Community and Citizen Science Sessions

Engaging Community Members to Become Empowered Community Scientists

Community and Citizen Science Session #1

Air quality is a growing concern for many communities around the world. New technological developments have the potential for communities to directly monitor and learn about their local air quality themselves. However, developing a community-based air quality monitoring program requires a significant learning investment on the part of community residents with the potential for them to develop into community scientists. This presentation will highlight a community-based participatory action research project focused on the development of community-led air monitoring programs using low-cost sensors. The experiences of four urban community groups (three environmental justice, one non-environmental justice) as they engaged in decision-making, planning, and implementing their individual monitoring programs will be shared. The focus will be on changes in their knowledge and understanding of their local air quality issues and their role as community scientists while participating in an intensive learning process to build community capacity to create and implement community-led air monitoring programs. This project is funded by EPA Star Grant #RD83618201.

Presenting Author:
Wendy Griswold
University of Memphis
Additional Authors:

Kansas City Transportation Local-Scale Air Quality Study (KC-TRAQS): Application of Citizen Science for Examining Local Air Quality

Community and Citizen Science Session #1

Increasingly, Citizen Scientists have been interested in collecting data in order to aid professional scientists in studies that impact their community directly, including air quality. These Citizen Scientists often include school groups and classrooms, community service groups, and individuals. In Fall 2017, the U.S. Environmental Protection Agency (EPA) launched the Kansas City Transportation Local-Scale Air Quality Study (KC-TRAQS), which included fixed air quality monitoring sites with federal reference methods, mobile monitoring, and low-cost sensors. This approach provided an opportunity for Citizen Scientists to borrow equipment, called AirMappers, and participate in the collection of particulate matter (PM) and carbon dioxide (CO2) levels with GPS locational data, which will be used to evaluate the AirMappers' performance in the field and the ability of Citizen Scientists to collect quality data. AirMappers are made available to groups by reservation or to individuals by checking out from local libraries. Incorporating Citizen Science into a large study presented opportunities for education and outreach as well as several unique challenges.

Presenting Author:
Stephen Krabbe
US EPA Region 7

Field Implementation of Citizen Science Air Quality and Exposure Study

Community and Citizen Science Session #1

Citizen scientists in Globeville, Elyria, and Swansea (GES), an environmental justice community north of Denver, conducted air quality and exposure measurement pilot studies with the support of researchers. Using two types of low-cost sensors, RTI MicroPEM (PM2.5) and Cairpol CairClip (NO2), citizen scientists deployed a sensor network consisting of 17 sites in their community for 3 weeks in August 2017, including 3 sites collocated with reference monitors. Citizens (n=10) collected personal exposure data and completed time-activity diaries for a 72-hour monitoring period.

Data collection rates for ambient and personal pilots were 89% and 100%, respectively. 7 participants wore the personal platform for at least 50% of their waking hours based on MicroPEM accelerometer calculations. MicroPEM showed moderate linearity with reference monitor (R2 >0.5), negatively impacted by drift at high daytime temperatures. Time-integrated ambient PM2.5 data showed spatial variability with up to 2.8 times difference in concentrations between site pairs, much greater than 2-16% among the site pairs with reference monitors. We observed high PM2.5 temporal correlations among 17 sites (Pearson r=0.67-0.96) with r=0.9 among the sites with reference monitors. Time-integrated personal PM2.5 exposure ranged from 7 to 43 Âµg/m3. Real-time peak concentrations matched participant-reported high exposure events, providing useful information for behavioral intervention. EPA Grant Number: RD83618701

Presenting Author:
Seung-Hyun Cho
RTI International
Additional Authors:

The Community Engagement Process in Studying the Use of Low-Cost Air Sensors in a Highly Impacted, Multi-Cultural Rural Setting

Community and Citizen Science Session #1

Rural lower Yakima Valley, WA is home to communities including Latinx farmworker families, the Confederated Tribes and Bands of the Yakama Nation, and Native Americans of other tribes. Episodic poor air quality impacts this region, reflecting sources of particulate matter (PM) that include residential wood smoke and agricultural biomass burning. University of Washington partnered with local institutions, Heritage University and White Swan High School, to develop community-engaged research on wood smoke. Engagement is multi-faceted. It involves undergraduates mentoring high school students in researching air quality using UW low-cost sensors. The students and a Project Advisory Committee (PAC) consisting of community partners responded to a needs assessment survey of air pollution knowledge and concerns. We created an air pollution curriculum for the students and trained the mentors in how to use the low-cost sensors. Students conducted projects investigating air quality in classrooms, outdoors, and in homes from several locations in the valley. These projects were shared with community members at a public meeting. PAC members and UW team members were interviewed about perspectives on trust building in the partnership and the cultural relevance of the project. Through evaluation of ongoing community engagement, this project is informing how low-cost air sensors may be useful to community members historically underserved in air quality research. EPA STAR grant #83618501.

