Air Sensors & Advanced Monitoring Technologies

NACAA Communicating Air Quality Conference
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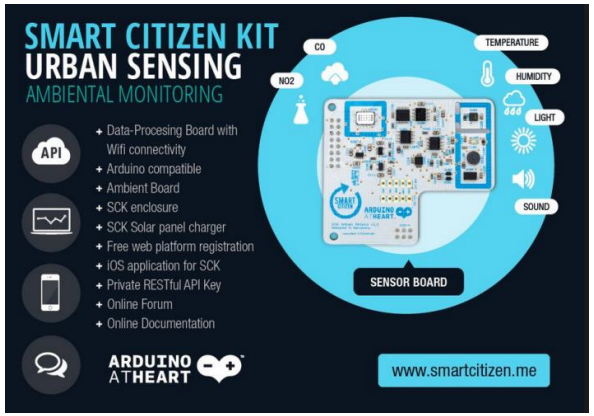
South Coast Air Quality Management District

Low-Cost Air Quality Sensors

- Rapidly proliferating
- Tremendous potential
  - Low cost
  - Ease of use
- Multiple potential applications
  - Spatial/Temporal air quality info
  - Fence-line applications
  - Regulatory/Academic/Citizen's science
- How reliable/accurate are they????
- Critical need to systematically evaluate their performance

EPA Village Green Project



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AQ-SPEC - Background

- Established in July 2014
  - Over $600,000 investment
- Main Goals & Objectives
  - Provide guidance & clarity for ever-evolving sensor technology & data interpretation
  - Catalyze successful evolution/use of sensor technology
  - Minimize confusion
- Sensor Selection Criteria
  - Commercially available
    - Optical
    - Electrochemical
    - Metal oxide
  - Real- or near-real time
  - Criteria pollutants & air toxics

AQMesh

CairClip

Shinyei

Dylos (prototype)

DC1100 Pro

SmartCitizens

AQ-SPEC - Overview

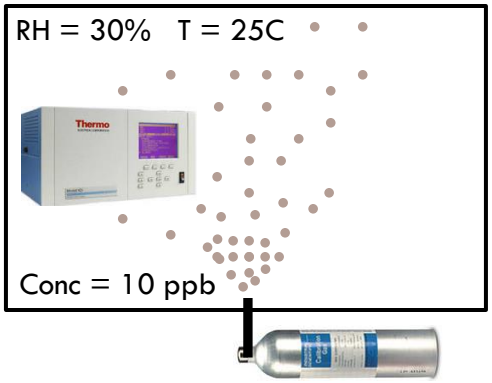
FIELD TESTING

(Side-by-side comparison w/ FRMs)

VS

LAB TESTING

(Controlled conditions)

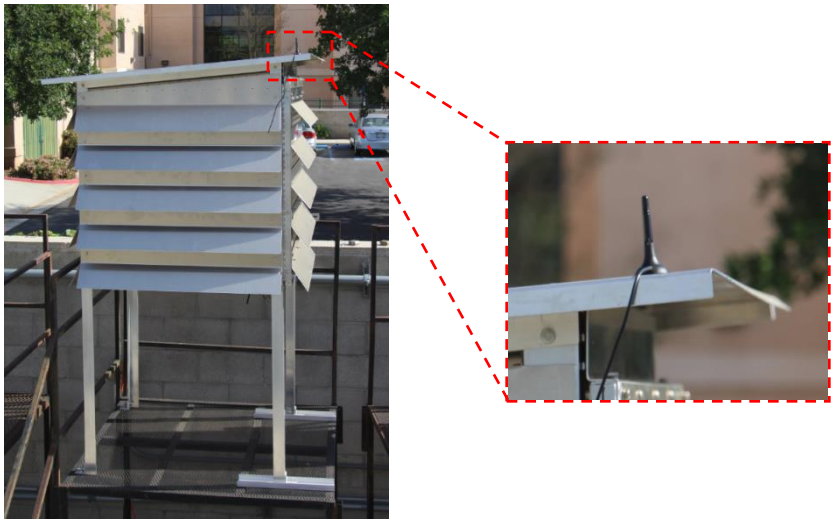


RESULTS

(Categorize sensors based on performance)

AQ-SPEC Field Testing

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



AQ-SPEC Field Testing

Sensors	Pollutant Measured	Approximate Cost
AeroQual Ozone S500	O3	$600
RTI MicroPEM	PM2.5 (real-time & integrated)	$2,000
Shinyei PM Sensor	PM 2.5	$1,000
MetOne Community Monitor	PM	$1,900
MetOne E-Sampler	PM	NA
Speck (CMU) Airviz, Inc	PM2.5	$200
Air Quality Egg	PM, CO, NO2	$300
Alphasense B4 NO2 (Alphasense ISB)	NO2	$90
Alphasense B4 NO2 with E-chem 328 board	NO2	$90
Alphasense B4 Ozone (Alphasense ISB)	Ozone	$90
Alphasense B4 Ozone with E-chem 328 board	Ozone	$90
Landtec AQ Mesh (V1)	NO, NO2 and O3, CO, and SO2	10,000
Landtec AQ Mesh (V2)	NO, NO2 and O3, CO, and SO2	10,000
Alphasense OPC	PM fractions	$450
Dylos DC1100/DC1700	Particle count	$300
Smart Citizen	NO, NO2, CO, RH, T	$175
AirBeam PM monitor	PM2.5	$200
SDL307 mini laser	PM10, PM2.5	$150
Sensaris Eco PM	PM2.5, VOC, T, RH	NA
Unitec Sense-it	CO, NO2, O3	2,000 Euros
Yoctopuce VOC	VOC	$230
Cube	T, RH, CO2, VOC	$125
Alphasense B4	O3, CO, CO2, H2S, SO2, NO, NO2, VOC	$90/each (~$450 for VOC)
China Way PM2.5 PC	PM2.5	$700
2B OEM	O3	5,000
Grove Dust Sensor	PM (PM2.5?)	$16
Sensorcon	CO	$160
Sharp PM2.5 Sensor	PM2.5	$20
ELM (Fomerly CarairIT)	Multi-gas and PM?	NA
Libelium	Multi-gas and PM	$3,000
Spec Sensors w/ Intel Edison	Multi gas	$1,350

AQ-SPEC Lab Testing

T and RH controlled: T (0-50 ^{0}C); RH (5-95%)

Particle testing

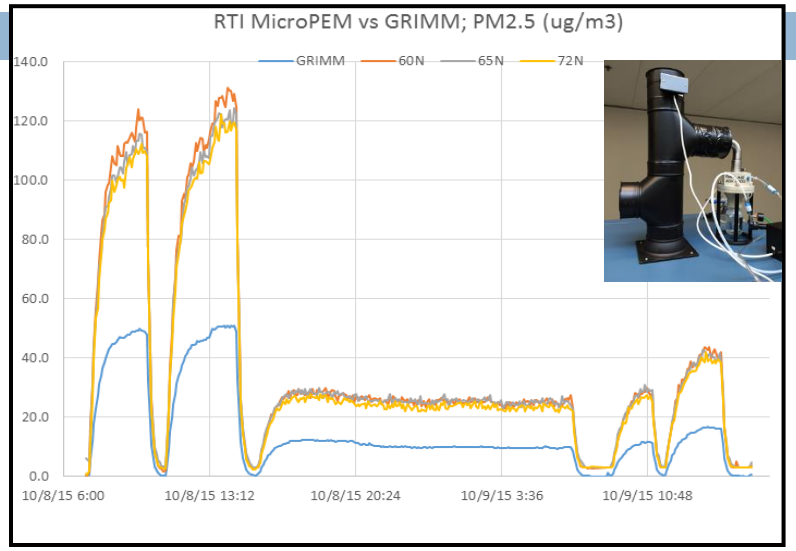
- Particle generation system
- Particle monitors: mass concentration and size distribution

Gas testing

- Gas generation / dilution system
- Gas monitors: CO, NOX, O3, SO2, H2S, CH4/NMHC

AQ-SPEC Lab Testing (continued)

T and RH controlled: T (0-50 ^{0}C); RH (5-95%)



Test for:

- Linearity of response (range)
- Accuracy & precision
- Lower detectable limit
- Concentration resolution
- Response time
- Interference equivalents
- RH and T influences
- Other

www.aqmd.gov/aq-spec

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South Coast Air Quality Management District

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

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Sensor List

Sort By | 9 products


Dylos - DC1100 PRO


Smart Citizen Kit


RTI - MicroPEM


Shinyei - PM Evaluation Kit


LANDTEC - AQMesh AQM-5


Aeroqual S-500


Dylos - DC1700


HabitatMap - AirBeam


Air Quality Egg

Sensor List

Sort By

Aeroqual S-500

Series 500 - Field Evaluation

General Description

The Aeroqual Series 500 handheld monitor can be used with a wide range of gas sensor heads. The sensor head used in this AQ-SPEC evaluation is the Ozone Ultra Low 0-0.15 ppm sensor head.

