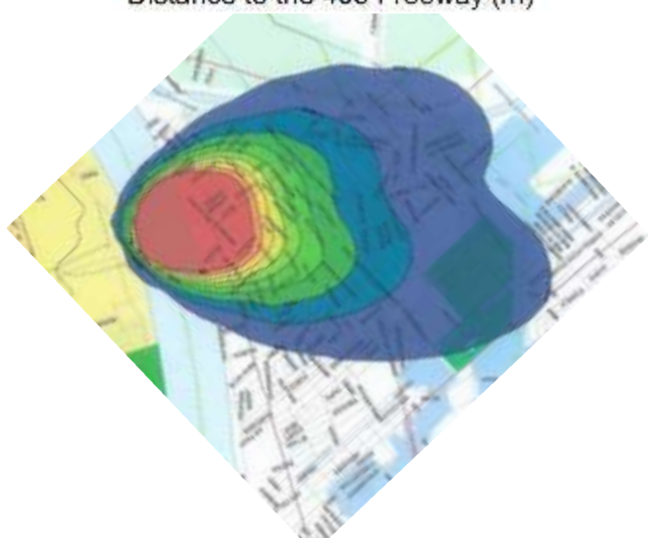


Localized Pollution









Air Toxics
Lead, CO

Usually less than one mile

Air Toxics

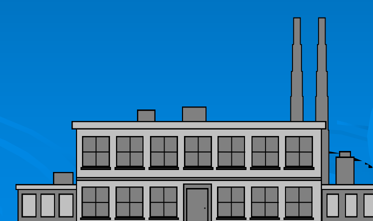
<u>Diesel Particulate Matter</u>

<u>Toxic Chemicals</u>

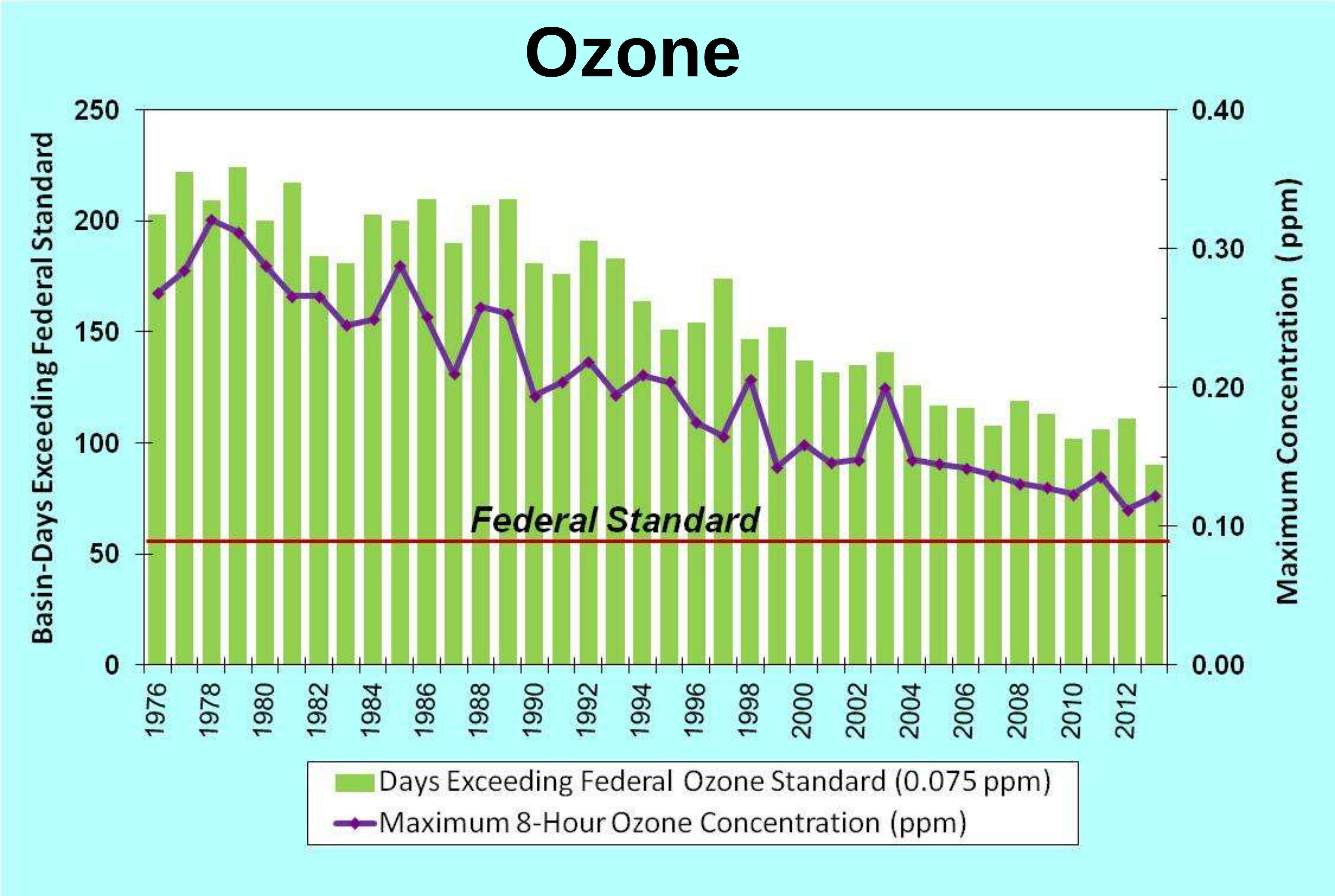
VOC (i.e. Benzene)

Metals (i.e. Nickel)

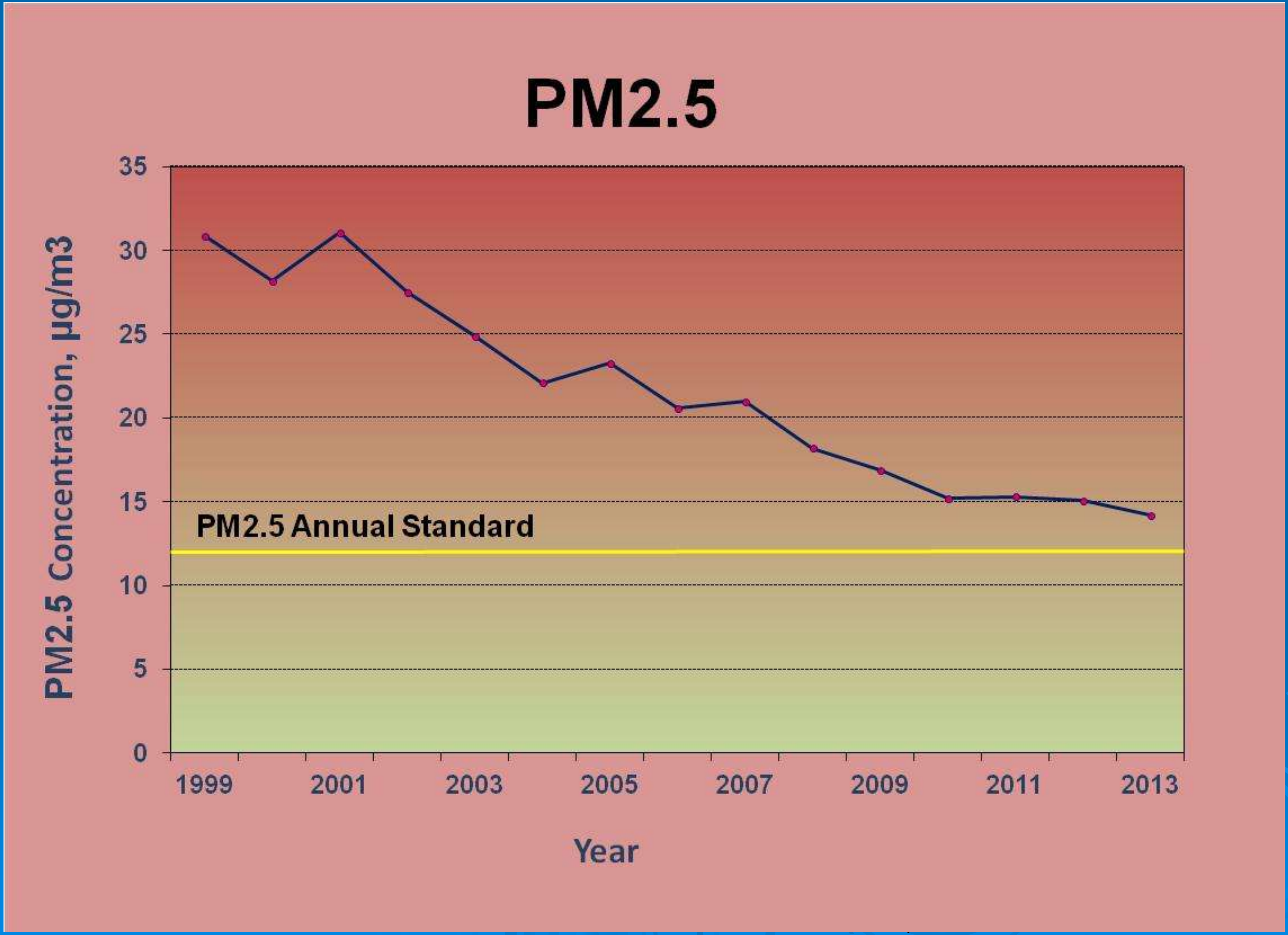
etc.

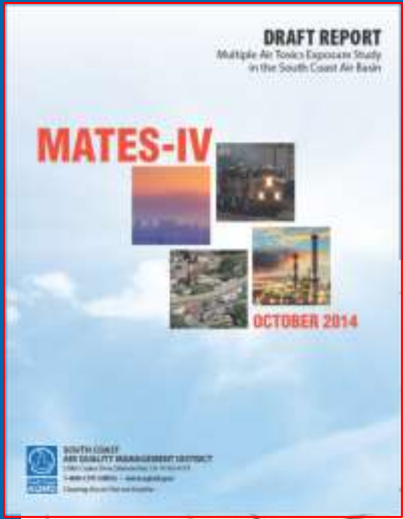


Air Quality Has Improved Significantly

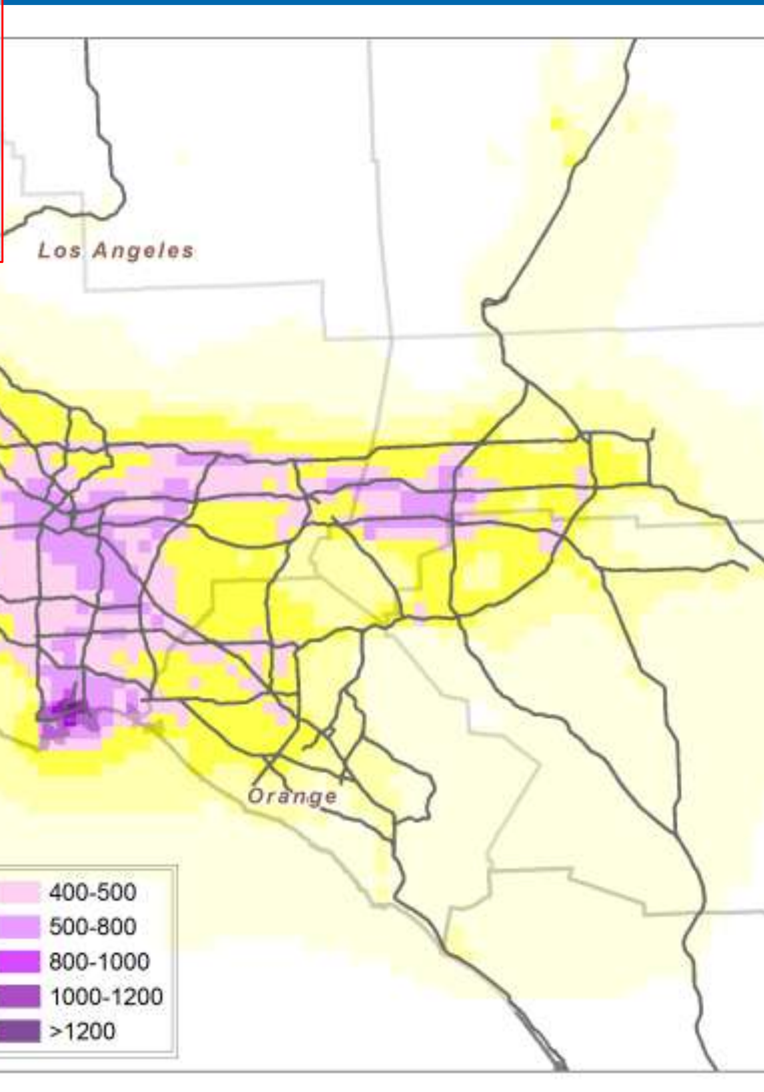


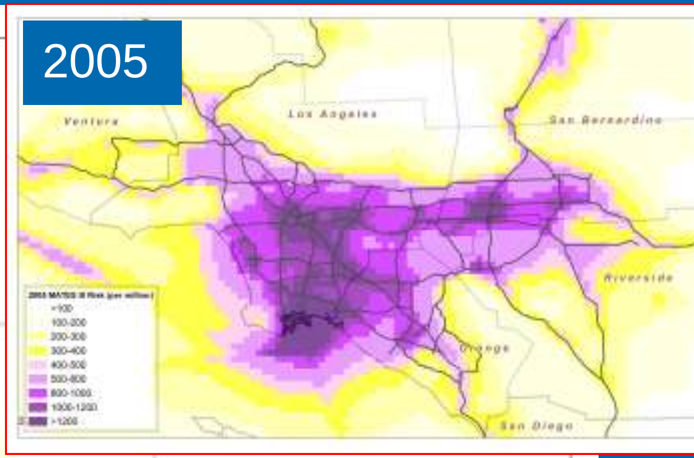
Air Quality Has Improved Significantly





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

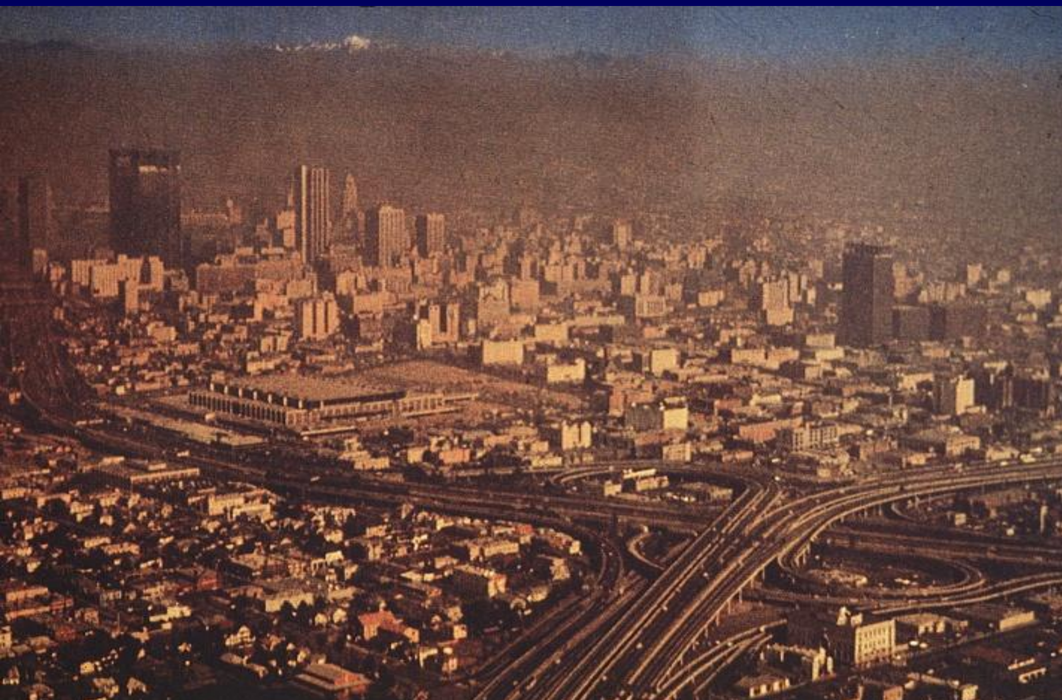
My Air Quality

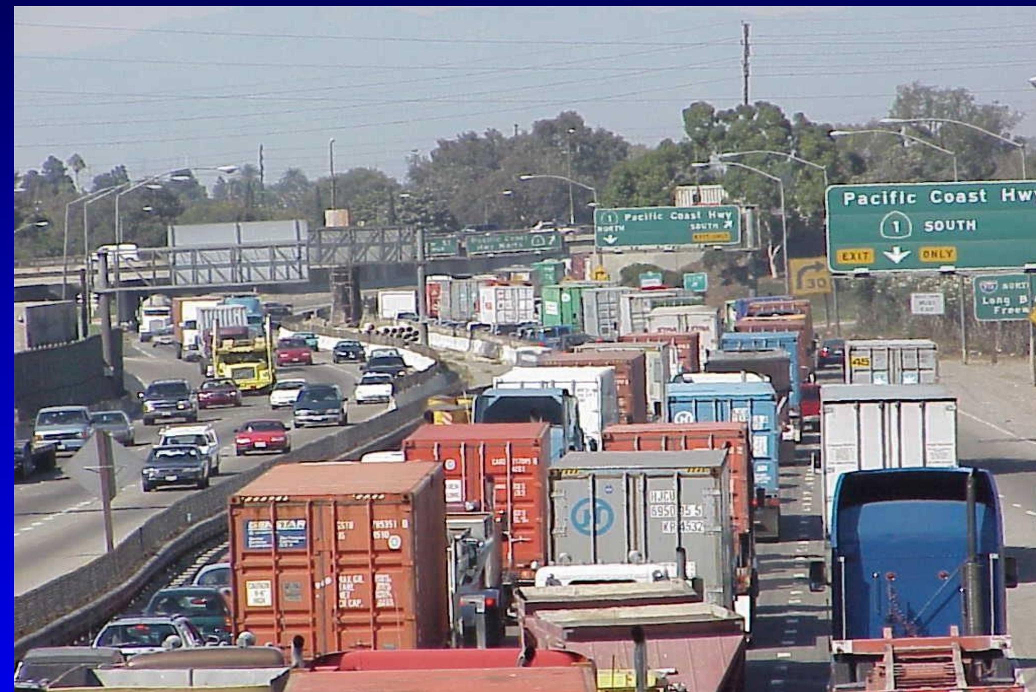
(SCAQMD, November 21, 2014)

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:**
    - **Brook RD, et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation. 2010;121:2331-2378**
  - **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**
    - **(Jerrett M, Burnett RT, Ma R, et al. Spatial analysis of air pollution and mortality in Los Angeles. *Epidemiology* 2005;16(6):727-36)**
  - **THICKER ARTERIES in southern Californians living in areas with higher particle pollution**
    - **(Kunzli N, Jerrett M, Mack WJ, et al. Ambient air pollution and atherosclerosis in Los Angeles. *Environ Health Perspect* 2005;113(2):201-6)**
  - **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**

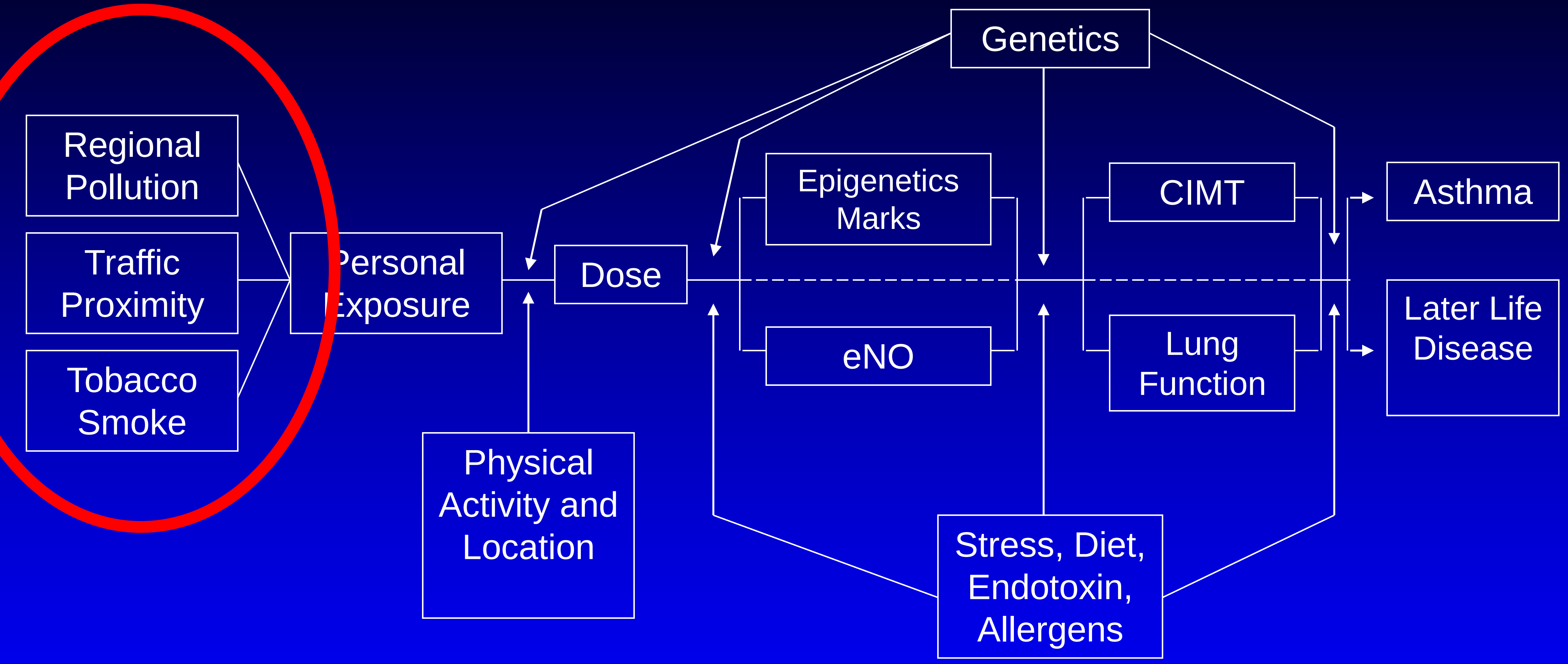
Ozone

- U.S. Environmental Protection Agency. Policy assessment for the review of the ozone national ambient air quality standard (2014). EPA 252/R-14-006.
  - Asthma exacerbation
    - Symptoms, medications, emergency department, hospitalizaiton
  - ?New onset asthma
  - Respiratory symptoms, hospitalization, school absence
  - Cardiovascular morbidity, hospitalization, mortality
  - ?Respiratory mortality

Summary Nearby Traffic Effects

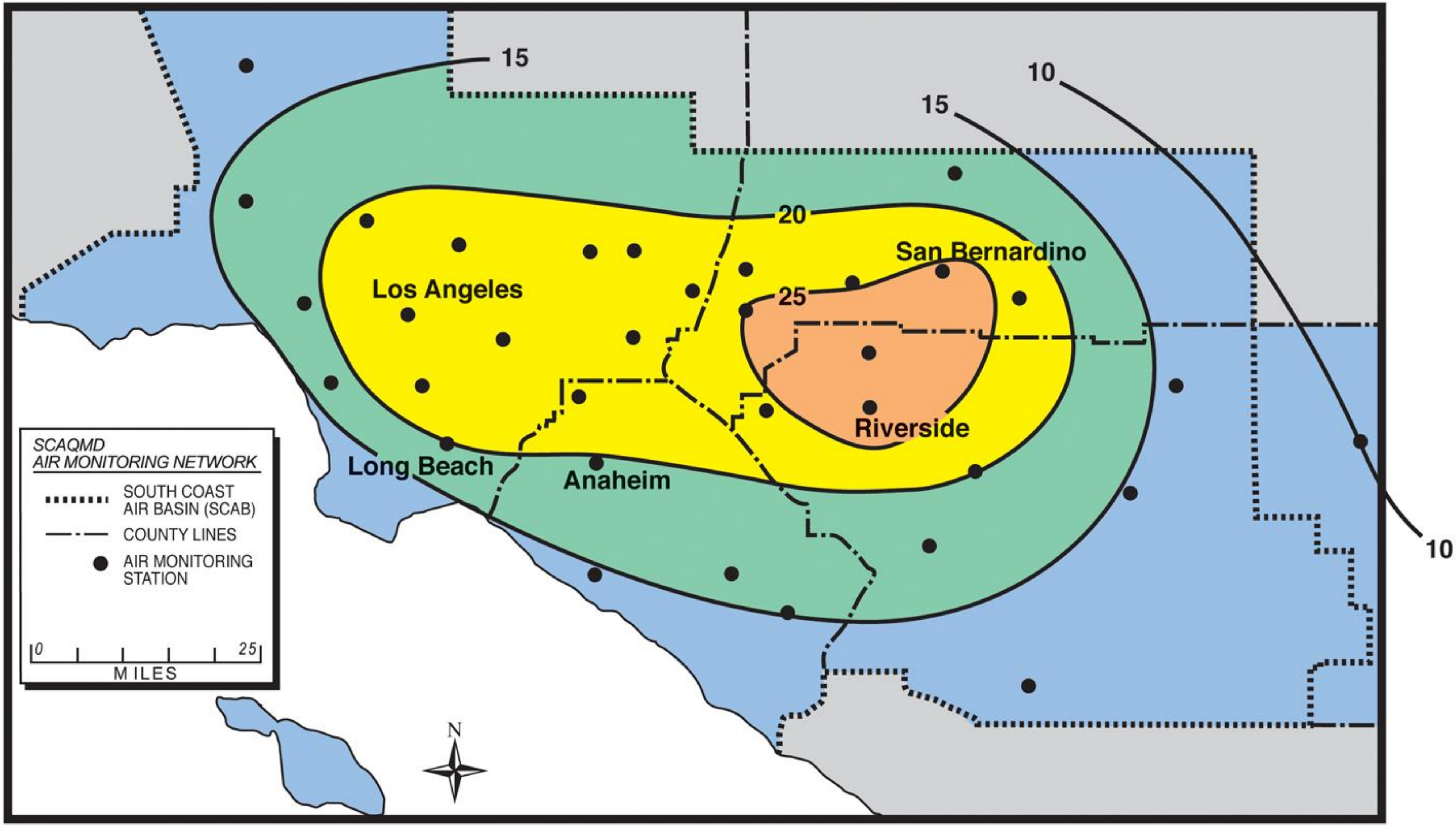
- **Studies in U.S. and in Europe show that**
  - **LIVING NEAR BUSY ROADS AND FREEWAYS – ESPECIALLY WITH LOTS OF TRUCK TRAFFIC – HAS BEEN LINKED TO:**
    - **Asthma**
      - Anderson H, et al. Air Qual Atmos Health 2013;6:47-56.; Salam MT, et. al. Curr Opin Pulm Med 2008;14:3-8.
    - **Heart attack (and other heart disease)**
      - Brook RD, et al. Circulation. 2010;121:2331-2378; Gan WQ, et. al. Epidemiology 2010;21:642-649; Gan WQ, et. al. Environ Health Perspect 2011;19:501-507.
  - **AND OTHER CONDITIONS:**
      - Health Effects Institute. Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects (special report 17). 2009
    - **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



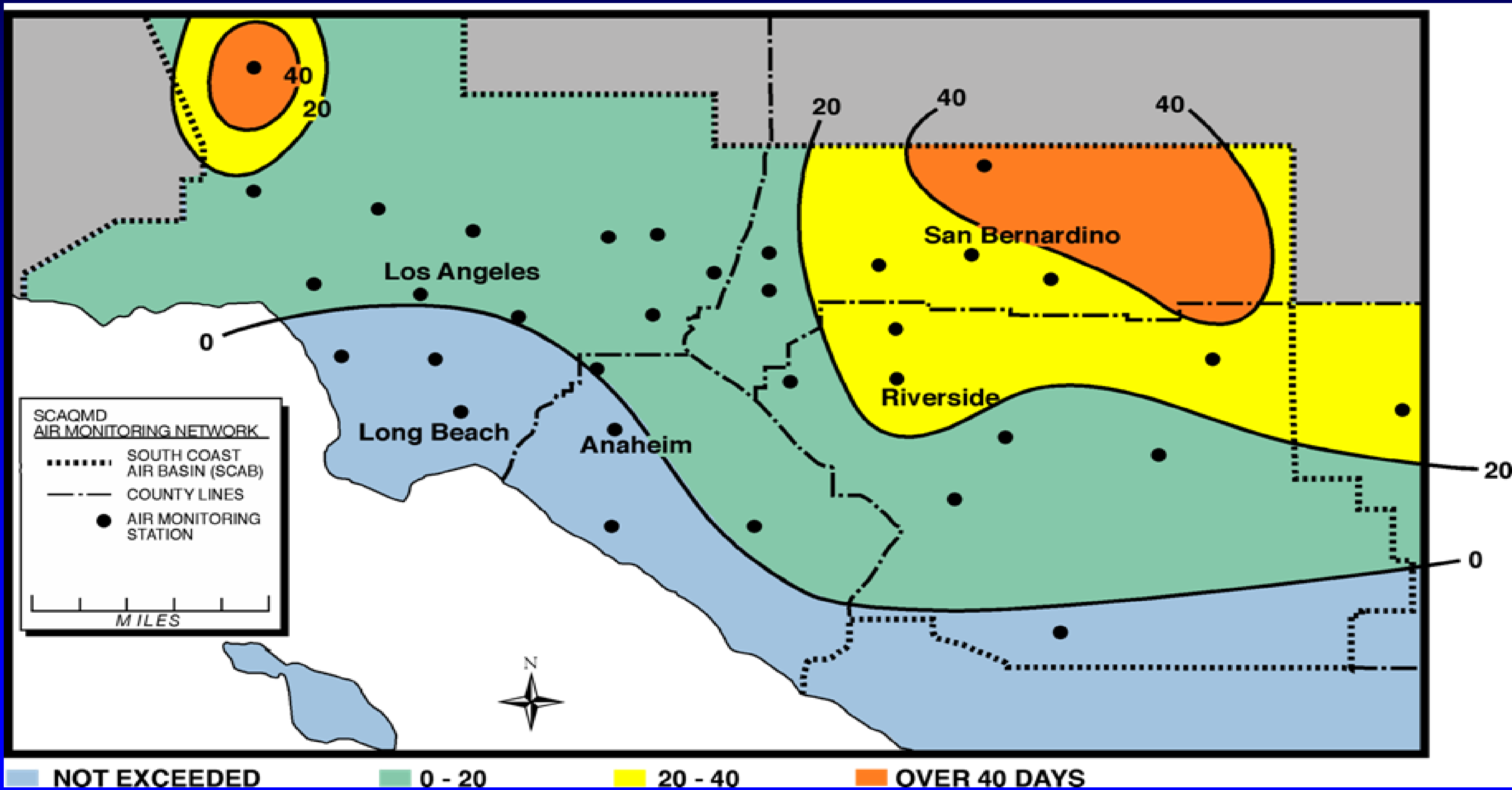
PM2.5

Annual Arithmetic Mean, μg/m³
(Federal Standard = 15 μg/m³)

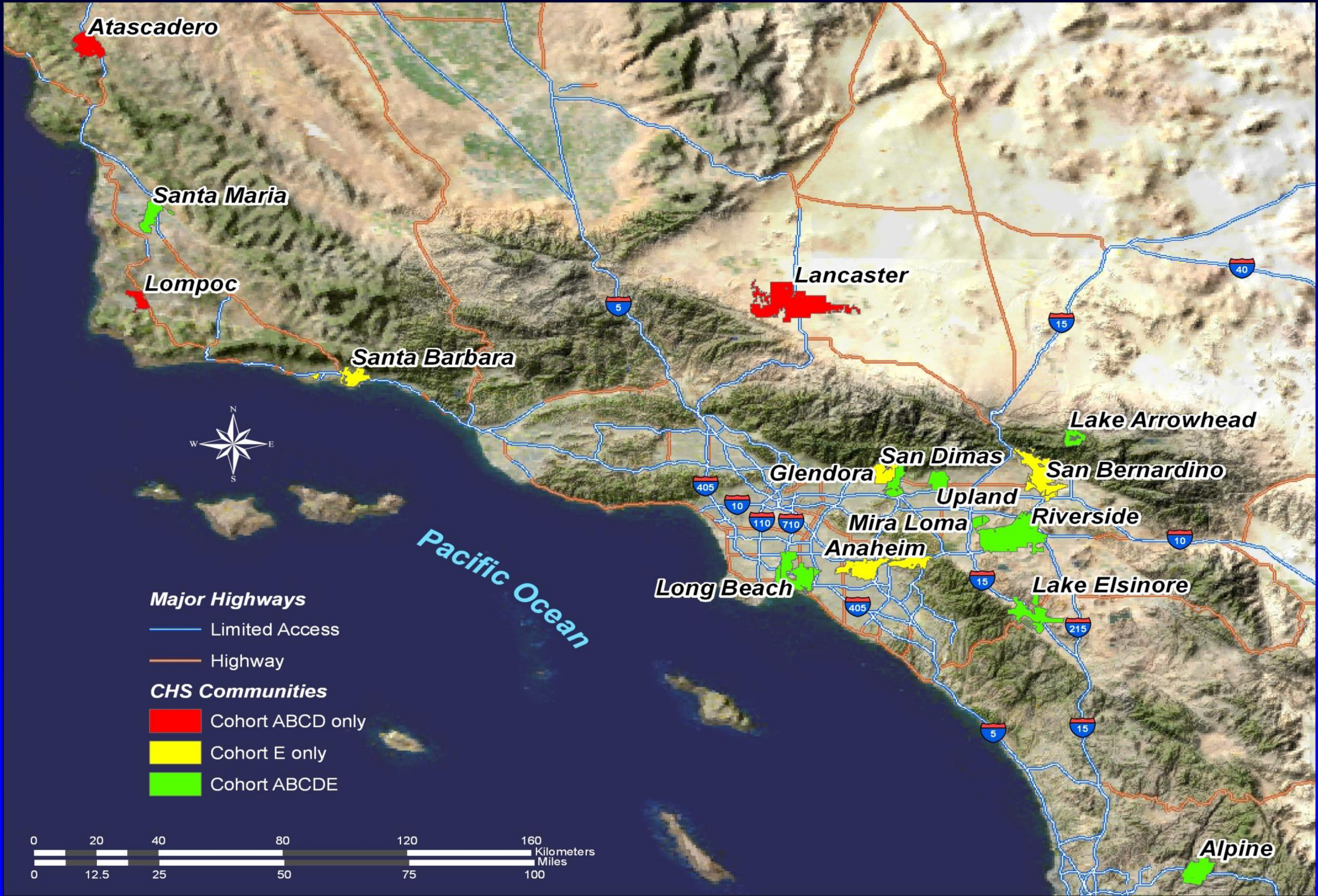


NOT EXCEEDED 15 - 20 20 - 25 OVER 25 μg/m³

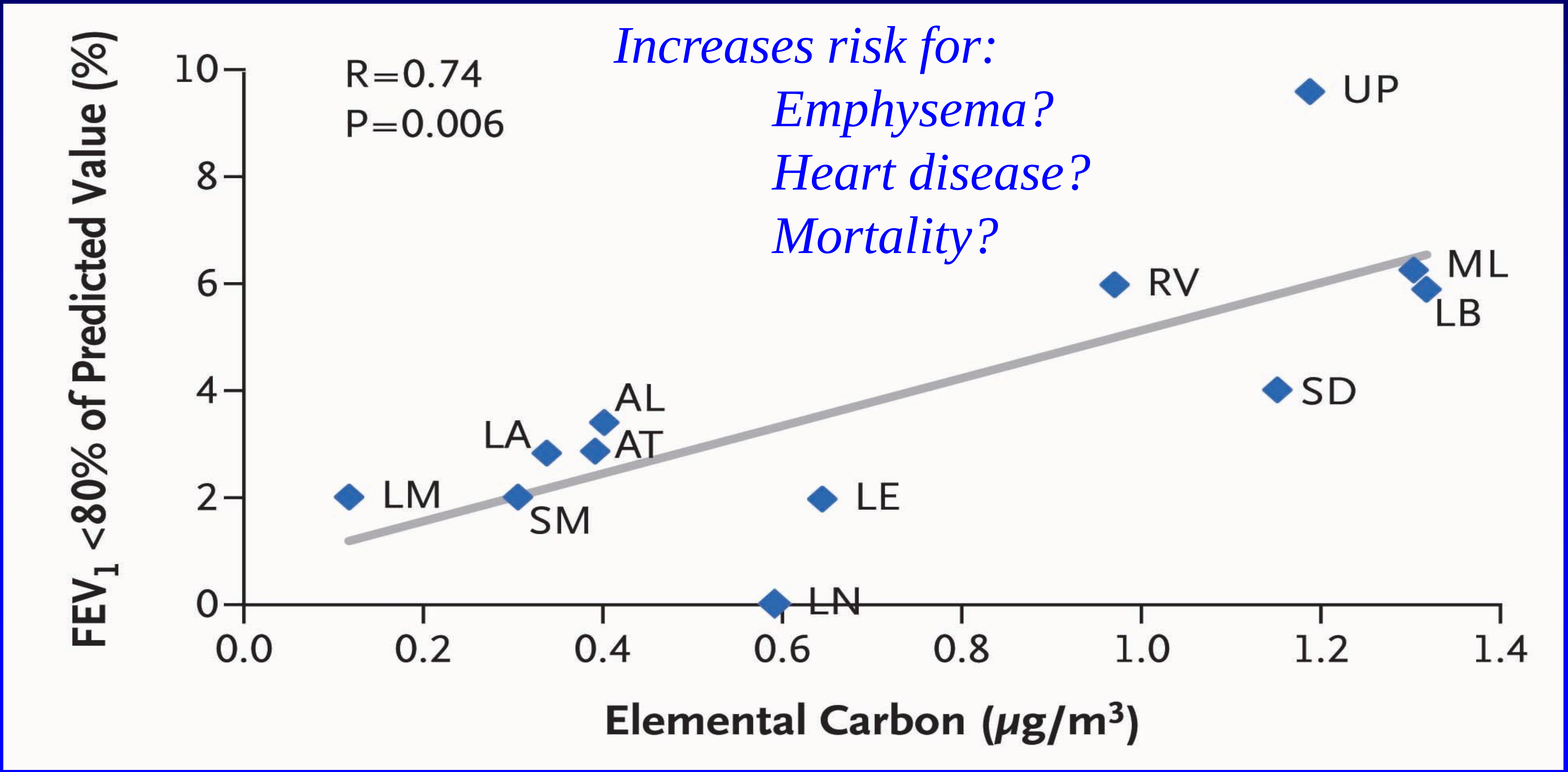
Number of Days Exceeding the U.S. Ozone Standard (8-hour average ozone > 0.08 ppm)



