行政院所屬各機關因公出國人員出國報告書

（出國類別：國際會議）

赴美國參加
2017 年空氣品質量測方法及技術研討會並研習 PM 自動監測儀器相關技術
Air Quality Measurement Methods and Technology

服務機關：行政院環境保護署

姓名職稱：林書庸技士

陳香宇特約環境監測技術師

派赴國家：美國

出國時間：106 年 11 月 6 日至 19 日

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摘要

2017 年「空氣品質量測方法及技術研討會(Air Quality Measurement Methods and Technology」假美國洛杉磯長灘萬麗酒店(Renaissance Long Beach Hotel)舉行，研討會由 Air & Waste Management Association (A&WMA)主辦，為期 3 天，共有 16 項主題專題演講，約 400 多名來自歐、美、亞及大洋洲等相關領域專業人員與會；講者為學者、儀器製造商、政府單位等，內容囊括大氣監測，室內空氣品質監測，固定污染源、移動污染源、溫室氣體及逸散源量測等，針對有害空氣污染物的監測分析技術、細懸浮微粒成分分析技術、監測網絡資料處理等相關近年環境監測技術發展趨勢進行交流與討論。

本次研討會議不乏探討低成本空氣品質感測裝置的應用面向，包含氣狀 VOC 或是粒狀污染物（如 $PM_{2.5}$、PM_{10} 等）的環境監測。此類低成本空氣品質感測裝置雖然測值數據不若傳統高階監測儀器精準，然而其易用與便於和物聯網結合的特點，已成為社群團體參與空氣品質議題的高效輔助工具，甚至傳統高階儀器廠商也開始提供相關配件來輔助高階粒狀污染物監測，以提供更小時間尺度的空氣品質監測數據。美國加州南岸空氣品質管理區（SCAQMD, South Coast Air Quality Management District）為目前國際社群中已建立感測裝置性能評估技術系統的少數機構，其相關案例分享，可作為本署建立感測裝置性能測試作業程序及測試驗證制度的參考，以利本署推動環境物聯網發展布建及執法應用，確保空氣品質感測裝置數據品質。

另本署自 102 年開始規劃更新運轉迄今逾 10 餘年的第 3 代空氣品質監測儀器，從設備到技術，全面性提升；104 年起依據環檢所發布實施之「空氣中細懸浮微粒手動及自動檢測方法比對規範」執行 $PM_{2.5}$ 自動監測儀器比對測試，發現

市場上各廠牌 PM 自動監測儀器，即使已取得國際認證的，仍須依臺灣環境特性進行儀器調校，爰此派員前往取得美國聯邦等似方法(Federal Equivalent Methods, FEM) 認證之懸浮微粒（PM_{10}）、細懸浮微粒（$PM_{2.5}$）自動監測儀器製造商 Met One 進行研習，包含 PM 自動監測儀器設計原理、出廠參數設定值的調校方法與儀器維護保養相關技術。

目錄

一、 前言

環保署長期監測臺灣各地空氣品質，監測項目有懸浮微粒、細懸浮微粒、臭氧、一氧化碳、二氧化硫、碳氫化合物等空氣污染物，亦包含臭氧前驅物、大氣汞等。在粒狀污染物的監測方面，本署標準空氣品質監測站用來測定 $PM_{2.5}$ 的儀器分成手動及自動二種，手動監測係由採樣人員使用調理過的濾紙到測站進行 24 小時採樣，再將濾紙送回實驗室，在控制的溫濕度條件下，進行秤重後計算濃度。這種方法的好處在於減少環境中可能干擾測定的因素，例如相對溼度對測值的影響。因此國際上一般會使用手動監測的結果作為空氣品質是否符合標準的判定依據，我國空氣品質標準亦明訂採手動監測結果判定空氣品質是否符合標準。然而，手動監測經過嚴謹的實驗室分析程序，需要 2 至 3 週才能完成，在空氣品質出現變異時，不能提供民眾預警，因此空氣品質監測需要使用自動連續監測，來提供預警或預報之需，而常見的空氣品質監測站的 $PM_{2.5}$ 自動監測儀器原理，包括貝他射線衰減法、錐形元件震盪天平法及光散射法等。

當空氣品質監測目的不同，使用的儀器種類、原理也會發生改變，受限標準測站的粒狀物自動監測儀器為了達到準確監測空氣品質的目的，各種自動監測儀器鈞會有去除干擾的設計，例如粒徑篩分器（去除粒徑大於 2.5 微米的粒子）、流量控制器（控制精準的流量）、氣溫、大氣壓力測定以及採樣氣流加溫（避免水分凝結）等，而使得製造成本高昂，不利於大量佈建於工業區或特定區域進行環境污染源追蹤，爰此本署於 106 年開始使用低成本的簡易型光學散射式感測裝置，來追蹤打擊不法業者，其優點為製造成本低、體積小、可提供分鐘尺度監測趨勢，對於不肖業者突如其來的污染源排放，可以即時發現，鎖定可疑污染來源。

然而近來民眾對於監測周介或居家環境空氣污染程度與趨勢變化，有較高程度關注，此類低成本感測裝置已成為社群團體參與空氣品質議題所選用的高效輔助工具，實際使用上的便利性，卻常使民眾忽略此類微型感測器在測定 $PM_{2.5}$ 時，為了減少感測器體積，各種可能干擾的因子，並未納入設計，包括粒徑、溫溼度干擾等，因此測值容易出現誤差。為了對此類微型感測器有更進一步瞭解，並與國際交流學習，故參與本次 AWMA 辦理的空氣品質量測方法及技術（Air Quality Measurement Methods and Technology）研討會研討會議。

二、 會議背景及目的

空氣和廢棄物管理協會（A＆WMA）成立於 1907 年，是一個非營利，的環保學術性機構，每年定期於美國舉辦國際性研討會議，提供各國會員進行討論交流，本次參加的空氣品質量測方法及技術（Air Quality Measurement Methods and Technology）研討會，就粒狀污染物的監測，從標準方法的手動監測，到各式強調機動性能、體積更小的自動監測儀器，以及製造成本更為低廉、能夠提供分鐘時間尺度的光學散射式儀器，皆有在研討會會場展示，從儀器的保養、維護與數據品質控管、品保、資料處理等，可以窺見目前空氣品質監測儀器的發展方向。

美國在低成本感測器的運用目的十分明確，較不會有低階感測器監測數據回過頭來質疑高階空氣品質監測儀器的情形，美國加州時常發生森林大火，境內也有許多開採的油井，這些須要大區域監測，以避免或降低火災等意外災害的低成本感測器監測數據，是不會被要求監測數據準確度須達到標準測站的性能範圍，更不會有感測器數據質疑標準測站數據的情形，因此透過參加本次的研討會，可以學習其他國家在推廣此類感測器的宣傳方式，以利本署後續推動環境物聯網布建時的參考。

另面對我國每年空氣品質逐漸改善，對於細懸浮微粒的空氣品質監測，需要有更精密的儀器性能，爰此本署於 104 年開始依據環檢所發布實施之「空氣中細懸浮微粒手動及自動檢測方法比對規範」執行 $PM_{2.5}$ 自動監測儀器比對測試，以瞭解市場上 $PM_{2.5}$ 監測儀器性能，參與比對的 7 個廠牌型號，均已通過美國（US-EPA,USA）、德國（TÜV Rheinland）或歐盟認證，但卻無任何一臺儀器通過本署 8 站季比對，顯示即使取得國際認證，仍須依臺灣環境特性進行儀器調校，爰此本署本次前往取得美國聯邦等似方法(Federal Equivalent Methods, FEM) 認證之懸浮微粒（PM10）、細懸浮微粒（PM2.5）自動監測儀器製造商 Met One，進行儀器調校技術的研習。

三、 會議過程及內容重點整理

相關議程如附件 2，主要行程及內容簡如下表：

日 期	工 作 內 容 概 要
106年11月6日	由臺北啟程前往美國加州長灘市
106年11月7日	2017年空氣品質量測方法及技術研討會大會報到，參加研討會開幕式、5場微型感測器專題演講及2項感測器主題論文發表會議
106年11月8日	參加大會6場懸浮微粒成分等數據網絡資料專題演講及1項主題論文發表會議
106年11月9日	上午參加大會1場工地空氣品質監測專題演講及3場有關氣象及阿拉斯加極地$PM_{2.5}$監測專題演講 下午搭機至奧瑞岡州
106年11月10日	上午至Met One Instruments討論PM自動監測儀器相關監測技術，下午討論該公司氣象監測儀器相關技術
106年11月11日至106年11月19日	結束研討會及研習討論會議行程，從奧瑞岡州途經波特蘭，由美國西雅圖返回臺北

圖 1.1 研討會會場　　　　圖 1.2 美國 Met One Instrument 工廠

（一） 2017年空氣品質量測方法及技術研討會於本（西元2017）年11月7至9日假美國洛杉磯長灘萬麗酒店（Renaissance Long Beach Hotel）舉行，旨在結合產業界（監測設備製造商）、學術界和政府機構，進行空氣品質監測

技術及方法開發等研討，促進各種科學領域人員的溝通，交流環境空氣品質監測相關技術發展，爰本署監資處派員參加，除可與世界環保先進國家及美國產官學界代表交流，亦藉此大會吸取先進國家經驗，提升我國環境空氣品質監測技術發展與策略，並與國際潮流充分接軌。本屆大會包含歐、美、亞及大洋洲多國專業人士與會，安排所有與會者共同參與約16項主題專題演講，講者為相關領域之學者、儀器製造商、政府單位等，內容含括大氣監測，室內空氣監測，固定污染源、移動污染源、溫室氣體及逸散源量測方式等，針對有害空氣污染物的監測分析技術、細懸浮微粒成分分析技術、監測網絡資料處理等相關近年發展趨勢進行演講，共計400多員各國相關領域人員參與本次研討會議。現場並有20多家儀器廠商展示說明最新技術監測儀器。

（二） MetOne為取得美國聯邦等似方法(Federal Equivalent Methods, FEM) 認證之懸浮微粒（PM_{10}）、細懸浮微粒（$PM_{2.5}$）自動監測儀器製造商，採用ß射線衰減（Beta Attenuation Monitor, BAM）原理分析空氣中粒狀物濃度；因粒狀污染物沒有標準氣體可供校驗，考慮臺灣北、中、南部粒狀污染物特徵不同，每部儀器內置參數設定如何因地制宜，須赴原廠深入瞭解各項參數設定值之測試方法及條件，爰擬派員研討相關參數設定技術，以利系統化建立本土粒狀污染物儀器參數設定及調教標準作業程序。

四、參加會議心得及建議

（一） 我國在微型空氣品質感測器的設置密度領先全球，研討會第一場專題報告中即提到臺灣在感測器發展的盛況，與本署推動環境物聯網之發展願景與規劃理念，包含前瞻計畫中本署推動感測器佈建的短、中、長期規劃，可見本署長官、同仁在環境監測技術的創新受到國際肯定。

（二） 利用光學原理偵測粒狀物的感測器，因具有低成本及監測時間尺度較為綿密的優勢，在環境監測上的空間應用將可更為彈性，尤其在美國加州常發生森林大火，布建此類低成本粒狀物感測器，可作為火災預警及防範等環境監測應用，美國更持續投入許多研究計畫發展此類感測器的創新應用；本署利用其時空尺度優勢，作污染源追蹤打擊不法業者，並投入相當資源開發更多創新加值應用，維護民眾環境生活品質。

（三） 國外普遍瞭解採用光學原理的低成本感測器監測數據偏差達50%以上，感測器的組裝方式，包含光源和偵測器之間的角度，採樣氣流的控制等，

都是影響此類感測器監測數據品質的關鍵。加州中部的沙加緬度（Sacramento）位處盆地地形，冬季時與臺灣一樣面臨較高濃度的粒狀物空氣污染，所作的感測器測試方法與本署相同，採用與標準測站線性迴歸的方式做比對，結果與本署相近；數據校正（正規化）的方法與本署佈建於觀音工業區的感測器校正方式相同。

（四）國外使用感測器的目的很明確，如加州有約2萬5,000口油井，可運用VOC微型感測器空間上的設置作環境監控，或使用粒狀物微型感測器作即時大範圍的森林大火預警與聯防，也普遍瞭解感測器的使用限制，較無感測器監測數據使用上的困擾。但臺灣除了環保署設置的感測器有明確的使用目的－污染源追蹤，民眾則常常陷入監測目的未臻明確，不瞭解此類低成本感測器數據偏差大，反過來懷疑造價高昂監測準確的環保署監測站數據。國內研究單位使用大數據分析的數據品質驗證方法則未被明確公開（如中研院有關$PM_{2.5}$感測器大數據的論文甫於2017年10月24日發表）或為相關空氣品質專家學者所接受，這都是未來本署在推動感測器加值應用等環境監測技術上，必須與產官學界更頻繁交流的地方。

（五）此次參訪Met One儀器製造商，得以窺見原廠是以一定的密閉空間（Smoke Chamber）下，同時點燃繞圓排列的放射狀線香，產生TSP（總懸浮微粒），不考慮懸浮微粒的粒徑大小，使用風扇將TSP均勻分布於空間，全新的五部儀器與經過FEM認證的標準儀器，在相同的採樣點採集粒狀物，比對調整五部儀器的內置參數值，而標準的FEM認證儀器，則是以相同方式與通過FRM認證的手動儀器比對後而得。

（六）β射線源強度是β射線衰減（Beta Attenuation Monitor, BAM）原理之自動監測儀器的核心，每部儀器以每小時偵測一次內置膜片的單位面積質量來做確認，惟膜片存在公差，因此出廠時是以兩臺比對的方式，來作個別單位面積質量值的確認，出廠時每片僅需約2分鐘即可完成。

（七）與原廠人員提到自動監測站的監測值每小時僅得1筆數據，是否有發展光學散射式儀器來提高監測時間解析度，原廠表示有對應的光學散射式套件（Real-Time Module,RTM；Instantaneous particulate mass trending option）可與標準測站平行連線，並以迴歸校正式產出相關性良好的監測數據，可供本署未來儀器採購的評估參考。

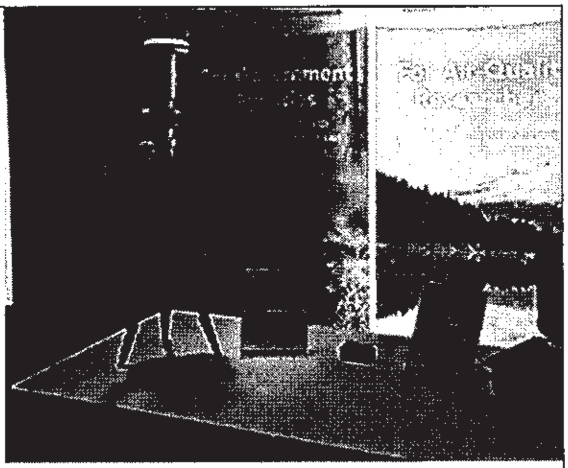
（八）有關氣象監測儀器的交流討論，Met One人員提到傳統類比式相對溼度自動監測儀器進行例行性校正時，在0%及90%校準後，相對濕度37%~45%之間，仍存在較大偏差，乃因相對濕度計測值與實際相對溼度非為完全線性相關，採用數位式相對溼度自動監測儀器可縮小這樣的誤差，可供

本署未來採購參考。

（九）Met One辦公室為溫馨的小木屋，工廠屬小型中小企業規模，所有空氣品質監測相關監測儀器，都由6名人員組裝，生產流程順暢，從產品測試的Smoke Chamber，氣象儀器測試的風洞，以及小型試產的空間，無不以最高空間運用效率來達成，包含自動化的洗床、車床機器人設備等流程動線，都在非常整潔且室內空氣品質良好的狀態下完成，人員甚可在各個辦公空間及廠區進行飲食，這樣舒適宜人的工作環境，除了體現美國在空氣品質監測技術的領先優勢，也暗示該國相關規範或測試方法常成為世界各國的參考，理由除了政治因素與國力的延伸外，臺灣更應把握目前在微型空氣品質感測器的發展優勢，使國內的監測技術，包含維護管理、數據品質驗證等寶貴經驗，行銷至全球，共創美好的環境予國人。

附件 1、 會議相關照片

研討會報到情形

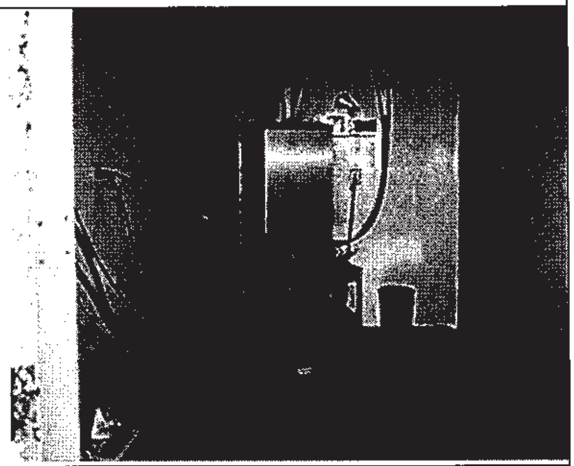


參展廠商之光散射粒狀物監測儀器

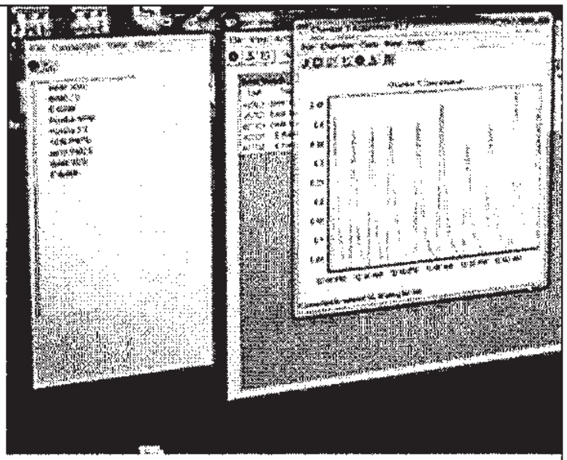
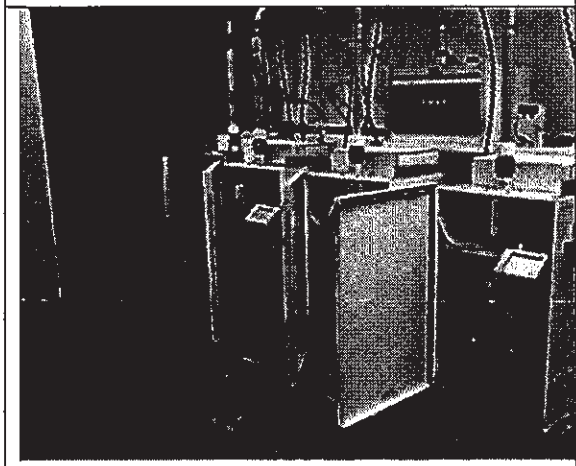
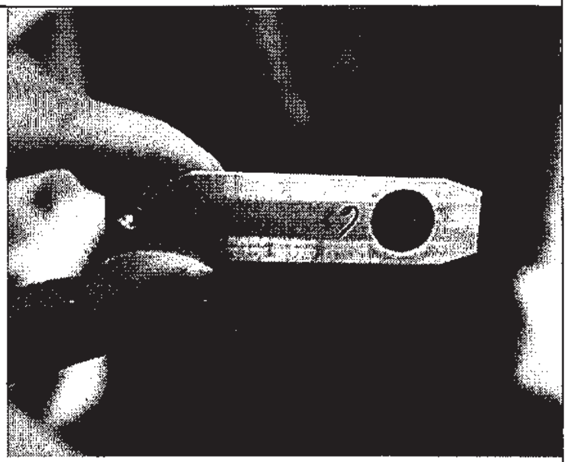
廠商說明其監測儀器產品性能

MetOne 生產線上由 6 人組裝，平均月 PM 自動監測儀器產能為 200 臺

與原廠人員討論儀器調教方法



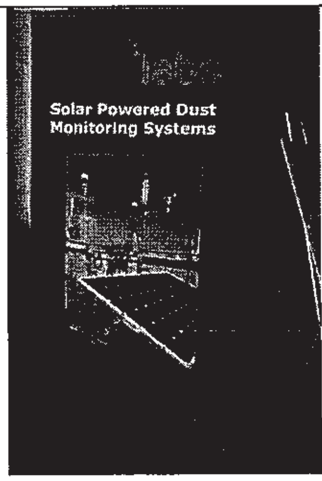
原廠 Smoke Chamber 現況

	
一對一標定 Span Check 膜片單位面積質量值	儀器出廠測試之數據畫面
	
新儀器比對 STD 之 FEM 監測儀器情形	Span Check 膜片
	
利用超聲波聲納原理設計之風速風向計，數據準確而單價高昂	結束整天的研討後於 MetOne 辦公室前合影，最右側為該公司負責人

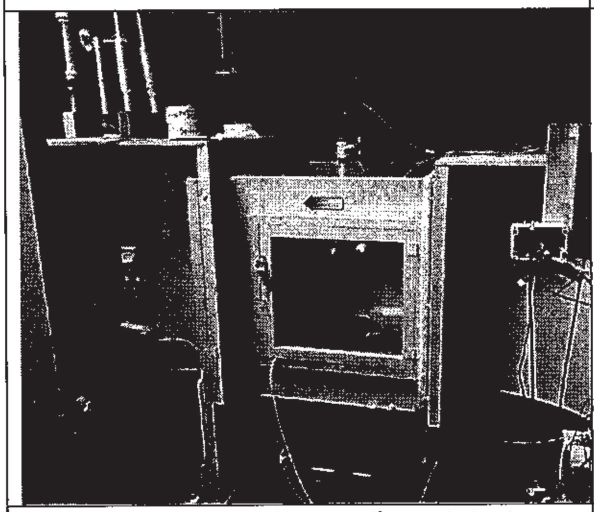
開幕儀式所舉辦的座談會

廠商展示監測粒狀物微型感測器

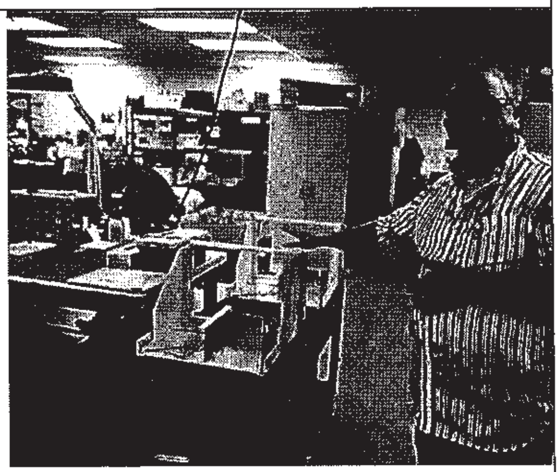
廠商研發粒狀污染物監測儀器



太陽能沙塵監測系統介紹



Metone 公司生產風向儀器測試場所



Metone 公司現場經理介紹各監測儀器生產及組裝方式

附件 2、2017 年空氣品質量測方法及技術研討會議議程

Air & Waste Management
Association
Since 1907

FINAL PROGRAM

AIR QUALITY MEASUREMENT
METHODS AND TECHNOLOGY
NOVEMBER 7-9, 2017 • LONG BEACH, CA

www.awma.org/measurements

FINAL PROGRAM

ABOUT THE CONFERENCE

Explore advances in measurement technology, data quality assurance, and data uses at the Air & Waste Management Association's Air Quality Measurement Methods and Technology. The conference continues the A&WMA legacy of promoting current air quality measurement methods and data use. Air quality issues related to greenhouse gas measurements, ambient monitoring, fugitive and area source air measurements, quality assurance, and data uses in order to improve models, emission inventories, and policy decisions will also be addressed.

The conference provides a forum for current advances in measurement technology covering all aspects of air quality, including ambient air, indoor air, point sources, and area sources. Both laboratory and field studies are welcomed. Past participants include a full range of investigators from academe, industry, consultants, and government agencies.

GENERAL INFORMATION

REGISTRATION

Register online at **www.awma.org/measurements before November 6.**

On site registration will be located at the Counter on the Second Floor and be open during the following hours:

Monday, November 6:	2:00 pm - 5:00 pm
Tuesday, November 7:	7:30 am - 4:30 pm
Wednesday, November 8:	7:30 am - 5:00 pm
Thursday, November 9:	7:30 am - 10:30 am

Your registration will not be processed without payment.

REFUND POLICY

If written notice of cancellation is received on or before October 16, 2017 payment will be refunded, less a $75 cancellation fee. (Cancellation fees apply regardless of payment method). Substitutions may be made at any time; payment for any difference is due at the time of substitution. This refund policy applies to all occurrences, including weather-related events and other natural disasters. In the unlikely occurrence of event cancellation, the Association is not liable for any expenses incurred by the registrant other than the full refund of registration fee(s) paid.

CONFERENCE PROCEEDINGS

Conference proceedings will be posted on the A&WMA website after the conference. Attendees will be notified via e-mail when the extended abstracts and presentations are available.

CONTINUING EDUCATION CREDIT

Conference attendees may be eligible for continuing education credits. For more information, please contact Gloria Henning at +1-412-904-6021 or glhenning@awma.org.

PRESENTERS' MEETING

Presenters and Session Chairs will meet on the day of their session involvement to review program details in Bixby 1, 2, and 5. Presenters should bring their presentations on a memory stick/USB to this meeting, as well as a brief biography.

CONFERENCE COMMITTEE

Conference Co-Chairs:
Ricky Tropp, Desert Research Institute
Eric Winegar, Exponent, Inc.

Technical Program Committee:
Tim Dye, TD Environmental Services
Sara Head, Yorke Engineering, LLC
Ray Merrill, U.S. EPA

LOCATION

Renaissance Long Beach Hotel
111 East Ocean Blvd., Long Beach, CA 90802
Phone: (562) 437-5900

ADA/SPECIAL REQUIREMENTS

The Air & Waste Management Association supports the Americans with Disabilities Act (ADA). Attendees requiring specific equipment or services should contact Cindy Fontanesi at cfontanesi@awma.org to make those needs known in advance. We will make every reasonable effort to accommodate them.

THANK YOU TO OUR SPONSORS

GOLD SPONSOR

SCAQMD is the air pollution control agency for Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. SCAQMD works proactively with its stakeholders in promoting advanced technologies and developing innovative control strategies so that its 17 million residents can breathe cleaner air and live healthier lives.

SILVER SPONSOR

Atmosphere (ISSN 2073-4433; IF: 1.487) is an international open access journal of scientific studies providing an advanced forum for atmospheric chemistry, atmospheric physics, and meteorology.

NETWORKING BREAK SPONSOR

Magee Scientific is the originator of the Aethalometer®, the most widely used instrument for real-time measurement of Black Carbon aerosols. The Optical Transmissometer measures the BC content of previously-collected filter samples. The new Total Carbon Analyzer measures the TC content, from which EC and OC may be derived.

GENERAL SPONSOR

Since 1994, Orsat has customized the installation and maintenance of hardware and software to produce a robust application for continuous unattended field measurement of VOCs in ambient air for Photochemical Assessment Monitoring Stations (PAMS). Orsat's services encompass all aspects of site operation and quality control from deployment to operator training.

GENERAL SPONSOR

Restek is a leading developer and manufacturer of chromatography products. We provide analysts around the world with the innovative tools they need to monitor the quality of air, water, soil, foods, pharmaceuticals, chemical, and petroleum products. We supply columns, standards, and accessories, manufactured under ISO 9001 certification and backed by the best service in the industry. From sample collection to preparation, from injection through separation to detection, build your liquid or gas chromatography solution with products and expertise from Restek.

EXHIBITION INFORMATION

Location: Bixby 3, 4, and Farrell's Lounge, Second Floor
Exhibition Hours: Tuesday, November 7, 9:00 am - 6:00 pm and Wednesday, November 8, 9:00 am to 4:00 pm.

EXHIBITORS

2B Technologies, Inc. Booth 5
www.twobtech.com

2B Technologies, Inc. is dedicated to the development and commercialization of portable analytical instruments for atmospheric and environmental measurements. We specialize in miniaturized instruments for measurements of ozone in air and water as well as NOx(NO/NO2) in air.

AethLabs Booth 23
www.aethlabs.com

AethLabs, located in San Francisco, California, designs and manufactures small, mobile Black Carbon monitors. AethLabs is focused on the development of high quality personal exposure and Black Carbon monitoring instruments. The microAeth® family of Black Carbon monitors consists of three new continuous, unattended, full spectrum, multi-week to multi-month instruments which complement the microAeth® AE51 personal exposure monitor. The new microAeth® MA series boasts many advanced features integrated into compact, lightweight form factors.

Ambilabs Booth 25
www.ambilabs.com

Ambilabs is a full services provider and integrator of air, environmental, and process monitoring solutions. We distribute, install, and train on a broad range of gas and particulate monitoring instrumentation. Our experienced staff provide expertise, engineering, software, instrumentation, systems and solutions for obtaining valid, accurate, and precise air quality data.

ARA Instruments Booth 24
www.arainstruments.com

ARA Instruments is a manufacturer of innovative ambient air monitoring equipment. We specialize in portable, battery-powered particulate samplers for air pollution research. We also offer flow calibration instruments and accessories for routine air monitoring. Our goal is to help our customers make important air quality decisions by providing affordable, versatile, reliable, and accurate equipment.

Atmosfir Optics, LTD Booth 7
www.atmosfir.net

Atmosfir is an innovative, advanced air monitoring Technology Company focused on providing our clients with the best air monitoring solutions. Atmosfir has unique intellectual properties and years of in-the-field experience. Our spectral and spatial data fusion algorithms all use the best available open path hardware, and innovative solutions to meet client needs.

Consolidated Analytical Systems (CAS) Booth 22
www.cas-en.com

Consolidated Analytical Systems (CAS) provides expertise in the design, manufacturing, integration and support of Monitoring Systems for ambient air, industrial fence line and natural gas pipeline sectors. The CAS-manufactured process and standalone Laboratories, Shelters and Enclosures are designed with LEED energy efficiency principles and instrument optimization in mind. CAS offers a complete line of industrial and field deployable gas chromatographs for VOCs and speciated sulfurs as well as Natural Gas impurity measurement, mercaptan identification and odorization.

Cooper Environmental Services Booth 8
www.cooperenvironmental.com

Cooper Environmental Services (CES) has the unique capability to measure and interpret elements using X-ray Fluorescence (XRF) in a fully-automated fashion. CES manufactures XRF-based multi-metals metals monitoring systems for both source and ambient applications. Beyond manufacturing, CES offers other services and knowledge to serve the needs of air quality issues.

DR DAS, LTD Booth 18
www.dr-das.com

DR DAS LTD is the pioneer in digital data collection. Learn about innovative data acquisition and control solutions for air quality, emissions and property line monitoring. Envidas Ultimate DAS, EnvistaARM and public information products (Websites, Kiosks, Telephony, Mobile Apps) will be on display. Learn why 40+ agencies rely on DRDAS.

ENMET Booth 10
www.enmet.com

ENMET manufactures a wide array of environmental and industrial health and safety monitoring instruments. Our new GC based products offer a new cost effective approach to benzene trace level detection (sub ppb) at the Fenceline and in the workplace with the ability to provide specific gas analysis in complex mixtures.

Entech Instruments, Inc. Booth 1
www.entechinst.com

Entech Instruments is a leading developer and manufacturer of analytical instrumentation that supports professionals in the Environmental, Industrial Hygiene, Food & Beverage, Product Testing, Forensic & Clinical Analysis markets. We specialize in the creation of inert sample collection equipment as well as GC & GC/MS sample preparation and introduction technologies.

Forest Technology Systems Booth 16
www.ftsinc.com

Forest Technology Systems (FTS) is a world leader in environmental monitoring with 3500+ weather stations deployed in the US. FTS has the capability to add air quality monitoring sensors to a large network of existing weather monitoring infrastructure. FTS has also developed a solar powered, remote communication camera system which can be used to monitor air quality impacting events, such as a wildfire.

EXHIBITORS CON'T.

Global Analyzer Systems Ltd. Booth 9
www.gasl.ca

Global Analyzer Systems Ltd. offers a wide array of continuous emission monitoring and ambient air technologies. We are excited to release our new Photolytic NO2 Converter. This product can be used as a simple retrofit to existing systems by directly replacing thermal metal converters typical of NOx analyzers, and offers linear conversion over a wide dynamic range providing true NO2.

LA Testing Booth 6
www.latesting.com

LA Testing offers a wide array of analytical testing services to support environmental investigations focused on asbestos, mold & bacteria (microbiology), lead paint, indoor air quality, and industrial hygiene applications. Our unmatched capacity coupled with a company wide focus on customer satisfaction makes no project too large or too small.

M&C TechGroup Booth 19
www.mc-techgroup.com

World Class manufacturer of Gas Sample Probes, Conditioners, Paramagnetic Oxygen Sensors, Hg Sorbent Trap Systems, and Automated Control Panels. Sample Probes and Conditioners are designed for Dilution and/or Straight Extractive Systems for hot/wet or dry source applications. M&C focuses on delivering solutions for a more reliable and trouble free system.

Magee Scientific Booth 15
www.mageescientific.com

Magee Scientific is the originator of the Aethalometer®, the most widely used instrument for real-time measurement of Black Carbon aerosols. The Optical Transmissometer measures the BC content of previously-collected filter samples. The new Total Carbon Analyzer measures the TC content, from which EC and OC may be derived.

Montrose Environmental Group, Inc. Booth 14
www.montrose-env.com

Montrose Environmental Group is a national environmental company offering Air Quality, Environmental Laboratory and Regulatory Compliance services to a diverse range of clients in industry and government. Our team of experienced engineers, scientists, chemists, and technicians provide reliable and timely environmental data using the highest technical and ethical standards.

New Star Environmental, Inc. Booth 13
www.NewStarEnvironmental.com

New Star Environmental has nearly 60 years combined experience in environmental monitoring and related markets with a focus in all applications of aerosol particle measurement. That experience combined with our extensive knowledge in the sampling and analysis of gases has made us the preferred provider of environmental monitoring instrumentation for research institutions, universities, government agencies, environmental, pharmaceutical, and industrial hygiene companies, and more.

Orsat Booth 17
www.orsat.com

Since 1994, Orsat has customized the installation and maintenance of hardware and software to produce a robust application for continuous unattended field measurement of VOCs in ambient air for Photochemical Assessment Monitoring Stations (PAMS). Orsat's services encompass all aspects of site operation and quality control from deployment to operator training.

Scion Instruments Booth 11
www.scioninstruments.com

SCION Instruments is a leading supplier of Gas Chromatography instrumentation and solutions. Building on the legacy of Varian GC and GC-MS, SCION develops, manufactures and markets systems ranging from simple stand-alone GC through to fully configured analyzers which are tailored for specific customers' complex applications and analysis.

Sonoma Technology Booth 20
www.sonomatech.com

Sonoma Technology, Inc. (STI) is an employee-owned firm that delivers innovative, science- and technology-based solutions for our clients' environmental needs worldwide. Our services include air quality research, atmospheric measurements, air quality and smoke forecasting, atmospheric modeling and analysis, instrumentation and data system development, software development, decision support systems, and outreach.

Sunset Labs Booth 22
www.sunlab.com

Sunset Laboratory has been leading the way for Organic/Elemental Carbon Aerosol (OCEC) measurements since 1984. We remain the market leader in OCEC instrumentation and analysis for filters with our Laboratory-based OCEC analyzer and in ambient monitoring with our Semi-Continuous OCEC aerosol analyzer. Our instrumentation has the ability to easily perform a variety of official analysis methods, such as NIOSH Method 5040, Improve-A, STN, EUSAAR2, as well as others.

Teledyne API Booth 12
www.teledyne.com

Teledyne Advanced Pollution Instrumentation offers a complete line of Air Quality Monitoring instrumentation, which complies with the US Environmental Protection Administration, European Union, and other requirements for the measurement of ambient air quality. Utilizing proven measurement principles, we also offer instruments for Continuous Emissions Monitoring and a number of other applications.

TISCH Environmental Booth 22
www.tisch-env.com

Tisch Environmental is a family business founded to develop and manufacture air pollution monitoring instruments. The Tisch family have produced nearly a half million devices for the air pollution monitoring community over the last 60 years. TEI is looking into the future needs of today's aerosol research professionals.

FINAL PROGRAM

EXHIBITORS CON'T.

TricornTech Corporation Booth 21
www.tricorntech.com

TRICORNTECH is a voc monitoring expert, offering a wide product ranges from high-tech portable instruments to online systems and comprehensive software. TRICORNTECH commits to providing integrated, cost-effective, and constructive solutions to assist valued customers solving problems. TRICORNTECH solutions make an excellent foundation for a proactive approach to maintenance, integrated in customers' normal maintenance activities. On Customers' request, TRICORNTECH puts together the monitoring equipment package best suited to your economic and technical requirements.

TSI, Inc. Booth 2
www..tsi.com

TSI, a world leader in particle measurements, offers a variety of aerosol monitors for real-time, direct-reading results. The new Environmental DustTrak™ measures PM1, PM2.5, respirable, PM10 and total PM size fractions, providing near-reference method quality data. In addition, TSI offers ultrafine particle monitors and next-generation lower cost PM2.5 sensors.

URG Corporation Booth 3
www.urgcorp.com

URG is helping to ensure the air we breathe is the best it can be by creating the Ambient Ion Monitor (AIM) for the time-resolved, direct measurement of gas (hydrogen chloride, nitric acid, nitrous acid, sulfur dioxide, ammonia) and artifact free particulate matter (nitrate, sulfate, nitrite, phosphate, chloride ammonium, sodium, calcium, potassium, magnesium) air pollutants. We specialize in Teflon coated cyclones with various cut-points and flow rates, and stainless steel cyclones for diesel emissions.

Yorke Engineering, LLC Booth 4
www.YorkeEngr.com

Yorke Engineering, LLC was founded in 1996 and has assisted over 650 customers with air quality and environmental compliance, engineering, and permitting issues. Our philosophy is to efficiently help government and industrial customers with the complex array of environmental rules and regulations issued by the local, state, and federal agencies.

EXHIBIT FLOOR PLAN - BIXBY 3, 4 and FARRELL'S LOUNGE

EXHIBITORS	BOOTH
2B Technologies, Inc.	5
AethLabs	23
Ambilabs	25
ARA Instruments	24
Atmosfir Optics LTD	7
Consolidated Analytical Systems	22
Cooper Environmental Services	8
DR DAS, LTD	18
ENMET	10
Entech Instruments, Inc.	1
Forest Technology Systems	16
Global Analyzer Systems Ltd.	9
LA Testing	6
M&C TechGroup	19
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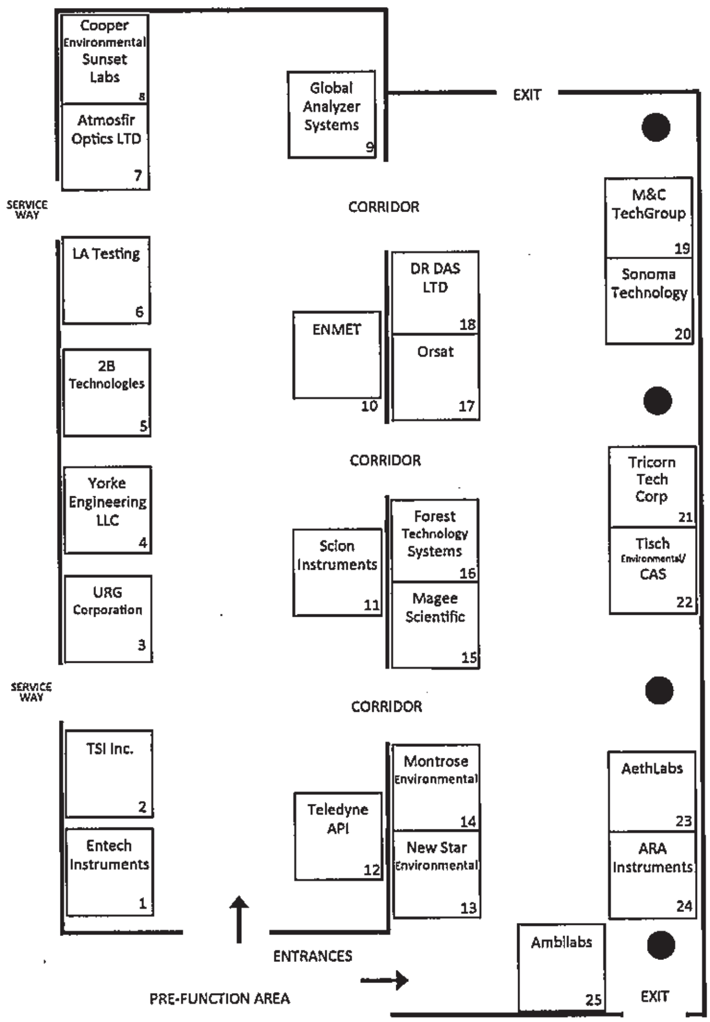
Tisch Environmental, Inc.	22
TricornTech Corporation	21
TSI Inc.	2
URG Corporation	3
Yorke Engineering, LLC	4



TECHNICAL PROGRAM - Monday, November 6

8:30 am - 5:00 pm
TRAINING COURSE
Dawson (Third Floor)

Optimizing Quality Assurance for Ambient Air Monitoring Programs

Instructors: Jason Low, Ph.D., QA Manager, South Coast Air Quality Management District; Eugenia McNaughton, Ph.D., QA Manager, U.S. EPA Region 9; Mathew Plate, Environmental Scientist, U.S. EPA Region 9

Broadly, the application of quality assurance principles and processes has three basic components. This training will start with EPA and air monitoring agencies optimization strategies for systematic planning and quality control. How to use the data quality objectives process in the development of an ambient air monitoring program will be discussed in detail. Reviewing the data and the quality system is the last "leg of the stool" and must include a well-defined corrective action process. These concepts will be used to develop and optimize a hypothetical air monitoring program.

Course Objectives:

- Learn quality system concepts
- Become aware of quality assurance resources for ambient air
- Gain a working knowledge on the development of ambient air monitoring quality systems
- Develop an understanding of air monitoring system oversight, improvement, and corrective action

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TECHNICAL PROGRAM - Tuesday, November 7

7:30 am - 4:30 pm
Conference Registration
Second Floor Counter

7:30 am - 8:30 am
Continental Breakfast and Presenters' Meeting
Bixby 1, 2, and 5

9:00 am - 6:00 pm
Exhibition Viewing
Bixby 3, 4, and Farrell's Lounge

8:30 am - 8:45 am
Conference Welcome and Introduction
Bixby 1, 2, and 5
Eric Winegar, Conference Co-chair, Exponent, Inc., and Sara Head, A&WMA Past President, Director, West Coast Section, Yorke Engineering, LLC

8:45 am - 9:45 am
Keynote Session
Bixby 1, 2, and 5

Opportunities for New Clean Air Collaboration
Wayne Nastri, Executive Officer, South Coast Air Quality Management District

Policies Driving California's Air Quality Measurement Priorities
Michael Benjamin, Chief, Monitoring and Laboratory Division, California Air Resources Board

REFESHMENT BREAK AND EXHIBITION VIEWING FOR ALL SESSIONS
9:45 am - 10:15 am
Bixby 3, 4 and Farrell's Lounge

FINAL PROGRAM

TECHNICAL PROGRAM - Tuesday, November 7

Session 1A:

SENSOR APPLICATIONS
[concurrent with Session 2A]
Broadlind

Chair: *Tim Dye, TD Environmental Services*

10:15 am – 10:40 am
ME79
State of Air Quality Sensing in 2017 - Where We Are, Where We're Going.
Tim Dye, TD Environmental Services, LLC, Petaluma, CA

10:40 am – 11:05 am
ME58
Design and Development of a "Low-Cost" Sensor Network to Measure Volatile Organic Compounds for Facility and Community Monitoring
Robert Wimmer, Olga Pikelnaya, Andrea Polidori; South Coast Air Quality Management District, Diamond Bar, CA

11:05 am – 11:30 am
ME70
"Low-cost" Sensors for Measuring Gaseous and Particle Air Pollutants: Performance Results from Three Years of AQ-SPEC Field and Laboratory Testing and Network Applications at the Fenceline and Community Level
Vasileios Papapostolou, Brandon Feenstra, Hang Zhang, Andrea Polidori, South Coast Air Quality Management District, Diamond Bar, CA

11:30 am – 11:55 am
ME59
Assessing Community Exposure to Hazardous Air Pollutants Using a Combination of Optical Remote Sensing and "Low-Cost" Sensor Technologies
Olga Pikelnaya, Andrea Polidori, Robert Wimmer, South Coast Air Quality Management District, Diamond Bar, CA; Johan Mellqvist, Jerker Samuelsson, Marianne Ericsson, Pontus Andersson, Samuel Brohede, Oscar Izos, FluxSense Inc., San Diego, CA

Session 2A:

OIL AND GAS MONITORING
[concurrent with Session 1A]
Pike 3

Chairs: *Ray Merrill and Ned Shappley, U.S. EPA*

10:15 am - 10:40 am
ME80
Addressing Public Outrage at an Oil Field Site in Down Town Los Angeles—An Air Monitoring and Risk Mitigation Model for Other Urban Oil and Gas Operations
Eric Winegar, Exponent, Inc.; Charles E. Lambert, Intrinsik, Inc., Sacramento, CA

10:40 am - 11:05 am
ME07
Fugitive Emissions Testing at California Natural Gas Production Facilities
David Ranum, TRICORD Consulting, LLC, Frisco, TX; Michael Hebert, Booth Environmental, Lake Charles, LA

11:05 am - 11:30 am
ME05
Indoor and Outdoor Assessment of PM Concentrations at Umm Al-Aish Oil Field-North Kuwait
Ashraf Ramadan, Environmental Pollution and Climate Program, Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, Safat, Kuwait

LUNCH PRESENTATION
Bixby 1, 2, and 5
12:00 pm – 1:30 pm

Welcome from Scott Freeburn, *A&WMA 2017 President*

AB617: Making What We Measure Matter
Janet Whittick, *Director of Policy, California Council for Environmental and Economic Balance*

TECHNICAL PROGRAM - Tuesday, November 7

Session 1B:
SENSOR APPLICATIONS
[concurrent with Session 2B]
Broadlind

Chair: *Tim Dye, TD Environmental Services*

1:30 pm – 1:55 pm
ME73
Variations in Wintertime PM among Communities in Sacramento Measured with a Combination of Traditional and Low-Cost Sensor Methods
Anondo Mukherjee, Steven G. Brown, Michael C. McCarthy, Sonoma Technology, Petaluma, CA; Aleta Kennard, Janice Lam Snyder, Stephen D'Andrea, Sacramento Metropolitan Air Quality Management District, Sacramento, CA

1:55 pm – 2:20 pm
ME56
Application of Consumer-grade Sensors to Study the Effect of Heatwaves on Indoor Air Quality
Gediminas Mainelis, Ruikang He, Department of Environmental Sciences, Rutgers University, New Brunswick, NJ; Ioanna Tsoulou, Sanjeevi Thirumurugesan, Brian Morgan, Stephania Gonzalez, Deborah Plotnik, Jennifer Senick, Clinton Andrews, Edward J. Bloustein School of Planning and Public Policy, Rutgers University, New Brunswick, NJ

2:20 pm – 2:45 pm
ME28
Development of Hybrid Microresonators for Optical Vapor Detection
Simin Mehrabani, South Coast Air Quality Management District, Diamond Bar, CA; Andrea M. Armani, University of Southern California, Los Angeles, CA

Session 2B:
OPTICAL GAS IMAGING AND MONITORING MEASUREMENTS
[concurrent with Session 1B]
Pike 3

Chairs: *Ray Merrill and Ned Shappley, U.S. EPA*

1:30 pm – 1:55 pm
ME29
Video Imaging Spectral Radiometry (VISR) Based Flare Monitor
Yousheng Zeng, Jon Morris, Srikanth Mutyala, Albert Sanders, Providence Photonics, Baton Rouge, LA

1:55 pm - 2:20 pm
ME30
Applications and Field Results for Quantitative Optical Gas Imaging
Jon Morris, Yousheng Zeng, Srikanth Mutyala, Albert Sanders, Providence Photonics, Baton Rouge, LA

2:20 pm - 2:45 pm
ME33
Dual-Cell FTIR Analyses of Semiconductor Point-of-Use Abatement Devices
Brian Adair, Geosyntec Consultants, Charlotte, NC; Curtis T. Laush, Geosyntec Consultants, Austin, TX

REFESHMENT BREAK AND EXHIBITION VIEWING FOR ALL SESSIONS
2:45 pm - 3:10 pm
Bixby 3, 4, and Farrell's Lounge

Session 1C: SENSOR APPLICATIONS PANEL
3:10 pm - 4:40 pm
Bixby 1, 2, and 5

Chair: *Tim Dye, TD Environmental Services*

Panelists include:

- Andrea Polidori, *Atmsopheric Measurements Manager South Coast Air Quality Management District* (Government)
- Michael Ogletree, *Air Quality Program Manager, Denver Dept. of Environmental Health* (City)
- Barbara Toole O'Neil, *Principal Scientist, Scan-It Technologies* (Private Sector)
- Gediminas "Gedi" Mainelis, Ph.D., *Professor, Rutgers University* (Academia)
- Luis Olmedo Velez, *Executive Director, Comite Civico del Valle* (Community)

NETWORKING RECEPTION AND EXHIBITION VIEWING
4:45 pm - 6:00 pm
Bixby 3, 4, and Farrell's Lounge

FINAL PROGRAM

TECHNICAL PROGRAM - Wednesday, November 8

7:30 am – 5:00 pm
Conference Registration
Second Floor Counter

7:30am - 8:30 am
Continental Breakfast and Presenters' Meeting
Bixby 1, 2, and 5

9:00 am - 4:00 pm
Exhibition Viewing
Bixby 3, 4, and Farrell's Lounge

Session 3A:
AIR TOXICS
[concurrent with Sessions 4A and 5A]
Broadlind

Chairs: *Julie Swift, ERG, and Stephen Dutz, South Coast Air Quality Management District*

8:30 am – 8:55 am
ME63
Exemptions and Studies in Reference to the EPA NATTS Carbonyl and Polycyclic Aromatic Hydrocarbon (PAH) Programs
Randy Bower and Julie Swift, ERG, Morrisville, NC

8:55 am – 9:20 am
ME64
Evaluation of U.S. EPA Method TO-11A for the Measurement of Carbonyls in Ambient Air
Ian C. MacGregor, Elizabeth A. Hanft, Brannon A. Seay, Naveen Shankar, Nicholas D. Skomrock, Martha W. McCauley, Larry A. Mullins, Dennis J. Tomcik, Christina Saeger, Douglas J. Turner, Marcie Lindner, Melissa L. Langton, Battelle, Columbus, OH

9:20 am – 9:45 am
ME67
Improving On-Line (PAMS) and Canister (TO-15) Analysis of Trace-Level Compounds in High-Humidity Ambient Air
Nicola Watson, Rui Li, Claire Keller; Markes International Inc, Gold River, CA

9:45 am – 10:10 am
ME83
Novel Approach to Measuring Non-Methane Organic Compounds (NMOC) with Cryo-Trapping
Randall Bramston-Cook, Edward Bramston-Cook, Lotus Consulting, Long Beach, CA

Session 4A:
NETWORK PM DATA
[concurrent with Sessions 3A and 5A]
Pike 3

Chair: *Ann Dillner, University of California, Davis*

8:30 am – 8:55 am
ME47
Chemical Speciation Network Data Validation: Techniques, Challenges, and Lessons Learned
Dominique E. Young, Sean M. Raffuse, Nicholas J. Spada, Nicole P. Hyslop, Krystyna Trzepla, Air Quality Research Center, University of California, Davis, Davis, CA

8:55 am – 9:20 am
ME40
Characterizing Carbonaceous Aerosols in Ambient Monitoring Networks using Fourier Transform Infrared Spectroscopy
Ann M. Dillner, Andrew T. Weakley, Bruno Debus, Alexandra J. Boris, University of California, Davis, Davis, CA; Adele Kuzmiakova, Satoshi Takahama, ENAC/IIE, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland

9:20 am – 9:45 am
ME45
Comparison of Three FTIR Instruments for the Prediction of Carbonaceous Aerosols in Large Particulate Speciation Networks – Is Calibration Transfer Required?
Bruno Debus, Andrew T. Weakley, Ann M. Dillner, University of California, Davis, Davis, CA; Matteo Reggente, Satoshi Takahama, ENAC/IIE, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland

9:45 am – 10:10 am
ME46
Quantification of Organic Aerosol Composition by Functional Groups: Using Infrared Spectroscopy to Measure Carbonyl Mass within the Southeastern Aerosol Research and Characterization (SEARCH) Network
Alexandra J. Boris, Andy T. Weakley, Bruno Debus, Ann M. Dillner, Air Quality Research Center, University of California Davis, Davis, CA; Satoshi Takahama, Swiss Federal Institute of Technology, Lausanne, Switzerland

REFRESHMENT BREAK AND EXHIBITION VIEWING FOR ALL SESSIONS
10:10 am - 10:40 am
Bixby 3, 4, and Farrell's Lounge

