Practical and Demonstrated Uses of Low-Cost Sensors from Regulation to Education: The Rest of the Story

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for

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Approach

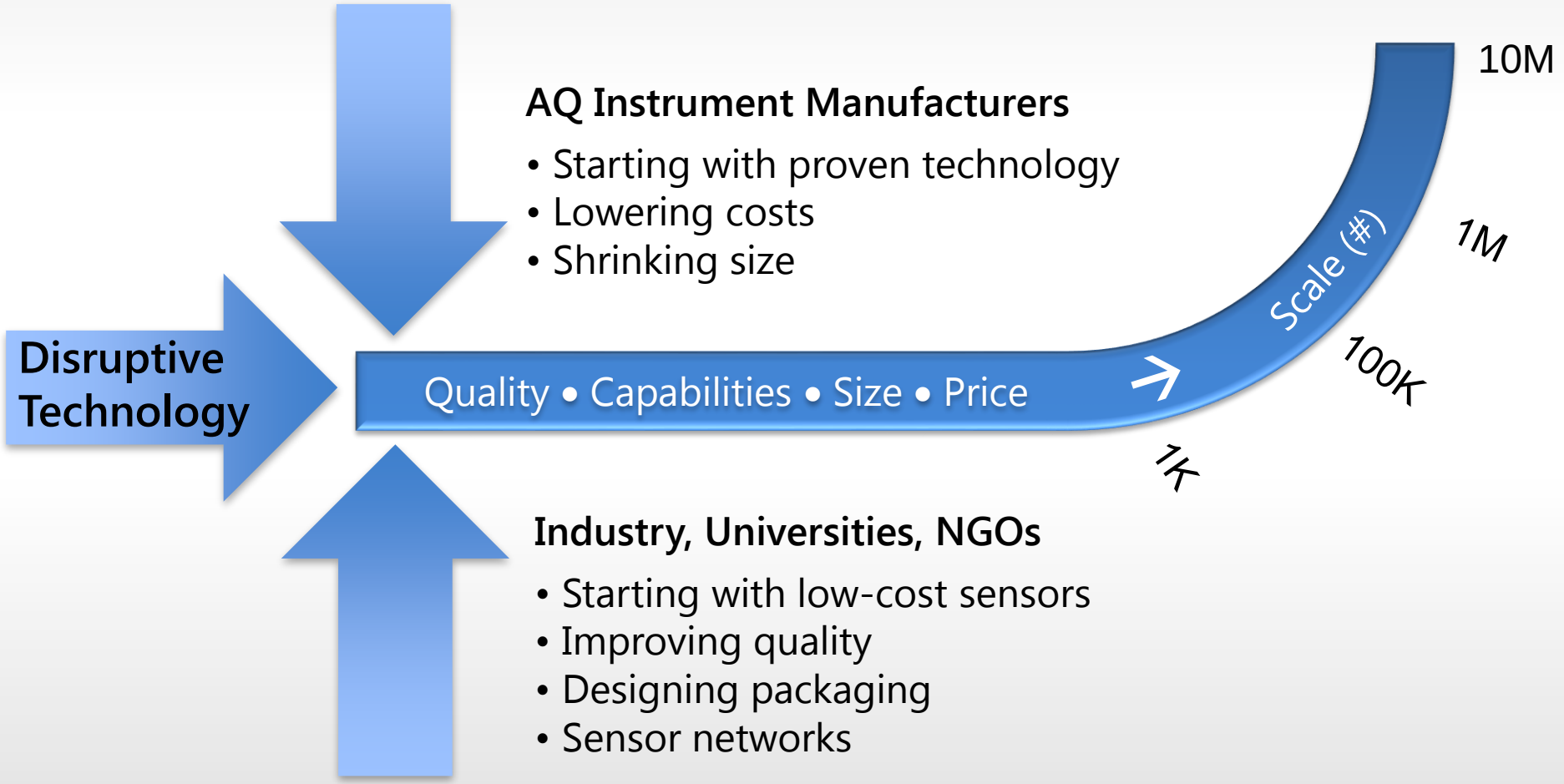
- Background
- Three examples
- Predictions

Take-home points

- Air sensors are already here
- Air sensors can be used for many applications
- Air sensor cost can be misleading

Low Cost Drives Innovation

What's Happening



Why This Is Happening

Drivers

- Microprocessors – cheaper
- Internet – everywhere
- Sensors – cost decreasing
- Online communities – growing
- Personalized health – rapidly increasing

Such Promise!