The USC Children's Health Study

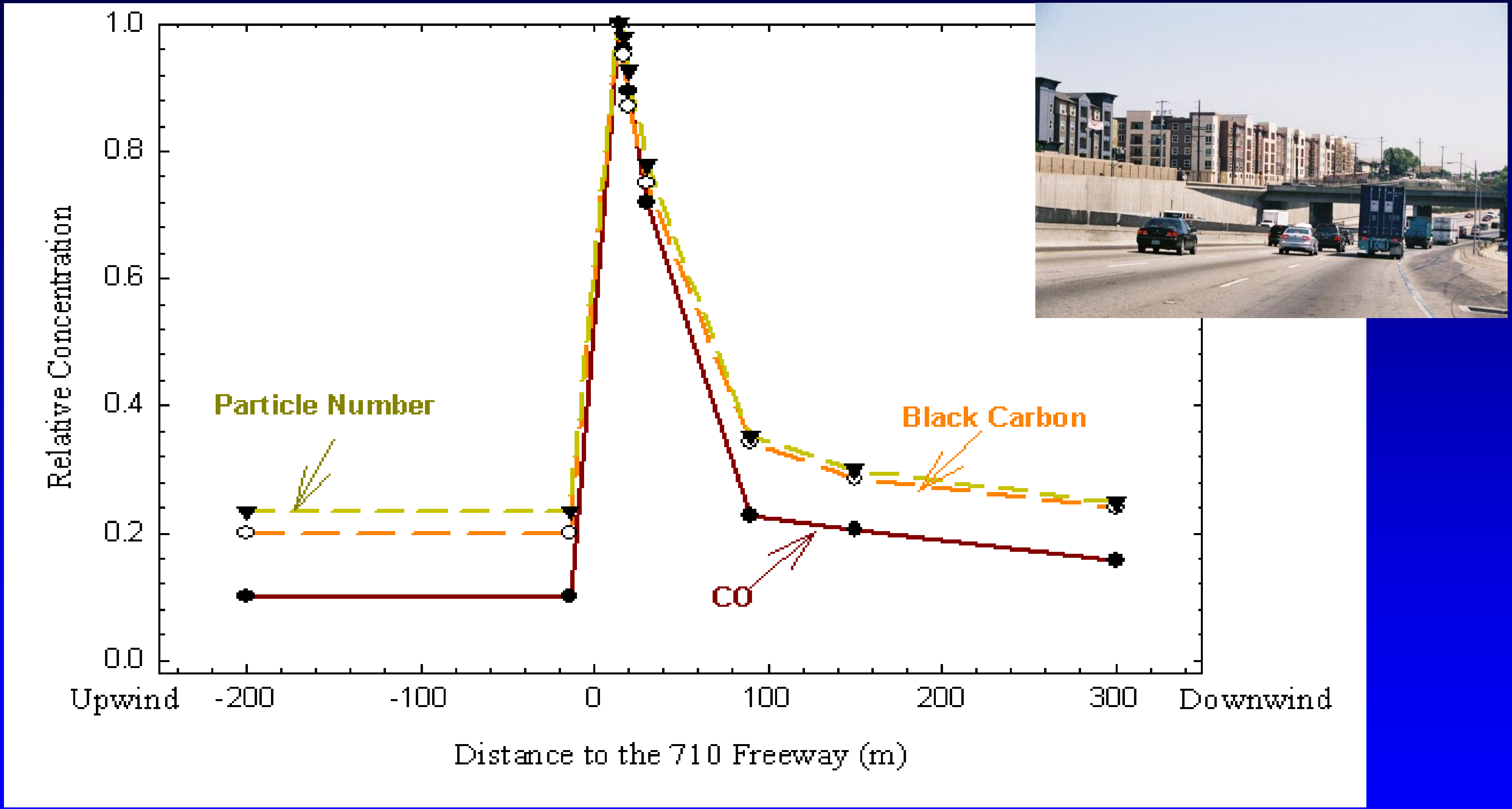


18-year-olds in Polluted Communities are 4-5 Times More Likely to Have Low Lung Function



Gauderman, et al, *N Engl J Med* 2004;351:1057-67

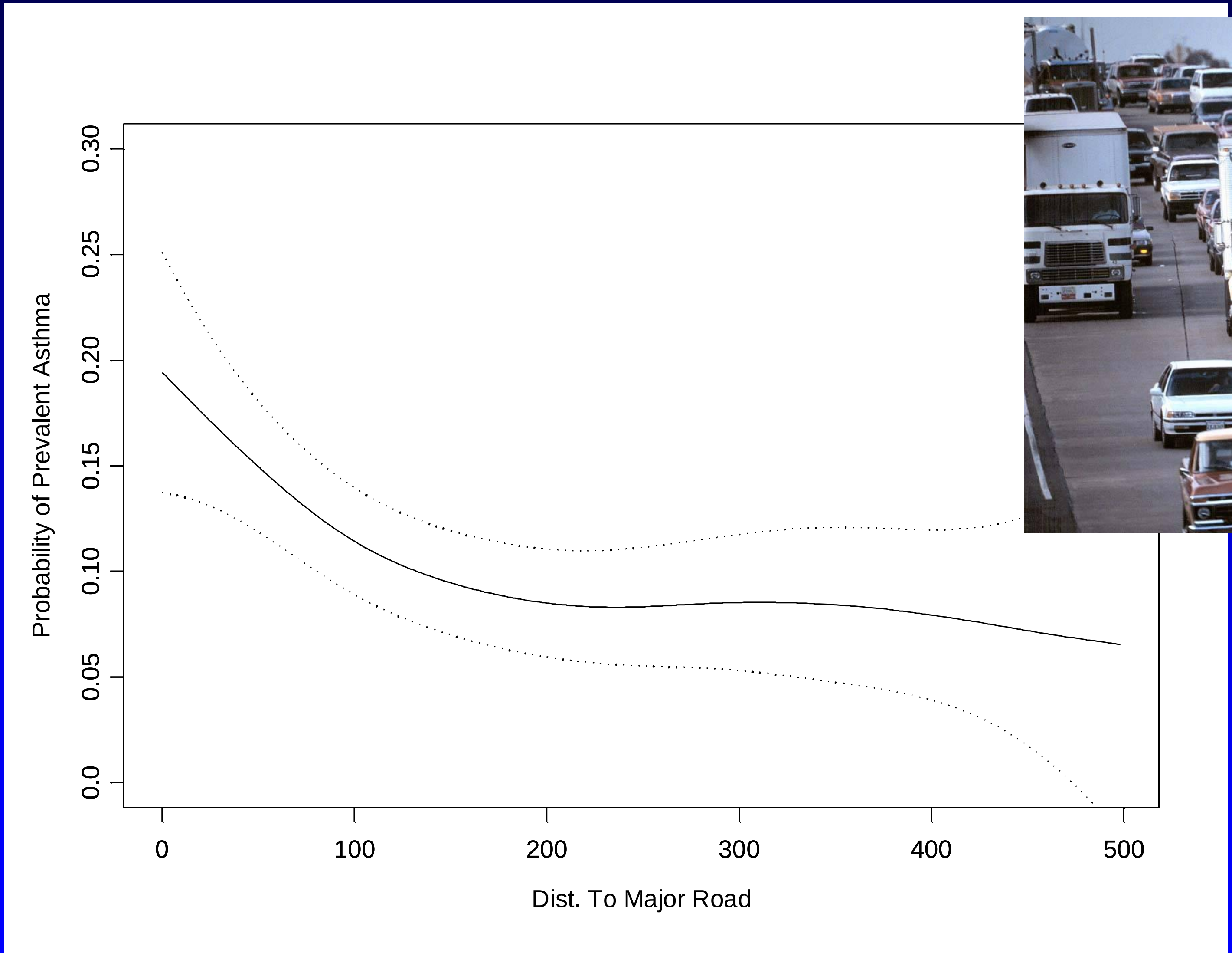
Air Quality is Worse Near a Freeway



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

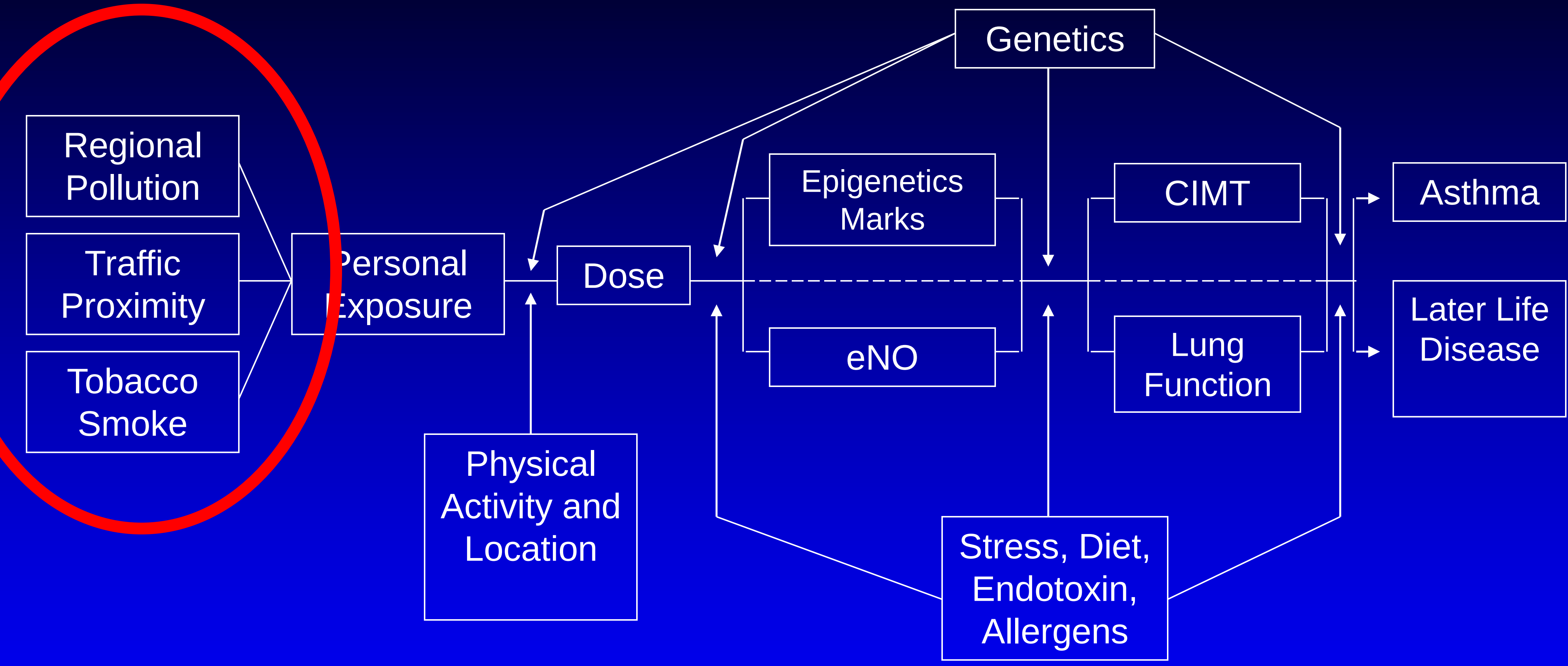
(Zhu et al., 2002, 2006)

Prevalent Asthma And Residential Distance To A Major Road



McConnell, et al, Environ Health Perspect 2006;114:766-772

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 $l00s/unit)
  - Time resolved
- Desirable
  - Accurate
  - Rugged
  - Wearable
  - Biologically relevant

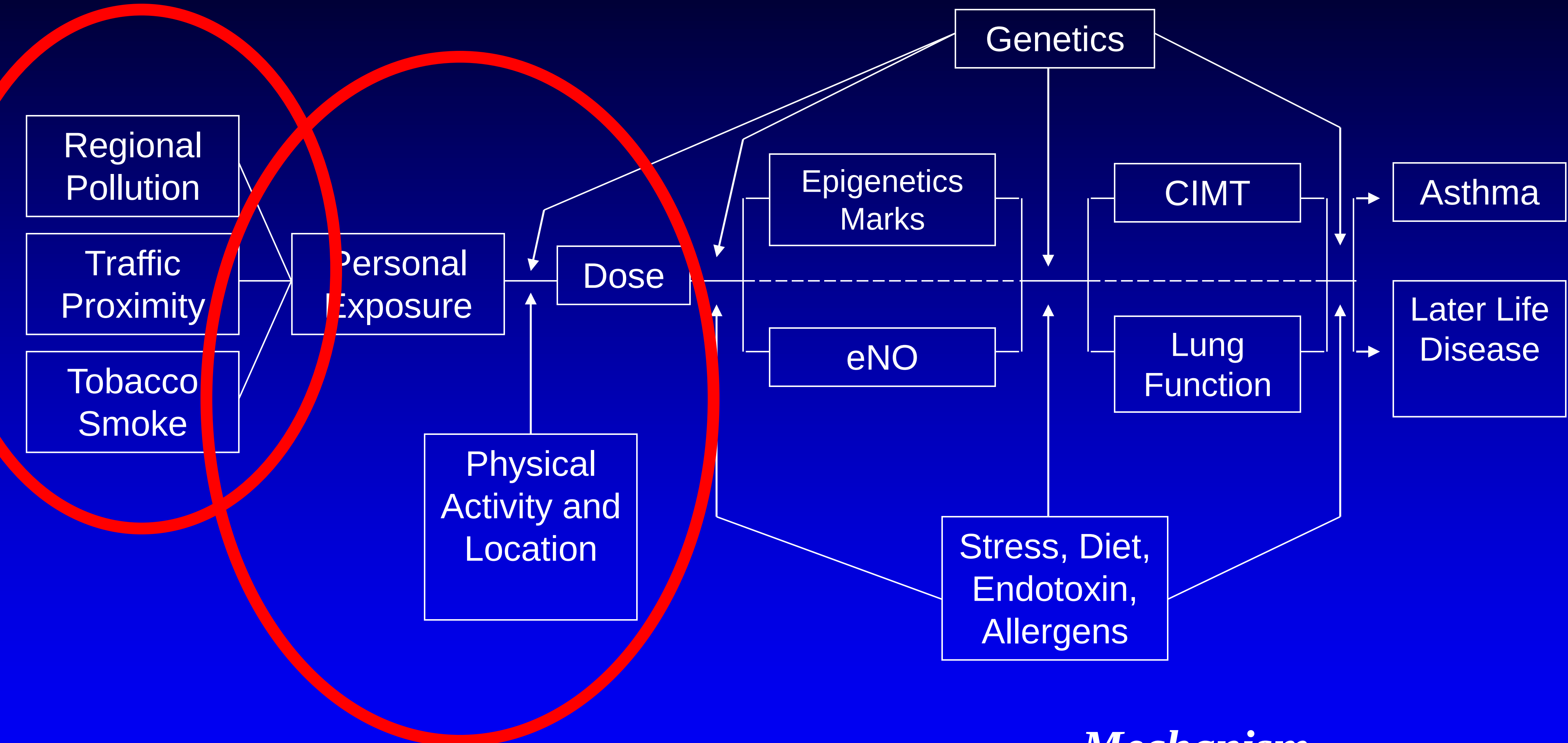
What Personal (or Distributed Microenvironmental) Markers to Measure?

- Traffic markers/occupational exposures, eg VOC’s, BTEX, CO
- New refinements
  - Eg criteria pollutants such as PM2.5 by nephelometry, NO_2
  - Black carbon by aethelometry (available commercially)
  - CO_2

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



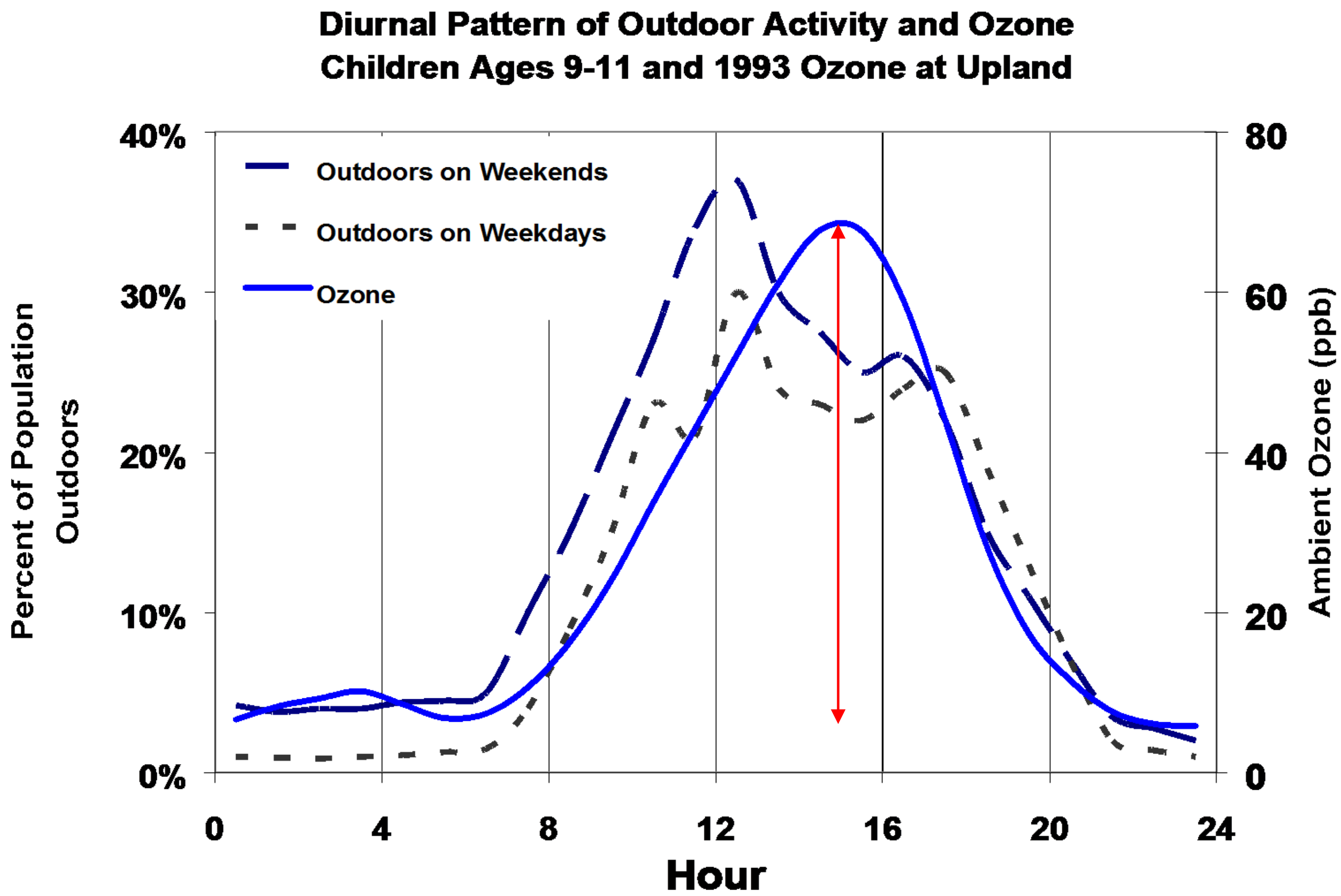
Mechanism
Causality
True size of effect
Where we might intervene

(Time Activity Assessment) Regional Ozone, Exercise and New Onset Asthma

	Low Ozone Towns			High Ozone Towns		
Sports	N cases	RR	(95% CI)	N cases	RR	(95% CI)
0	58	1.00	---	46	1.00	---
1	50	1.28	(0.87-1.88)	40	1.28	(0.83-1.79)
2	20	0.82	(0.49-1.38)	16	1.28	(0.71-2.30)
≥3	9	0.79	(0.38-1.63)	20	3.31	(1.89-5.81)

McConnell, et. al. Lancet 2002;359:386-91

Essentially all O3 exposure occurs outside and summer cannot be ignored



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?

Bay Area Air Quality Management District

What to Consider When Developing a Monitoring Strategy

Alpine Mono Inyo

Eric Stevenson, BAAQMD

Daniel Johnson, GBUAPCD

Before We Start…

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

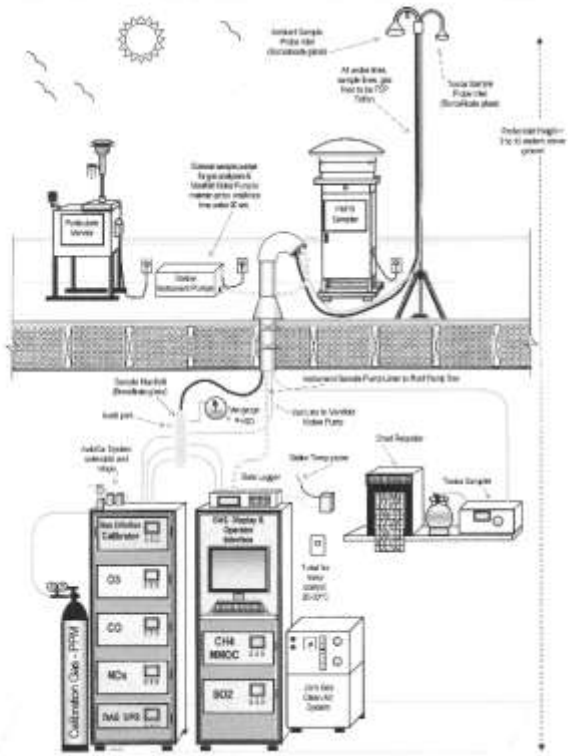
- Provide air pollution information to the general public
- Determine compliance with air quality standards
- Support air pollution research studies

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



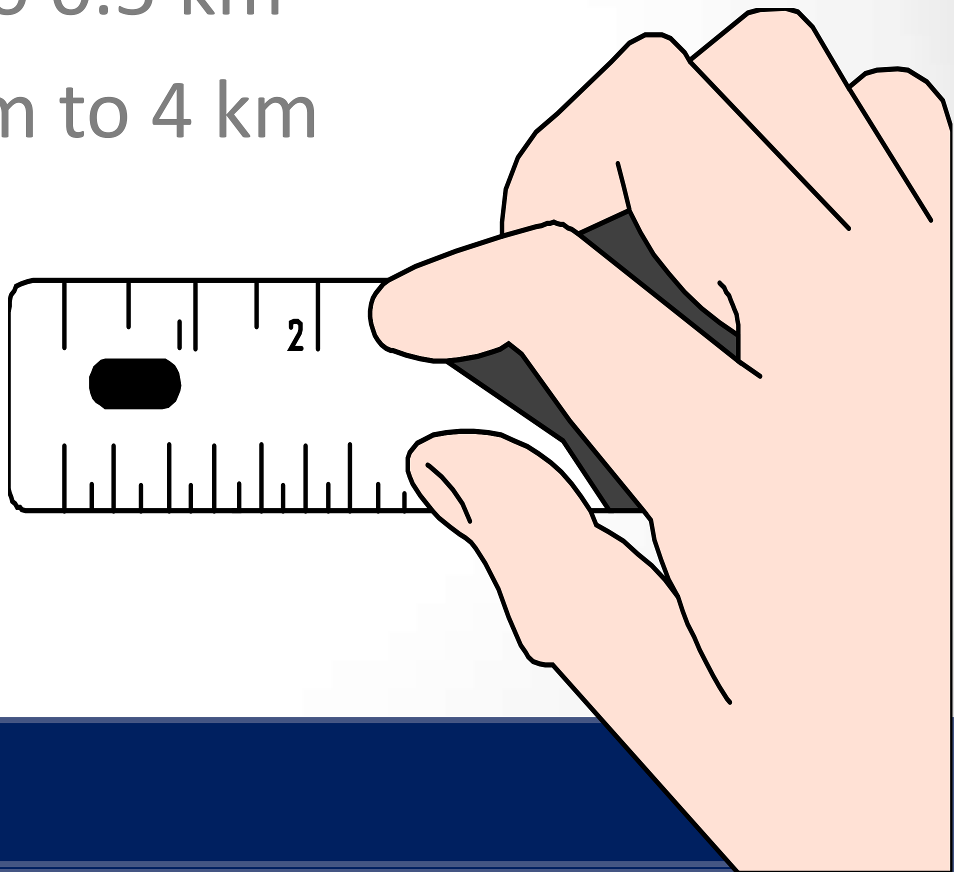
B.A.A.Q.M.D. "Full Station" Air Monitoring Site

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

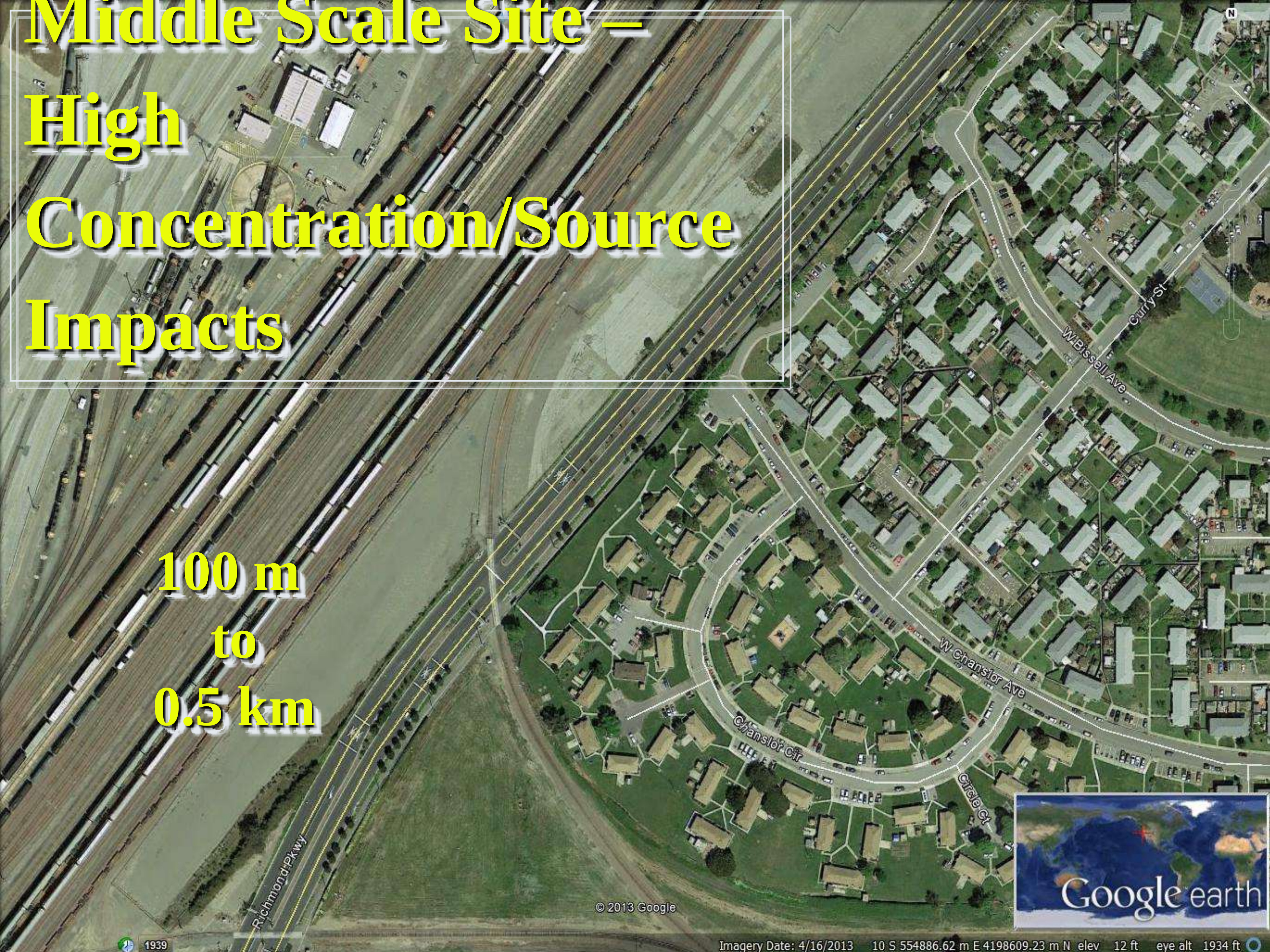
Scales of Representativeness

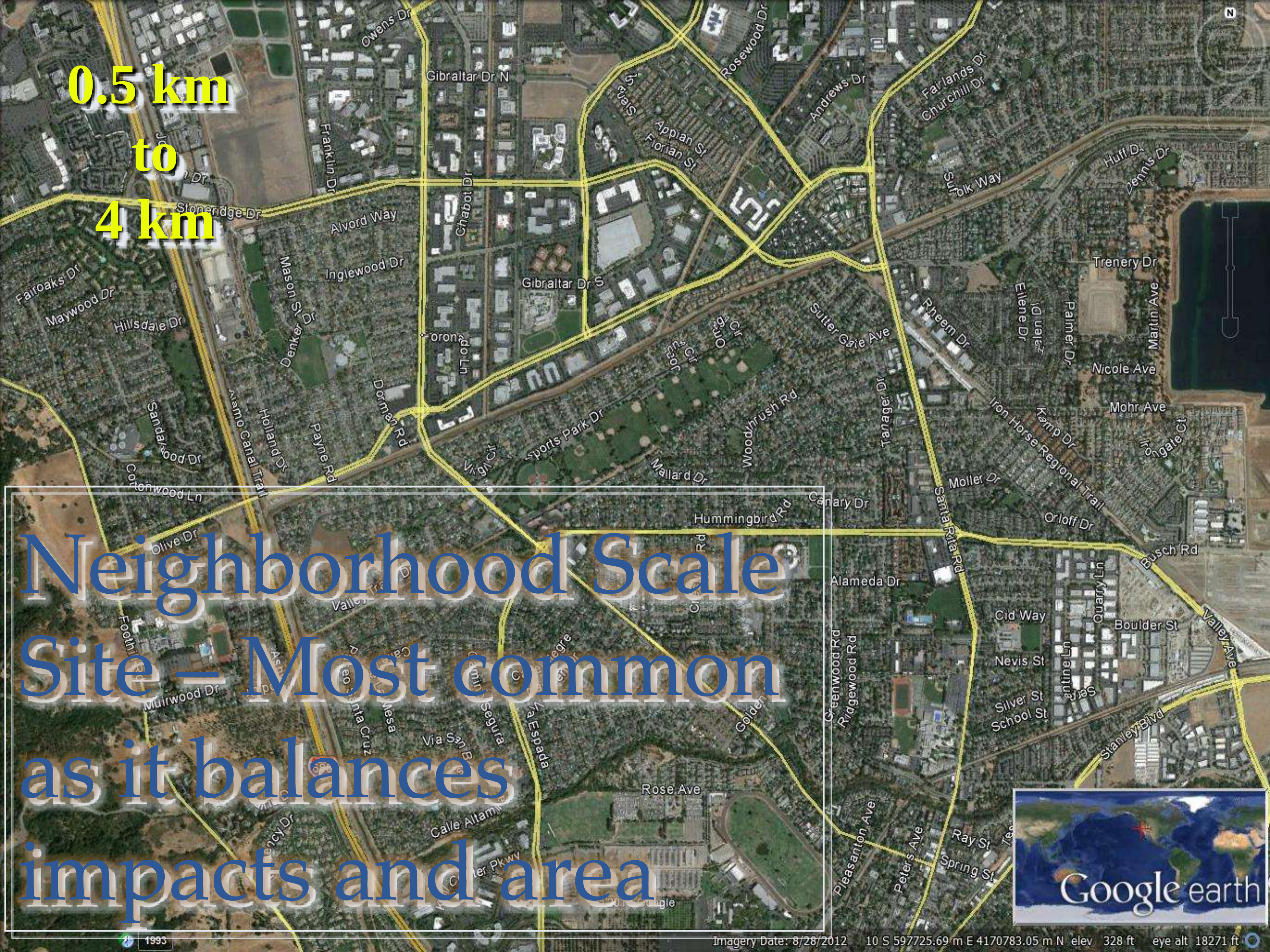
- Micro – 100 meters or less
- Middle – 100 meters to 0.5 km
- Neighborhood – 0.5 km to 4 km