Session 5A:
FUGITIVE MODELING
[concurrent with Sessions 3A and 4A]
Pike 2

Chair: *Ray Merrill and Ned Shappley, U.S. EPA*

8:30 am – 8:55 am
ME61
The TEMMAS project "Teledetection, Measure, Modeling of Atmospheric Pollutants on Industrial Sites": Confrontation of PM Analysis with Dispersion Models (non-reactive Lagrangian Model and Plume in Grid model with Chemical Mechanism)
Olivier Duclaux, Laboratoire Qualité de l'Air, TOTAL RESEARCH CENTER, Solaize, France; Valentin RAFFORT CEREA, Ecole des Ponts ParisTech/EDF R&D, Université Paris-Est, France; Jonathan LEMUS, Laboratoire Qualité de l'Air, TOTAL RESEARCH CENTER, Solaize, France; Pierre Yves FOUCHER ONERA, The French Aerospace Lab; Edouard Belin, Toulouse, France; YELVA ROUSTAN CEREA, Ecole des Ponts ParisTech/EDF R&D, Université Paris-Est, 77455 Champs-sur-Marne, France; Alexandre ARMENGAUD AIRPACA, Marseille, France; Henri WORTHAM Laboratoire Chimie et de l'Environnement, Université Apix-Marseille

8:55 am – 9:20 am
ME19
NonParametric Trajectory Analysis of R2Pier Data
Ronald C. Henry, University of Southern California, Los Angeles, CA; Gayle Hagler, U. S. EPA Office of Research and Development, Research Triangle Park, NC; Daniel Birkett, U.S. EPA Region 2, New York, NY

9:20 am – 9:45 am
ME62
Quantification of VOC Emission by Remote Monitoring: Reverse Dispersion Modeling in Complex Industrial Site for Quantification of VOC Emission in Waste Water Treatment of a Refinery Implementing Micro-Sensors Network
Olivier Duclaux, Jonathan Lemus, Ludovic Donnat, Catherine Juery, TOTAL Refining & Chemistry, Laboratoire Qualité de l'Air, TOTAL RESEARCH CENTER, Solaize, France; Brice Hellio, Azzedine Ben Daoud, CAIRPOL, Environnement S.A group, POISSY CEDEX 4 – FRANCE

TECHNICAL PROGRAM - Wednesday, November 8

Session 3B:

AIR TOXICS
[concurrent with Sessions 4B and 5B]
Broadlind

Chairs: *Julie Swift, ERG, and Stephen Dutz, South Coast Air Quality Management District*

10:40am – 11:05 am
ME12
Taking Your Lab to the Field: AutoGC Systems and the Data they Generate
Carol J. Meyer, Orsat, LLC, Pasadena, TX

11:05 am – 11:30 am
ME82
Extremely Wide Concentration Ranges for Toxic Analytes in Air with Lotus Consulting TO15 Analyzer and Scion SQ Mass Spectrometer
Randall Bramston-Cook, Edward Bramston-Cook, Lotus Consulting, Long Beach, CA; Stefan D'Angona, Charles Reinero, Enthalpy Analytical LLC., Berkeley, CA; Mark Scesny, M Solutions, Terrell, TX

11:30 am – 11:55 am
ME72
A New Cryogenless TO15 Canister Preconcentrator with Substantially Reduced System Carrier-Over When Exposed to Higher Concentration Samples
Daniel B Cardin, Jiewen Zhang, Tom Robinson, Victoria Noad, Entech Instruments, Inc., Simi Valley, CA

Session 4B:

NETWORK CARBONACEOUS PM
[concurrent with Sessions 3B and 5B]
Pike 3

Chair: *Ann Dillner, University of California, Davis*

10:40 am – 11:05 am
ME48
Fourier Transform Infrared Determination of Organic and Elemental Carbon in PM2.5 Collected from Federal Reference Method Samplers
Andrew T. Weakley, Ann M. Dillner, Air Quality Research Center, University of California Davis, Davis, CA; Satoshi Takahama, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland

POSTER PRESENTATIONS

11:05 am – 11:30 am
ME44
Determination of Carbonaceous Aerosols in IMPROVE Network Samples Based on FTIR Spectroscopy – Assessing the Impact of Spectral Processing Methods
Bruno Debus, Andrew T. Weakley, Ann M. Dillner, University of California, Davis, Davis, CA; Matteo Reggente, Satoshi Takahama, ENAC/IIE, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland

11:30 am – 11:55 am
ME49
Fourier Transform Infrared Determination of Organic and Elemental Carbon: Addressing Anomalous Predictions Related to Aerosol Sources
Andrew T. Weakley, Ann M. Dillner, Air Quality Research Center, University of California Davis, Davis, CA; Satoshi Takahama, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland

Session 5B:

FUGITIVE FENCELINE MONITORING
[concurrent with Sessions 3B and 4B]
Pike 2

Chair: *Clinton Macdonald and Hilary Hafner, Sonoma Technology, Inc.*

10:40 am – 11:05 am
ME74
Assessment of Technology Needed to Meet Refinery Air Quality Fenceline Monitoring Rules
Clinton MacDonald, Paul Roberts, Hilary Hafner, Sonoma Technology, Petaluma, CA

11:05 am – 11:30 am
ME55
Field Study on Online Monitoring Network of Air Toxics and Source Tracking at Petrochemical Industrial Park
Yu-Cheng Chen, Chin-Yu Hsu, National Environmental Health Research Center, National Health Research Institutes, Miaoli, Taiwan; Ching-Lin Hsiao, TricornTech Corporation, Taipei, Taiwan; Li-Peng Wang, Tsung-Kuan A. Chou, TricornTech Corporation, San Jose, CA

11:30 am – 11:55 am
ME 36
Assessment of Benzene Fenceline Monitoring Data for Corrective Action Planning and Near-field Source Correction
David L. Elam, Jr., TRC Companies, Raleigh, NC

LUNCH FOR ALL SESSIONS
12:00 pm - 1:30 pm
Bixby 1, 2, and 5

FINAL PROGRAM

TECHNICAL PROGRAM - Wednesday, November 8

Session 3C:
AIR TOXICS
[concurrent with Sessions 4C and 5C
Broadlind

Chair: *Ian MacGregor, Battelle*

1:30 pm – 1:55 pm
ME01
Migration from Analog to Digital Data Acquisition in an Ambient Air Quality Measurement Network
Yousaf Hameed, Clark County Department of Air Quality, Las Vegas, NV

1:55 pm – 2:20 pm
ME09
Source Profiles and Ozone Formation Potentials (OFPs) of Volatile Organic Compounds (VOCs) of Port Industries
Qiaoli Wang, State Key Laboratory of Clean Energy Utilization, Institute for Thermal Power Engineering, College of Energy Engineering, Zhejiang University (Yuquan Campus), Hangzhou, China; Wei LI, Key Laboratory of Biomass Chemical Engineering of Ministry of Education, Institute of Industrial Ecology and Environment, College of Chemical and Biological Engineering, Zhejiang University (Yuquan Campus), Hangzhou, China; Sujing LI, Key Laboratory of Biomass Chemical Engineering of Ministry of Education, Institute of Industrial Ecology and Environment, College of Chemical and Biological Engineering, Zhejiang University (Yuquan Campus), Hangzhou, China; Xiang GAO, State Key Laboratory of Clean Energy Utilization, Institute for Thermal Power Engineering, College of Energy Engineering, Zhejiang University (Yuquan Campus), Hangzhou, China; Dongxiao Zhang, Henan Tianguan Group Co., Ltd. Nanyang, China

2:20 pm – 2:45 pm
ME41
Increasing Interest in and Use of Passive Diffusive Samplers in Vapor Intrusion Investigations
Samantha Henningsen, ALS Group Air Quality Laboratory, Simi Valley, CA

Session 4C:
PM SPECIATION
[concurrent with Sessions 3C and 5C]
Pike 3

Chair: *Ricky Tropp, Desert Research Institute*

1:30 pm – 1:55 pm
ME39
NonParametric Trajectory Analysis of CMAPS Data
Ronald C. Henry, University of Southern California, Los Angeles, CA; Gary A. Norris, U. S. EPA, Research Triangle Park, NC

1:55 pm – 2:20 pm
ME54
Positive Matrix Factorization (PMF) and Data Quality Assessment of EPA's PM2.5 Chemical Speciation Network (CSN) Derived from Six Collocated CSN Sites for the Period 2010 - 2013
Richard J. Tropp, Division of Atmospheric Sciences, Desert Research Institute, Reno, NV; L.-W. Antony Chen, Department of Environmental and Occupational Health, University of Nevada Las Vegas, Las Vegas, NV

2:20 pm – 2:45 pm
ME86
A New Method and Instrument for the Measurement of Carbonaceous Aerosols
M. Rigler; Aerosol d.o.o. Ljubljana, Slovenia, L. Drinovec, G. Močnik, Aerosol d.o.o., Ljubljana, Slovenia, Jozef Stefan Institute, Slovenia; A. D. A. Hansen, Magee Scientific Corp., Berkeley, CA

2:45 pm – 3:10 pm
ME14
Assessing Continuous PM2.5 Monitoring with FEM SHARP 5030 in Ontario, Canada
Yushan Su, Uwayemi Sofowote, Jerzy Debosz, Luc White, Anthony Munoz, Ontario Ministry of the Environment and Climate Change, Toronto, Ontario, Canada

REFRESHMENT BREAK AND EXHIBITION VIEWING
3:10 pm - 3:40 pm
Bixby 3, 4, and Farrell's Lounge

Session 5C:
FUGITIVE ADVANCED MONITORING
[concurrent with Sessions 3C and 4C]
Pike 2

Chair: *Clinton Macdonald and Hilary Hafner, Sonoma Technology, Inc.*

1:30 pm – 1:55 pm
ME68
Long Distance Detection of Aromatics with UV LED-Based Absorption Correlation Spectroscopy
Pascal Dufour, François Babin, Félix Cayer, and Jean-François Y. Gravel, INO, Québec City, QC, Canada

1:55 pm – 2:20 pm
ME85
Advanced Remote Sensing Solutions Accommodating Petrochemical/Chemical Industrial Monitoring Needs and Challenges
Gilad Shpitzer, Atmosfir Optics Ltd, A.S. Research Services

2:20 pm – 2:45 pm
ME71
Combining US EPA Methods TO15 and 325A/B on a Single GC/MS
Daniel B Cardin, Jiewen Zhang, Tom Robinson, Victoria Noad, Entech Instruments, Inc., Simi Valley, CA

2:45 pm – 3:10 pm
ME03
Assessment of Ambient Air Pollution Levels at Umm Al-Aish Oil Field-Kuwait
Ashraf Ramadan, Mufreh Al-Rashidi, Environmental Pollution and Climate Program, Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, Safat, Kuwait

TECHNICAL PROGRAM - Wednesday, November 8

Session 3D:
STATIONARY SOURCE METHODS
[concurrent with Sessions 4D and 5D]
Broadlind

Chair: *Ned Shappley, U.S. EPA*

3:40 pm - 4:05 pm
ME84
Performance of a Non-Methane Organic Compound Analyzer - EPA Method 25 and South Coast AQMD Method 25.3
Randall Bramston-Cook, Edward Bramston-Cook, Lotus Consulting, Long Beach, CA; Douglass Williams, Almega Environmental, Cypress, CA

4:05 pm – 4:30 pm
ME88
An Emerging Technique for Low-Concentration Measurement of Particulate Emissions from Gas-Fired Gas Turbines
Kevin J. Crosby, Montrose Air Quality Services, LLC, Antioch, CA; Glenn C. England, Ramboll Environ, Irvine, CA

4:30 pm - 4:55 pm
ME27
Application of Real-Time and On-Site Air Emissions Measurement Technologies to Optimize the Use of Mixed and Alternate Fuels
Thomas A. Dunder, TRC Environmental Corporation, Raleigh, NC

4:55 pm - 5:20 pm
ME90
Electrochemical Portable Analyzer Test Method Update
Wendy Coulson and Jim McCarthy, Innovative Environmental Solutions, Inc., Cary, IL

Session 4D:
OTHER NEW METHODS
[concurrent with Sessions 3D and 5D]
Pike 3

Chair: *Ricky Tropp, Desert Research Institute*

3:40 pm – 4:05 pm
ME87
Comparison Study of Particulate Matter Light-Scattering Mass Monitor to Beta Attenuation and Gravimetric Methods
Rachel Kolberg, Piotr Nowinski, Mick Turner, Clark County Department of Air Quality, Las Vegas, NV

4:05 pm – 4:30 pm
ME25
A Comparative Study of Sensor Output from Solar Radiation Sensors with Varying Spectral Responses and the Impacts on Aermod Modeling Results: Part I Monitoring Results
Shane L. Hansen, Inter-Mountain Labs, Sheridan, WY; Ronn G. Smith, Independent Consultant, Powell, WY

POSTER PRESENTATIONS

4:30 pm – 4:55 pm
ME22
An Alternative Approach to Ambient Nitrogen Dioxide (NO2) Monitoring
Doug Haugen and Patrick King, Teledyne Advanced Pollution Instrumentation, San Diego, CA

4:55 pm – 5:20 pm
ME06
Open-Path Hydrocarbon Laser Sensor for Oil and Gas Facility Monitoring
Betsy M. Farris, Colorado State University, Fort Collins, CO; Eben Thoma, U.S. Environmental Protection Agency, Research Triangle Park, NC; Parikshit J. Deshmukh, Jacobs Technology Inc., Research Triangle Park, NC; Azer P. Yalin, Colorado State University, Fort Collins, CO

Session 5D: CRITERIA POLLUTANTS METHOD DEVELOPMENT
[concurrent with Sessions 3D and 4D]
Pike 2

Chair: *Eric Winegar, Exponent, Inc.*

3:40 pm – 4:05 pm
ME52
A Standalone True NO2 Converter for Upgrading Chemiluminescence Analyzers
Charles A. Odame-Ankrah, Carlyn L.F. McGeean, Charles E. Grimm, Brian W. Rosentreter, Brodie D. Biggar, Global Analyzer Systems Limited, Calgary, AB, Canada

4:05 pm – 4:30 pm
ME31
Field Evaluations of Newly Available "Interference-free" Monitors for Ozone (O3) Interferences and Inlet Height O3 Gradients at Rural and Urban NAAQS Compliance Sites
Will M. Ollison, API, Washington, DC; Alan R. Leston, AirQuality Research & Logistics, LLC, Lebanon, CT

4:30 pm – 4:55 pm
ME60
Evaluation of Epifluorescence Methods for Quantifying Bioaerosol in Air Quality Samples
L.-W. Antony Chen, Ting Liu, Mi Zhang, Rachel Kolberg, Department of Environmental and Occupational Health, University of Nevada Las Vegas, Las Vegas, NV; Judith C. Chow, John G. Watson, Division of Atmospheric Sciences, Desert Research Institute, Reno, NV

4:55 pm – 5:20 pm
ME51
Real-Time PM Measurement Using BAMs and High-Volume Samplers
Bipul Saraf and Greg Wolffe, Yorke Engineering, LLC, San Juan Capistrano, CA

ALL ATTENDEES INVITED:
A&WMA West Coast Section and Orange County Chapter Meeting
6:00 pm - 9:30 pm
L'Opera Restaurant, 101 Pine Avenue, Long Beach, CA

Welcome and Introduction from Scott Freeburn, A&WMA President

Feature Presentation: Air Pollution and Human Health: What's Climate Got to Do With It?
Michael T. Kleinman, Ph.D., *Professor and Associate Director of the Air Pollution Health Effects Laboratory in the Department of Medicine at University of California at Irvine*

Cost: $35 A&WMA Members; $50 Nonmembers
Register online at: https://wcsawma_dinner_meeting_lb_nov_8.eventbrite.com/.

Contact Chhai Chorn at CCHorn@aqmd.gov or Sara Head at SHead@YorkeEngr.com.

FINAL PROGRAM

TECHNICAL PROGRAM - Thursday, November 9

7:30 am – 10:30 am
Conference Registration
Second Floor Counter

7:30am - 8:30 am
Continental Breakfast and Presenters' Meeting
Bixby 1, 2, and 5

Session 6A:
AGRICULTURE/LANDFILL MEASUREMENTS
[concurrent with Session 7A and 8A]
Broadlind

Chair: *Greg Wolffe, Yorke Engineering, LLC*

8:30 am – 8:55 am
ME53
Real-Time Nuisance Odor Monitoring and Notification System
Greg Wolffe and Bipul K. Saraf, Yorke Engineering, LLC, San Juan Capistrano, CA

8:55 am – 9:20 am
ME42
Identification of Agricultural Emissions – What's That Smell?
Samantha Henningsen, ALS Group Air Quality Laboratory, Simi Valley, CA

9:20 am – 9:45 am
ME17
Assessment of Odor Impacts from Landfill Operations
Paul W. Schafer, SCS Engineers, Sacramento CA; Thomas J. Rappolt, SCS Engineers, Carlsbad CA,

9:45 am – 10:10 am
ME50
New Instrument for Ambient Air Monitoring
Pete Manautou, Barbara Toole O'Neil, Scanit Technologies, San Francisco, CA

Session 7A:
COMMUNITY ASSESSMENT
[concurrent with Session 6A and 8A]
Bixby 3

Chair: *Laki Tisopulos, South Coast Air Quality Management District*

8:30 am - 8:55 am
ME23
Swansea Elementary School Fixed Site Demonstration Project for Monitoring of Construction Air Quality
Michael R. Ogletree, Department of Environmental Health (DEH), City & County of Denver, CO

8:55 am – 9:20 am
ME02
Rehabilitation of Mercury Polluted Industrial Site by the Construction and Accommodation of an Official Building
Layla Al-Awadi, Abdul Rehman Khan, Environmental Pollution and Climate Program (EPCP); Mufreh Al-Rashidi, Crisis Decision Support Program (CDS), Environment and Life Sciences Research Center (ELSRC), Kuwait Institute for Scientific Research, Kuwait

9:20 am – 9:45 am
ME04
Assessment of Noise Levels Spatial Distribution at Umm Al-Aish Oil Field-Kuwait
Ashraf Ramadan, Environmental Pollution and Climate Program, Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, Safat, Kuwait

REFRESHMENT BREAK
10:10 am - 10:30 am
Second Floor Prefunction Hallway

Session 8A:
ADVANCED FUGITIVE MONITORING
[concurrent with Session 6A and 7A]
Bixby 4

Chair: *Ricky Tropp, Desert Research Institute*

8:30 am – 8:55 am
ME43
FluxSense Technology PlatformMobile Measurements of Fugitive Emissions from Refineries, Oil & Gas Production, Dairy Production, CAFOs and More
Marianne Ericsson, FluxSense, Inc., San Diego, CA; Johan Mellqvist, FluxSense AB, Jerker Samuelsson, Samuel Brohede, Pontus Andersson, John Johansson, Oscar Isoz, FluxSense AB, Gothenburg, Sweden

8:55 am – 9:20 am
ME11
Area Fugitive Remote Sensing Campaign for Tailings Ponds and Mine Faces
James Beck, Daniel M. Burt, Suncor Energy Services Inc., Calgary, Alberta, Canada

TECHNICAL PROGRAM - Thursday, November 9

Session 6B:

AGRICULTURAL/LANDFILL MEASUREMENTS
[concurrent with Session 7B]
Broadlind

Chair: *Greg Wolffe, Yorke Engineering, LLC*

10:30 am – 10:55 am
ME89
Automated Landfill Gas Collection Increases Revenues, Lowers Costs, and Reduces Fugitive Emissions
Joseph G. Michels, Sarah M. Rizk, William D. Bingham, Ian S. Martin, Peter A. Quigley, Loci Controls Inc., Fall River, MA

10:55 am – 11:20 am
ME32
Validation of Tracer Dispersion Method for Quantifying Whole Landfill Methane Emission
Jacob Mønster, FORCE Technology, Brøndby, Denmark; Charlotte Scheutz, Technical University of Denmark, Lyngby, Denmark; Anders Fredenslund, Technical University of Denmark, Lyngby, Denmark

11:20 am - 11:45 am
ME16
Uncertainty Analyses of Backward Lagrangian Stochastic Inverse-Dispersion Technique
Kyoung S Ro, Jerry H Martin, USDA-ARS Coastal Plains Soil, Water & Plant Research Center, Florence, SC; Steven Trabue, USDA-ARS National Laboratory for Agriculture and the Environment, Ames, IA

Session 7B:

NETWORK DESIGN
[concurrent with Session 6B]
Bixby 3

Chair: *Laki Tisopulos, South Coast Air Quality Management District*

10:30 am – 10:55 am
ME75
Considerations for Effective Upper-Air Meteorological Networks
Clinton MacDonald, Kevin Smith, Max Dillon, Sonoma Technology, Petaluma, CA

10:55 am – 11:20 am
ME37
Wintertime PM2.5 Saturation Network in North Pole, Alaska
David H. Bush, David L. Yoho, T&B Systems, Valencia, CA; Tom Carlson, Sierra Research, Sacramento, CA; Barbara Trost, Alex Edwards, Alaska Department of Environmental Conservation, AK

11:20 am – 11:45 am
ME38
Wintertime PM2.5 Mobile Measurements in North Pole, Alaska
David H. Bush, David L. Yoho, T&B Systems, Valencia, CA; Tom Carlson, Sierra Research, Sacramento, CA; Barbara Trost, Alex Edwards, Alaska Department of Environmental Conservation, AK

CONFERENCE ADJOURNS
11:45 am

Thank you for attending the Air Quality Measurements Conference.

Please complete the conference survey that will be sent to you via email in the next few weeks. Your feedback is important to us and we will use it to improve future conferences.

AIR & WASTE MANAGEMENT
ASSOCIATION
◆
SINCE 1907

ABOUT THE AIR & WASTE MANAGEMENT ASSOCIATION

A&WMA is a not-for-profit, nonpartisan professional organization that enhances knowledge and expertise by providing a neutral forum for technology exchange, professional development, networking, public education, and outreach to more than 5,000 environmental professionals in 65 countries. A&WMA also promotes global environmental responsibility and increases the effectiveness of organizations to make critical decisions that benefit society. For more information, please visit **www.awma.org.**

附件 3、會議討論資料

Met One
Instruments, Inc.

μ is the Beta Ray Absorption Cross Section

- μ characterizes how easily material can be penetrated by a beam of light, sound, particles, or other energy or matter.

- It is similar to the mass attenuation coefficient, but defines the effective area per unit mass instead of per particle.

- As beta rays pass through matter they become attenuated. This degradation of the beta ray intensity can be described by the Beer-Lambert exponential attenuation law: $I = I_0 e^{-\mu x}$

Factory Calibration of μ in the BAM 1020

- Beer-Lambert Law is modified for mass in our BAM 1020 to become: $I = I_0 e^{-\mu M/S}$

where:

I_0 is the measured beta ray flux across clean filter tape

I is the measured flux across aerosol-laden filter tape

M is the aerosol mass deposited on the filter tape

S is the spot area

Factory Calibration of μ in the BAM 1020

Continued

- μ compensates for the density of the particulate on the filter spot as it is measured.
- Its value hardly varies for particulates of different density and chemical composition.
- μ is determined from the mass of the reference membrane.
  - The logarithmic ratio of intensity counts on clean filter tape over intensity counts on the membrane determines this mass.
  - μ is related to the ratio of this experimentally determined membrane mass to the predetermined mass of the membrane.

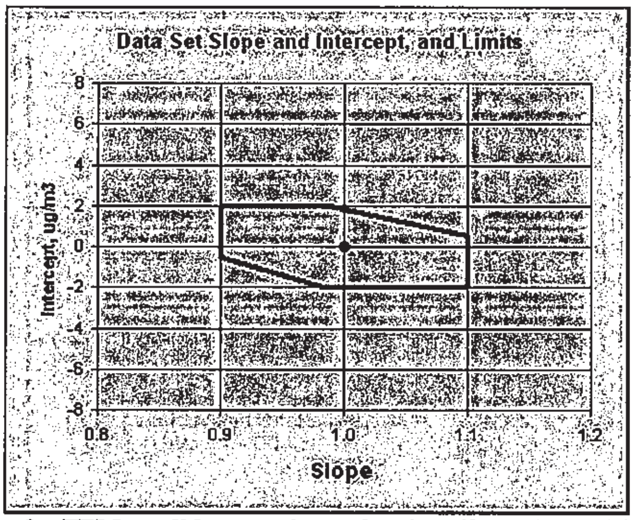
Met One Technical Bulletin
Revised: April 21, 2009 **By:** Dennis Hart

Met One Instruments, Inc.
1600 N.W. Washington Blvd.
Grants Pass, OR 97526
(541) 471-7111
www.metone.com

What is the Difference Between the New BAM-1020 PM2.5 FEM and Older BAM-1020 Monitors?

The Met One Instruments, Inc model BAM-1020 was the first instrument to obtain U.S. EPA Class III Federal Equivalent Method (FEM) designation for PM2.5 continuous particulate monitoring. In order to meet the requirements for the designation, the BAM-1020 was updated with a series of design improvements. These design improvements were required because of several general factors:

- The EPA criteria for PM2.5 FEM designation testing are much more strenuous that the older criteria for PM10 designation. Only a narrow range of slope and offset characteristics are allowed.
- PM2.5 particulate levels are, by nature, much more difficult to measure than PM10 or TSP due to normally low ambient concentrations. Measurement errors of just a couple of micrograms can result in large proportional errors. Also, volatile compounds are often a significant proportion of PM2.5, causing measurement difficulties for both FRM filter samplers and continuous monitors.



U.S. EPA acceptance window for FEM candidate monitors, showing allowable combinations of slopes and offsets.

The BAM-1020 was designated as a PM10 FEM in 1998, and since then thousands of units have been deployed worldwide. Some BAM-1020 users would add a PM2.5 Sharp-Cut Cyclone (SCC, Met One BX-807) or WINS Impactor (Met One BX-804) to these earlier BAMs in order to measure PM2.5 levels for particulate studies, even though this was not an EPA-designated method. Field test results from this early type of PM2.5 configuration showed that the BAMs needed some minor design upgrades before PM2.5 designation:

- The BAM-1020 slopes (multiplier) when compared to PM2.5 FRM filter samplers in linear regressions of 24 hour average measurements, were typically adequate and usually between 0.9 and 1.1, as long as the sample RH was properly controlled and there was a reasonable variety of concentration levels in the data set.
- There was typically a small positive Y-intercept offset (additive bias) of about +2 to +3 micrograms in the linear regressions of the BAM compared to an FRM.

- The hourly noise levels of the earlier BAMs made accurate measurements in concentrations below about 10 micrograms difficult.
- The old wrap-around inlet heaters often did not adequately control the sample RH levels in higher humidity environments. Controlling the sample RH to 35% results in better correlation results.

As a result of these characteristics, design improvements for the BAM-1020 were developed by Met One Instruments during 2006. Improvements were made to the BAM-1020 hardware, firmware, accessories, and calibration:

Hardware:

- The entire BAM-1020 mechanical tape control "transport" system was redesigned for filter tape positioning accuracy of better than 0.001 inch (0.025mm) on all axis. This reduced the hourly noise band of the BAM by ensuring that the exact same point of filter tape is measured clean and dirty.
- The beta source was moved 25% closer to the filter tape, increasing the count rate and improving the signal-to-noise ratio.

Firmware:

- The beta count time for the hourly clean spot (I_0) and the dirty spot (I) count periods was increased from 4 minutes to 8 minutes as a required setting for all PM2.5 FEM units, improving the statistical noise stability by 40%, known as the "2X" effect. This reduced the hourly noise band of the BAM.
- The flow calibration was changed to a three-point slope instead of a single point calibration. This improved the dynamic flow control accuracy.
- Extra flow statistics data files were added, similar to those in FRM samplers.

Accessories:

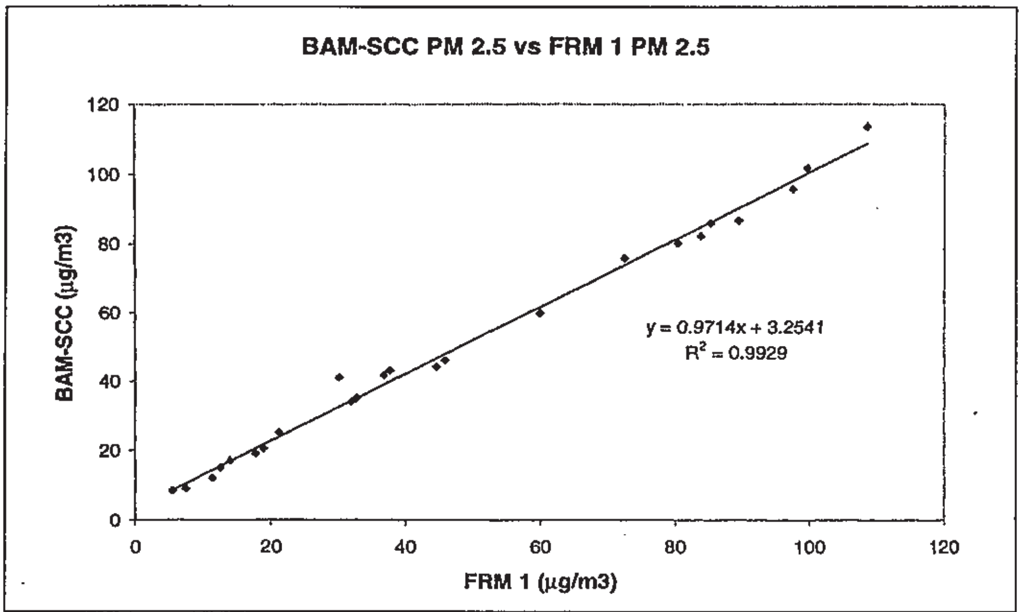
- The BX-596 ambient temperature and barometric pressure combination sensor was developed as a required accessory for the PM2.5 FEM BAM-1020. This provides a larger -40 to +55 C temperature range, and allows the BAM to measure the ambient pressure throughout the sample hour, improving flow control.
- The BX-302 zero filter kit was adapted as a required accessory for all PM2.5 FEM units. This allows users to adjust the background correction offset (BKGD) on each BAM to suit the local characteristics of the sample site. This improves the Y-intercept offset to near zero when compared to a collocated FRM sampler.
- The BX-827 or BX-830 Smart Heater with a 35% RH setpoint was adapted as a required accessory for PM2.5 FEM units. This controls the sample RH levels to prevent measurement errors due to moisture mass, while limiting affects on volatile compounds.
- The BX-961 automatic flow controller was changed from optional to a standard part on all BAMs, and is required for all PM2.5 FEM BAMs, which all must use actual volumetric flow control.
- The BGI Inc. model VSCC-A PM2.5 Very-Sharp-Cut Cyclone (Met One stock number BX-808) was adapted as the required PM2.5 particle separator for the BAM-1020 PM2.5 FEM. This is because the VSCC is a U.S. EPA FRM designated particle separator, while the older SCC cyclones are not. The VSCC has improved PM2.5 cut-point characteristics compared to the SCC cyclones.

Calibration:

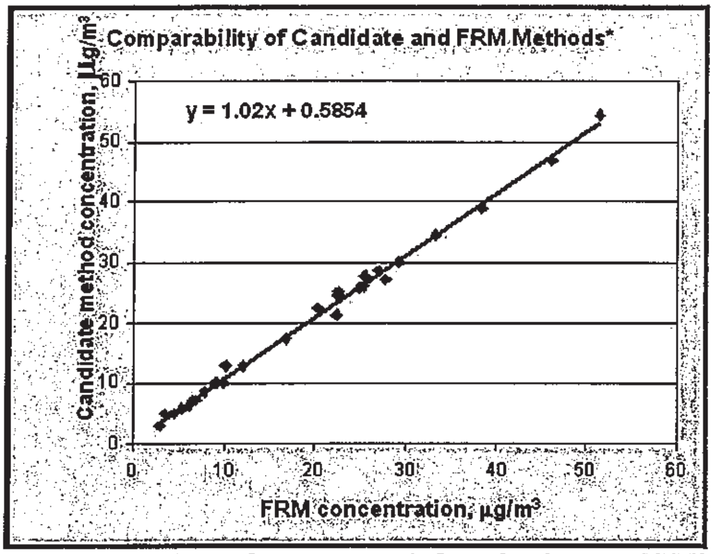
- The BAM-1020 calibration process was modified slightly to improve the accuracy of the unit in ambient concentrations below 50 micrograms.
- Test criteria were added to ensure the hourly noise levels of each BAM meet the specifications.

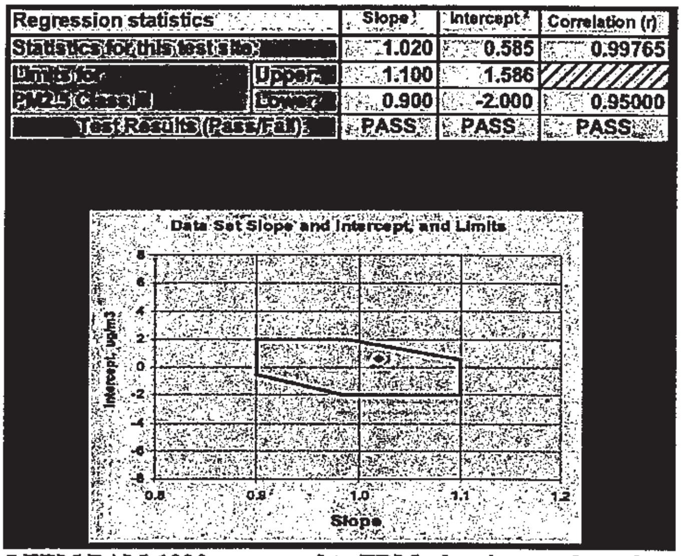
The result of these design improvements is that the BAM-1020 PM2.5 FEM units are more accurate for both hourly and 24 hour average PM2.5 measurements, and are able to pass the EPA PM2.5 FEM criteria as described in 40CFR part 53, when properly operated and maintained.

- The 24-hour average linear regression slopes of the BAM-1020 FEM compared to an FRM sampler are typically very close to one (1) when the filter RH control system is set properly and when there are is a reasonable variety of concentration levels in the data set.
- The Y-intercept of the linear regression between the BAM-1020 FEM and an FRM is typically within 1 microgram of zero, when the field background test with the zero filter has been done correctly, and data is collected digitally to prevent conversion errors.
- The standard deviation (sigma, σ) of the hourly noise band of the BAM improved from about 3.0 micrograms typical for old units, to about 1.8 micrograms typical on new FEM units. This results in an hourly detection limit (2σ) of typically less than 3.6 micrograms, and a 24-hour detection limit (2σ/√24) of typically less than 0.7 micrograms.

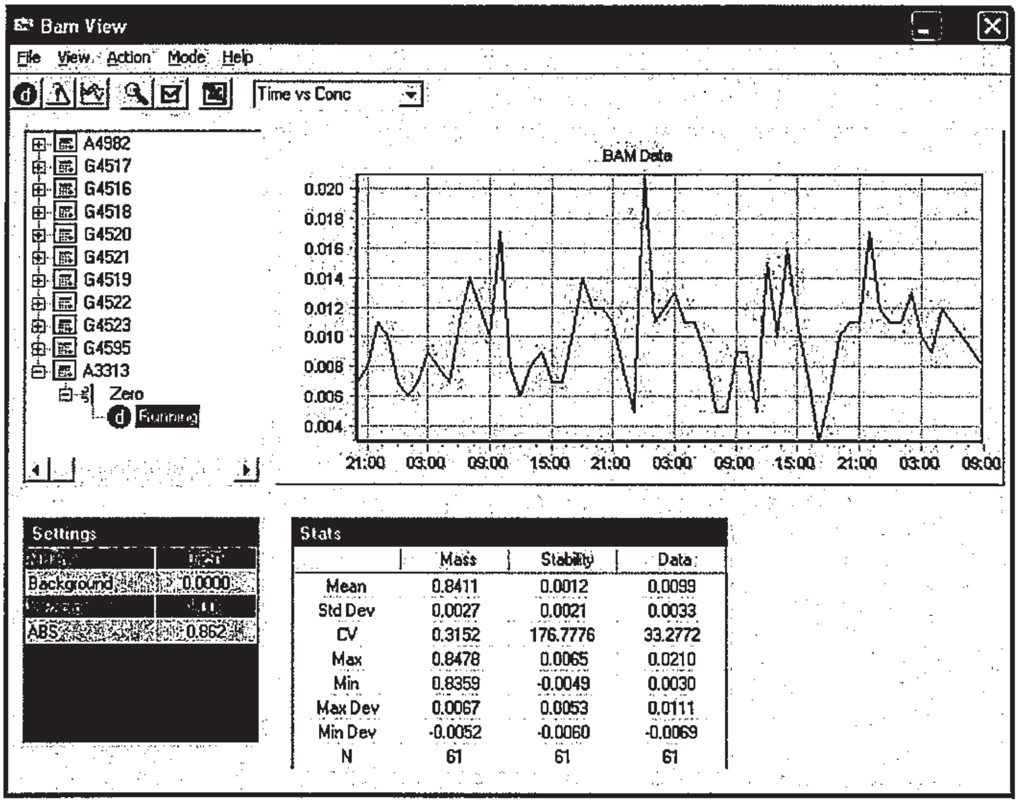


Linear regression of an older (unimproved) BAM-1020 compared to FRM, showing acceptable slope but typical positive Y-intercept offset.

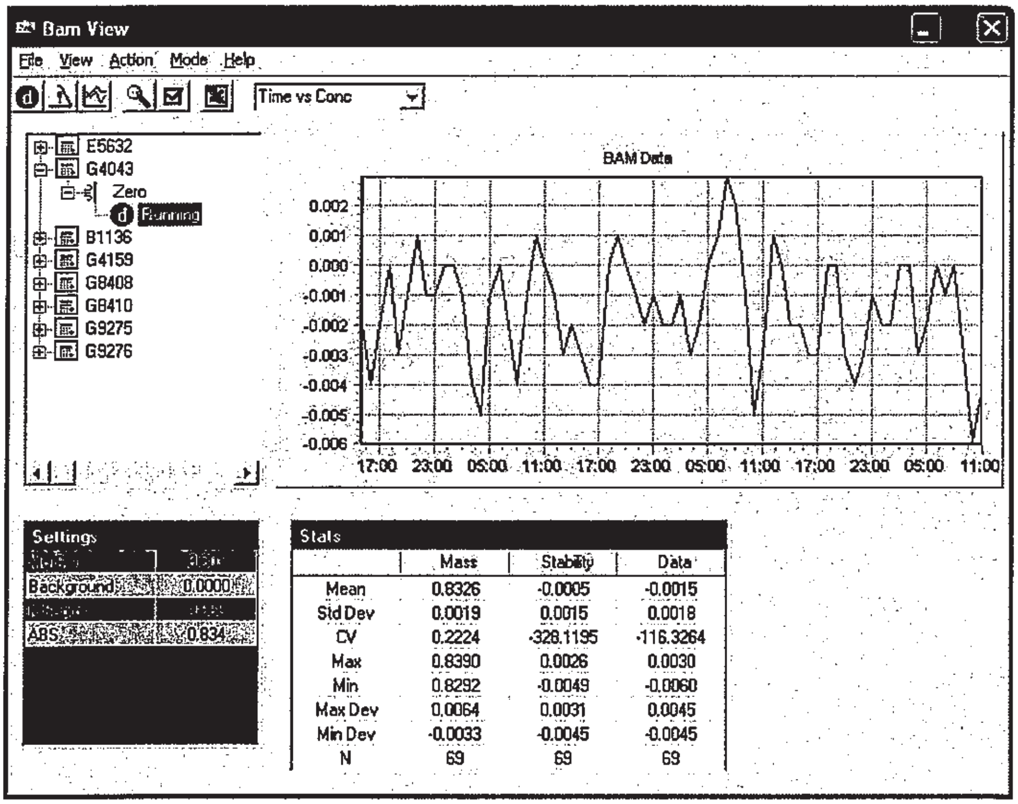




Linear regression and acceptance window of an improved PM2.5 FEM BAM-1020 compared to FRM, showing good results.



Zero filter test from an older (unimproved) BAM-1020 showing typical higher hourly noise levels (3.3 ug sigma).



Zero filter test from a new (improved) BAM-1020 with close geometry source, 8-minute counts, and improved tape transport showing typical lower hourly noise levels (1.8 ug sigma).

These improvements were released for new units in March, 2007. All BAM-1020 units built after this are PM2.5 FEM compatible when equipped with the appropriate firmware (Rev 3.2 or later) and the appropriate accessories. EPA PM2.5 FEM designation was officially obtained for the BAM-1020 in March 2008.

- PM2.5 FEM units must be equipped with the BX-808, BX-596, BX-302, BX-827 or 830, BX-802, and Rev 3.2.4 or later firmware.
- New PM10 BAMs have all of the latest hardware and calibration, and are exactly the same as PM2.5 FEM units, except that they have different firmware (only 4-minute beta counts allowed), and the extra accessories such as the BX-808 cyclone, BX-302 zero filter, and BX-596 AT/BP sensor are not required.
- All PM2.5 FEM BAM-1020 units can still be used for PM10 by simply removing the VSCC cyclone and changing a few settings in the user-interface.
- Older BAM-1020 units built after 2003, but before March, 2007 (serial numbers starting with D, E, and F) can usually be upgraded to the PM2.5 FEM type. This upgrade can only be done at the Met One factory, because a full recalibration is necessary. All upgraded units will be tested to meet new-unit specifications. Contact the Technical Service Department.
- Old units built in 2003 or earlier (serial numbers starting with C, B, A, Z, Y, X) Are generally too old to upgrade due to many obsolete parts. These may be traded in for a new unit at a significant discount. Contact the Sales Department.

Measuring PM in Sacramento Communities with a Combination of Traditional and Low-Cost Sensor Methods

Extended Abstract #ME73

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INTRODUCTION

Residential wood smoke is a contributor to wintertime particulate matter (PM) in Sacramento, California[1]. To understand how wood smoke contributions and PM concentrations varied across Sacramento, and between environmental justice (EJ) and non-EJ communities, we conducted measurements during December 2016 and January 2017 of air toxics and black carbon (BC) with Aethalometers at six locations, of particulate matter (PM) with low-cost AirBeam sensors at 15 locations, of hourly $PM_{2.5}$ with beta attenuation monitors (BAMs) and 24-hour PM via filter measurements at two locations, and of levoglucosan via filter measurements at three locations. This work focuses on the PM measurements; using low-cost sensors offers an opportunity to gain large spatial coverage of measurements at a fraction of the cost of traditional measurements. Many field studies have shown that, within given urban regions, there can be significant spatial variability of PM at small scales, driven by heterogeneous local emissions and the variability of meteorology conditions.[2] Low-cost sensors have the potential to give valuable information on the spatial and temporal variability of PM and other pollutants, if the quality of the measurement is robust enough to meet the given objectives.[3,4] Here we summarize the results of the sensor deployment.

The 19 AirBeam sensors had extremely high precision during the pre- and post-study collocations, with AirBeam-to-AirBeam correlation coefficients (R^2) greater than 0.95. AirBeams also had very high precision with very little drift at two locations with collocated AirBeams throughout the study. Since each AirBeam had a consistent PM concentration response relative to the other collocated AirBeams, we developed an AirBeam-specific normalization based on the collocated data. The normalized AirBeam data will be used to assess with high confidence how PM varied across communities. We also determined the extent to which AirBeam data can be corrected to BAM or 24-hr filter measurements using meteorological data.

METHODS

AirBeam sensors were used for measuring PM at community sites. HabitatMap, Inc., has developed the AirBeam following an open-source platform and has made the schematics of the instrument, as well as the default firmware, available online (http://aircasting.org/about). The AirBeam measures PM using an optical technique. Scattered light from an incoming aerosol stream in one size bin is measured and converted to mass concentration using a retrieval algorithm assuming a pre-determined size distribution; the October 2016 version of software provided by HabitatMap was used. The AirBeam system includes a default retrieval algorithm that is used to convert the raw measurement of hundreds of particles per cubic feet (hppcf) to $PM_{2.5}$ mass concentration, assuming a constant particle density. A U.S. Environmental Protection Agency (EPA) study examined the performance of the AirBeam compared to the BAM-1020 instrument and found high precision and moderate accuracy, with modest improvements from meteorology corrections.[5]

Each AirBeam was set up on a tripod underneath a covering to prevent rain from interfering with the sensor. AirBeam data were streamed directly from the sensor to a database at STI. Data were streamed at 1-minute intervals and rolled up to hourly averages, with a 75% completeness requirement for each hour.

Meteorological instruments, a BAM-1020, and a daily federal reference method (FRM) filter sampler were operated by SMAQMD at the Del Paso Manor site and by the California Air Resources Board (ARB) at the T Street site during the study. The BAM measures hourly $PM_{2.5}$ by sampling ambient air through a sharp cut cyclone and depositing particles on a filter tape, then exposing the filter tape to a source of beta radiation. Data for these measurements were reported to and accessed from EPA's Air Quality System (AQS).

The AirBeams were deployed in three distinct phases for the study:

- **Pre-Study Collocation Period** (11/10/2016 – 11/16/2016), 19 AirBeams collocated with a BAM-1020 and meteorological instruments at the Del Paso Manor site, to determine bias corrections and precision.
- **Study Period** (2 months, 12/1/2016 – 02/1/2017), 19 AirBeams deployed at 15 monitoring sites. The Del Paso Manor and T Street sites each had three AirBeams collocated with a BAM-1020 in order to assess sensor precision, bias, and drift throughout the study period.
- **Post-Study Collocation Period** (2/4/2017 – 3/8/2017), as during the pre-study collocation period, 19 AirBeams collocated with a BAM-1020 and meteorological instruments at the Del Paso Manor site to determine bias corrections and precision.

RESULTS

Using the data from the collocation periods, we determined the bias of each AirBeam, and then developed a correction for each AirBeam so that their data can be compared. We found that these biases were consistent throughout the study period, i.e., there was little change in a given AirBeam's bias between the pre-study and post-study collocation periods. In addition, collocated AirBeams at Del Paso Manor during the study confirmed there was little to no drift over the three-month period.

The coefficient of determination (R^2 value) of each individual AirBeam compared to the 19-AirBeam mean provides a representation of sensor precision. The AirBeams demonstrated very high precision during these collocation periods, with R^2 values ranging from 0.983 to 0.999.

The three sets of AirBeams that were collocated at the T Street and Del Paso monitor sites throughout the study period were also examined to assess precision. A stable linear relationship was seen for these sets of AirBeams throughout the study period. For the two sets of three AirBeams collocated during the study period, computed correlation R^2 values range from 0.987 to 0.995. The standard deviation of the residuals, the difference between the linear regression model and the true AirBeam value, was computed for these six collocated AirBeams, and these values range from 1.33 $\mu g\ m^{-3}$ to 2.99 $\mu g\ m^{-3}$, reflecting the consistent precision performance during the study period.

The stability and the high precision of the measurements allow for a normalization correction using the slopes and intercepts of regression against the mean. The formula for this normalization correction using the slopes and intercepts of regression from the pre- and post-study collocations is:

Normalized AirBeam Concentration = (Raw AirBeam Concentration – Intercept)/ Slope

In order to normalize the AirBeam measurements, an average of the pre-study and post-study intercepts and slopes were used for the linear correction for the study period. For five AirBeams, the pre-study regressions alone were used for the correction factor for the study period, due to invalid data in the post-study period that led to a limited range of PM values.

DISCUSSION

Individual AirBeams demonstrated large inter-instrument bias. However, these biases were extremely consistent, meaning they could be corrected. By conducting pre-, post- and during-study collocations, we were able to characterize and correct these biases. These steps are critical for deploying sensors in a community setting. Results will be used to understand differences in $PM_{2.5}$ among communities in Sacramento, and the methods provide a template to use in future applications.

The AirBeams were also modestly correlated (R^2= 0.58 - 0.60) with the collocated BAM-1020 values at the Del Paso Manor site during the study period (Figure 1). In Figure 1, there is a range of AirBeam values for a given BAM concentration, with AirBeam measurements ranging from a factor of one to three times higher for the majority of measurements. As seen in the scatter plots, dewpoint temperature appears to be the most influential meteorological variable in the AirBeam-to-BAM relationship, with approximately a 1:1 relationship under low dewpoints (below 5°C) and nearly a 3:1 relationship under higher dewpoints.

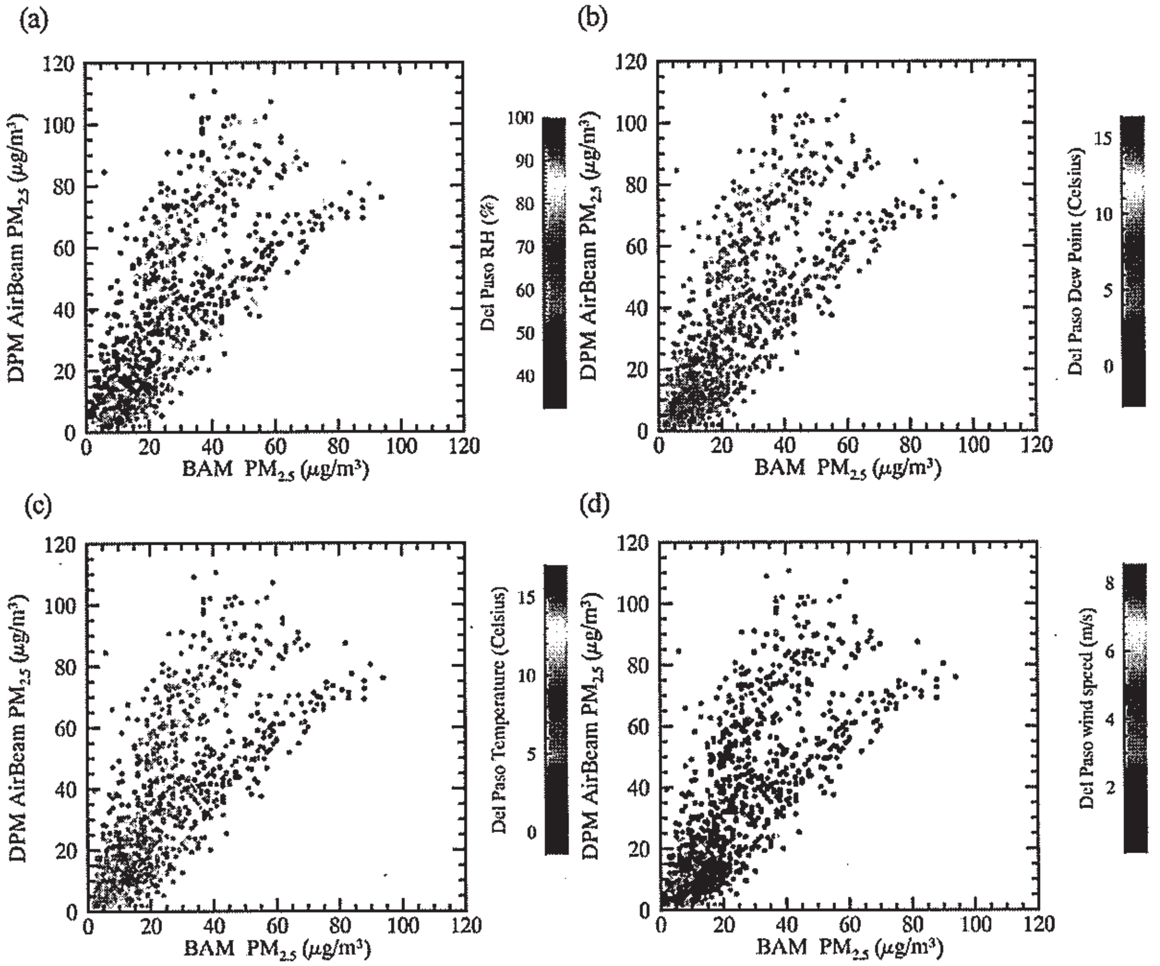

Figure 1. Collocated AirBeam and BAM data at the Del Paso Manor site during December 2016–January 2017, colored by (a) relative humidity, (b) dewpoint temperature, (c) temperature, and (d) wind speed.

SUMMARY

The 19 AirBeam sensors had extremely high precisions during the pre- and post-study collocations, with AirBeam-to-AirBeam correlation coefficients (R^2) greater than 0.95. The AirBeams also had very high precision with very little drift at the two locations with collocated AirBeams throughout the study. Since each AirBeam had a consistent PM concentration response relative to the other collocated AirBeams, we developed an AirBeam-specific normalization based on the collocated data. The normalized AirBeam data will be used to assess how PM varied across communities. We also found that the AirBeams were biased compared to the BAM, and that the comparison was strongly impacted by dewpoint.