Presenting Author:
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Community Sensor Training: Best Practices and Lessons Learned

Community and Citizen Science Session #1

The South Coast AQMD is leading a U.S. EPA Science To Achieve Results (STAR) grant, entitled "Engage, Educate, and Empower California Communities on the Use and Applications of Low-Cost Air Monitoring Sensors." The grant team includes UCLA; Sonoma Technology; the Bay Area Air Quality Management District; and other CAPCOA agencies. This project aims to provide California communities with the knowledge necessary to appropriately select, use, and maintain low-cost sensors; analyze sensor data; and interpret the data. Part of the project includes deploying sensors in California communities. Ultimately, a toolkit will be developed to aid communities in deploying low-cost sensors.

As of April 2018, SCAQMD has issued more than 250 sensors to 11 communities; more than 60% of these sensors have been installed. Community engagement has included:

- Initial contact to get communities interested
- Initial meetings to inform the community about the project and air quality monitoring
- Technical workshops to provide hands-on training on installing and using sensors and understanding collected data
- Initial surveys about community air quality concerns and perception
- Follow-up conversations to discuss findings, and follow-up surveys to gain a measure of the changes in community awareness about air quality

We will discuss our approach, progress made and initial findings, lessons learned and challenges we faced, and development of best practices based on our community engagement experience.

Presenting Author:
Hilary Hafner
Sonoma Technology, Inc.
Additional Authors:

Lessons from the Shared Air/Shared Action: Community Empowerment through Low-Cost Air Pollution Monitoring Project

Community and Citizen Science Session #1

The EPA-funded Shared Air/Shared Action (SASA): Community Empowerment through Low-Cost Air-Pollution Monitoring project brings together universities, non-profits, and community organizations in a citizen-science exploration of local air quality in four Chicago neighborhoods. The neighborhoods, three of which are environment justice communities, are spread across Chicago's south and west sides â€“ the location of many of the city's most significant manufacturing sites and freight corridors. In each neighborhood, residents set up stationary monitors and conducted mobile monitoring using multiple examples of up to five different models of low- to mid-cost monitors in the summer of 2017 and the winter/spring of 2018. The community organizations, with support from the university and non-profit groups, developed air monitoring plans, deployed the equipment using local volunteers, and collected the monitoring data. This presentation focuses on the citizen science experience of using local knowledge to develop the monitoring plans, the challenges of implementing those plans â€“ from setting up the equipment to managing volunteers â€“ and the efforts to translate the torrent of monitoring data into meaningful information. This experience identifies the myriad challenges to deploying low-cost air monitoring devices for citizen science projects in environmental justice communities, offers successful solutions for some of those challenges, and suggests areas for future research.

Presenting Author:
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Kansas State University
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Establishing a Community Based Air Sensor Network: Lafayette Engagement and Research Network

Community and Citizen Science Session #1

LEaRN: Lafayette Engagement and Research Network EPA Smart City Air Challenge

Lafayette Engagement and Research Network (LEaRN) is a collaborative of government, higher and K-12 education, and the private sector formed initially to response to the 2016 EPA Smart City Air Challenge. In the first year of its inaugural air quality monitoring project, LEaRN has built a robust and active community of dedicated collaborators with the goal of deploying ~250 low-cost air quality monitors throughout Lafayette, Louisiana. These air quality monitors contain sensors able to measure O_3, PM2.5, temperature, and humidity. In March 2017, the LEaRN team was able to deploy a prototype data management system as well as two prototype O_3 sensors after just three months of work. Since then, we have been refining our sensor designs, procuring sensor components, and further developing our data management system. In this talk, we will describe: (1) the air quality sensor platform designed and deployed in Lafayette; (2) the validation methodologies used for these sensors; (3) the software architecture of the Kinota based open source data management solution; (4) the network topology employed to connect the sensors to the data management solution; (5) the methodology used to site sensors throughout the community; and (6) sensor fabrication and STEM education aspects of the LEaRN collaborative.