Micro Scale Site
Usually Source
Oriented
Up
to
100 m
Richmond Ln
© 2013 Google
Google earth
1939
Imagery Date: 4/16/2013 10 S 552281.82 m E 4200579.63 m N elev 15 ft eye alt 1003 ft

Middle Scale Site – High Concentration/Source Impacts





0.5 km to 4 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

Conclusion

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

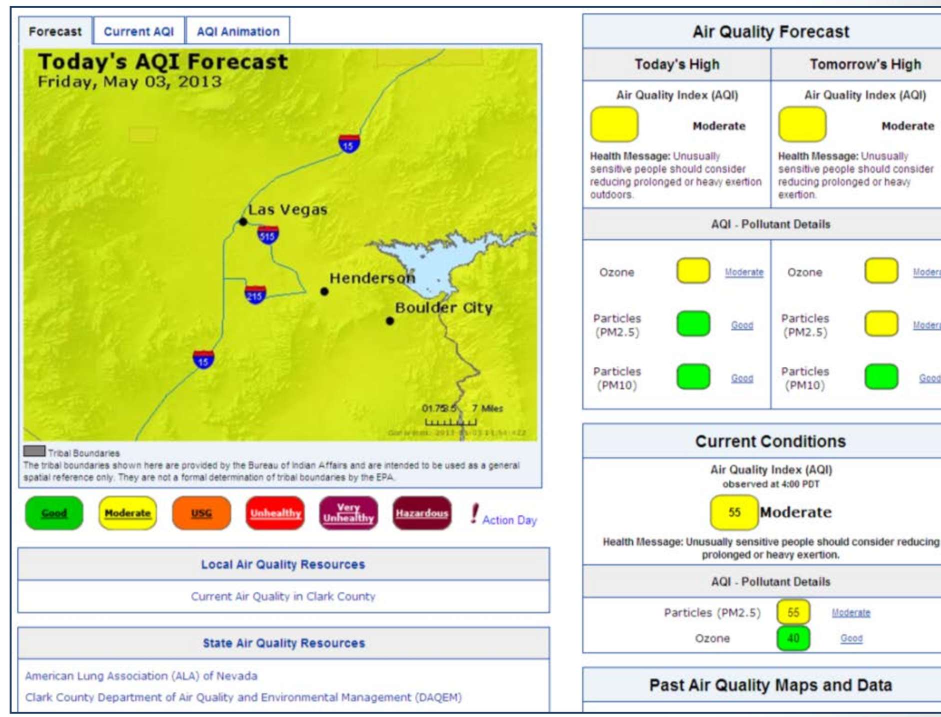
Goals of this talk

- 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

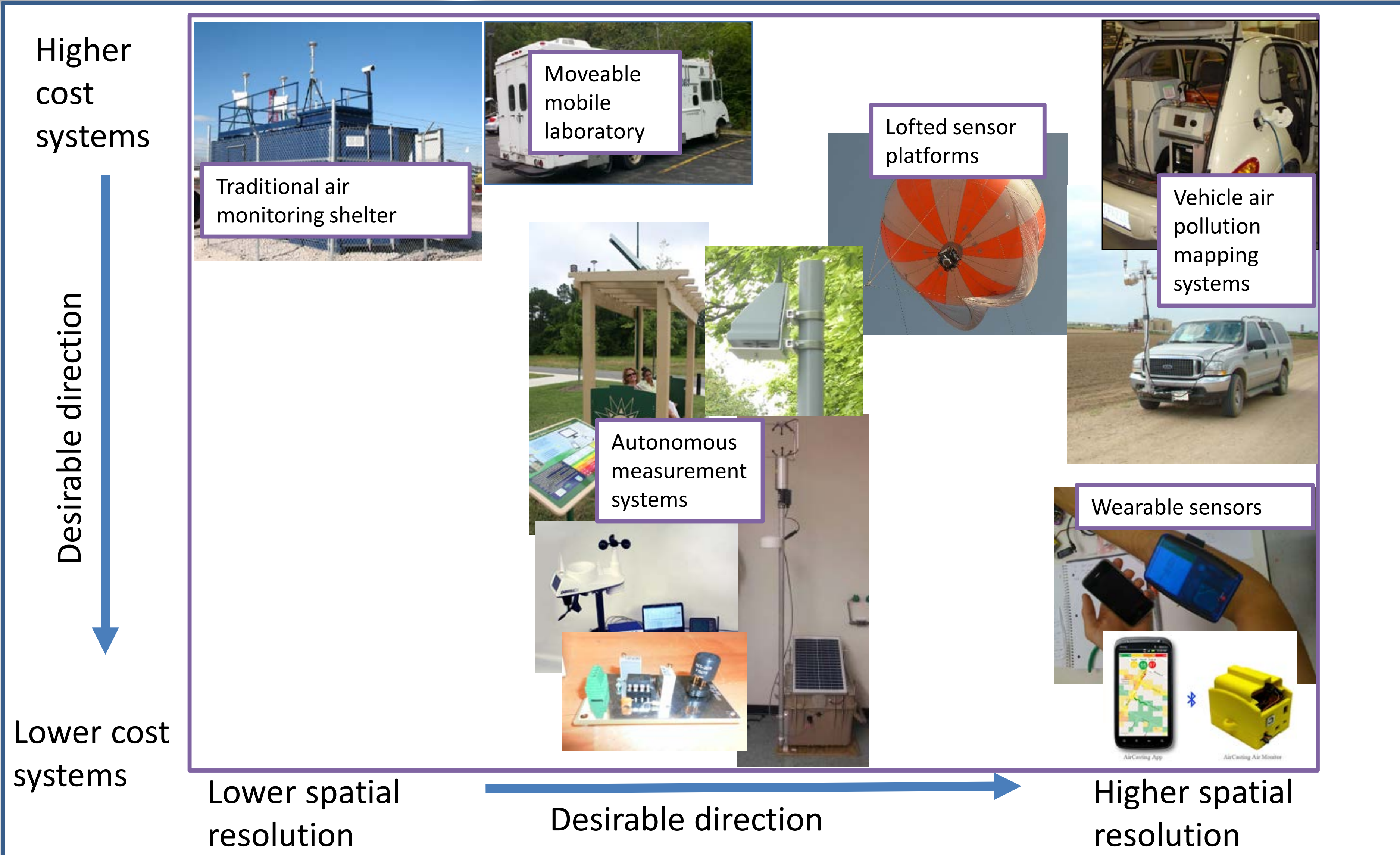


Motivation for new approaches

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



Emergence of low cost sensors

Particle-phase

Larger particles (>0.1 µm)

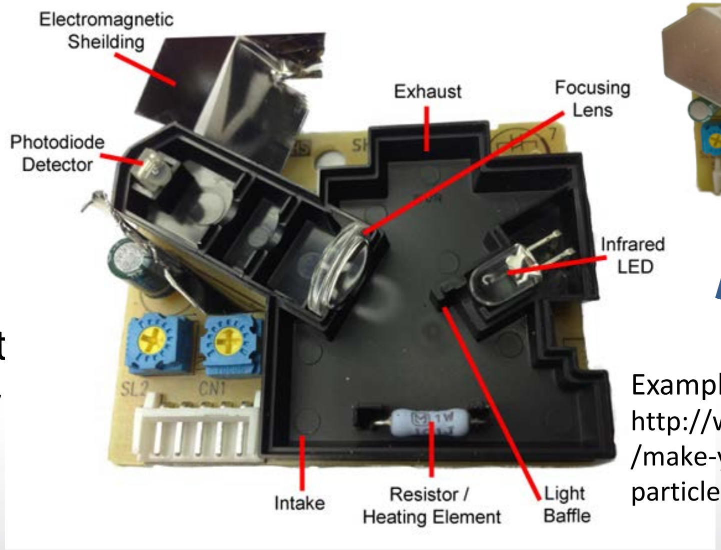
Sensor detection:

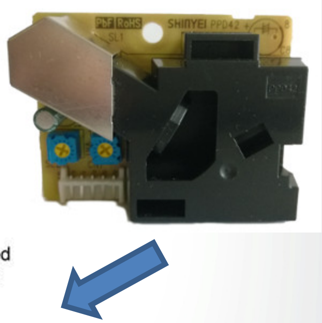
- Most emerging particle sensors operate using a **light-scattering measurement** principle.
- Most **do not have a physical size cut** (cyclone, impactor).
- Some use a passive means to move air through sensing region; others have a fan.

Possible sensor measurement issues:

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

Emerging sensors (examples):



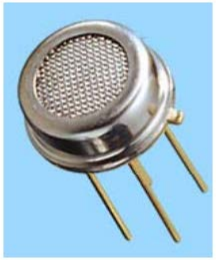


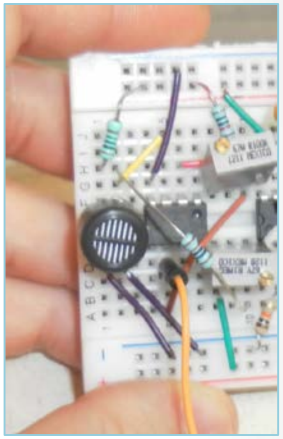
Example diagram (from: http://www.takingspace.org/make-your-own-aircasting-particle-monitor/)

Emergence of low cost sensors

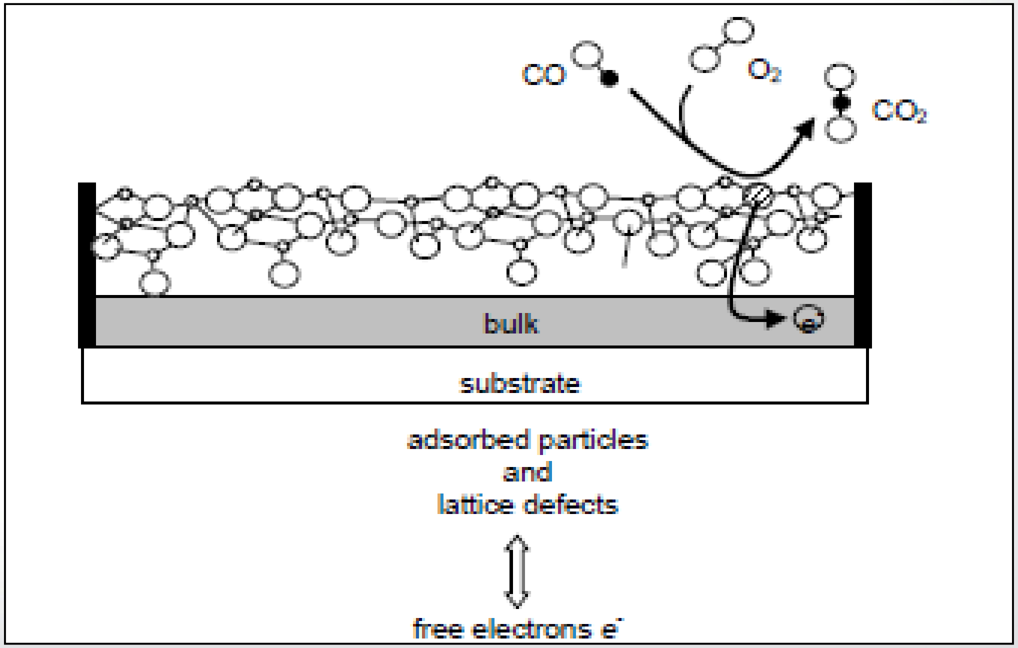
Gas-phase

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

<u>**Electrochemical sensors**</u>:
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

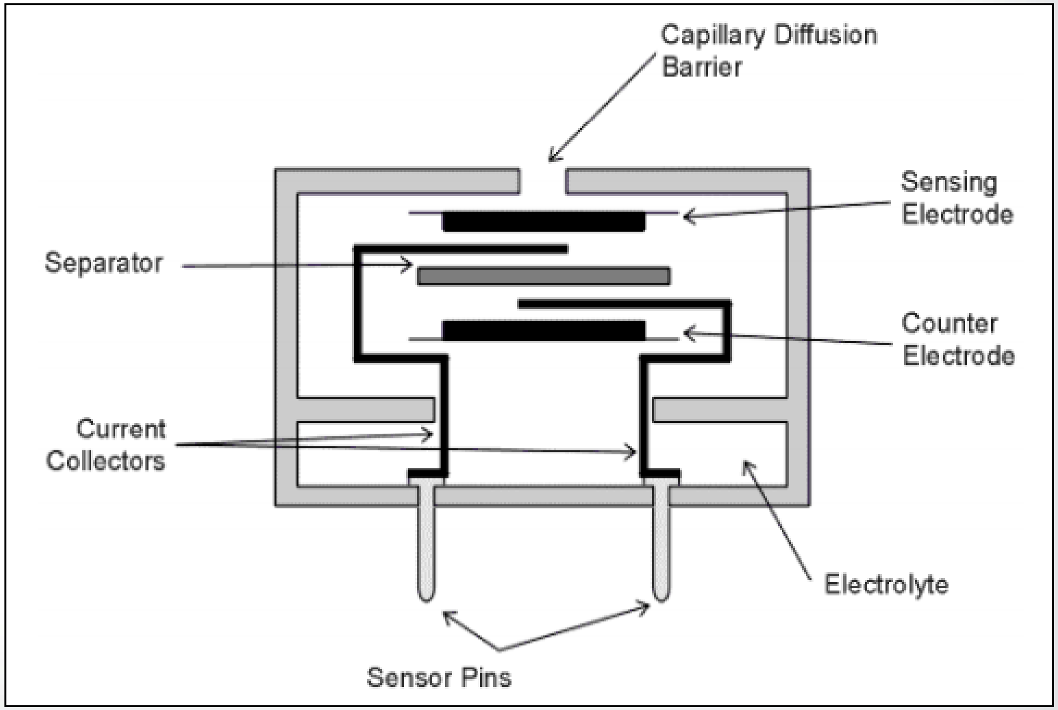


Figure. Electrochemical sensor (e2v, 2007)

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

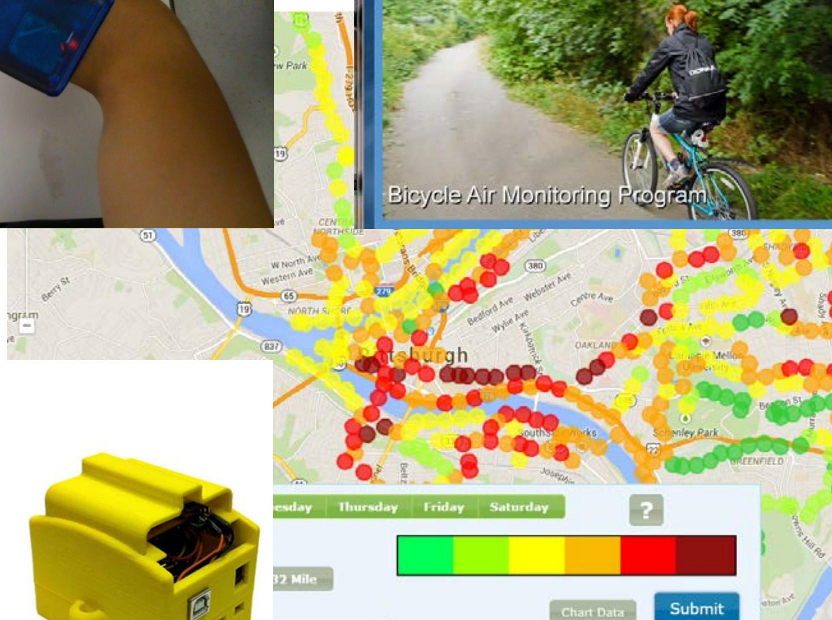
Sensor applications

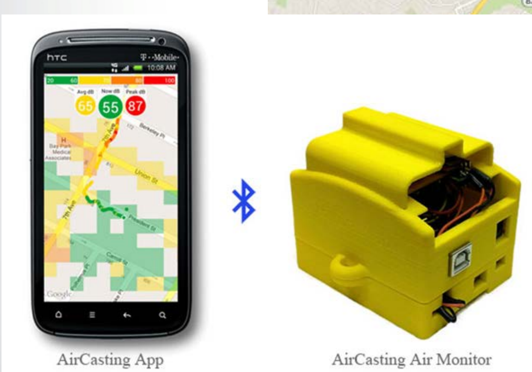
Stationary mode – source fence-line, community measurements

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

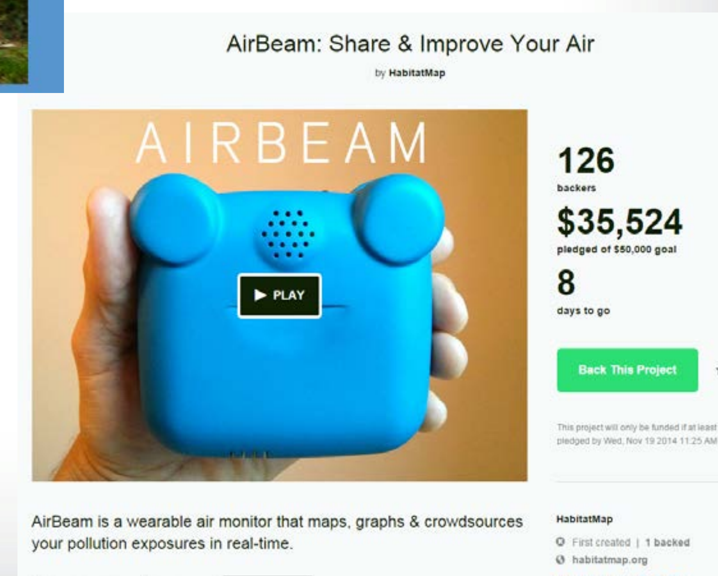
Sensor applications

Mobile mode:





- Personal monitoring
- Community group monitoring
- Mapping spatial trends



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


EPA
United States Environmental Protection Agency

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

Sensor Evaluation Report

Office of Research and Development
National Exposure Research Laboratory

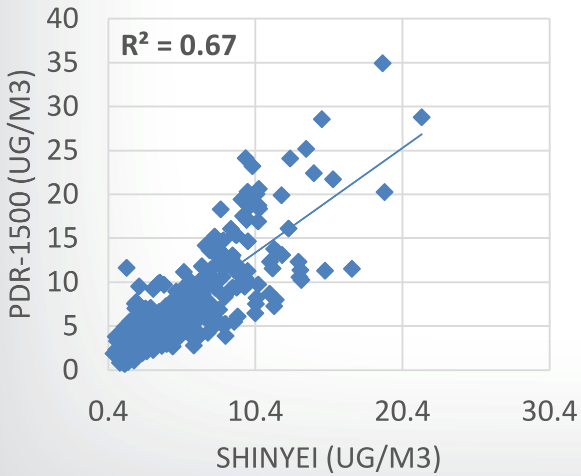
Ongoing side-by-side evaluation:

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

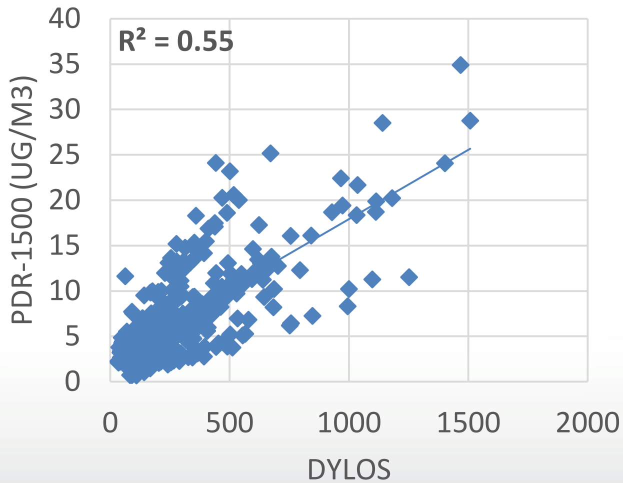
Are any sensors “good enough”?

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

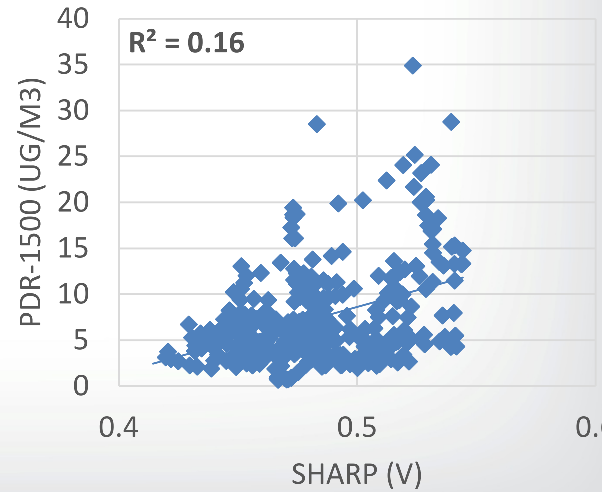
SHINYEI



DYLOS



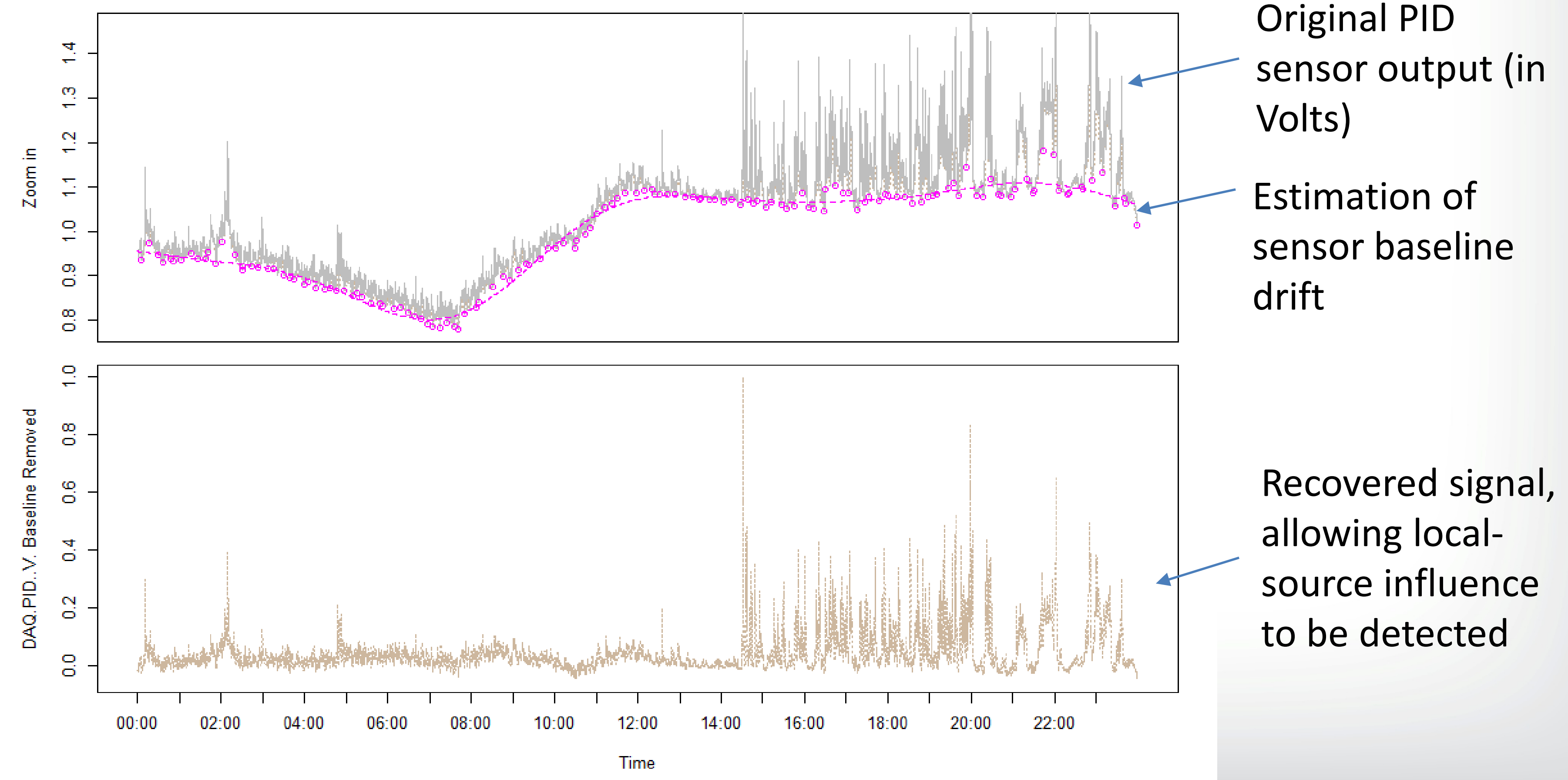
SHARP



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



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

Next-generation air monitoring research at EPA

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: CAIRSENSE Project
- Data visualization support: RETIGO
- Mobile

Legend:

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

<u>We are looking forwards to keeping in touch!</u>

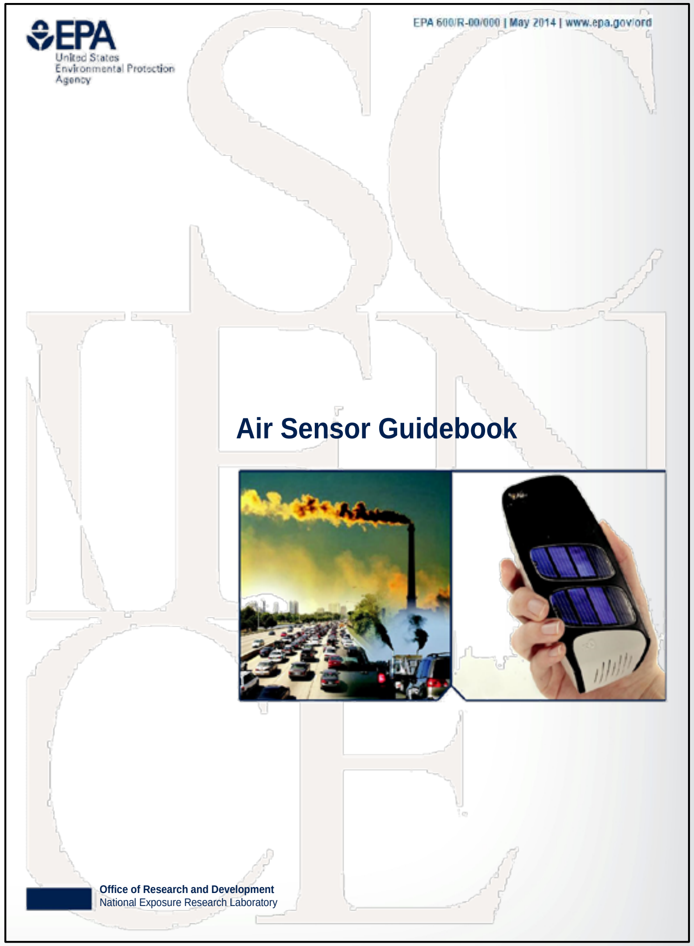
Resources available

- 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

- Many EPA staff involved: Ron Williams, Eben Thoma, Russell Long, Melinda Beaver, Rachelle Duvall, Brian Gullett, Wan Jiao, Xiaochi Zhou, Amanda Kaufman, Paul Solomon, Ryan Brown, Daniel Garver, Dan Costa, Alan Vette, Tim Watkins, Stacey Katz, Gail Robarge, Peter Preuss

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*

CCAEJ Center for Community Action and Environmental Justice

LACEEN L.A. Community Environmental Enforcement Network

Southern California Environmental Health Sciences Center

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

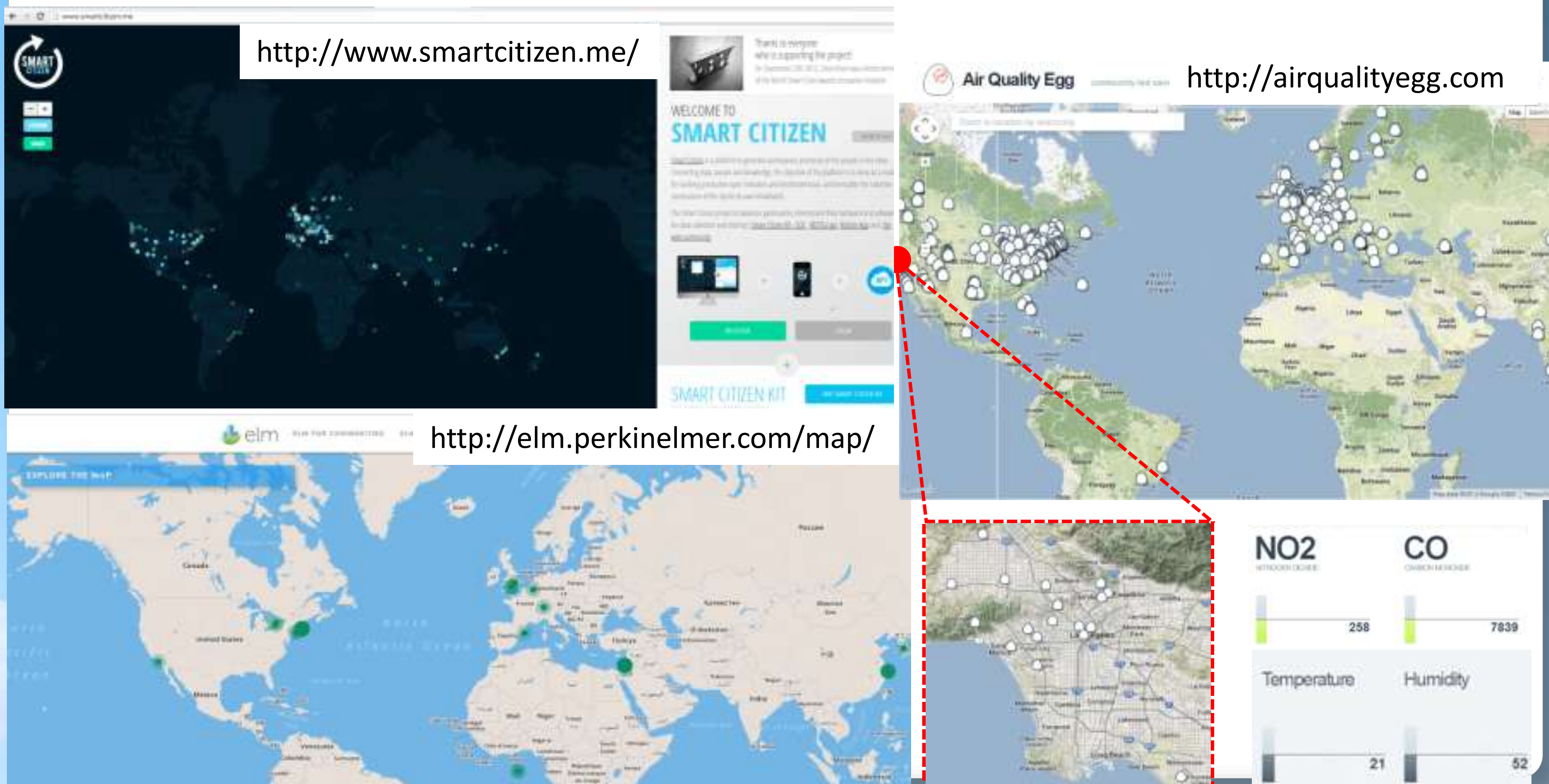
Moderate cost
($8K – 10K)

Unknown

Lower cost
($0.5K – 10K)

Low Cost Sensor Technology

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



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”
    - *Northern California (BAAQMD): November 19, 2014*
    - *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

AQMesh

CairClip

Shinyei

- 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)

Dylos (prototype)

DC1100 Pro

SmartCitizens

AQ-SPEC Overview

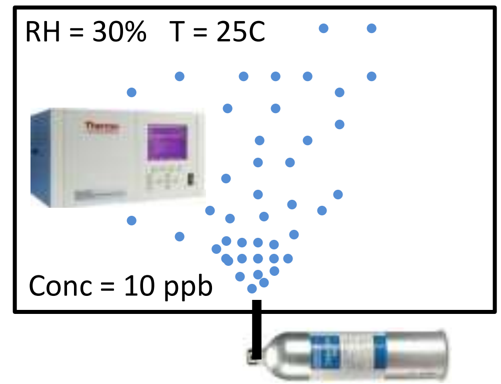
FIELD TESTING

(Side-by-side comparison w/ FRMs)

vs

LAB TESTING

(Controlled conditions)



RESULTS

(Categorize sensors based on performance)

AQ-SPEC Overview

SCAQMD
Website / Clearinghouse

RESULTS

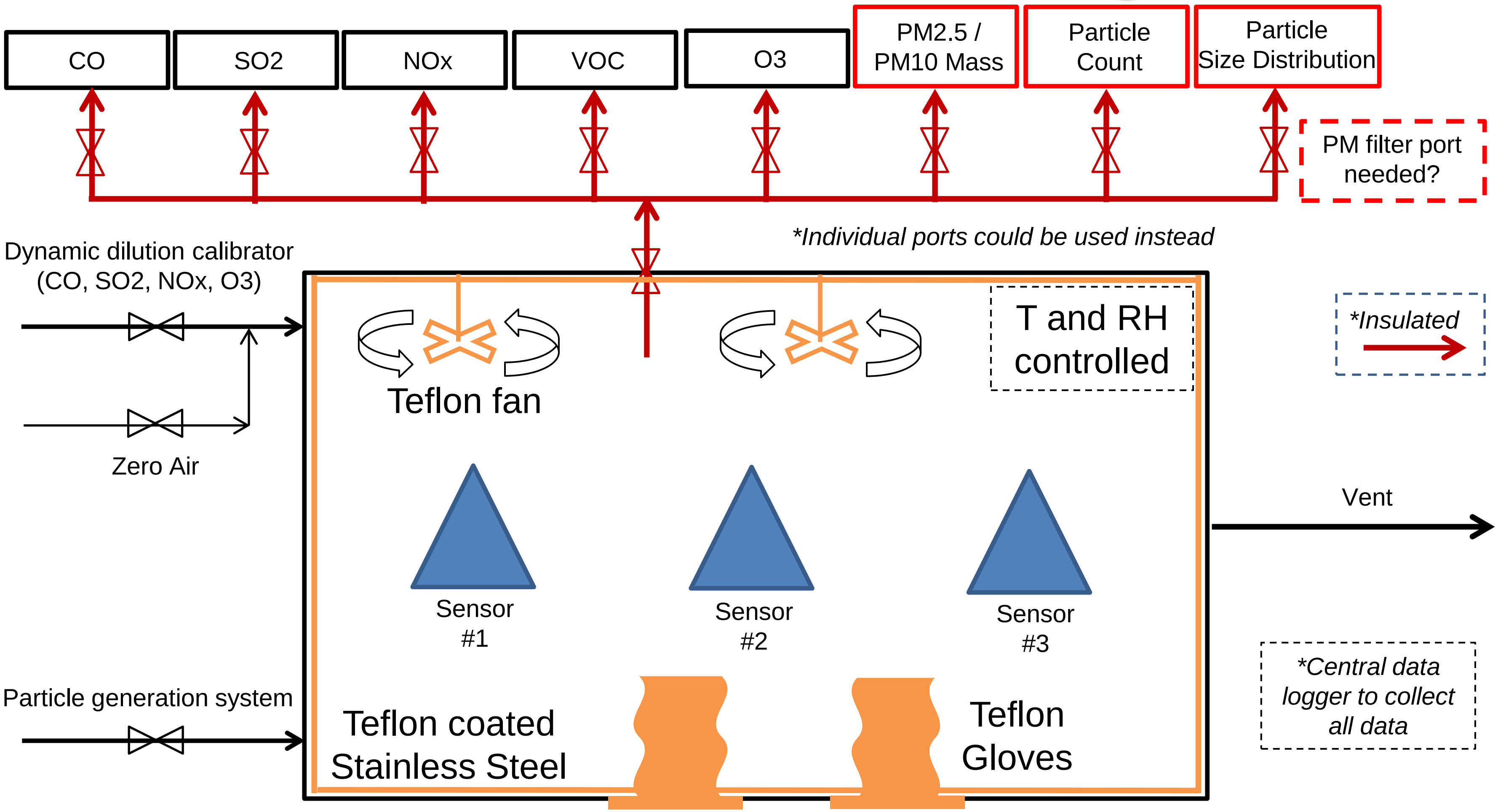
AQ-SPEC Field Testing

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

	Pollutant(s) Measured						
Sensor / Manufacturer	**PM**	**CO**	**NO2**	**SO2**	**O3**	**VOCs**	**Other**
Dylos particle counter^	X						
MetOne 831^	X						
AQMesh*		X	X	X	X		NO
Cairclip (NO2/O3)^			X		X		
AeroQual Ozone card^					X		
Cairclip VOC^						X	
ELM*	X		X				
SmartCitizen^		X	X				

^Purchased; *Loaned

AQ-SPEC Lab Testing

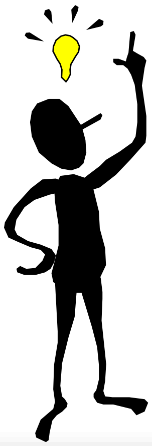


<u>Design considerations</u>: Dimensions, material

<u>T and RH controlled</u>: T (0-50 ^{0}C; +/- 5 ^{0}C); RH (5-95%; +/- 5%)

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

Next?