REFERENCES

1. MacDonald, C. P.; K. J. Craig; J. L. DeWinter; A. N. Pasch; S. G. Brown; N. J. M. Wheeler. *Evaluation of Sacramento Metropolitan Air Quality Management District's Check Before You Burn Program*; Final report prepared for the Sacramento Metropolitan Air Quality Management District, Sacramento, CA, by Sonoma Technology, Inc., Petaluma, CA, 2009, STI-909014-3612-FR2.
2. Britter, R. E.; S. R. Hanna (2003) Flow and dispersion in urban areas. *Annual Review of Fluid Mechanics*, 35(1), 469-496, doi: 10.1146/annurev.fluid.35.101101.161147, January. Available at http://www.annualreviews.org/doi/abs/10.1146/annurev.fluid.35.101101.161147.
3. Kumar, P.; L. Morawska; C. Martani; G. Biskos; M. Neophytou; S. Di Sabatino; M. Bell; L. Norford; R. Britter (2015) The rise of low-cost sensing for managing air pollution in cities. *Environment International*, 75(Supplement C), 199-205, doi: https://doi.org/10.1016/j.envint.2014.11.019, February. Available at http://www.sciencedirect.com/science/article/pii/S0160412014003547.
4. Lewis, A. C.; J. D. Lee; P. M. Edwards; M. D. Shaw; M. J. Evans; S. J. Moller; K. R. Smith; J. W. Buckley; M. Ellis; S. R. Gillot; A. White (2016) Evaluating the performance of low cost chemical sensors for air pollution research. *Faraday Discussions*, 189, 85-103, doi: 10.1039/c5fd00201j. Available at http://dx.doi.org/10.1039/C5FD00201J.
5. Jiao, W.; G. Hagler; R. Williams; R. Sharpe; R. Brown; D. Garver; R. Judge; M. Caudill; J. Rickard; M. Davis; L. Weinstock; S. Zimmer-Dauphinee; K. Buckley (2016) Community Air Sensor Network (CAIRSENSE) project: evaluation of low-cost sensor performance in a suburban environment in the southeastern United States. *Atmos. Meas. Tech.*, 9(11), 5281-5292, doi: 10.5194/amt-9-5281-2016. Available at https://www.atmos-meas-tech.net/9/5281/2016/.

KEY WORDS

wood smoke, sensors, particulate matter, community monitoring

State of Air Quality Sensing in 2017

(Extended Abstract #: ME79)

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A&WMA's Air Quality Measurement
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Introduction

For decades organizations have used air quality instruments to monitor air pollution for research and regulatory applications. These instruments are accurate, precise, reliable, and typically installed and operated by experts or researchers. Within the last ten years, a new class of air quality monitors has emerged in the marketplace. Commonly called microsensors or low-cost sensors systems, these devices are comprised of inexpensive off-the-shelf air quality sensors, microcontrollers, power supplies, and communications (e.g., cellular). People from civil society, community groups, and other organizations can now afford to purchase and operate an air quality sensor system to monitor air pollution at their home, neighborhood, or in their vehicle.

Development of inexpensive air quality sensors began over a decade ago when researchers and artists used off-the-shelf components, microprocessors, and cellphones to create devices that measured air quality.[1,2] For example as shown in Figure 1, Intel Berkeley built a mobile sensing pod that measured pollutants using low-cost sensors. These researchers then deployed the handheld monitors with a community group in West Oakland, CA[3] and on street sweepers in the San Francisco Bay area. Within the past five years, many organizations begin building, evaluating, deploying, and using these novel devices for education, spatial gradient studies, citizen science, and research applications. Some notable events include:

- 2012: U.S EPA started evaluating the low-cost air quality sensors in their laboratories in Research Triangle Park, NC and then conducted several field campaigns to evaluate sensors.[4]
- 2012: The Air Quality Egg was funded via Kickstarter - a crowdfunding website. Led by Pachube and Wicked Devices, over 900 people funded this project the produced 800 air quality sensing eggs. The eggs measured carbon monoxide, nitrogen dioxide, temperature, and humidity with low-cost sensors. This project created tremendous buzz, but the poor accuracy of the eggs frustrated and soured many users.
- 2016: Argonne National Laboratory and the University of Chicago started building the Array of Things that will deploy 500 air quality sensor systems throughout Chicago.[5]

- 2015-2017: Companies are actively marketing dozens of consumer devices that measure air quality. A search on Amazon for "air quality sensors" will reveal the wide range of products available.

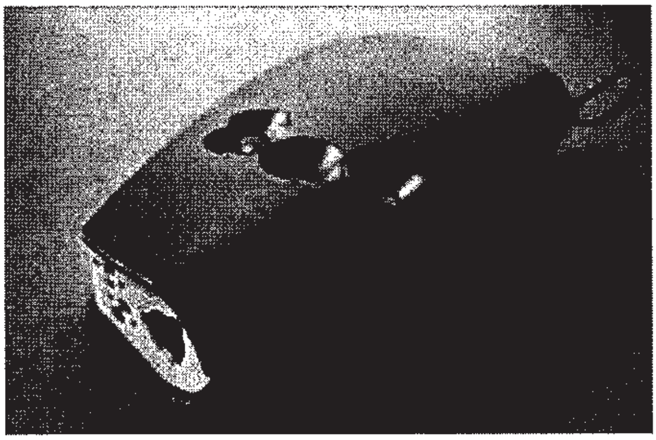

Figure 1. Intel Berkeley sensor pod that measured ozone, NO_2, CO, temperature, and humidity using low-cost sensors.

Since these types of devices emerged, many people have questioned the accuracy of these low-cost air sensors compared to reference instruments. EPA and European research organizations began early evaluations of these devices.[4,6] More recently, the South Coast Air Quality Management District in Los Angeles set up a comprehensive evaluation center for air sensors. Called the Air Quality Sensor Performance Evaluation Center (AQ-SPEC)[7] it evaluates the accuracy and usability of commercially available, low-cost air quality sensors. As of May 2017, the AQ-SPEC program evaluated 29 sensor systems. Evaluation results indicate that some gas sensors (notably ozone, and NO_2) and particle sensors (mostly $PM_{2.5}$) show decent performance when compared to reference instruments. Other gas sensors are available, but the performance can be good for specific applications[8], but a focus on improving sensors performance is needed.

The air quality monitoring industry has reached a tipping point where there are now more low-cost air sensors than reference instruments. In the coming years, a number of driving factors will lead to hundreds of thousands of air sensors deployed. These factors are

- Continued research is showing the link between air pollution and negative health effects.
- Increasing public awareness of air pollution that governments must address; especially true in large industrial countries (India, China) and the developing world.
- Ubiquitous communications are enabling any device to send data to anyone in the world.

- Inexpensive and easy to use hardware and software enable startup, community groups, and do-it-yourselfers to create air sensor systems quickly.
- An innate desire of people to measure different characteristics of themselves, their environment and home, and neighborhoods.

Value Chain

Several hundred organizations are working on various aspects of this new technology to create a benefit (e.g., improve the air, identify and fix problems, or save money). Figure 2 shows the Value Chain - a method to describe the process by which businesses/organizations take raw materials or a product and then add value through various processes to create a final product/benefit. With a new technology like air quality sensors, the value chain is not seamlessly connected and therefore it's important to understand where companies or organization fit, and how their product or service will deliver benefits.

As shown in Figure 2, the value chain starts with Sensor Manufacturers that create small, inexpensive hardware to measure pollutants. Next, Sensor Integrators, companies and organizations, assemble the sensors with other support hardware (communications, power management, enclosure, displays) to make a product. Currently, there are over 100 different organizations and companies either manufacturing sensors or integrating air sensor systems. Next, Data Aggregators collect data from air sensor and other networks, merge and store data, and then redistribute data. An example data aggregator is the Environmental Defense Fund's Air Sensor Working Group, which is developing a data platform for ingesting, processing, and visualizing air sensor data.[9] Solution Providers use sensor data combined with other data to create actionable information that can be used by Action Organizations to take a specific steps toward improving air quality; ultimately, achieving a benefit (e.g., improved air quality, greater understanding, or financial savings). Like other nascent technology transitions, low-cost air sensors are dominated by lots of startups and small companies creating sensors and integrating systems into commercial products and then seeking to create a market to achieve solutions, actions, and benefits.

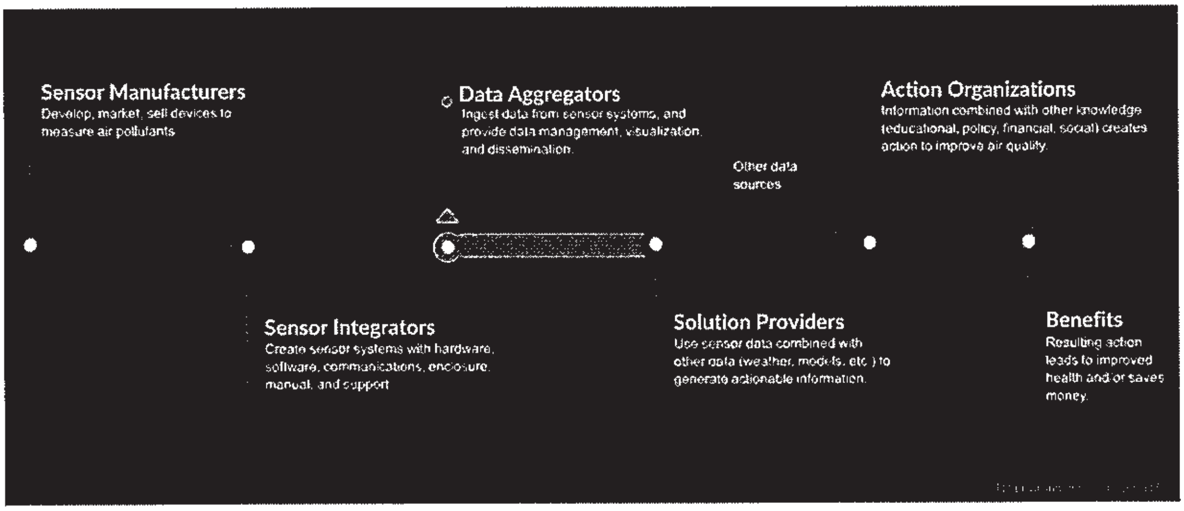

Figure 2. Value chain for low-cost air sensors.

Future of Air Sensing

Air quality monitoring is no longer just for trained professionals using expensive instruments. Now a large and growing group of organizations and individuals are monitoring the quality of their air. The number of installed air sensors worldwide has surpassed the number of reference instruments. The consumer market of individuals buying air monitoring products for indoor and outdoor applications will grow fastest as people buy nice-looking devices with vivid displays and apps to show data. City governments, as part of smart city initiatives, will begin installing, evaluating, and using these devices to make informed decisions about emission reduction plans, traffic flow, health studies, and more. Lastly, more state, local, and federal air quality agencies find ways to use this information to examine spatial pattern, work collaboratively with communities, and education civil society.

References

[1] W. Willett, P. Aoki, N. Kumar, S. Subramanian, and A. Woodruff. "Common Sense Community: Scaffolding Mobile Sensing and Analysis for Novice Users." Proc. 8th International Conf. on Pervasive Computing (Pervasive 2010), Helsinki, Finland, May 2010, 301-318.

[2] Portable Devices Allow Tracking of Real-Time Exposure to Airborne Contaminants". Seed magazine. September 27, 2006.

[3] U.S. EPA, Community Action for a Renewed Environment (CARE) Program: Promises and Practices to Improve Community Performance and Sustainability, June 2010, EPA-530-F-10-005, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1007VOV.pdf#page=18

[4] Williams, R., R. Long, M. Beaver, A. Kaufman, F. Zeiger, M. Heimbinder, I. Hang, R. Yap, B. Acharya, B. Ginwald, K. Kupcho, S. Robinson, O. Zaouak, B. Aubert, M. Hannigan, R. Piedrahita, N. Masson, B. Moran, M. Rook, P. Heppner, C. Cogar, N. Nikzad, AND W. Griswold. Sensor Evaluation Report. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/143 (NTIS PB2015-100611), 2014.

[5] AoT, Array of Things, 2017, https://arrayofthings.github.io/index.html#

[6] Aleixandre M, Gerboles M. Review of small commercial sensors for indicative monitoring of ambient gas. Chemical Engineering Transactions, 30: 169-174, 2012. (Abstract, DOC. 23 KB)

[7] AQ-SPEC: http://www.aqmd.gov/aq-spec/home

[8] D. H. Hagan, G. Isaacman-VanWertz, J. P. Franklin, Lisa M. M. Wallace, Benjamin D. Kocar, Colette L. Heald, and J. H. Kroll (2017); Calibration and assessment of electrochemical air quality sensors by co-location with reference-grade instruments, Atmospheric Measurement Techniques, submitted.

[9] EDF (2017). Air Sensor Working Group. https://www.edf.org/health/air-sensor-workgroup

"Low-cost" Sensors for Measuring Gaseous and Particle Air Pollutants: Performance Results from Three Years of AQ-SPEC Field and Laboratory Testing and Network Applications at the Fenceline and Community Level

A&WMA's 2017 Air Quality Measurement Methods and Technology
November 7-9, 2017
Long Beach, CA

Extended Abstract Control # ME70

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INTRODUCTION

Because of recent technological advancements in the areas of electrical engineering and wireless networking, manufacturers have recently begun marketing "low-cost" air monitoring sensors to measure air pollution in real-time (e.g. seconds to minutes)[1]. Considering how fast this type of technology is evolving, it is likely that the type and numbers of these sensors will substantially increase in the near future. These devices, assuming they produce reliable data, can significantly augment and improve current ambient air monitoring capabilities that predominantly rely on the more sophisticated and expensive federal-reference or federal-equivalent methods (FRM and FEM, respectively) operating at fixed sites. Given their low cost, these sensors are becoming an attractive means for local environmental groups and individuals to independently evaluate air quality. This new approach is receiving acknowledgement from U.S. EPA and may shift air monitoring towards a different paradigm in which traditional monitoring by air quality agencies is supplemented by community-based monitoring using "low-cost" sensors[2].

However, despite new potential applications, there are often no independent or systematic means by which these devices are evaluated, and data from these monitors are usually accepted at face value. Preliminary tests performed in the U.S. and Europe seem to suggest that many of the commercially available sensors have poor reliability, do not perform well in the field under "actual" ambient conditions, and do not typically correlate well with data obtained using FRM/FEM methods employed by regulatory agencies[3]. Poor quality data obtained from unreliable sensors (especially when in conflict with data obtained from traditional, more sophisticated monitoring networks) may not only lead to confusion but also jeopardize the successful evolution of "low-cost" sensor technology. Therefore, there is an urgent need to better characterize the actual performance of air monitoring sensors and their long-term reliability.

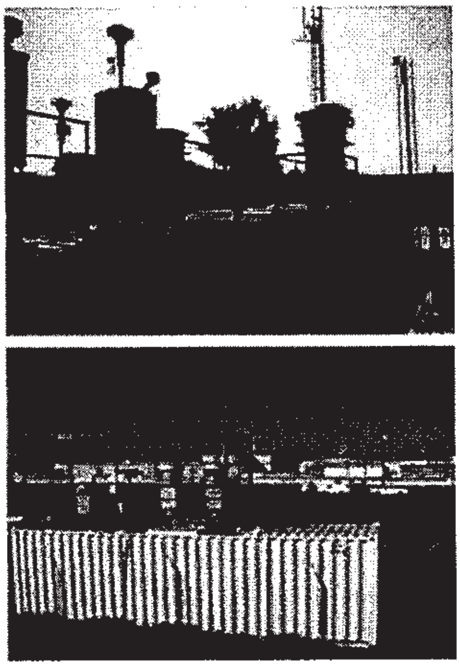
In an effort to address this specific problem, in June 2014 the South Coast Air Quality Management District (SCAQMD) has established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC). This program aims at conducting a thorough and systematic characterization of currently available "low-cost" sensors under ambient (field) and controlled (laboratory) conditions. In this paper, the results from three years of field and laboratory testing will be discussed in detail along with the major strengths and weaknesses of some of the most commonly available particle and gaseous sensors. Additionally, two projects will highlight the use of creating air quality network applications with one deployed at the fence-line of a facility and the other set at a community level.

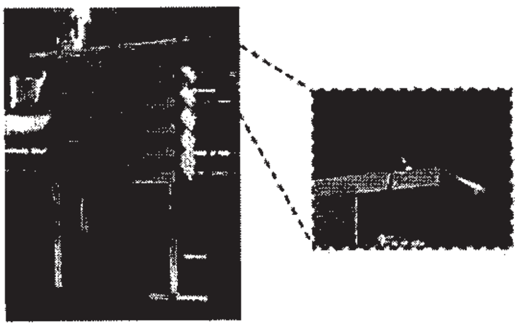
METHODS

Field Testing

Within AQ-SPEC, air quality sensors are operated side-by-side with FRM and FEM instruments routinely used to measure the ambient concentration of gaseous or particle pollutants for regulatory purposes. Field testing activities are conducted at one of SCAQMD's existing air monitoring stations in Rubidoux, CA, and at a near-roadway site close to the I-710 freeway. (Figure 1). All sensors are evaluated in triplicates and for a period of at least two months to provide better statistical information about the comparability with FRM/FEM instruments measuring the same pollutant(s) and their overall performance.

Figure 1. Overview of the two field testing sites in Rubidoux (top right) and near the I-710 freeway (bottom right). A picture of the custom-made enclosure used for testing all sensor devices is also included below





Laboratory Testing

Sensors that demonstrated a nominal level of performance in the field are then brought back to the AQ-SPEC laboratory, where a custom-made "characterization chamber" is used to challenge the them with known concentrations of different particle and gaseous pollutants and under variable temperature (T) and relative humidity (RH) levels (Figure 2). Also in this case, sensors are evaluated in triplicates. A laboratory testing protocol has been developed to properly characterize sensor performance.

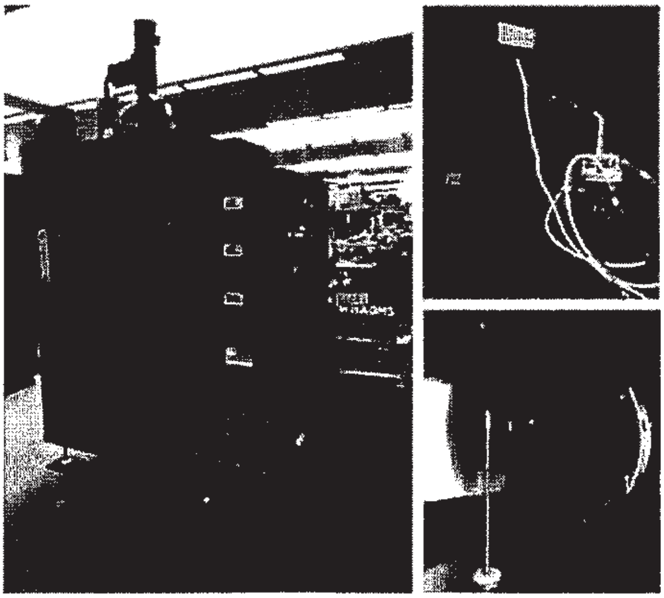


Figure 2. Picture of the custom-made chamber developed for AQ-SPEC. The chamber is able to generate known amounts of gaseous and particle pollutants. T and RH levels can be pre-set to reproduce different environmental conditions. An array of FRM/FEM instruments is used to monitor "actual" gaseous and particle pollutant concentrations inside the chamber. An integrated software controls the various operating/experimental parameters.

Sensor Network Applications

Sensor networks are designed and implemented according to the specific application requirements and goals. Two sensor networks using particulate matter sensors have been implemented with one at the fence-line of a waste transfer facility and the other as a community scale monitoring project. The fence-line application was designed to monitor fugitive dust emissions from a waste processing facility in southern California. A network of nine solar-powered sensor nodes equipped with an Optical Particulate Counter (Model OPC-N2, Alphasense, UK) and a 900 MHz mesh network gateway were deployed at the fence-line of the facility. The OPC-N2 reports PM mass concentrations for three PM size fractions (i.e., PM_{10}, $PM_{2.5}$, and $PM_{1.0}$), while the gateway allowed the nodes to transmit data to a central cellular communication gateway.

Figure 3. Picture of the custom-made enclosure for the Alphasense Optical PArticel Counter. Other components include a solar panel, charge controller, 12V batter, power converter, and Meshify gateway

The community scale application was designed to investigate the spatial and temporal variability of PM between locations at a community scale. A network of 23 low-cost PM sensors (Purple Air PA-II) were deployed at citizen scientist homes in east San Bernardino County focusing around Redlands, CA. The PA-II sensor reports PM mass concentrations for three PM size fractions (i.e., PM_{10}, $PM_{2.5}$, and $PM_{1.0}$), and is equipped with Wi-Fi capability for data logging. The data can be visualized by the citizen scientist in real-time on a map at www.map.purpleair.org.

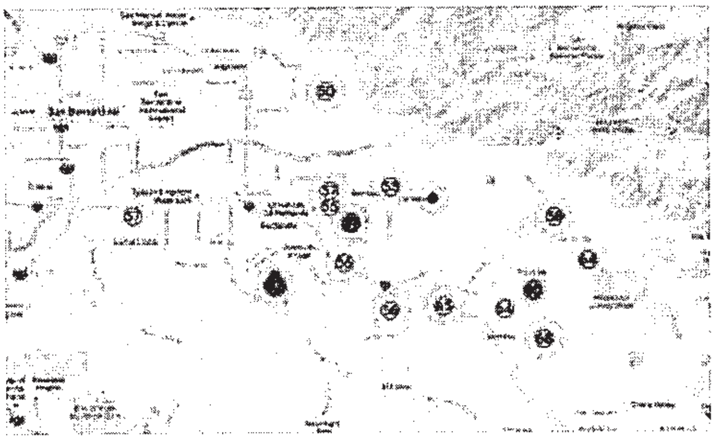


Figure 4. Map of sensor locations taken from map.purple.org

RESULTS

Lab and Field testing

Field testing of commercially available sensors began in September 2014. At the time of this writing, the AQ-SPEC team has evaluated more than 30 sensors. Eight of these devices have also been tested in the AQ-SPEC laboratory. A summary of the main field testing results is illustrated in Figure 3. In general, optical particle counters reporting particle number and/or mass concentrations showed medium to high correlations with more expensive and reliable FEM (EPA approved) methods. Our results suggest that, in most cases, particle sensors may need to be calibrated at each location before being used for monitoring purposes. Some of the sensors used to measure primary combustion pollutants such as carbon monoxide (CO) and nitrogen monoxide (NO) also exhibited good correlations with the corresponding FRM instruments. Metal oxide sensors for measuring ozone (O_3) also performed well during our field measurements, although previous studies have shown that sensor durability may be an issue for long-term deployments[4]. Finally, O_3 and nitrogen dioxide (NO_2) measurements performed using electrochemical sensors may be complicated by potential interferences between these two pollutants. This has also been observed during other field and laboratory testing conducted by the U.S. EPA[5]. Detailed technical reports for each device tested within AQ-SPEC and other relevant information about this program can be found online @ www.aqmd.gov/aq-spec. This website is intended to educate the public about the capabilities of commercially available sensors and their potential applications.

Figure 5. Table summarizing the testing results for common particle gaseous sensors.

PM Sensors							
Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	[1]Field R^2	[1]Lab R^2	Summary Report
	AethLabs (microAeth)	Optical	BC (Black Carbon)	~$6,500	R^2 ~ 0.79 to 0.94		
	Air Quality Egg (Version 1)	Optical	PM	~$200	R^2 ~ 0.0		
	Air Quality Egg (Version 2)	Optical	PM	~$240	$PM_{2.5}$: R^2 ~ 0.79 to 0.85 PM_{10}: R^2 ~ 0.31 to 0.40		
	Alphasense (OPC-N2)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$450	$PM_{1.0}$: R^2 ~ 0.63 to 0.82 $PM_{2.5}$: R^2 ~ 0.38 to 0.80 PM_{10}: R^2 ~ 0.41 to 0.60	R^2 ~ 0.99	PDF (1,291 KB)
	Dylos (DC1100)	Optical	$PM_{(0.5-2.5)}$	~$300	R^2 ~ 0.65 to 0.85	R^2 ~ 0.89	PDF (1,384 KB)
	Foobot	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.55		
	HabitatMap (AirBeam)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.65 to 0.70	R^2 ~ 0.87	PDF (1,144 KB)
	Hanvon (Hanvon N1)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.52 to 0.79		
	MetOne (Neighborhood Monitor)	Optical	$PM_{2.5}$	~$1,900	R^2 ~ 0.53 to 0.67		
	Moji China (Airnut)	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.81 to 0.88		
	Naneos (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	PM_{10}: R^2 ~ 0.1 $PM_{2.5}$: R^2 ~ 0.2		
	Origins (Laser Egg)	Optical	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: R^2 ~ 0.58 PM_{10}: R^2 ~ 0.0		
	Perkin Elmer (ELM)	Optical	PM	~$5,200	R^2 ~ 0.0		
	PurpleAir (PA-I)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$150	$PM_{1.0}$: R^2 ~ 0.93 to 0.95 $PM_{2.5}$: R^2 ~ 0.77 to 0.92 PM_{10}: R^2 ~ 0.32 to 0.44	$PM_{1.0}$: R^2 ~ 0.95 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.97	PDF (1,072 KB)
	PurpleAir (PA-II)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: R^2 ~ 0.96 to 0.98 $PM_{2.5}$: R^2 ~ 0.93 to 0.97 PM_{10}: R^2 ~ 0.66 to 0.70		
	RTI (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	R^2 ~ 0.65 to 0.90	R^2 ~ 0.99	PDF (1,087 KB)
	Shinyei (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	R^2 ~ 0.80 to 0.90	R^2 ~ 0.93	PDF (1,156 KB)
	Speck	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.32		
	TSI (AirAssure)	Optical	$PM_{2.5}$	~$1,500	R^2 ~ 0.82		

[1]The correlation coefficient (R^2) is a statistical parameter indicating how well the performance of each sensor compares to that of a Federal Reference or Federal Equivalent Method (FRM and FEM, respectively) instrument. An R^2 approaching the value of 1 reflects a near perfect agreement, whereas a value of 0 indicates a complete lack of correlation. All R^2 values reported in this table are based either on a 5-min or 1-hr average data. Laboratory evaluations are still pending to confirm field results. An ad-hoc rating system will be developed to summarize the overall performance of these sensors once both field and laboratory data become available.

Sensor Network Applications
The results from the sensor network applications show spatial and temporal variations in PM concentrations. Temporal variations include hourly, day of week, and monthly variations in the concentration levels. Temporal variations in the fence-line project include up-wind and downwind variation and proximity to specific waste streams in the facility. Spatial variations at the community level include variation within a city, between cities, and the distance from large roadway. Two examples can be seen in the figures below.

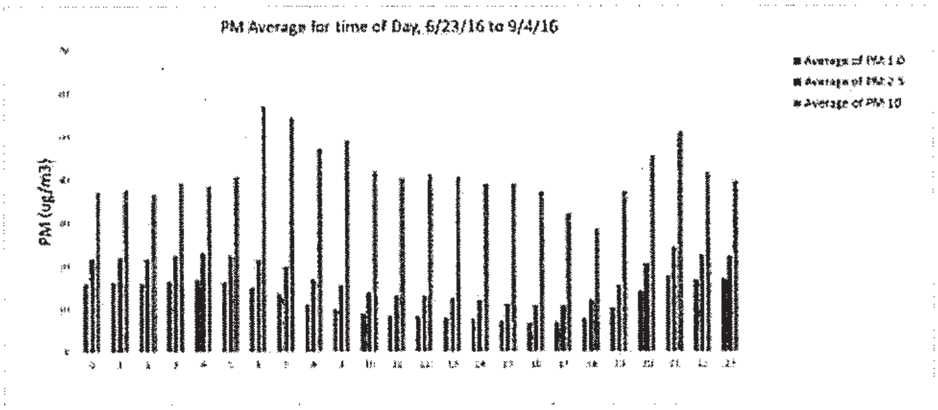


Figure 6. Temporal variation in PM concentration of fence-line monitoring

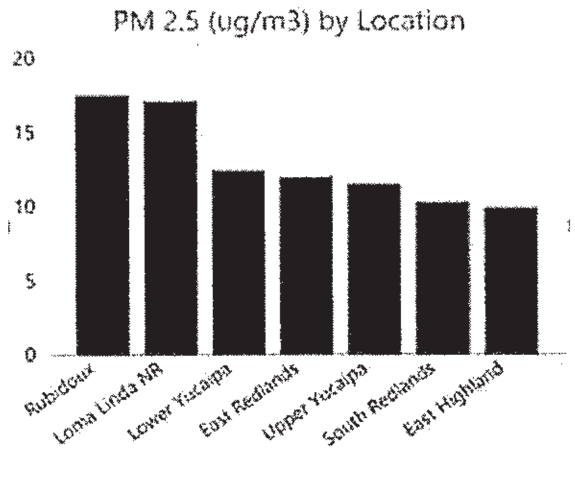


Figure 7. Spatial variation between locations in the community scale

SUMMARY

In an effort to inform the general public about the actual performance of "low-cost" air quality sensors, in June 2014 the SCAQMD has established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC). This program aims at performing a thorough characterization of available "low-cost" sensors under ambient (field) and controlled (laboratory) conditions. Considerable effort has been spent to develop the field and laboratory testing protocols and, to date, more than 30 particle and gaseous sensors have been evaluated. Overall, our results have shown that some of these devices (especially those measuring particulate matter) compare favorably well to more expensive and reliable FRM/FEM instruments. Sensor technology is still advancing with ongoing research and development to improve the capability of low-cost air quality sensors. The SCAQMD sensor network applications have provided the opportunity to investigate the potential use of low-cost sensors in real world applications to provide meaningful data able to provide insights into spatial and temporal variation in air quality.

REFERENCES

[1]Snyder, E., Watkins, T., Thoma, E., Williams, R., Solomon, P., Hagler, G., Shelow, D., Hindin, D., Kilaru, V., Preuss, P. (2013) "Changing the paradigm for air pollution monitoring" Environmental Science and Technology; 47: 11369-11377

[2]Roadmap for Next Generation Air Monitoring-US Environmental Protection Agency-US Environmental Protection Agency (2013) (www.epa.gov/research/airscience/docs/roadmap-20130308.pdf)

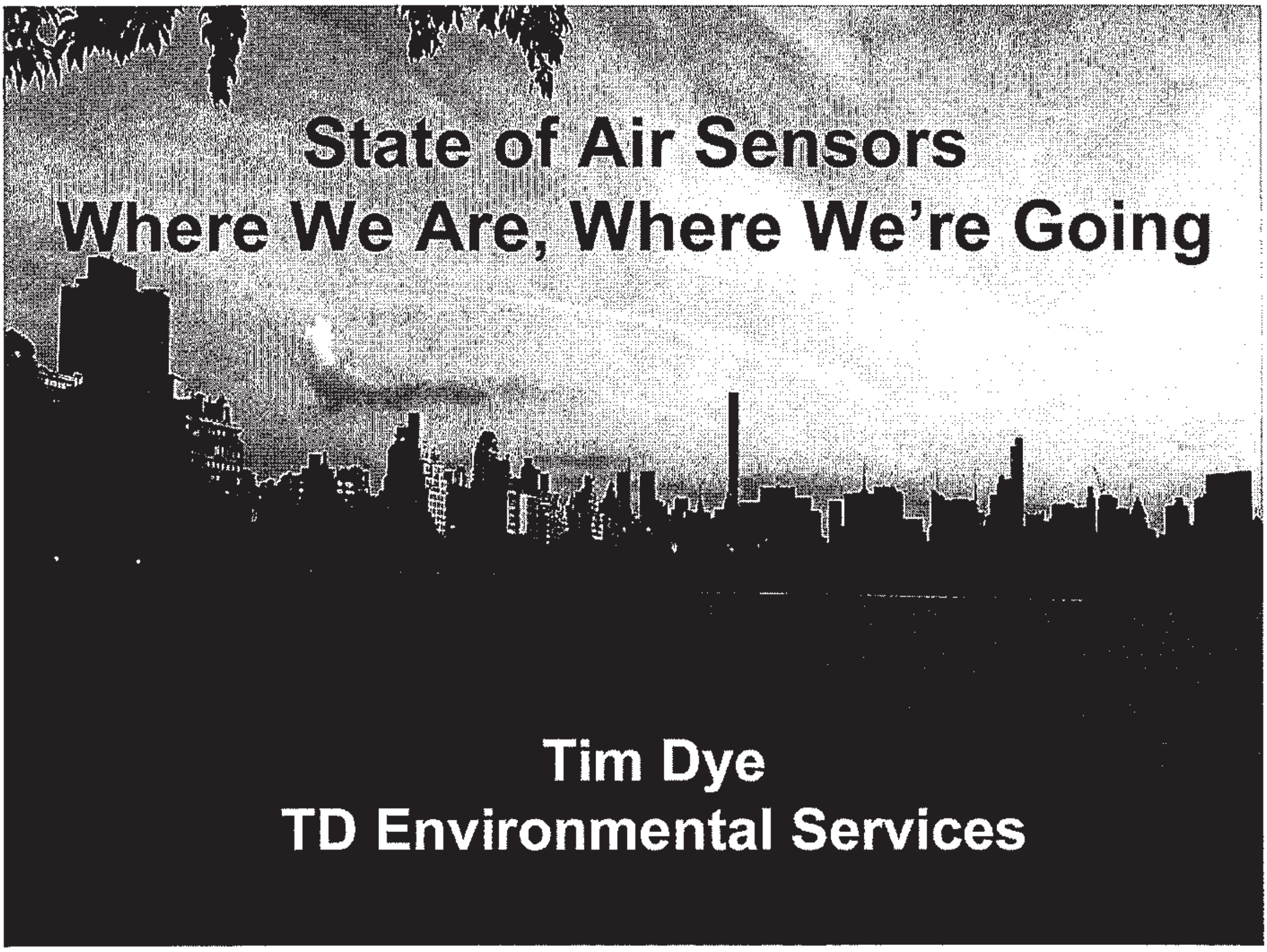
[3]Vallano, D., Snyder, E., Kilaru, V., Thoma, E., Williams, R., Hagler, G., Watkins, T. Air Pollution Sensors (2012) "Highlights from an EPA workshop on the evolution and revolution in low cost participatory air monitoring" Environmental Manager; Issue, 28-33

[4]Sonoma Technology, Inc. (2014) "Ozone Concentrations In and Around the City of Arvin, California" (https://www.valleyair.org/Air_Quality.../OzoneSaturationStudy.pdf)

[5]Williams R. Kilaru V., Snyder E., Kaufman A., Dye T., Rutter A., Russell A., Hafner H. (2014) "Air Sensor Guidebook. Report prepared by the U.S. Environmental Protection Agency Office of Research and Development" (www.epa.gov/airscience/docs/air-sensor-guidebook.pdf)

KEYWORDS

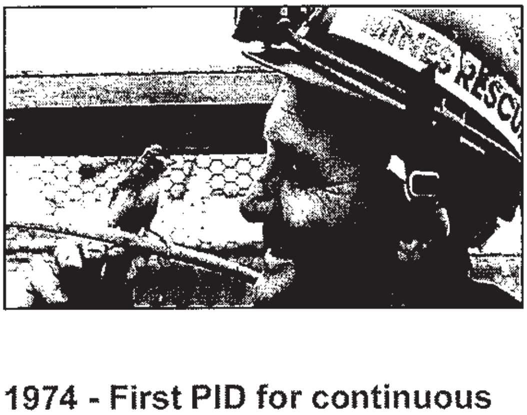
Air quality sensors; Sensor testing; Community monitoring; Citizen Science



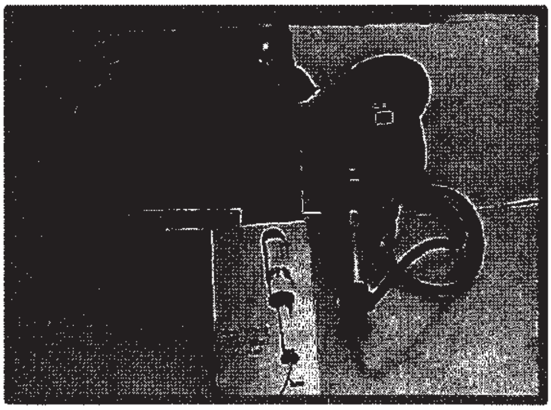
Brief History of Air Quality Sensors

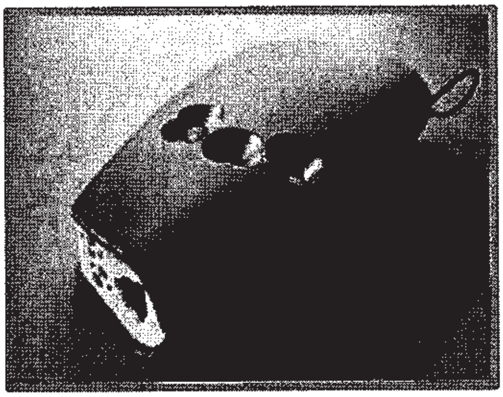
It started long ago.

1800s to 1900s - Canaries save lives
Canaries in coal mines provided advance warning of toxic gases.



1974 - First PID for continuous sensing
Photoionization detector (PID) introduced as a hand-held instrument to detect leaks for Volatile Organic Compounds (VOCs). First introduced in 1974, early portable PIDs were bulky, heavy (9 lbs.), and had a separate hand-held probe and a controller carried by a shoulder strap.



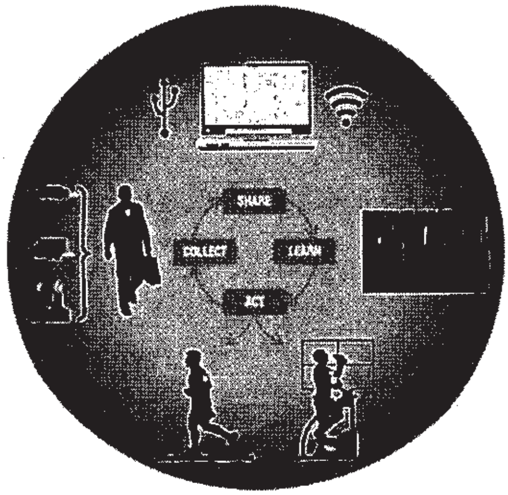


2008 - Air sensing pod used by communities

Common Sense program by Intel Berkeley built a mobile sensing pod that measured pollutants using low-cost sensors.

2011 Crowdsourced radiation data makes an impact

Safecast started in response to the meltdown of the Fukushima Daiichi Nuclear Power Plant in Japan. Where a group of volunteers quickly began monitoring, collecting, and openly sharing information on environmental radiation.



2012 - First U.S. meeting for low-cost air quality sensing

The U.S. EPA hosted the first comprehensive meeting on air quality sensors. The workshop helped set a path for EPA's low-cost air sensor program.

2012 - Low-cost sensor created by crowdfunding

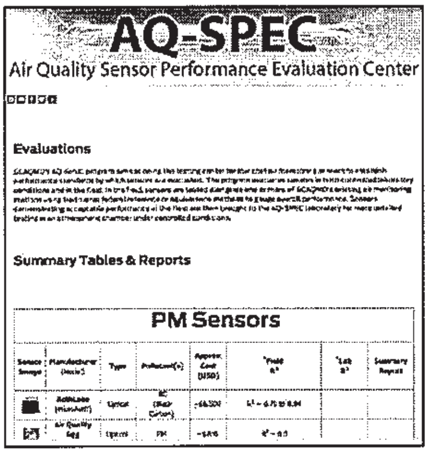
Air Quality Egg funded via Kickstarter produced 800 air quality sensing eggs. The eggs measured carbon monoxide, nitrogen dioxide, temperature, and humidity using low-cost sensors, but poor accuracy of the eggs frustrated and soured many users.

2013 - Good advice provided by U.S. EPA

Air Sensor Guidebook provided practical information on types of pollutants, what to consider when buying air sensors, steps to collect useful data, how to assess performance, and more.

2014 - Open-source PM sensor system launches

AirBeam, an open-source air sensor system, was released by HabitatMap for personal monitoring for $PM_{2.5}$. Users crowdsourced data on the AirCasting app and website to vividly show a region's particle levels.

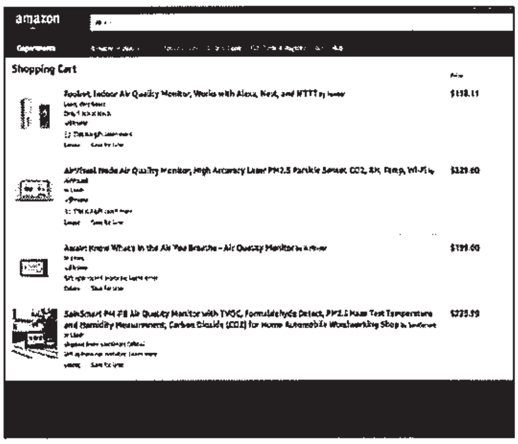


2014 – Game-changing evaluation center launches

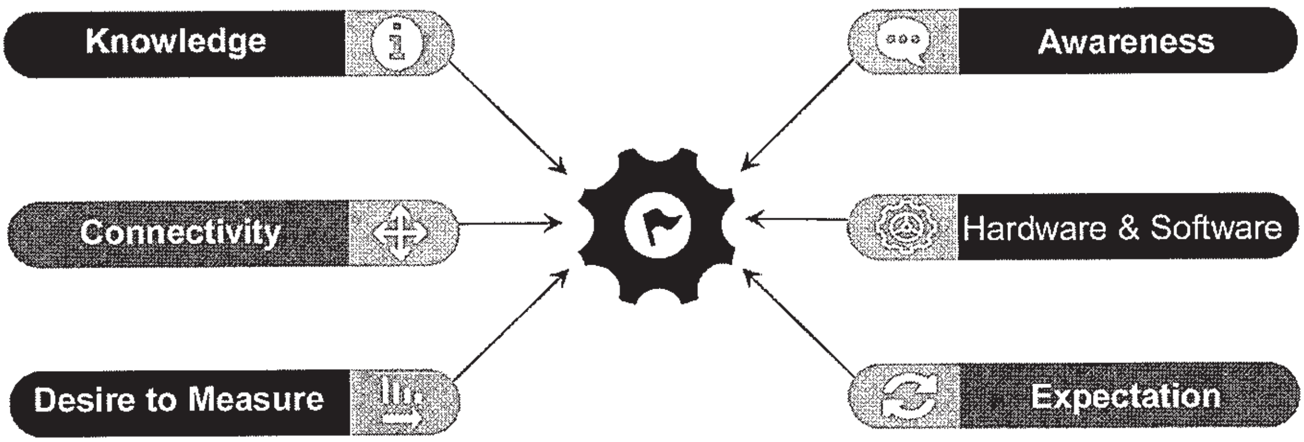
The South Coast Air Quality Management District in Los Angeles set up a comprehensive evaluation center for air sensors. It evaluated the accuracy and usability of commercially available, low-cost air quality sensors.

2016 - Startup and more startups

At a pace of almost one new company per week, startups seek to develop air quality sensor for the consumer market. You can buy air sensor systems for around $200 on Amazon. Many devices look beautiful with flashy apps, videos, and websites. While many of them look interesting, the accuracy and quality of the data often remains elusive.



Tipping Point



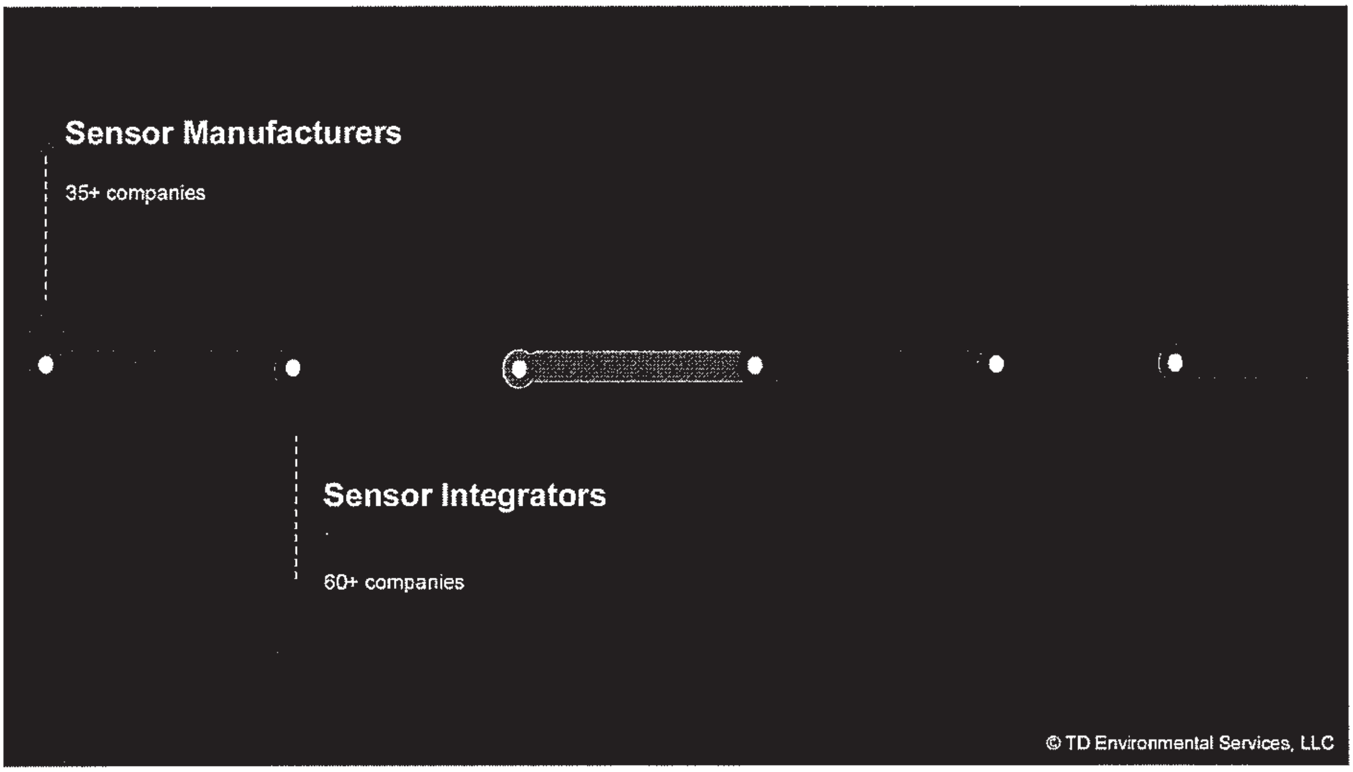
State of the Market

- Dominated by startups and small hardware/software companies
- Large unknowns about sensor performance
- Few standards exist, no regulations accepting of sensors
- Lots of interest in monitoring local air quality
- Funding for demonstration and proof-of-concept projects
- Some early results are promising

Value Chain

Lots of work needed to create actions and benefits

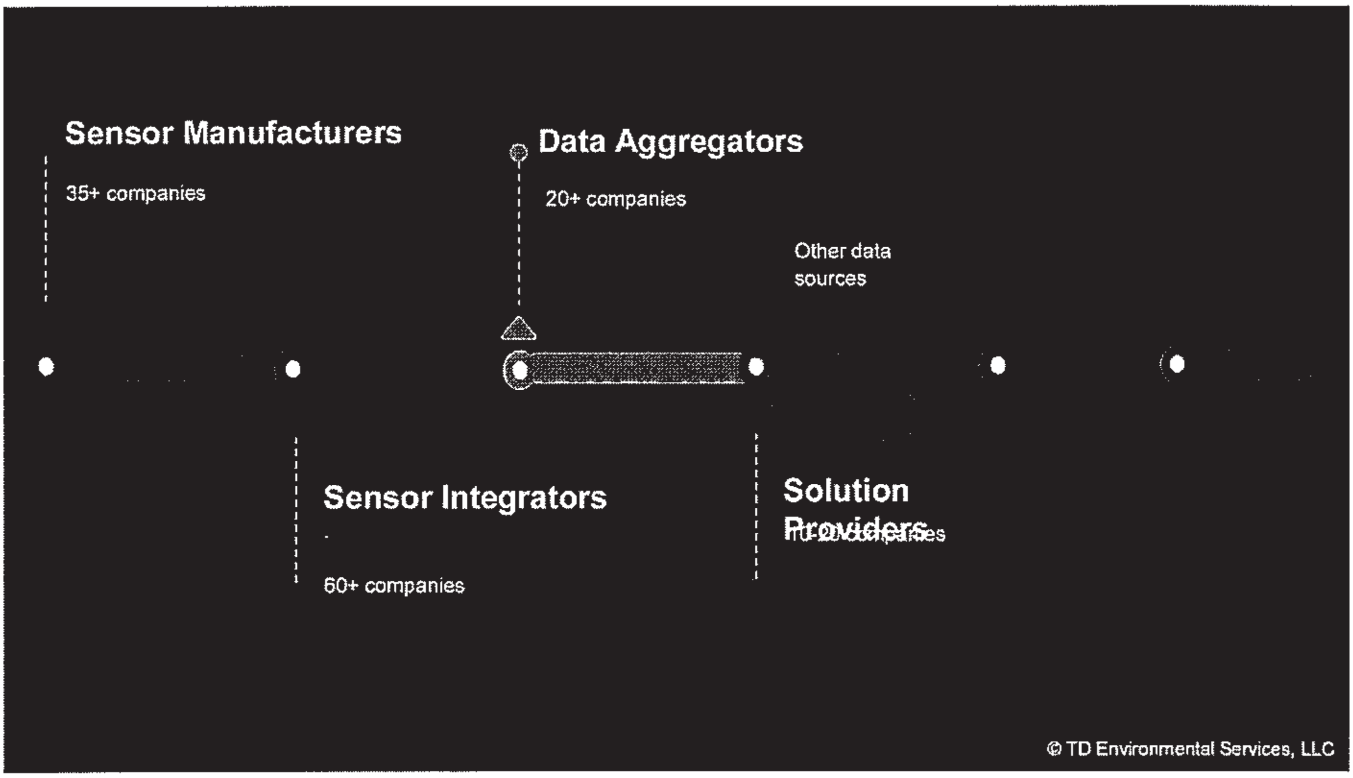
Definition, Roles, and Current Status



Value Chain

Lots of work needed to create actions and benefits

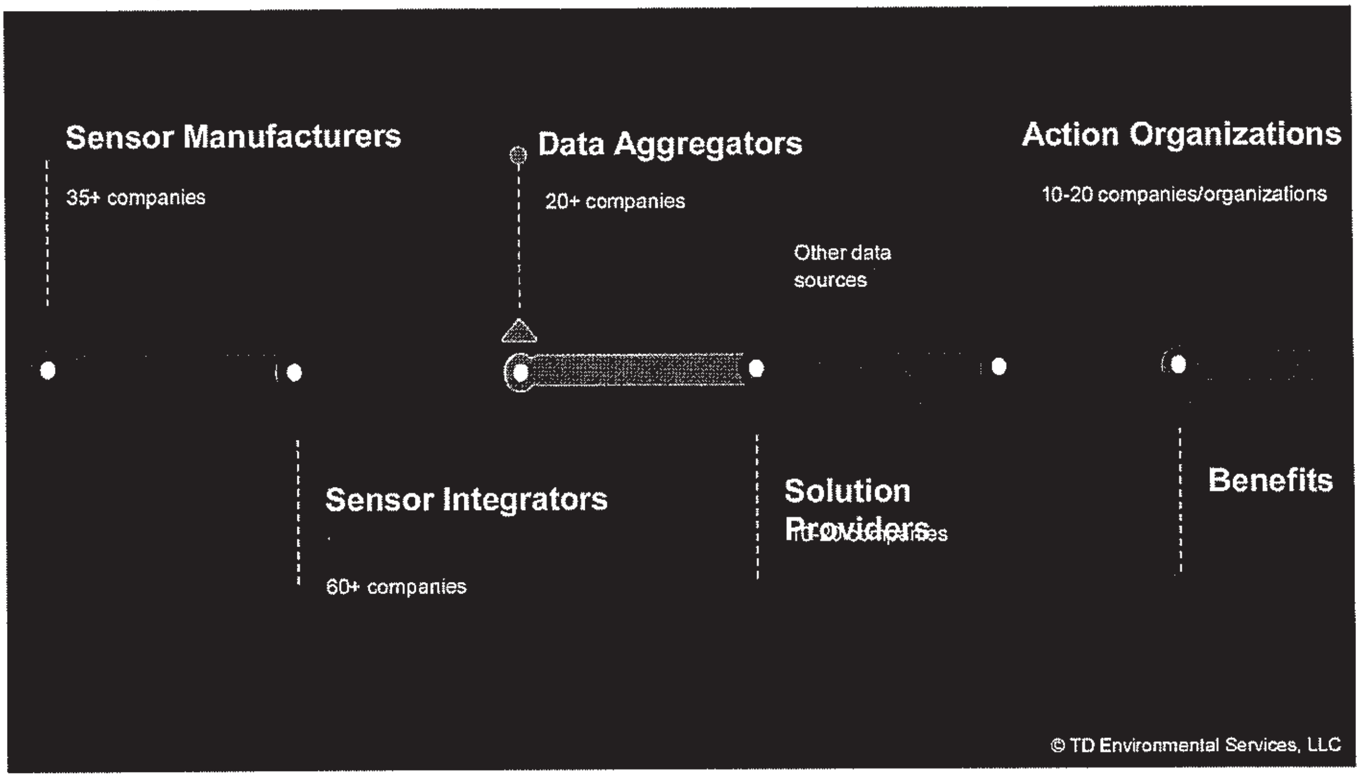
Definition, Roles, and Current Status



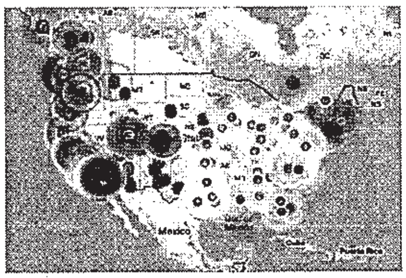
Value Chain

Lots of work needed to create actions and benefits

Definition, Roles, and Current Status



Sample Project - Purple Air



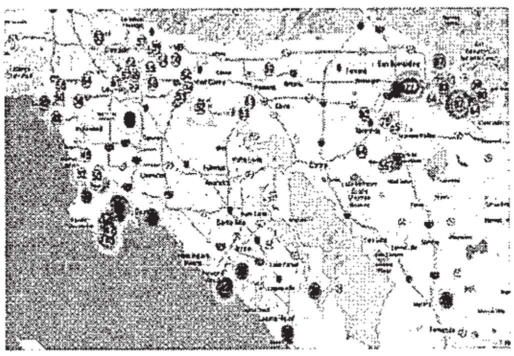
Organization: Purple Air

Dates: 2015+

Objectives: Helping others monitor air quality

Pollutants:

- PM_1, $PM_{2.5}$, PM_{10},
- 550 sites
- Growing rapidly (200+ per month)



"People really care. They want to monitor PM for their health, exercising, when to open windows, buying a house, wildfire smoke, and more". - Adrian Dybwad, Founder of PurpleAir

Sample Project - Taiwan

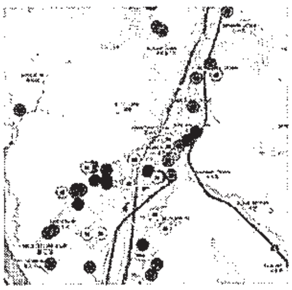
Organizations: Academia Sinica and National Taiwan Normal University

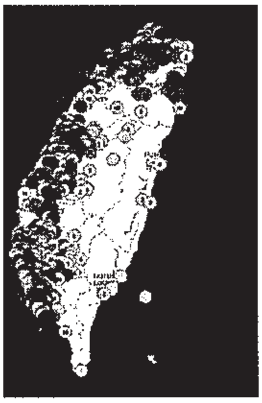
Dates: 2016+

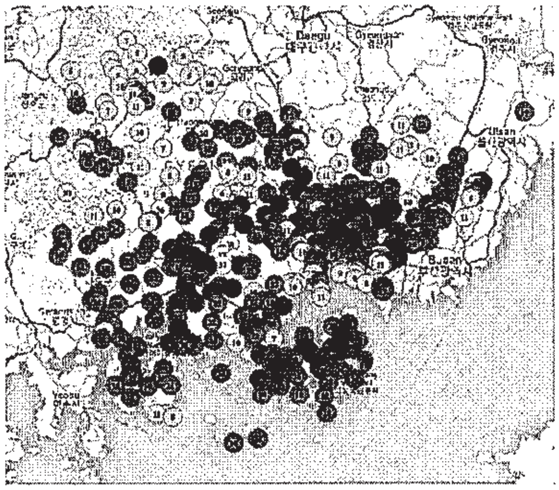
Objective: Create a participatory urban sensing framework

Pollutants:

- $PM_{2.5}$
- 3000+ sites







https://www.dropbox.com/s/8oxggb7rbb4ofgw/17_IEEE_Access-AirBox.pdf?dl=0

Sample Project - Taiwan

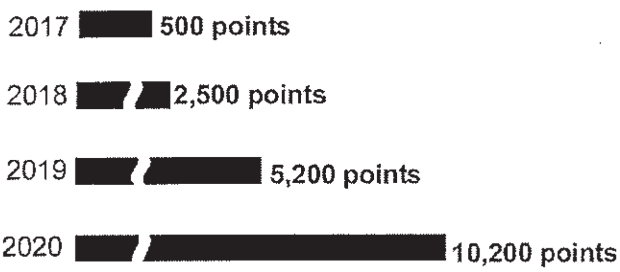
Organizations: Taiwan EPA and Industrial Technology Research Institute

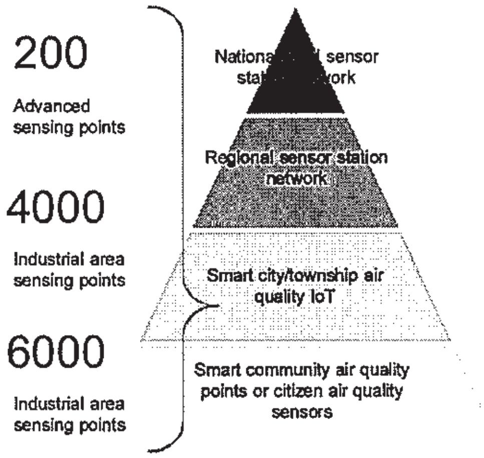
Dates: 2017-2020

Objective: Deploy air sensors in major industrial areas, metropolitan areas, and townships

Pollutants:

- $PM_{2.5}$
- 10,200+ sites





Kun-Hsing Liu, ITRI, Taiwan EPA and Industrial Technology Research Institute

Sample Analysis – Wine Country Fires

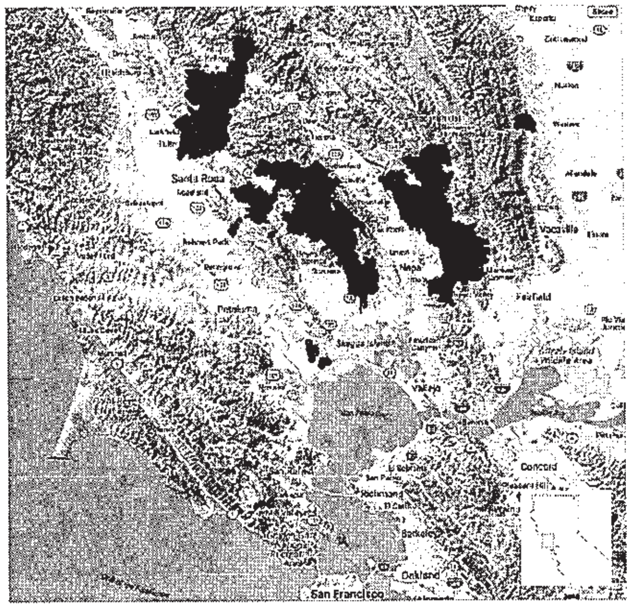
Location: San Francisco North Bay Counties

Dates: October 8-20, 2017

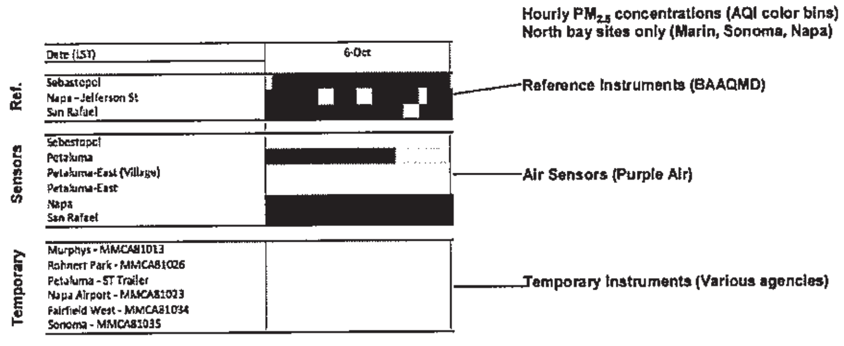
Issue: Smoke from fires ($PM_{2.5}$)

Statistics:

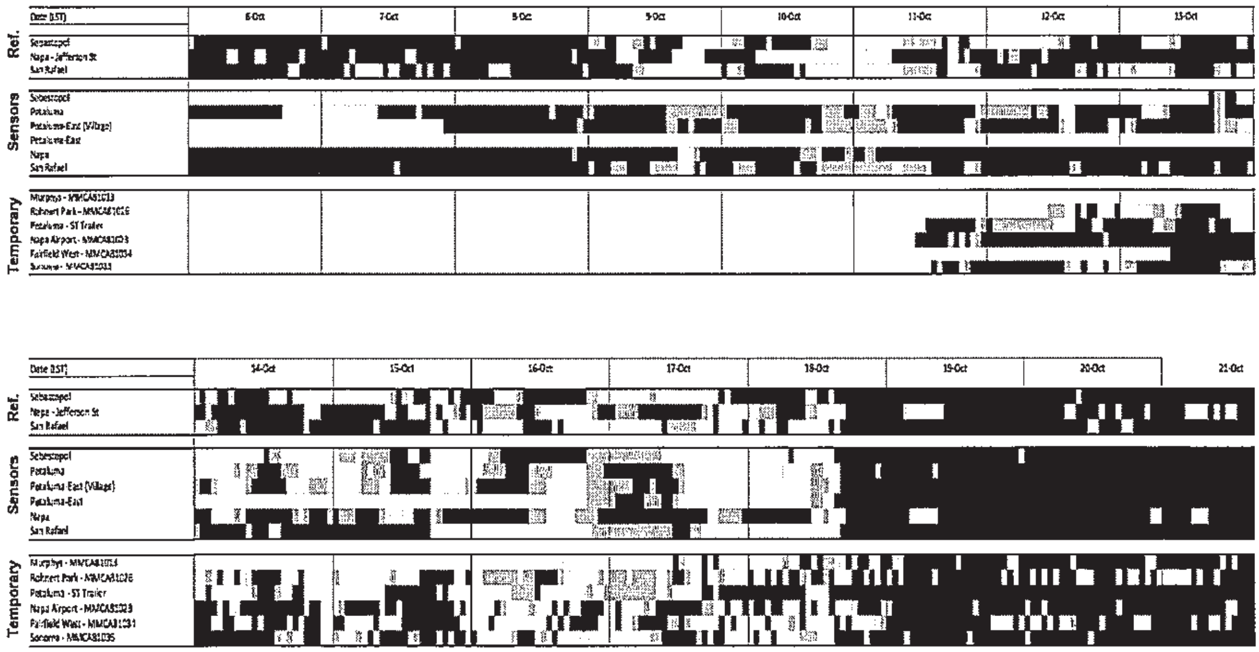
- 4 large fires: Tubbs, Atlas, Nuns, Pocket
- 162,000 acres burned
- 8,900 houses and businesses destroyed
- 43 people killed
- Deadliest fires in California history



Sample Analysis – Wine Country Fires



Sample Analysis – Wine Country Fires



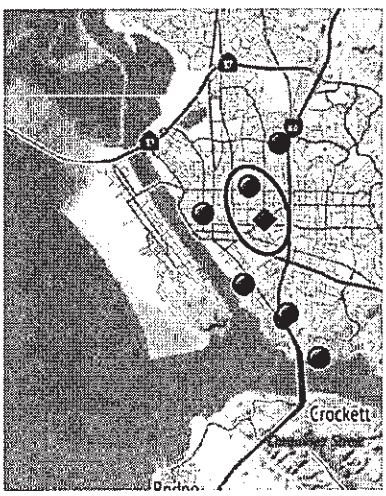
Sample Analysis – Wine Country Fires

Compare Sensors to FEM

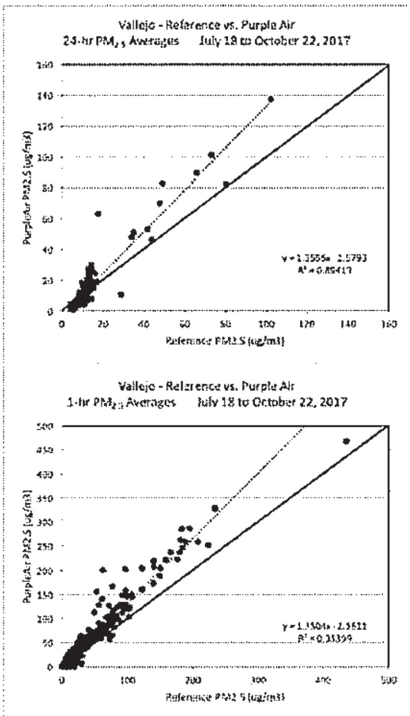
Location: Vallejo, CA

Instrument: BAM 1020

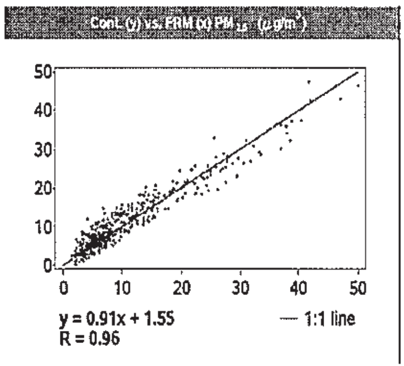
Sensor: Purple Air



Purple Air vs. FEM (2017)

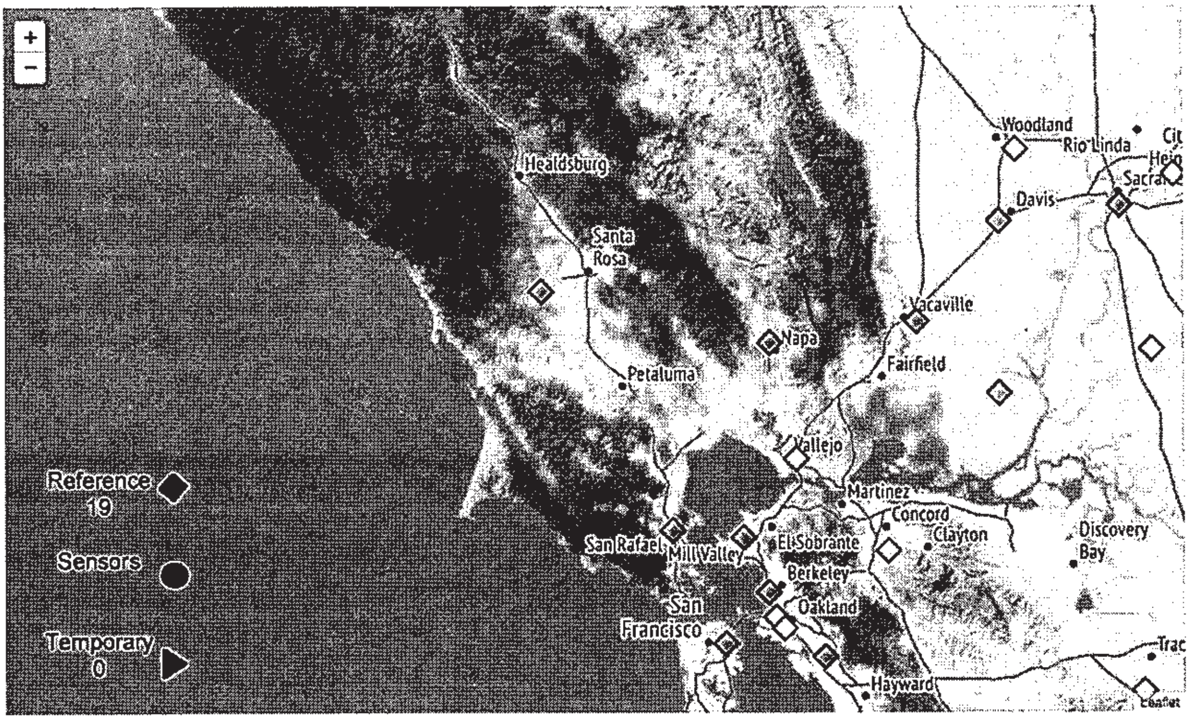


FEM vs. FRM (2008-2010)



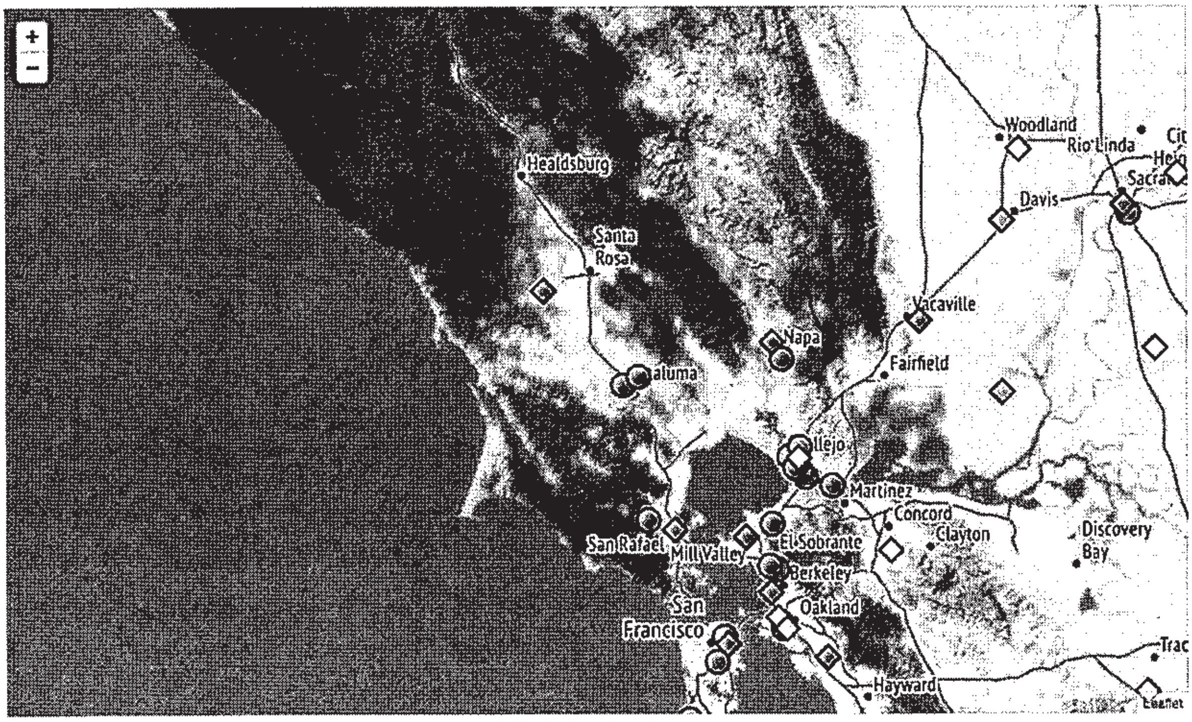
Source: EPA's Air Data

Sample Analysis – Wine Country Fires



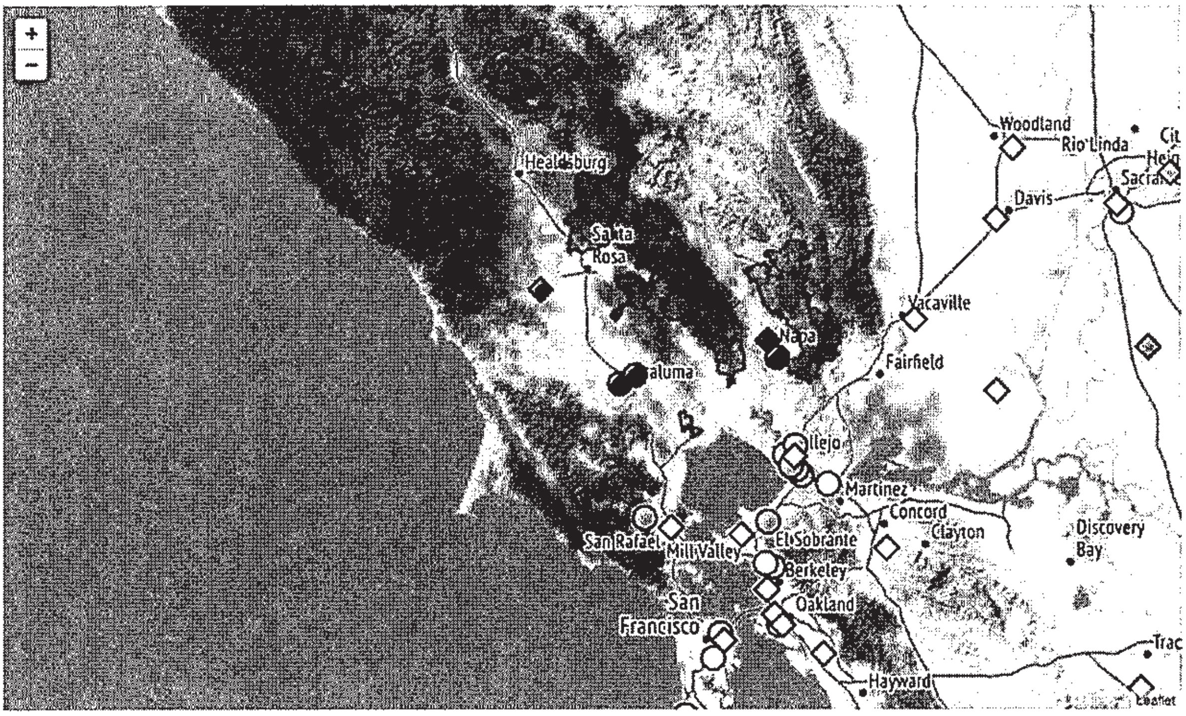
October 8, 2017 1200 LST

Sample Analysis – Wine Country Fires



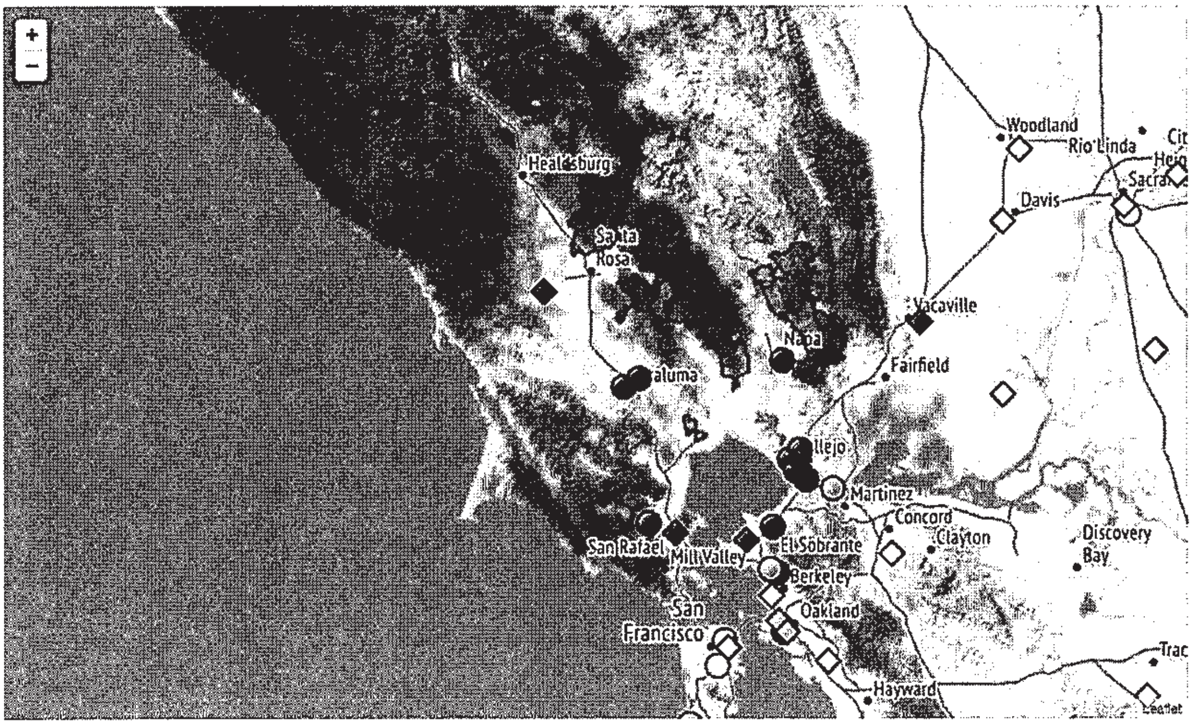
October 8, 2017 1200 LST

Sample Analysis – Wine Country Fires



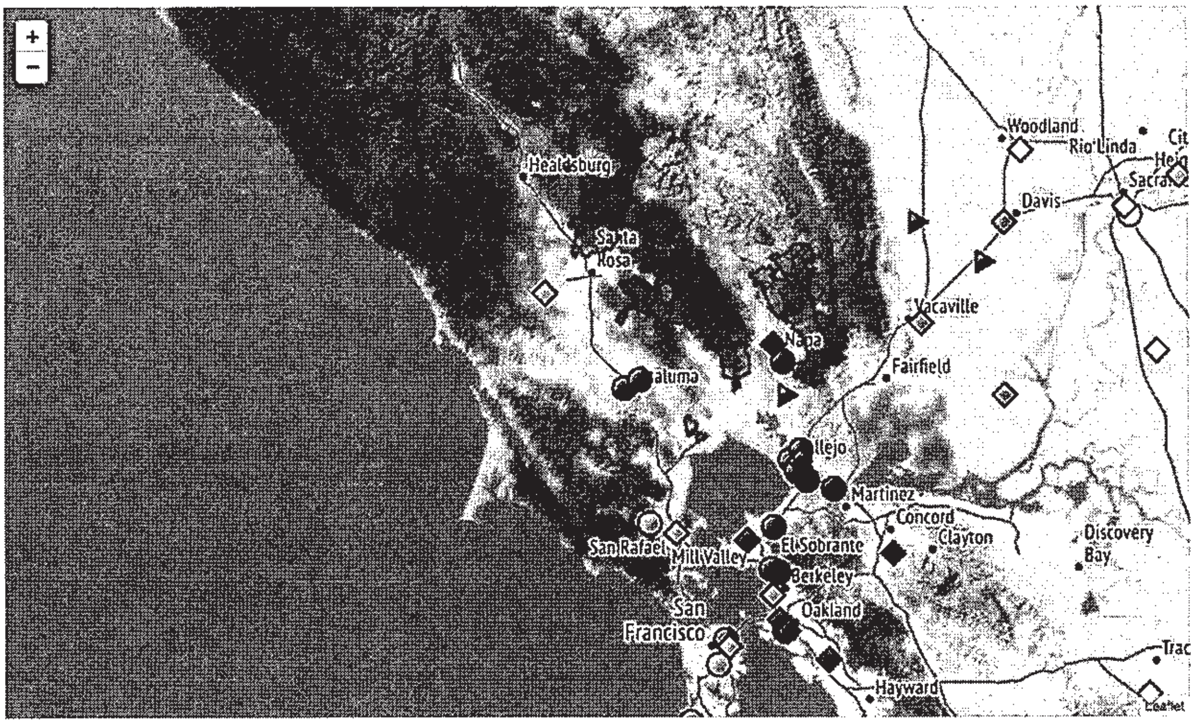
October 9, 2017 1200 LST

Sample Analysis – Wine Country Fires



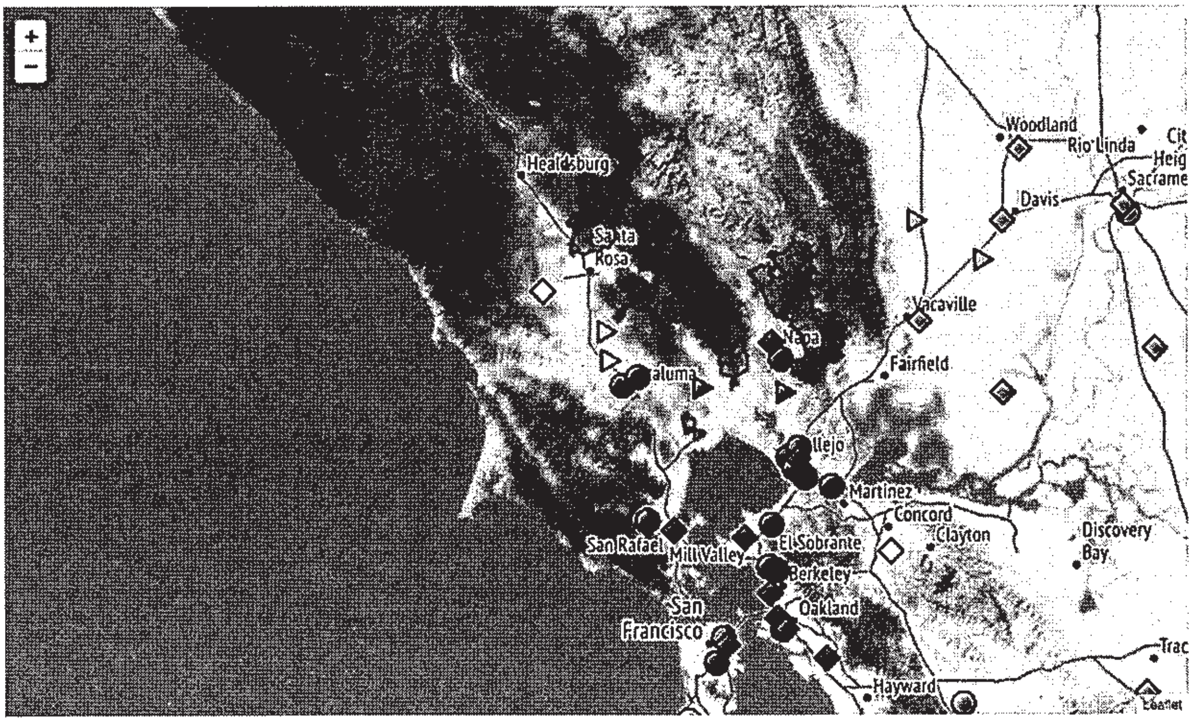
October 10, 2017 1200 LST

Sample Analysis – Wine Country Fires



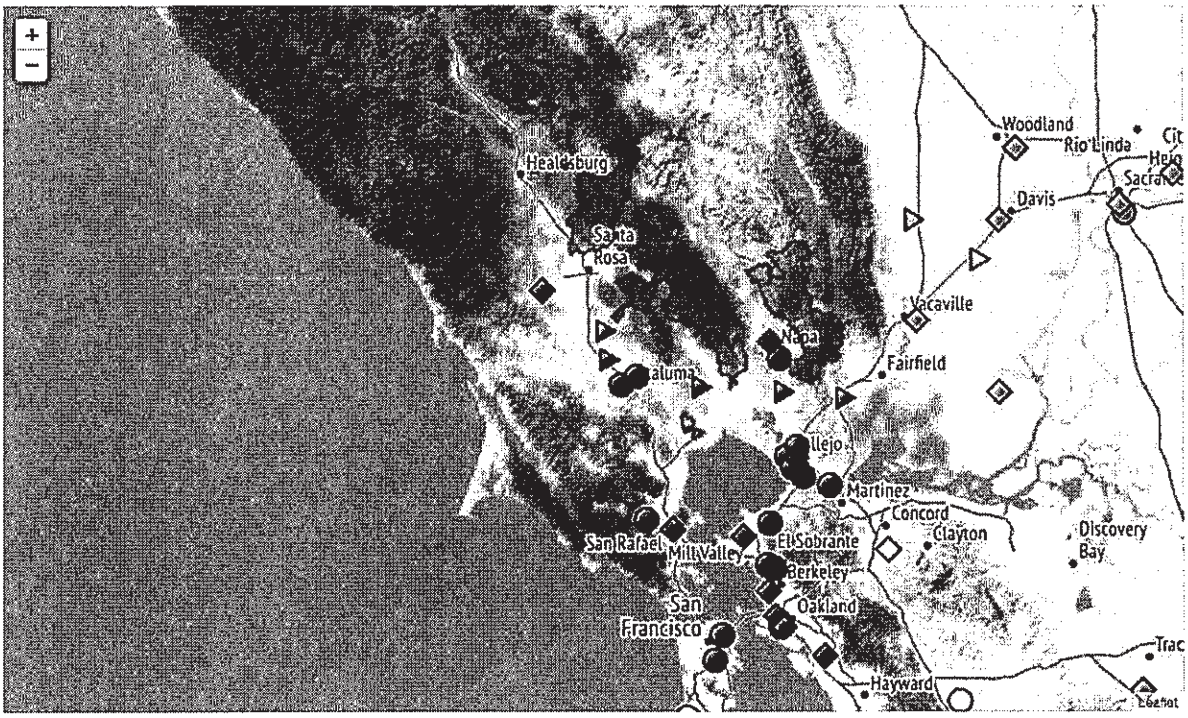
October 11, 2017 1200 LST

Sample Analysis – Wine Country Fires



October 12, 2017 1200 LST

Sample Analysis – Wine Country Fires



October 13, 2017 1200 LST

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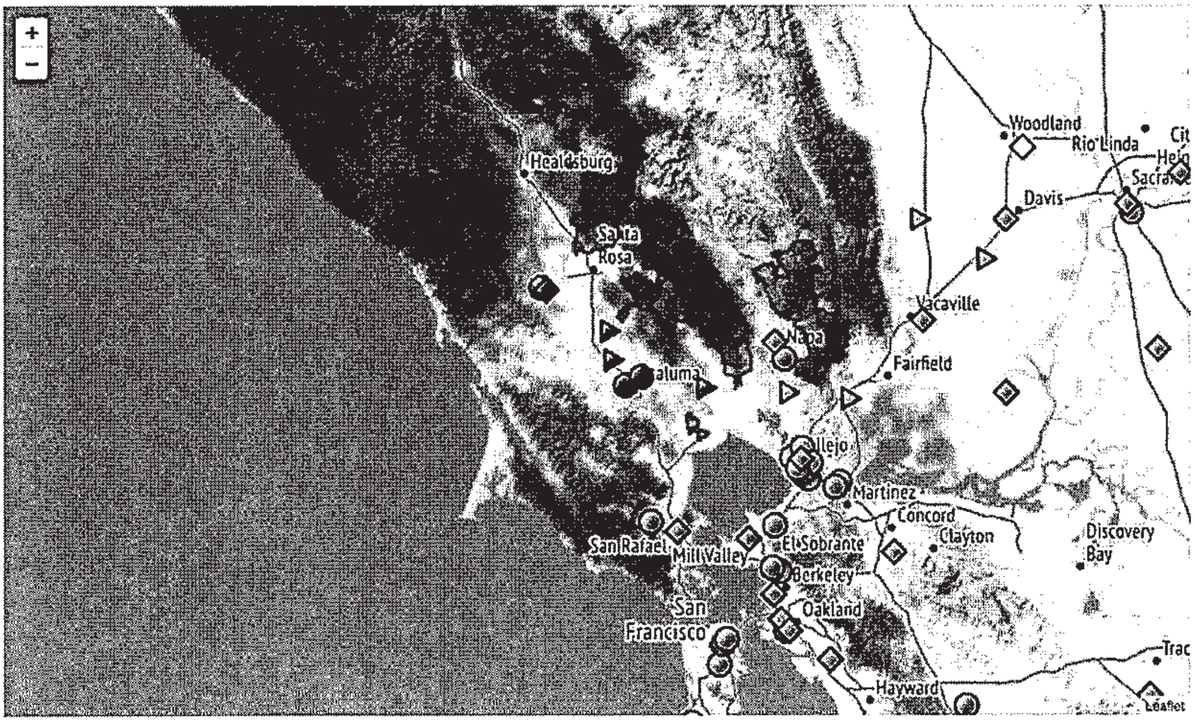
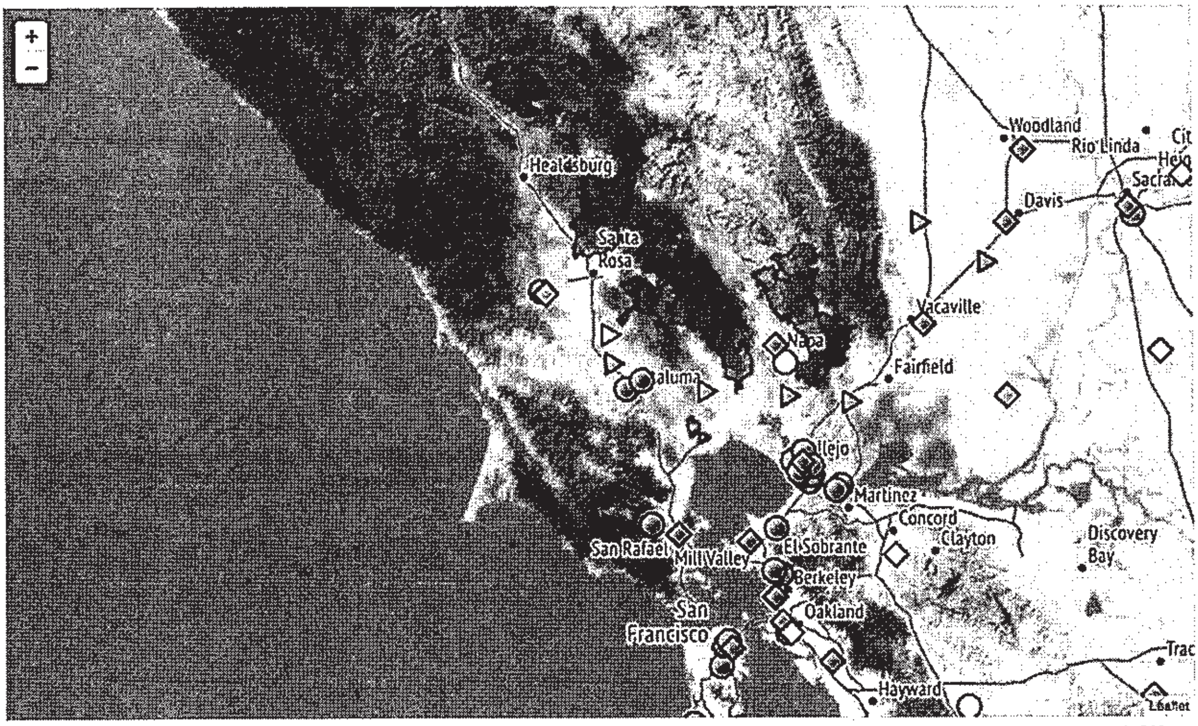
Te

Sample Analysis – Wine Country Fires



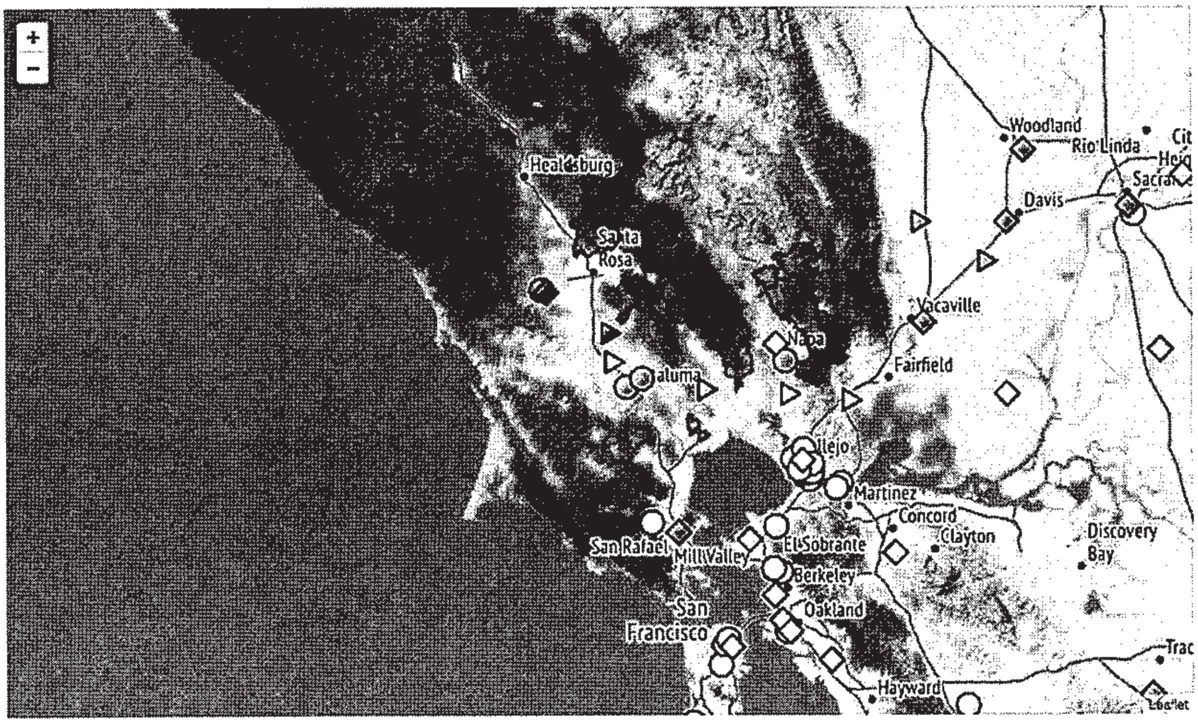
October 14, 2017 1200 LST

Sample Analysis – Wine Country Fires



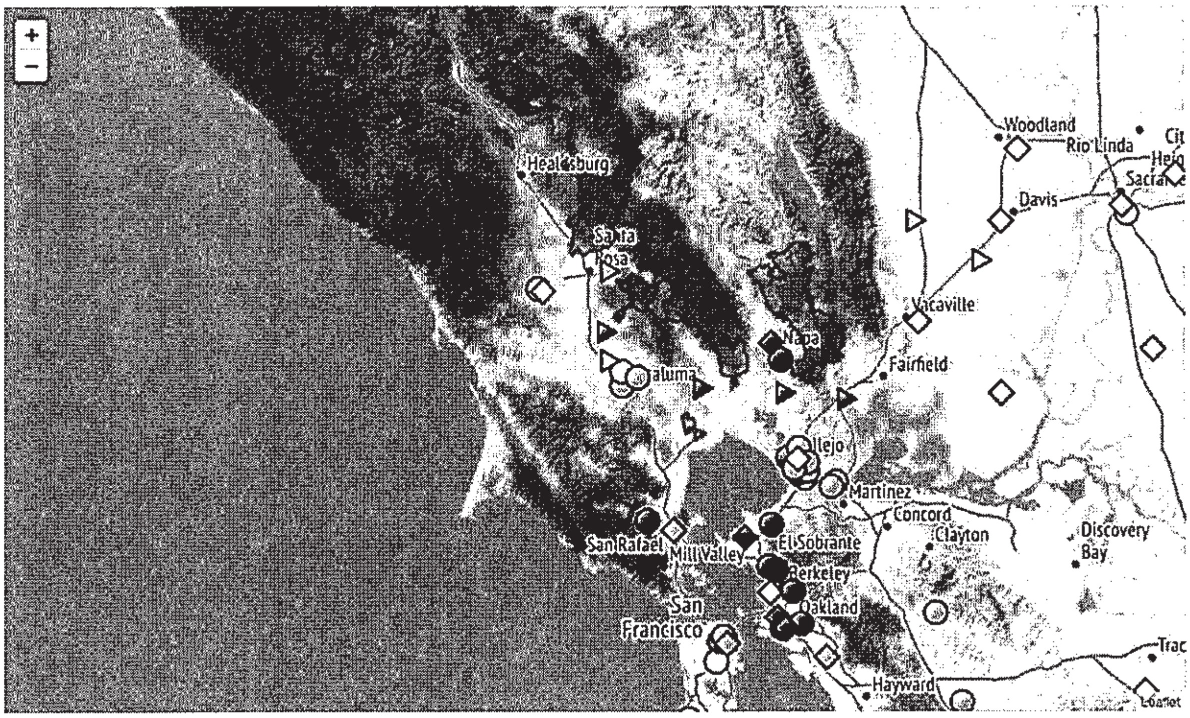
October 15, 2017 1200 LST

Sample Analysis – Wine Country Fires



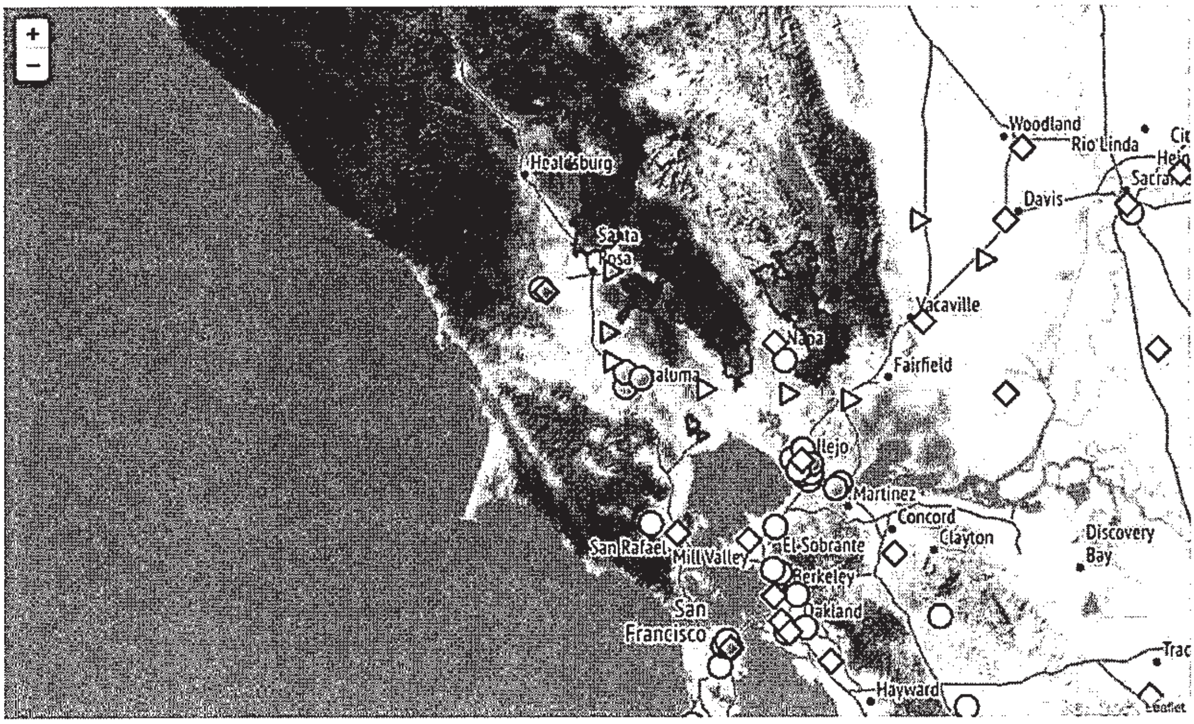
October 16, 2017 1200 LST

Sample Analysis – Wine Country Fires



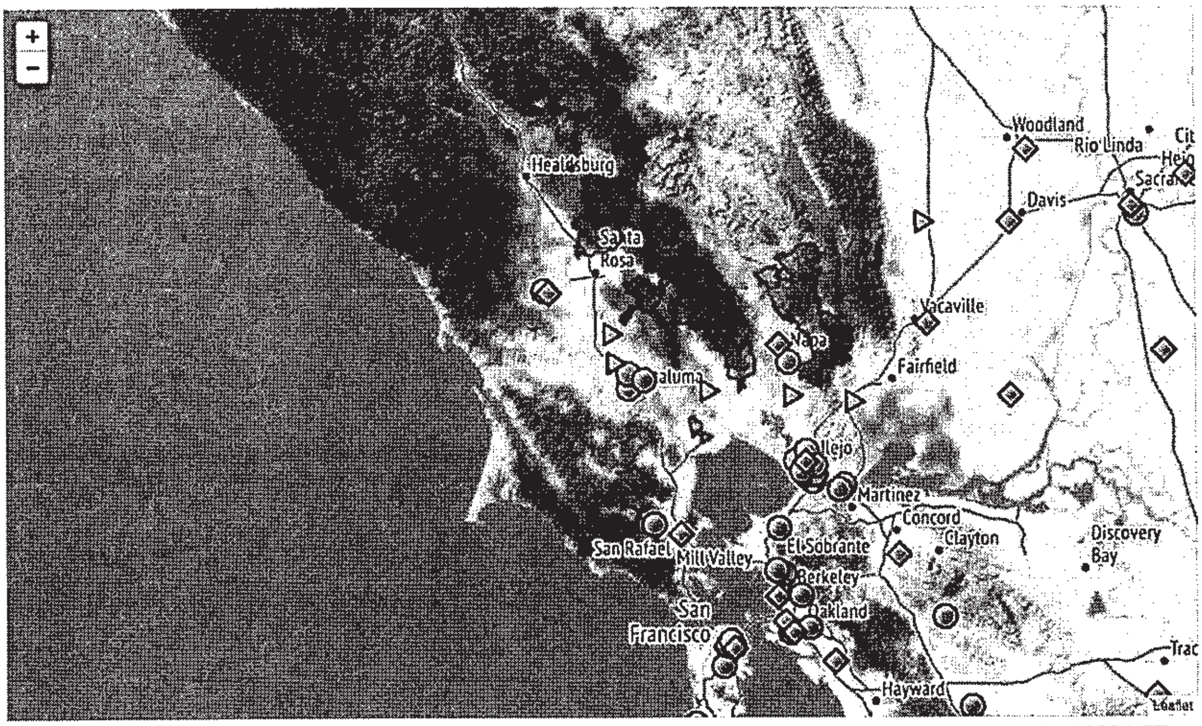
October 17, 2017 1200 LST

Sample Analysis – Wine Country Fires



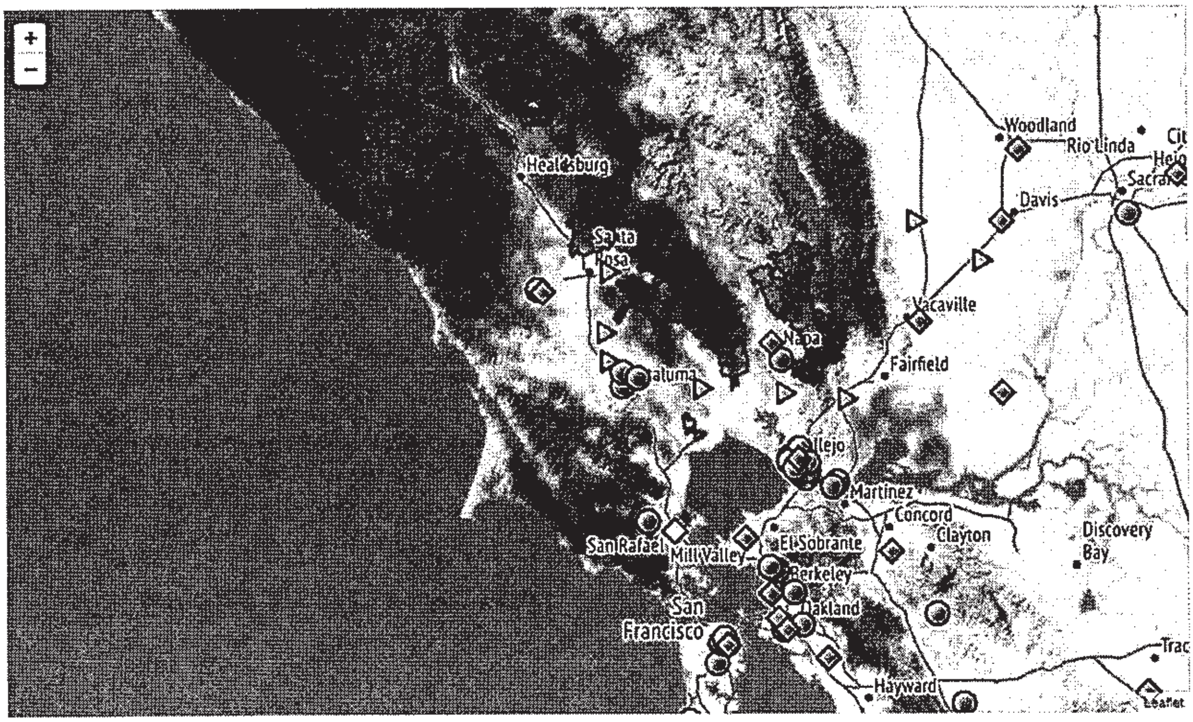
October 18, 2017 1200 LST

Sample Analysis – Wine Country Fires



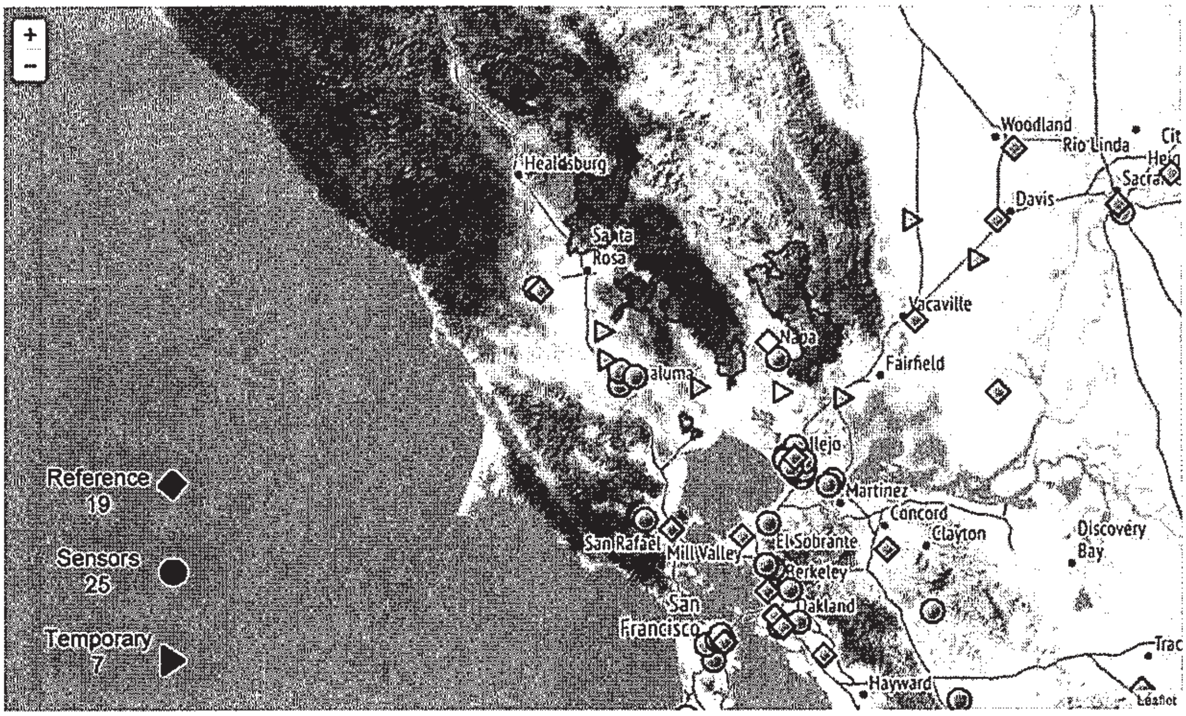
October 19, 2017 1200 LST

Sample Analysis – Wine Country Fires



October 20, 2017 1200 LST

Sample Analysis – Wine Country Fires



October 21, 2017 1200 LST

What's Needed?