Principle of Operation

The device uses a sensitive metal oxide semiconductor that relies on the conductance of heated tungstic oxide (WO_3). In the presence of ozone, surface conductance of WO_3 decreases. Changes in the conductance are calibrated to measure ozone concentrations. During a "flow" state the sensor responds to incoming ozone the sensor conductance decreases. The ozone measurement is proportional to the sensor conductance difference between a no-flow and flow states.

Features

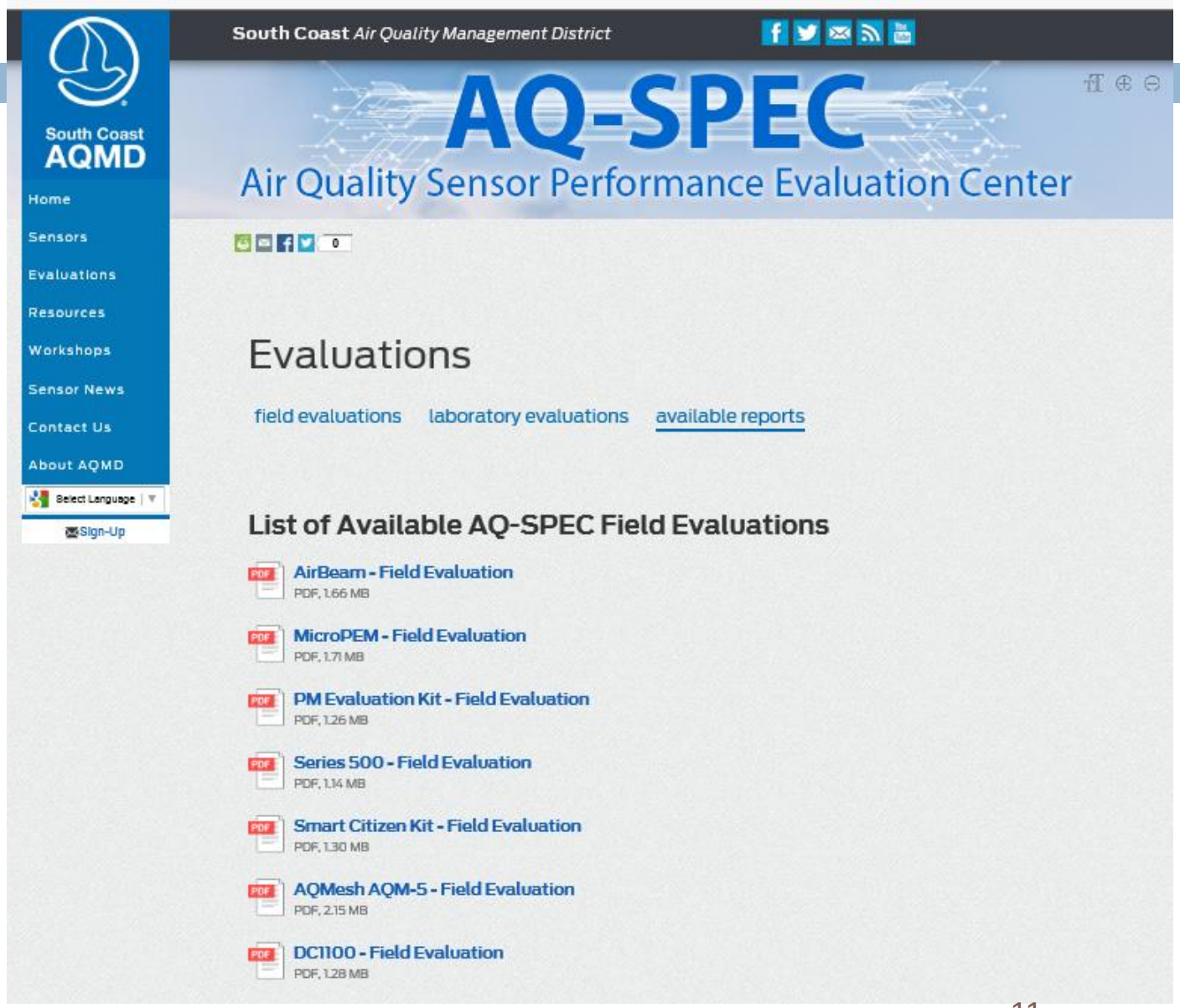
- Dimensions: 195 x 122 x 54 mm
- Weight: <460 g
- Battery: Yes (Lithium 11.1V)
- Power supply: Yes (12V DC (power adaptor/charger supplied 100-250V AC)
- Sensor lifetime: N/A
- Clock function: Yes (Real time)
- Sampling mechanism: Fan
- Environmental operating conditions: Temp: -40°C to 124°C; RH: 0 to 100%
- Internal data logging: Yes (8188 total data points)
- PC data logging: Yes (with provided Aeroqual software + cable)
- Communications: monitor to USB cable
- Weatherproof: No

Applications

- Source and leak detection
- Process control
- Health and safety monitoring
- Indoor air quality

Manufacturer's product webpage

www.aqmd.gov/aq-spec

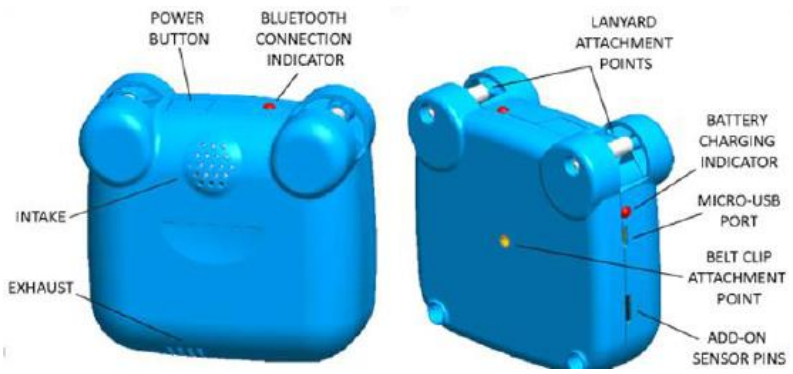


FIELD TESTING RESULTS

(Examples)

AirBeam PM Sensor

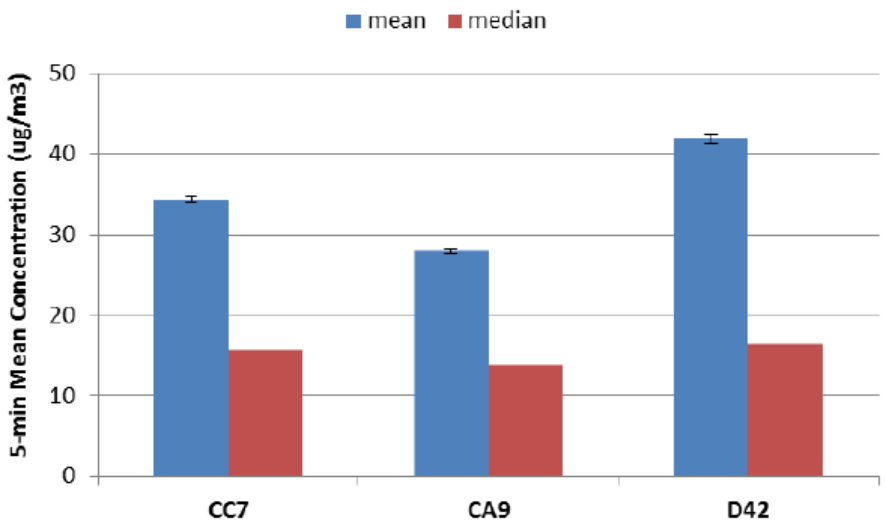
- AirBeam Sensor (3 units tested):
  - Optical particle counter (non-FEM)
  - PM2.5 count (hundred particles/ft3) and PM2.5 mass (ug/m3)
  - Time resolution: 1-min
  - Unit cost: ~$200