- Safe to assume that the performance of “low-cost” sensors will soon match that of FRM/FEM instruments…..but when?

Next?

Background

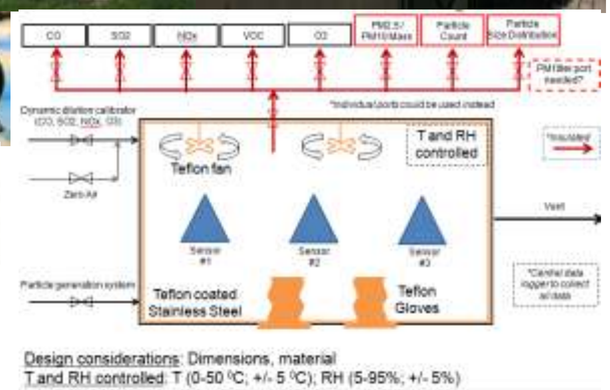
- Many deciding factors, including:
  - Advancements in sensor technology
  - Performance & cost of microprocessors
  - Growing public interest
  - Large tech-company involvement

"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

AQ-SPEC

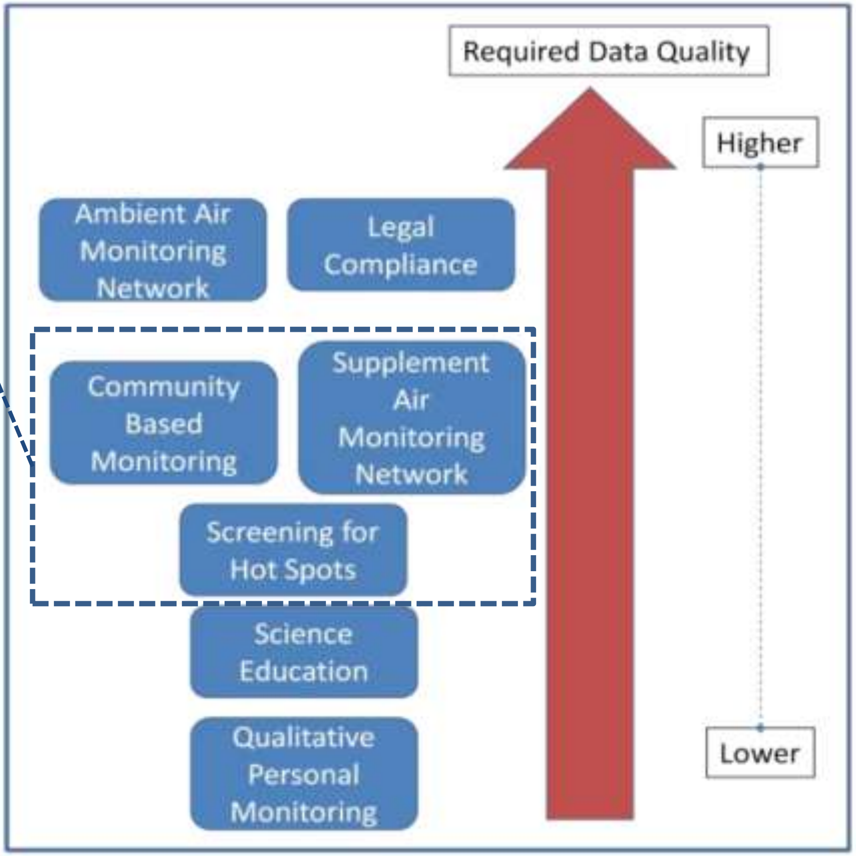
- Evaluation (not certification) program
- Field and chamber testing
- Determine parameters affecting sensor performance and data quality:
  - *Detection range*
  - *Linearity*
  - *Detection limit*
  - *Accuracy*
  - *Precision*
  - *Response time*
  - *Intra-model variability*
  - *Co-pollutant interference*
  - *RH and T influences*
  - Durability



Categorize sensors based on performance

Several novel applications

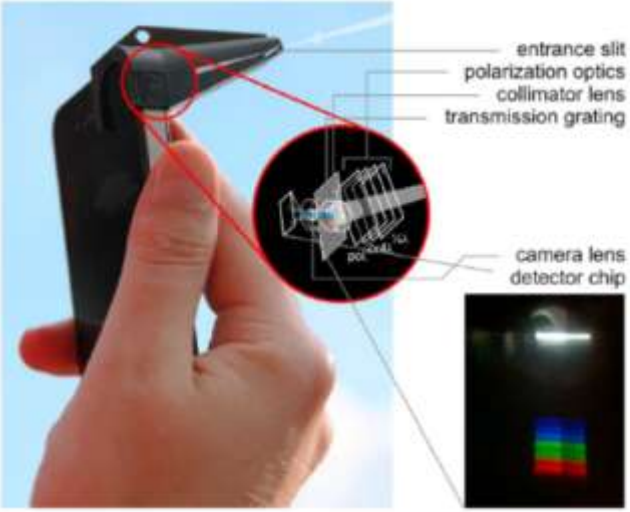
- Characterize spatial variations
  - Wide area coverage
- Improve network design
  - Identify high concentration areas
- Permitting
  - Monitor before and after construction
- Fence-line monitoring
  - Large refineries and emission sources
- Community concerns
  - Local impact of freeways, airports,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

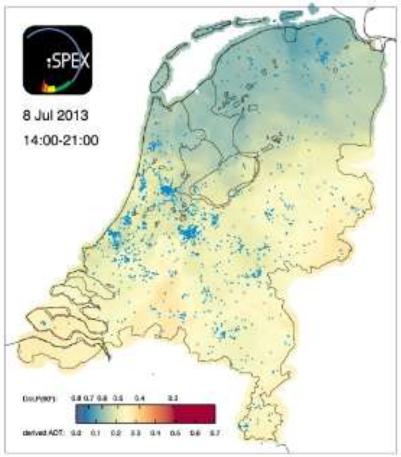


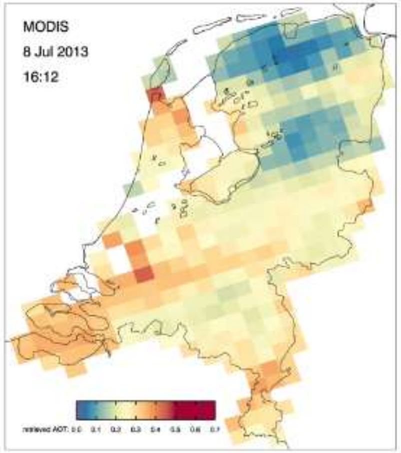
EPA's "*DRAFT Roadmap for Next Generation Air Monitoring*"

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 to for three days in 2013
- Results comparable to ground-based, network, and satellite measurements

http://ispex.nl/en/

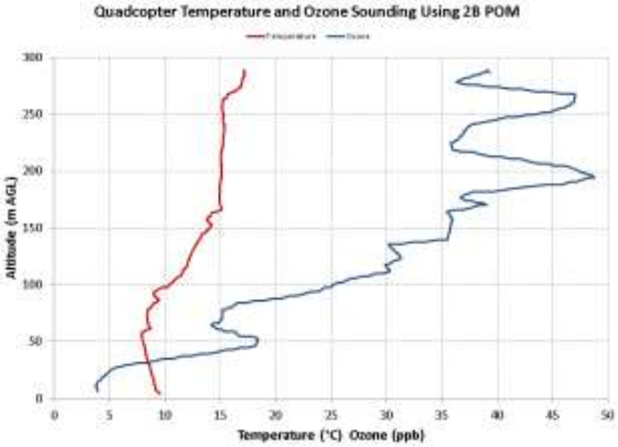
Novel Applications (example): Aerial Measurements

- <u>Unmanned Aerial Vehicles</u>
  - 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

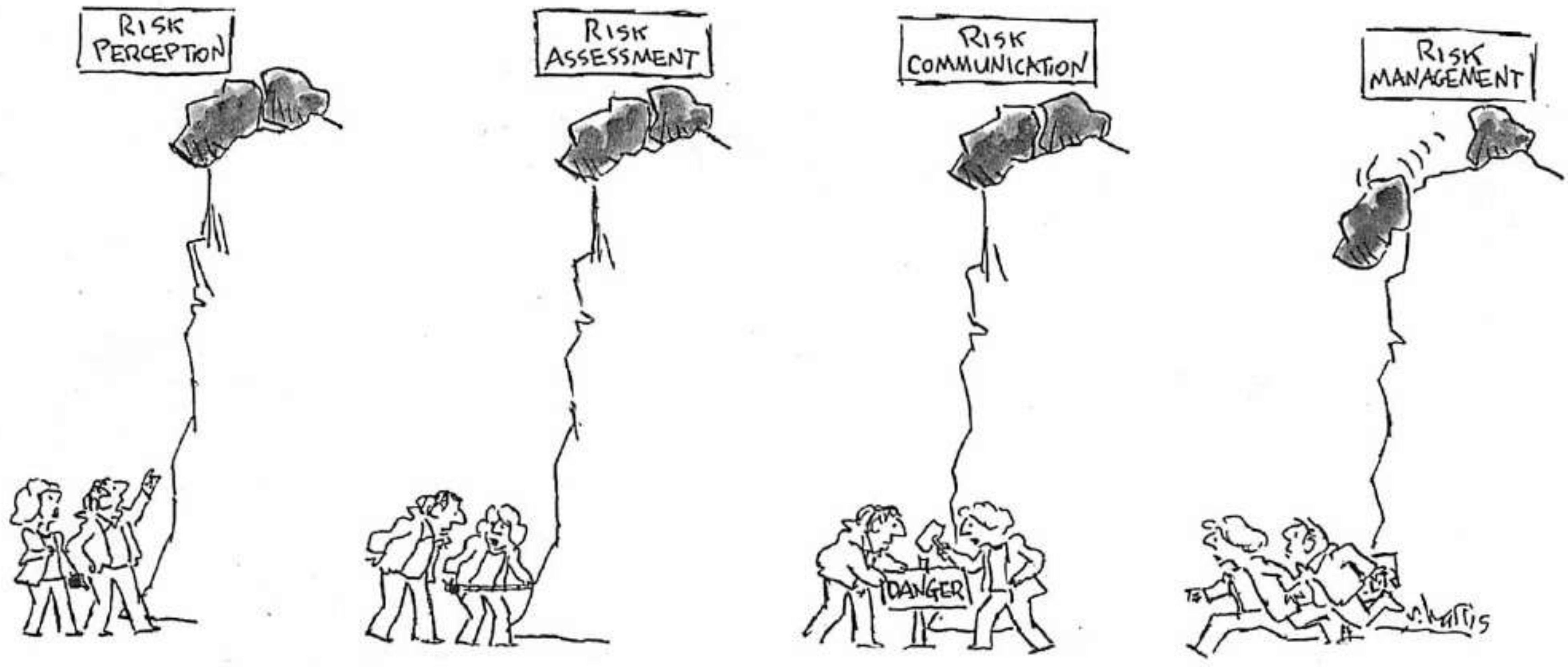
U.S. Environmental Protection Agency

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.


RISK PERCEPTION
RISK ASSESSMENT
RISK COMMUNICATION
DANGER
RISK MANAGEMENT
S. Harris

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

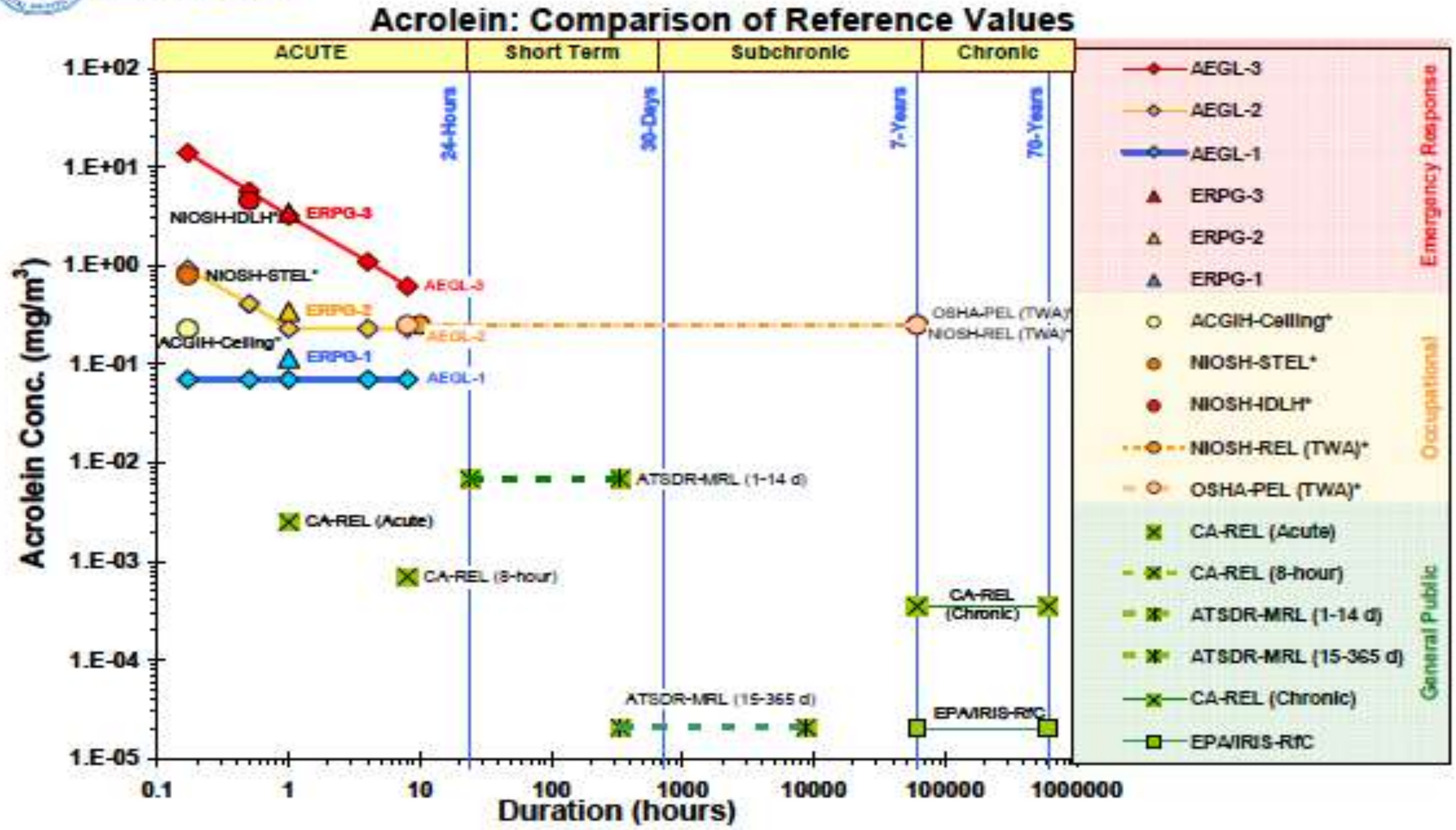
Air Reference Value Evaluation

United States Environmental Protection Agency

EPA/600/R-09/061

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

Office of Research and Development
National Center for Environmental Assessment
Research Triangle Park, NC



* 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 2-1. Summary of Available Inhalation Reference Values for 24 Chemicals

	Emergency Response			Occupational							General Public				
	AEGL	ERPG	TEEL	IDLH	TLV	PEL	REL	CDC WPL	STEL	Ceiling	RfC	MRL	CA-REL	CDC GPL	WHO Air Quality Guideline
Acrolein	X	X		X		X	X		X	X	X	X	X		
Ammonia	X	X		X	X	X	X		X		X	X	X		
Arsine (SA)*	X	X		X	X	X				X	X		X		
Chlorine*	X	X		X	X				X	X	X	X	X		
Chromium VI			X	X	X	X	X				X	X	X		
Cyanogen Chloride*		X								X					
Etyhlene Glycol Methyl Ether			X	X	X	X	X				X		X		
Ethylene Oxide	X	X		X	X	X	X			X		X	X		
Formaldehyde	X	X		X		X	X		X	X		X	X		X
Soman (GD) + Cyclosarin (GF)*	X			X					X						
Hydrogen Cyanaide (AC)*	X	X		X		X			X	X	X		X		
Hydrogen Fluoride	X	X		X	X	X	X		X			X	X		
Hydrogen Sulfide	X	X		X	X				X	X					
Lewisite (L)*	X							X						X	
Mercury	X	X		X	X		X			X	X	X	X		
Methylene Chloride	X	X		X	X	X			X			X	X		X
Percholoroetyhlene	X	X		X	X	X	X		X	X		X	X		
Phosgene (CG)*	X	X		X	X	X	X			X	X		X		
Phosphine*	X	X		X	X	X	X		X		X		X		
Sarin (GB)*	X			X				X	X					X	
Styrene	X	X		X	X	X	X		X	X	X	X	X		X
Sulfur Mustard (HD)*	X			X				X	X			X		X	
Tabun (GA)*	X			X				X	X					X	
VX*	X			X				X	X					X	

* 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) <u>does not match up with standard</u>
e.g., a one minute reading of 85 ppb does not mean the standard has been exceeded

What is “Normal” Air Quality?

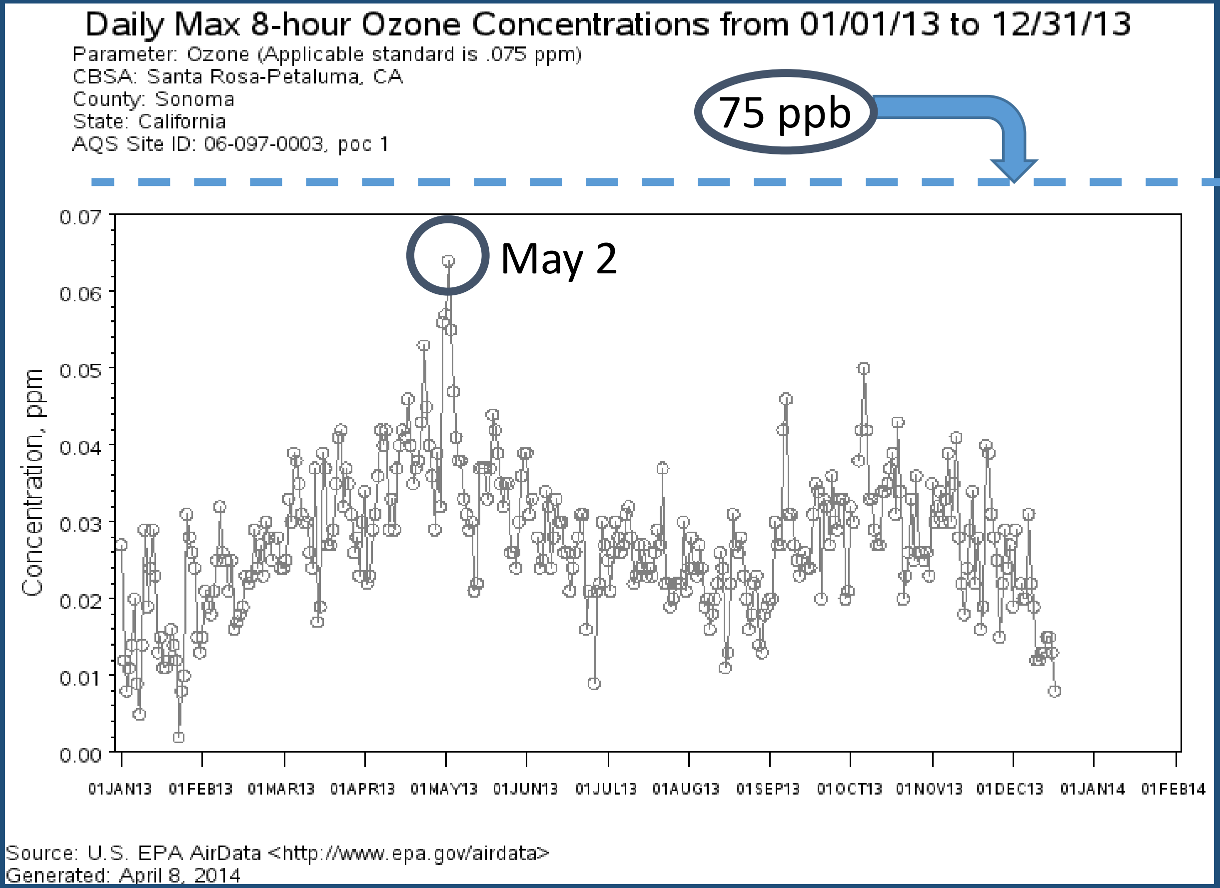
- Examine one year of data (2013) at two contrasting sites near San Francisco, California (“higher concentration” vs. “lower concentration”)
  - Results should not be generalized. Relationships and patterns likely vary for other geographic locations, monitoring equipment, etc.
  - 1-minute data provided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

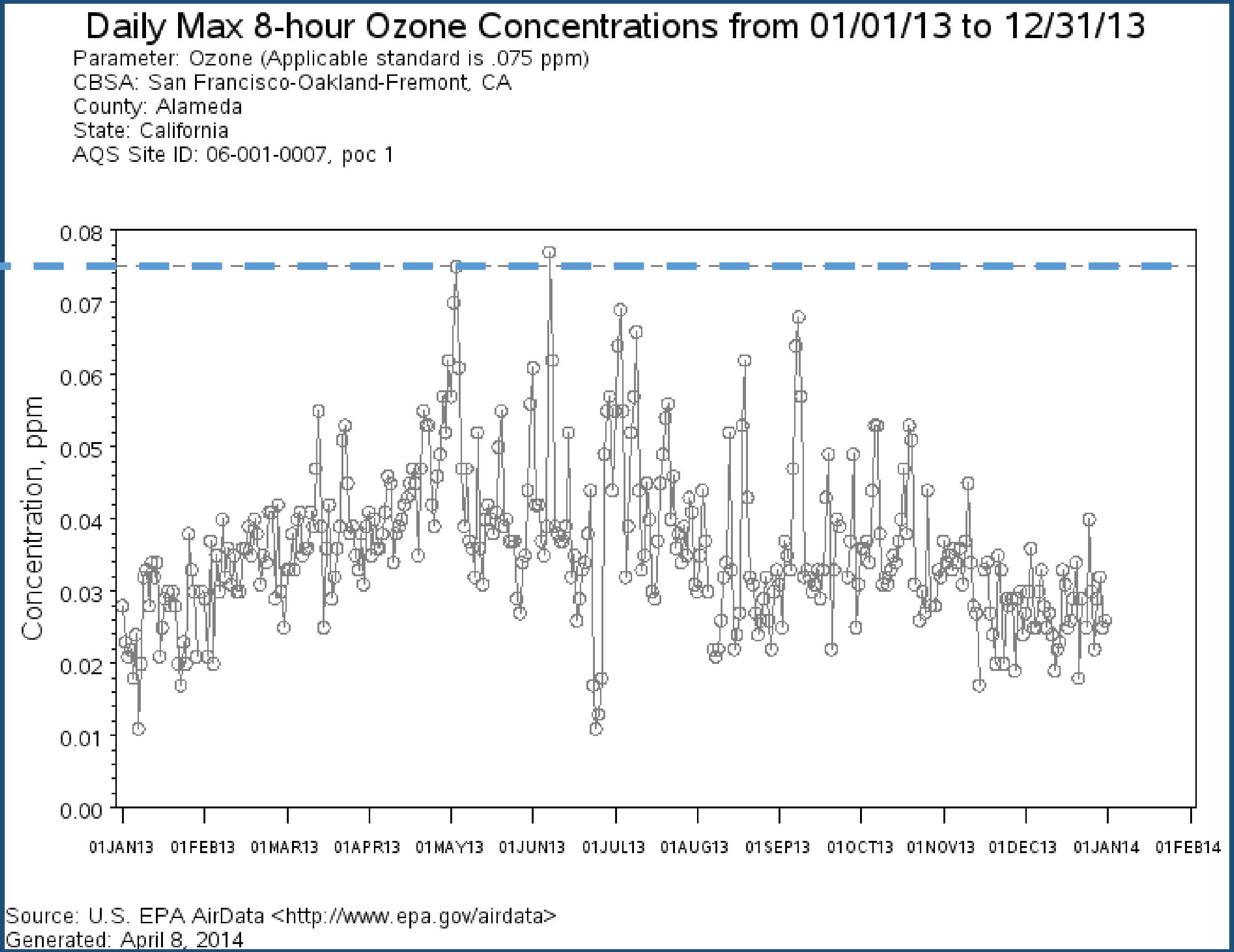
Santa Rosa

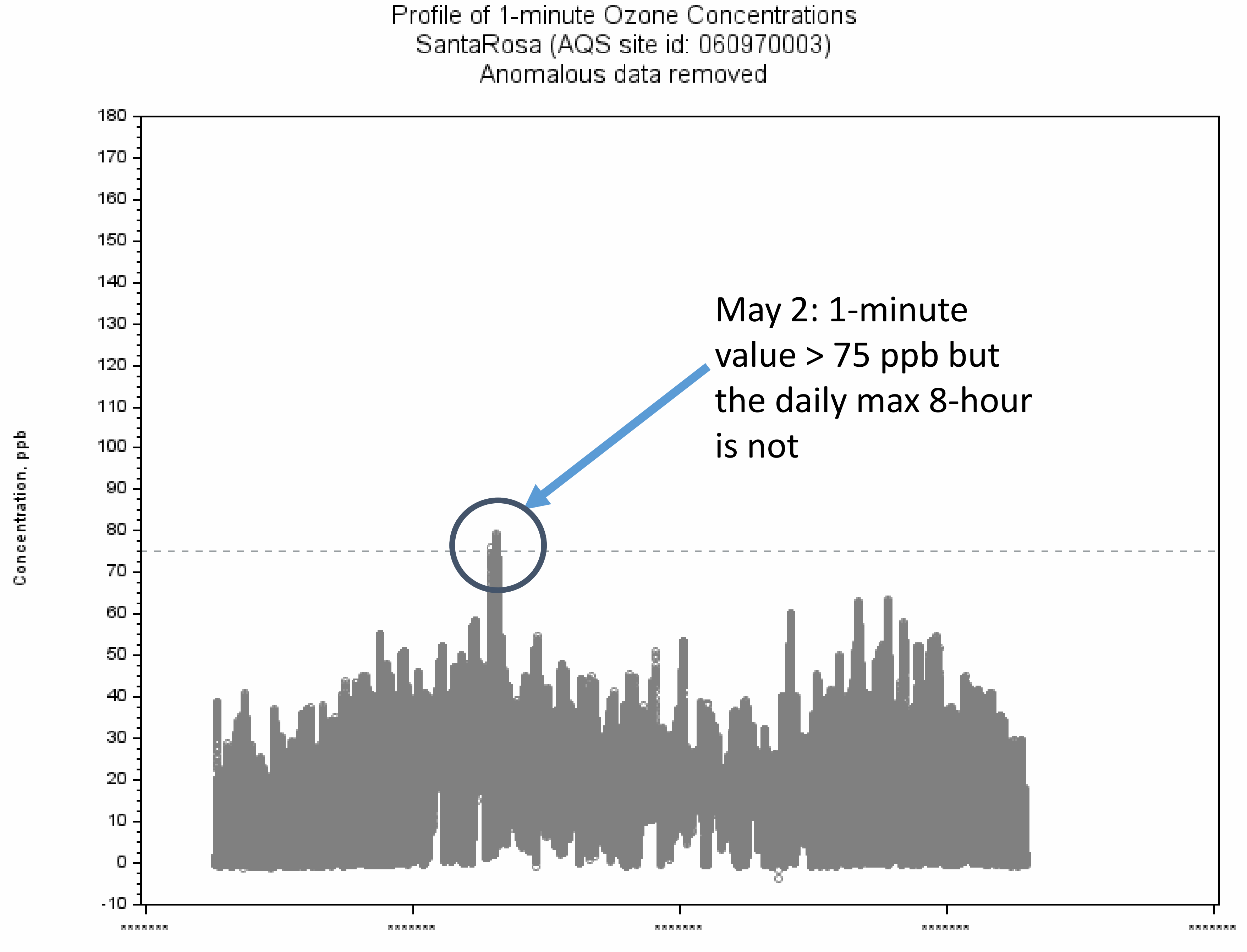
(lower concentration)

Livermore

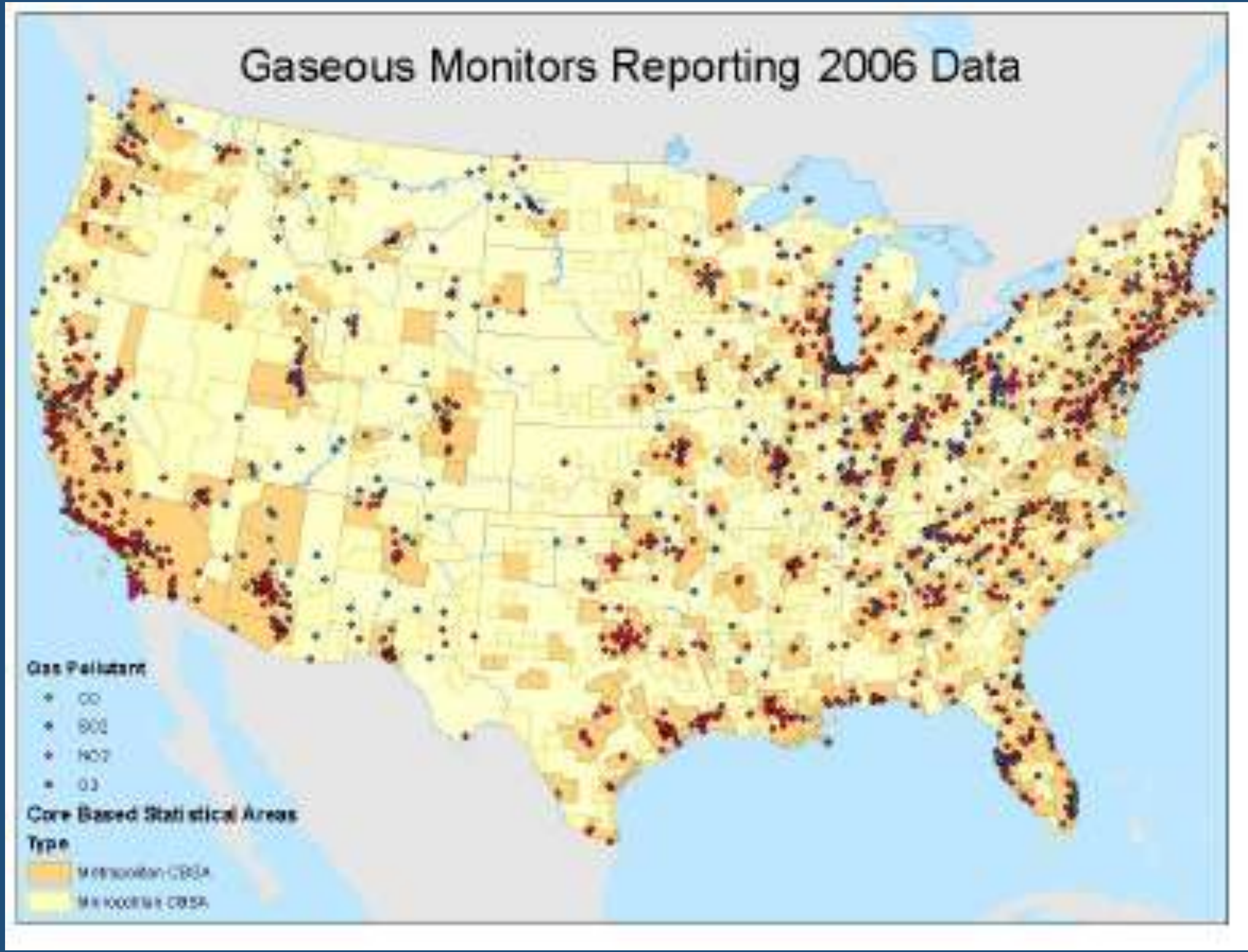
(higher concentration)






Profile of 1-minute Ozone Concentrations
SantaRosa (AQS site id: 060970003)
Anomalous data removed
Concentration, ppb
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
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