Sensor Performance

Need to increase quality, durability, and longevity of air sensors (both gas and PM)

Successful Proof-of-Concepts

This new technology requires demonstration of the benefits.

Standards

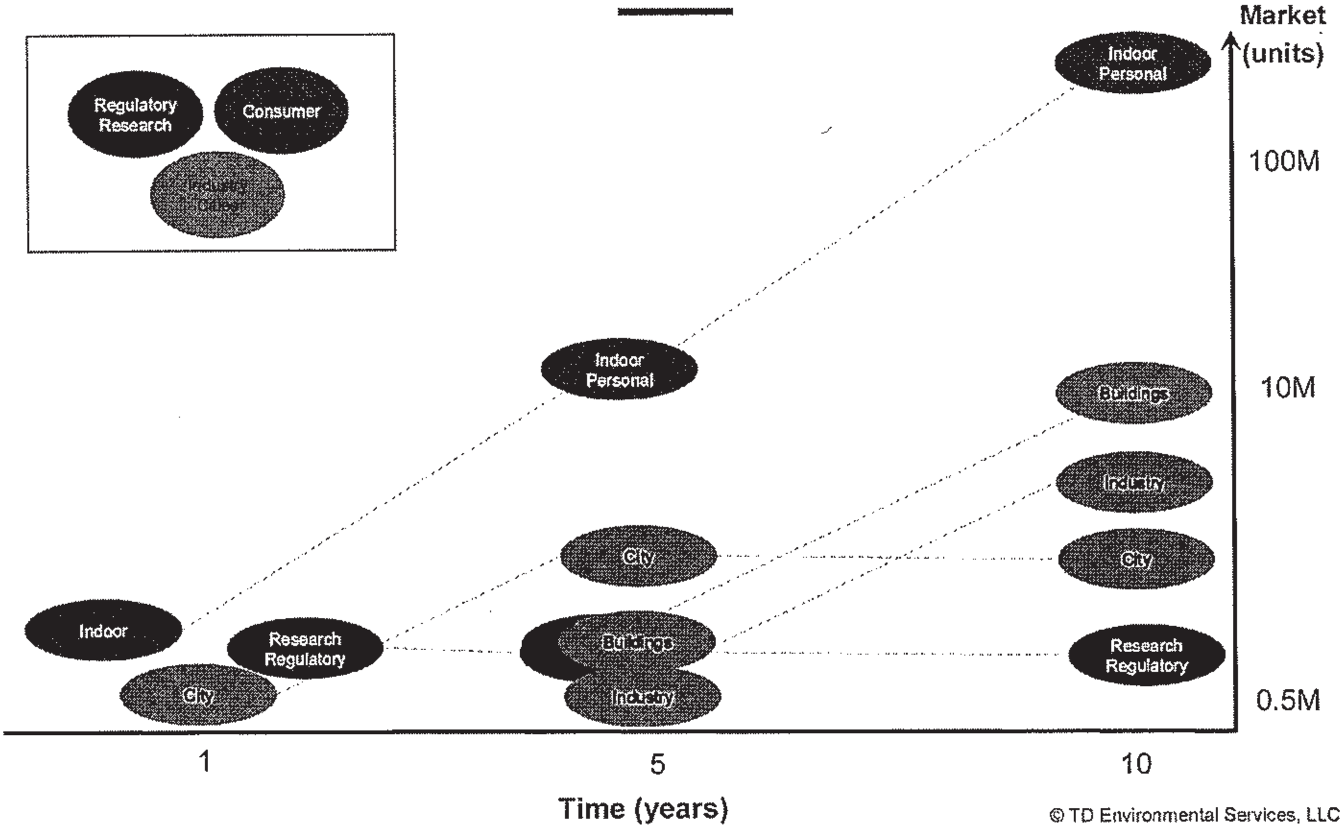
Long-term business growth for regulatory, industry, and buildings will result from regulations and codes incorporating this new technology.

Ecosystem – Users & Suppliers

Ultimately create a market with users and businesses meeting their near- and long-term needs

Market Evolution

Market growth in next 10 years



Contact information

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DEVELOPMENT OF A LOW COST SENSOR NETWORK FOR FACILITY AND COMMUNITY MONITORING

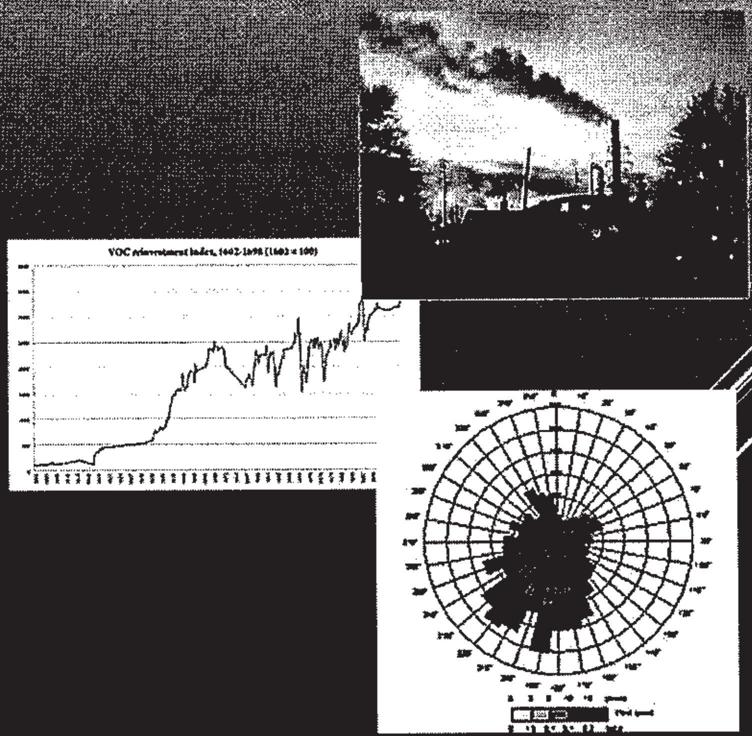
Robert Wimmer, Olga Pikelnaya, Ross Cheung and Andrea Polidori
South Coast Air Quality Management District

WHY MONITOR FOR VOCs?

- VOC emission and composition from industrial sources are not fully understood
- Mounting evidence that current emission inventories are underestimating actual VOC emissions
- VOC's contribute to photochemical smog formation
- Some VOC's are also air toxics
- Monitoring equipment for VOCs is costly
- Need to find cost-effective solutions for fenceline and community-scale monitoring of VOC's
- "Low-cost" VOC sensors can meet this challenge

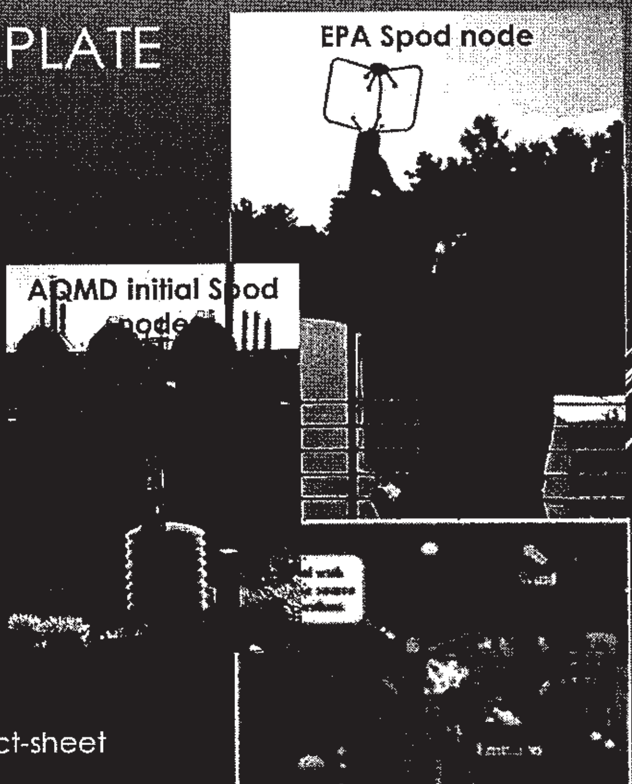
REQUIREMENTS FOR "LOW-COST" VOC SENSOR SYSTEM

- Small and self contained
- Capable of long-term, unattended operations
- Capture wind and meteorological conditions at the site for source attribution
- Wireless, real-time data transfer



SPOD DESIGN AS A TEMPLATE

- Open source VOC fenceline monitor
- 3D printed parts
- Mocon PID VOC sensor
- Short range point-to-point data radio (XBEE S1)
- Used EPA ORD Spod design as a starting point
- Modified Spod design to enhance functionality and add capabilities

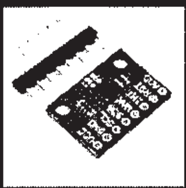


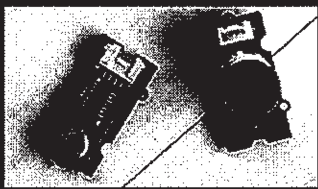
https://www.epa.gov/air-research/spod-fact-sheet

TYPES OF "LOW-COST" VOC SENSORS

- PID (photoionization detector) - from ~$400


- MOX (Metal oxide sensors) - from $30





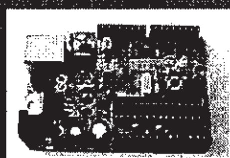
Sensor selection will depend on application and deployment requirements

- Advantages:
  - High accuracy and precision
  - Fast response
  - Long lifetime
- Disadvantages
  - Sensitive to RH changes
  - Baseline drift overtime
- Advantages:
  - Fast response time
  - Automatic correction for T and RH changes
  - Low cost
- Disadvantages
  - Require weatherproofed enclosure
  - Performance not well-characterized

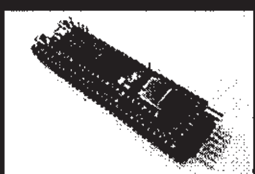
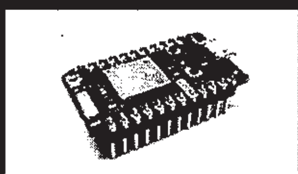
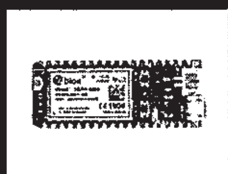
HOST PROCESSORS

- Arduino based Boards and Clones ~$30 - $70



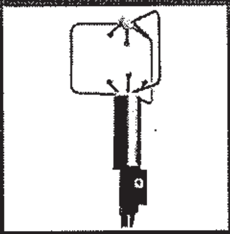
- Arduino based chipsets with hybrid capabilities ~$17 to $130

- Best selection based on hybrid resident components.
- Better ADC and a good number of UART serial ports and possible resident communication facilities.

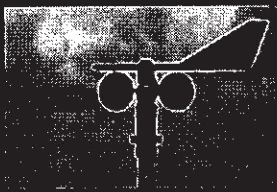
WIND MEASUREMENTS

- Ultrasonic anemometer (~$800 and up)



- Advantages
  - Serial capabilities
  - Highly accurate and precise
- Disadvantages
  - high in price
  - high in power consumption

- Traditional anemometer (~$80 and up)


- Advantages
  - low cost
  - Low power consumption
- Disadvantages
  - units may vary in precision.
  - Greater wear and tear due to bearing surfaces

Wind meter selection is based on interface protocol. Serial data interface is preferred.

TELEMETRY OPTIONS

- Localized telemetry radios



- Advantages
  - Inexpensive
  - Some models can be "meshed"
- Disadvantages
  - Limited range
  - Require line of sight
  - Data transmission can not be timed

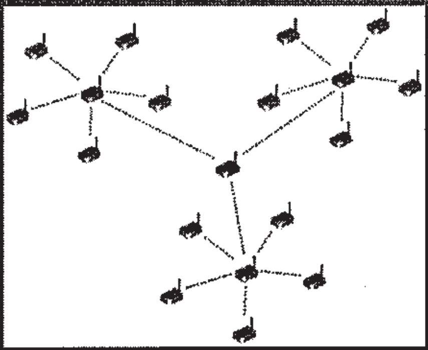
- Cellular

- Advantages
  - Line of sign is not required
  - Unlimited number of units
- Disadvantages
  - Require data plan

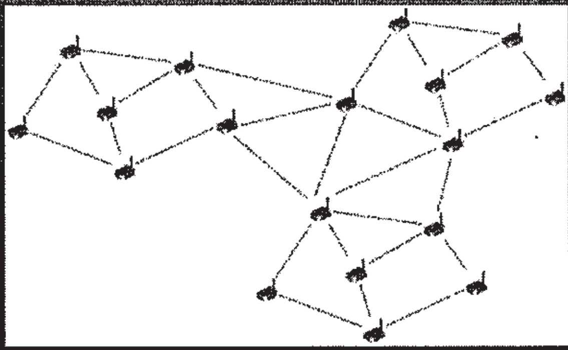
Fence-line locales do not necessarily guarantee line of site
Point to point data is not sufficient; units need to "net" together and route data

ROUTABLE TELEMETRY DATA RADIOS

Current "star" network design



Desired "meshed" network design



Early XBEE S2 pro and S3 Pro units allowed for a "star" configurations or "multi-star" configuration. Such nomenclature included end points, routers and a single coordinator. Easy to design and troubleshoot

Zigbee protocol is shared amongst different device manufactures (digi and loRaw)
Self healing network. It will route data around obstacles. Makes mating with a cellular gateway tricky. Good for long term in house monitoring systems

Both systems can be "chatty" No resident collision detection.

SPOD DATA FORMAT

"Clean" data sample

```
spod2,1:9:40 8-8-2017,022,00.0,12.32,78.80,760.17,22.54,74.94,14,21,24,0.14964
spod4,1:10:46 8-8-2017,266,00.8,12.45,85.90,759.89,22.25,76.62,20,29,30,0.14067
spod1,1:10:20 8-8-2017,012,03.0,12.87,87,80,759.96,21.83,78.65,17,23,33, 0.05730
spod3,1:10:16 8-8-2017,353,02.7,12.05,108.20,759.54,22.28,76.04,17,30,32, 0.06769
spod2,1:9:42 8-8-2017,315,00.8,12.33,88.40,760.17,22.54,74.95,14,21,22,0.14067
spod4,1:10:48 8-8-2017,300,01.1,12.45,85.90,759.89,22.25,76.61,19,27,30,0.15122
spod1,1:10:22 8-8-2017,012,02.5,12.86,88.10,759.95,21.82,78.67,17,23,32, 0.05868
spod3,1:10:18 8-8-2017,003,02.3,12.06,106.40,759.55,22.29,76.07,16,24,28, 0.0330
spod2,1:9:44 8-8-2017,331,01.5,12.32,86.90,760.18,22.55,74.94,14,21,22,0.13516
spod4,1:10:50 8-8-2017,330,02.0,12.45,85.90,759.92,22.25,76.61,20,27,31,0.16106
spod1,1:10:24 8-8-2017,007,02.9,12.86,86.10,759.97,21.83,78.68,17,23,32, 0.06282
spod3,1:10:20 8-8-2017,002,01.7,12.05,109.70,759.56,22.29,76.07,16,23,26, 0.07107
spod2,1:9:46 8-8-2017,003,01.3,12.33,86.10,760.20,22.55,74.95,14,21,22,0.13792
```

"Stepped on" data sample

```
spod1,1:10:8 8-8-2017,350,02.0,12.87,96.30,759.96,21.85,78.57,18,27,33, 0spod2,1:9:30 8-8-
2017,336,00.8,12.33,86.70,760.18,22.54,74.94,16,21,25,0.15722
.04418
spod3,1:10:4 8-8-2017,351,02.9,12.05,106.30,759.57,22.33,75.95,20,27,36, 0.05753
spod4,1:10:36 8-8-2017,281,00.8,12.45,85.90,759.90,22.24,76.63,19,29,32,0.15403
spod2,1:9:32 8-8-2017,336,00.0,12.32,83.40,760.18,22.54,74.95,16,21,25,0.spod1,1:10:10 8-8-
2017,351,02.7,12.86,84.70,759.94,21.84,78.60,17,24,32, 13930
0.07939
spod3,1:10:6 8-8-2017,339,02.7,12.04,114.30,759.56,22.32,75.97,20,30,38, 0.08630
spod4,1:10:38 8-8-2017,235,00.7,12.45,85.90,759.90,22.24,76.63,19,29,32,0.17654
spod2,1:9:34 8-8-2017,269,00.0,12.32,81.50,760.18,22.54,74.95,16,22,26,0.spod1,1:10:12 8-8-
2017,001,02.9,12.86,92.00,759.97,21.84,78.61,17,23,30, 13792
0.04832
```

- Xbee equipped units "stepped on" each other, resulting in interrupted data strings
- Frequency of such interruption is dependent on transmission frequency
- Interrupted data strings had to be filtered out before inclusion into the database, resulting in data loss
- This can be remedied by holding back transmission before data is sent
- Cellular unit will not be susceptible to this problem

DATA ROUTING PROCEDURE

Data String Picked up by Rasp Pi radio

```
spod3,0:1:42 8-8-2017,287,04.8,12.04,110.60,759.59,22.58,74.13,16,24,26, 0.0550
spod4,0:2:14 8-8-2017,299,02.7,12.45,64.60,759.88,22.77,73.46,19,20,29,0.16398
spod1,0:1:48 8-8-2017,287,03.3,12.89,85.80,759.97,22.46,75.10,16,23,26, 0.05799
spod2,0:1:10 8-8-2017,295,03.8,12.33,94.80,760.20,22.88,72.71,14,21,24,0.14205
spod3,0:1:44 8-8-2017,294,04.3,12.06,116.60,759.60,22.57,74.15,17,24,25, 0.02538
```

↓

Data checked for inconsistencies (i.e "stepped on" data strings)

→

Packet is parsed for individual data elements

Spod3	Name of device
0:1:42 8-8-2017	Time-Date
287	Dir of wind
04.8	Speed in MPH
12.04	Voltage on system
110.60	Milliamps of draw
759.59	Atmospheric pressure
22.58,	Temp (c)
74.13	Relative Humidity
16	PM 1
24	PM2.5
24	PM1
0.0550	VOC VOLTAGE

↓

Device health check

Spod3	Name of device
0:1:42 8-8-2017	Time-Date
287	Dir of wind
04.8	Speed in MPH
110.60	Milliamps of draw
....	

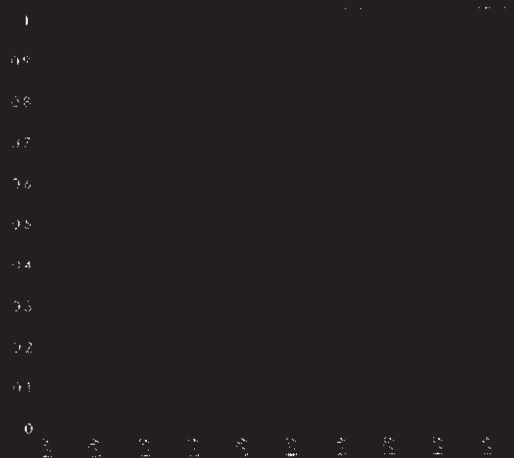
←

Insertion into a MySQL relational database resident on Rasp PI

DATA STORAGE AND ANALYSIS OPTIONS

MySQL on a local computer

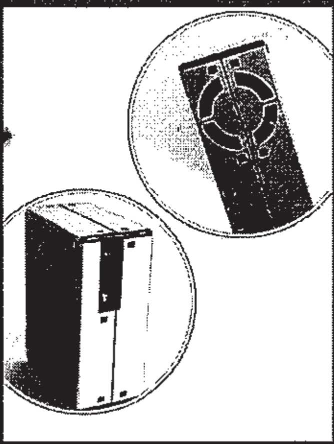
- In-house data plotting and analysis
- Devise health check
- Data quality monitoring



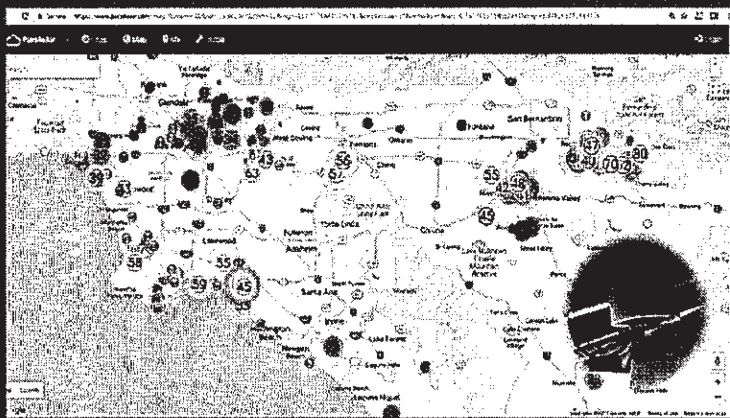
Web-based utility

- EnviroSuite web-hosting utility
- Real-time data visualization
- Modeling and source-apportionment

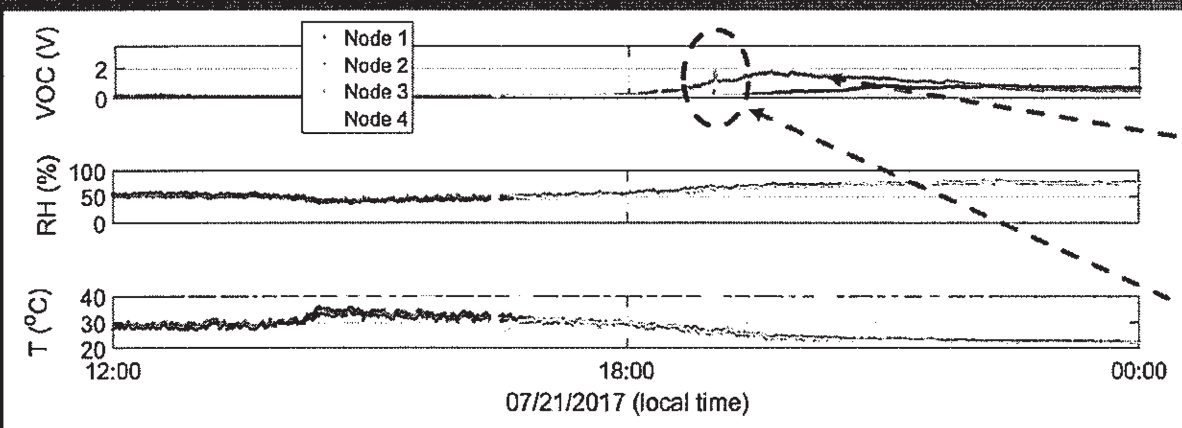
PARTICULATE MATTER SENSOR



- Particulate matter "low-cost" sensor manufactured by Plantower
- Same sensor as in Purple Air II PM sensor nodes



RELATIVE HUMIDITY EFFECTS

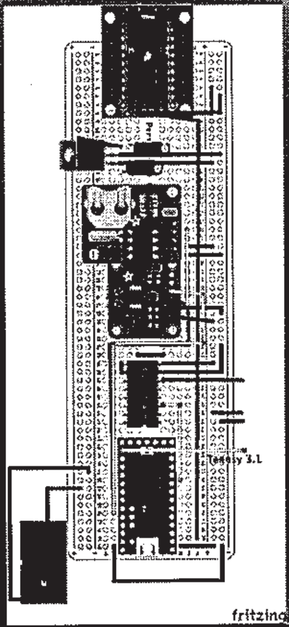


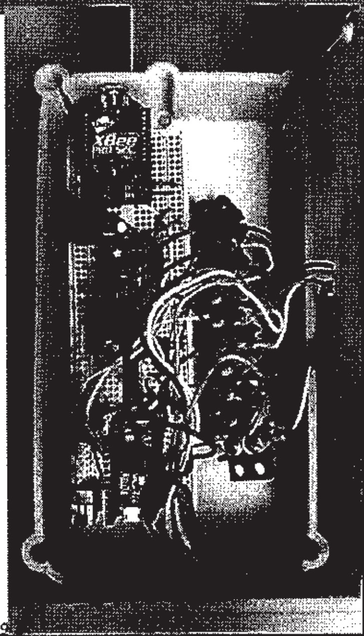
Affect of RH

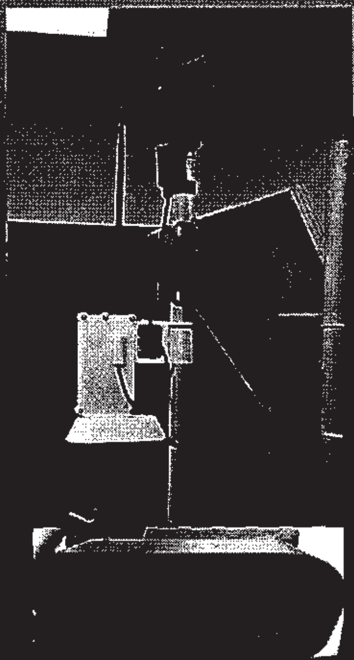
VOC "event"

- Baseline changes due to relative humidity
- Onset may be different for each sensor
- IonScience PID's may be less susceptible to RH effects then Mocon PID's

AQMD VOC POD NODE





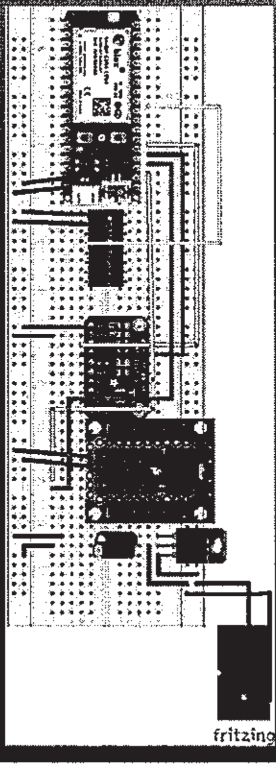


- DC to DC module (~12v to 5v)
- Voltage/Current sensor for health monitoring
- IonScience PID VOC sensor
- Added Plantower PM sensor
- Real-time clock chipset
- Dedicated RH/T/P sensor
- Xbee S2CPro for star configuration
- Ultrasonic anemometer

FIELD DATA COLLECTION AND TRANSFER

- Raspberry Pi 3
- Touch Screen for field access and monitoring
- Xbee2C pro and USB adapter
- Digi multi port cellular modem
- Large battery

AQMD VOC POD ASSEMBLY V2



- Add auxiliary MOX sensor
- Add PM/formaldehyde sensor
- Resident cellular modem
- Analog Anemometer
- 16bit voltage resolution
- Not dependent on a "base unit"
- However, still retain the ability to communicate with a base unit.

CONCLUSIONS

- Designed a field-deployable "low-cost" sensor node for monitoring of VOC's and PM
- Developed SQL database for in-house data processing and monitoring of data quality
- Interfaced with EnviroSuite for web-based data visualization and dispersion modeling
- "Star" network configuration is only feasible for a small network deployment
  - Up to 10 units surrounding a small facility w/o tall structures
- Nodes equipped with individual cell modems are required for large network deployments
  - E.g. fenceline of a complex facility or community deployment
- Initial field deployment of IonScience PID indicate that this sensor is less affected by RH changes, but more detailed testing is needed
- Sensor network can be used for collecting highly time- and space- resolved VOC and PM data

FUTURE WORK

- Include cellular processor to each unit
  - Eliminates the need for a "master" data collection unit
- Depending on application and deployment configuration replace sonic anemometers in some units with traditional wind meter in order to lower power consumption and cost
- Establish Drop-off, turn-on, Confirm Operation and Leave" type of deployment
- Develop unit calibration protocol
- Use current design elements for other sensor types and/or add more sensors to current node design
- Develop algorithm to correct for RH dependence and baseline drift

AWKWARD SILENCE EMERGENCY SLIDE

STUFF I WOULD ASK ABOUT…

ASSESSING COMMUNITY EXPOSURE TO HAZARDOUS AIR POLLUTANTS USING A COMBINATION OF OPTICAL REMOTE SENSING AND "LOW-COST" SENSOR TECHNOLOGIES

OLGA PIKELNAYA[1], ANDREA POLIDORI[1], ROBERT WIMMER[1], JOHAN MELLQVIST[2], JERKER SAMUELSSON[2], MARIANNE ERICSSON[2], SAMUEL BROHEDE[2], OSCAR IZOS[2]

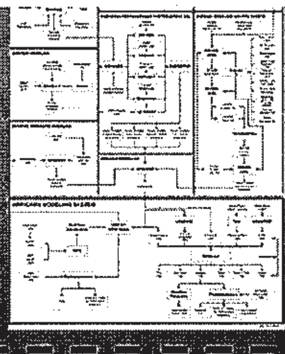
[1]SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT, DIAMOND BAR, CALIFORNIA,
[2]FLUXSENSE INC., SAN DIEGO, CALIFORNIA

South Coast AQMD

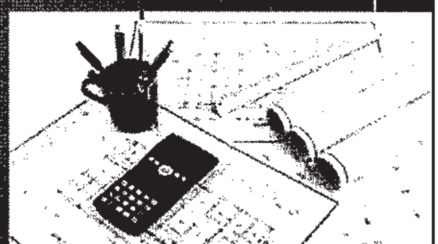
TRADITIONAL APPROACH TO ACCESS AIR QUALITY

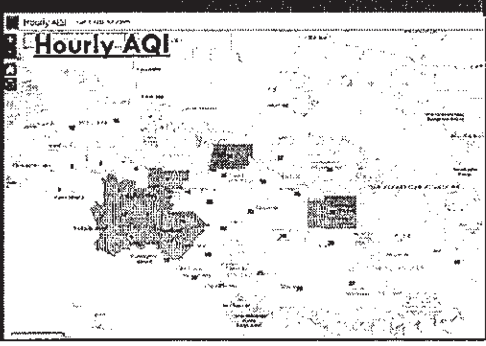
Air Monitoring Stations

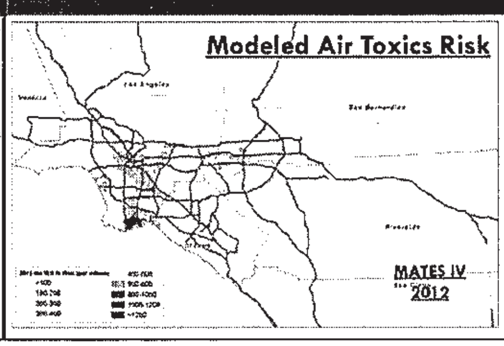
Air Quality Modeling



Emissions Estimates







ADVANCED MONITORING METHODS

- New promising technologies emerged and matured over the past decade
  - Optical Remote Sensing (ORS) Technologies
    - Fully automated / continuous / no calibration required
    - Ideally suited for long-term fenceline monitoring, allow to characterize and quantify emissions
    - Can be deployed from various mobile platforms for rapid leak detection, emission flux measurements, and community monitoring
  - "Low-cost" air quality sensors
    - Automated / continuous
    - Deployed in large numbers to obtain granular air quality information
    - Can be used for fenceline and community monitoring applications
  - Mounting evidence that current emission inventories are underestimating actual VOC emissions - measurements can provide more realistic emission estimates
  - Mobile ORS and "low-cost" sensors offer enhanced capabilities for community and fenceline monitoring

SCAQMD'S OPTICAL REMOTE SENSING PROGRAM

2008
LP-DOAS for fenceline monitoring – contractor failed to fulfill its obligations

2013 – 2014
Two successful technology demonstration projects aimed on refineries monitoring

2015
ORS measurement campaign to study emissions from refineries, small sources, and ships

2016 –
ORS and low-cost sensors to study affects of HAPs on communities. Support for MATES V, upcoming rules, and recent CA legislations

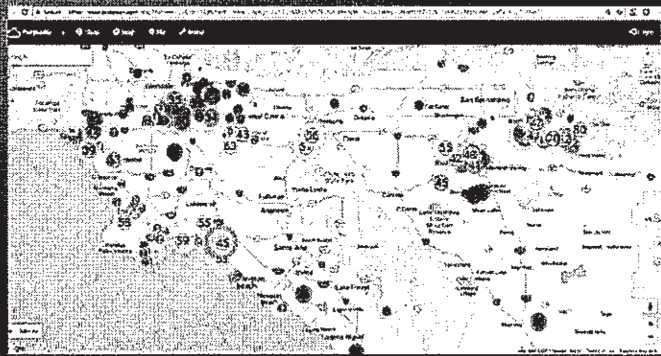
AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Field Testing

Laboratory Testing

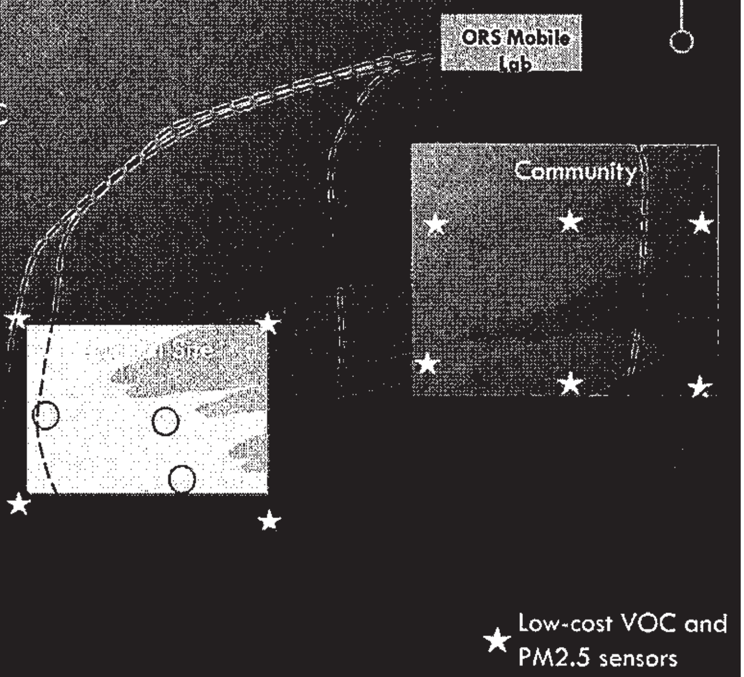
PM Sensor Deployments



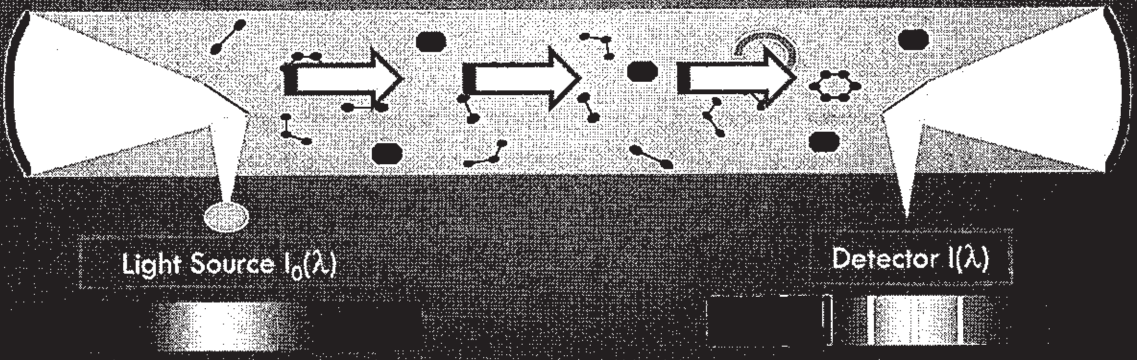
See presentation ME70 for more details

COMMUNITY-SCALE AIR TOXICS AMBIENT MONITORING

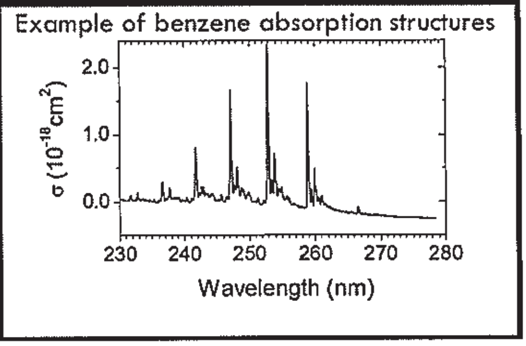
- ORS mobile laboratory (quarterly surveys) to
  - monitor HAP emissions from refineries and oil processing facilities, and estimate their annual VOC emissions
  - conduct community monitoring
- "Low-cost" sensors (long-term VOC/PM2.5 monitoring to
  - obtain long-term VOC trends at facility fenceline
  - address the impact of industrial HAP emissions on surrounding areas via community deployment



PRINCIPLE OF OPTICAL REMOTE SENSING



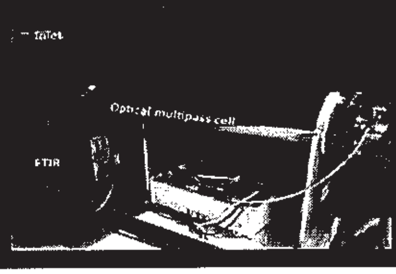
- Trace gases in the atmosphere absorb light in a unique way
  - Each molecule has its own "fingerprint"
- Multiple gases can be observed simultaneously
- Light source can be an artificial light or a natural sunlight
- Measurements can be conducted away from the source(s)
- Combined with meteorological data, ORS can be used for emission monitoring



OPTICAL REMOTE SENSING METHODS

Suite of optical instrumentation on a mobile platform

- Flux measurements (Sun as a light source)
  - Solar Occultation Flux (SOF) - alkanes
  - Sky DOAS - HCHO, NO_2, SO_2
  - Daytime measurements only
- Concentration mapping (artificial light sources)
  - Mobile extractive FTIR (MeFTIR) - speciated alkanes, methane, ammonia, etc
  - Mobile White Cell DOAS (MWDOAS) BTEX, phenol, styrene, trimethylbenzene
  - Daytime and nighttime measurements

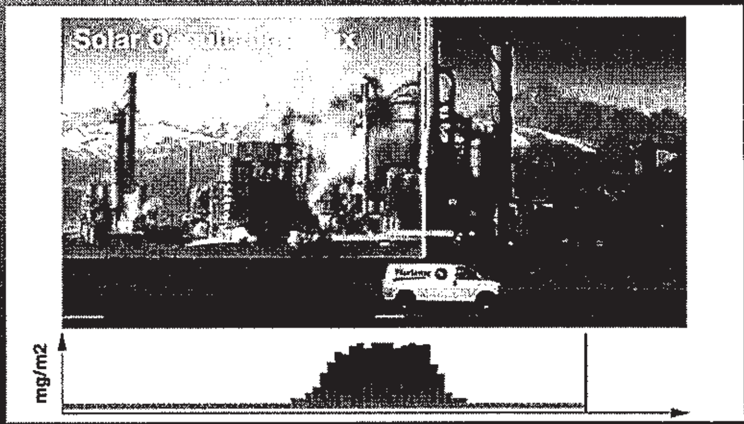


Accurate wind data for flux calculations is obtained using SCAQMD's wind profiling LIDAR

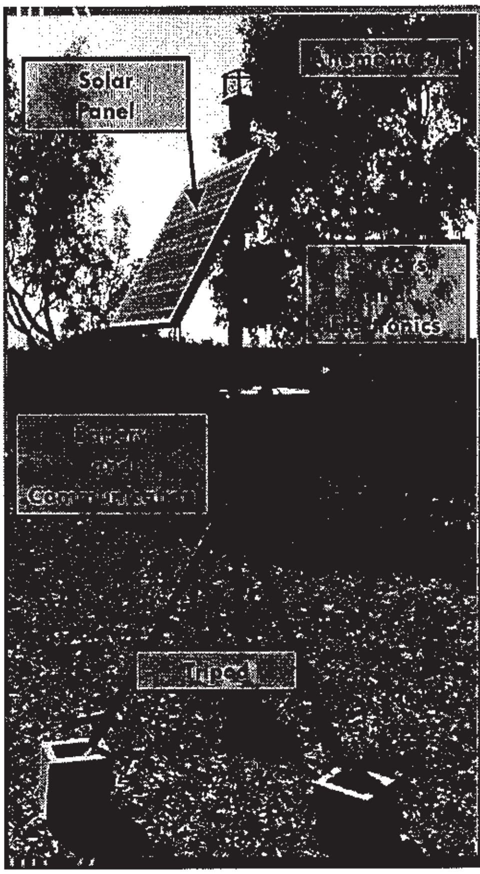
See presentation ME43 for more details

FLUX MEASUREMENTS APPROACH

- Mobile measurements to record total mass of molecules along path traveled
- SOF: light source is direct sunlight
- Sky DOAS: light source is scattered sunlight
- Remote sensing and wind measurements are combined to calculate emission fluxes
- Accurate wind data obtained using SCAQMD's LIDAR

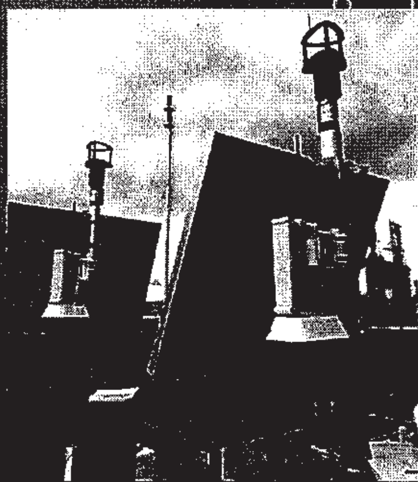


VOC SENSOR NODE

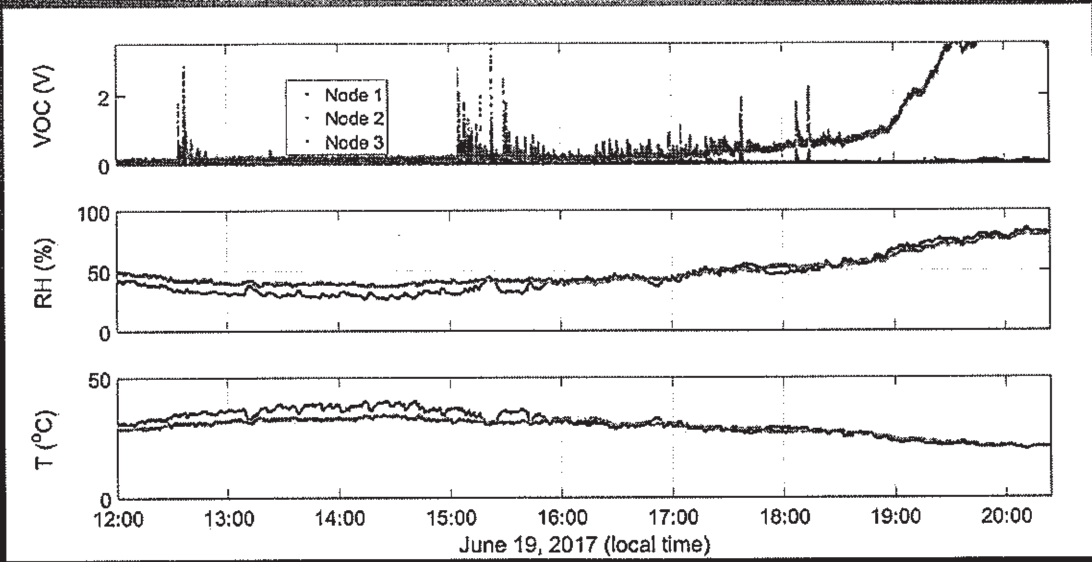


- Self-contained VOC/PM sensor node for autonomous long-term operation
- Complements mobile ORS surveys
- Alerts of elevated VOC levels
- Wireless data transfer to a cloud for analysis and source identification
- Stationary and mobile (with GPS) nodes

See presentation ME58 for details

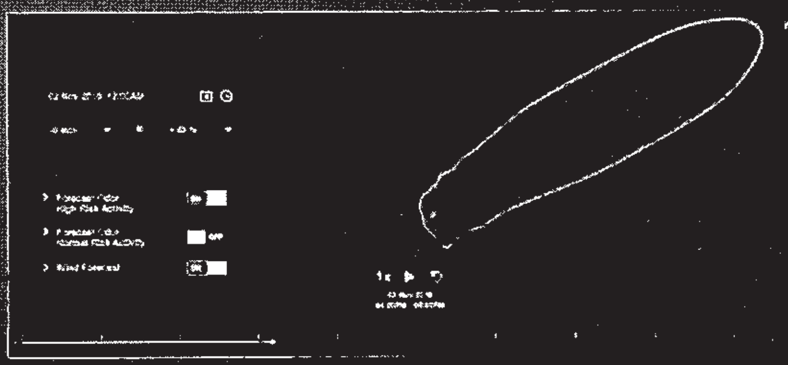


EXAMPLE OF SENSOR DATA



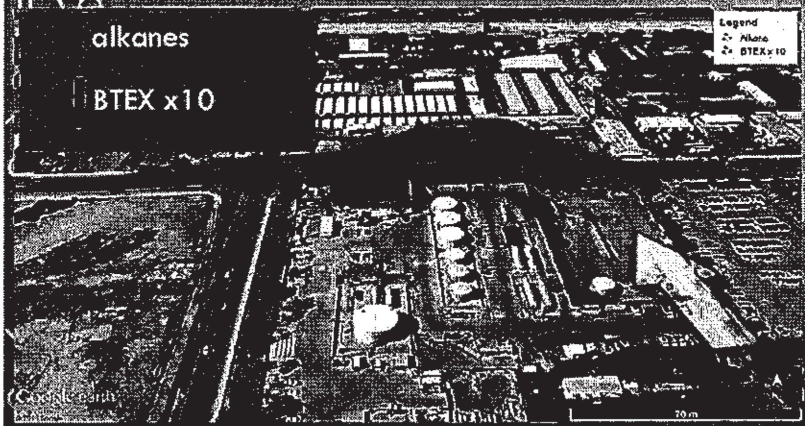
- Co-located sensor testing at AQMD's Fenceline Monitoring Laboratory in Carson, CA
- High temporal resolution is required to resolve individual VOC plumes
- Baseline drift and other corrections of sensor data may be required

VISUALIZATION AND ANALYSIS OF SENSOR DATA

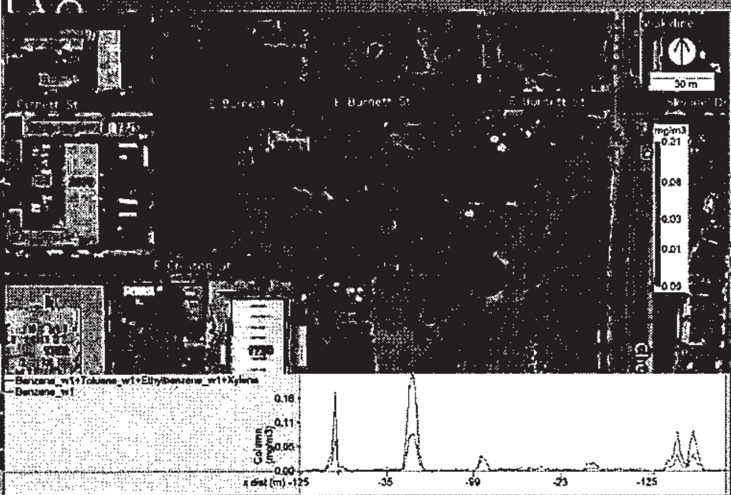


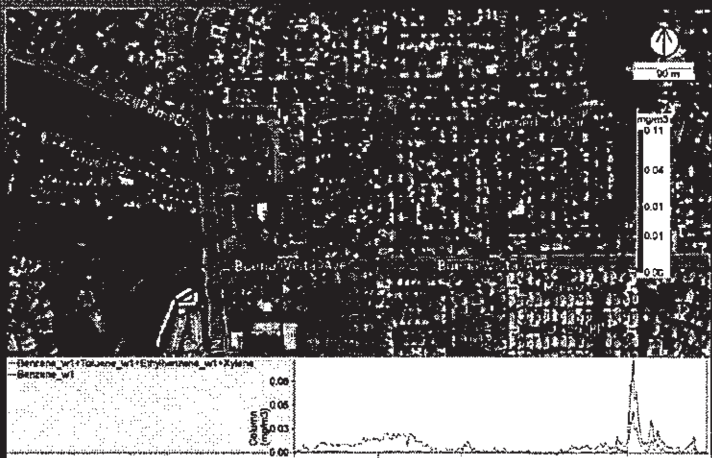
- Alert when set air quality threshold(s) are exceeded
- Assess impacts of emissions
- Identify emission sources

DETECTION OF AIR TOXICS PLUMES

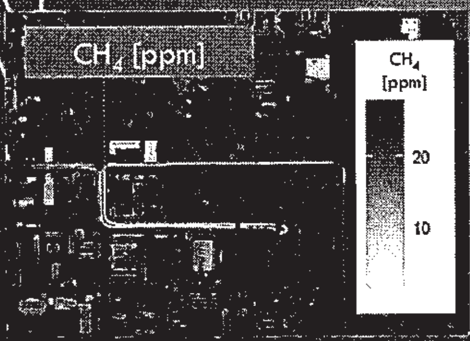


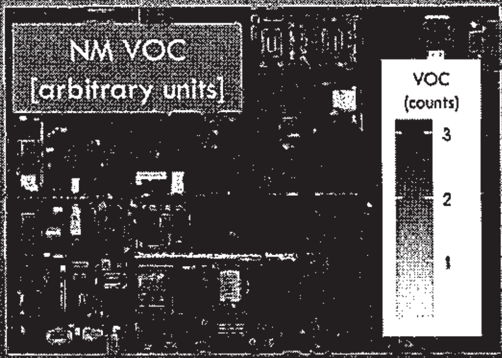
CONCENTRATION MAPPING

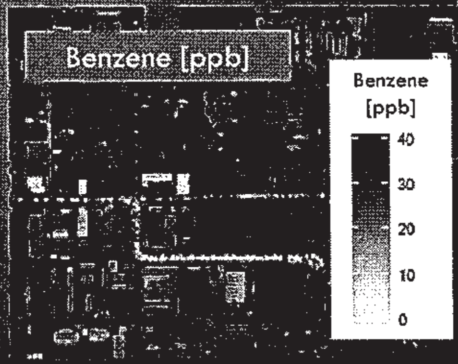


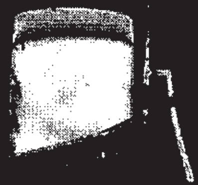


COLLOCATED ORS AND SENSOR OBSERVATIONS









- Elevated VOC levels detected by a "low-cost" VOC node downwind of oil pump and storage tank
- Detection confirmed by mobile lab
- Emissions observed by FLIR camera

CONCLUSIONS

- Low-cost" VOC sensor nodes can provide a long-term qualitative record of ambient VOC levels on the community level
- ORS methods offer quantification of emissions from large sources
  - May supplement or even replace emission inventories
- ORS instruments on a mobile platform offer air toxics concentration mapping capabilities
  - Identify pollution "hot spots"
  - Conduct detailed investigations of elevated levels detected by "low-cost" sensors
- "Low-cost" sensor and ORS technologies will play a fundamental role in the implementation of recent and upcoming California laws
  - AB 617 - Nonvehicular air pollution: criteria air pollutants and toxic air contaminants
  - AB1647 – Petroleum refineries air monitoring systems

THANK YOU FOR YOUR ATTENTION

Olga Pikelnaya, South Coast Air Quality Management Dostrict

opikelnaya@aqmd.gov

(909) 396-3157

AWMA - Air Quality Measurement Methods and Technology, Long Beach, 2017

Low-cost Sensors for Measuring Gaseous and Particle Air Pollutants: Performance Results from Three Years of AQ-SPEC Field and Laboratory Testing and Network Applications at the Fenceline and Community Level

Vasileios Papapostolou, Sc.D.
Air Quality Specialist
South Coast Air Quality Management District
Diamond Bar, CA

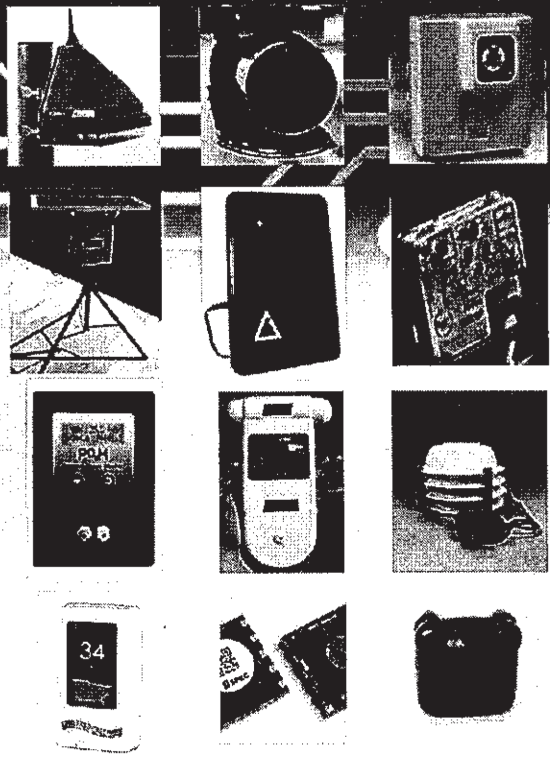
Low-Cost Air Quality Sensors

- Rapidly proliferating
- Tremendous potential
  - Low-cost
  - Ease of use
- Multiple potential applications
  - Spatial/Temporal air quality info
  - Fence-line applications
  - Community monitoring
- Need to systematically evaluate their performance
  - Accuracy, precision, durability, reliability
  - Calibration and drift
  - Other performance issues

…and more!