"What if every mobile device had an air quality sensor?"
CommonSense

"50 billion devices will be connected to the Internet by 2020."
Cisco

"Air sensors can lead to better protection of public health and the environment…."
EPA Roadmap for Next Generation Air Monitoring

"I think [air sensing] is going to have a big impact in the future."
Charles Elkan, Computer Science professor at UC San Diego

"The Internet of things will augment your brain."
Eric Schmidt, Google

A Reality Check

- Low cost – kind of
- Small – yes
- Sufficient quality – that depends
- Lot of devices – many sizes, shapes, costs, etc.
- Useful – depends
- Promise to change the world – I think so

Many Components Enable Air Sensing

Sensor or Instrument Component	Sensor Cost Relative to Traditional Instruments
Sensing device	Cheaper
Microprocessor	Cheaper
Power	Same
Communications	Same
Shelter	Cheaper
Quality Assurance	More expensive
Data Processing Software	More expensive
Quality Control	More expensive
Data Interpretation	More challenging

Three Studies Using Air Sensors

1. Ozone Gradient Study

2. Heathrow Airport Sensor Network

3. Kids Making Sense

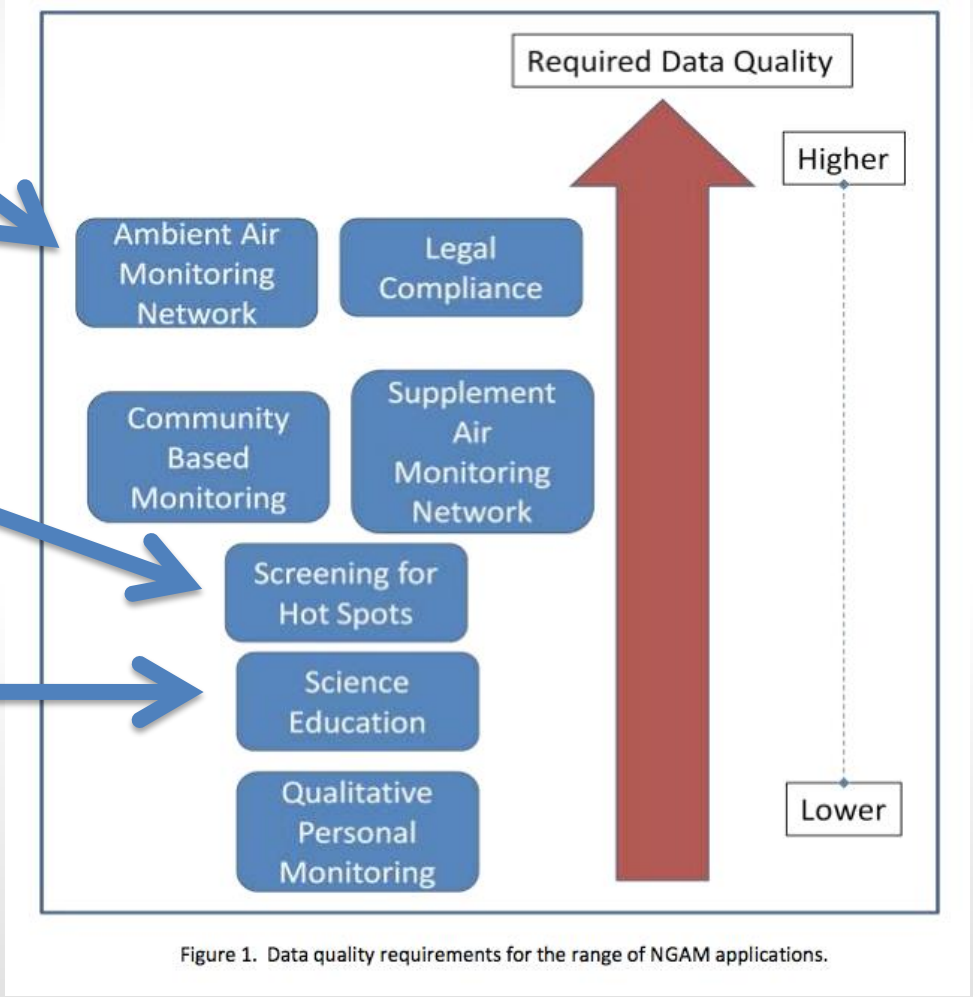


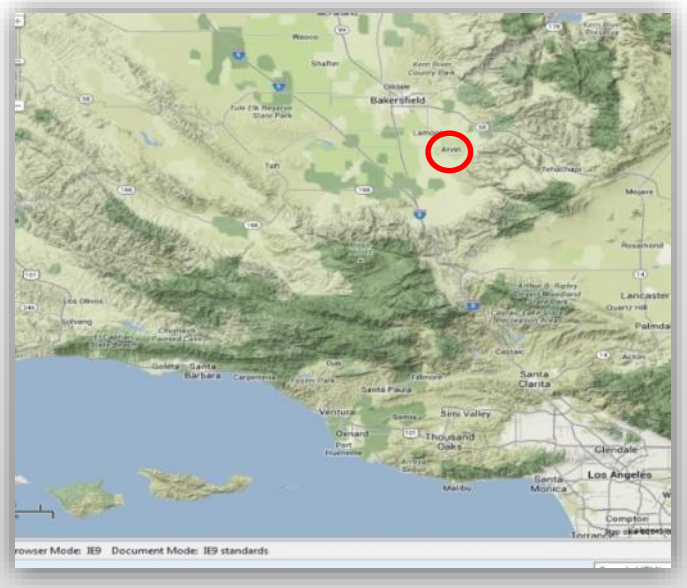
Figure 1. Data quality requirements for the range of NGAM applications.

http://www.epa.gov/research/airscience/docs/roadmap-20130308.pdf

Ozone Gradient Study Background

- Objective – Examine ozone gradients around new monitoring site
- Sponsored by San Joaquin Valley Unified Air Pollution Control District
- Six weeks, late summer 2013

New site showed ozone concentrations that were about 10% lower than those at the old site. This issue raised concerns in the community, and the U.S. EPA has indicated that the differences may hinder EPA's ability to determine whether the region has reached attainment.