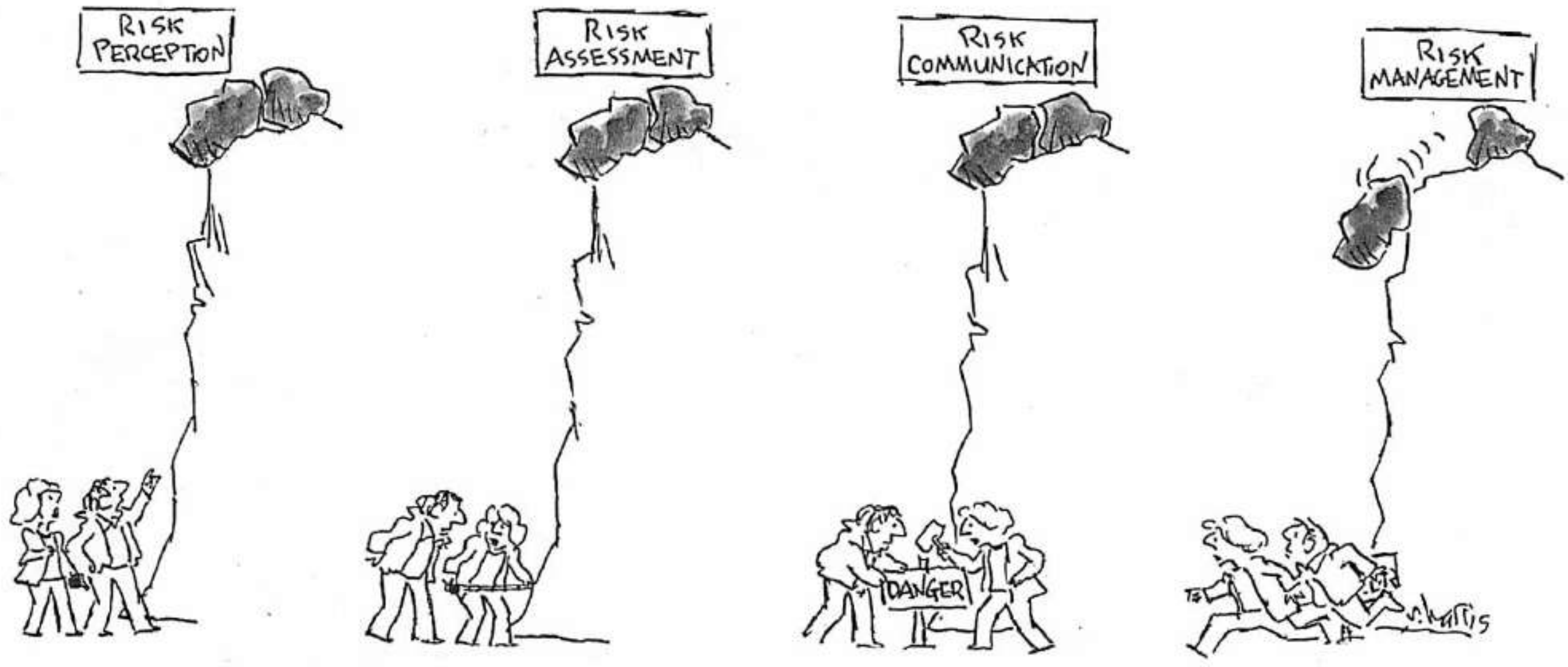


Messaging for $PM_{2.5}$ is also under development

Monitoring data is limited for most Hazardous Air Pollutants, i.e. what is "normal" more difficult to evaluate

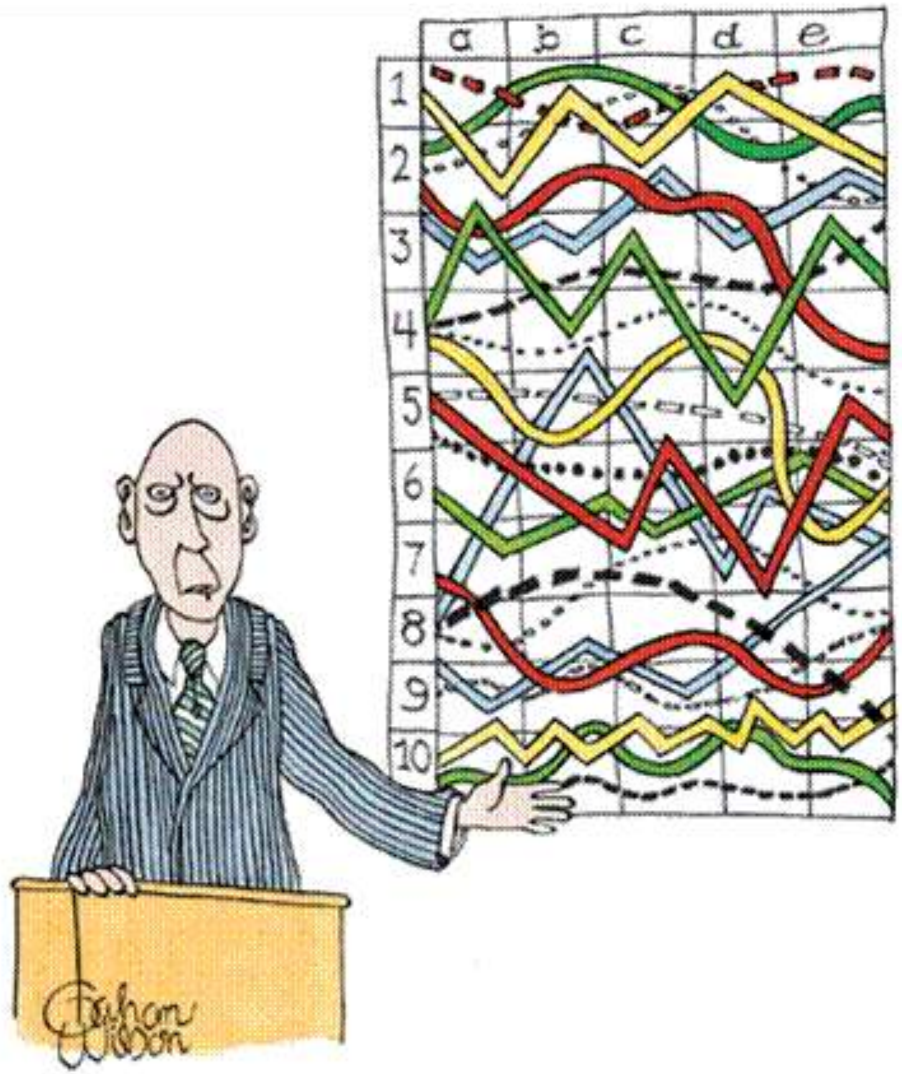
Conclusions

- 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


RISK PERCEPTION
RISK ASSESSMENT
RISK COMMUNICATION
DANGER
RISK MANAGEMENT
S. Harris

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 presents 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

Wright Brothers Institute Student Project 2012

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

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

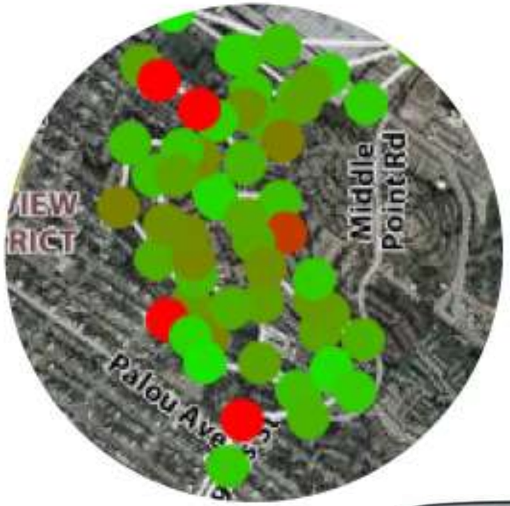
Data Uses: Research

- 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 place 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

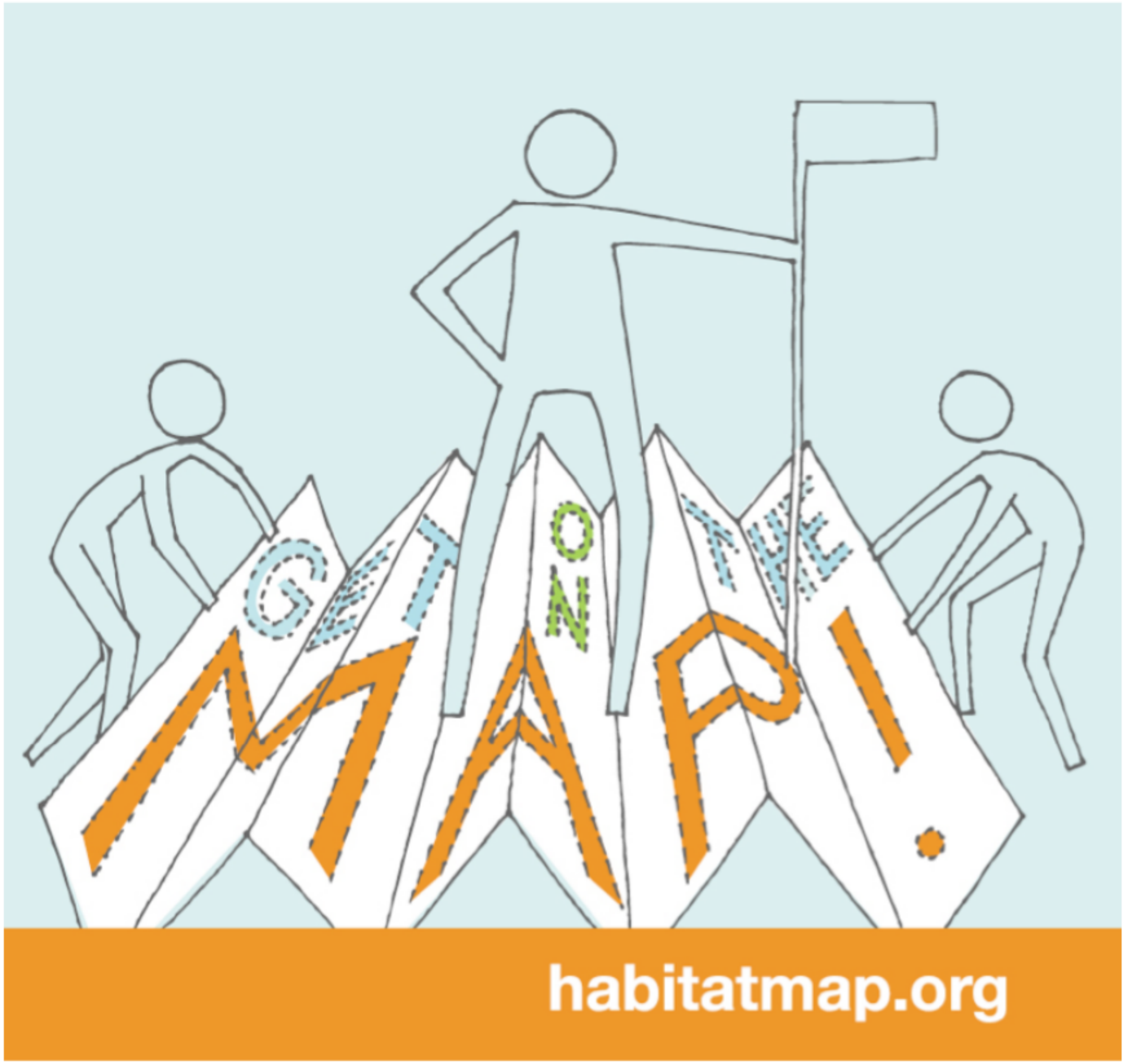
“Huge volumes of data may be compelling at first glance, but without an interpretive structure they are meaningless.”

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

Thanks!

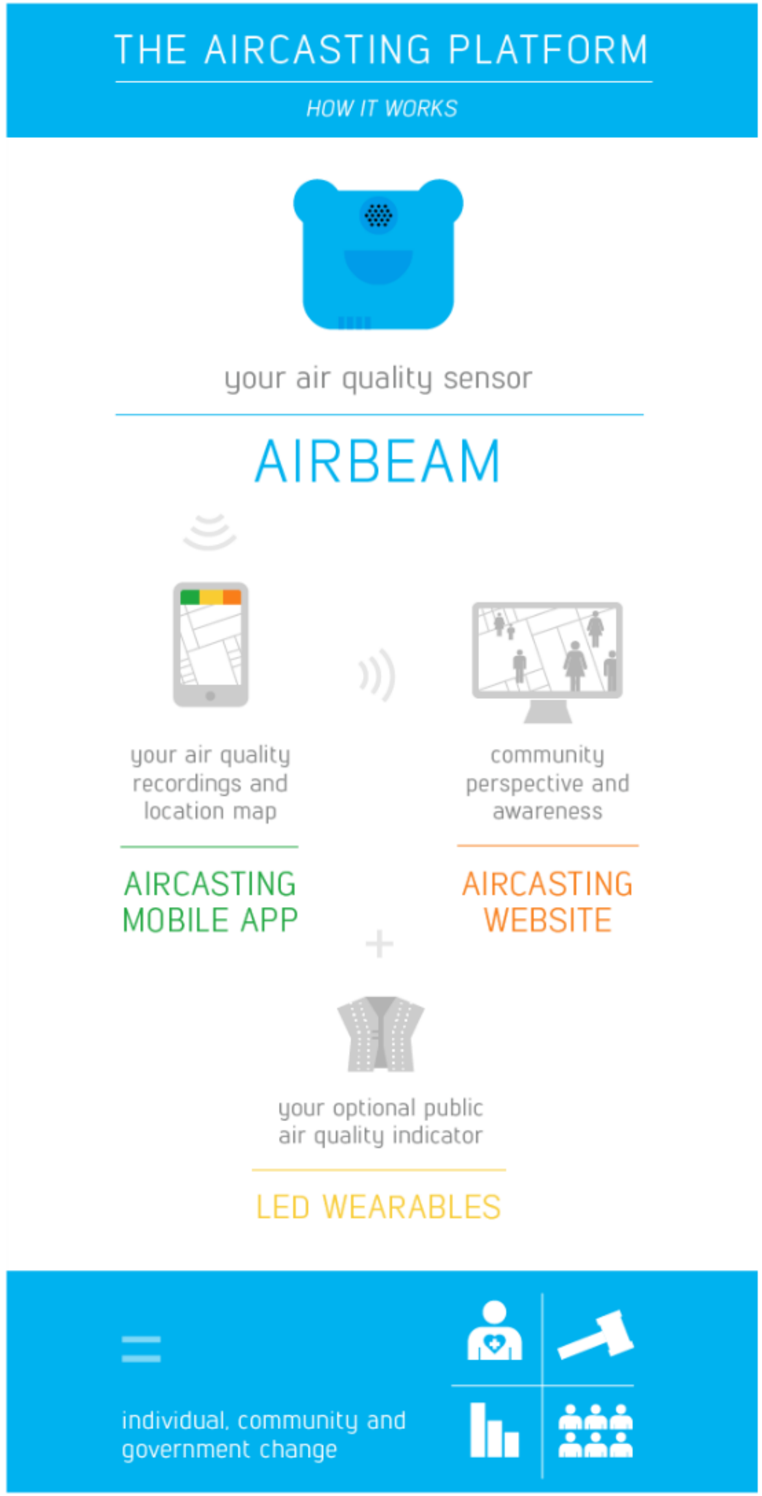
Contact information: Dena Vallano (vallano.dena@epa.gov)

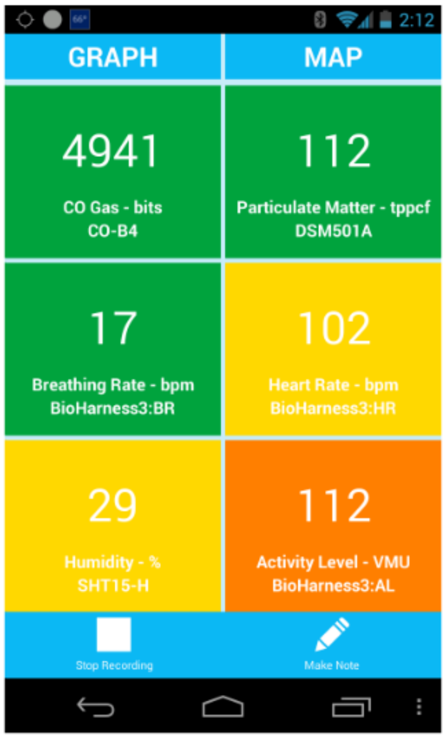
Disclaimer: Mention of commercial products does not constitute endorsement or recommendation for use and are provided here solely for informational purposes

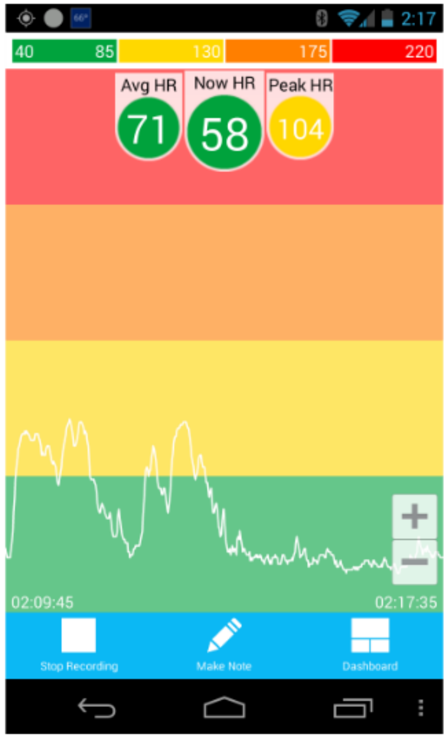

GET ON THE
MAP!
habitatmap.org

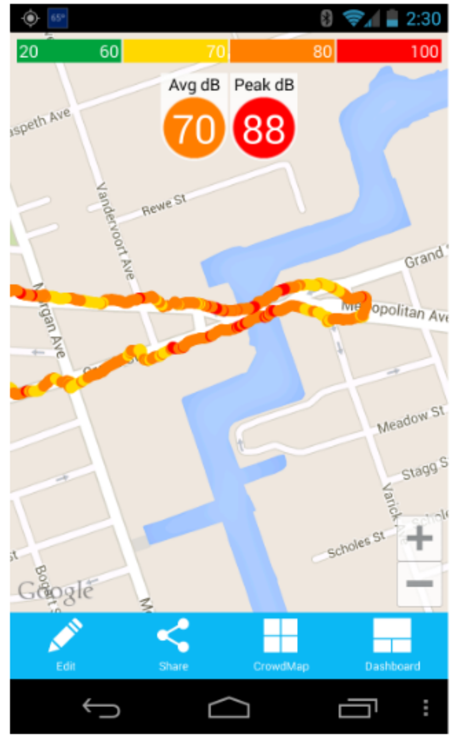

HABITATMAP.ORG
GET ON THE
MAP

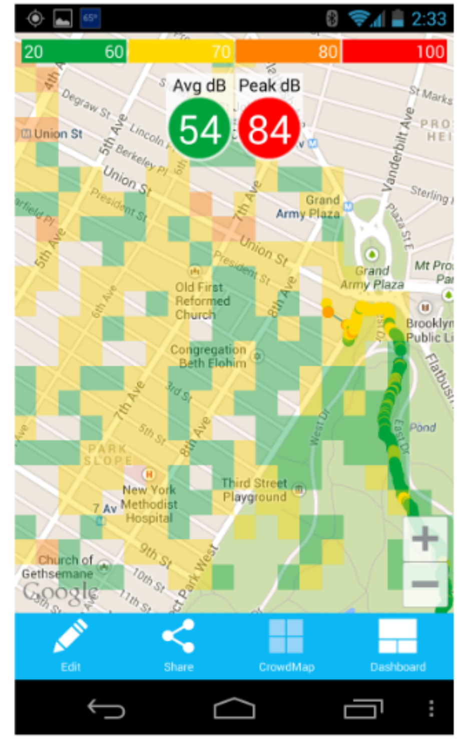
AIR
CASTING

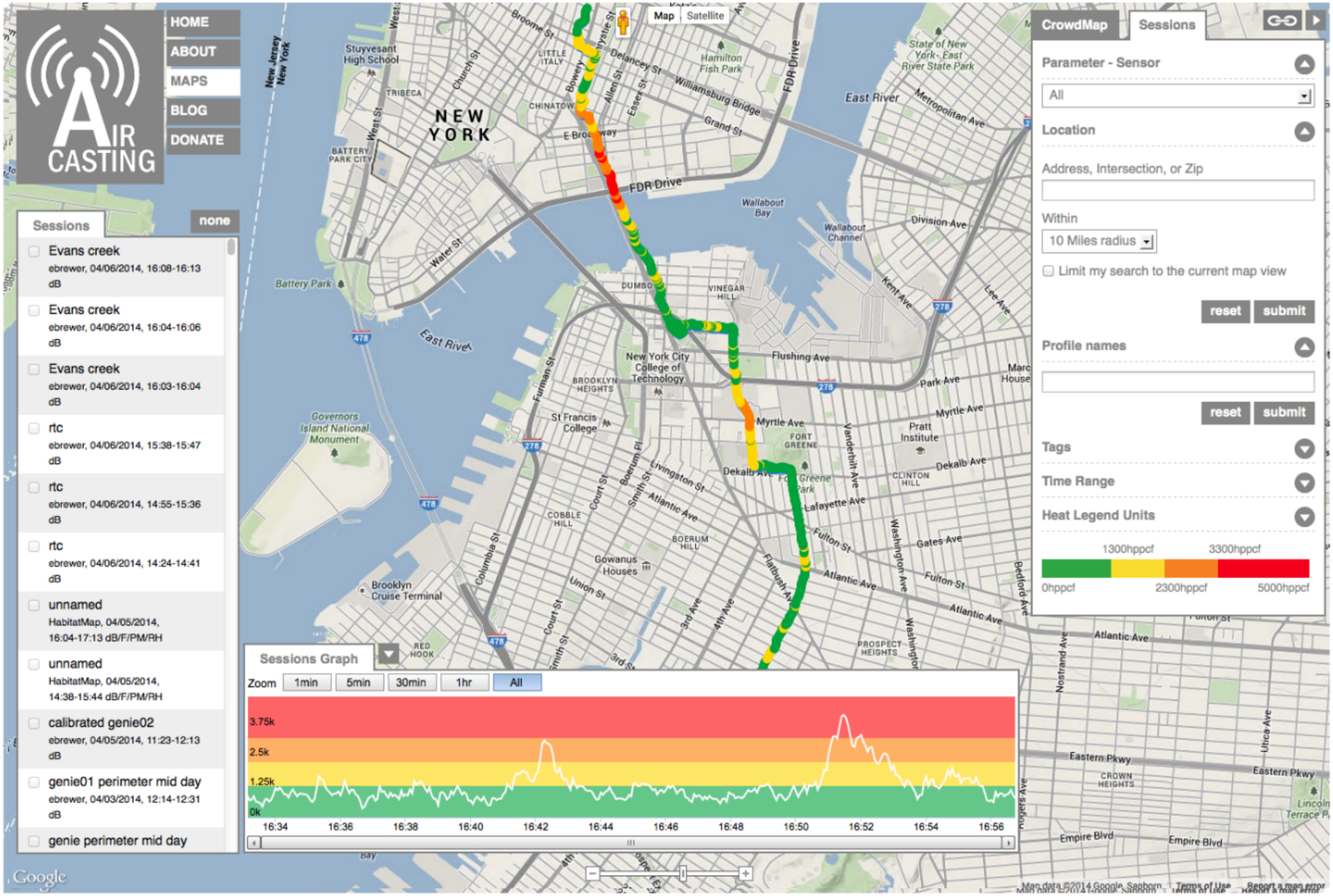

THE AIRCASTING PLATFORM
HOW IT WORKS
your air quality sensor
AIRBEAM
your air quality recordings and location map
AIRCASTING MOBILE APP
community perspective and awareness
AIRCASTING WEBSITE
+
your optional public air quality indicator
LED WEARABLES
=
individual, community and government change

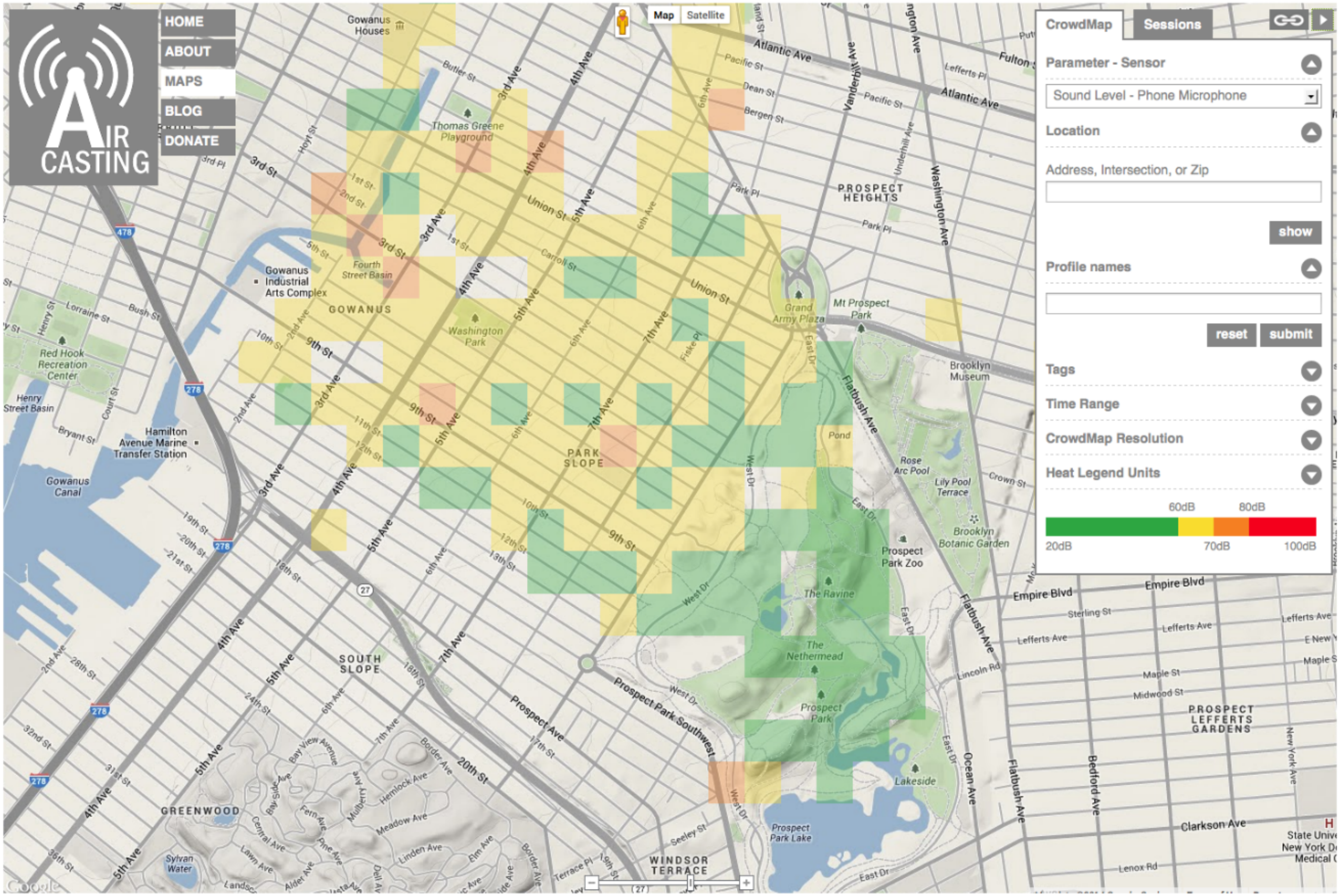

2:12
GRAPH
MAP
4941
CO Gas - bits
CO-B4
112
Particulate Matter - tppcf
DSM501A
17
Breathing Rate - bpm
BioHarness3:BR
102
Heart Rate - bpm
BioHarness3:HR
29
Humidity - %
SHT15-H
112
Activity Level - VMU
BioHarness3:AL
Stop Recording
Make Note


2:17
40
85
130
175
220
Avg HR
71
Now HR
58
Peak HR
104
02:09:45
02:17:35
Stop Recording
Make Note
Dashboard

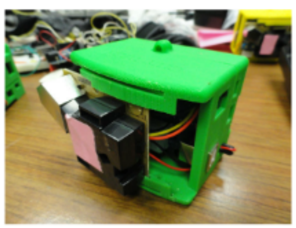

2:30
20
60
70
80
100
Avg dB
70
Peak dB
88
Edit
Share
CrowdMap
Dashboard

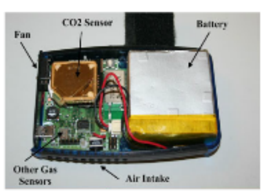

2:33
20
60
70
80
100
Avg dB
54
Peak dB
84
Edit
Share
CrowdMap
Dashboard


HOME
ABOUT
MAPS
BLOG
DONATE
AIR CASTING
Sessions
none
Evans creek
ebrewer, 04/06/2014, 16:08-16:13
dB
Evans creek
ebrewer, 04/06/2014, 16:04-16:06
dB
Evans creek
ebrewer, 04/06/2014, 16:03-16:04
dB
rtc
ebrewer, 04/06/2014, 15:38-15:47
dB
rtc
ebrewer, 04/06/2014, 14:55-15:36
dB
rtc
ebrewer, 04/06/2014, 14:24-14:41
dB
unnamed
HabitatMap, 04/05/2014,
16:04-17:13 dB/F/PM/RH
unnamed
HabitatMap, 04/05/2014,
14:38-15:44 dB/F/PM/RH
calibrated genie02
ebrewer, 04/05/2014, 11:23-12:13
dB
genie01 perimeter mid day
ebrewer, 04/03/2014, 12:14-12:31
dB
genie perimeter mid day
Map
Satellite
NEW YORK
CrowdMap
Sessions
Parameter - Sensor
All
Location
Address, Intersection, or Zip
Within
10 Miles radius
Limit my search to the current map view
reset
submit
Profile names
reset
submit
Tags
Time Range
Heat Legend Units
1300hppcf
3300hppcf
0hppcf
2300hppcf
5000hppcf
Sessions Graph
Zoom
1min
5min
30min
1hr
All
3.75k
2.5k
1.25k
0k
16:34
16:36
16:38
16:40
16:42
16:44
16:46
16:48
16:50
16:52
16:54
16:56
Google

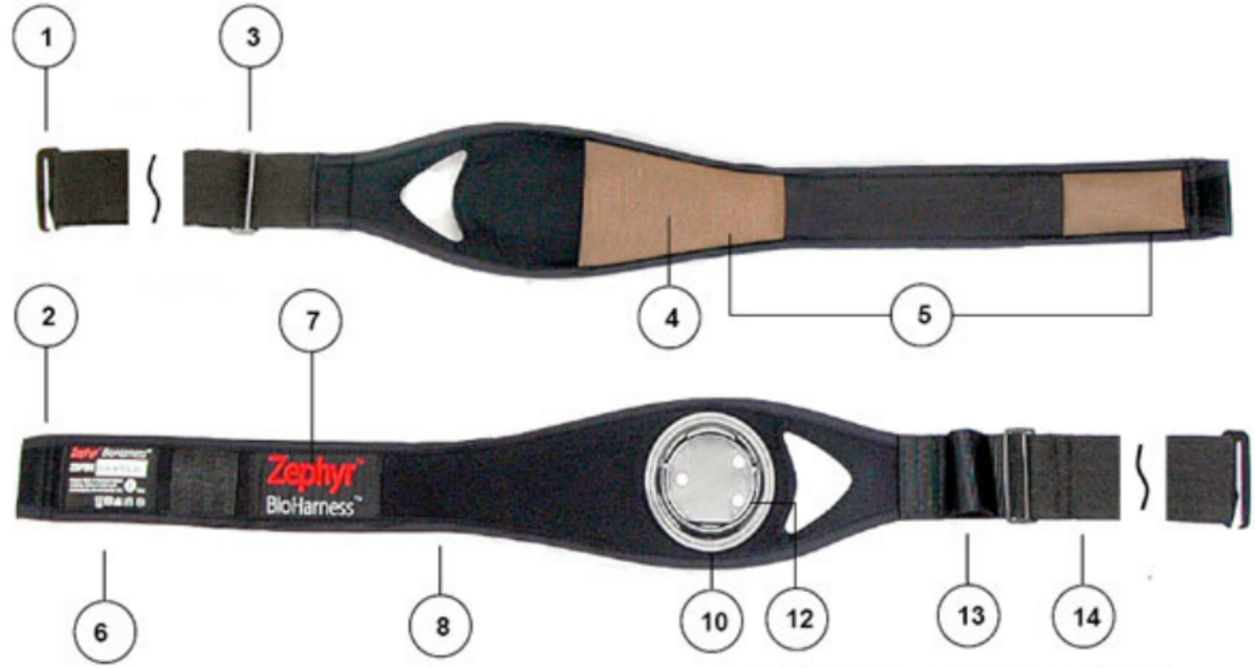

AIR CASTING
HOME
ABOUT
MAPS
BLOG
DONATE
Map
Satellite
CrowdMap
Sessions
Parameter - Sensor
Sound Level - Phone Microphone
Location
Address, Intersection, or Zip
show
Profile names
reset
submit
Tags
Time Range
CrowdMap Resolution
Heat Legend Units
60dB
80dB
20dB
70dB
100dB
GOWANUS
PARK SLOPE
SOUTH SLOPE
PROSPECT HEIGHTS
GREENWOOD
WINDSOR TERRACE
PROSPECT LEFFERTS GARDENS
Prospect Park
Prospect Park Lake
Grand Army Plaza
Brooklyn Museum
Brooklyn Botanic Garden
Prospect Park Zoo
Washington Park
Gowanus Canal

The AirCasting Family






MQ-3
Gadgeteer AirCasting @lotzh



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


Thermo
SCIENTIFIC
ESC
ENTER

My Air My Health

U.S. Department of Health and Human Services
U.S. Environmental Protection Agency