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center



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

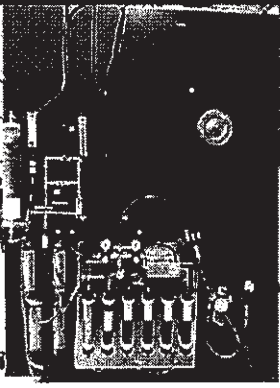
South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Field Testing

- Started in September, 20
  - Over 30 sensors evaluated
- Process
  - Sensor tested in triplicates
  - Two month deployment
  - < ~ $2,000: purchase
  - > ~ $2,000: lease or borrow
- Location
  - Rubidoux station (main)
    - Inland site
    - Fully instrumented

AQ-SPEC
Air Quality Sensor Performance Evaluation Center



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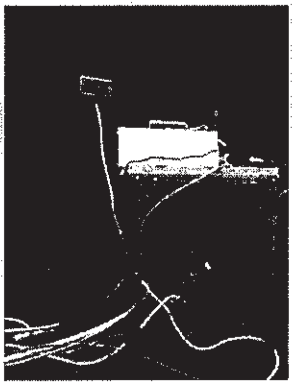

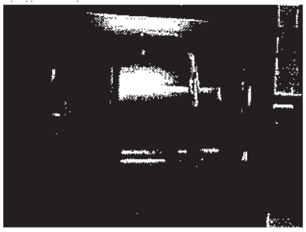
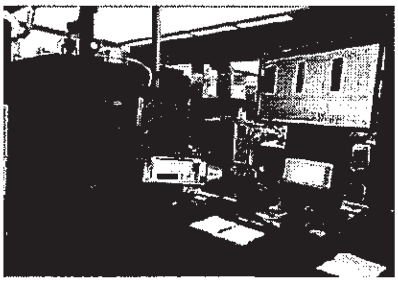

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

South Coast AQMD

Methods - Protocol

- Temperature control: - 32 to + 177 °C
- Relative Humidity control: 5 to 95 %
- PM sensors are tested with known aerosol concentrations/size range
- Gaseous sensors are tested with known concentrations of target and interferent gases

- Intra-model variability
- Accuracy
- Precision
- Lower Detection Limit
- Linear Correlation Coefficient
- Interferents
- Climate Susceptibility
- Data Recovery
- Sensor decay and degradation
- Baseline drift
- Response to loss of power

*Papapostolou V, Zhang H, Feenstra B and Polidori A. Development of an Environmental Chamber for the Laboratory Evaluation of "Low-Cost" Air Quality Sensors, Atmospheric Environment, 171: 82-90, **2017***

www.aqmd.gov/aq-spec

South Coast AQMD

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AQ-SPEC

Air Quality Sensor Performance Evaluation Center

AQ-SPEC

AQ-SPEC
Air Quality Sensor Pe... ...ce Evaluation Center

Recently added/updated:

- Article by Papapostolou et al. at South Coast AQMD
- Wrap Up! "Making Sense of Sensors"
- Conference Poster Presentations
- Conference Platform Presentations

Background

In an effort to inform the general public about the actual performance of commercially available "low-cost" air quality sensors, the SCAQMD has established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) program. The AQ-SPEC program aims at performing a thorough characterization of currently available "low-cost" sensors under ambient (field) and controlled (laboratory) conditions.

Main Goals & Objectives

- Evaluate the performance of commercially available "low-cost" air quality sensors in both field and laboratory settings
- Provide guidance and clarity for ever-evolving sensor technology and data interpretation
- Catalyze the successful evolution, development, and use of sensor technology

Sensor Selection Criteria

- The sensor shall have potential for near-term use.

PM Sensors

Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	AethLabs (microAeth)	Optical	BC (Black Carbon)	~$6,500	R^2 ~ 0.79 to 0.94		
	Air Quality Egg (Version 1)	Optical	PM	~$200	R^2 ~ 0.0		
	Air Quality Egg (Version 2)	Optical	PM	~$240	$PM_{2.5}$: R^2 ~ 0.79 to 0.85 PM_{10}: R^2 ~ 0.31 to 0.40		
	Alphasense (OPC-N2)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$450	$PM_{1.0}$: R^2 ~ 0.63 to 0.82 $PM_{2.5}$: R^2 ~ 0.38 to 0.80 PM_{10}: R^2 ~ 0.41 to 0.60	R^2 ~ 0.99	PDF (1,291 KB)
	Dylos (DC1100)	Optical	$PM_{(0.5-2.5)}$	~$300	R^2 ~ 0.65 to 0.85	R^2 ~ 0.89	PDF (1,384 KB)
	Foobot	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.55		
	HabitatMap (AirBeam)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.65 to 0.70	R^2 ~ 0.87	PDF (1,144 KB)
	Hanvon (Hanvon N1)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.52 to 0.79		
	MetOne (Neighborhood Monitor)	Optical	$PM_{2.5}$	~$1,900	R^2 ~ 0.53 to 0.67		
	Moji China (Airnut)	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.81 to 0.88		
	Naneos (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	$PM_{1.0}$: R^2 ~ 0.1 $PM_{2.5}$: R^2 ~ 0.2		
	Origins (Laser Egg)	Optical	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: R^2 ~ 0.58 PM_{10}: R^2 ~ 0.0		
	Perkin Elmer (ELM)	Optical	PM	~$5,200	R^2 ~ 0.0		
	PurpleAir (PA-I)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$150	$PM_{1.0}$: R^2 ~ 0.93 to 0.95 $PM_{2.5}$: R^2 ~ 0.77 to 0.92 PM_{10}: R^2 ~ 0.32 to 0.44	$PM_{1.0}$: R^2 ~ 0.95 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.97	PDF (1,072 KB)
	PurpleAir (PA-II)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: R^2 ~ 0.96 to 0.98 $PM_{2.5}$: R^2 ~ 0.93 to 0.97 PM_{10}: R^2 ~ 0.66 to 0.70	$PM_{1.0}$: R^2 ~ 0.99 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.95	PDF (1,328 KB)
	RTI (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	R^2 ~ 0.65 to 0.90	R^2 ~ 0.99	PDF (1,087 KB)
	Shinyei (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	R^2 ~ 0.80 to 0.90	R^2 ~ 0.93	PDF (1,156 KB)
	Speck	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.32		
	TSI (AirAssure)	Optical	$PM_{2.5}$	~$1,500	R^2 ~ 0.82		

Results

- Moderate intra-model variability
- Strong correlation (R^2) with EPA "approved" instruments (e.g., FEM)

However...

- Sensor "calibration" is needed in most cases
- Very small particles (e.g. < 0.5 µm) are not detected
- Bias in algorithms used to convert particle counts to particle mass

Gaseous Sensors

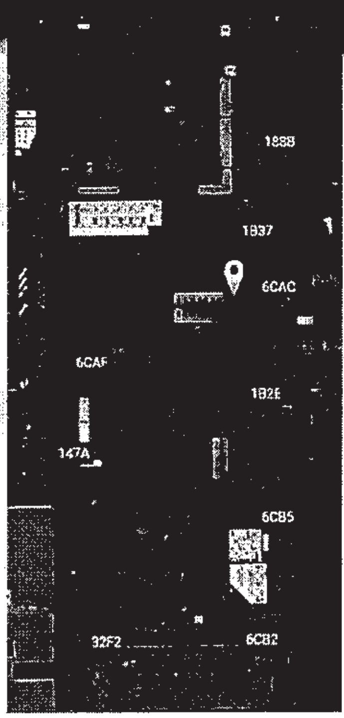
Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	2B Technologies (POM)	UV absorption (FEM Method)	O_3	~$4,500	$R^2 \sim 1.00$	$R^2 \sim 0.99$	PDF (1,295 KB)
	Aeroqual (S-500)	Metal Oxide	O_3	~$500	$R^2 \sim 0.85$	$R^2 \sim 0.99$	PDF (1,197 KB)
	Air Quality Egg (Version 1)	Metal Oxide	CO, NO_2 & O_3	~$200	CO: $R^2 \sim 0.0$ NO_2: $R^2 \sim 0.40$ O_3: $R^2 \sim 0.85$		
	Air Quality Egg (Version 2)	Electrochem	CO & NO_2	~$240	CO: $R^2 \sim 0.0$ NO_2: $R^2 \sim 0.0$		
	Air Quality Egg (Version 2)	Electrochem	O_3 & SO_2	~$240	O_3: $R^2 \sim 0.0$ to 0.20 SO_2: R^2 n/a		
	AQMesh (v.4.0) (Discontinued)	Electrochem	CO, NO, NO_2 & O_3	~$10,000	CO: $R^2 \sim 0.42$ to 0.80 NO: $R^2 \sim 0.0$ to 0.44 NO_2: $R^2 \sim 0.0$ to 0.46 O_3: $R^2 \sim 0.46$ to 0.83		
	Perkin Elmer (ELM)	Metal Oxide	NO, NO_2 & O_3	~$5,200	NO: R^2 n/a NO_2: $R^2 \sim 0.0$ O_3: $R^2 \sim 0.89$ to 0.96		
	Smart Citizen Kit	Metal Oxide	CO, NO_2	~$200	CO: $R^2 \sim 0.50$ to 0.85 NO_2: $R^2 \sim 0.0$		
	Spec Sensors	Electrochem	CO, NO_2 & O_3	~$500	CO: $R^2 \sim 0.84$ to 0.90 NO_2: $R^2 \sim 0.0$ to 0.16 O_3: $R^2 \sim 0.0$ to 0.24		
	UNITEC (SENS-IT)	Metal Oxide	CO, NO_2 & O_3	~$2,200	CO: $R^2 \sim 0.33$ to 0.43 NO_2: $R^2 \sim 0.60$ to 0.65 O_3: $R^2 \sim 0.72$ to 0.83	CO: $R^2 \sim 0.99$ O_3: $R^2 \sim 0.82$ to 0.90	CO: PDF (1,283 KB) O_3: PDF (1,177 KB)

Results

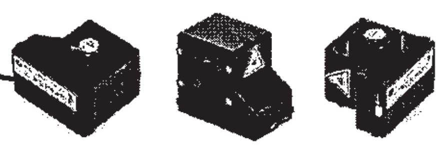
- Acceptable data recovery
- Wide intra-model variability range
- CO; NO; O_3 (when measured alone): good correlation with FRMs
- $O_3 + NO_2$: low correlation with FRM (potential O_3/NO_2 interference)
- SO_2; H_2S; VOC: difficult to measure with available sensors

South Coast AQMD

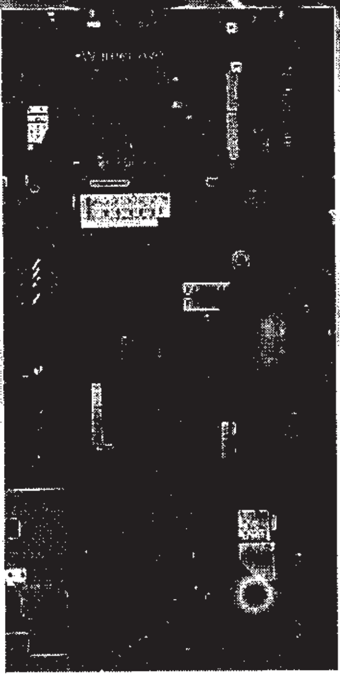
Sensor Network: Fenceline Study



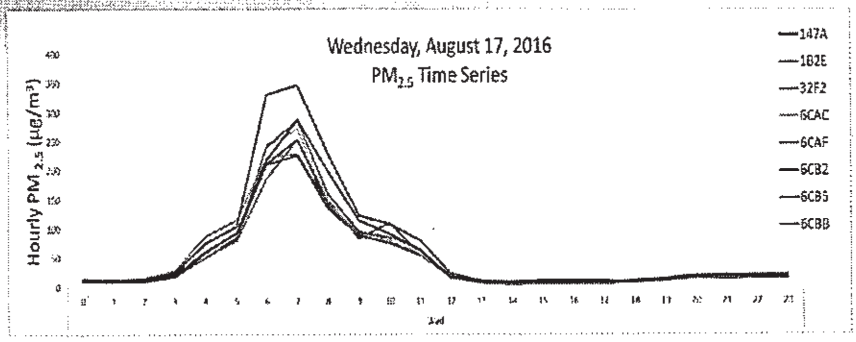
- Monitor fugitive emissions [illegible] Disposal facility in Southern California
- 9 sensor nodes deployed at facility fenceline on June 2016
- Wireless network / remote server
- Real-time PM_1, $PM_{2.5}$ and PM_{10} monitoring



Sensor Network: Fenceline Study

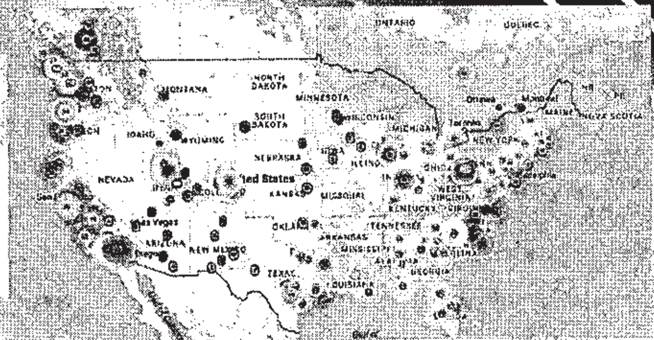


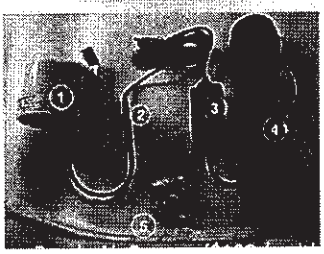
- Data analytics
- Email and/or text alerts
- Project benefits
  - *Correlate PM measurements w/ on-site activities*
  - *Measure PM levels before and after facility upgrades*



Sensor Network: Outdoor Study...

PurpleAir PM sensor network

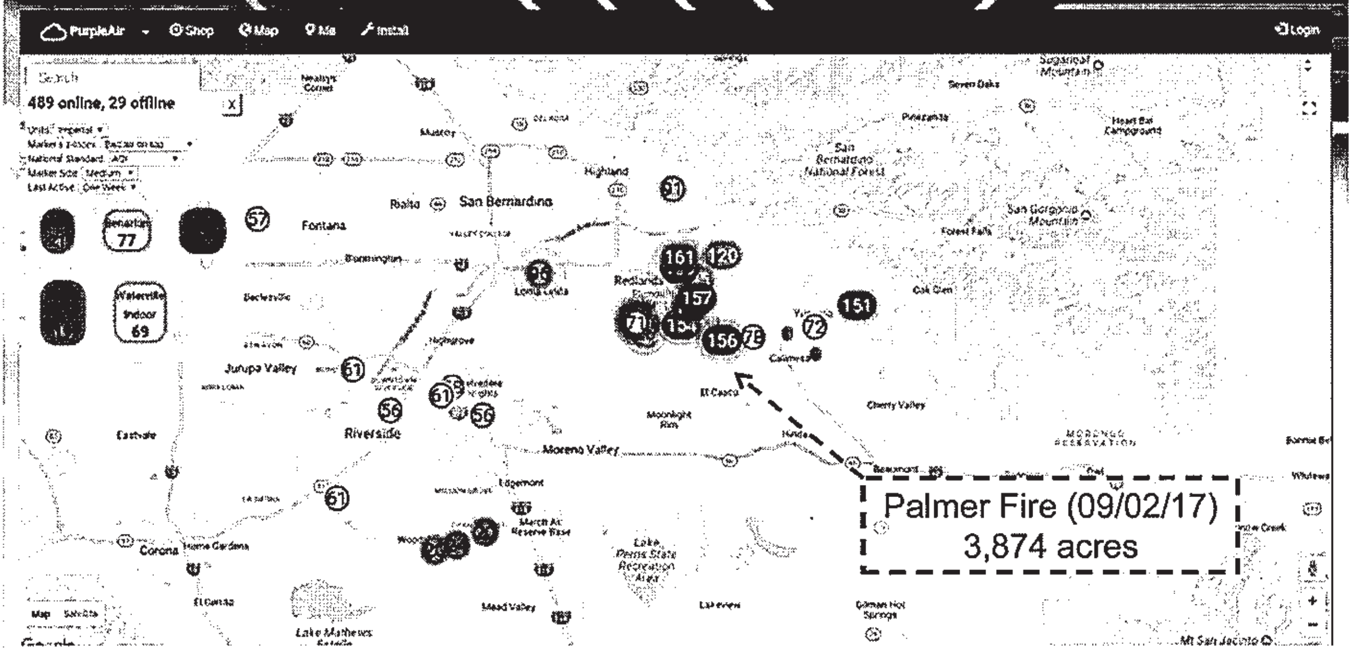




- ➢ Real-time PM_1, $PM_{2.5}$ and PM_{10} monitoring
- ➢ Wireless network / remote server
  - o *Sensor device/data management: Microsoft Azure IoT + Power Bi*
- ➢ Project goals
  - o *Test sensor durability*
  - o *Show ability to scale up*
  - o *Help improve accuracy of satellite data*
  - o *Study spatial/temporal PM variability*
  - o *Provide monitoring during wildfires*

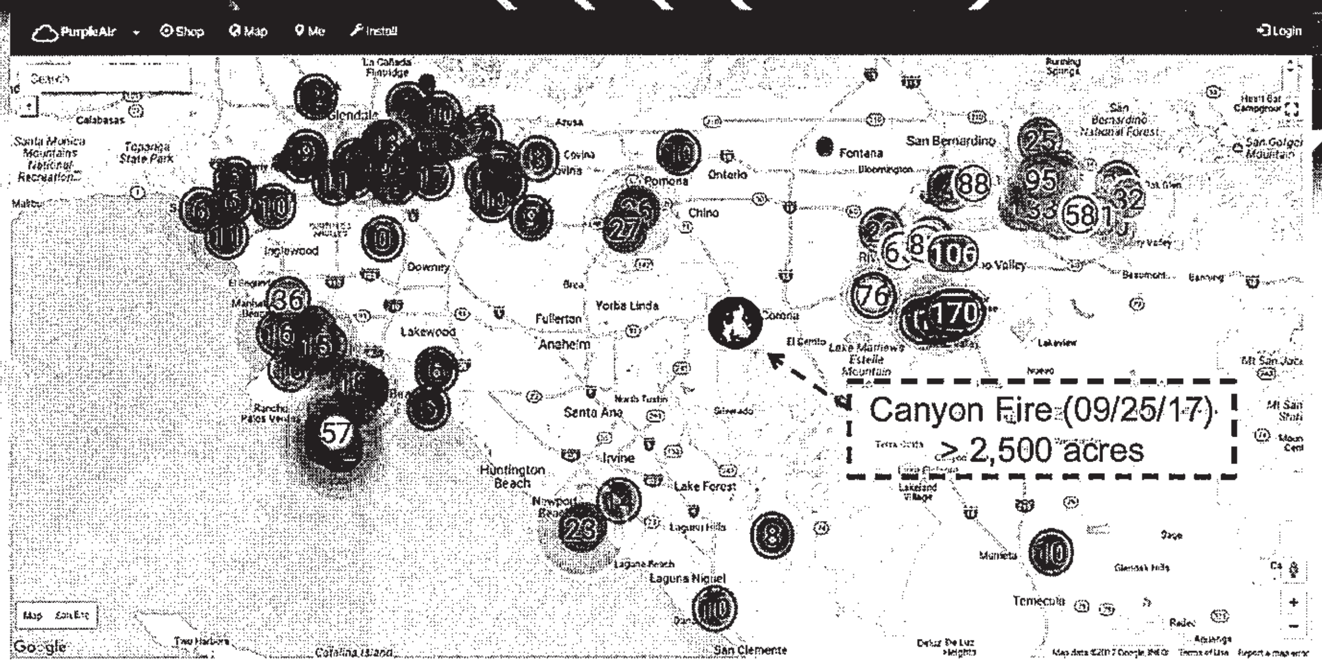
South Coast AQMD

Capturing wildfire events...



South Coast AQMD

Capturing wildfire events...



Note: Values are reported as AQI units

Community project (EPA funded)

- Use "SPODs" to:
  - o *Monitor VOC emissions from refineries in real time*
  - o *Assess potential impacts on nearby communities*
  - o *Study temporal and spatial dispersion of VOCs*

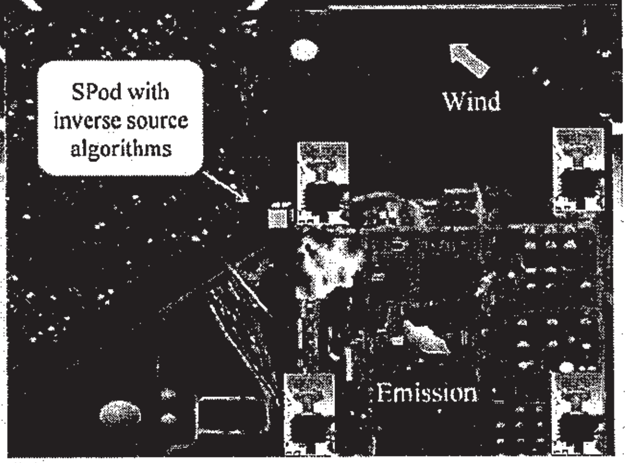
  (Technology: PID sensor + 2D anemometer)

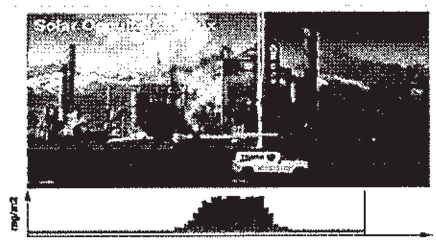
- Use Optical Remote Sensing to:
  - o *Validate "SPOD" data*
  - o *Estimate annual refinery VOC emissions*

  (Technology: SOF/DOAS/FTIR)

- Use Low-cost sensors to:

  Long-term monitoring of VOC and $PM_{2.5}$ at facility fenceline and inside communities





U.S. EPA Science To Achieve Results (STAR) Grant

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

UCLA

STi Sonoma Technology, Inc.

- ➢ Four specific aims:
  1. Develop educational material for communities
  2. Evaluate / identify candidate sensors for deployment
  3. Deploy selected sensors in California communities
  4. Communicate the lessons learned to the public

- ➢ On-going:
  - o Wide Spread Sensor Deployment across California
    - 430 PM sensors
    - 100 Aeroqual nodes (i.e., PM, O_3, NOx)
  - o Cloud Based Platform Development
    - Data ingestion and storage
    - Data visualization and mapping
    - Data dissemination

Next…

- Start/Continue the conversation ab[illegible] SPEC becomin[illegible] verification/sensor certification program
- ✓ Develop methods to test VOC and CH_4 sensors (CA state rule AB 617, South Coast [illegible]
- ✓ Develop test standards (i.e., ASTM) for IAQ sensors measuring $PM_{2.5}$ and NO_2/RH
- Calibrate sensors for the various AQMD/AQ-SPEC sensor deployments (e.g., EPA STAR Grant, other citizen science)
- Study performance of stationary sensors under non-ambient conditions (e.g., wildfires, emergency/incidence response)
- Study performance of mobile sensors mounted on Unmanned Aerial Vehicles – Drones (e.g., landfills, marine vessels)
- Integrate satellite AOD data with ground-level low/high cost sensor data

Thanks!

Vasileios Papapostolou, Sc.D.
Brandon Feenstra
Hang Zhang, Ph.D.
Berj Der Boghossian
Olga Pikelnaya, Ph.D.
Andrea Polidori, Ph.D. (Lead)

Traditional and Low-Cost Sensor Methods to Measure Variations in Wintertime PM Among Communities in Sacramento

Anondo Mukherjee[1,2], Steven G. Brown[1], Michael C. McCarthy[1], Hilary Hafner[1], Aleta Kennard[3], Janice Lam Snyder[3], Stephen D'Andrea[3]

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[2]University of Colorado, Boulder, CO

[3]Sacramento Metropolitan Air Quality Management District, Sacramento, CA

2017 AWMA Measurements Conference
Long Beach, CA
November 2017

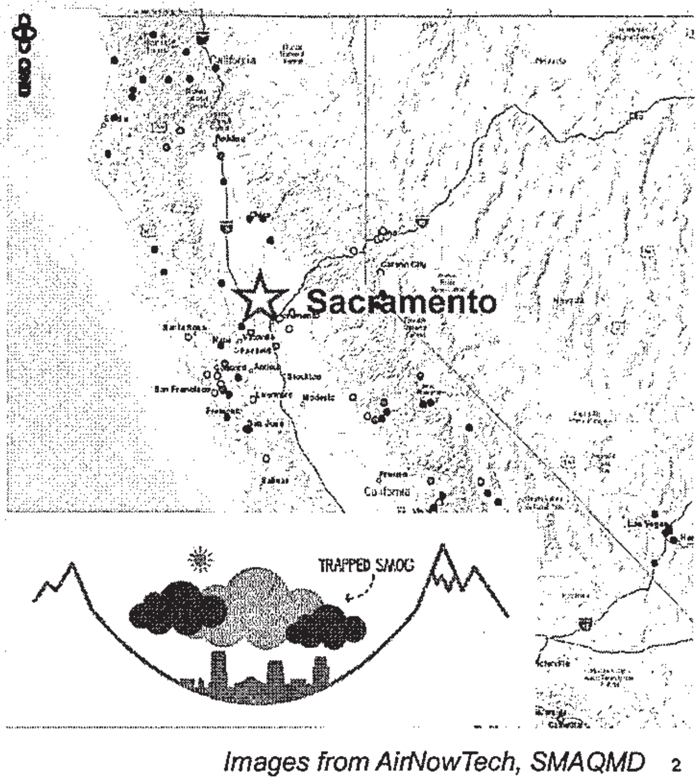
SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT

STi Sonoma Technology, Inc. *Innovative Environmental Solutions*

6725

Sacramento Background

- **Winter time**
  - Inversion = trapped emissions
  - High Winter PM
  - Wood burning > 50% PM Emission Inventory
- PM Spatial scale and wood smoke toxic contribution is unknown



Images from AirNowTech, SMAQMD

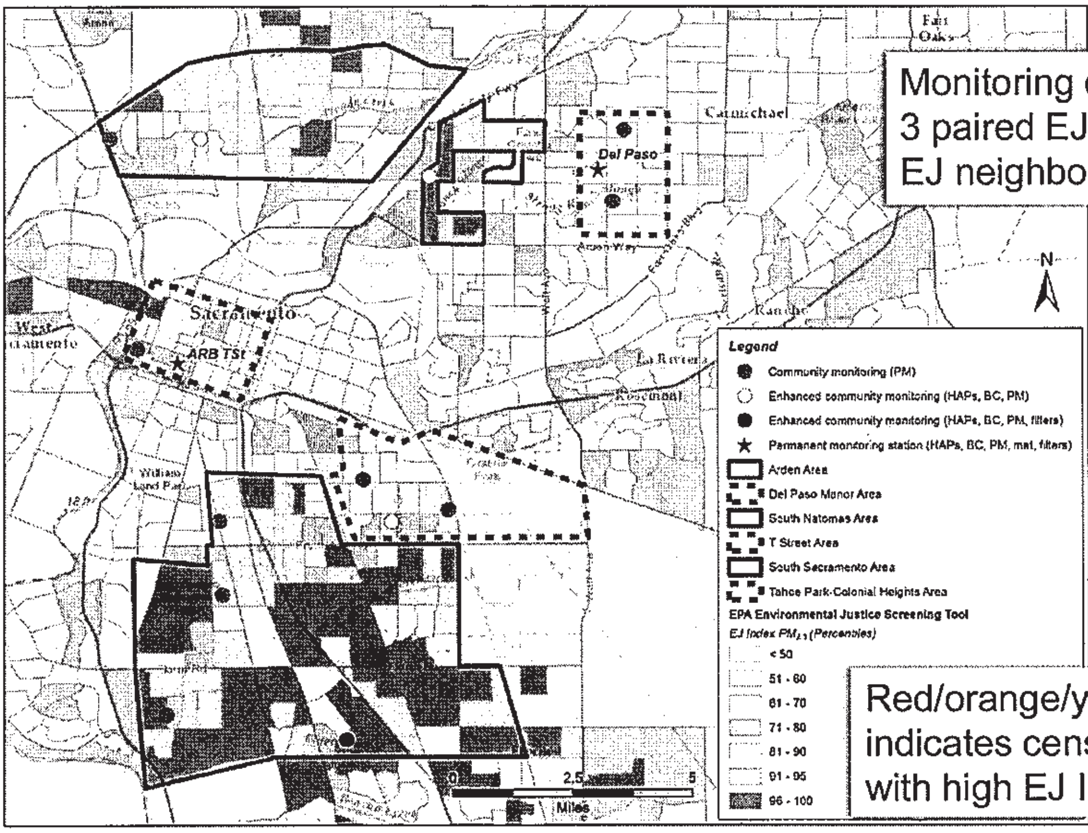
Overview

- **Project Objective:** Understand the wintertime PM spatial differences between environmental justice (EJ) and non-EJ communities in Sacramento County
- **Collected measurements:** December 2016 and January 2017
  - PM with AirBeam sensors and BAMs
  - Black carbon (BC) with Aethalometers
  - Air toxics with canisters
  - Levoglucosan and organic and elemental carbon (OC, EC) with filters
  - Wood burning activity via community survey

Study Design: PM Measurements

- **Traditional Regulatory Grade Monitors** – 2 Locations: Filter (FRM) and Continuous (non-FEM BAMS)
- **Low Cost (AirBeam) sensors:** 1 – 3 locations in 3 EJ and 3 non-EJ communities
- **Collocation:**
  - (Pre & Post Study) Sensors were collocated with BAM and FRM instruments to determine: Sensor Bias, Drift, & Precision
  - (During Study) 2 sensors were collocated during December 2016–January 2017.
- **Data streamed via cellular communications**
  - Central database
  - Data were validated and consolidated to 1-minute and 1-hour values.

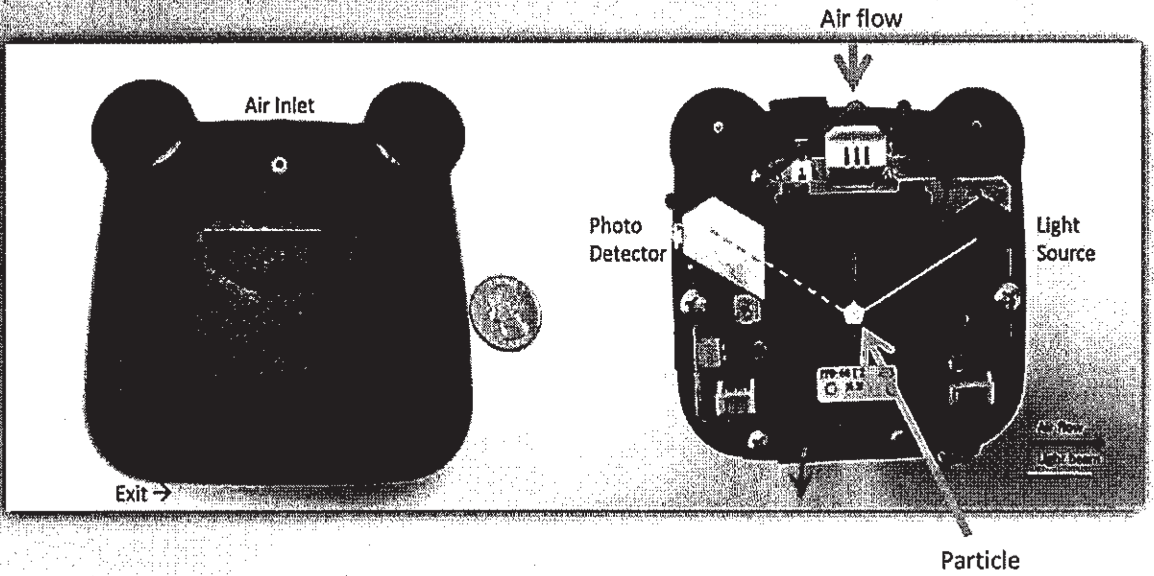
Study Locations



Monitoring occurred in 3 paired EJ and non-EJ neighborhoods

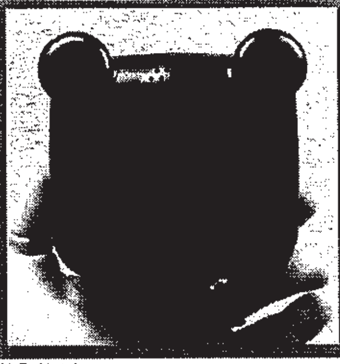
Red/orange/yellow indicates census blocks with high EJ Index

AirBeam "Nuts and Bolts"

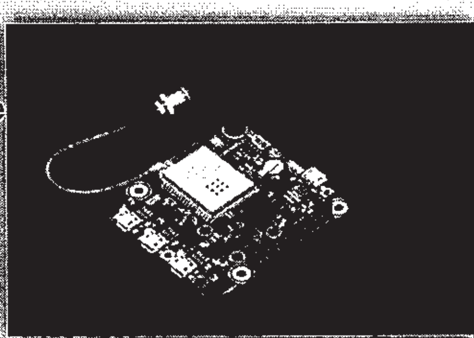


AirBeams measure light scattering from particles with an LED light source, and convert the light scattering to a PM concentration.
A fan draws air through the detector.
Unit cost ~$300. Firmware updated Oct 2016.

Sensor Communications

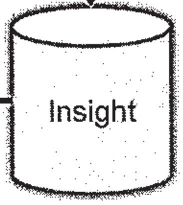


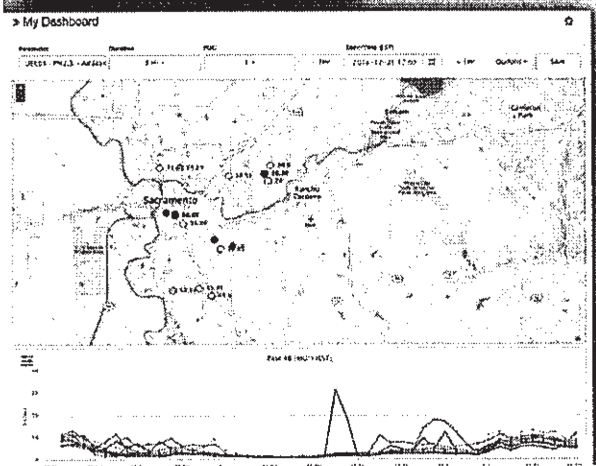
Pushes data multiple times a minute



Data acquired via VALARM Yocto Hub

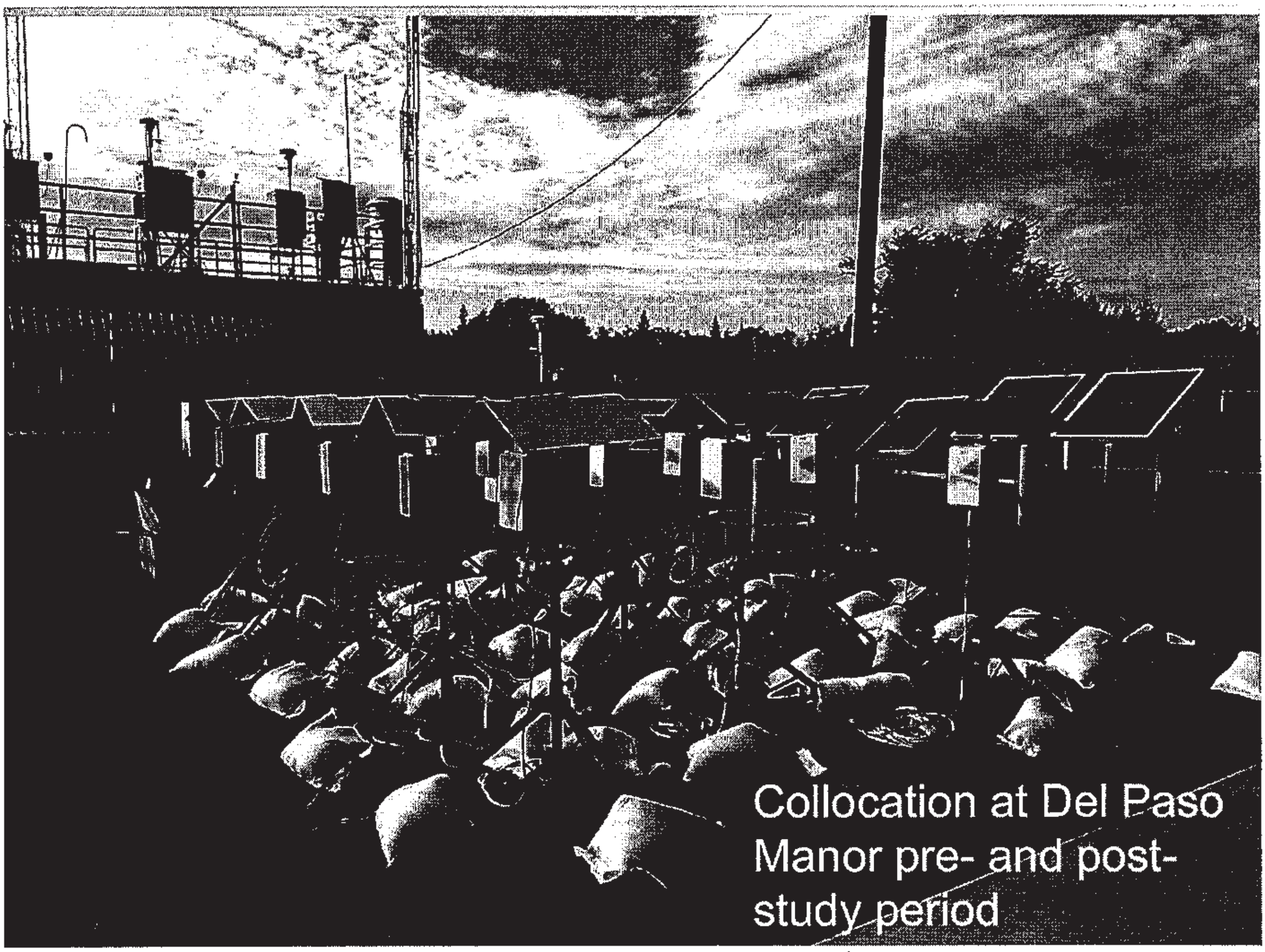
Data pushed via API to STI's data management system (Insight)



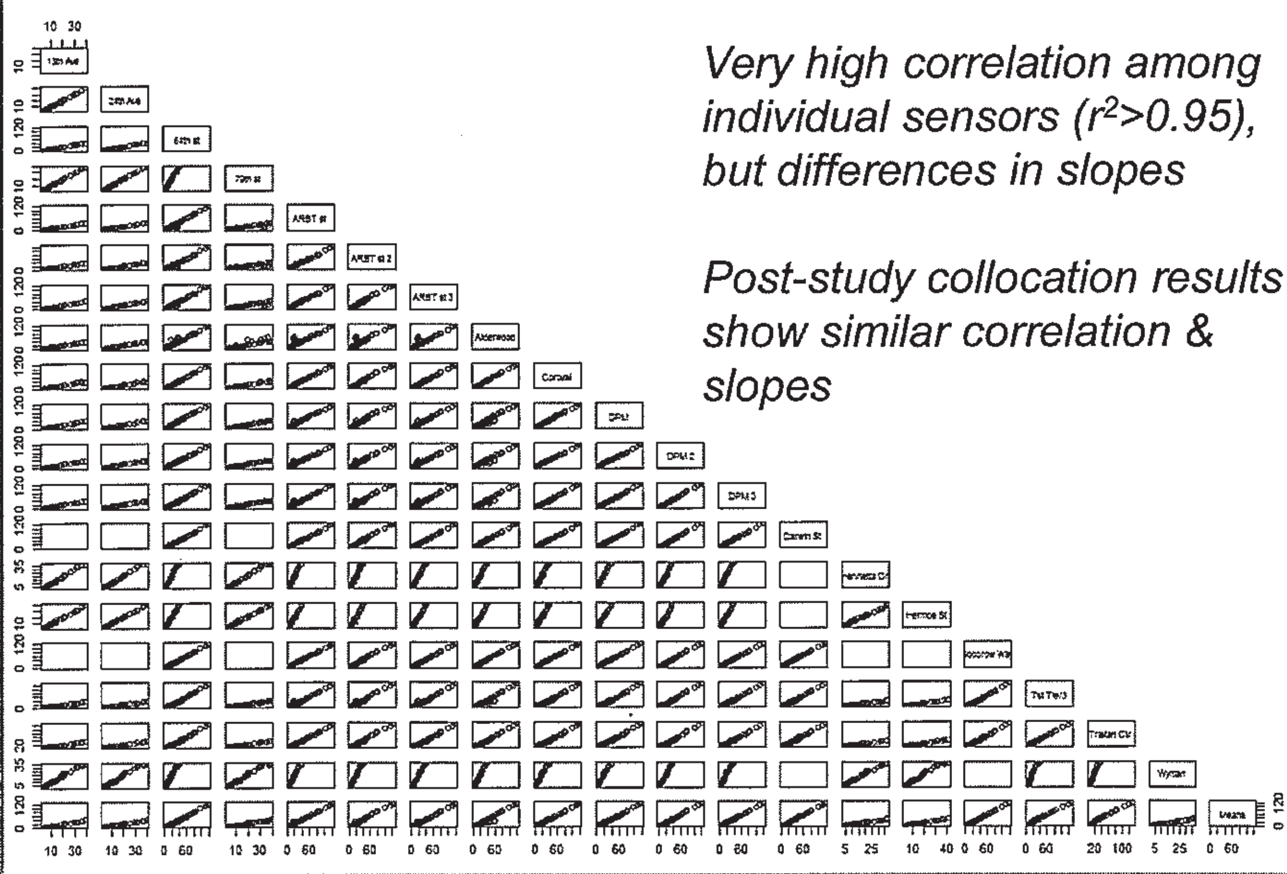


Data graphed and updated every minute on STI's web app for visualizing real-time data

- Powered through:
  - Solar panels with rechargeable batteries
  - Power Outlets
- Shielded with a "hat" to minimize rain/fog impacts
- Hardware box housed VALARM hub and cell modem



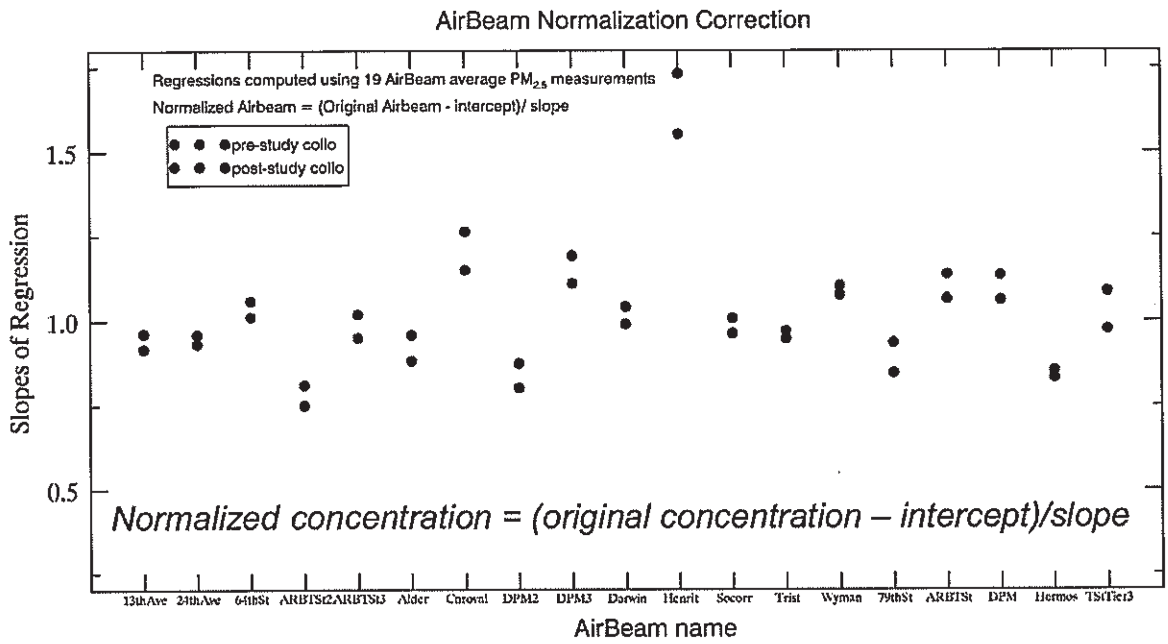
Pre-Study Collocation



Very high correlation among individual sensors (r^2>0.95), but differences in slopes

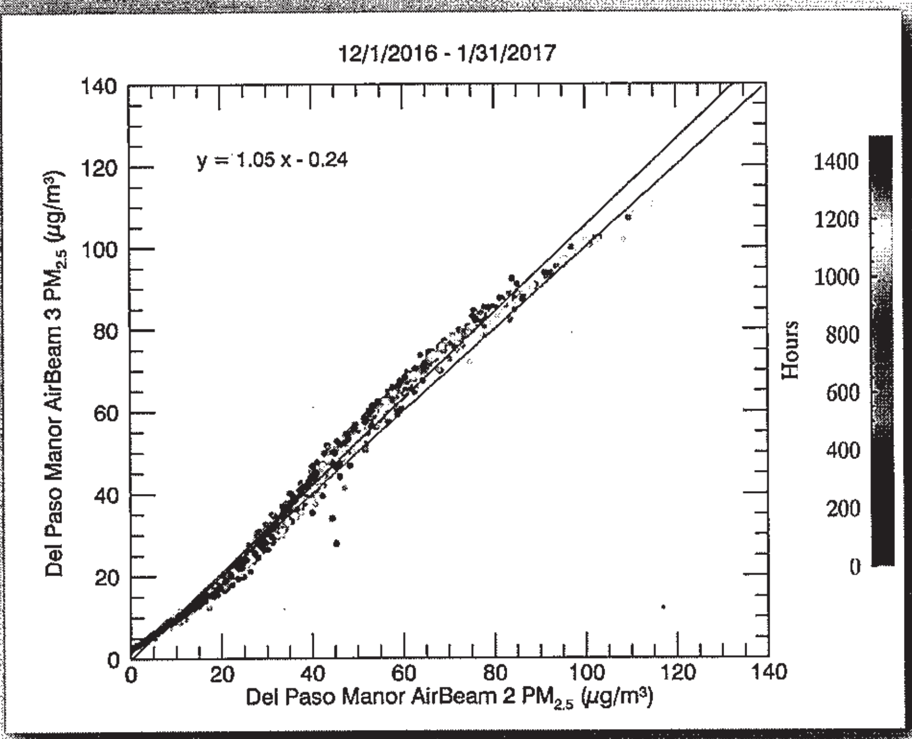
Post-study collocation results show similar correlation & slopes

Individual Air Beam Bias Consistent During Study



Data points show the slope of the regression between each individual AirBeam and the AirBeam average during the pre- and post-study collocations. There is a consistent bias and little drift, enabling correction.

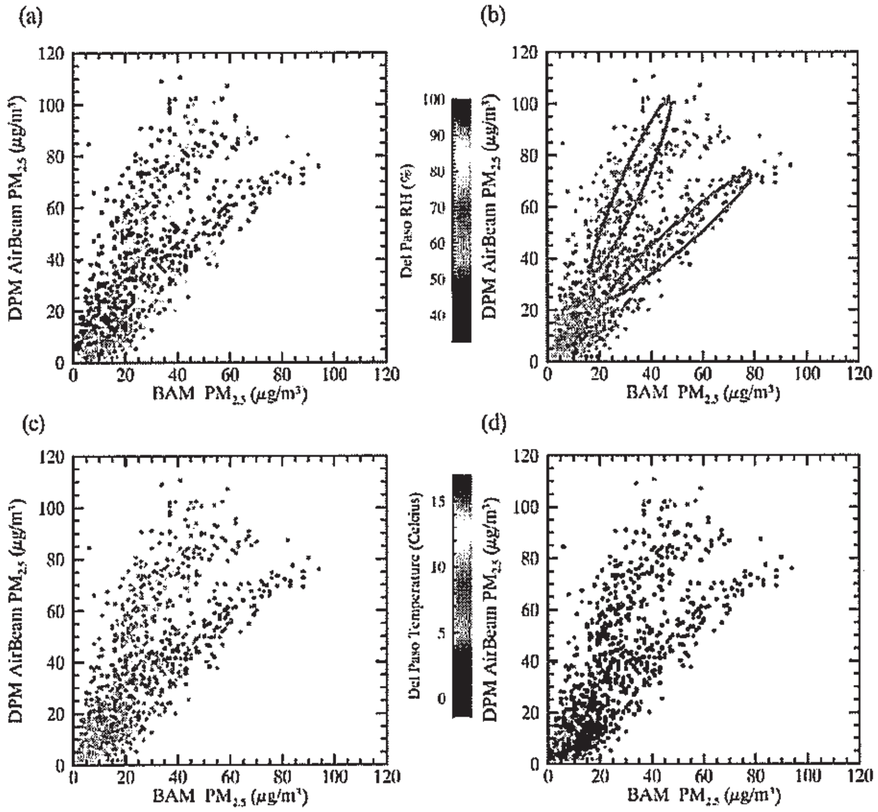
Bias Results of Collocated AirBeams During Study Period



Collocated data at Del Paso Manor show very consistent bias hour by hour

Standard deviation of residuals between linear regression and measured values was 2 µg/m³

Correlation: AirBeam to BAM

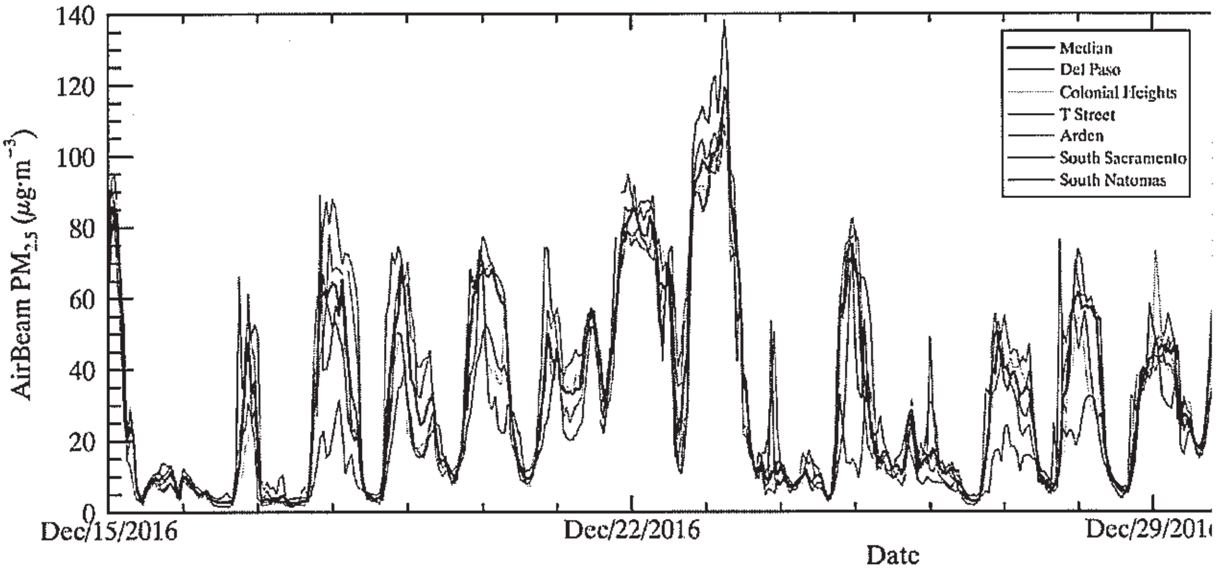


($r^2 = 0.65$)

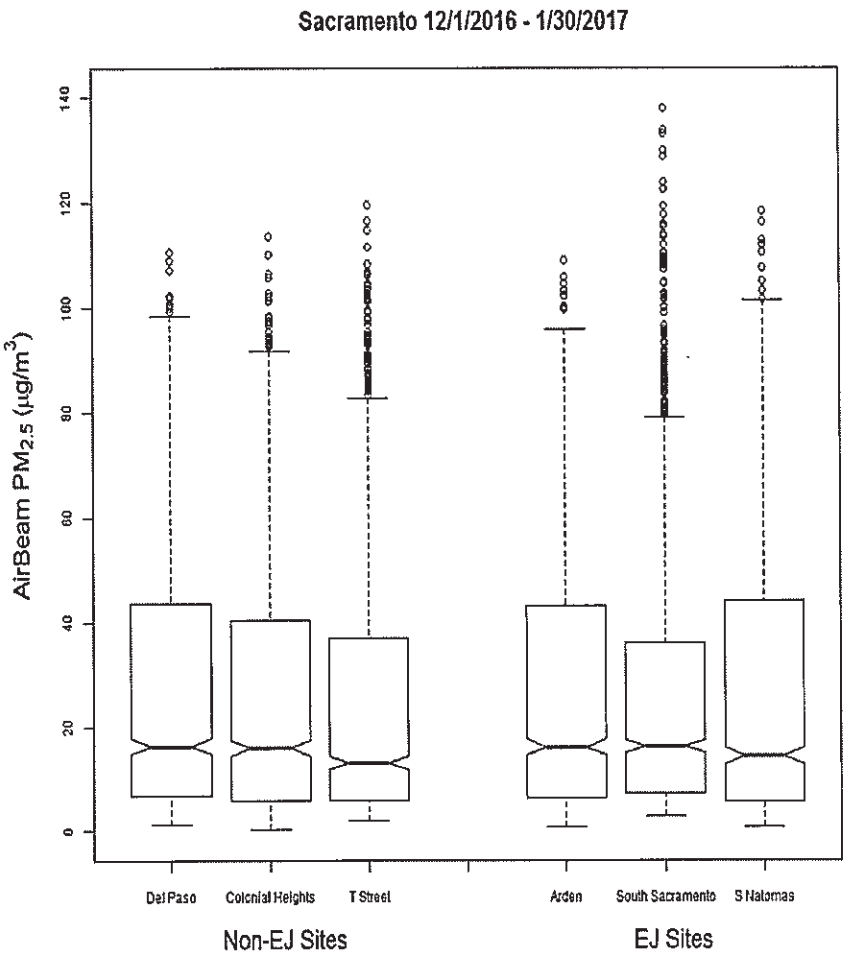
We looked at how AirBeam to BAM varies with meteorology

Dew point was the most explanatory variable

Neighborhood Differences



- In general, sites tend to trend together in a diurnal pattern, however on any given hour, there can be differences of > 20 μg/m³ across neighborhoods.