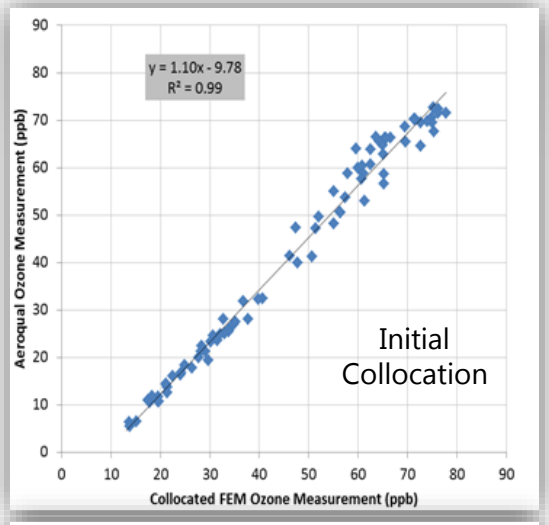


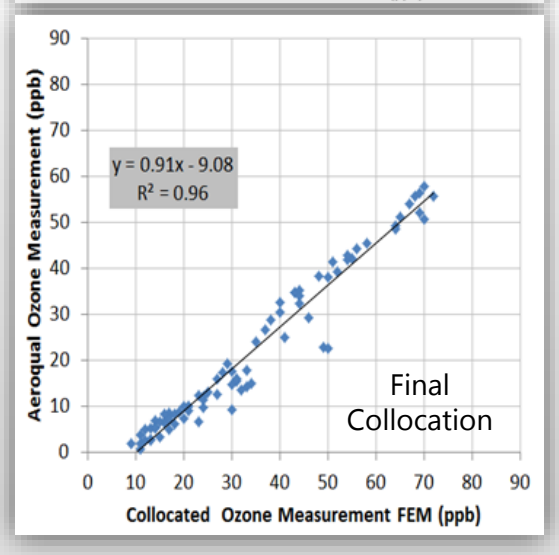
Air Sensor Usage

Components

- 21 sites (18 sensors; 3 collocated with Federal Equivalent Method [FEM] monitors)
- Sub-hourly ozone data using low-cost, low-power, portable Aeroqual S500 sensors
- Collocation study at beginning and end to calibrate sensors against an FEM monitor
- Quality control and data analysis