AirGo

Carbon Monoxide
Particulate Matter
Temperature
Relative Humidity

Phone

Sound Levels

BioHarness

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

AirCasting Greenpoint

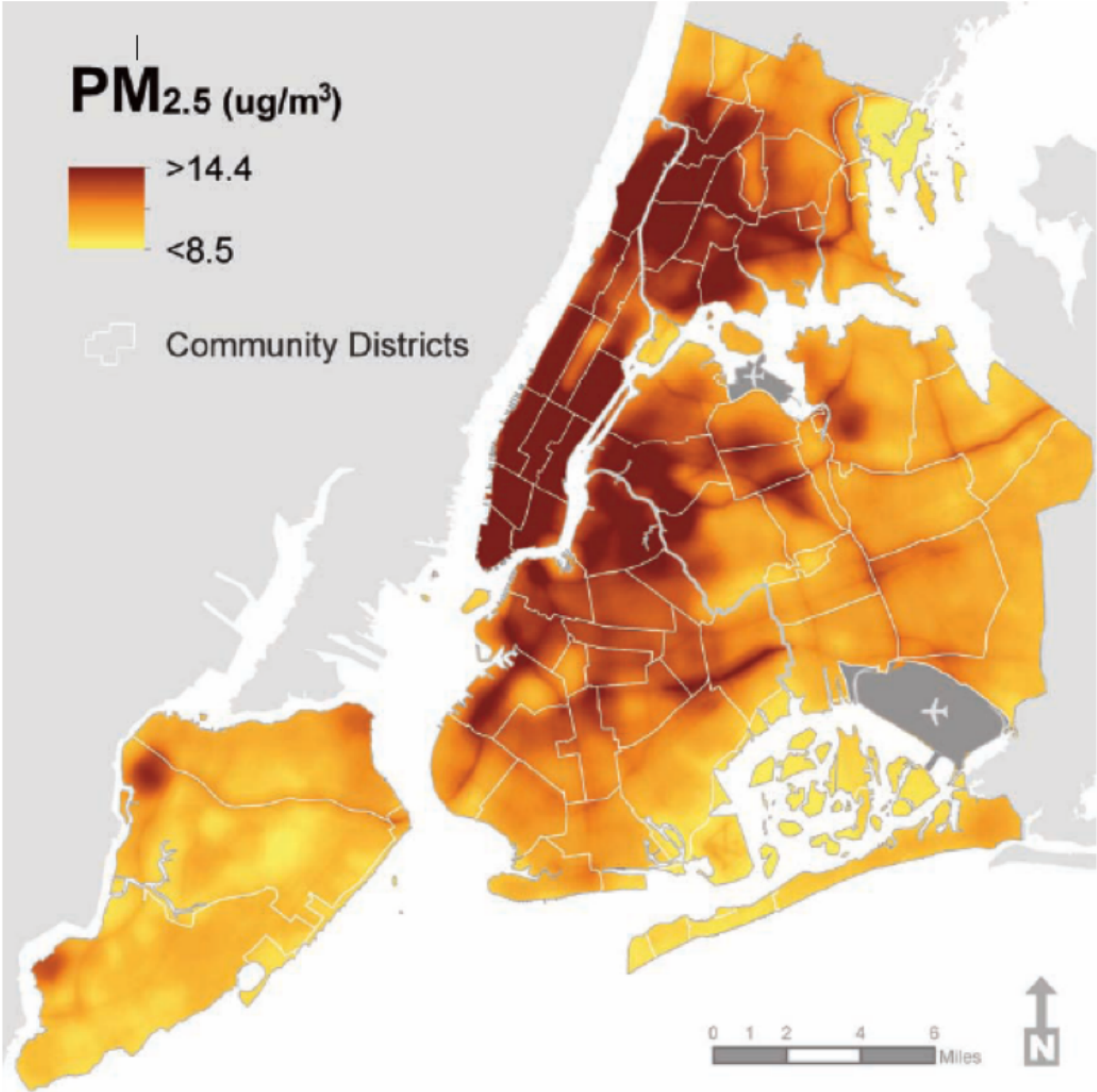
Citizen Science for Clean Air

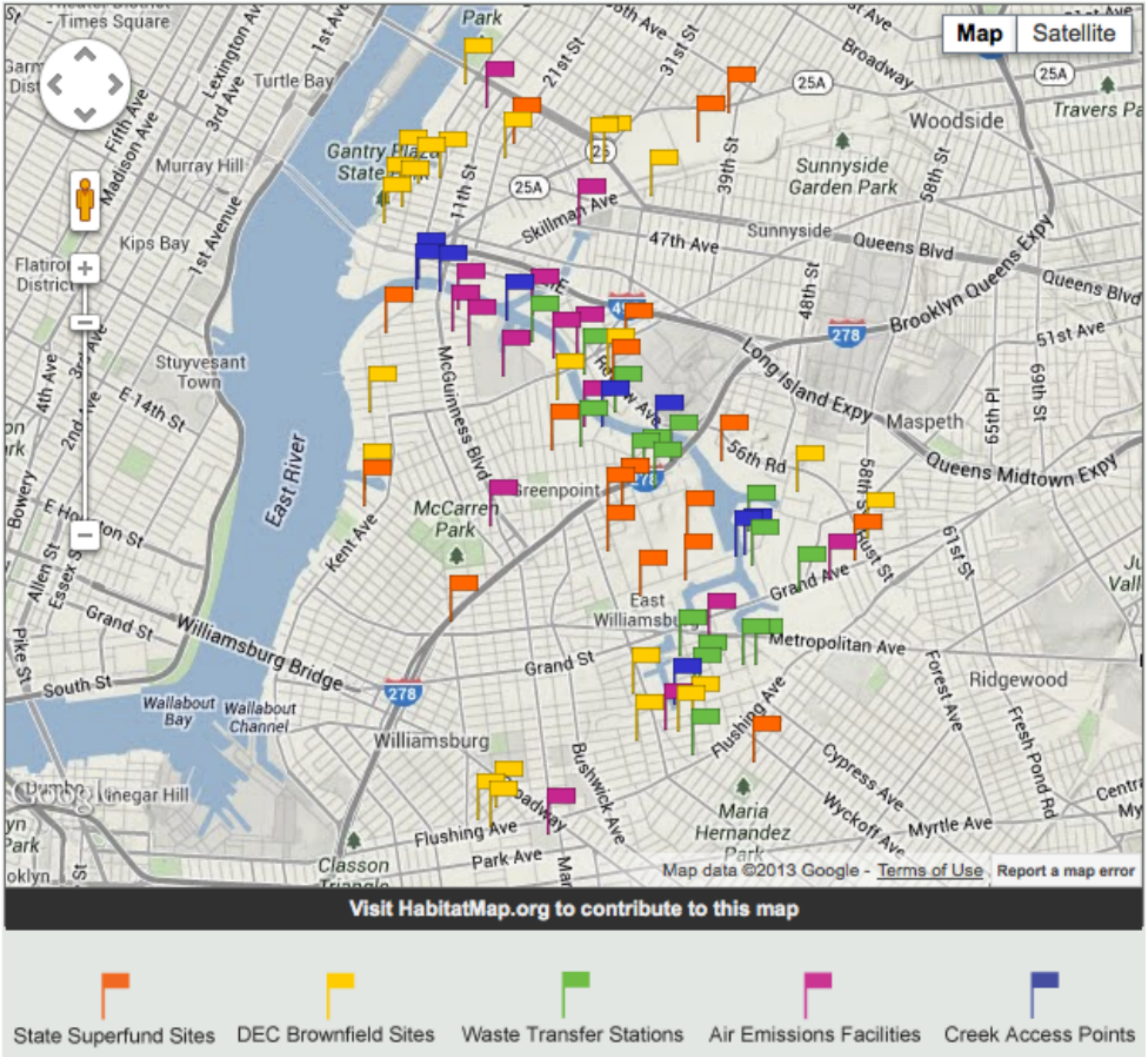
A Community based participatory research project that will:

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?


PM2.5 (ug/m3)
>14.4
<8.5
Community Districts
0 1 2 4 6
Miles
N


Map
Satellite
Times Square
Turtle Bay
Murray Hill
Kips Bay
Gantry Plaza State Park
Stuyvesant Town
East River
Woodside
Sunnyside Garden Park
Sunnyside
Skillman Ave
47th Ave
Queens Blvd
Brooklyn Queens Expy
Long Island Expy
Maspeth
Queens Midtown Expy
56th Rd
51st Ave
McGuinness Blvd
Greenpoint
McCarren Park
Kent Ave
East Williamsburg
Grand Ave
Metropolitan Ave
Grand St
Williamsburg Bridge
Wallabout Bay
Wallabout Channel
Williamsburg
South St
Flushing Ave
Bushwick Ave
Maria Hernandez Park
Cypress Ave
Wyckoff Ave
Myrtle Ave
Ridgewood
Forest Ave
Fresh Pond Rd
Classon
Park Ave
Vinegar Hill
Map data ©2013 Google - Terms of Use
Report a map error
Visit HabitatMap.org to contribute to this map
State Superfund Sites
DEC Brownfield Sites
Waste Transfer Stations
Air Emissions Facilities
Creek Access Points

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

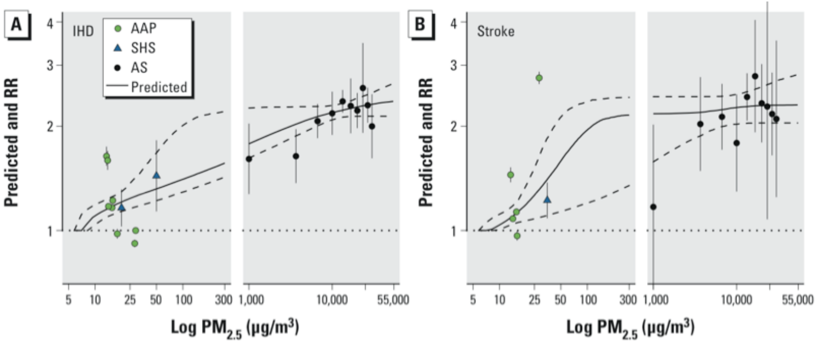


Figure 1: Burnett et al (2014) *Environ Health Persp*

Motivation and background

Figure 2: Chulha stove and traffic congestion. [*Wikimedia*]

Study 1

Study 1: commodity hardware

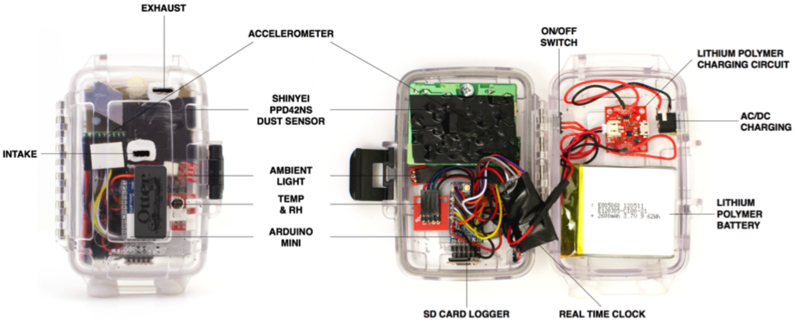


Figure 3: Prototype incorporating PPD42NS sensor.

Study 1: colocation at Oakland BAAQMD site

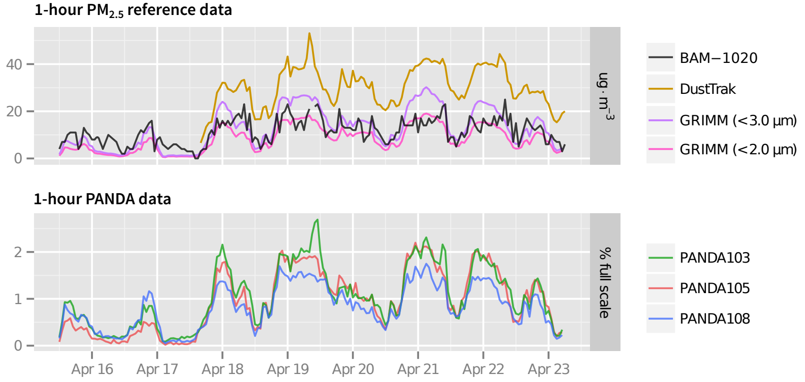


Figure 4: Holstius D, Pillarisetti A, Smith KR, Seto E. Field calibrations of a low-cost aerosol sensor at a regulatory monitoring site in California. *Atmos Meas Tech* 7, 1121–1131, 2014.

Study 1: $R^2 = 0.72$ vs. 24 h FEM $PM_{2.5}$

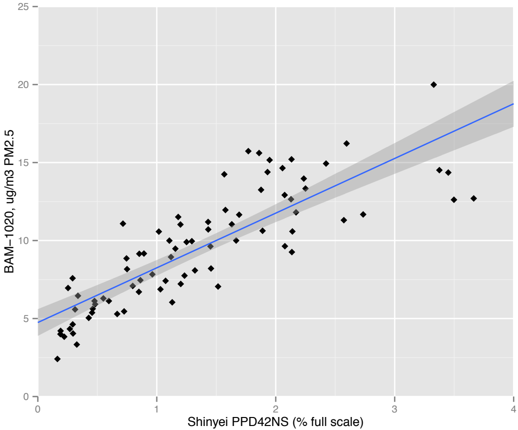


Figure 5: Holstius D, Pillarisetti A, Smith KR, Seto E. Field calibrations of a low-cost aerosol sensor at a regulatory monitoring site in California. *Atmos Meas Tech* 7, 1121–1131, 2014.

Study 2

Study 2: larger-scale evaluation ($n = 48$)

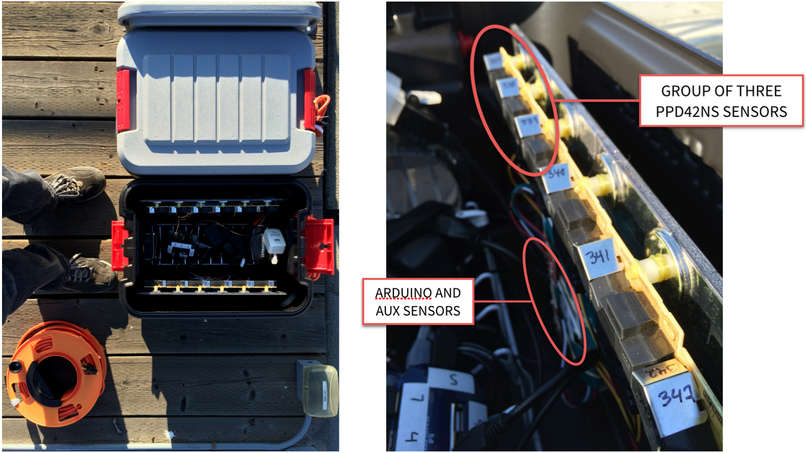


Figure 6: Holstius D. *Monitoring PM w/Commodity Hardware*, 2014.

Study 2: exchange near-road ↔ background sites

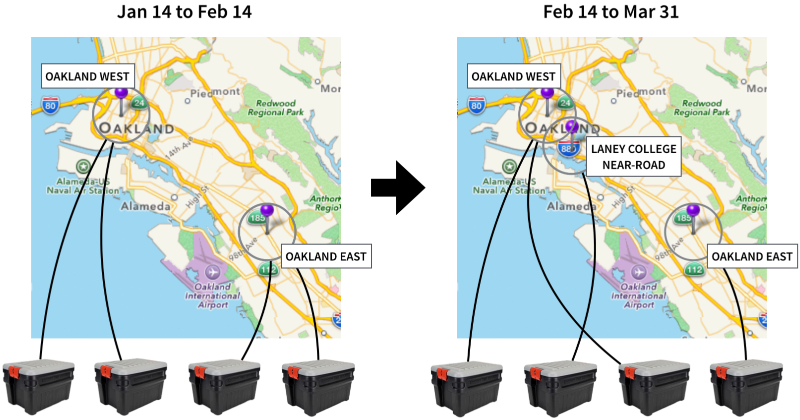


Figure 7: Holstius D. *Monitoring PM w/Commodity Hardware*, 2014.

Study 2: single-parameter calibrations

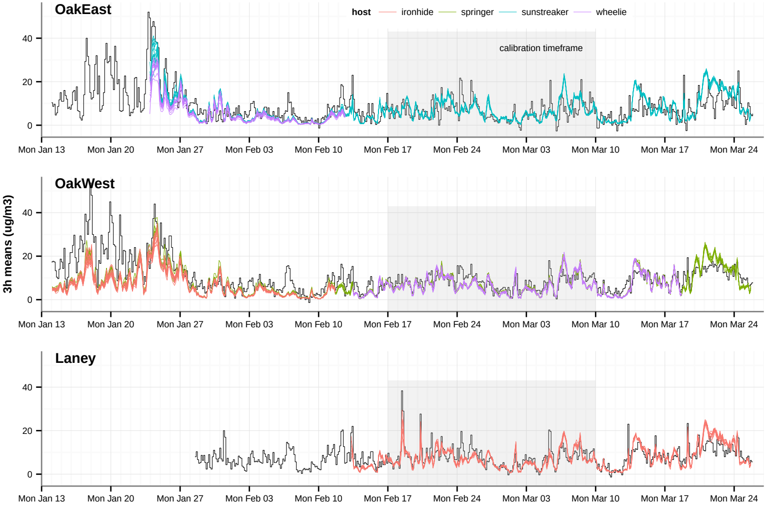


Figure 8: Holstius D. *Monitoring PM w/Commodity Hardware*, 2014.

Study 2: near-road site

Figure 9: Laney College site, looking southeast along I-880

Study 2: localized elevations at < 1 h scale

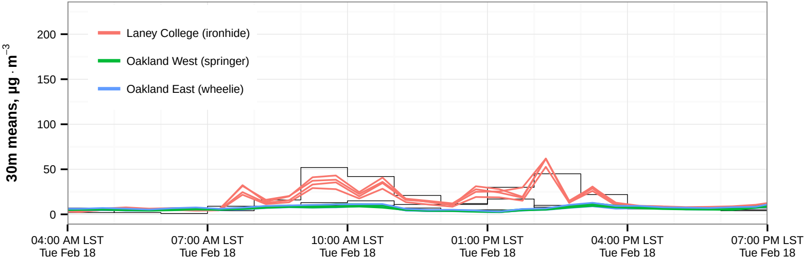


Figure 10: Sensor data, 30 min scale (near-road, background, background). Black steps = 1 h $PM_{2.5\text{-FEM}}$ (reference).

Study 2: localized elevations at < 1 h scale

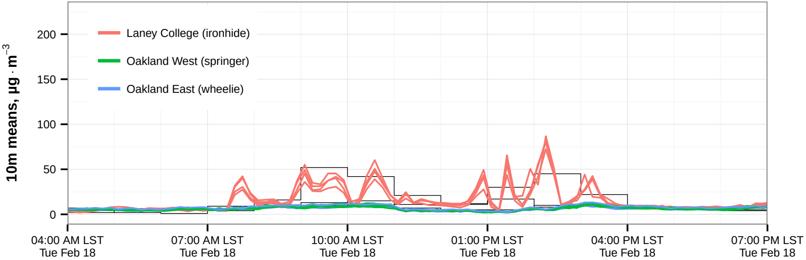


Figure 11: Sensor data, 10 min scale (near-road, background, background). Black steps = 1 h $PM_{2.5\text{-FEM}}$ (reference).

Study 2: localized elevations at < 1 h scale

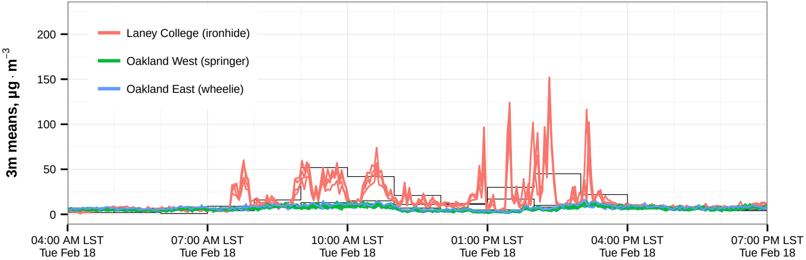


Figure 12: Sensor data, 3 min scale (near-road, background, background). Black steps = 1 h $PM_{2.5\text{-FEM}}$ (reference).

Study 2: localized elevations at < 1 h scale

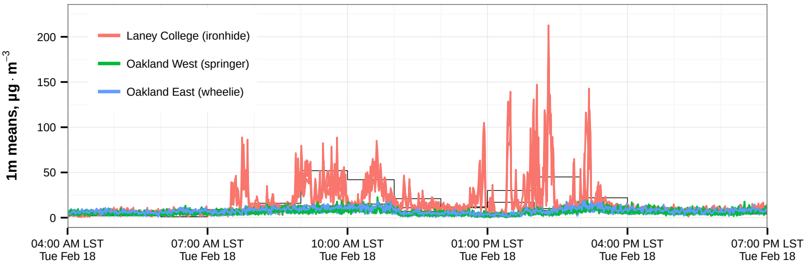


Figure 13: Sensor data, 1 min scale (near-road, background, background). Black steps = 1 h $PM_{2.5\text{-FEM}}$ (reference).

Study 2: localized elevations at < 1 h scale

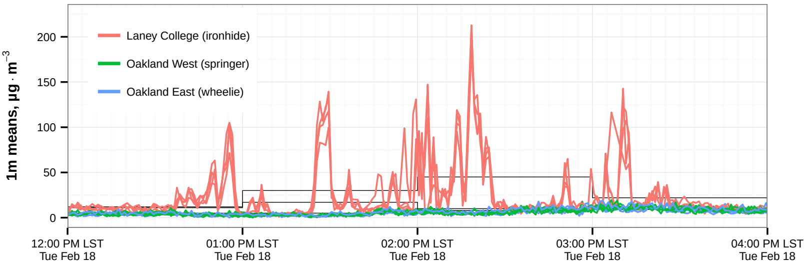


Figure 14: Sensor data, 1 min scale (near-road, background, background). Black steps = 1 h $PM_{2.5\text{-FEM}}$ (reference).

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** $\boldsymbol{\beta_1}$ 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 2nd BAM
  - σ for BAM is 2 – 2.4 $\mu g \cdot m^{-3}$ at 1 h scale

Summary of findings

Utility. Simple model has reasonable fit:

- β_0 very close to zero
- modest variation in β_1
- 10 % error in β_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).

Selected references

Burnett R et al. An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environ Health Perspect* 112(4), 2014.

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.

Holstius D. Monitoring Particulate Matter with Commodity Hardware. Ph.D. thesis, University of California, Berkeley. 2014.

Snyder E et al. The Changing Paradigm of Air Pollution Monitoring. *Environ Sci Technol*, 2013, 47 (20), 11369–11377.

Additional slides

Study 1: colocation

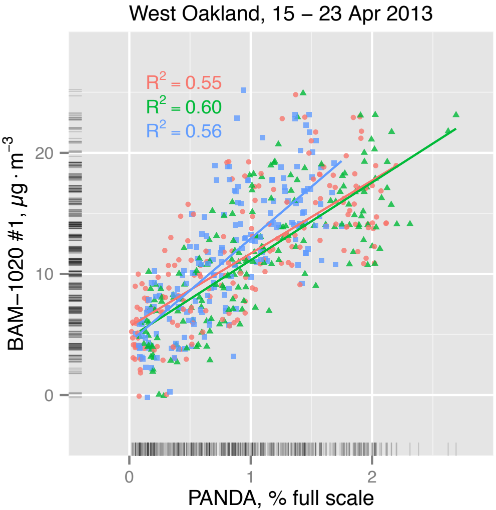


Figure 16: PPD42NS vs BAM at 1 h scale. ($R^2 \approx 0.6$)

Study 1: colocation

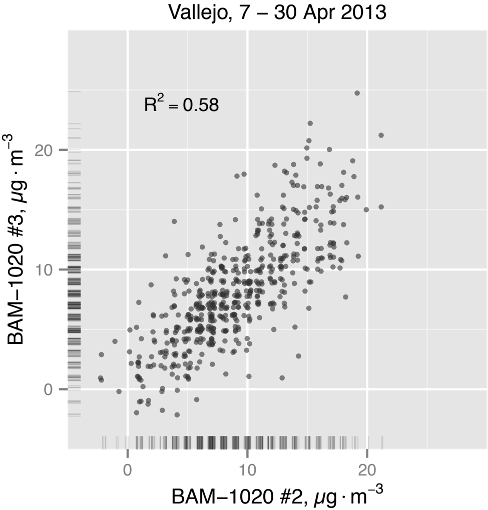


Figure 17: BAM vs BAM at 1 h scale. ($R^2 \approx 0.6$)

BEACO$_2$N: Dense networks for air quality and climate research

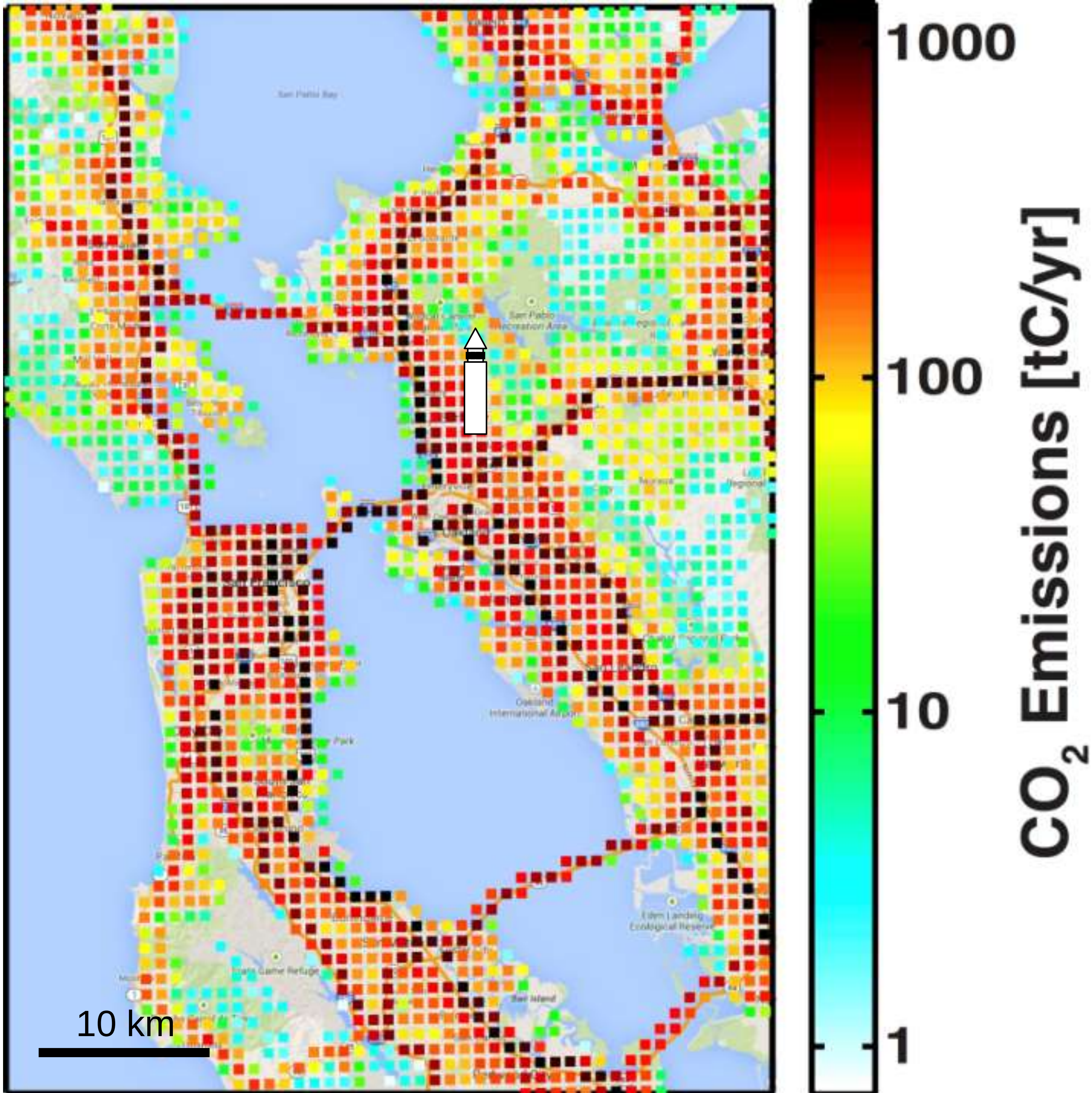
Ronald C. Cohen
Professor of Chemistry
Professor of Earth and Planetary Science
UC Berkeley

$NSF, BAAQMD, HEI, UC Berkeley

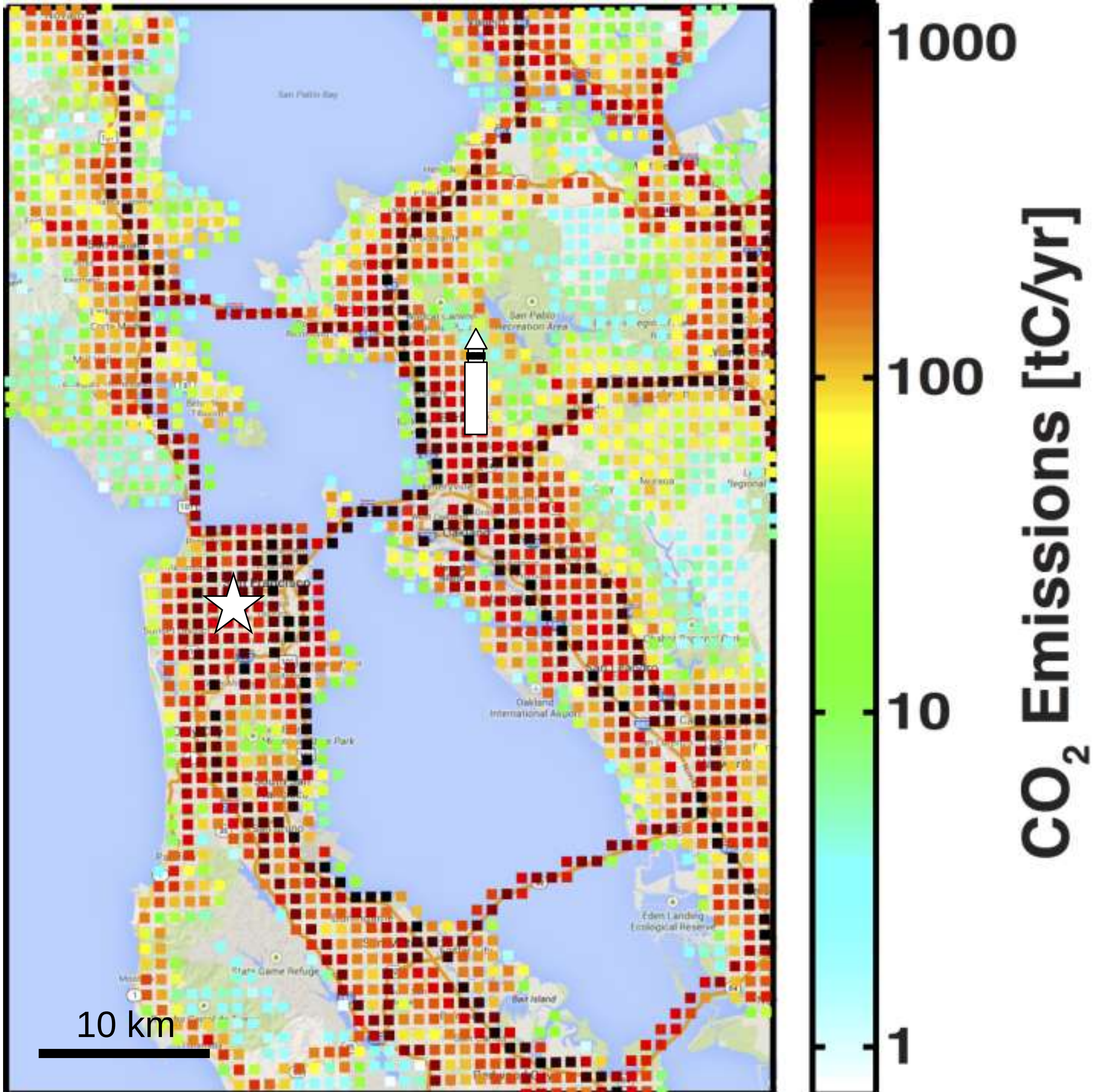
Climate

Air Quality

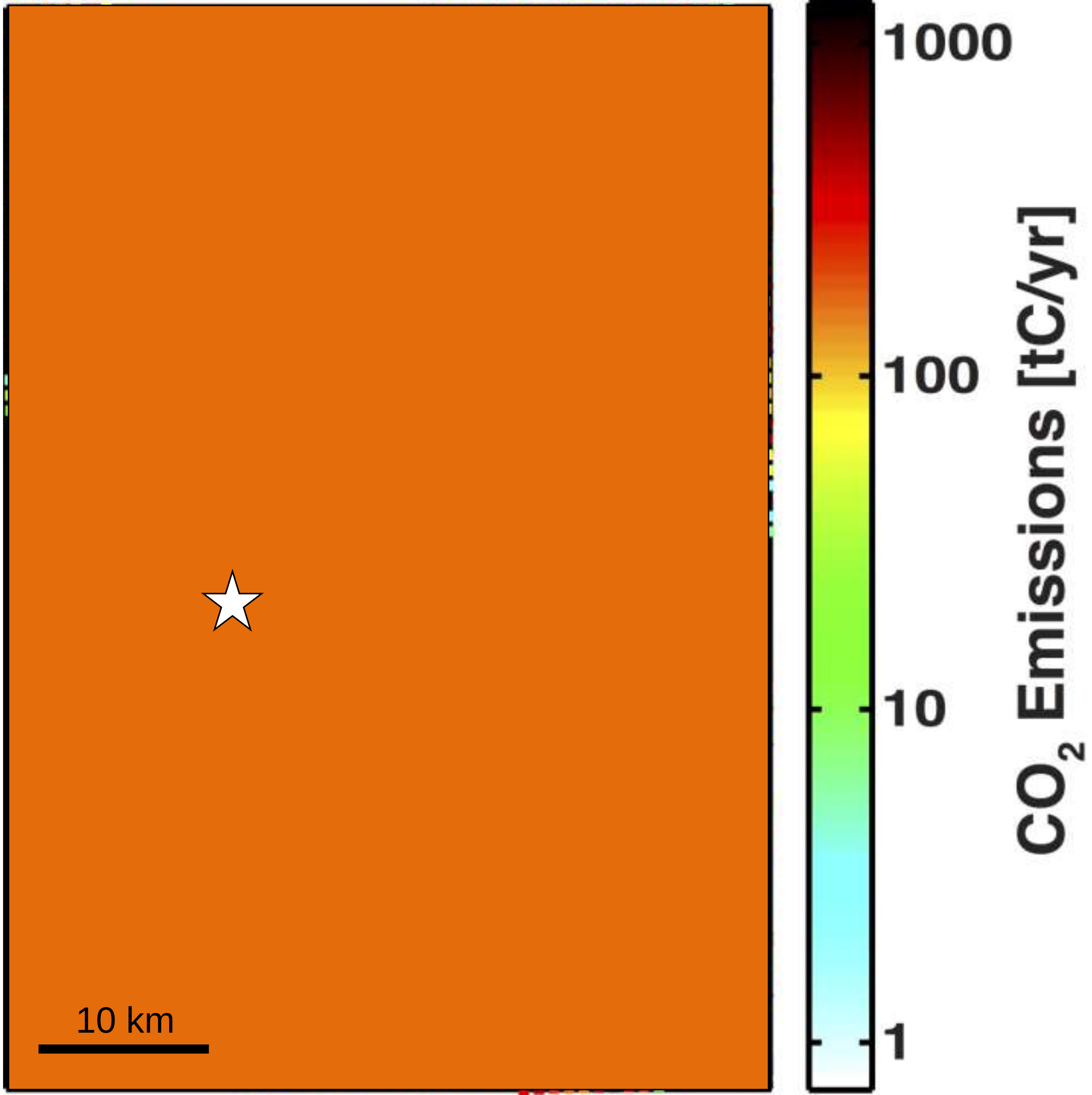
Illustration by John Heinly



c/o Alex Turner

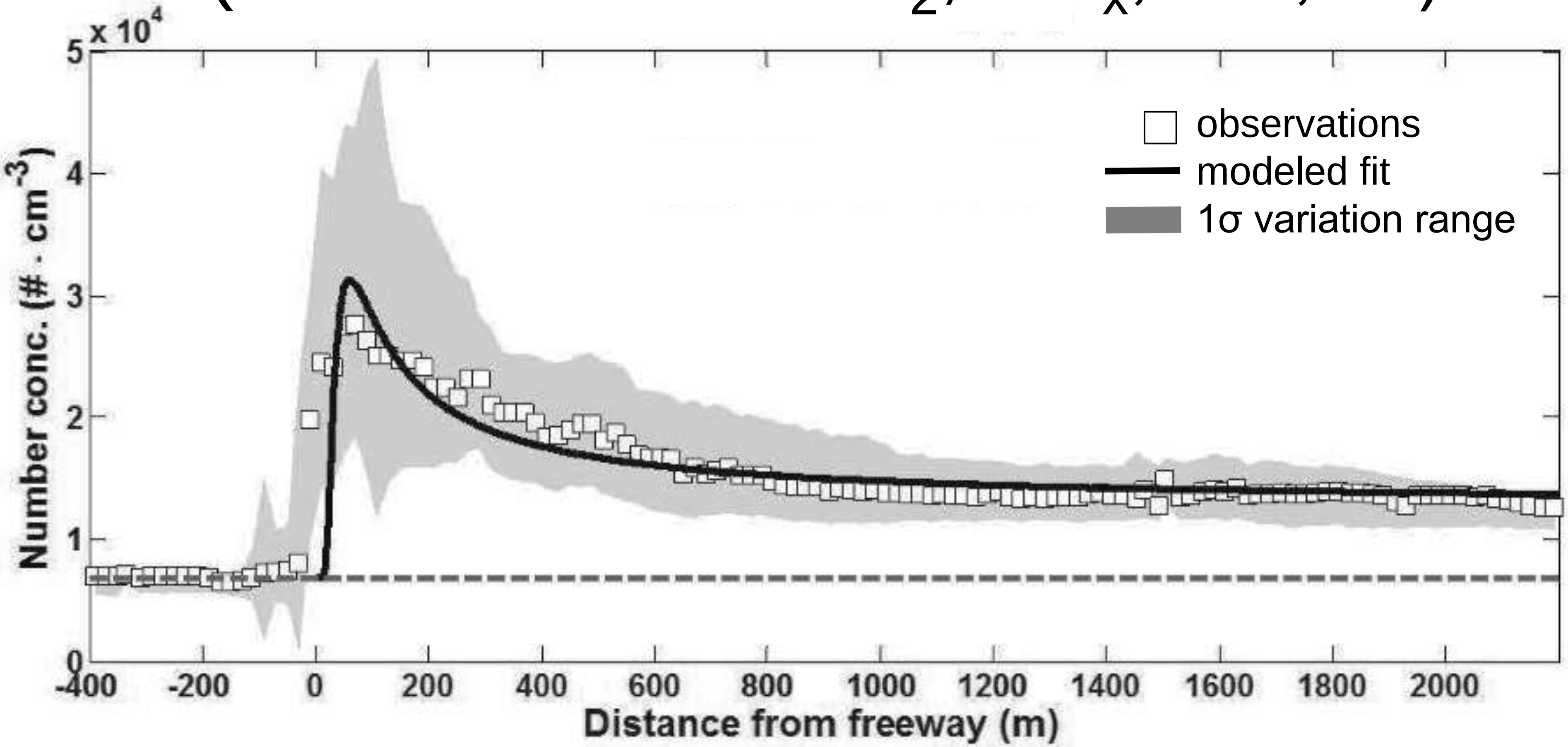


c/o Alex Turner



c/o Alex Turner

Particulate Matter
(co-emitted with CO_2, NO_x, CO, …)