- Distinctive Difference at T Street site than at other sites
- Other than T street, PM is similar across neighborhoods.
- Overall, no statistically significant difference between EJ and non-EJ sites.

Summary

- AirBeam output was very consistent during the study, allowing us to correct the raw data and compare concentrations across sites.
- AirBeams had a modestly high correlation with the BAM (correlation was variable by dew point).
- PM was modestly variable across neighborhoods, and while there were some inter-neighborhood differences, overall there was no statistically significant difference between EJ and non-EJ areas.

Acknowledgements

- Funding provided by SMAQMD and EPA via Community Air Toxics Grant
- Additional support for measurements and study design from
  - **STI:** Levi Stanton, Max Dillon, Justin Dumas, Mike Kong, Clint MacDonald, & Hilary Hafner,
  - **SMAQMD:** Frank Wulff ,Jaspreet Gosal,& Danny Kam
  - **CARB:** Mike Miguel and Patrick Rainey
  - **EPA:** Eugenia McNaughton, Matthew Plate, Dena Vallano & Gwen Yoshimura
- Community outreach provided by Prosio contracted by SMAQMD.

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STi Sonoma Technology, Inc. Sacramento Metropolitan AIR QUALITY Management District

References

- **Source Apportionment of Fine (PM1.8) and Ultrafine (PM0.1) Airborne Particulate Matter during a Severe Winter Pollution Episode** Michael J. Kleeman, Sarah G. Riddle, Michael A. Robert, Chris A. Jakober, Phillip M. Fine, Michael D. Hays, James J. Schauer, and Michael P. Hannigan *Environmental Science & Technology* **2009** *43* (2), 272-279 DOI: 10.1021/es800400m

AirBeam Methods

- Determine whether AirBeams drift over time, via collocations before, during, and after the study.
- Determine whether AirBeams have a consistent relationship to each other; if so, can bias correct the AirBeams to be comparable among sites.
- Examine AirBeam-to-AirBeam scatter during collocations before, during, and after the study.

ASSESSING COMMUNITY EXPOSURE TO HAZARDOUS AIR POLLUTANTS USING A COMBINATION OF OPTICAL REMOTE SENSING AND "LOW-COST" SENSOR TECHNOLOGIES

OLGA PIKELNAYA[1], ANDREA POLIDORI[1], ROBERT WIMMER[1], JOHAN MELLQVIST[2], JERKER SAMUELSSON[2], MARIANNE ERICSSON[2], SAMUEL BROHEDE[2], OSCAR IZOS[2]

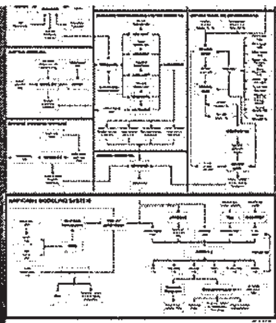
[1]SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT, DIAMOND BAR, CALIFORNIA,
[2]FLUXSENSE INC., SAN DIEGO, CALIFORNIA

South Coast AQMD

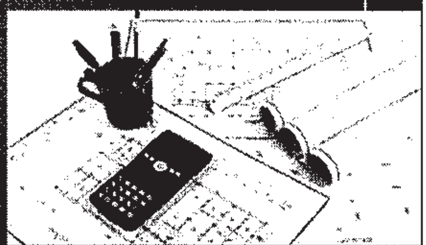
TRADITIONAL APPROACH TO ACCESS AIR QUALITY

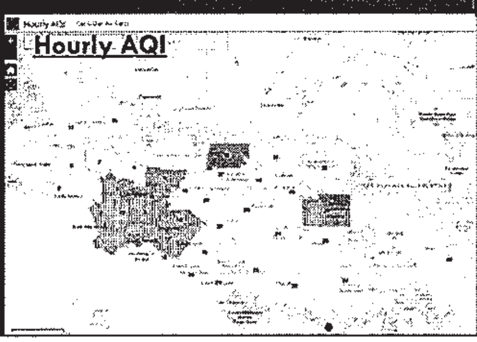
Air Monitoring Stations

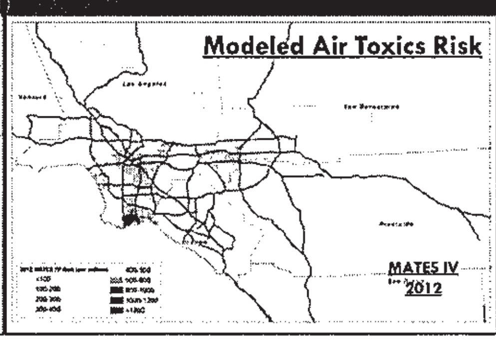
Air Quality Modeling



Emissions Estimates





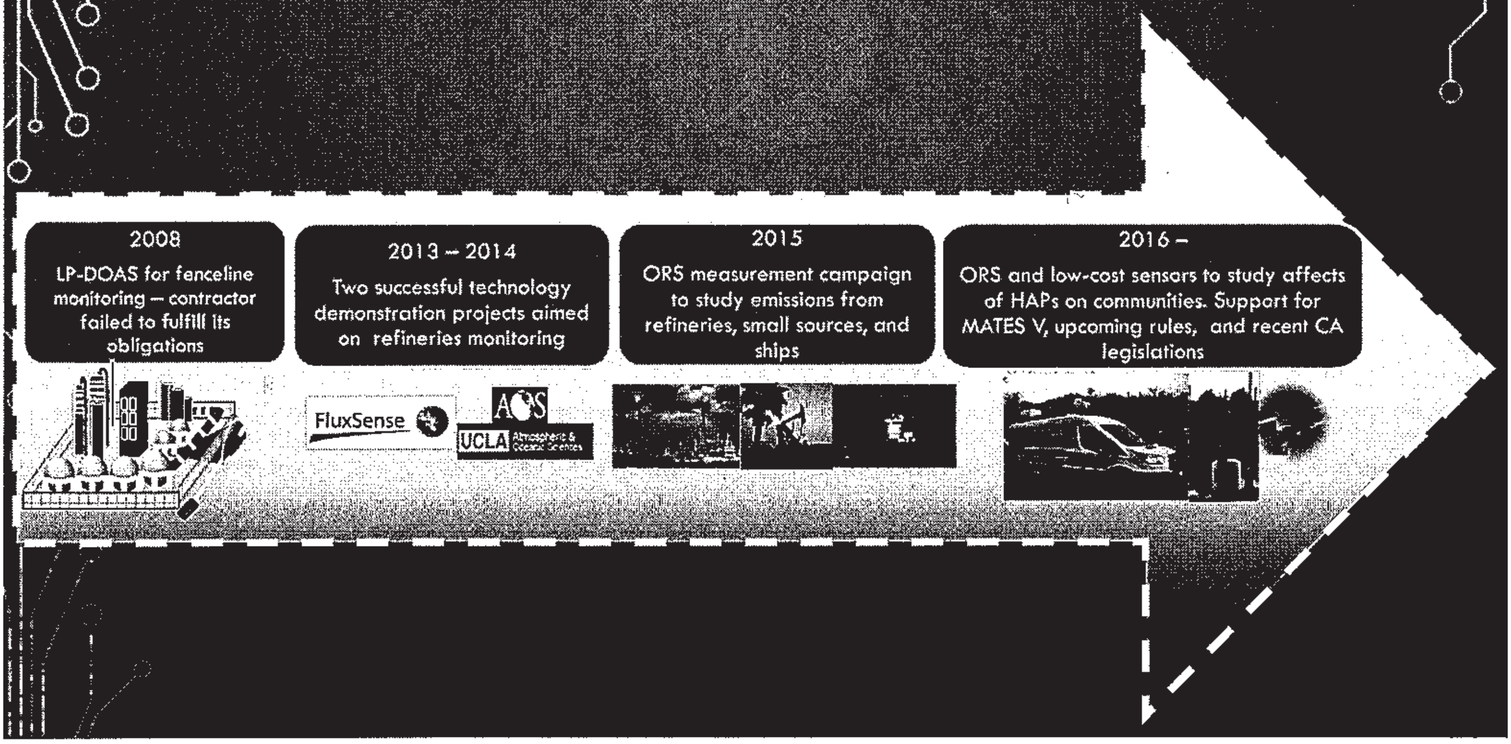


ADVANCED MONITORING METHODS

New promising technologies emerged and matured over the past decade

- Optical Remote Sensing (ORS) Technologies
  - Fully automated / continuous / no calibration required
  - Ideally suited for long-term fenceline monitoring, allow to characterize and quantify emissions
  - Can be deployed from various mobile platforms for rapid leak detection, emission flux measurements, and community monitoring
- "Low-cost" air quality sensors
  - Automated / continuous
  - Deployed in large numbers to obtain granular air quality information
  - Can be used for fenceline and community monitoring applications
- Mounting evidence that current emission inventories are underestimating actual VOC emissions - measurements can provide more realistic emission estimates
- Mobile ORS and "low-cost" sensors offer enhanced capabilities for community and fenceline monitoring

SCAQMD'S OPTICAL REMOTE SENSING PROGRAM



AQ-SPEC

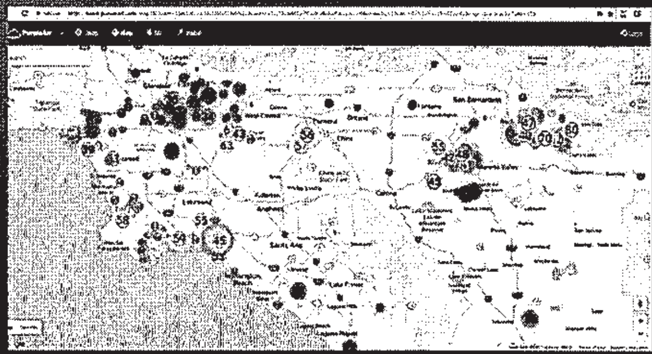
South Coast AQMD

Air Quality Sensor Performance Evaluation Center

Field Testing

Laboratory Testing

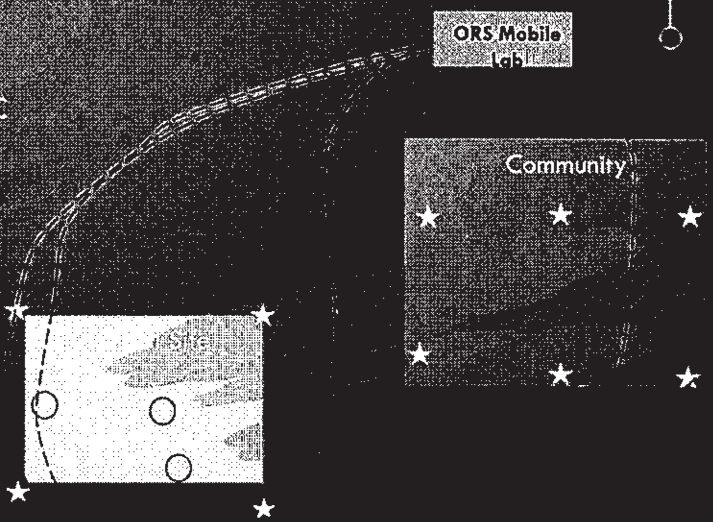
PM Sensor Deployments



See presentation ME70 for more details

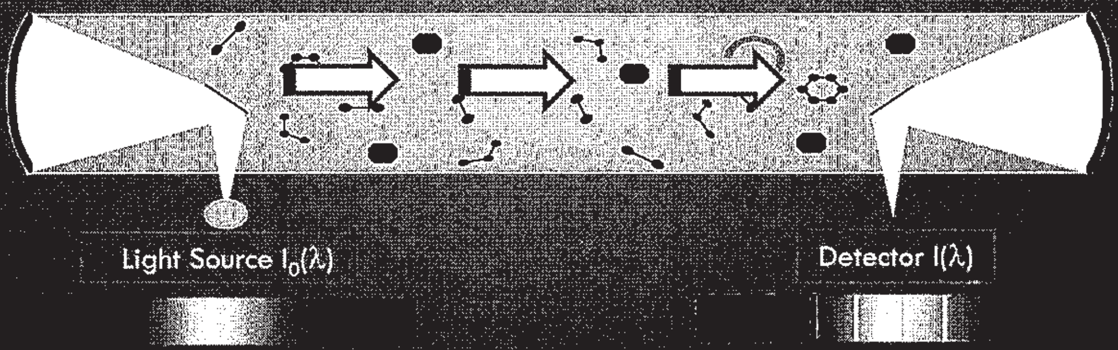
COMMUNITY-SCALE AIR TOXICS AMBIENT MONITORING

- ORS mobile laboratory (quarterly surveys) to
  - monitor HAP emissions from refineries and oil processing facilities, and estimate their annual VOC emissions
  - conduct community monitoring
- "Low-cost" sensors (long-term VOC/PM2.5 monitoring to
  - obtain long-term VOC trends at facility fenceline
  - address the impact of industrial HAP emissions on surrounding areas via community deployment

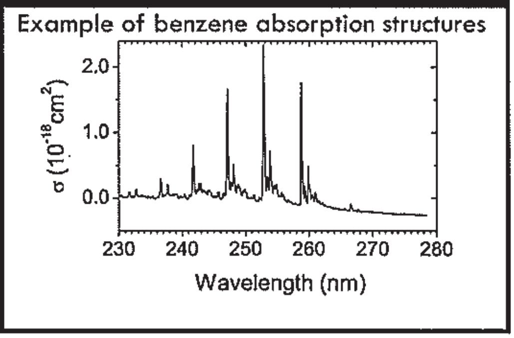


★ Low-cost VOC and PM2.5 sensors

PRINCIPLE OF OPTICAL REMOTE SENSING



- Trace gases in the atmosphere absorb light in a unique way
  - Each molecule has its own "fingerprint"
- Multiple gases can be observed simultaneously
- Light source can be an artificial light or a natural sunlight
- Measurements can be conducted away from the source(s)
- Combined with meteorological data, ORS can be used for emission monitoring



OPTICAL REMOTE SENSING METHODS

Suite of optical instrumentation on a mobile platform

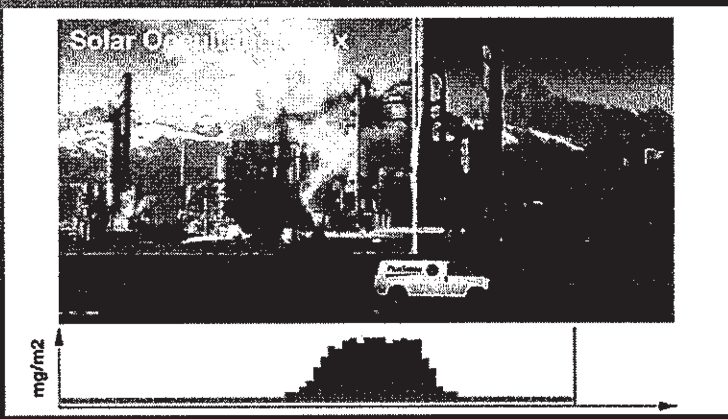
- Flux measurements (Sun as a light source)
  - Solar Occultation Flux (SOF) - alkanes
  - Sky DOAS - HCHO, NO_2, SO_2
  - Daytime measurements only
- Concentration mapping (artificial light sources)
  - Mobile extractive FTIR (MeFTIR) - speciated alkanes, methane, ammonia, etc
  - Mobile White Cell DOAS (MWDOAS) BTEX, phenol, styrene, trimethylbenzene
  - Daytime and nighttime measurements

Accurate wind data for flux calculations is obtained using SCAQMD's wind profiling LIDAR

See presentation ME43 for more details

FLUX MEASUREMENTS APPROACH

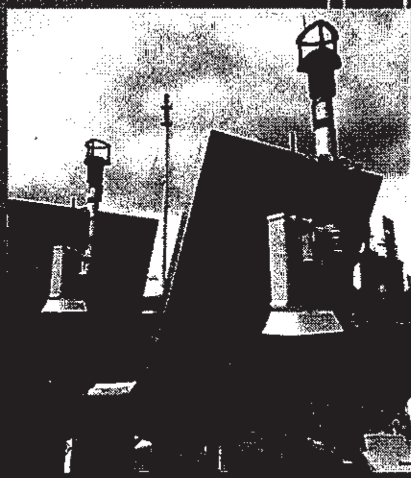
- Mobile measurements to record total mass of molecules along path traveled
- SOF: light source is direct sunlight
- Sky DOAS: light source is scattered sunlight
- Remote sensing and wind measurements are combined to calculate emission fluxes
- Accurate wind data obtained using SCAQMD's LIDAR



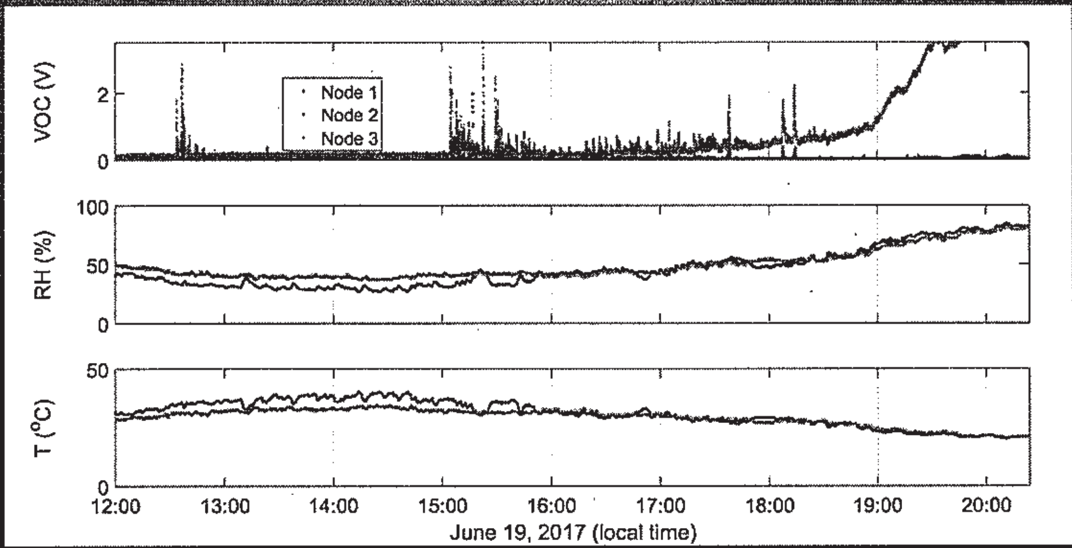
VOC SENSOR NODE

- Self-contained VOC/PM sensor node for autonomous long-term operation
- Complements mobile ORS surveys
- Alerts of elevated VOC levels
- Wireless data transfer to a cloud for analysis and source identification
- Stationary and mobile (with GPS) nodes

See presentation ME58 for details

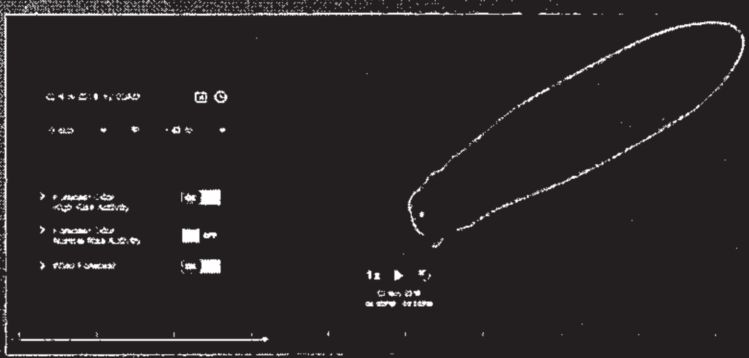


EXAMPLE OF SENSOR DATA

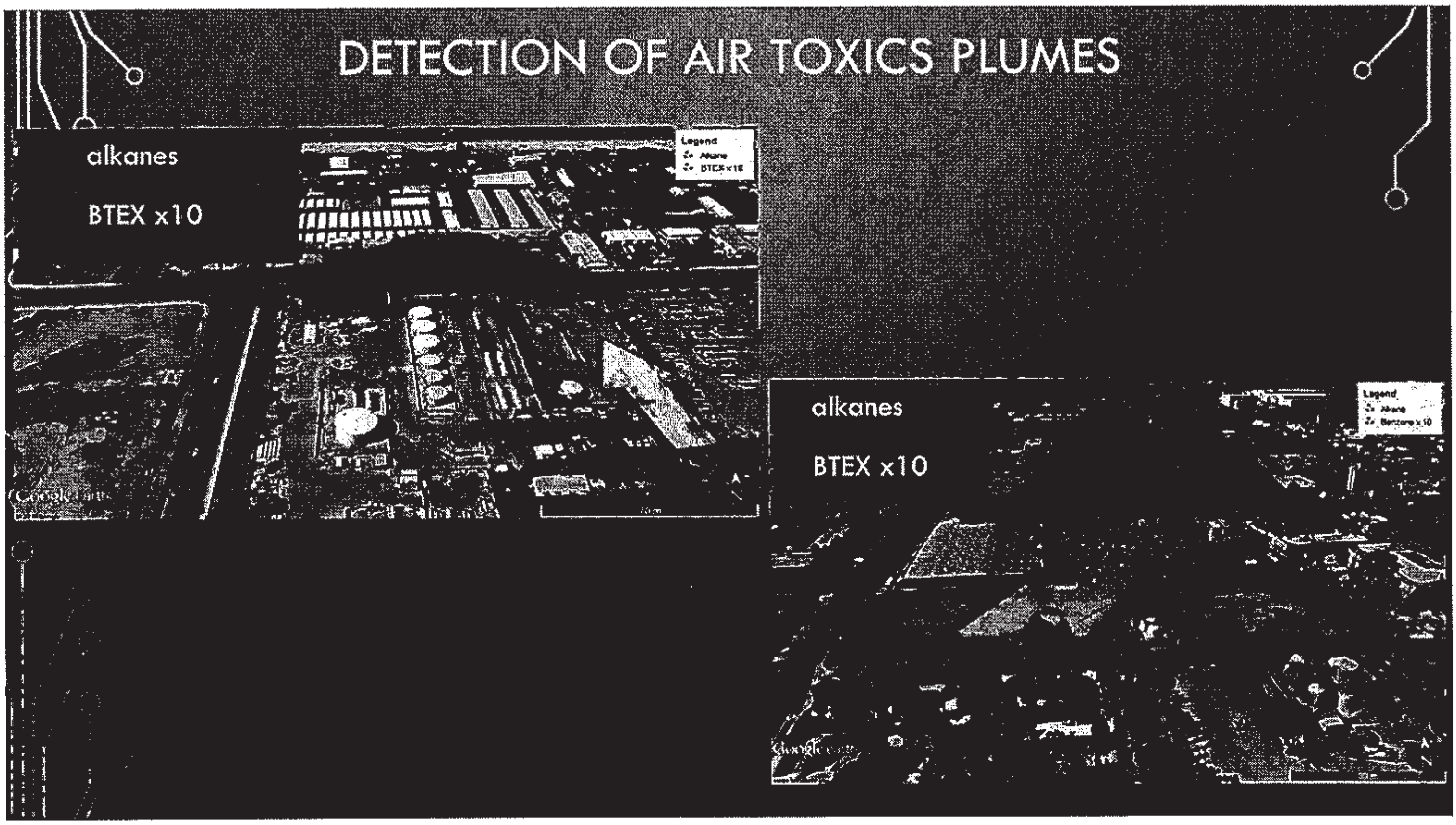


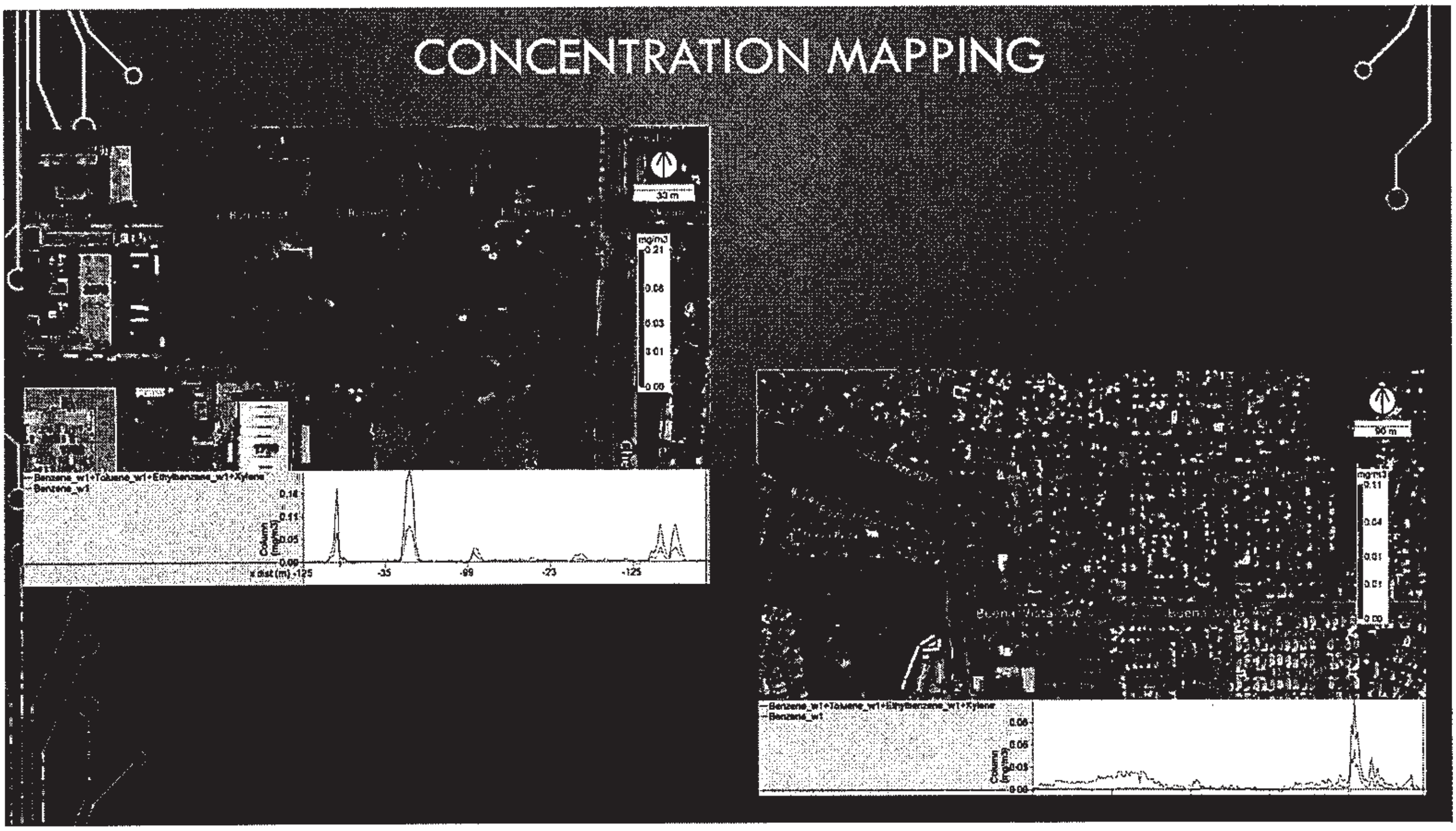
- Co-located sensor testing at AQMD's Fenceline Monitoring Laboratory in Carson, CA
- High temporal resolution is required to resolve individual VOC plumes
- Baseline drift and other corrections of sensor data may be required

VISUALIZATION AND ANALYSIS OF SENSOR DATA

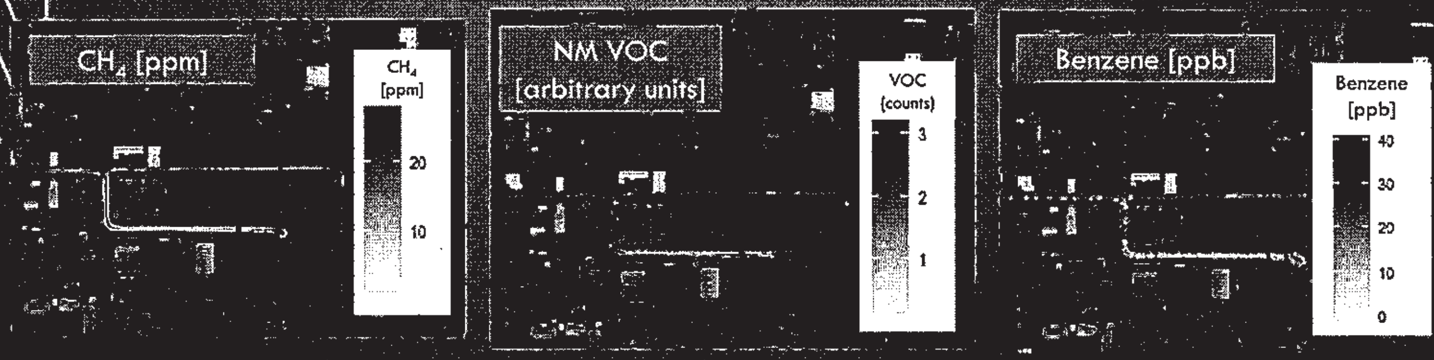


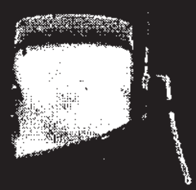
- Alert when set air quality threshold(s) are exceeded
- Assess impacts of emissions
- Identify emission sources


DETECTION OF AIR TOXICS PLUMES
alkanes
BTEX x10
Legend
alkanes
BTEX x10
Legend


CONCENTRATION MAPPING

COLLOCATED ORS AND SENSOR OBSERVATIONS





- Elevated VOC levels detected by a "low-cost" VOC node downwind of oil pump and storage tank
- Detection confirmed by mobile lab
- Emissions observed by FLIR camera

CONCLUSIONS

- Low-cost" VOC sensor nodes can provide a long-term qualitative record of ambient VOC levels on the community level
- ORS methods offer quantification of emissions from large sources
  - May supplement or even replace emission inventories
- ORS instruments on a mobile platform offer air toxics concentration mapping capabilities
  - Identify pollution "hot spots"
  - Conduct detailed investigations of elevated levels detected by "low-cost" sensors
- "Low-cost" sensor and ORS technologies will play a fundamental role in the implementation of recent and upcoming California laws
  - AB 617 - Nonvehicular air pollution: criteria air pollutants and toxic air contaminants
  - AB1647 – Petroleum refineries air monitoring systems

THANK YOU FOR YOUR ATTENTION

Olga Pikelnaya, South Coast Air Quality Management Dostrict

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DEVELOPMENT OF A LOW COST SENSOR NETWORK FOR FACILITY AND COMMUNITY MONITORING

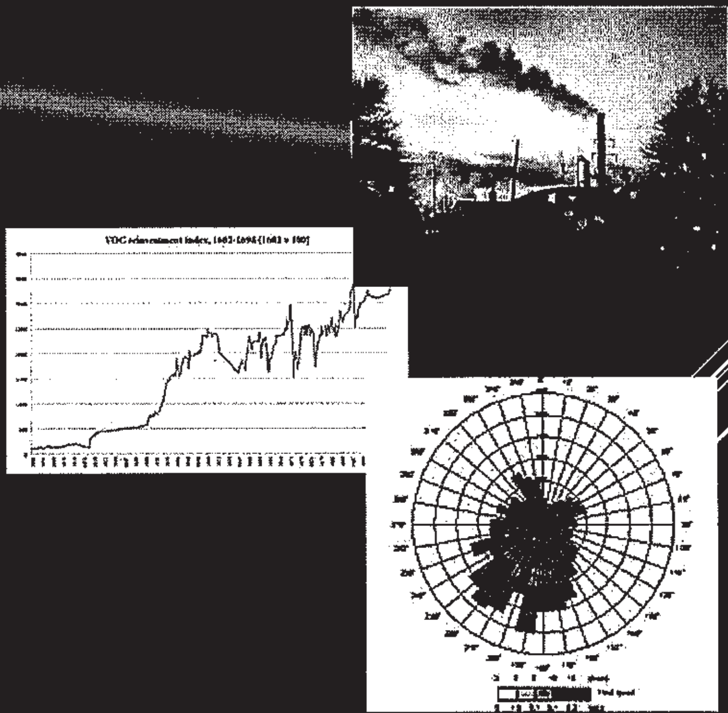
Robert Wimmer, Olga Pikelnaya, Ross Cheung and Andrea Polidori
South Coast Air Quality Management District

WHY MONITOR FOR VOCs?

- VOC emission and composition from industrial sources are not fully understood
- Mounting evidence that current emission inventories are underestimating actual VOC emissions
- VOC's contribute to photochemical smog formation
- Some VOC's are also air toxics
- Monitoring equipment for VOCs is costly
- Need to find cost-effective solutions for fenceline and community-scale monitoring of VOC's
- "Low-cost" VOC sensors can meet this challenge

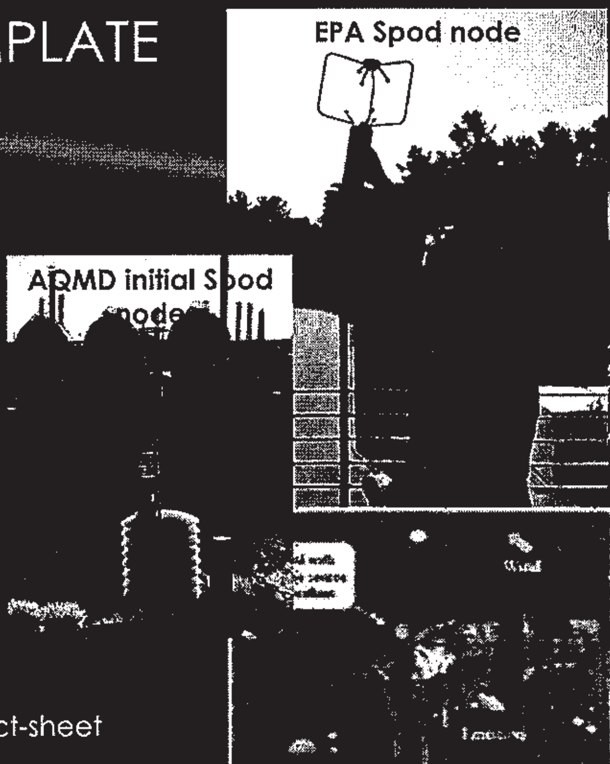
REQUIREMENTS FOR "LOW-COST" VOC SENSOR SYSTEM

- Small and self contained
- Capable of long-term, unattended operations
- Capture wind and meteorological conditions at the site for source attribution
- Wireless, real-time data transfer



SPOD DESIGN AS A TEMPLATE

- Open source VOC fenceline monitor
- 3D printed parts
- Mocon PID VOC sensor
- Short range point-to-point data radio (XBEE S1)
- Used EPA ORD Spod design as a starting point
- Modified Spod design to enhance functionality and add capabilities



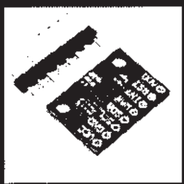
https://www.epa.gov/air-research/spod-fact-sheet

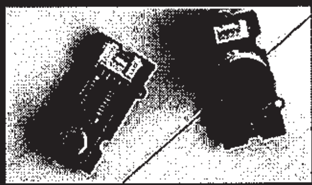
TYPES OF "LOW-COST" VOC SENSORS

- PID (photoionization detector) - from ~$400


- Advantages:
  - High accuracy and precision
  - Fast response
  - Long lifetime
- Disadvantages
  - Sensitive to RH changes
  - Baseline drift overtime

- MOX (Metal oxide sensors) - from $30





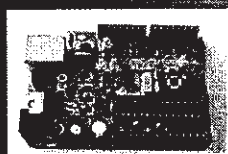
- Advantages:
  - Fast response time
  - Automatic correction for T and RH changes
  - Low cost
- Disadvantages
  - Require weatherproofed enclosure
  - Performance not well-characterized

Sensor selection will depend on application and deployment requirements

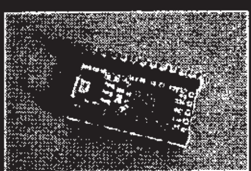
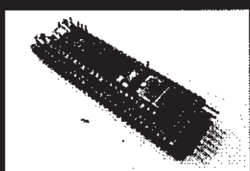
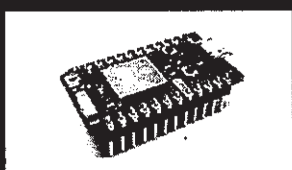
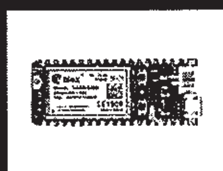
HOST PROCESSORS

- Arduino based Boards and Clones ~$30 - $70



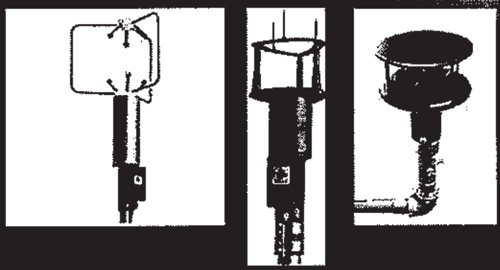
- Arduino based chipsets with hybrid capabilities ~$17 to $130

- Best selection based on hybrid resident components.
- Better ADC and a good number of UART serial ports and possible resident communication facilities.

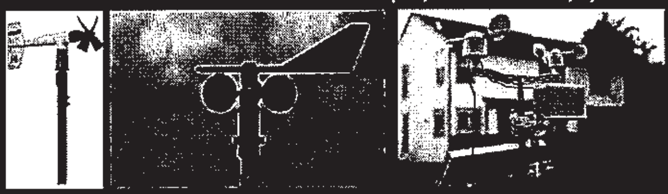
WIND MEASUREMENTS

- Ultrasonic anemometer (~$800 and up)



- Advantages
  - Serial capabilities
  - Highly accurate and precise
- Disadvantages
  - high in price
  - high in power consumption

- Traditional anemometer (~$80 and up)



- Advantages
  - low cost
  - Low power consumption
- Disadvantages
  - units may vary in precision.
  - Greater wear and tear due to bearing surfaces

Wind meter selection is based on interface protocol. Serial data interface is preferred.

TELEMETRY OPTIONS

- Localized telemetry radios

- Advantages
  - Inexpensive
  - Some models can be "meshed"
- Disadvantages
  - Limited range
  - Require line of sight
  - Data transmission can not be timed

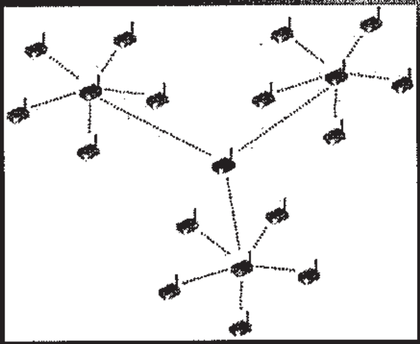
- Cellular

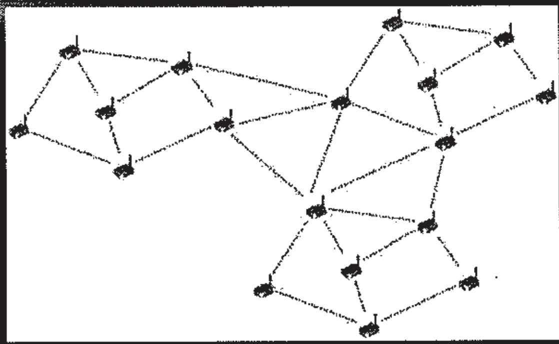
- Advantages
  - Line of sign is not required
  - Unlimited number of units
- Disadvantages
  - Require data plan

Fence-line locales do not necessarily guarantee line of site
Point to point data is not sufficient; units need to "net" together and route data

ROUTABLE TELEMETRY DATA RADIOS

Current "star" network desig





Early XBEE S2 pro and S3 Pro units allowed for a "star" configurations or "multi-star" configuration. Such nomenclature included end points, routers and a single coordinator. Easy to design and troubleshoot

Zigbee protocol is shared amongst different device manufactures (digi and loRaw)
Self healing network. It will route data around obstacles. Makes mating with a cellular gateway tricky. Good for long term in house monitoring systems

Both systems can be "chatty" No resident collision detection.

SPOD DATA FORMAT

"Clean" data sample

```
spod2,1:9:40 8-8-2017,022 00.0,12.32,78.80,760.17,22.54 74.94 14.21 24 0.14964
spod4,1:10:46 8-8-2017,266,00.8,12.45 85.90,759.89,22.25,76.62 20.29 30.0. 4067
spod1,1:10.20 8-8-2017,012,03.0,12.87,87.80,759.96,21.83 78.65,17,23.33, 0.05730
spod3,1:10:16 8-8-2017,353,02.7 12.05,109.70,759 54,22,23,76.04,17,30,32, 0.06769
spod2,1:9:42 8-8-2017,315,00 8,12.33,88.40,760.17 22,54 74.95,14.21,22,0.14067
spod4 1:10:48 8-8-2017,300 01.1 12.45 85.90,759.89,22.25,76.61 19.27 30 0.15122
spod1,1:10:22 8-8-2017,012,02 5,12 86.88,10,759.95,21.82,78.67,17,23.32, 0.09868
spod3,1:10.18 8-8-2017,003,02.3,12.06,106.40,759.55,22.29,76.07,16 24,28 0.0330
spod2,1:9:44 8-8-2017 331,01.5,12.22,86.90,760.18,22.55,74.94,14.21 22,0.13516
spod4,1:10.50 8-8-2017,330,02.0,12 45.85,90,759,92,22.25,76.61,20.27,31,0.16106
spod1,1,10:24 8-8-2017,007,02.9 12.86 86.10,759.97,21,83,78.68,17,23.32, 0.06282
spod3,1:10:20 8-8-2017,002,01.7,12.05,105.70 759.56 22.29,76 07,16 23,26, 0.07107
spod2,1:9:46 8-8-2017,003 01.3,12.33,86.40,760.20,22.55,74.95 14.21,22,0.13792
```

"Stepped on" data sample

```
spod1,1:10:8 8-8-2017,350,02.0,12.87,96.30,759.96,21.85,78.57,18,27,33, 0spod2,1:9.30 8-8-
2017 336.00.8,12.33,86.70,760,18,22.54,74.94,16,21,25,0.15722
.04418
spod3,1:10:4 8-8-2017,351,02 9,12.05,106.30 759.57,22.33,75.95,20,27,36, 0.05753
spod4,1:10:36 8-8-2017,281 00.8 12.45,85.90,759.90,22.24,76.63,19,29,32,0.15403
spod2,1:9.32 8-8-2017,336,00.0,12.32,83.40 760.18 22.54,74.95,16 21,25,0.spod1,1:10:10 8-8-
2017 351,02.7,12.86,84.70 759,74,21 84,78,60,17,24 32, 13930
0.07937
spod3,1:10:6 8-8-2017,339,02.7,12.04,114.30,759.56 22.32,75.97,20,30,35, 0.08639
spod4,1:10:38 8-8-2017,235,00.7 12.45,85.90,759.90,22.24,76.63,19,29 32,0.17654
spod2,1:9.34 8-8-2017,269,00.0,12.32,81.50 760.18 22.54,74.95,16,22,26,0.spod1,1:10:12 8-8-
2017 001,02.9 12.86 92.00 759.77,21,84,78,61,17,23 30, 13792
0.04932
```

- Xbee equipped units "stepped on" each other, resulting in interrupted data strings
- Frequency of such interruption is dependent on transmission frequency
- Interrupted data strings had to be filtered out before inclusion into the database, resulting in data loss
- This can be remedied by holding back transmission before data is sent
- Cellular unit will not be susceptible to this problem

DATA ROUTING PROCEDURE

Data String Picked up by Rasp Pi radio

spod3,0:1:42 8-8-2017,287,04.8,12.04,110.60,759.59,22.58,74.13,16,24,26, 0.0550
spod4,0:2:14 8-8-2017,299,02.7,12.45,84.60,759.88,22.77,73.46,19,28 29,0.16388
spod1,0:1:48 8-8-2017,287,03.3,12.89,85.80,759.97,22.46,75.10,16,23,26, 0.05799
spod2,0:1:10 8-8-2017,295,03.8,12.33,94.80,760.20,22.88,72.71,14,21 24,0.14205
spod3,0:1:44 8-8-2017,294,04.3,12.06,116.60,759.60,22.57,74.15,17,24,25, 0.02536

↓

Data checked for inconsistencies
(i.e "stepped on" data strings)

→

Packet is parsed for individual data elements

Spod3	Name of device
0:1:42 8-8-2017	Time Date
287	Dir of wind
04.8	Speed in MPH
12.04	Voltage on system
110.60	Milliamps of draw
759.59	Atmospheric pressure
22.58,	Temp (c)
74.13	Relative Humidity
6	PM 1
24	PM2.5
24	PM1
0.0550	VOC VOLTAGE

↓

Device health check

Spod3	Name of device
0:1:42 8-8-2017	Time Date
287	Dir of wind
04.8	Speed in MPH
110.60	Milliamps of draw

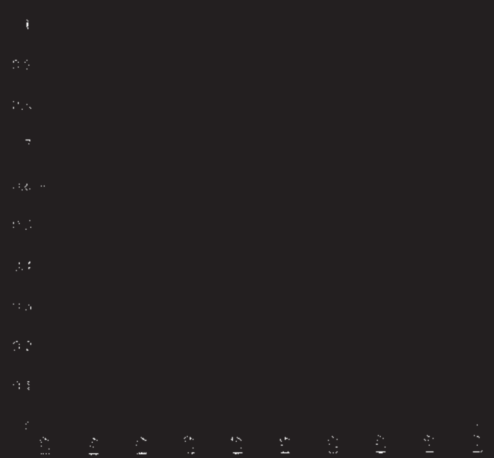
←

Insertion into a MySQL relational database resident on Rasp PI

DATA STORAGE AND ANALYSIS OPTIONS

MySQL on a local computer

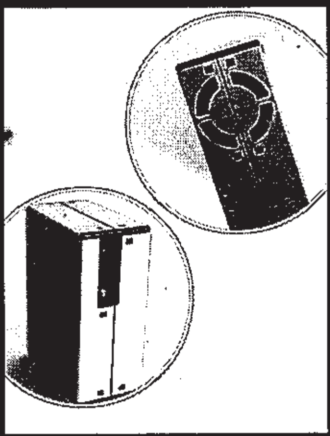
- In-house data plotting and analysis
- Devise health check
- Data quality monitoring



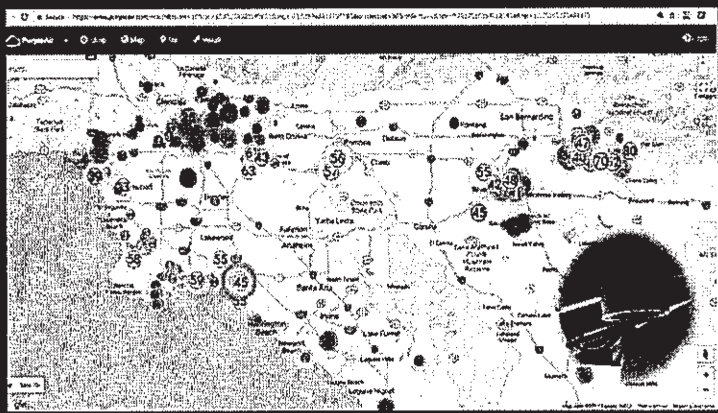
Web-based utility

- EnviroSuite web-hosting utility
- Real-time data visualization
- Modeling and source-apportionment

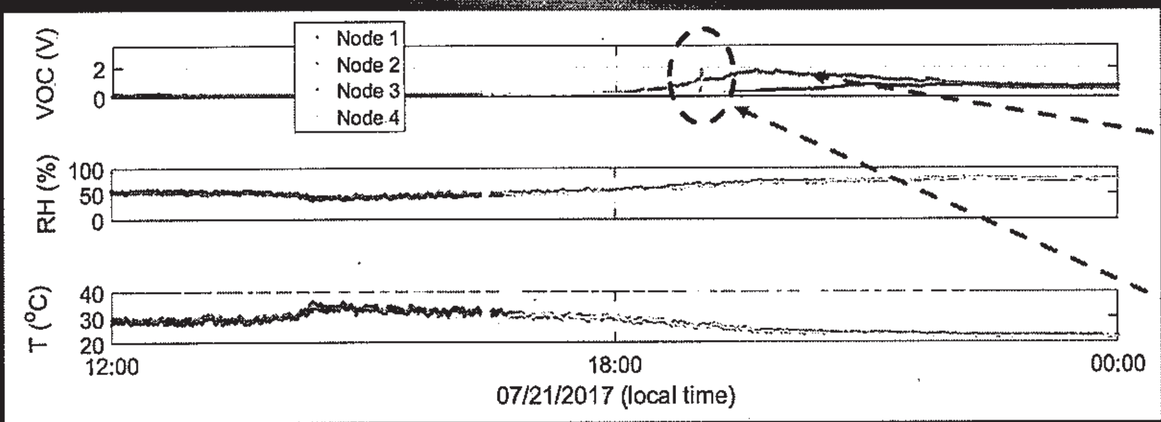
PARTICULATE MATTER SENSOR



- Particulate matter "low-cost" sensor manufactured by Plantower
- Same sensor as in Purple Air II PM sensor nodes



RELATIVE HUMIDITY EFFECTS

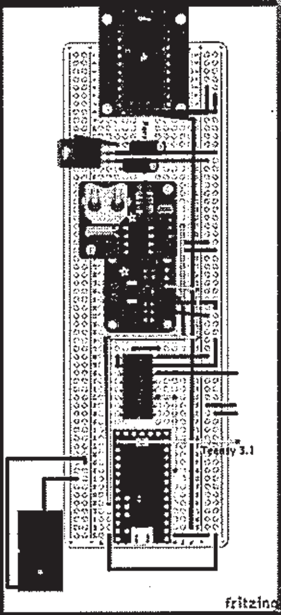


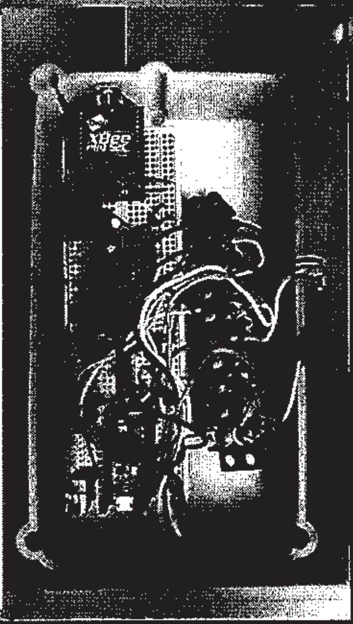
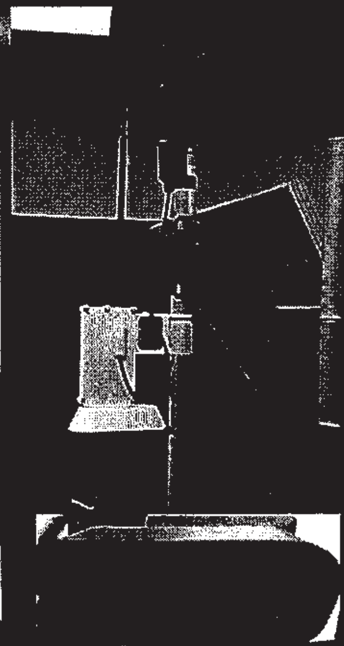
Affect of RH

VOC "event"

- Baseline changes due to relative humidity
- Onset may be different for each sensor
- IonScience PID's may be less susceptible to RH effects then Mocon PID's

AQMD VOC POD NODE



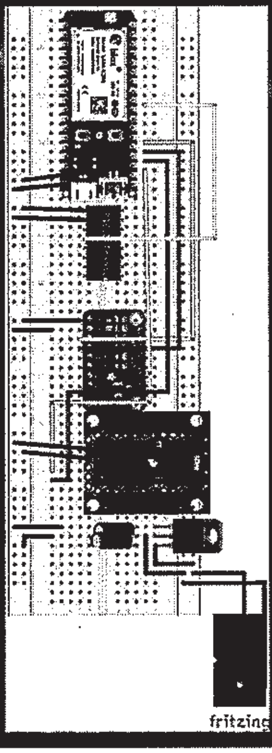



- DC to DC module (~12v to 5v)
- Voltage/Current sensor for health monitoring
- IonScience PID VOC sensor
- Added Plantower PM sensor
- Real-time clock chipset
- Dedicated RH/T/P sensor
- Xbee S2CPro for star configuration
- Ultrasonic anemometer

FIELD DATA COLLECTION AND TRANSFER


- Raspberry Pi 3
- Touch Screen for field access and monitoring
- Xbee2C pro and USB adapter
- Digi multi port cellular modem
- Large battery

AQMD VOC POD ASSEMBLY V2



- Add auxiliary MOX sensor
- Add PM/formaldehyde sensor
- Resident cellular modem
- Analog Anemometer
- 16bit voltage resolution
- Not dependent on a "base unit"
- However, still retain the ability to communicate with a base unit.