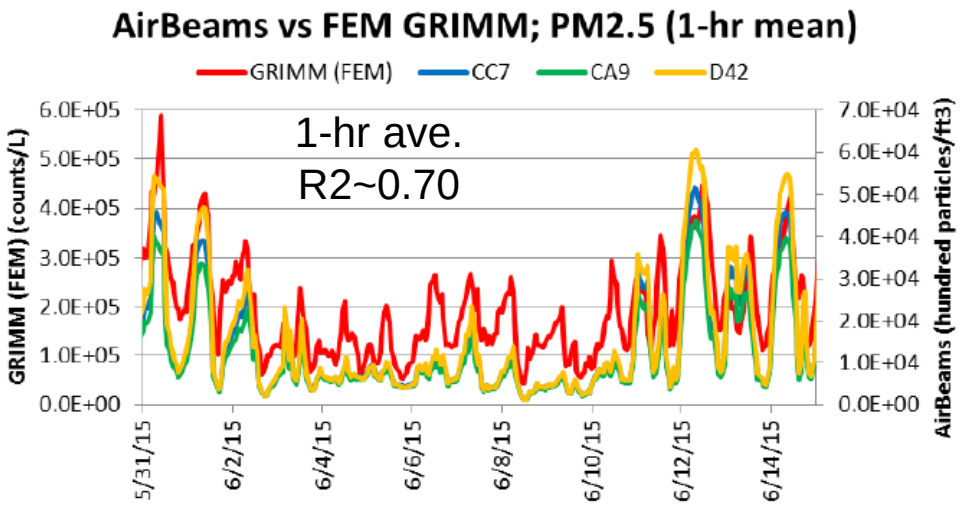
- MetOne BAM (*reference method*):
  - Beta-attenuation monitor (FEM)
  - Measures PM2.5
  - Cost: ~$20,000
  - Time resolution: 1-hr

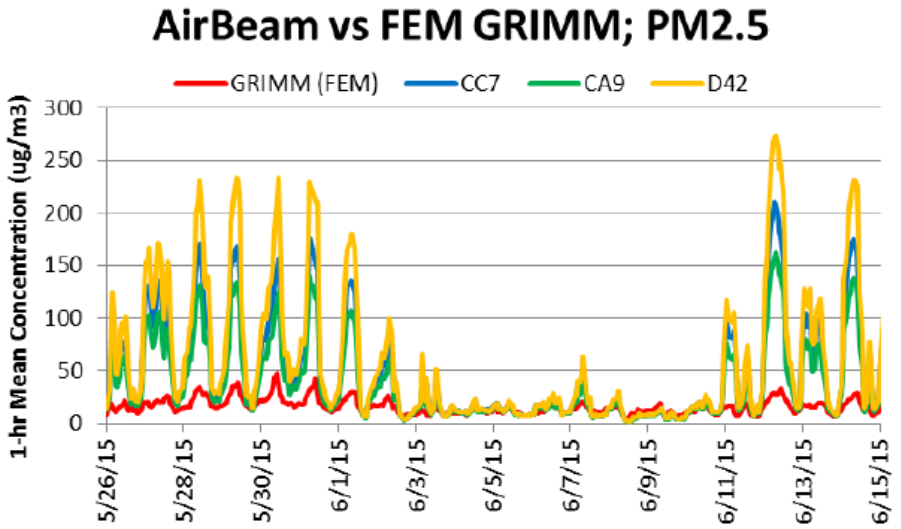
- GRIMM (*reference method*):
  - Optical particle counter (FEM)
  - Uses proprietary algorithms to calculate total PM, PM2.5, and PM1 from particle number measurements
  - Cost: ~$25,000 and up
  - Time resolution: 1-min

AirBeam PM Sensor (continued)



- Preliminary results:
  - High intra-model variability
  - Particle count conc.
    - Good correlation with FEM
  - Particle mass conc.
    - Calibration issues
  - AirBeam v2 recalibrated using field testing data





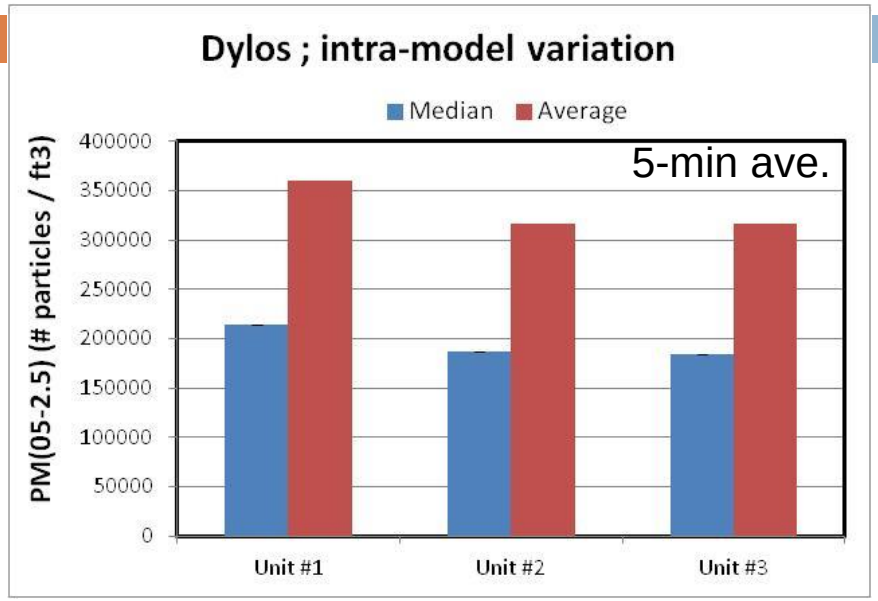
Dylos DC1100/DC1700

- Dylos (*3 units tested*):
  - Optical particle counter (non-FEM)
  - Three different size fractions including PM(0.5-2.5) (used as an estimate of PM2.5)
  - Time resolution: 1-min
  - Cost: ~$300

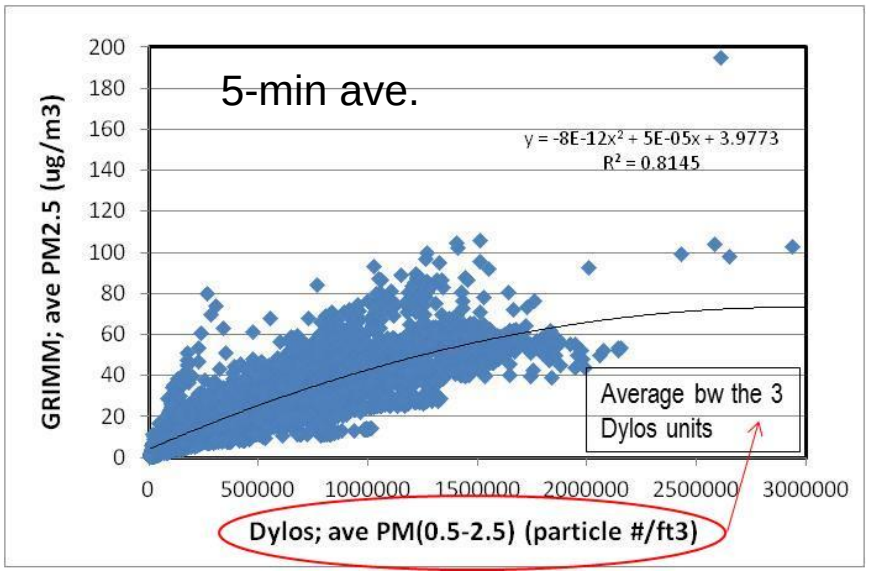
- MetOne BAM (*reference method*):
  - Beta-attenuation monitor (FEM)
  - Measures PM2.5
  - Cost: ~$20,000
  - Time resolution: 1-hr