Extensive QA Program



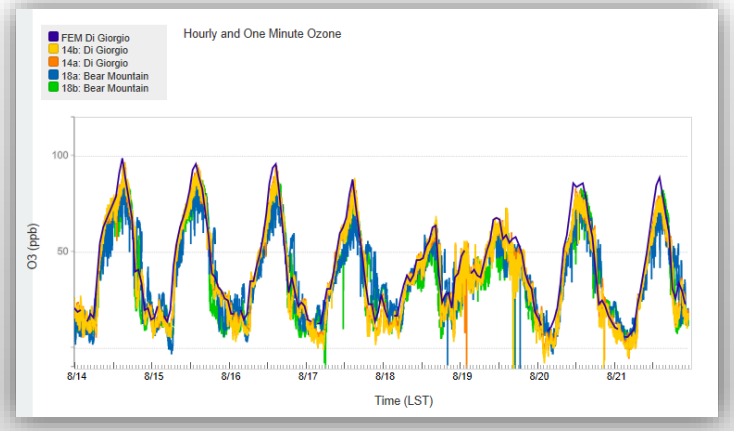


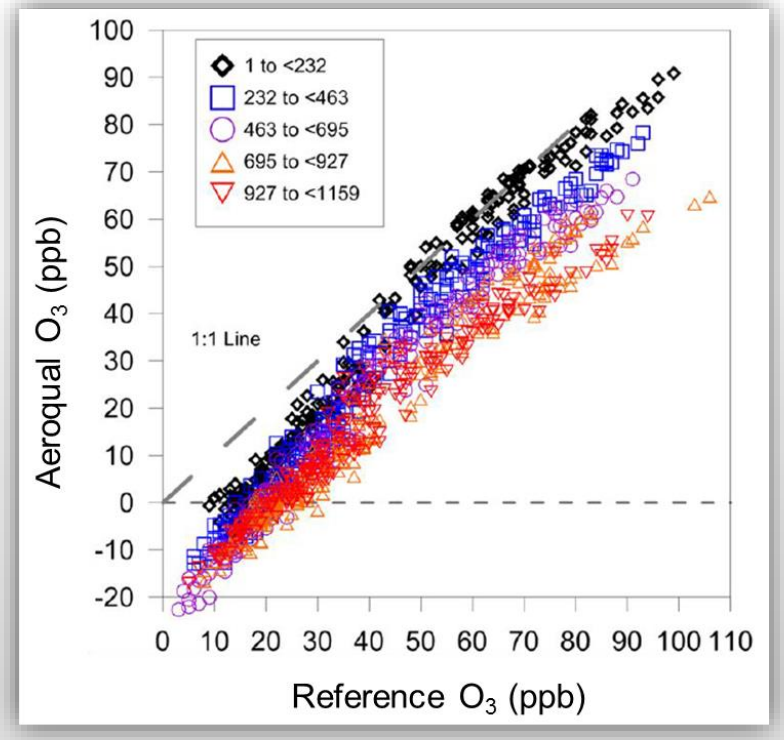
Results

- The accuracy of the 1-hr measurements is about 3 ppb
- The precision is ±4% at the 95% confidence level
- Data meet data accuracy requirements for understanding spatial gradients
- New site is representative of old site
- Analysis used by air agency in their Attainment Determination Request to EPA

Lessons Learned

- Sensor systems needed additional integration/testing
- Drift was an issue
- Unknown interferences
- Required substantial QA program





Heathrow Airport Study Background

- Objectives
  - Evaluate sensor network deployment approaches
  - Calculate emission factors
  - Evaluate dispersion modeling
- One year of monitoring (completed)
- Research in progress
- Funded by the National Environment Research Council and the Engineering and Physical Sciences Research Council

Air Sensor Usage

- 50 sensor nodes
- Measured NO, NO_2, CO, CO_2, SO_2, O_3, VOCs, PM
- Transmitted data every 20 sec

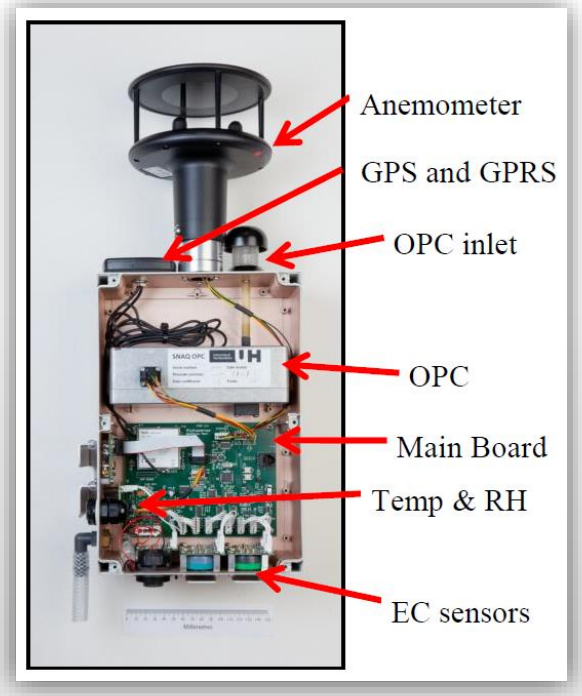
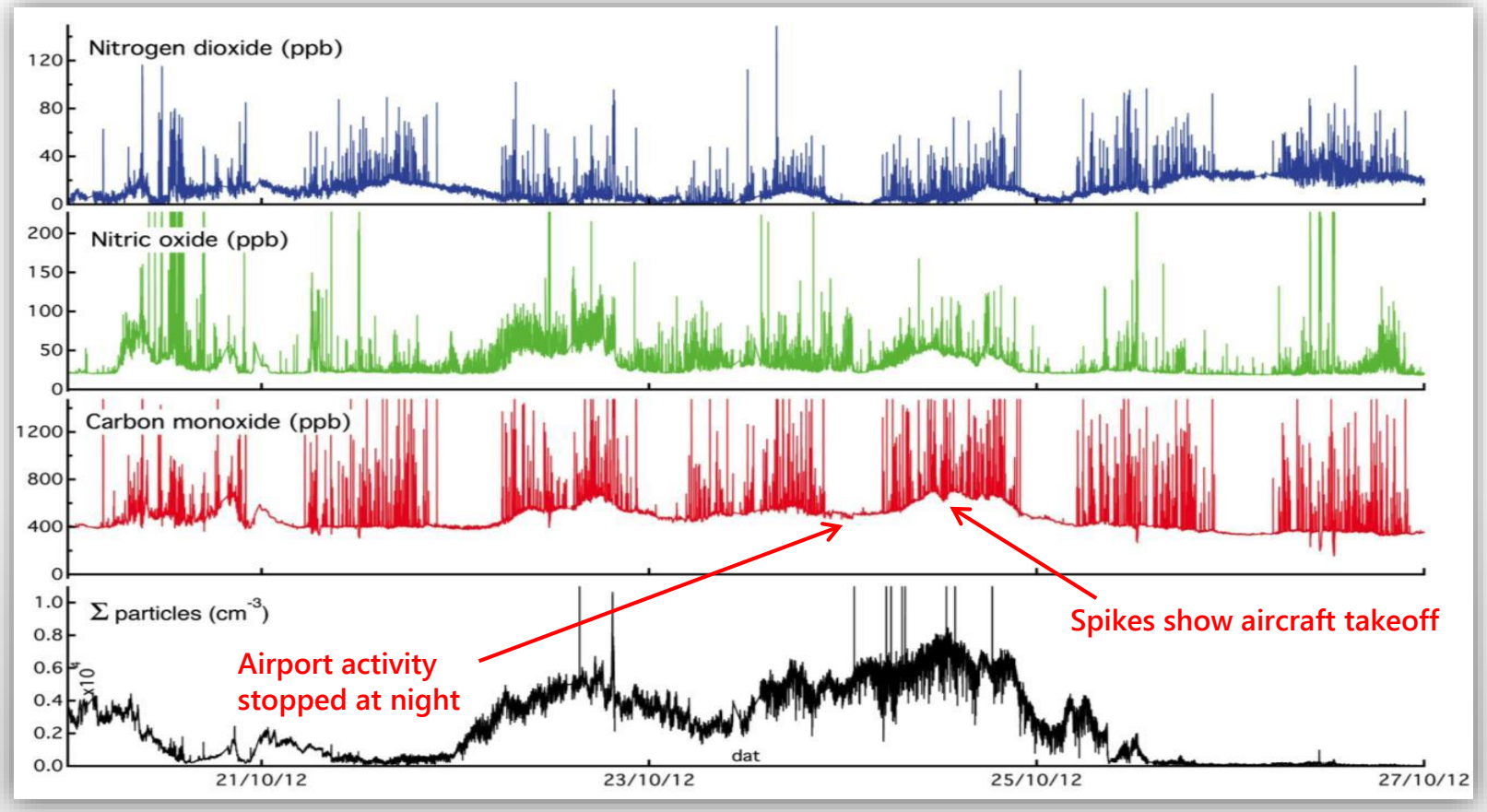