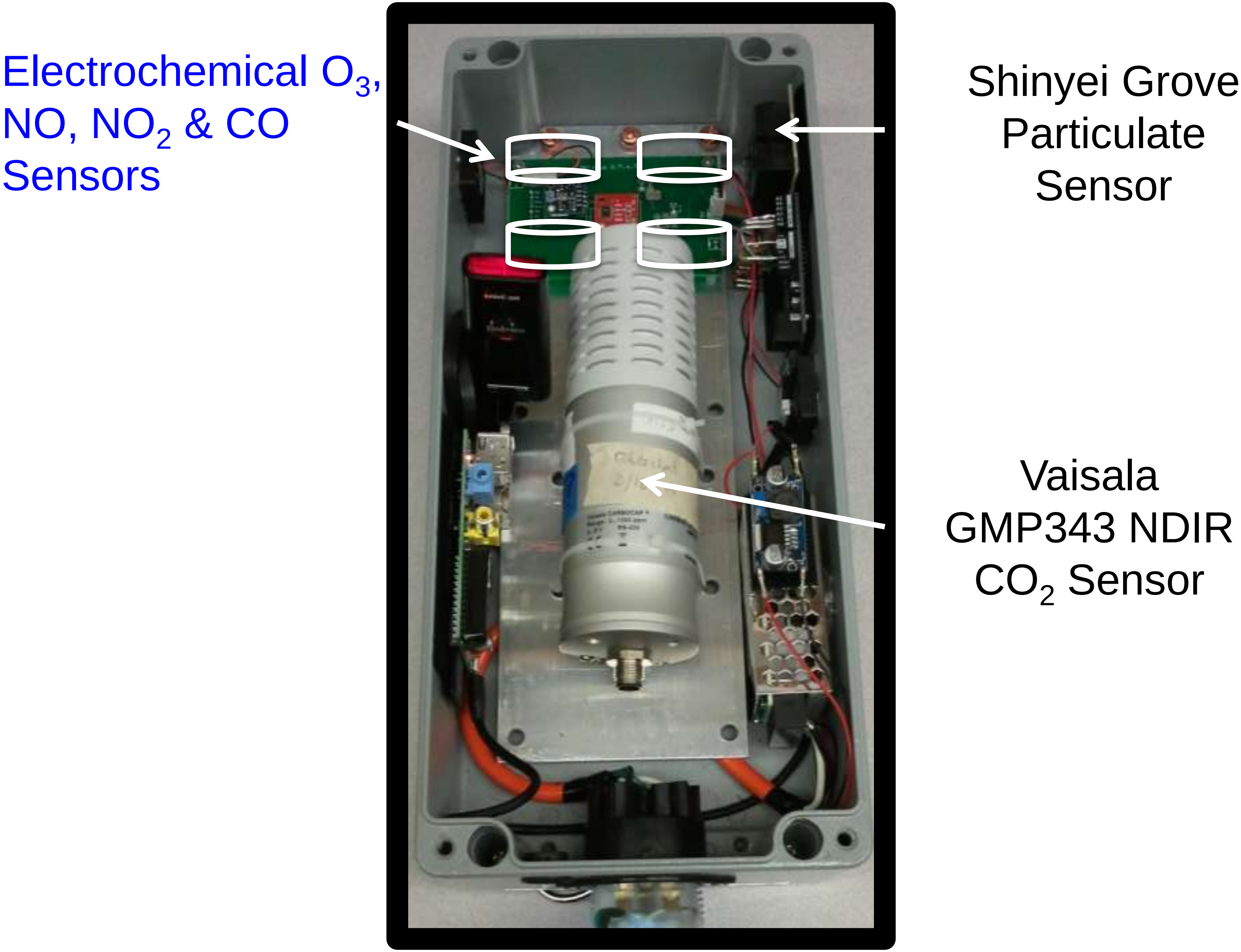


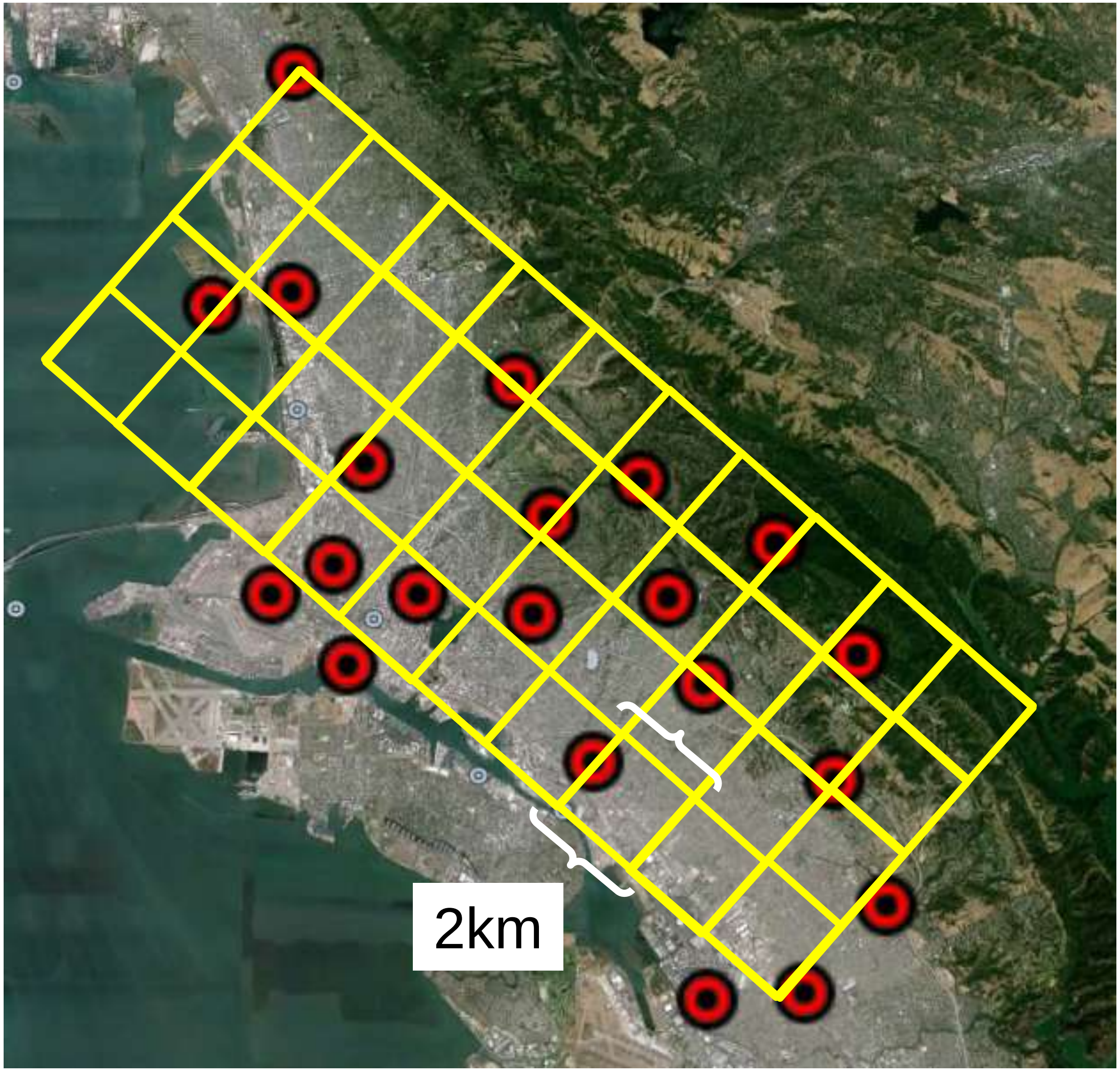
from Choi et al. 2014

Vaisala
GMP343 NDIR
CO_2 Sensor

Shinyei Grove Particulate Sensor

Vaisala GMP343 NDIR CO_2 Sensor


Electrochemical O_3, NO, NO_2 & CO Sensors
Shinyei Grove Particulate Sensor
Vaisala GMP343 NDIR CO_2 Sensor



BErkeley

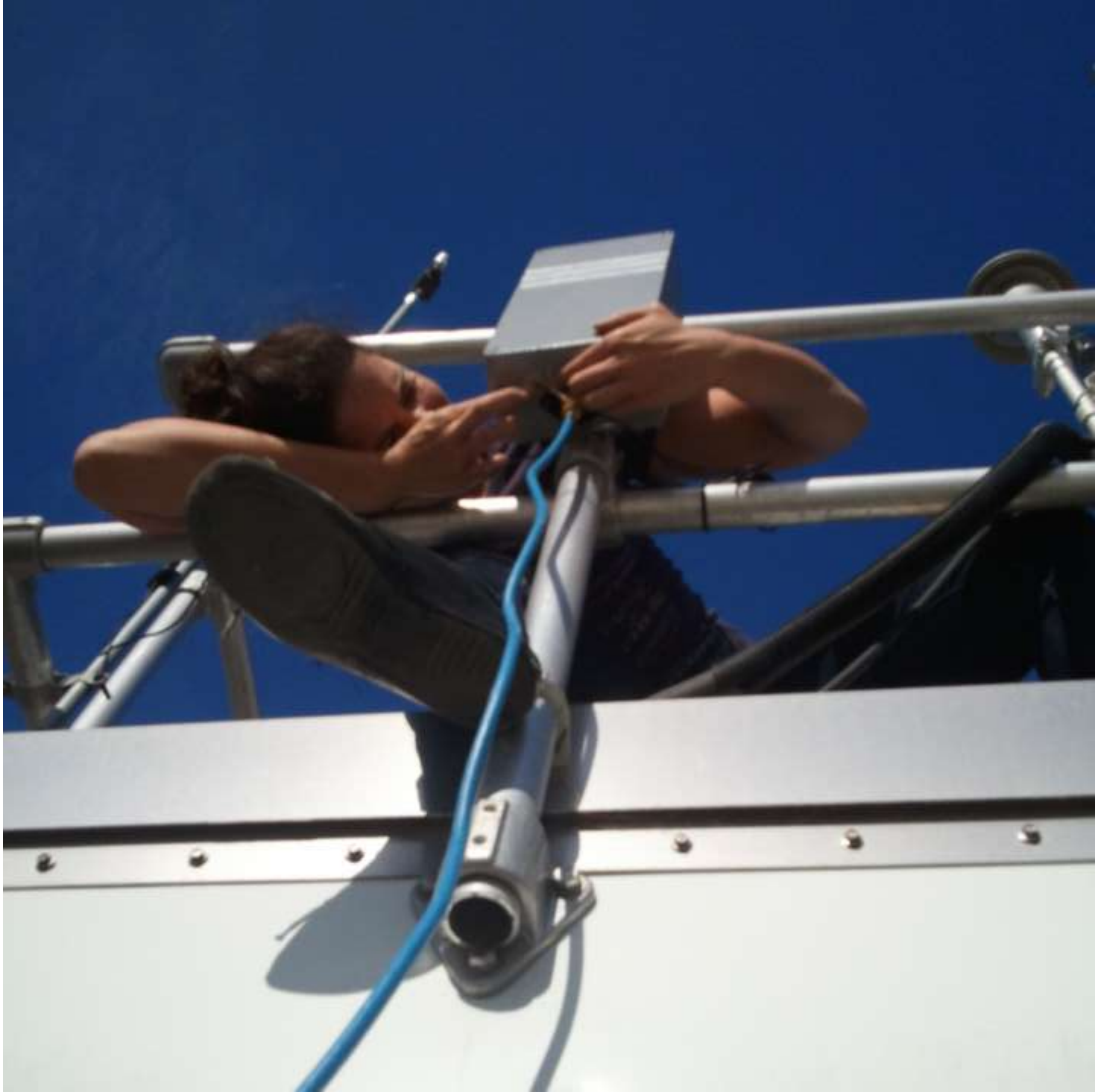
Atmospheric

CO_2

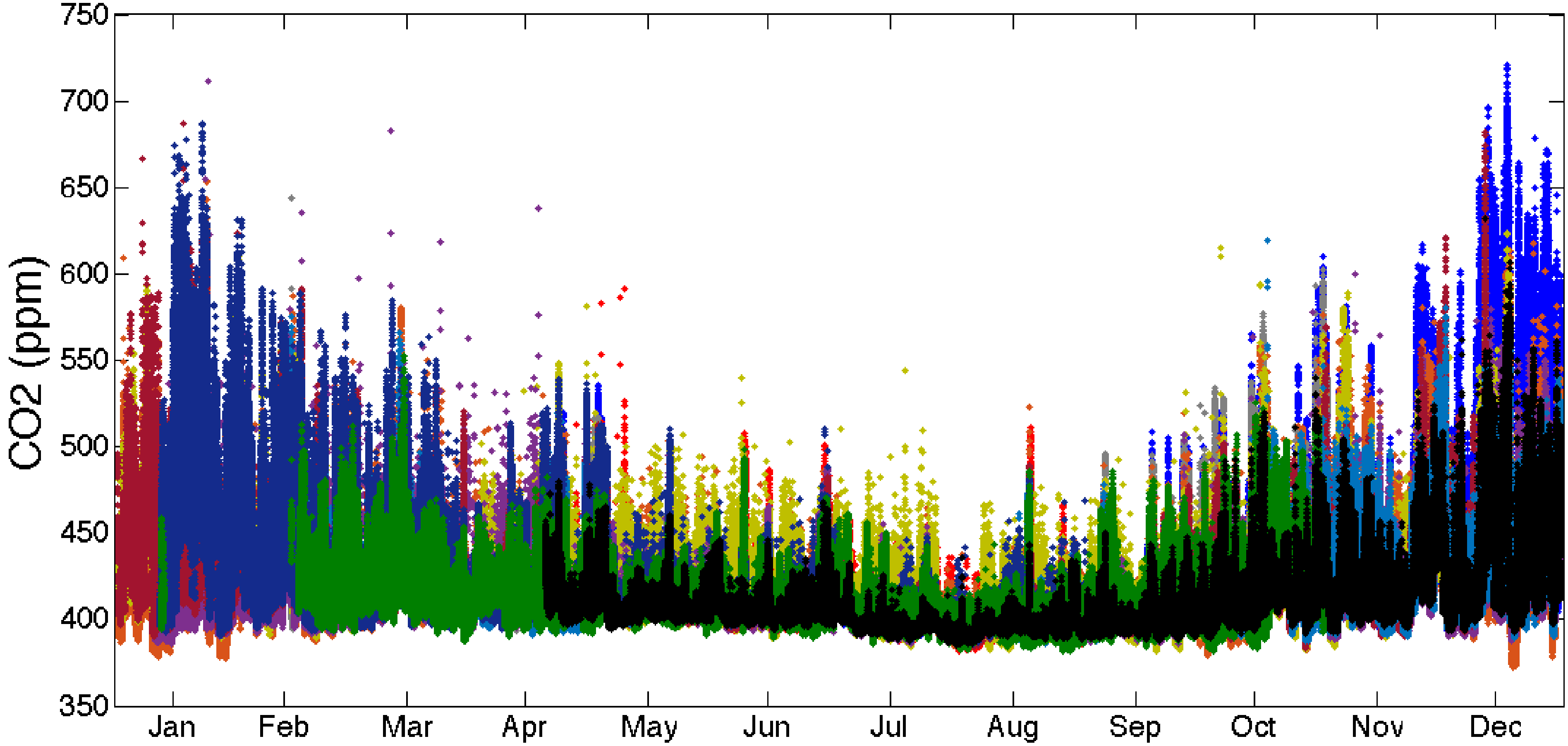
Observation

Network

Performance	Picarro G2301	Vaisala GMP343
Accuracy	± 1 ppm	± 7 ppm
Precision	± < 0.2 ppm (5s)	± 3 ppm (2s)
Drift	± 6 ppm/yr	± 8 ppm/yr
Weight	58 lbs	0.8 lbs
Price	$50,000-100,000	$3,000



BEACO$_2$N CO$_2$ 2013



Sites:

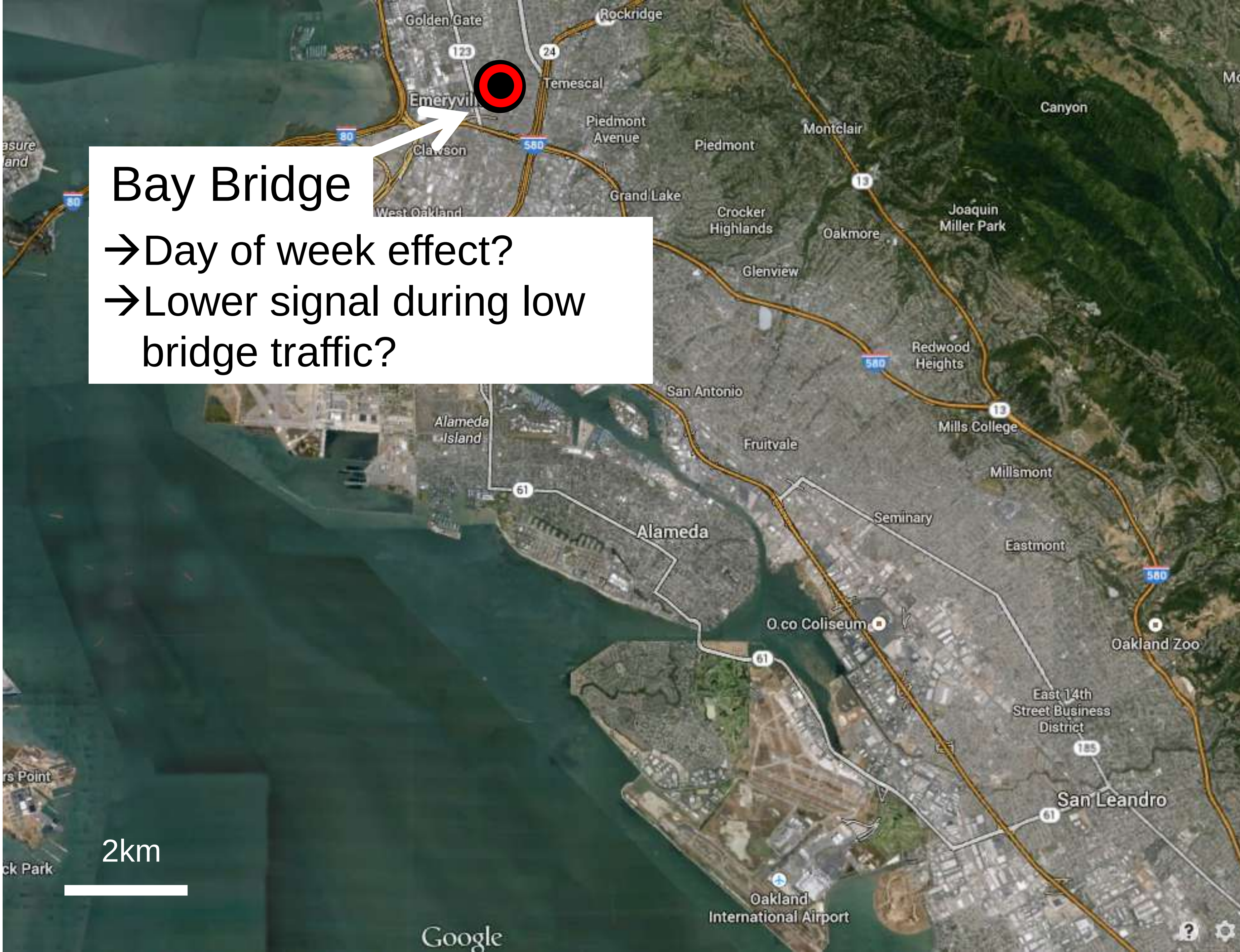
Burckhalter
Prescott
Laurel
Kaiser
CollegePrep
Korematsu
ODowd
StLiz
HeadRoyce
ElCerrito
NOakland

Downwind of Bay Bridge
Downwind of Port of Oakland
wind
2km
Golden Gate
Rockridge
Emeryville
Temescal
Clawson
West Oakland
Adams Point
Oakland
Oakmore
Glenview
Joaquin Miller Park
Canyon
Redwood Heights
Mills College
Fruitvale
Millsmont
Seminary
Eastmont
Alameda
O.co Coliseum
Oakland Zoo
East 14th Street Business District
San Leandro
Oakland International Airport
Google

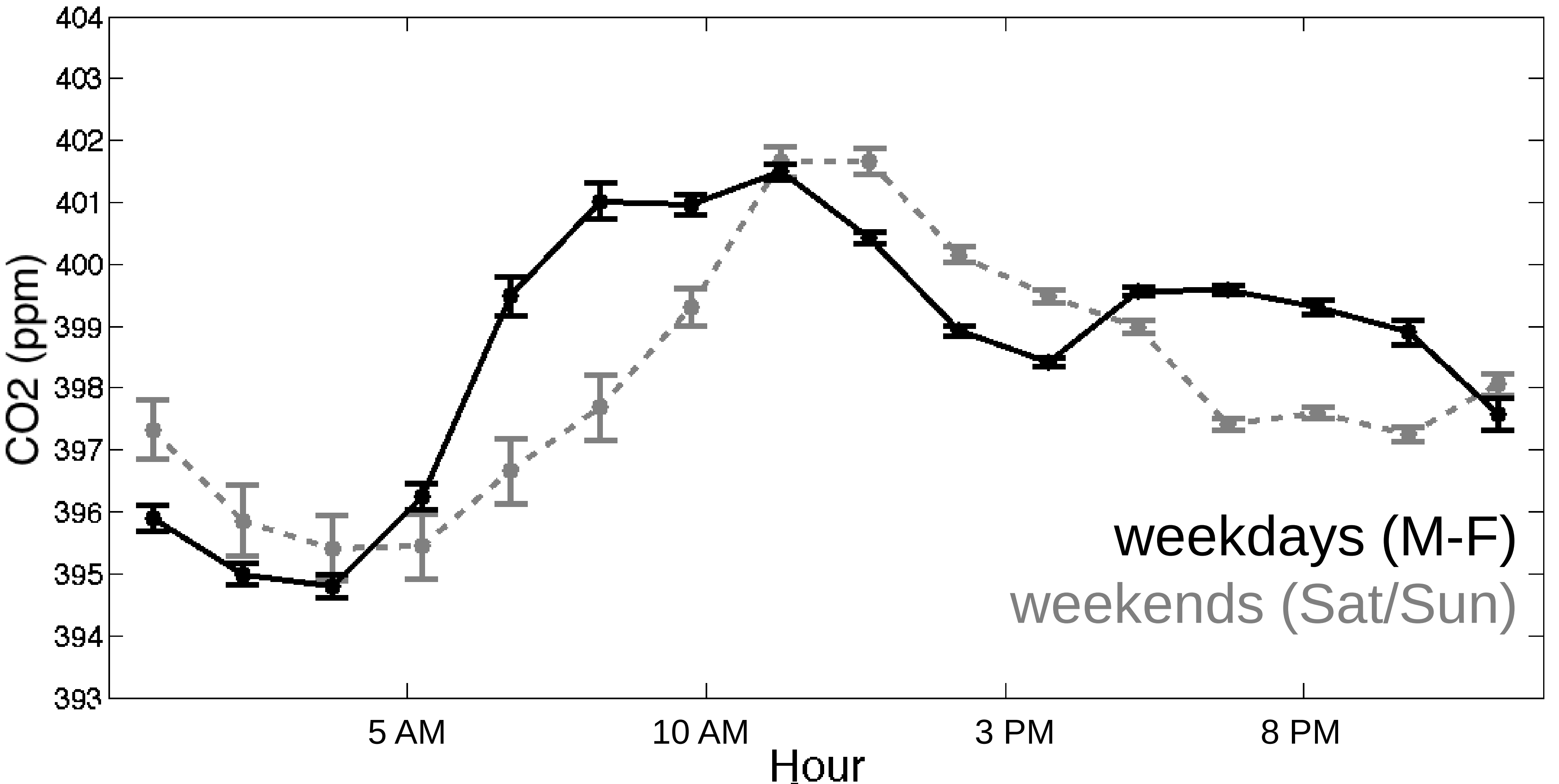
Bay Bridge

→Day of week effect?

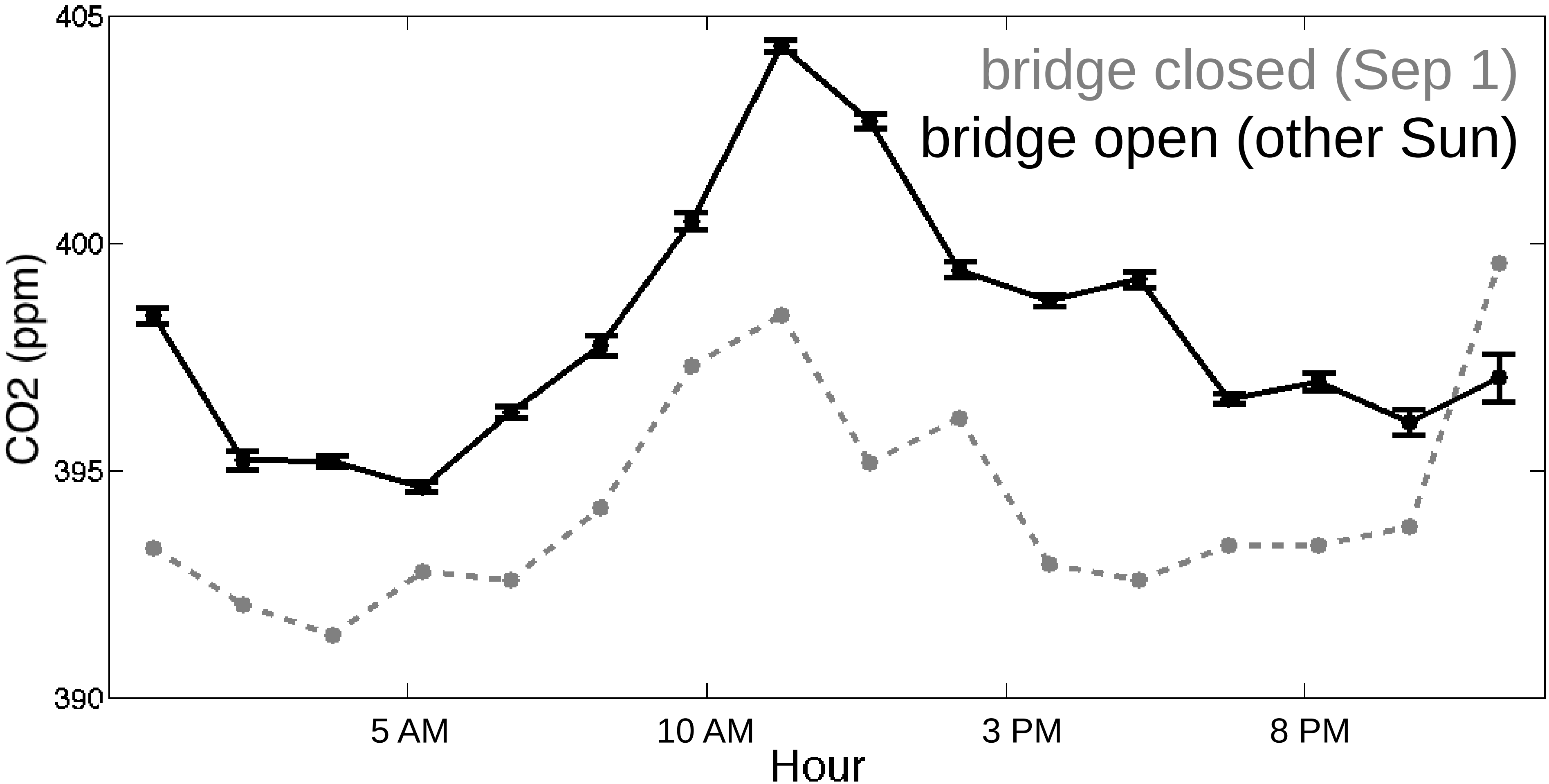
→Lower signal during low bridge traffic?