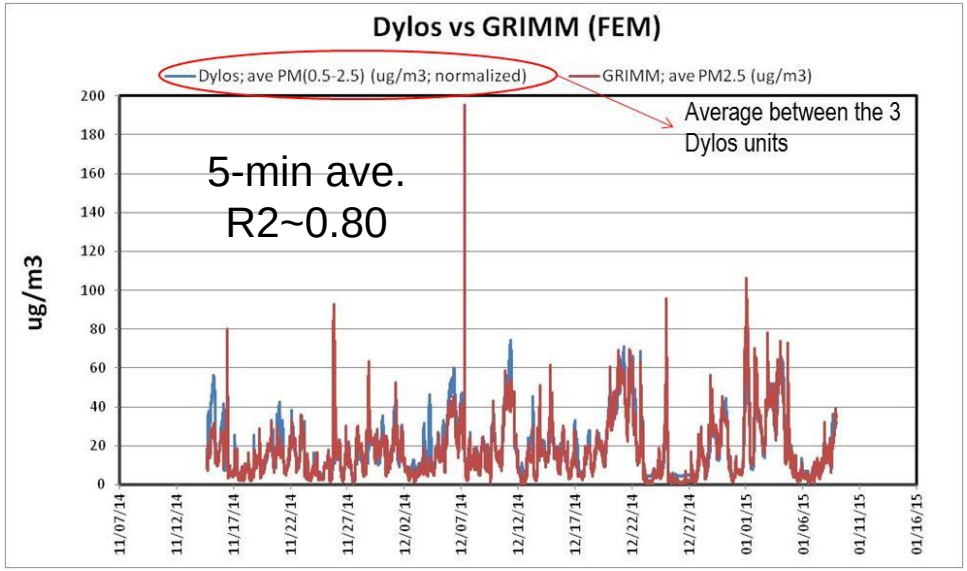
- GRIMM (*reference method*):
  - Optical particle counter (FEM)
  - Uses proprietary algorithms to calculate total PM, PM2.5, and PM1 from particle number measurements
  - Cost: ~$25,000 and up
  - Time resolution: 1-min

Dylos DC1100/DC1700 (continued)



- Preliminary results:
  - Modest intra-model variability
  - Particle count conc.
    - Good correlation with FEM
  - Particle mass conc.
    - Can be derived via FEM calibration

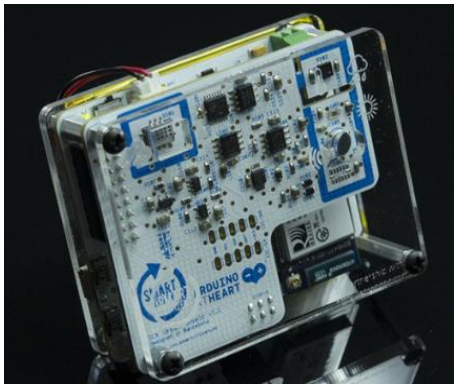




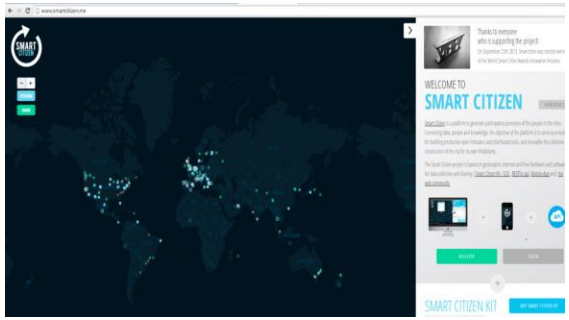
SmartCitizen Kit

- Smart Citizen Kit (*3 units tested*):
  - Metal-oxide sensor (non-FEM)
    - CO (kOhm), NO2 (kOhm),
  - Temperature (C) and Relative Humidity (%)
  - Time resolution: 1-min
  - Unit cost: ~$200

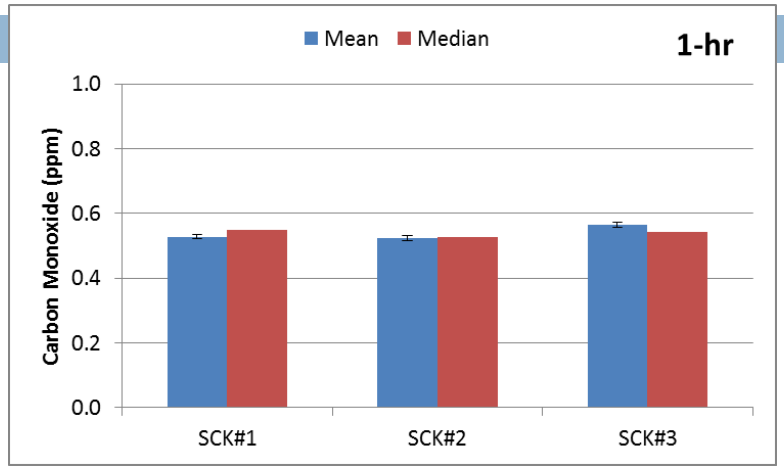
- SCAQMD FRM instruments:
  - CO instrument; cost: ~$10,000
    - Time resolution: 1-min
  - NOx instrument; cost: ~$11,000
    - Time resolution: 1-min
  - Meteorological station (wind speed, wind direction temperature, relative humidity, and pressure); cost: ~$5,000
    - Time resolution: 1-min

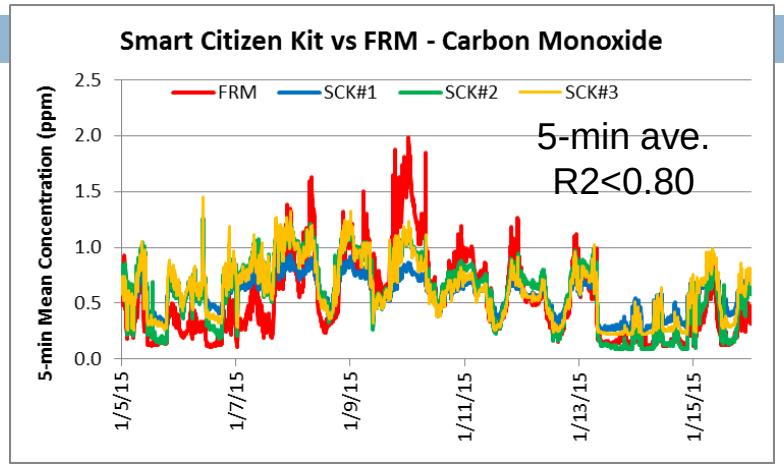


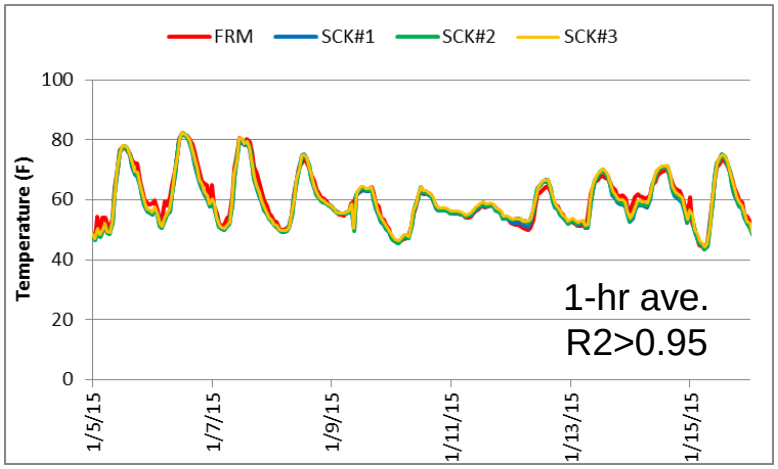
http://www.smartcitizen.me/

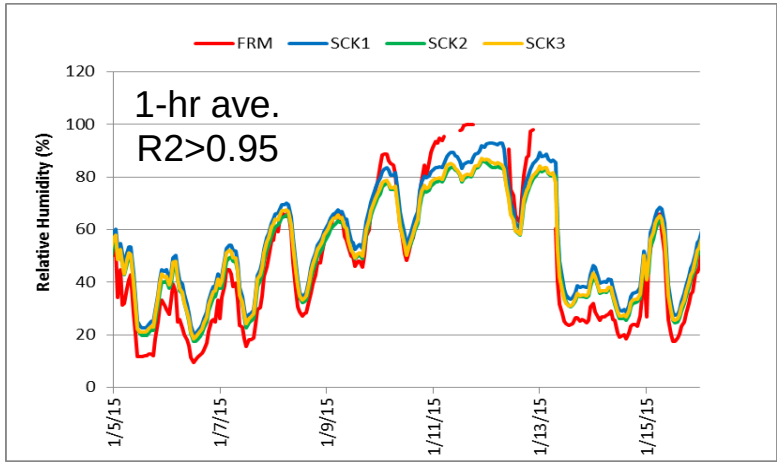


SmartCitizen Kit (continued)