Figure source: Popoola et al. (2013) A portable low-cost high-density sensor network for air quality at London Heathrow Airport. Poster presented at the EGU General Assembly, 7-12 April 2013, Vienna, Austria.

Results

Time-Series Plot of Data from One Sensor Node at Heathrow Airport



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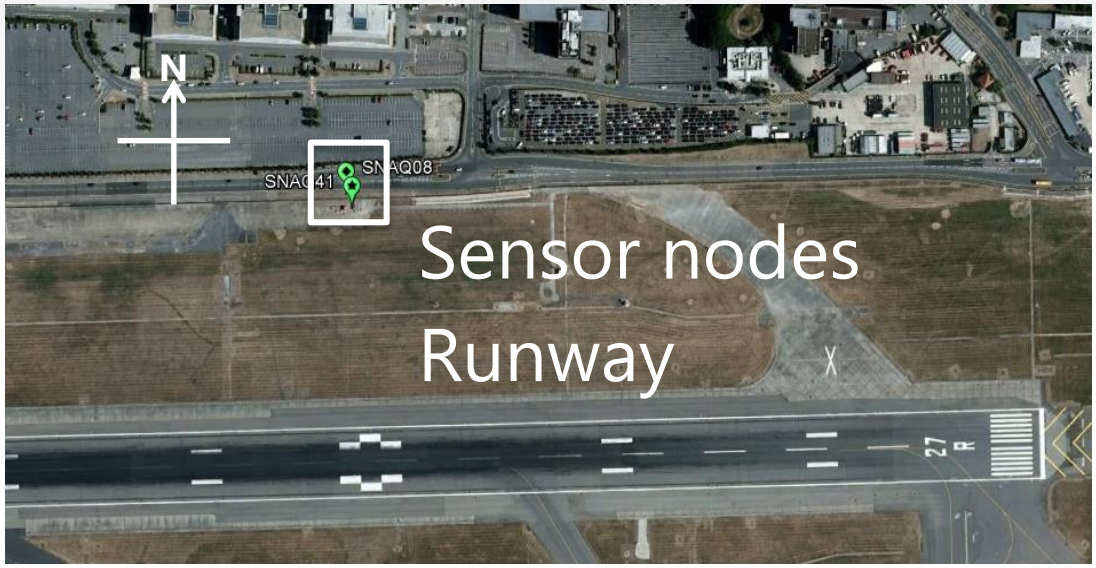
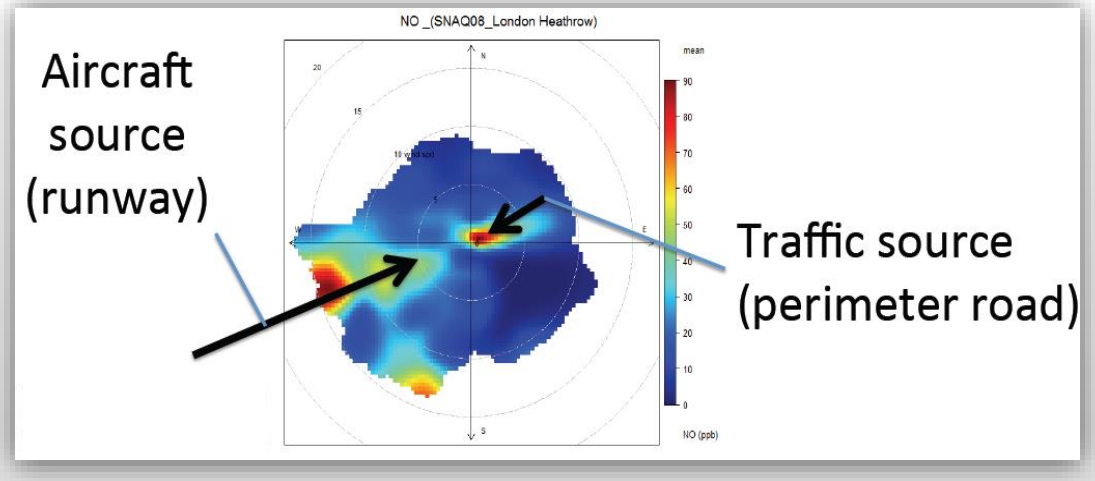




Pollution rose showing NO concentrations (color scale), wind speed, and wind direction from a sensor node at Heathrow Airport.