CONCLUSIONS

- Designed a field-deployable "low-cost" sensor node for monitoring of VOC's and PM
- Developed SQL database for in-house data processing and monitoring of data quality
- Interfaced with EnviroSuite for web-based data visualization and dispersion modeling
- "Star" network configuration is only feasible for a small network deployment
  - Up to 10 units surrounding a small facility w/o tall structures
- Nodes equipped with individual cell modems are required for large network deployments
  - E.g. fenceline of a complex facility or community deployment
- Initial field deployment of IonScience PID indicate that this sensor is less affected by RH changes, but more detailed testing is needed
- Sensor network can be used for collecting highly time- and space- resolved VOC and PM data

FUTURE WORK

- Include cellular processor to each unit
  - Eliminates the need for a "master" data collection unit
- Depending on application and deployment configuration replace sonic anemometers in some units with traditional wind meter in order to lower power consumption and cost
- Establish Drop-off, turn-on, Confirm Operation and Leave" type of deployment
- Develop unit calibration protocol
- Use current design elements for other sensor types and/or add more sensors to current node design
- Develop algorithm to correct for RH dependence and baseline drift

STUFF I WOULD ASK ABOUT...

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-
-
-
-
-

Real-Time PM Measurement Using BAMs and High-Volume Samplers
#ME51

Bipul K. Saraf

A&WMA Air Quality Measurements Conference
November 8, 2017

Yorke Engineering, LLC
www.YorkeEngr.com
Office Locations: Los Angeles, Orange County, Riverside, Ventura, San Diego, Fresno, Berkeley
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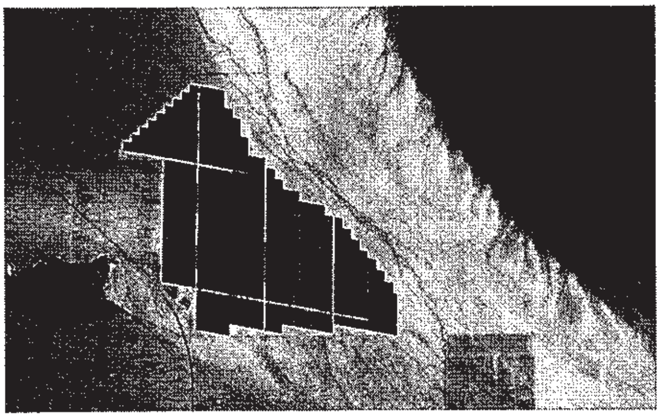
Presentation Outline

- Project Background
- Monitoring Requirements
- Instrumentation Used
- Operation and Maintenance
- Data Collection and Reporting
- Program Results

Project Background



- 550-MW PV solar power project
- In Riverside County, near Joshua Tree National Park
- Located in the Mojave Desert Air Basin portion of the SCAQMD
- On land managed by the BLM

Yorke ENGINEERING, LLC
www.YorkeEngr.com

Project Background

- Area is classified as PM_{10} non-attainment for the California ambient air quality standard
- Project EIS completed in 2011, potential concerns included:
  - Fugitive dust impacts and deterioration of air quality
  - Dust impacts on sensitive habitats and endangered/threatened species

- Monitoring required to minimize impacts on air quality and biological resources

Yorke ENGINEERING, LLC
www.YorkeEngr.com

Mitigation Requirements

- Develop and implement an SCAQMD Rule 403 Dust Control Plan
- Install four monitoring stations
- Monitor local air quality for 6 years: 3 years during construction and 3 years during operation
- Relocate/transplant endangered species – animals and plants

Monitoring Requirements

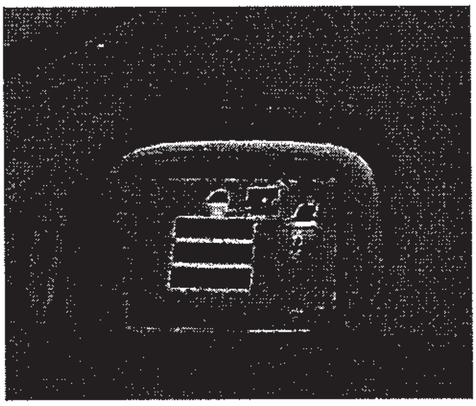
- Conduct real-time continuous monitoring for PM_{10} and $PM_{2.5}$
- Measure diesel particulate matter
- Measure heavy metals, such as arsenic
- Measure meteorological parameters
- Report data monthly

Instrumentation Used

- Continuous $PM_{2.5}$ and PM_{10} with beta-attenuation monitors (BAMs) (MetOne Instruments)
- Total suspended particulates (TSP), heavy metals, and diesel particulate matter (DPM) by high-volume sampler (Tisch Environmental)
- Meteorological parameters (Davis Instrument)
- Temperature-controlled shelter (ShelterOne)

Power Requirements – Each Site

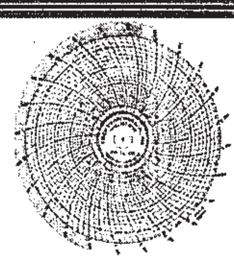
- Self-sufficient, dedicated solar power plant, with 30 solar panels
- Backup propane-fired generator
- Sufficient power per site to operate two BAMs, one high-volume sampler, and one meteorological station/wireless router



PM_{10} and $PM_{2.5}$ BAMs

- Two co-located BAMs for PM_{10} and $PM_{2.5}$ operated in parallel at each station
- Enclosed in a temperature-controlled shelter
- Follow EPA Class III Federal Equivalency Method (FEM, EQPM-1013-209)
- Hourly PM_{10} and $PM_{2.5}$ data collected continuously
- Maintenance includes weekly site visits, annual 72-hour background tests, monthly flow audits, and periodic filter replacement

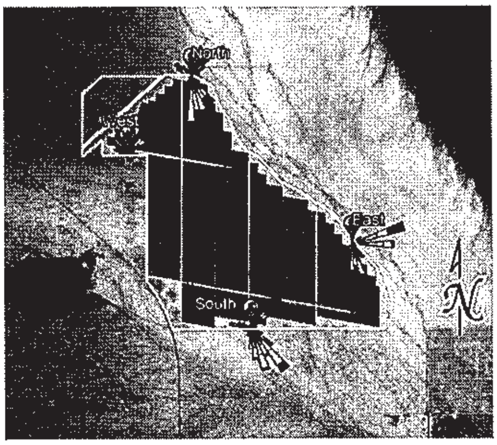
High-Volume Samplers



- One high-volume sampler at each station, bolted on a concrete slab
- Follow 40 CFR Part 50 requirements
- Collect weekly 24-hour single sample for TSP, heavy metals, DPM, and natural elements; each sample is collected on a QFF and analyzed by a nationally accredited lab
- Maintenance includes replacing carbon every 400 hours and blower motors every 1,000+ hours; a NIST-traceable calibration is done whenever blower is serviced

Meteorological Station

- One weather station at each site, positioned on the fenceline
- Weather data are logged and retrieved remotely
- Meteorological parameters collected continuously include wind speed, wind direction, temperature, barometric pressure, and rainfall
- Wind roses are generated to show wind pattern



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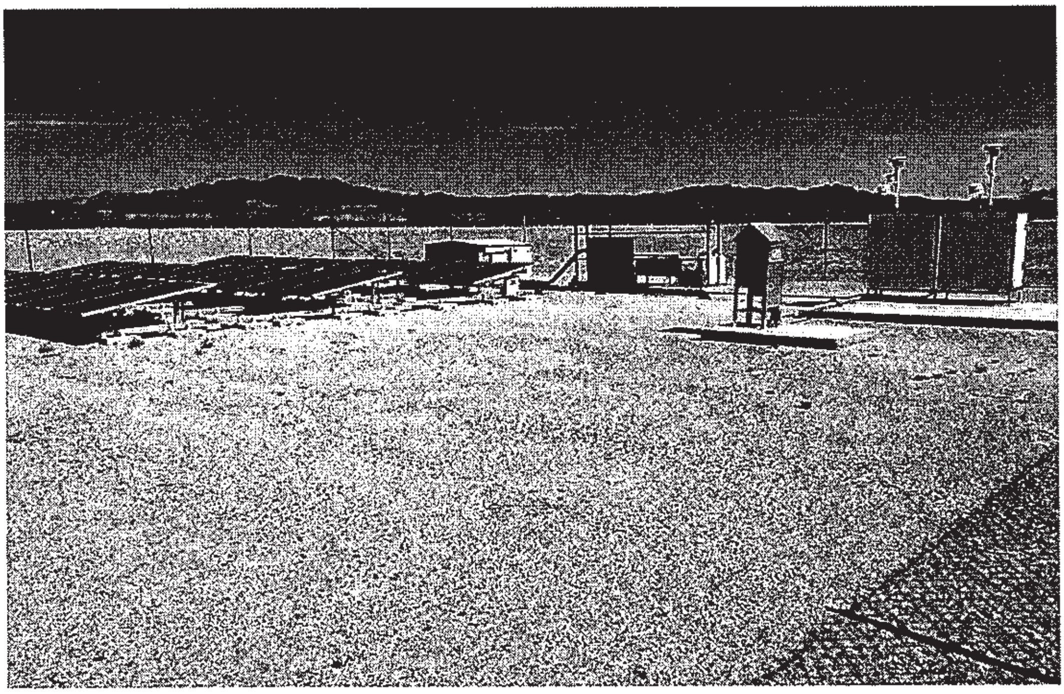
Monitoring Site Photo



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Data Validation

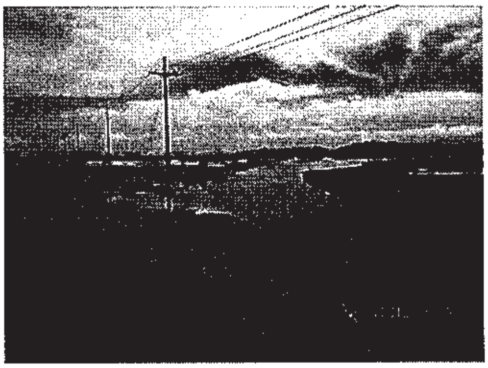
- Needed for determining a valid 24-hour $PM_{10}/PM_{2.5}$ sample
- Data excluded from the 24-hour average:
  - Error code produced by the BAM
  - Hourly wind speed > 25 mph
  - An out-of-range concentration
  - Hourly shelter temperature change exceeding the instrument tolerance

Data Collection and Reporting

- Yorke prepares electronic monthly reports
- Reports are provided to the BLM
- Each report summarizes PM_{10}, $PM_{2.5}$, heavy metals, DPM, and meteorological data
- Variability of PM concentrations shown
- Reports are posted on the Project website
- Monitoring expected to end at the end of this year (2017)

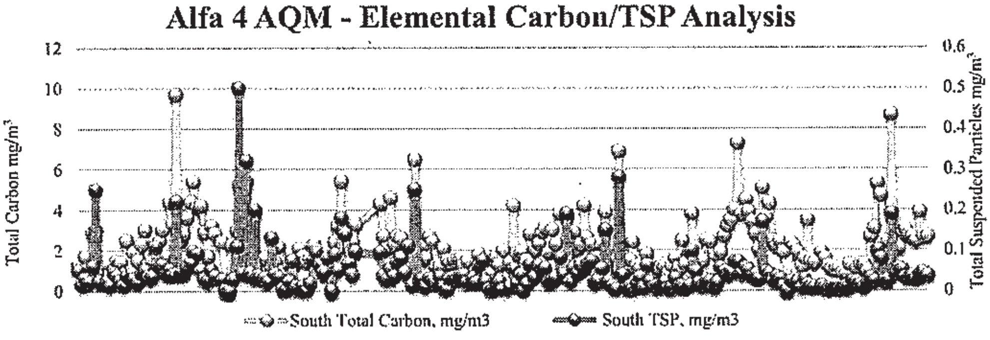
Data Collection Challenges

- Harsh desert conditions, with large temperature differences
- Flash flooding during intense storms
- Wildfires
- High wind conditions:
  - A tornado caused over $1 million in damage to the solar project, but the monitoring stations were not damaged



Data Collection Results

- Air monitoring station operating for 6 years, data recovery 95+ percent
- Concentrations have been generally very low, except during wildfires



Questions?

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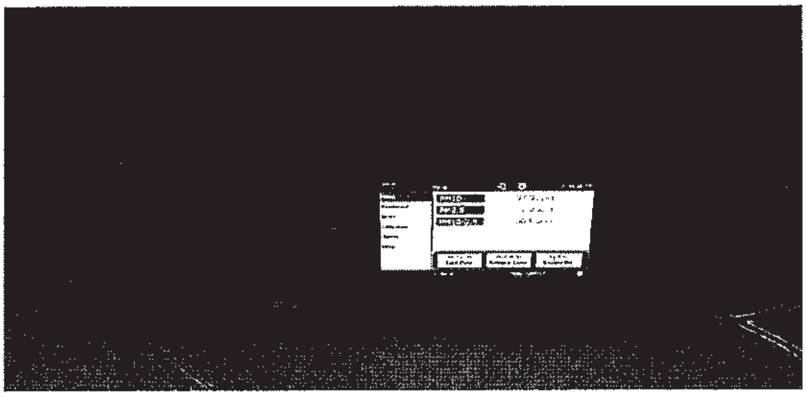
Comparison Study of Particulate Matter Light Scattering Mass Monitor to Beta Attenuation and Gravimetric Methods



Rachel Kolberg Piotr Nowinski Mickey Turner
Clark County Department of Air Quality

Project Outline

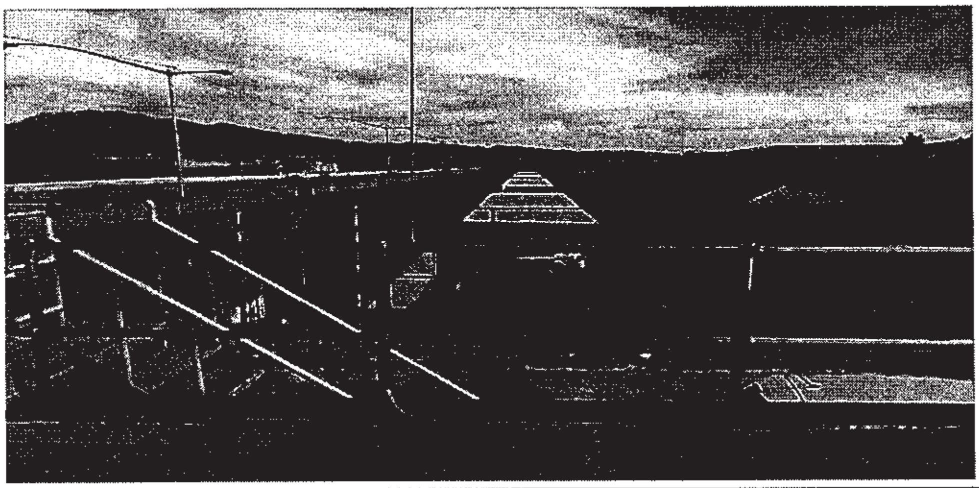
- Introduction
- Compared Methods
  - *Thermo Fisher Scientific Partisol® 2025i*
  - *Met One Models BAM 1020*
  - *Teledyne API Model T640 PM Mass Monitor*
- Instrumentation
- Results
- Discussion
- Conclusions

Introduction

- Particulate matter (PM) contains components that cause health risks
  - Nitrates, sulfates, dust, heavy metals, trace elements, organics, liquid droplet particles
- PM can easily bypass body's defense mechanisms
  - PM_{10} (<10 μm), $PM_{2.5}$ (<2.5 μm), and $PM_{2.5-10}$ (2.5-10 μm)
  - Size is directly related to health impacts. The smaller particles can reach deep in the respiratory system. Smallest particles can reach bloodstream
- Use of real-time monitoring of PM measures our compliance with NAAQS
  - Information from air monitors helps to implement restrictions and to issue advisories

Introduction

- NCore Site (National Core Multipollutant Monitoring Network)
  - Neighborhood scale site (view to east shown below)
  - Contains FEM $PM_{2.5}$, $PM_{10,}$ and Primary and Collocated FRMs ($PM_{2.5}$)
    - Used both FRMs data to get more statistics for comparative analysis

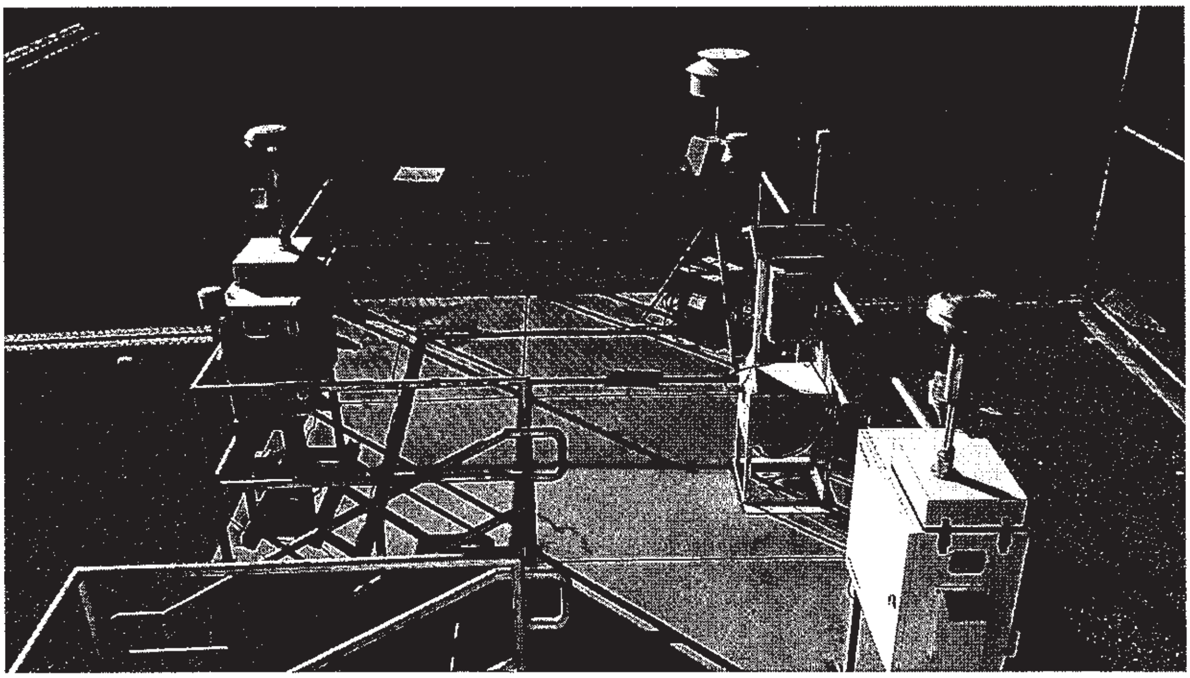


Introduction

- Six week trial test of light scattering PM monitor
  - Tested Teledyne PM mass monitor T640
- Compared $PM_{2.5}$, PM_{10}, and $PM_{2.5-10}$
- MetOne BAM 1020 and Thermo 2025i sequential $PM_{2.5}$ air sampler
- Hourly and 24-hour averages for data evaluation
- Why test the new instruments?
  - Looking for an upgrade alternative to the BAM instruments
  - To address maintenance issues and to cut down how much space is used at our monitoring sites

Thermo Fisher Scientific Partisol® 2025i Sequential PM2.5 Air Sampler

Manual Reference Method: RFPS-0498-118



Air Quality
Protecting the air we share

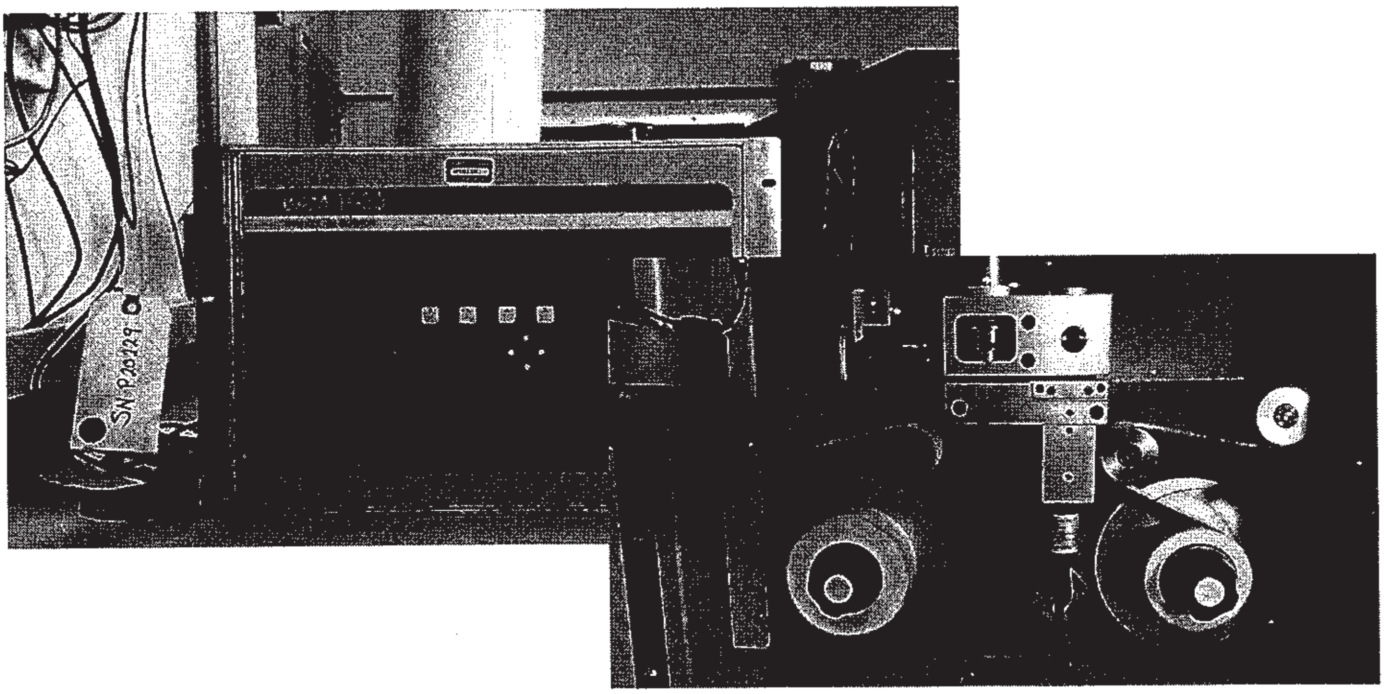
Thermo Fisher Scientific Partisol® 2025i Sequential PM2.5 Air Sampler
Manual Reference Method: RFPS-0498-118

- BX-802 EPA PM_{10} inlet with Very Sharp Cut Cyclone (VSCC™) particle size separator
- 24-hour continuous sampling
- Modified filter shuttle mechanism
- Sample collection filters specified in 40 CFR Part 50, Appendix L.

- **Pros:** direct gravimetric method, designated as Federal Reference Method (FRM)
- **Cons:** manual, filters, non-continuous, shuttle problems, possible loss of VOCs, risk of contamination, filter handling

(Federal Register: Vol. 67, page 15567, 04/02/2002; Latest modification: 06/ 2011)

Met One Instruments, Inc. BAM-1020 Monitor – $PM_{2.5}$ and PM_{10} FEM
Automated Equivalent Method: EQPM-0308-170



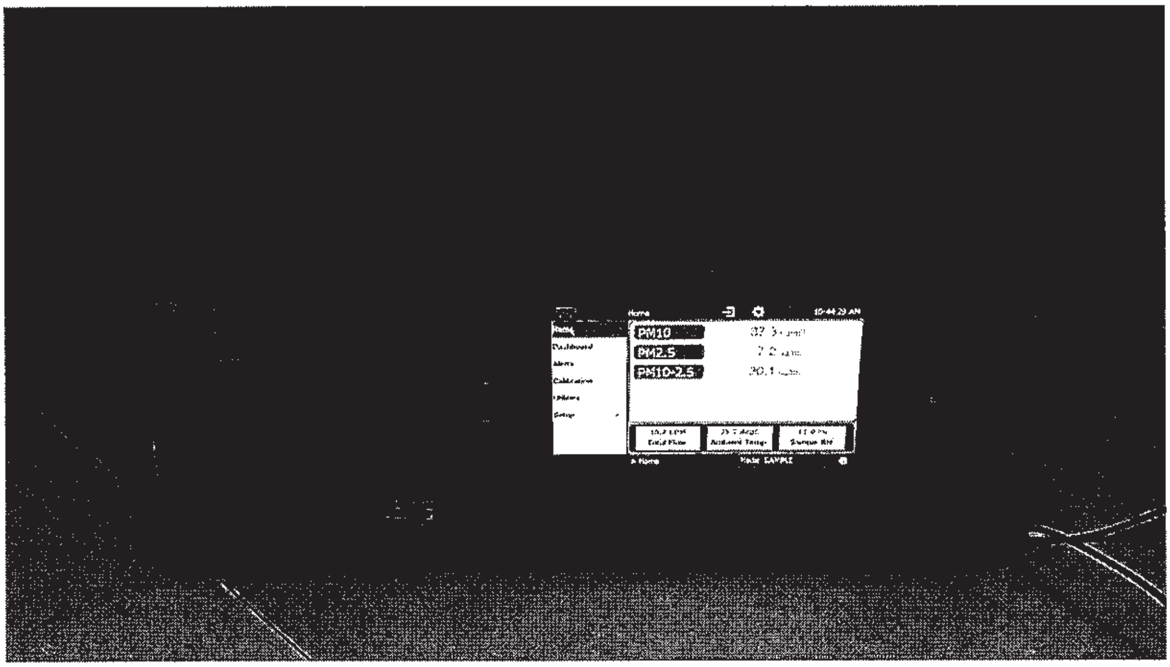
Met One Instruments, Inc. BAM-1020 Monitor – $PM_{2.5}$ and PM_{10} FEM
Automated Equivalent Method: EQPM-0308-170

- Standard BX-802 EPA PM_{10} inlet and with a BGI VSCC™ Very Sharp Cut Cyclone
- 24/1-hour average measurements
- Ambient temperature and barometric pressure sensor
- Automatic flow controller operated in Actual (volumetric) flow control mode
- Heater RH set to 35% and the temperature control set to "off"
- Tape control transport assembly
- Standard glass fiber filter tape
- SAMPLE TIME parameter set for 42 minutes

- **Pros:** automated, continuous, accurate, designated FEM
- **Cons:** tape, 42 min sample data, single parameter measurements

(Federal Register: Vol. 73, page 13224, 03/12/2008; Latest modifications: 07/2010; 08/2010; 08/2012; 03/2015; 09/2015)

Teledyne Advanced Pollution Instrumentation Model T640 PM Mass Monitor
Automatic Equivalent Method: EQPM–0516–236



Teledyne Advanced Pollution Instrumentation Model T640 PM Mass Monitor
Automatic Equivalent Method: EQPM–0516–236

- Continuous ambient particulate monitor
- LED light scattering and algorithm to determine PM mass
- Volumetric flow rate of 5.0-Lpm (no external pump)
- 5-Lpm sample inlet
- Aerosol sample
- Without T640X accessories it is only designated to read PM2.5 measurements

- **Pros:** easy to operate, low maintenance, no tape or filters, designated FEM, multi-parameter measurements, one-minute intervals
- **Cons:** No standard EPA inlet (only 640X), price

(Federal Register: Vol. 81, page 45285, 07/13/2016)

Air Quality
Protecting the air we share

Time Series $PM_{2.5}$

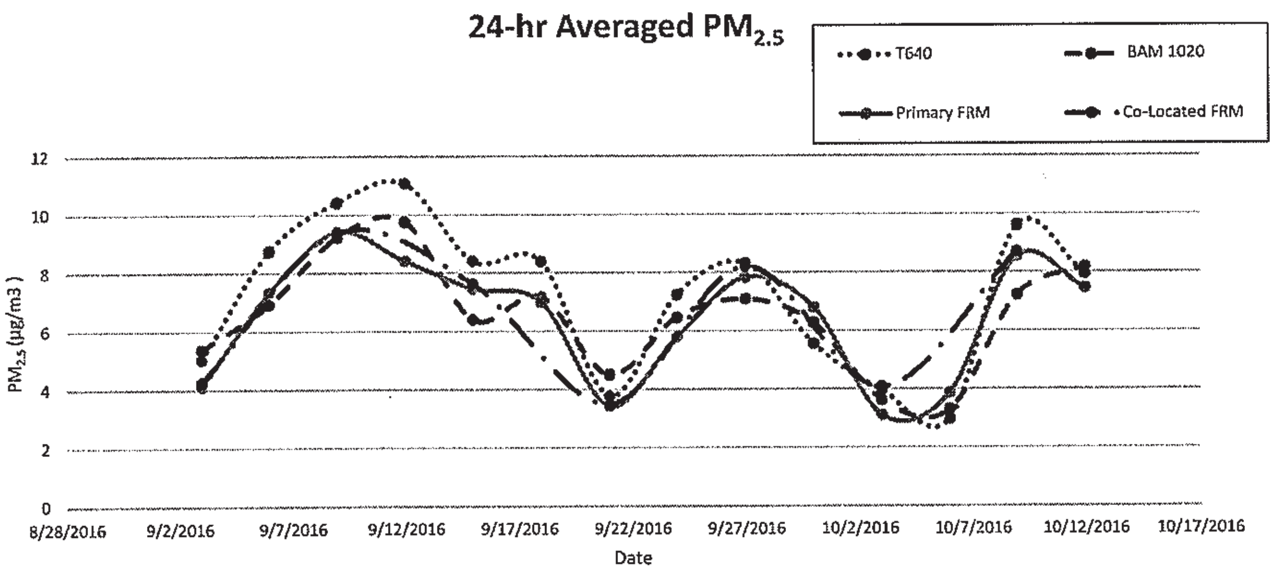
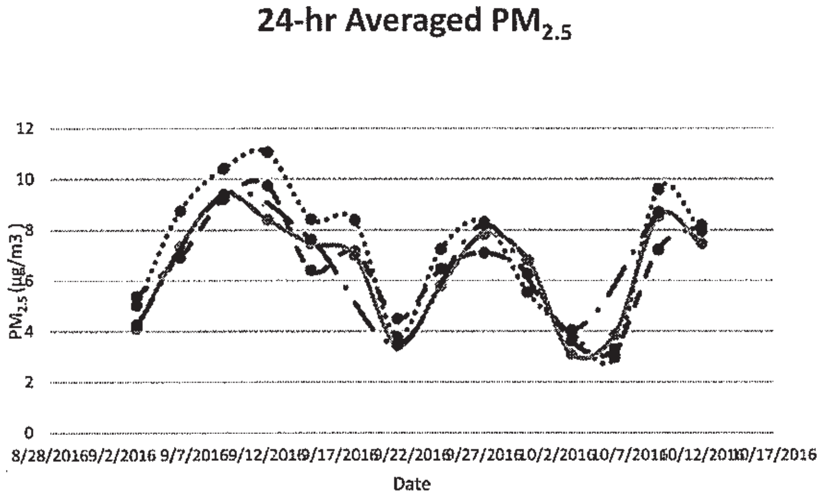


Figure 1. Time series of $PM_{2.5}$ measurements: T640, BAM 1020, primary FRM sampler, and a collocated FRM. (9/3/2016 thru 10/12/2016, averaged for a 24-hr period)

Air Quality
Protecting the air we share

Time Series $PM_{2.5}$



- T640 runs higher because it averages continuous one minute data readings
- FRM has possible VOC loss
- BAM 1020 only samples 42 minute averages per hour
    - Could cause data to go either higher or lower with the other 18 min. averaged in

Figure 1. Time series of $PM_{2.5}$ measurements: T640, BAM 1020, primary FRM sampler, and a collocated FRM. (9/3/2016 thru 10/12/2016, averaged for a 24-hr period)

Time Series (24-hr average) $PM_{2.5}$ – Continuous Instruments

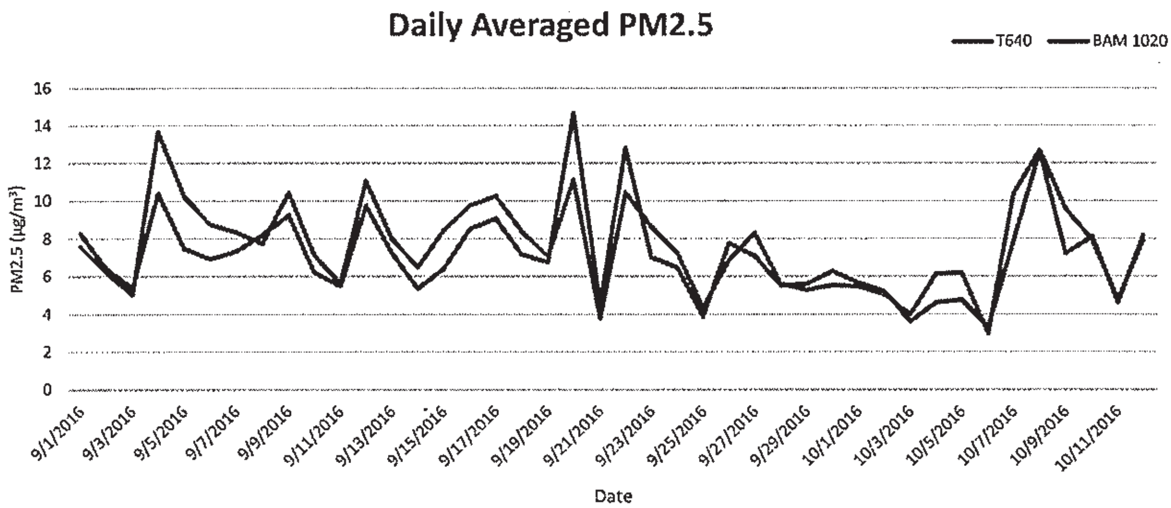


Figure 2. 24-hr averaged time series analysis of $PM_{2.5}$; BAM 1020 and T640.

Time Series (24-hr average) PM_{10} – Continuous Instruments

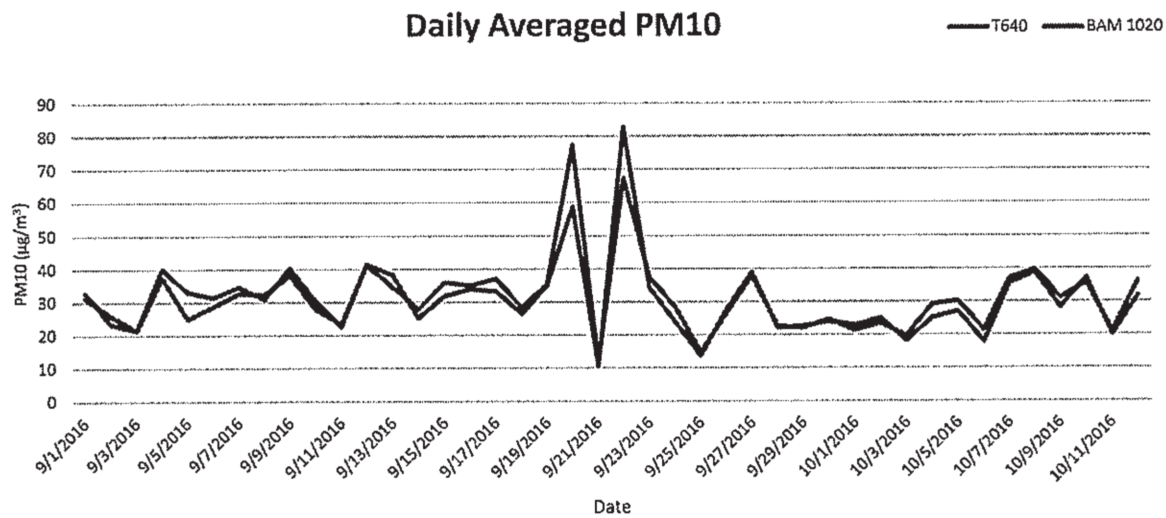


Figure 3. 24-hr averaged time series analysis of PM_{10}; BAM 1020 and T640.

Time Series (24-hr average) $PM_{2.5-10}$ – Continuous Instruments

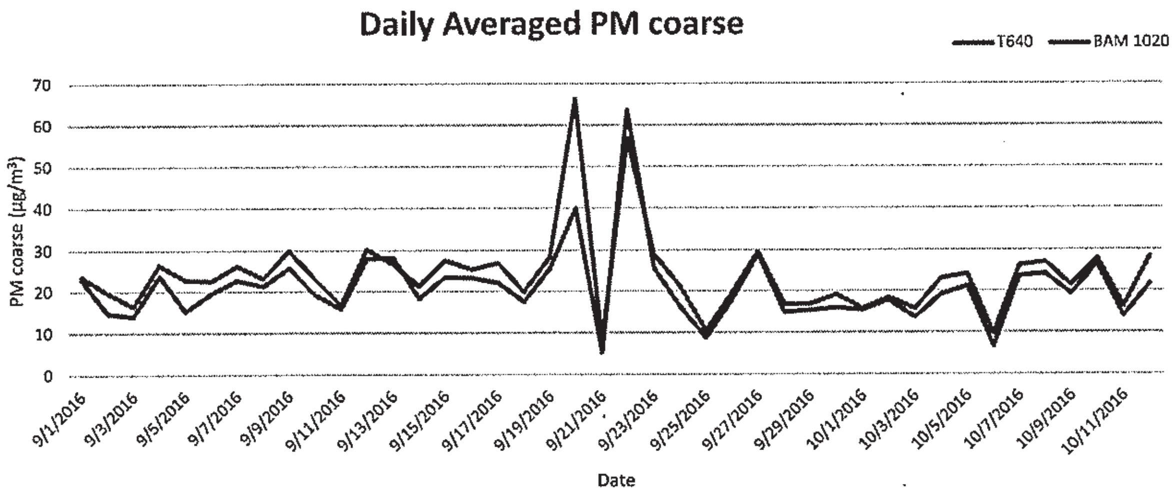


Figure 4. 24-hr averaged time series analysis of $PM_{2.5-10}$; BAM 1020 and T640.

Statistical Analysis

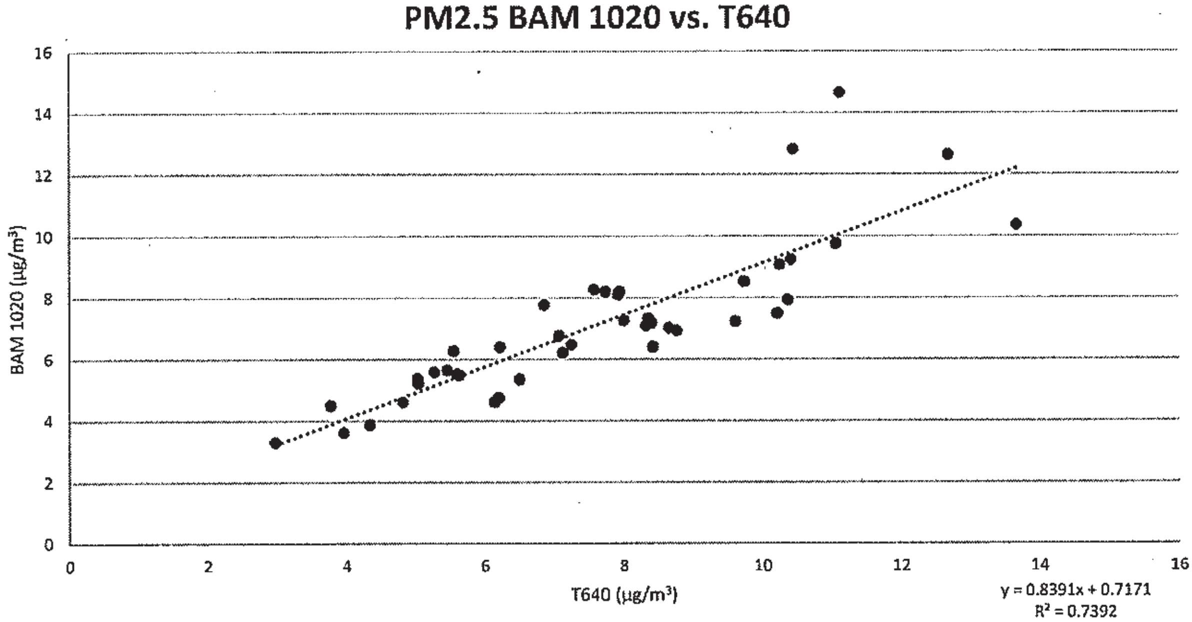
- Linear Regression Analysis
  - *T640 vs BAM 1020 – PM_{10} $PM_{2.5}$ $PM_{2.5\text{-}10}$*
  - *T640 vs Primary FRM – $PM_{2.5}$*
  - *T640 vs Collocated FRM – $PM_{2.5}$*
- t-Test: Two-Sample Assuming Unequal Variances
  - *T640 vs BAM 1020 – PM_{10} $PM_{2.5}$ $PM_{2.5\text{-}10}$*
  - *T640 vs Primary FRM – $PM_{2.5}$*
  - *T640 vs Collocated FRM – $PM_{2.5}$*

Results – Regression Analysis (24-hr averages)

	Coefficient of Determination (R^2)	Regression Slope	Correlation Coefficient (r)	Intercept (µg/m³)
FEM BAM 1020 ($PM_{2.5}$)/T640 ($PM_{2.5}$)	0.74	0.84	0.86	0.72
FEM BAM 1020 (PM_{10})/T640 (PM_{10})	0.88	0.95	0.93	0.30
FEM BAM 1020 (PM coarse)/T640 (PM coarse)	0.82	0.82	0.91	1.21
FRM Primary ($PM_{2.5}$) / T640 ($PM_{2.5}$)	0.88	1.17	0.94	0.31
FRM Collocated ($PM_{2.5}$) / T640 ($PM_{2.5}$)	0.98	1.10	0.99	0.08

Table 1. Regression statistics for comparison T640 PM instrument with collocated FEM BAM 1020 and FRM PM instruments.

Linear Regression - PM$_{2.5}$ BAM 1020 vs. T640



$R^2 = 0.7392$

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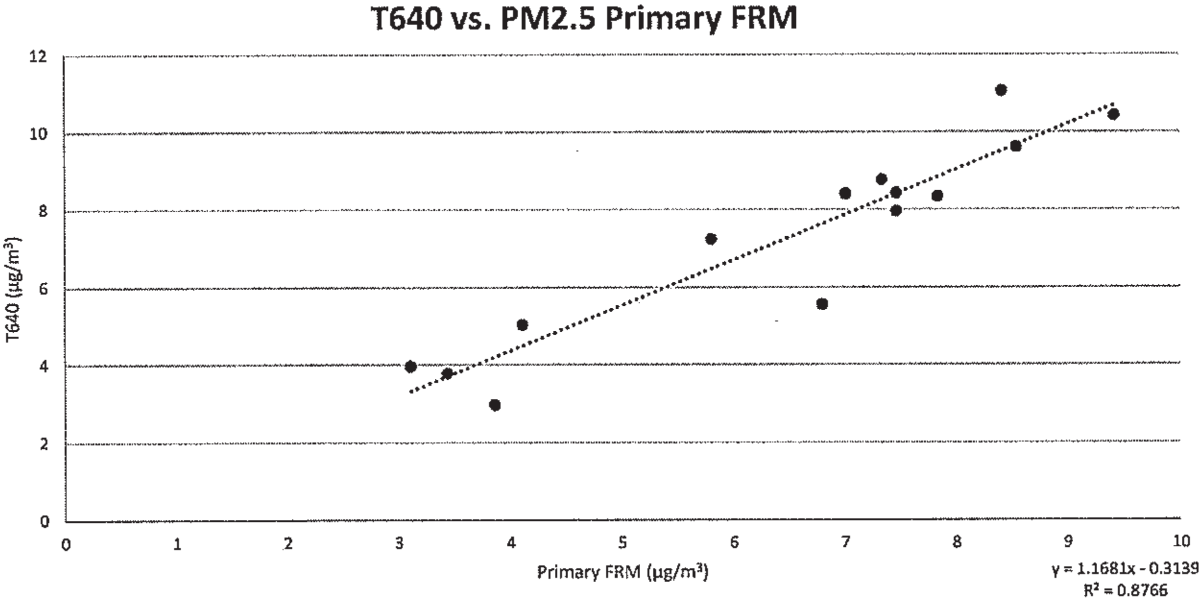
Linear Regression - PM$_{2.5}$ T640 vs. Primary FRM



$R^2 = 0.8766$

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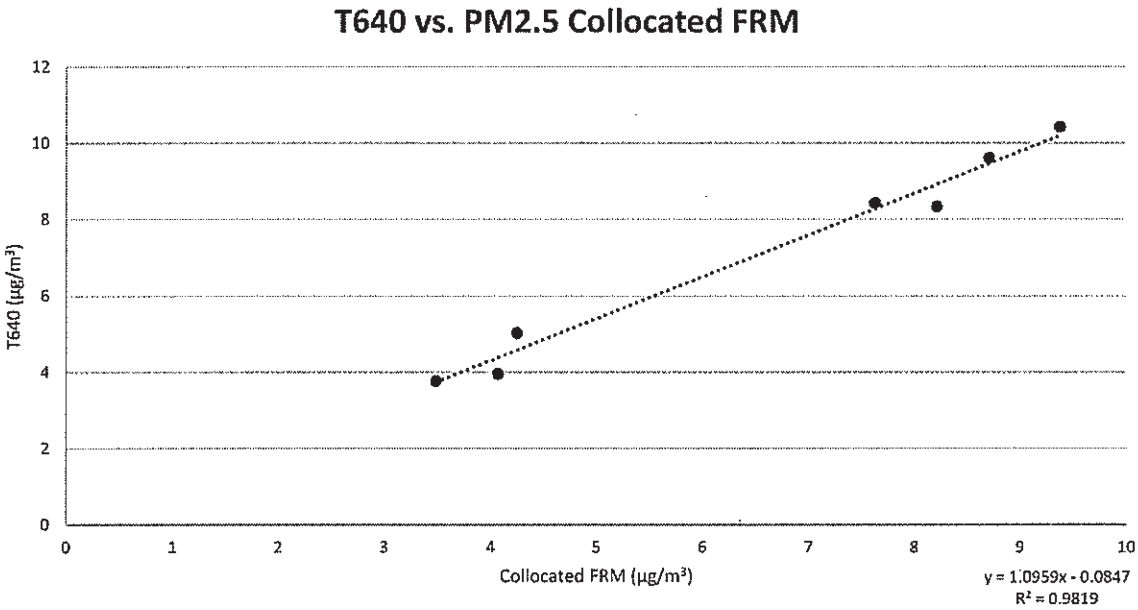
Linear Regression - $PM_{2.5}$ T640 vs. Collocated FRM



$R^2 = 0.9819$

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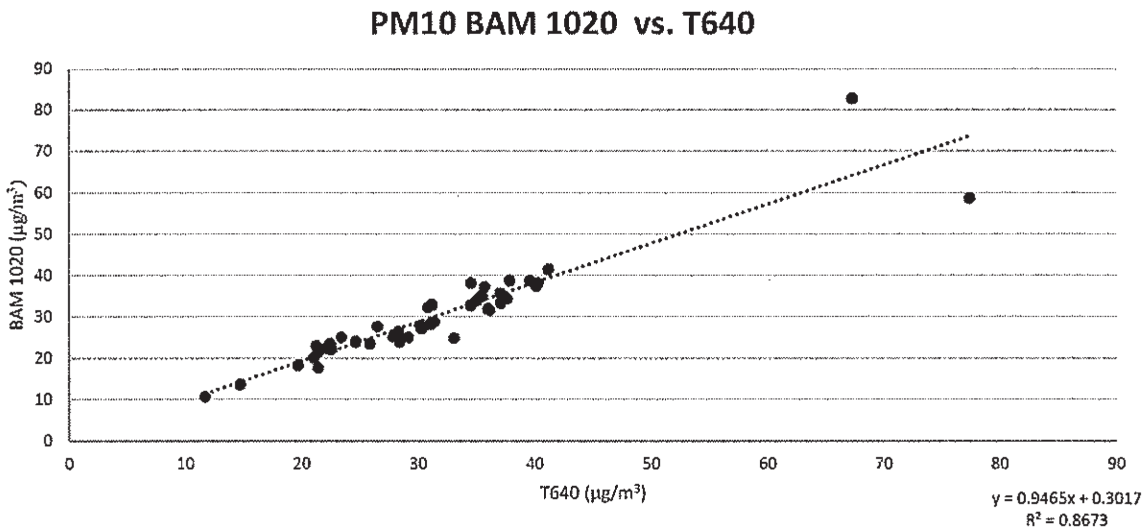
Linear Regression - PM_{10} BAM 1020 vs. T640



$R^2 = 0.8673$

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Results – t test

- t-Test: Two-Sample Assuming Unequal Variances (P = 0.05)

  - ***T640 vs BAM 1020*** *–* PM_{10} (P(T<=) two-tail (0.3355)) *and* $PM_{2.5}$ (P(T<=) two-tail (0.1021)); *no significant difference in the means of each sample*

  - ***T640 vs BAM 1020 –*** $PM_{2.5\text{-}10}$ (P(T<=) two-tail (0.0039)) *data rejects the null hypothesis; the average PM mass measurements differ significantly*
    - *The BAM 1020 had negative* $PM_{2.5\text{-}10}$ *data points that resulted in the differing data set means*

Results – t test

- t-Test: Two-Sample Assuming Unequal Variances (P = 0.05)

  - ***T640 vs Primary FRM –*** $PM_{2.5}$ (P(T<=) two-tail (0.3873)); *no significant difference in the means of each sample*

  - ***T640 vs Collocated FRM*** *–* $PM_{2.5}$ (P(T<=) two-tail (0.7068)); *no significant difference in the means of each sample*

Discussion

- Study performed during low concentration days of PM
- PM mass measurements have high predictability to the various comparisons with the T640
  - *T640 could be used as FEM with great confidence in data*
- T640 closely tracks with BAM 1020 in each 24-hour period
- BAM 1020 and T640 followed well with the primary and collocated FRM
- The correlation coefficient for all measurements > 0.85, a strong positive relationship

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Conclusions

- The light scattering method measures all three PM parameters with one instrument
- The light scattering method effectively measured PM with accurate real-time data readings
  - Easy to operate and reliable; with no tape breaks or missing out on measurements during part of the hour
- The light scattering method would be a reasonable replacement for BAMs instruments for NAAQS compliance monitoring

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Thank you

https://www.teepublic.com/kids-hoodie/1944925-vegas-strong

http://www.kto-env.com/wp-content/uploads/2014/08/clean-air-monitoring-595x229.jpg