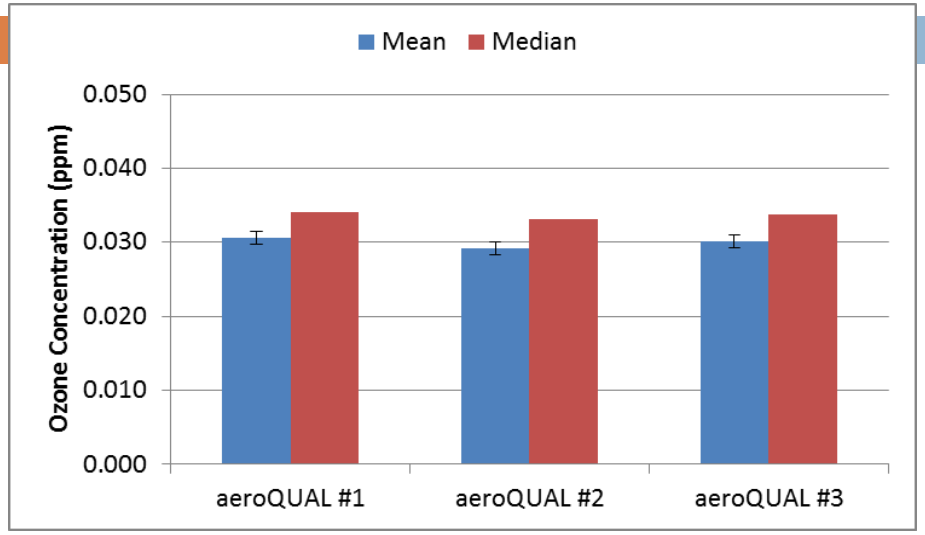
- Preliminary results:
  - ➢Low intra-model variability
  - ➢CO: good correlation with FRM
  - ➢NO2: no correlation with FRM
  - ➢Reliable T and RH data

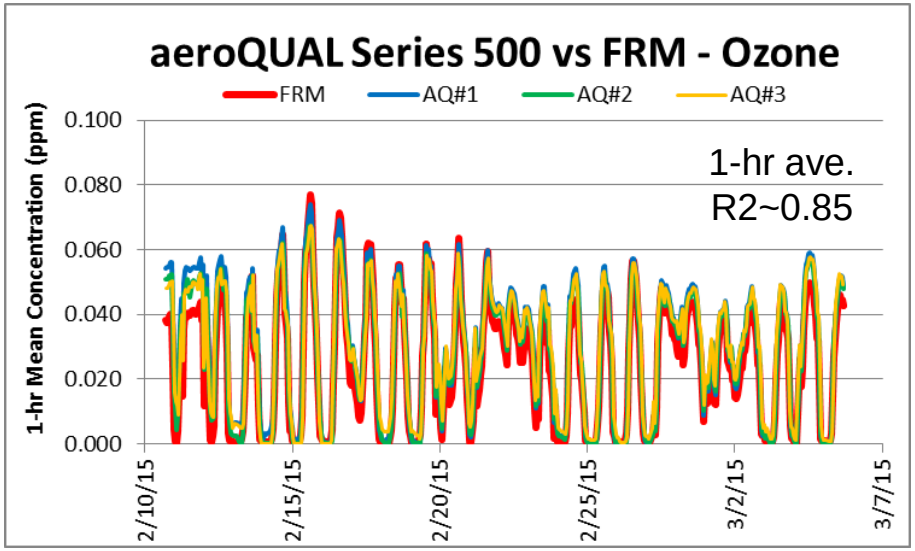
AeroQUAL S-500

- AeroQUAL S-500 (*3 units tested*):
  - Metal-oxide sensor (non-FRM)
    - Ozone (pphm)
  - Temperature (C) and Relative Humidity (%)
  - Time resolution: 1-min
  - Unit cost: ~$500

- SCAQMD FRM instruments:
  - Ozone instrument; cost: ~$7,000
    - Time resolution: 1-min
  - Meteorological station (wind speed, wind direction temperature, relative humidity, and pressure); cost: ~$5,000
    - Time resolution: 1-min

AeroQUAL S-500 (continued)





- Preliminary results:
  - Low intra-model variability
  - Ozone conc.
    - Good correlation with FEM
  - Slight signal degradation over time (sensor replacement available)

Field Testing - Discussion

PM (optical) sensors:

- Minimal down time
- Low intra-model variability
- Strong correlation (R^2) with two different FEM instruments
- Sensor "calibration" may be needed
- Potential sources of error:
  - Sensors cannot detect very small particles (e.g. <0.5 µm for Dylos)
  - Bias in algorithms used to convert particle counts to particle mass

Gaseous sensors:

- Minimal down time
- Low intra-model variability
- CO; NO; O3 (when measured alone): good correlation with FRMs
- O3 and/or NO2: low correlation with FRM (potential O3 NO2 interference)
- SO2: difficult to measure with current electrochemical sensors

- Chamber testing is necessary to fully evaluate the performance of these sensors
- All results are still preliminary

Field Testing - Summary

	Manufacturer (Model)	Type	Pollutant(s)	Cost	Time Resolution	Sensor vs FEM/FRM Method*
	**HabitatMap** (AirBeam)	Optical	PM2.5	~$200	1 min	R^2~0.70
	**Dylos** (DC1100)	Optical	PM(0.5-2.5)	~$300	1 min	R^2~0.85
	**Alphasense** (OPC-N2)	Optical	PM1 PM2.5 PM10	~$400	15 sec	R^2~0.85 R^2~0.90 R^2~0.80
	**Shinyei** (PM Evaluation Kit)	Optical	PM2.5	~$1,000	1 min	R^2~0.85
	**MetOne** (Neighborhood Sensor)	Optical	PM2.5	~$1,900	15 sec	R^2~0.70
	**RTI (MicroPEM)**	Optical	PM2.5	~$2,000	10 sec	R^2~0.80

*Comparisons refer to 1-hr average data; results are still preliminary; laboratory evaluations needed to confirm field results

Field Testing – Summary (cont.)

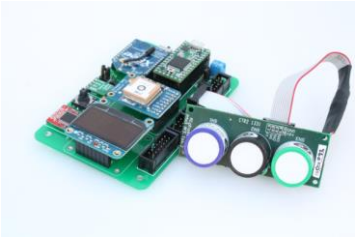
	Manufacturer (Model)	Type	Pollutant(s)	Cost	Time Resolution	Sensor *vs* FEM/FRM Method*
	**Smart Citizen Kit**	Metal oxide	CO, NO_2	~$200	1 min	R2(CO)~0.85 R2(NO2): unreliable
	**Aeroqual (S-500)**	Metal oxide	O_3	~$500	1 min	R^2~0.85
	**Landtec (AQMesh AQM-5)**	Electrochem.	CO, NO, NO2, SO2, and O3	~$10,000	1-15 min	R2(CO)~0.85 R2(NO)~0.85 R2(NO2)<0.50 R2(O3)<0.50 R2(SO2): unreliable

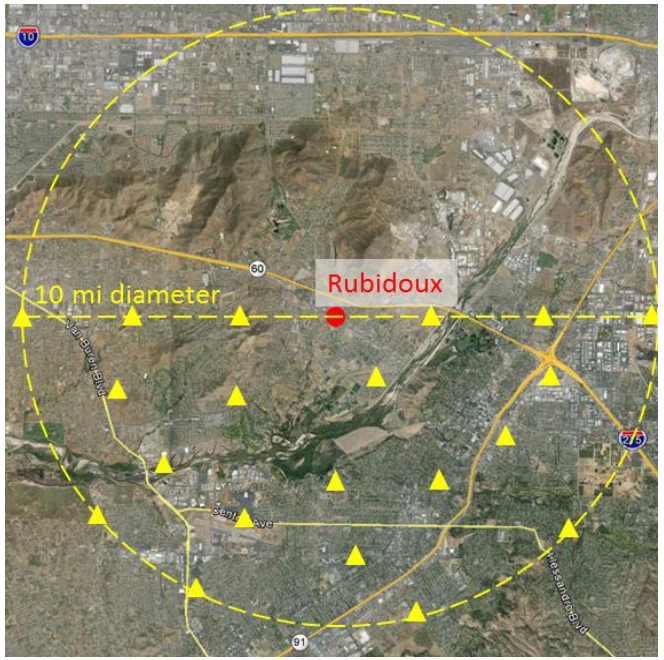
*Comparisons refer to 1-hr average data; results are still preliminary; laboratory evaluations needed to confirm field results

Upcoming SCAQMD Activities

Pilot Study #1:

- Create a small sensor network
  - ➢ 20-25 sensors deployed @
    - ✓ Existing monitoring stations
    - ✓ Near road sites
    - ✓ Public and private locations
  - ➢ Target PM, O3, NO2, CO
  - ➢ Test sensor durability
  - ➢ Show ability to scale up in future
- Test connectivity options
  - ➢ Cellular
  - ➢ LoRa WAN
  - ➢ Digi mesh
- Explore various data ingestion, storage, and analytics solutions





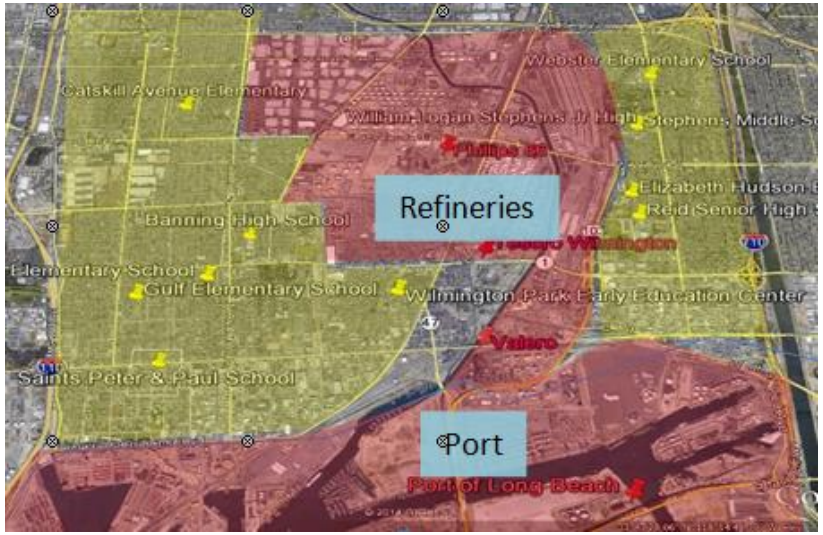
Upcoming SCAQMD Activities

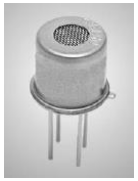
Pilot Study #2:

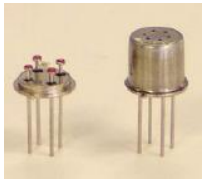
- Explore fence-line applications (use as a screening tool)
- Monitor PM emissions from a waste disposal facility
  - ➢ 15-20 sensors deployed
    - ✓ Around the facility
    - ✓ Inside the facility
    - ✓ Downwind of facility
  - ➢ Test sensor durability
- Use wireless mesh network
- Explore various data ingestion, storage, and analytics solutions
- Provide real-time feedback and alerts

Upcoming SCAQMD Activities

- US EPA "Community-scale Air Toxics Ambient Monitoring" grant: *"Application Of Next Generation Air Monitoring Methods To Characterize Hazardous Air Pollutant Emissions From Refineries and Assess Potential Impacts To Surrounding Communities"*
- June 1, 2015 – May 31, 2018
- Use Optical Remote Sensing (ORS) methods to monitor Hazardous Air Pollutant (HAP) emissions from refineries and to estimate their annual VOC emissions
- Use of ORS methods and "low-cost" sensors to assess the impact of industrial HAP emissions on surrounding communities

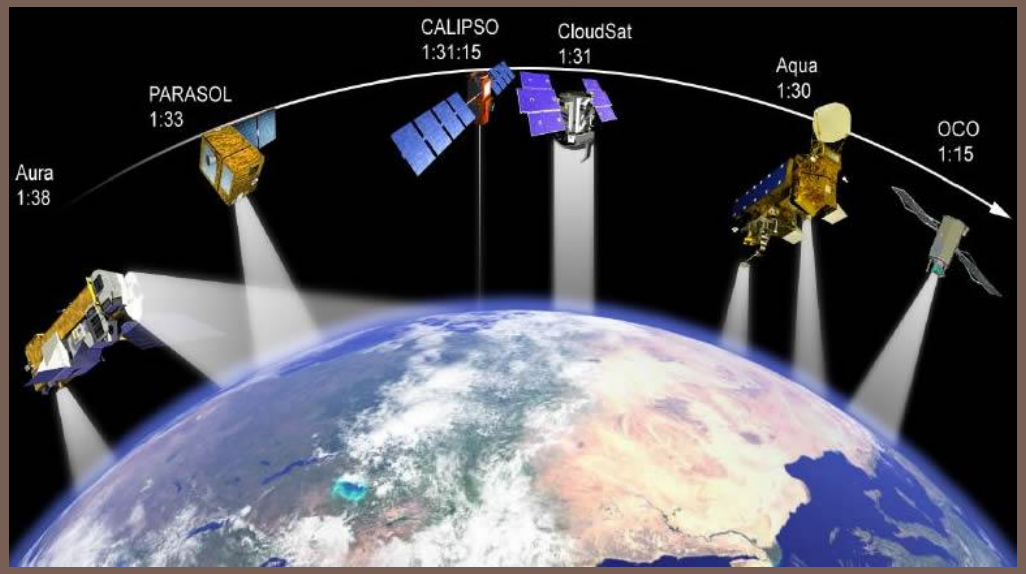






Expected Results and Next Steps

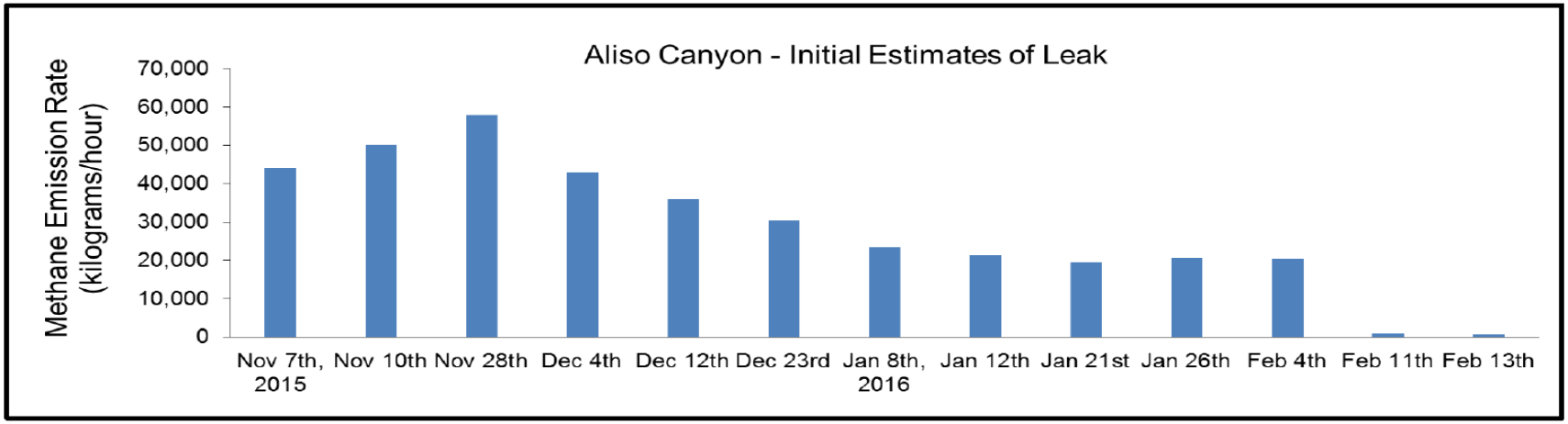
- ✓ Provide the knowledge necessary to appropriately select, use, and maintain sensors and correctly interpret their data
- ✓ Promote a better and more responsible use of sensors
- ✓ Discover new and more effective ways to interact with local communities
- ✓ Provide manufacturers with valuable feedback for improving current and next generation sensor technology
- ✓ Create a "sensor library" to make "low-cost" sensors available to communities, schools, and individuals across California