Presenting Author:
Brian Miles
CGI
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Use of Citizen Science Tools to Engage, Inpower, and Advance Environmental Justice and Health Equity

Community and Citizen Science Session #2

Citizen science has emerged as a way to increase public participation in scientific research. In many parts of the country, many communities impacted by environmental justice issues do not have adequate access to monitoring infrastructure. The use of citizen science particularly community-driven citizen science has been quite important in increasing the knowledge of populations who live in communities differentially burdened by multiple environmental hazards and locally unwanted land uses (LULUs) including power plants, incinerators, landfills, industrial animal operations, concrete plants, and other facilities. The use of low-cost real-time sensors such as the Airbeam, Purple Air, and Atmotube in combination with visualization tools including the US Environmental Protection Agency's EJ Screen and a new mapping tool focused on the state of Maryland known as Maryland EJ Screen has provided these communities with technological resources that can help fill their knowledge gap about environmental burdens and exposures to toxicants emitted from these hazards. In this presentation, authors will discuss the use of low-cost real-time sensors and mapping tools to engage communities overburdened by environmental hazards, increase knowledge and awareness of impacted stakeholders, inpower residents to act, and detail success of community-driven citizen science efforts in improving environmental health and health equity. The authors will highlight the use of these tools by communities impacted by concrete plants and traffic, industrial chicken farms, natural gas infrastructure, goods movement, and power plants. The authors will also discuss best practices related to the use of these tools with stakeholders from overburdened communities in both community-driven and contributory citizen science initiatives.

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School of Public Health, University of Maryland-College Park
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Developing a Community-Engaged Low-cost Air Monitoring Network in Seattle, Washington

Community and Citizen Science Session #2

The Community Air Monitoring in Puget Sound (CAMPS) network is being developed as part of a community-engaged research study to provide neighborhood level air quality data to groups that are concerned about air quality. The goal of this study is to collect and provide air quality data to residents in order to support individual and community actions to reduce exposures to improve their health. In addition to university academics, partners in the study include child care centers, community clubs, and youth clubs. Groups were invited to participate if they reside in Seattle, were near major highways or roadways, and were concerned about air quality. The study encourages community partners to be an integral part the study design, including selecting monitoring sites, data collection, and report back process. A comprehensive needs assessment was completed through a community survey, focus groups, and community steering committees. Findings will be presented from the ongoing monitoring network that uses 10 low-cost air monitors to measure real-time PM2.5 (particulate matter with aerodynamic diameter <2.5 Î¼m), nitrogen dioxide, carbon monoxide and ozone data. Preliminary results in our monitoring network have found mean background PM2.5 at 8.01 ug/m3 and 13.47 ug/m3 near roadways. This submission will present the results of the needs assessment, discuss motivating factors related to community participation in CAMPS, and summaries of CAMPS air monitoring.

Presenting Author:
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University of Washington, Department of Environmental and Occupational Health Sciences
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Air Quality Community Action Network (AQ-CAN)

Community and Citizen Science Session #2

As one of the fastest-growing U.S. cities, Denver is experiencing significant increases in construction and traffic congestion, worsening our air quality. According to the American Lung Association, Denver is ranked as having the country's 8th-worst air quality among major cities, yet only 53% of residents realize the health and environmental impacts of poor air quality. Air pollution harms everyone, but children are more susceptible to its acute and long-term health effects, including decreased lung function, increased respiratory infections, missed days of school and over $3,000 in annual asthma-related healthcare costs per child. While multiple factors influence a child's exposure to air pollution, schools are an ideal intervention point for education and empowerment.

Our vision? Real-time, hyper-local air quality data and programming empowering communities, families, and schools to limit exposure and reduce pollution through behavior change, advocacy, and community engagement. Using the rich social networks of schools, we are co-designing and delivering air quality and respiratory health education, behavioral interventions, school-based community challenges, and other programming to empower people and communities, decreasing the health and financial burden of air pollution for the most vulnerable Denver residents.