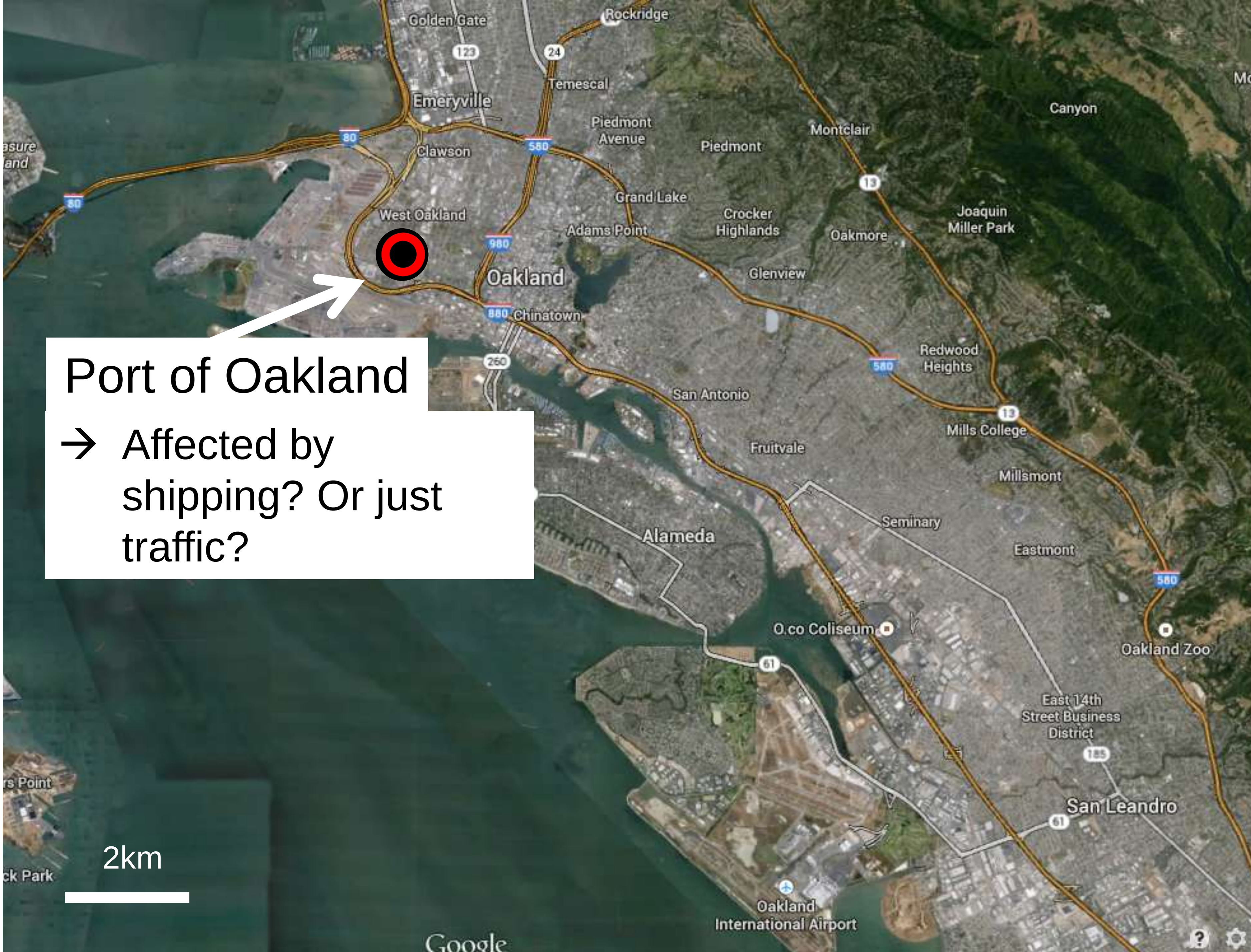


Bay Bridge Aug/Sept Diurnal Cycle

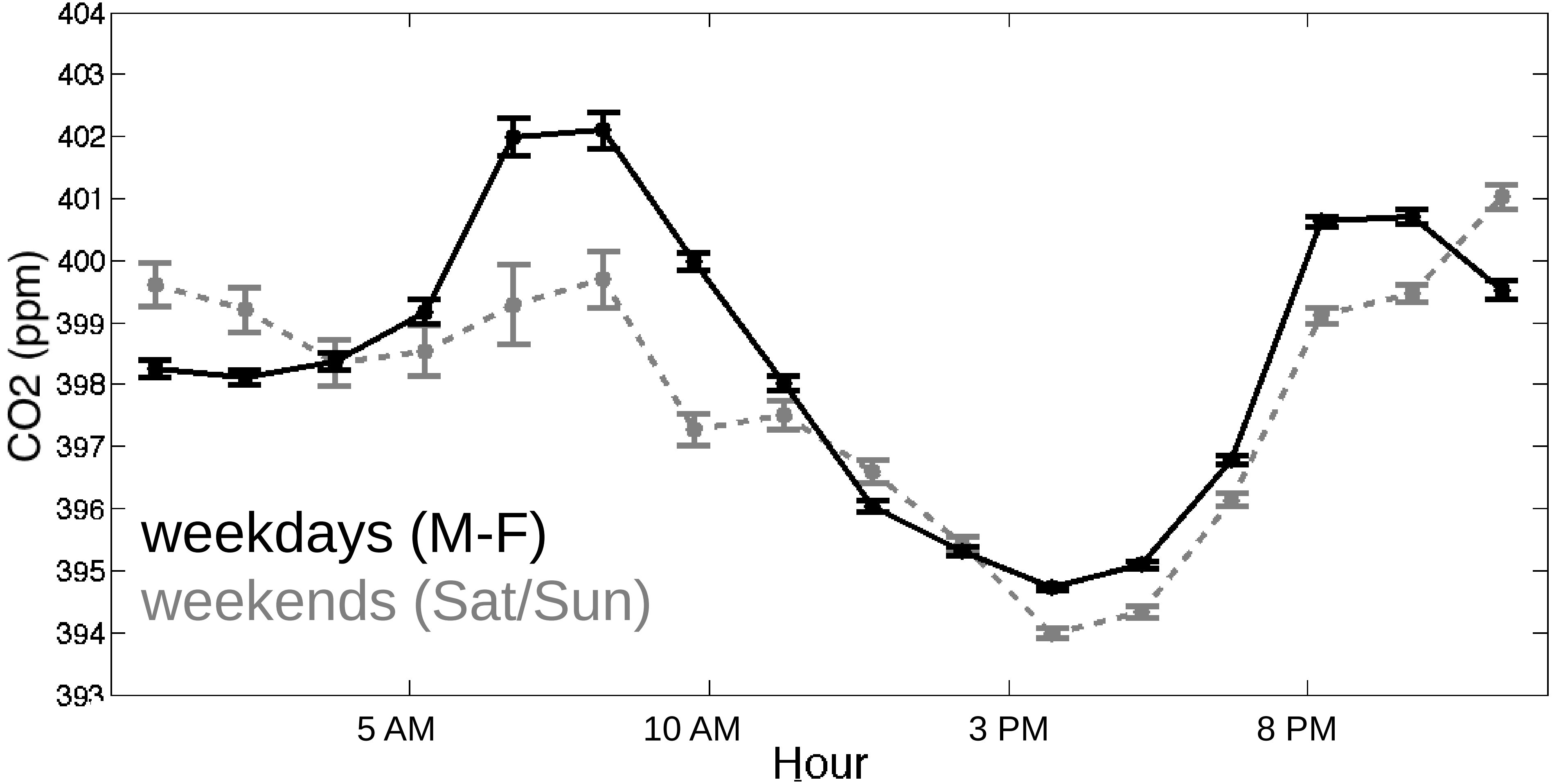


Bay Bridge Closure Diurnal Cycle

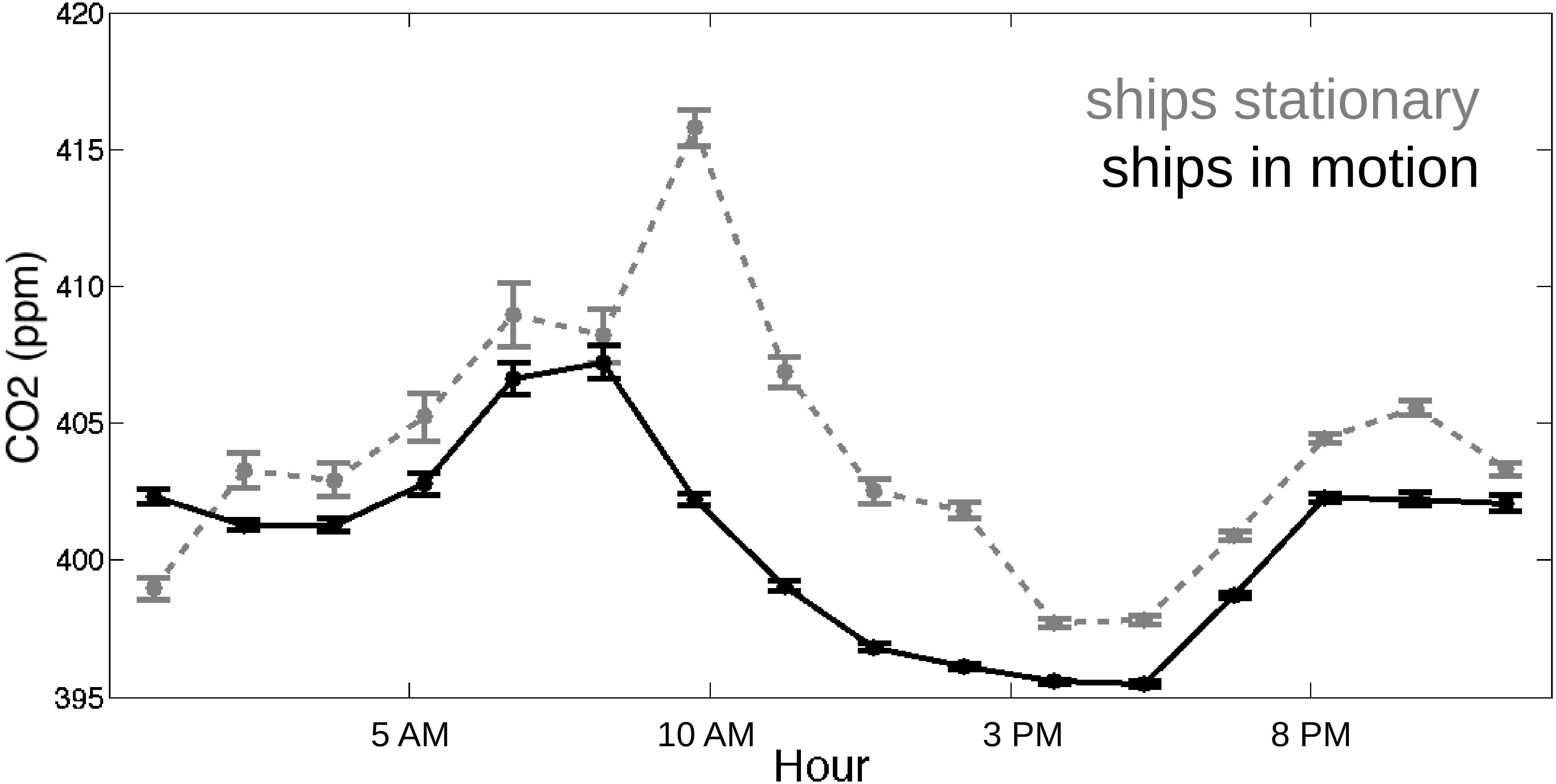



Port of Oakland
→ Affected by shipping? Or just traffic?
2km
Golden Gate
Rockridge
Emeryville
Temescal
Piedmont Avenue
Clawson
Piedmont
Montclair
Canyon
Grand Lake
West Oakland
Adams Point
Crocker Highlands
Oakmore
Joaquin Miller Park
Oakland
Glenview
Chinatown
Redwood Heights
San Antonio
Mills College
Fruitvale
Millsmont
Seminary
Alameda
Eastmont
O.co Coliseum
Oakland Zoo
East 14th Street Business District
San Leandro
Oakland International Airport
Google

Port Aug/Sept Diurnal Cycle

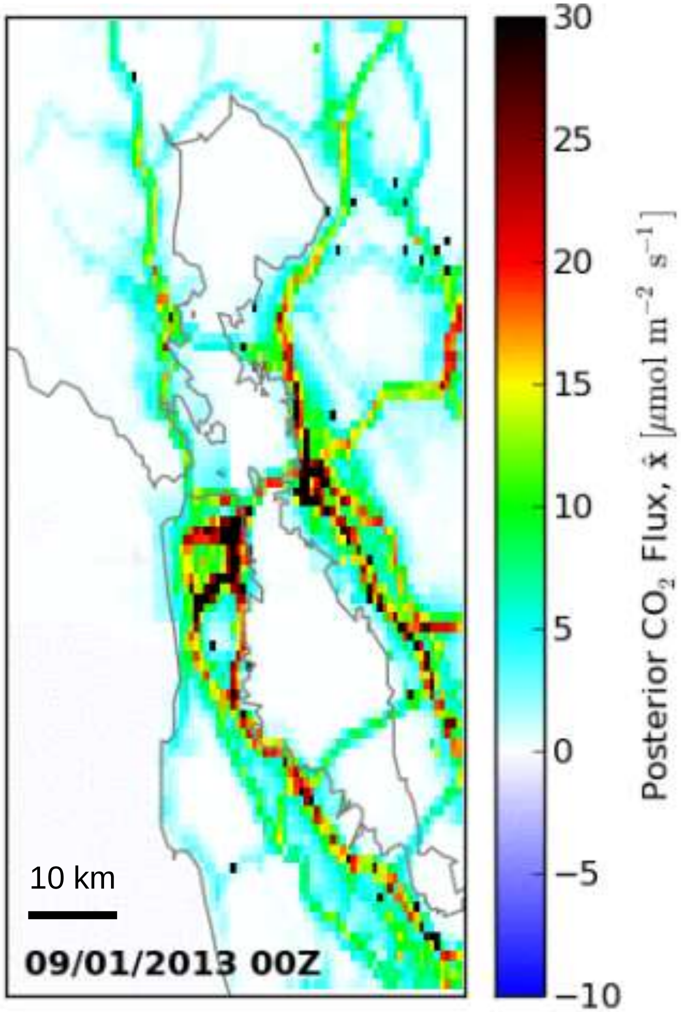


Port Diurnal Cycle by Ship Movement




☑ Sensitivity
☑ Spatial Resolution
☑ Temporal Resolution
2km
Golden Gate
Rockridge
Emeryville
Temescal
Piedmont Avenue
Piedmont
Montclair
Canyon
Clawson
Grand Lake
West Oakland
Adams Point
Crocker Highlands
Oakmore
Joaquin Miller Park
Oakland
Glenview
Chinatown
Redwood Heights
San Antonio
Alameda
Mills College
Fruitvale
Millsmont
Seminary
Eastmont
O.co Coliseum
Oakland Zoo
East 14th Street Business District
San Leandro
Oakland International Airport
Google

Interpreting the observations



c/o Alex Turner

WRF-STILT

$$Kx + \varepsilon = y$$

forward →

y = concentrations (BEACO$_2$N observations)

x = emissions

K = “footprint” mapping from x to y

ε = error

WRF-STILT

$$Kx + \varepsilon = y$$

forward →

← inverse

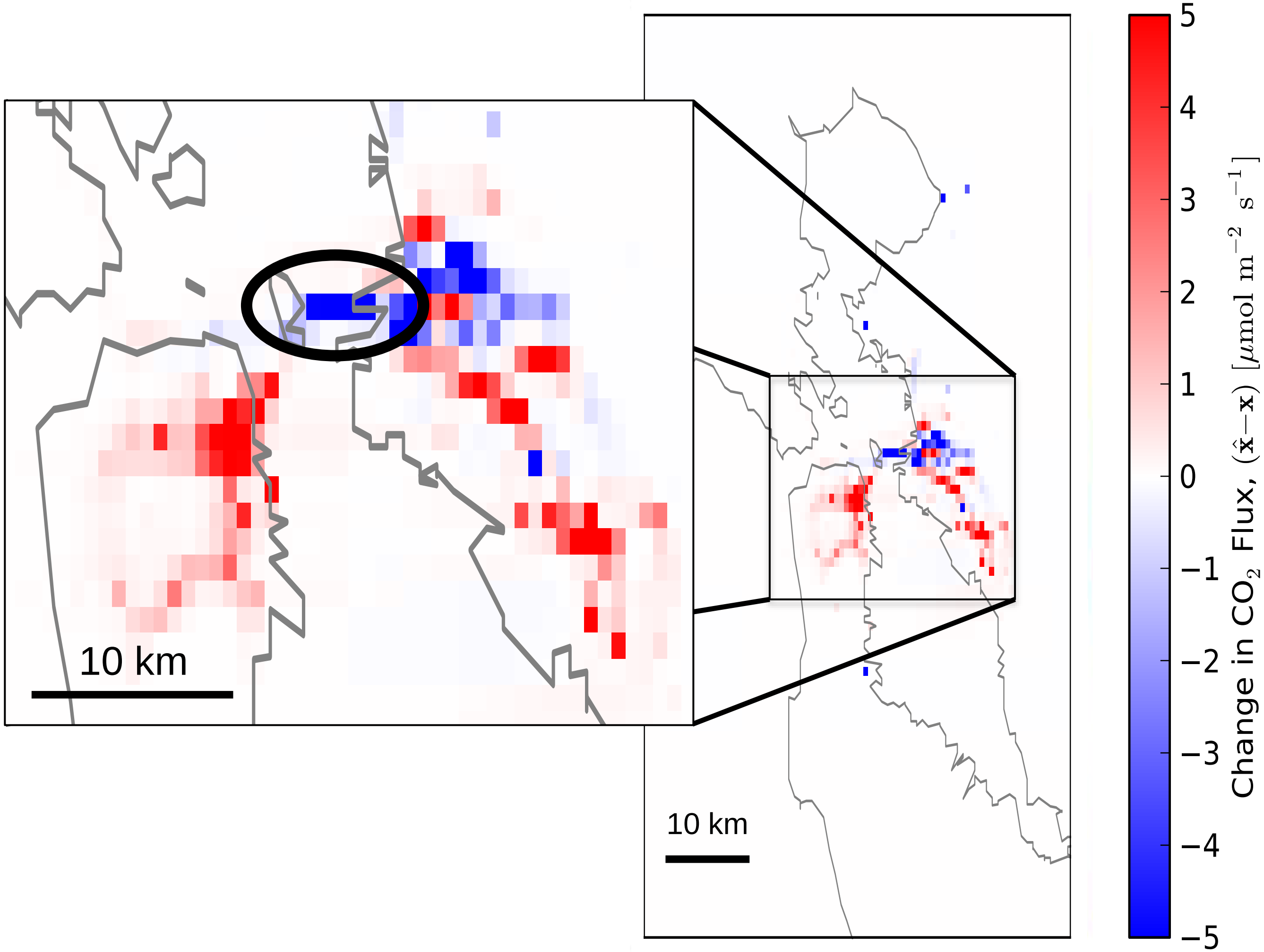
y = concentrations (BEACO$_2$N observations)

x = emissions

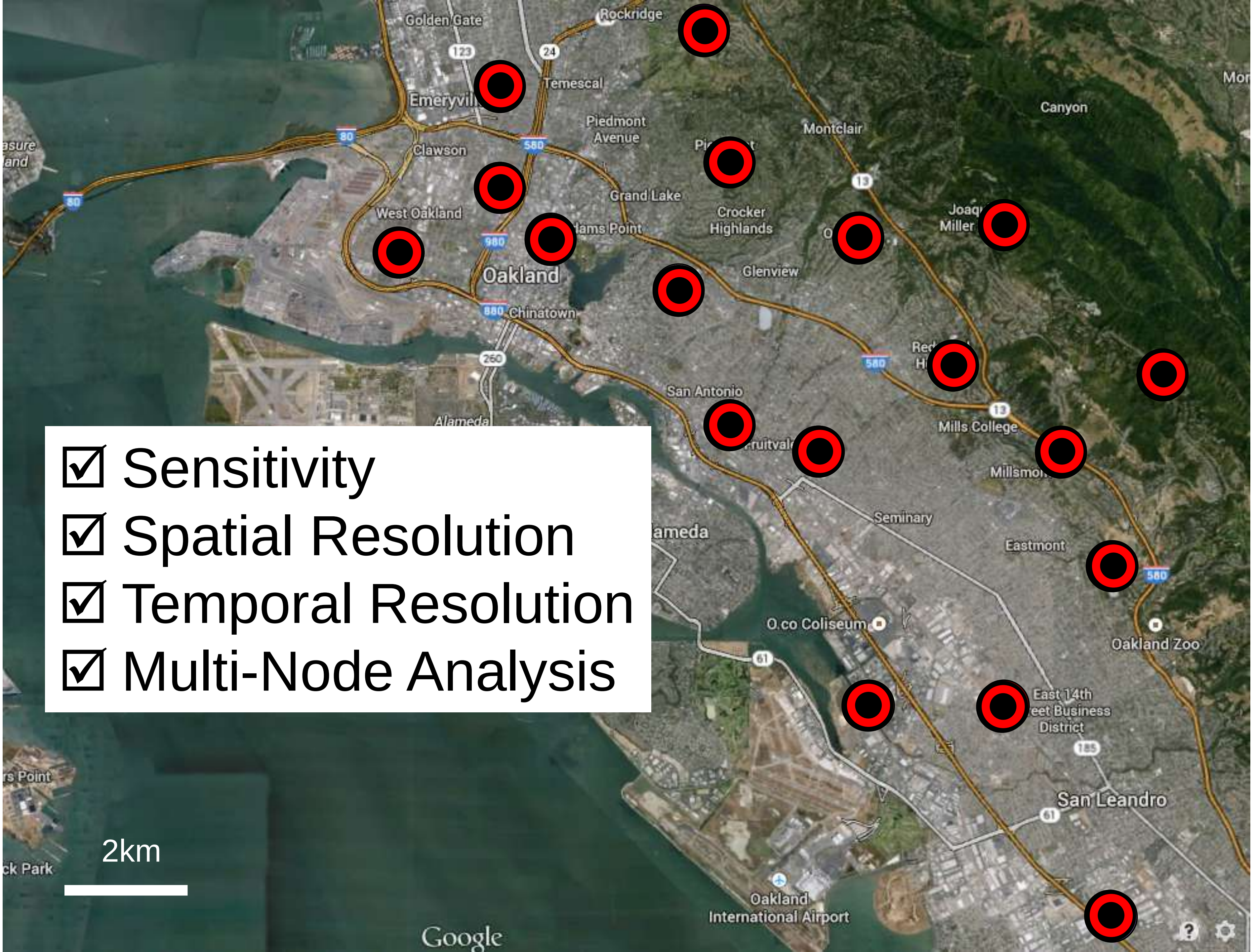
K = “footprint” mapping from x to y

ε = error

WRF-STILT for day bridge was closed

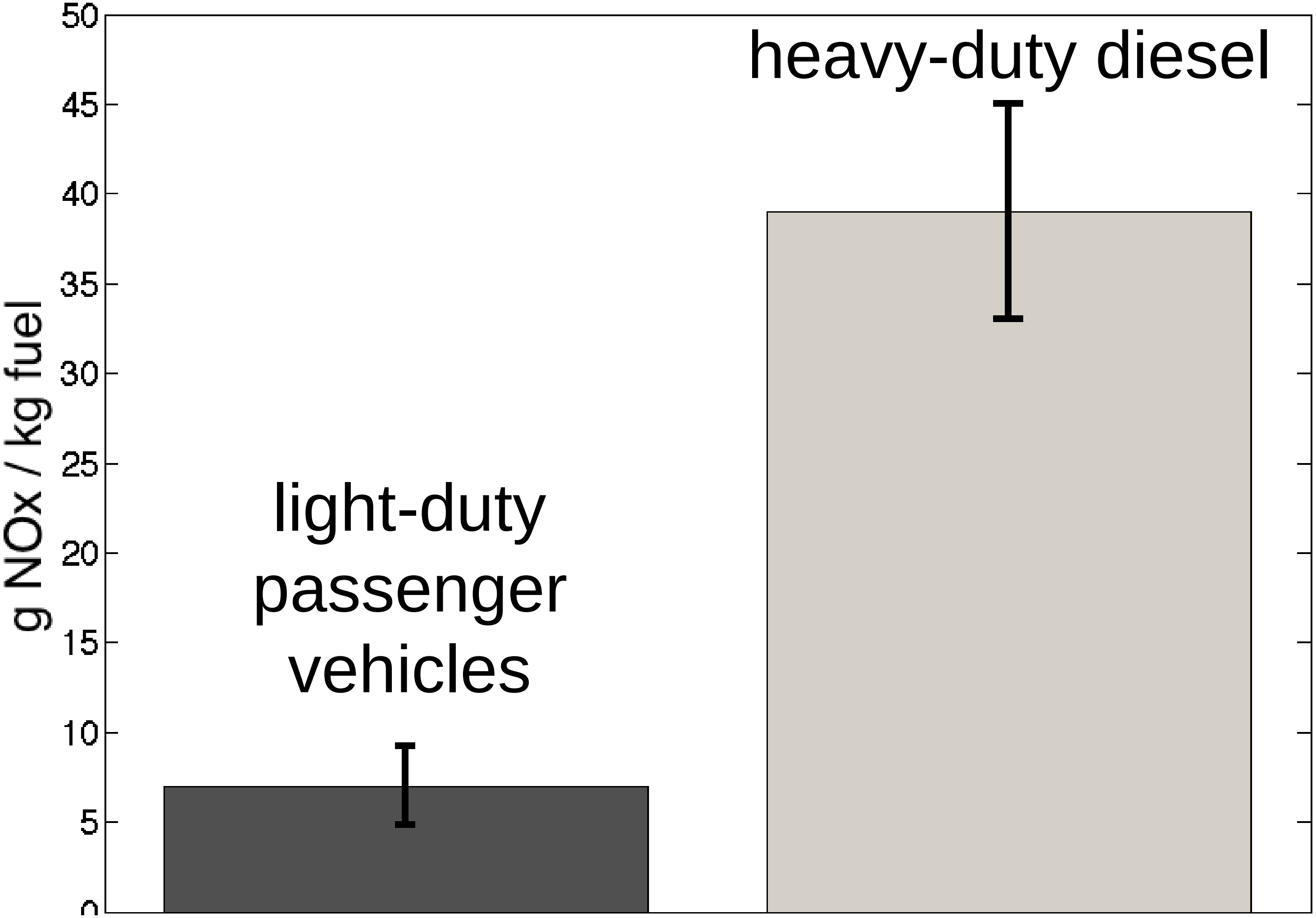


c/o Alex Turner

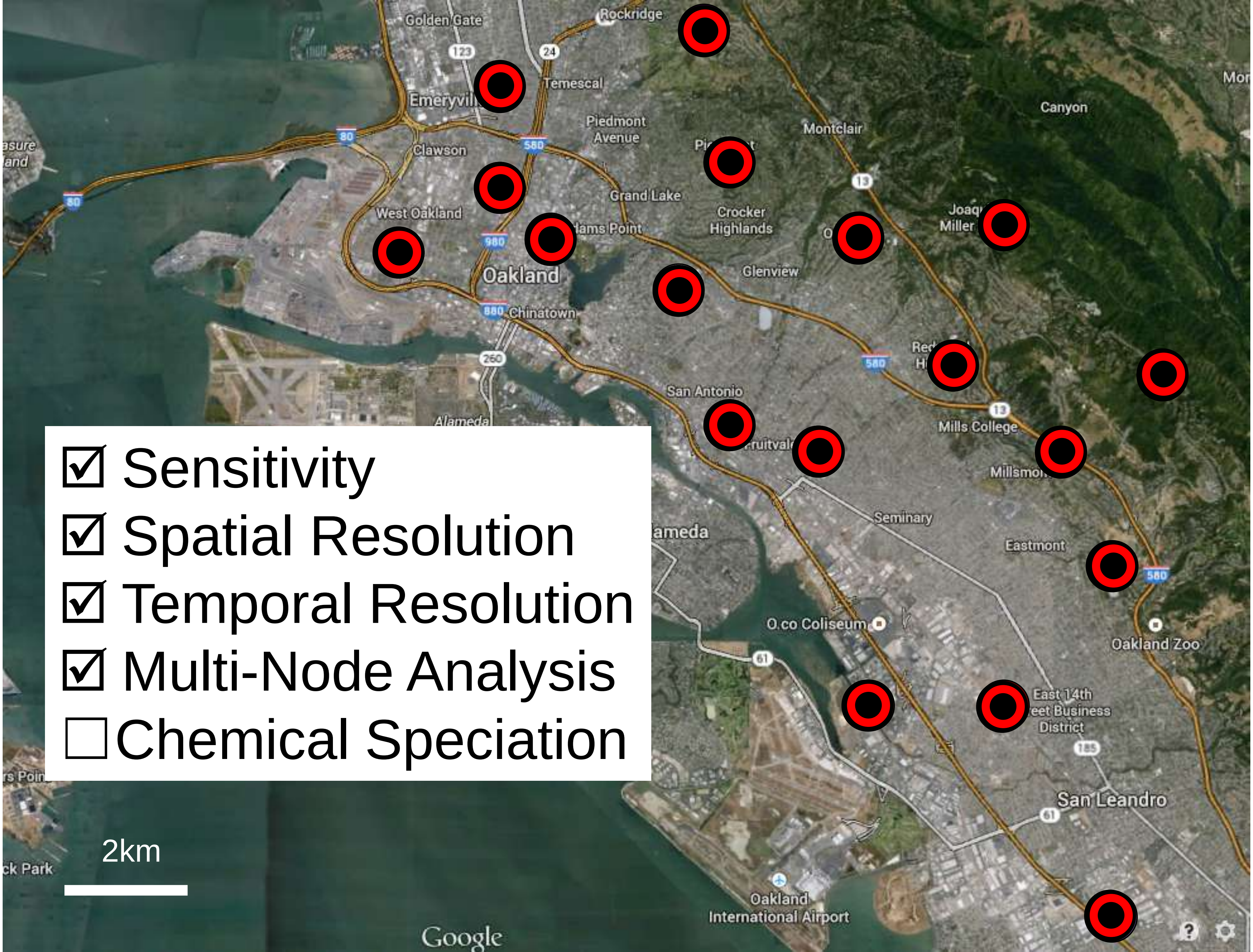


☑ Sensitivity
☑ Spatial Resolution
☑ Temporal Resolution
☑ Multi-Node Analysis
2km
Golden Gate
Rockridge
Temescal
Piedmont Avenue
Montclair
Canyon
Clawson
Grand Lake
Crocker Highlands
West Oakland
Oakland
Chinatown
Glenview
San Antonio
Mills College
Seminary
Eastmont
O.co Coliseum
Oakland Zoo
East 14th
District
San Leandro
Oakland International Airport
Google

1999-2000 Emissions Factors



Harley et al. 2005



☑ Sensitivity
☑ Spatial Resolution
☑ Temporal Resolution
☑ Multi-Node Analysis
☐ Chemical Speciation
2km
Golden Gate
Rockridge
Temescal
Emeryville
Piedmont Avenue
Montclair
Canyon
Clawson
Grand Lake
Crocker Highlands
West Oakland
Oakland
Chinatown
Glenview
San Antonio
Mills College
Seminary
Eastmont
O.co Coliseum
Oakland Zoo
East 14th
District
San Leandro
Oakland International Airport
Alameda
Google

Thank you!

Jill Teige

Alex Turner

Catherine Newman

Alexis Shusterman David Holstius

Jill Teige

Alex Turner

Catherine Newman

Thank you!

Using Data from Small Sensors to Address Air Quality Issues

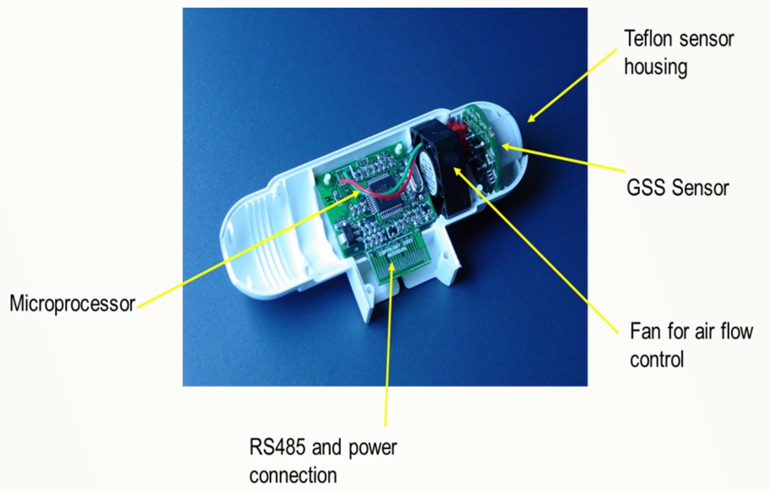
Clinton P. MacDonald, Timothy S. Dye, Briana J. Gordon, Hilary R. Hafner
Sonoma Technology, Inc., Petaluma, California

Sonoma Technology, Inc.
Environmental Science and Innovative Solutions

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



Aeroqual S500 ozone sensor.

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 $PM_{2.5}$

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 $PM_{2.5}$ 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

Strong changes in $PM_{2.5}$ concentrations associated with localized wood burning emissions in Santa Rosa, CA.

Regulatory

Representativeness of Federal Reference Method Ozone Monitors in Arvin, CA

Funding: San Joaquin Valley Air Pollution Control District (SJVAPCD)

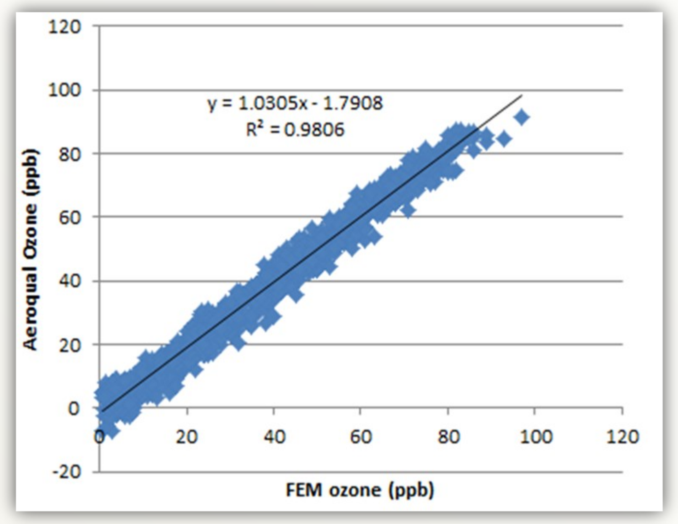
Goal: Determine whether the location of a key regulatory ozone monitor that was moved to a new site still represented peak ozone concentrations in the area

Method: Deployed 23 low-cost Aeroqual ozone sensors for six weeks

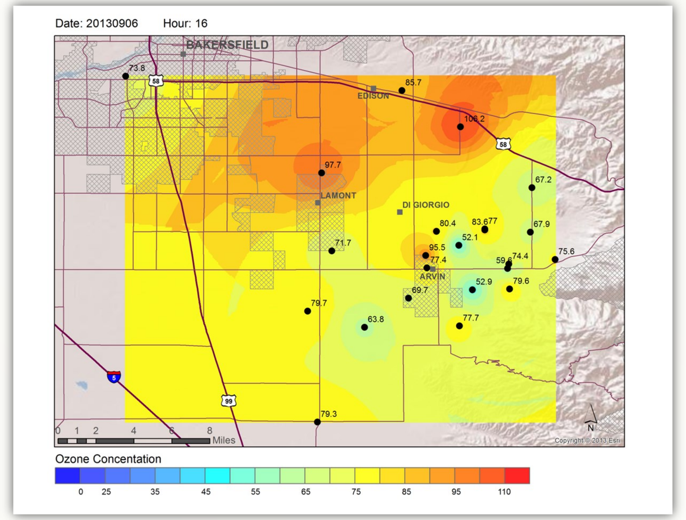
Key Findings

- 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 where 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



Excellent correlation between Aeroqual and FRM ozone monitors.



Large spatial variations in ozone concentrations measured by Aeroqual sensors around Arvin, CA.

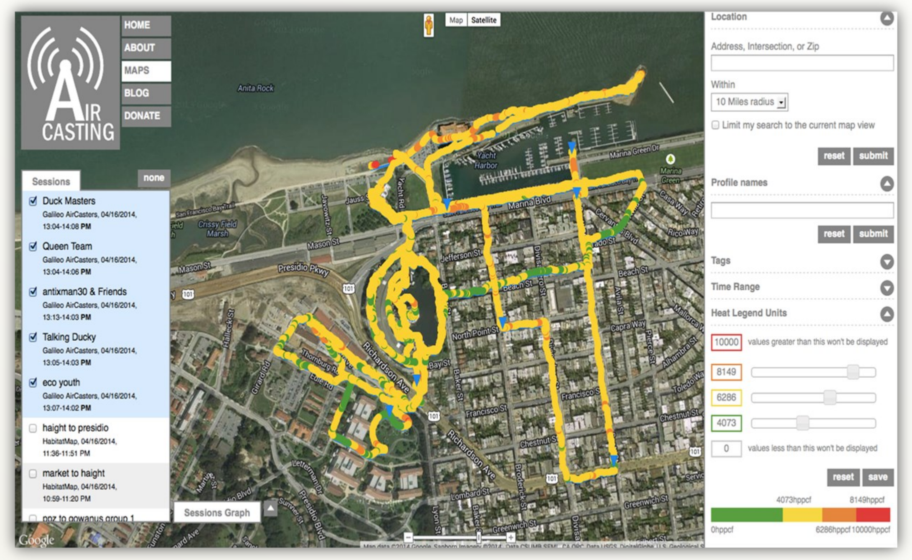
Education

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



Street-level PM concentrations measured by students in San Francisco, CA.

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

Students in Brooklyn, NY, learn about air quality.

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).