UNIVERSITY OF CAMBRIDGE

Kids Making Sense - Background

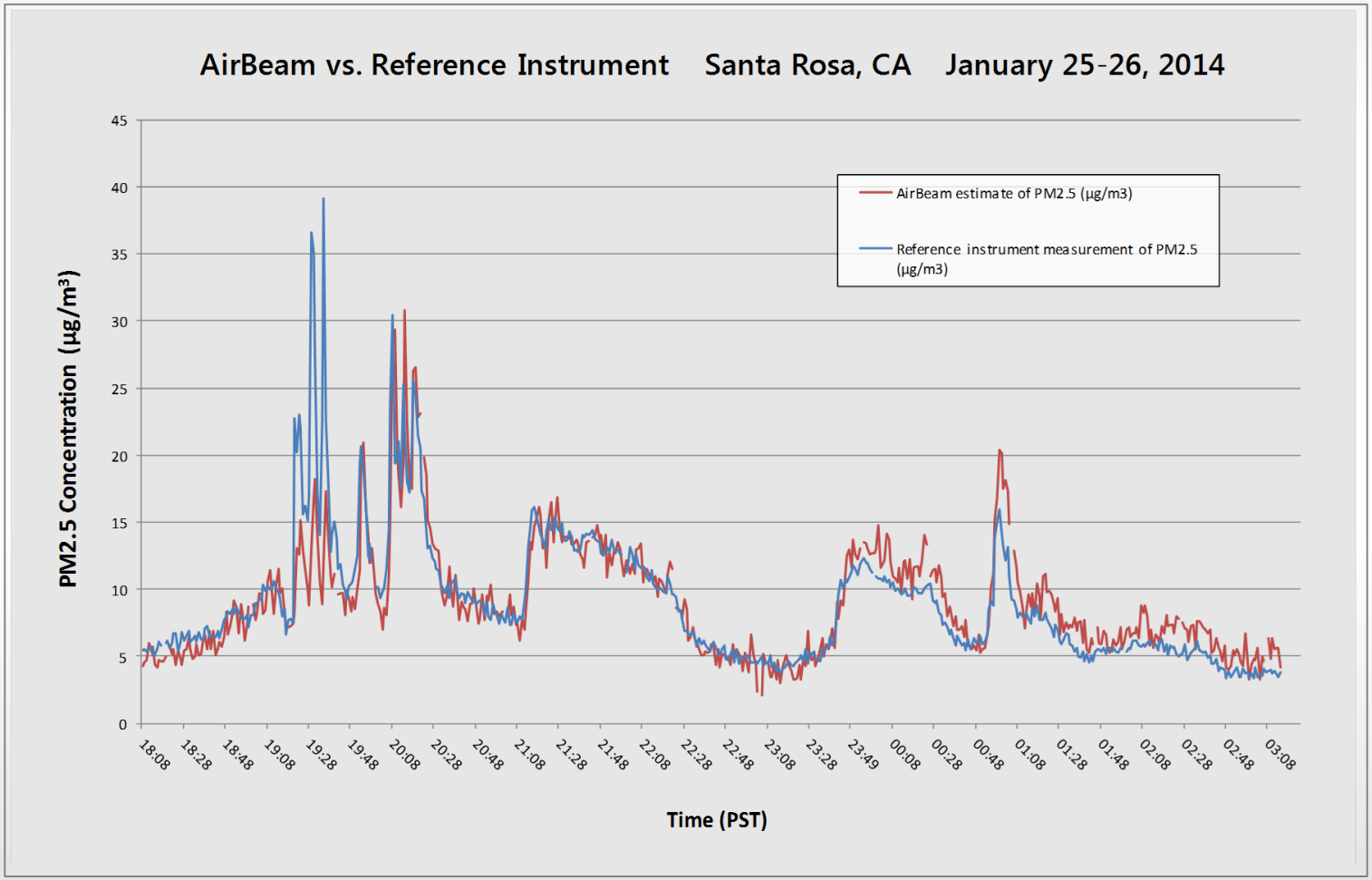
Kids Making Sense (KMS) aims to teach youth how to measure particle pollution using air quality sensors and to interpret the data they collect. Pilot workshops in Brooklyn, San Francisco, Washington DC, and Los Angeles.