South Coast AQMD

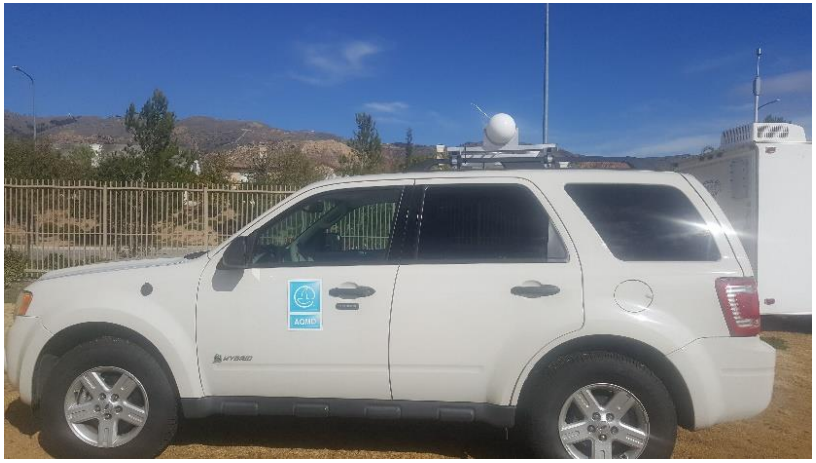
UPCOMING NEW TECHNOLOGIES

Scientific Aviation
Mooney TLS Aircraft / Measuring CH4

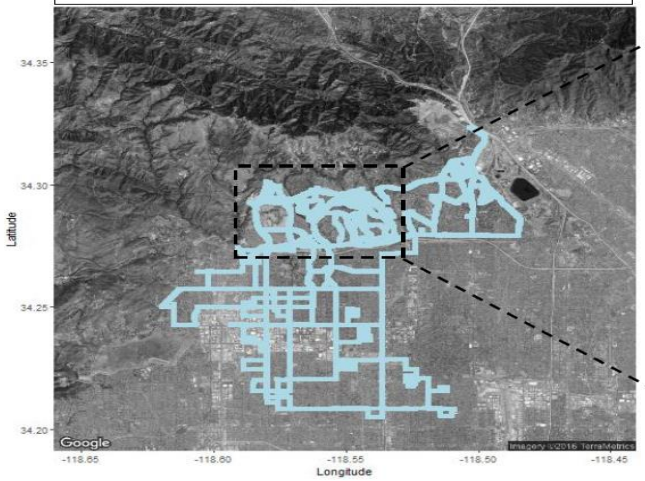


More information at http://www.arb.ca.gov/research/aliso_canyon_natural_gas_leak.htm

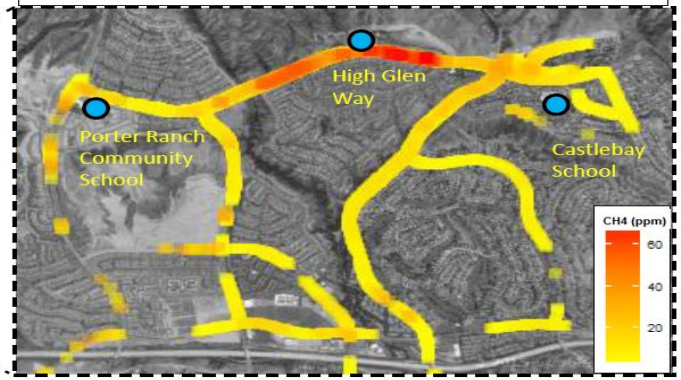
SCAQMD's Mobile Methane Measurement Platform



Area covered by mobile measurements between 12/21/15 and 01/29/16



Map of the highest (12-70 ppm) methane concentration measurements collected between 12/21/15 and 01/29/16



Current SCAQMD measurement sites

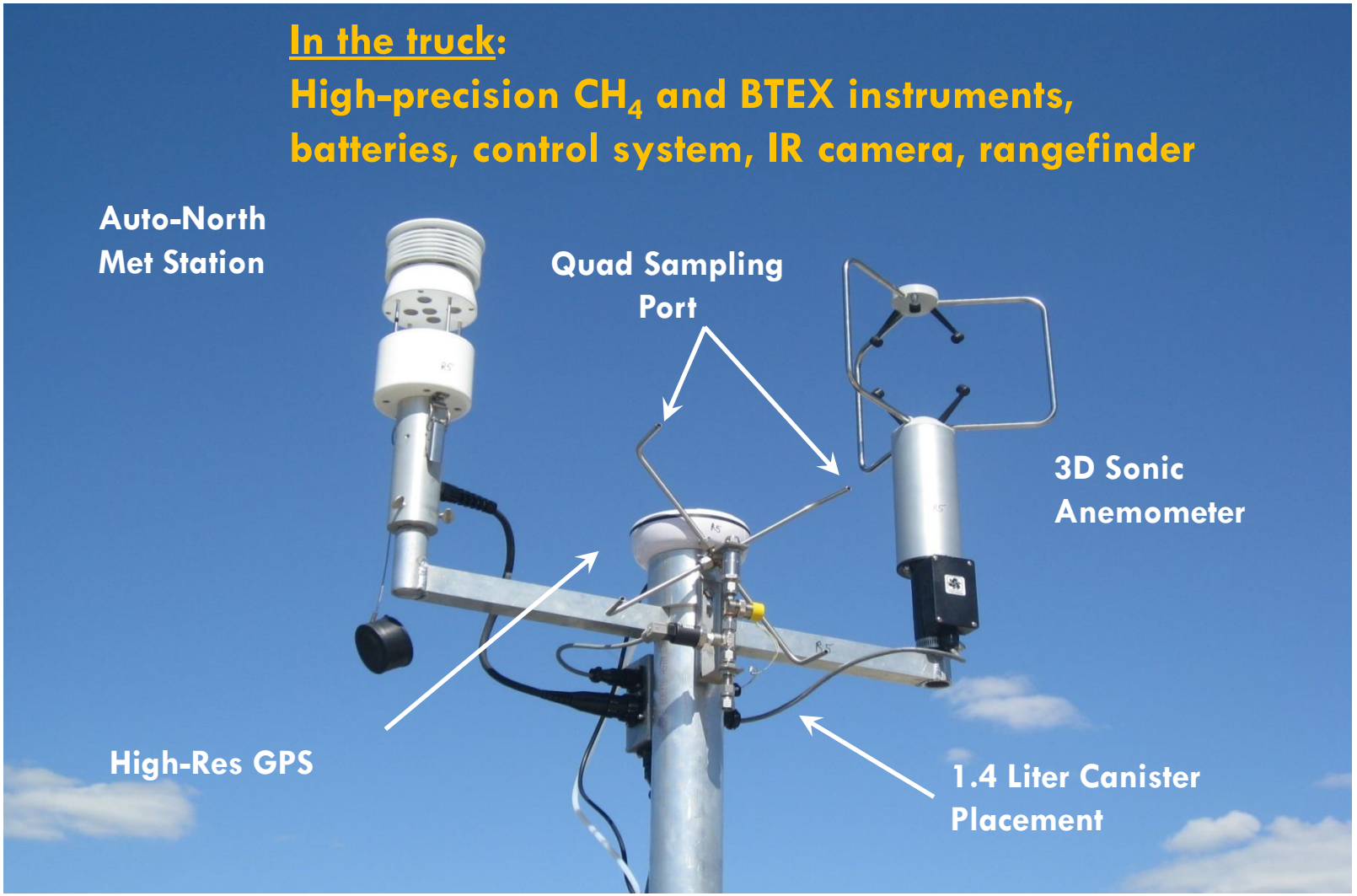
Geospatial Measurement of Air Pollution (GMAP)

U.S. EPA
National Enforcement Investigation Center (NEIC)