http://www.sonomatech.com/project.cfm?uprojectid=1203

Background

- Kids Making Sense concept
  - Use sensor measurements to “Make Sense” of air quality
  - Have students “Make Air Sensors”
- Funded by Knight News Foundation and Taiwan EPA (STI and HabitatMap)
- Engage students with their environment
  - Train teachers, engage students to build air quality sensors
  - Deploy sensors, collect data, interpret and share results, identify causes of local air pollution
  - Create civic action to protect public health

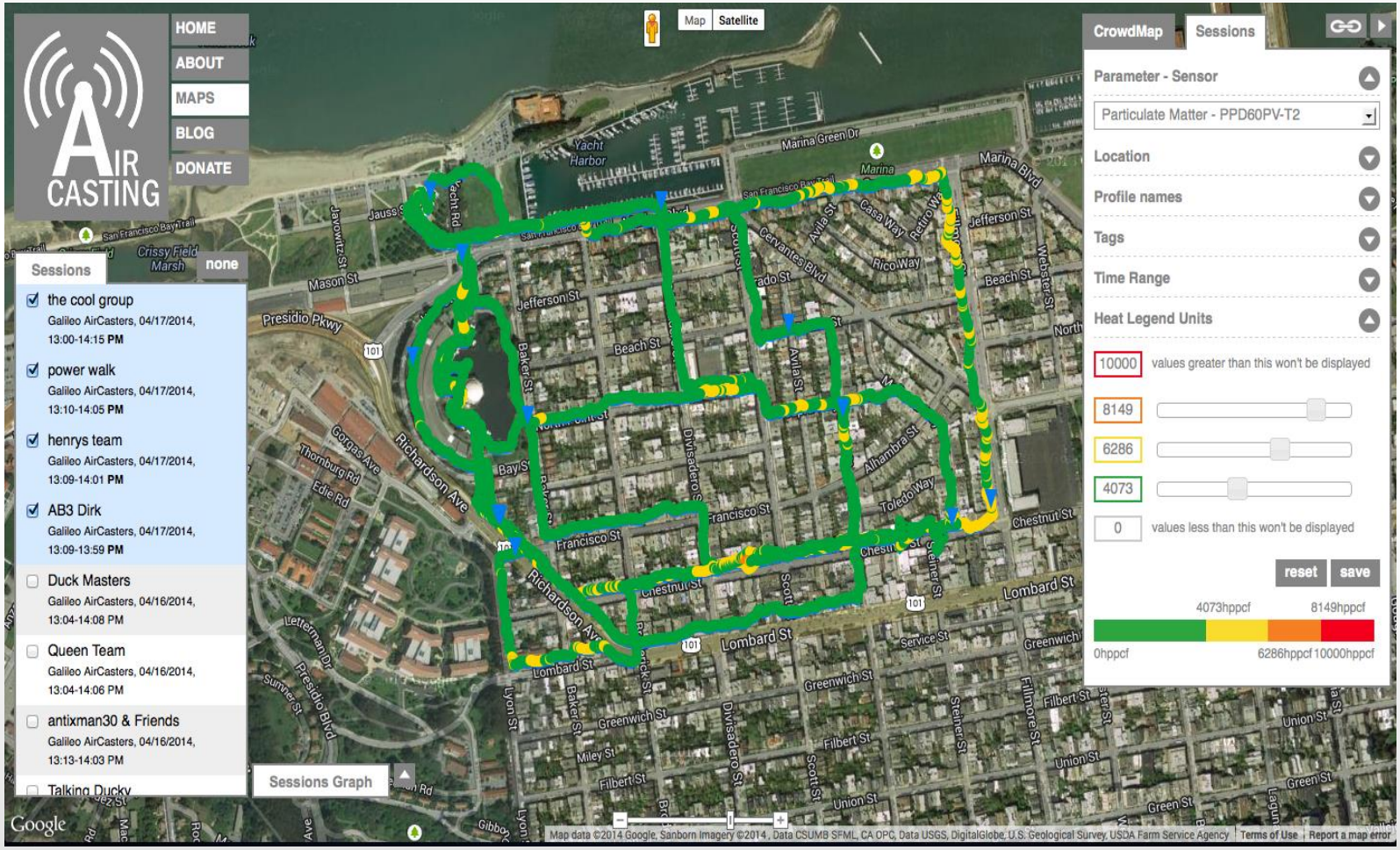
Results


AirBeam vs. Reference Instrument Santa Rosa, CA January 25-26, 2014
PM2.5 Concentration (µg/m³)
45
40
35
30
25
20
15
10
5
0
AirBeam estimate of PM2.5 (µg/m3)
Reference instrument measurement of PM2.5 (µg/m3)
18:08
18:28
18:48
19:08
19:28
19:48
20:08
20:28
20:48
21:08
21:28
21:48
22:08
22:28
22:48
23:08
23:28
23:49
00:08
00:28
00:48
01:08
01:28
01:48
02:08
02:28
02:48
03:08
Time (PST)

Results

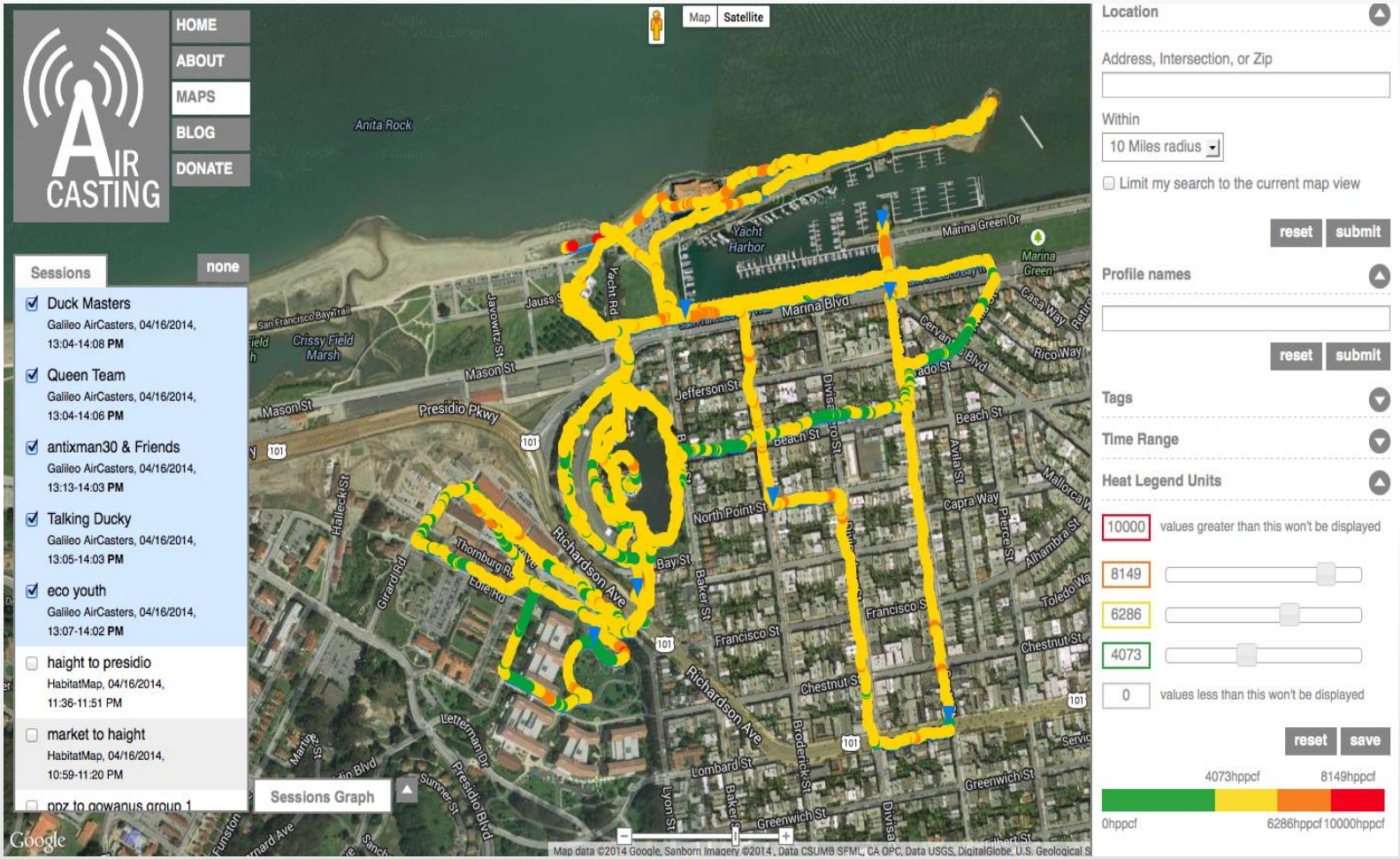

Planned Service Changes
Weekdays
Weekends
March 10 to 14
March 7 to 10
Bus Time
Every bus,
in every borough,
in real time.

Class Field Exercise 4/17/14



units = hundreds of particles per cubic foot

Class Field Exercise 4/18/14



Lessons Learned

- All engaged – youth and teachers
- Real-time feedback maintained participants' attention
- More devices would foster more individual learning
- Components need updating
  - Curriculum and teaching aids
  - Website software

Future of Air Sensing

Metric	Now
Pollutants	Ozone, CO, NO_2, PM
# of devices	1000s
Users	Researchers, communities
Companies	Startups, instrument developers
Quality	Variable
Price	$300-$2500

Future of Air Sensing

Metric	Now	2 Years
Pollutants	Ozone, CO, NO_2, PM	$PM_{2.5}$
# of devices	1000s	1 million +
Users	Researchers, communities	AQ agencies, industry
Companies	Startups, instrument developers	Large tech companies
Quality	Variable	Improving
Price	$300-$2500	$50-$100

Future of Air Sensing

Metric	Now	2 Years	5 Years
Pollutants	Ozone, CO, NO_2, PM	$PM_{2.5}$	Benzene, BC, some toxics
# of devices	1000s	1 million +	10 million +
Users	Researchers, communities	AQ agencies, industry	Cities, individuals
Companies	Startups, instrument developers	Large tech companies	"Phone" manufacturers
Quality	Variable	Improving	Very good
Price	$300-$2500	$50-$100	<$50

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