GMAP Vehicle

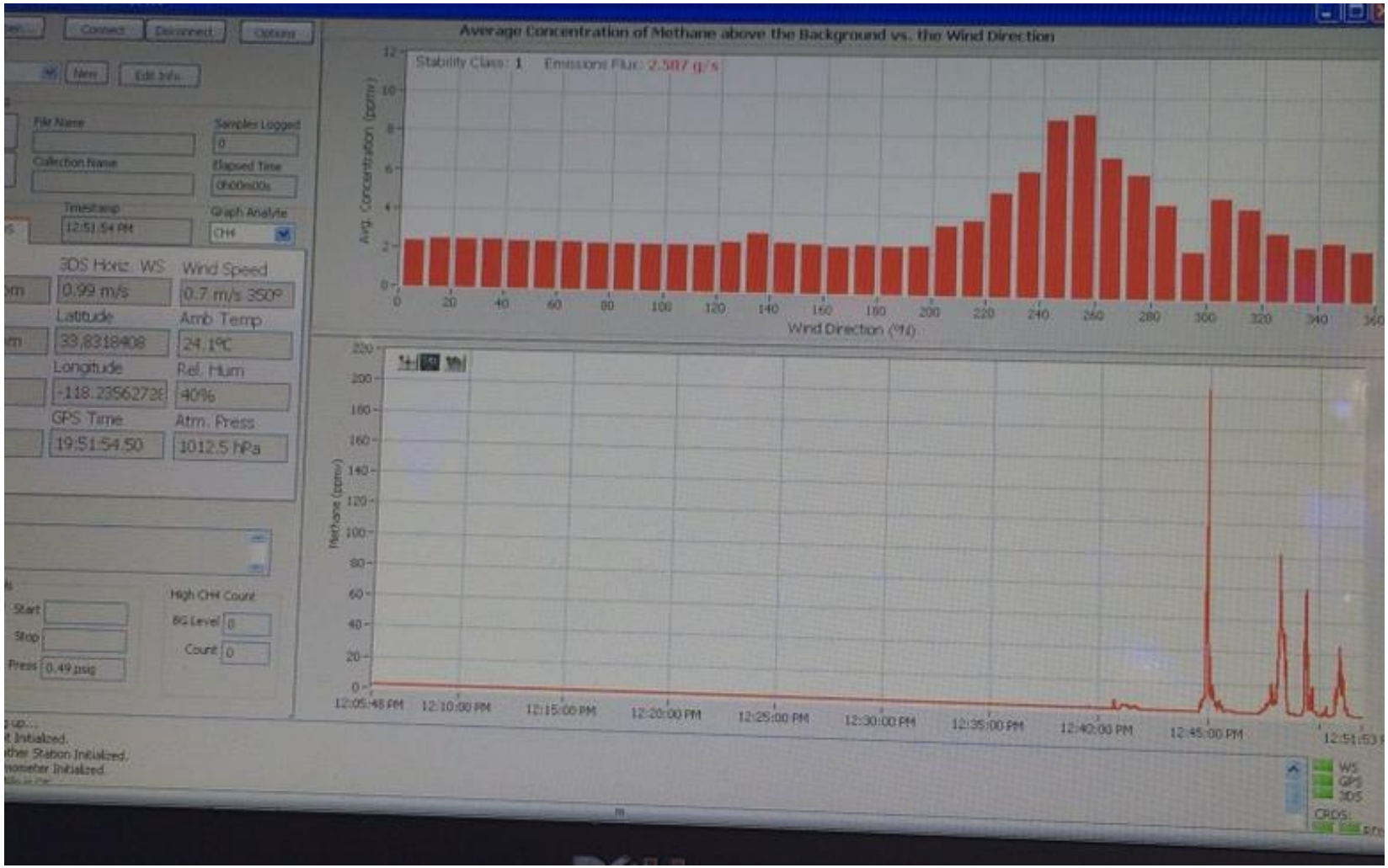
- Utilizes a vehicle equipped with measurement technology to:
  - Identify sources of air pollution from a distance
  - Quantify the observed emissions (modeled rates)
  - Map/visualize the results

GMAP REQ Measurement Equipment



GMAP – Benzene at a Tank Farm

GMAP – Methane at an LNG Fueling Station

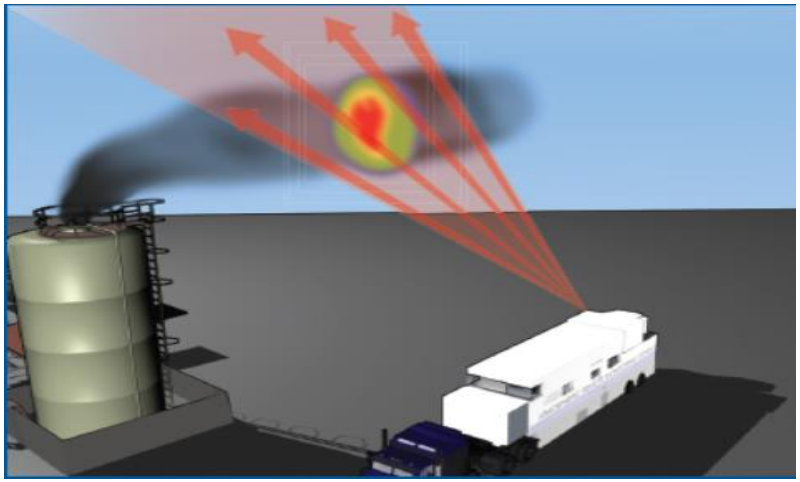


Upcoming New Technologies: Optical Remote Sensing

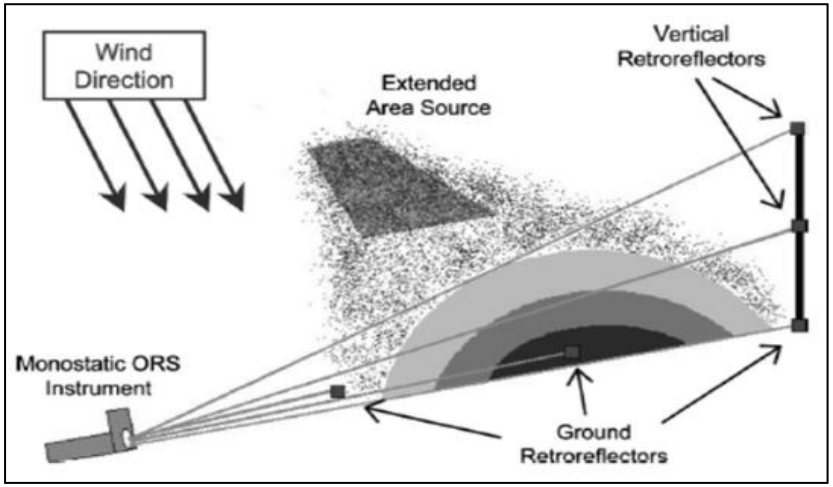
- Upcoming SCAQMD projects using optical remote sensing (ORS) methods to characterize/quantify fugitive and stack emissions from large refineries, small point sources, and marine vessels($1.1 million)

Solar Occultation Flux

Differential Absorption Lidar



Fourier transform infrared spectroscopy



Upcoming New Technologies: Optical Remote Sensing

Three Projects in 2015 –

Four Vendors:

- FluxSense (SOF+FTIR+DOAS)
- National Physical Laboratories (DIAL)
- Atmosfir Optics, Ltd. (Open-Path FTIR)
- Kassay Field Services (Open-Path FTIR)

Ongoing Projects - 2015

Project 1 - Quantify fugitive emissions from large refineries

- *Main measurements: FluxSense*
  - SOF+FTIR+DOAS / mobile measurements (daytime only)
  - 5 week study at 5 refineries (6 sites)
  - Facility-wide emissions of methane, non-methane VOCs, NOx, SO2
  - Accurate meteorological (LIDAR) data to reduce uncertainty

- *Validation measurements: NPL*
  - DIAL / stationary measurements
  - (daytime and nighttime)
  - 1 week study at 1 refinery
  - Facility-wide emissions of methane, non-methane VOCs, NOx, SO2
  - Not suited for long-term measurements but ideal for field validation

- *Validation measurements: Atmosfir*
  - Open-path FTIR / stationary measurements (daytime and nighttime)
  - 5 week study at 1 refinery
  - Prolonged measurements of methane, non-methane VOCs, NOx, SO2
  - Higher detection limits but thoroughly validated method (EPA OTM-10)

Ongoing Projects – 2015 (continued)

Project 2 - Quantify gaseous emissions from small point sources

- *Main measurements: FluxSense*
  - SOF+FTIR+DOAS / mobile measurements (daytime only)
  - 5 week study at 50 to 100 oil wells, 20 to 40 gas stations, and other point sources
  - Methane and non-methane VOCs
  - Accurate meteorological (LIDAR) data to reduce uncertainty

- *Validation measurements: NPL*
  - DIAL / stationary measurements (daytime and nighttime)
  - 1 week study at 7 point sources
  - Methane and non-methane VOCs
  - Ideal for field validation

- *Validation measurements: Kassay*
  - Open-path FTIR / stationary measurements (daytime and nighttime)
  - 5 week study at 50 point sources
  - Methane and non-methane VOCs
  - Higher detection limits but proven method (EPA TO-16)

Ongoing Projects – 2015 (continued)

Project 3 - Quantify stack emissions from marine vessels

- *Main Measurements: FluxSense*
  - Optical + ”traditional” methods / on-shore and off-shore (ship) measurements
  - 4 week study @ POLA or POLB
  - “Real world” emissions (g/s) of SO2 and NO2 and “actual” emission factors (g/Kg fuel burnt) of SO2, NOx and particulates from individual ships

Schedule for Projects 1-3

- Completion of measurement campaign: end of October 2015
- Final Reports: 1st Quarter 2016