The city & county of Denver is creating a citywide, real-time, hyper-local air sensor monitoring system that will empower communities, families, and schools to protect children's respiratory health. We are using low-cost cutting-edge air pollution sensor technology redeveloped with solar, battery storage, and data connectivity for widescale deployment. The heart of our innovation is collaborative, culturally-appropriate and scientifically-validated approach to programming and interventions. Currently, Denver only has five air monitoring sites. This program is placing 100 sensors' one outside each school with an asthma rate above the median. Denver will be launching a School-Based Community Challenge, sourcing ideas on how to disseminate air pollution data to provide school communities with air pollution and respiratory health education and programming

Funding for this pilot program comes from Bloomberg Philanthropies. As one of the Champion Cities of the 2018 Bloomberg Mayors Challenge, Denver is working closely with the Bloomberg organization to rethink the way Cities embrace innovative solution to addressing pressing issues within their boundaries. As one of the few cities in the Mayors Challenge addressing a global issue, Denver's hope is to provide a framework for city led air sensor application to address inequitable exposure to air pollution to one of the world's most sensitive populations, children.

Presenting Author:
Michael Ogletree
City & County of Denver; Department of Public Health & Environment
Additional Authors:

City government, academia, and local communities: Cooperative approaches to citizen data collection

Community and Citizen Science Session #2

Demand for increased air quality measurements in cities has led to the proliferation of new low-cost, portable air quality sensors, allowing virtually anyone to measure air pollution. To effectively use data collected by these sensors, cooperation between city agencies, researchers, community groups, and citizen scientists is needed, ensuring that scientific integrity is maintained while providing a means of transferring information between government agencies and communities interested in supporting environmental action. In 2017, New York City Department of Health & Mental Hygiene in partnership with Queens College at the City University of New York launched a Citizen Science Program to evaluate the use of low-cost sensors and to engage community groups in the process of developing and implementing community-based air quality monitoring networks. This poster will describe development of the Citizen Science Program, focusing on the process of evaluating new instrumentation, soliciting community support and participation, engaging with City agencies, deploying fixed site and personal monitoring studies to assess community exposures, and creating toolkits for communities to deploy sensors on their own. Through describing this program's development, unique insight will be offered into successes and challenges encountered in developing these new and innovative approaches to monitoring and community engagement in the context of a large US city's air quality program.

Presenting Author:
Margaret Rice

New York City Department of Health & Mental Hygiene
Additional Authors:

Citizen Sensing: From Data to Action

Community and Citizen Science Session #2

A number of environmental sensing technologies and practices are emerging that seek to enable citizens to use DIY and low-tech monitoring tools to understand and act upon environmental problems such as air pollution. These "citizen sensing"projects intend to gather data sets, which can indicate environmental change and give rise to political action. This presentation will discuss work from the Citizen Sense research group, including citizen-sensing efforts related to monitoring PM2.5. The examples of citizen-sensing practices will span from the gas fields of northeastern Pennsylvania, to the congested streets of Southeast London. The presentation will discuss the ways in which citizen sensing and citizen-gathered data have generated new insights for understanding air pollution, as well as strategies for improving air quality.

Presenting Author:
Jennifer Gabrys
Citizen Sense, Goldsmiths, University of London
Additional Authors:

Citizen science and regulatory monitoring: bridging the gap?

Community and Citizen Science Session #2

This presentation explores the potential benefits and challenges of an Environmental Protection Agency (EPA) incorporating citizen science into its national monitoring. It shows the important possibilities of this arena in improving the scale and scope at which data is available by supplementing limited and expensive monitoring equipment with widespread, low-cost sensors led by citizen monitoring. Participants in this field are highly motivated due to the societal importance of environmental issues, but EPAs and citizen science project leaders need to address issues of data quality and sensor calibration, and to provide appropriate feedback to reward and motivate participation. The trial projects RIVM has been involved in clearly point to the potential advantage of these methods for EPAs, such that it has now adopted a framework to further incorporate citizen science in its monitoring processes. This framework includes a knowledge portal, an interactive data portal, and facilities for people to test their low-cost sensors against regulatory monitors. The experience gained may provide ways forward for other EPAs and official government agencies seeking to improve their traditional practices by engaging with the potential of citizen science.

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Greater Baltimore Open Air

Community and Citizen Science Session #2

Anthropogenic activities alter the urban surface and surface atmosphere, generating heat and pollutants that have known detrimental impacts on health. Monitoring these environmental variables in urban environments is made difficult by the spatial heterogeneity of urban environments, meaning that two nearby locations may have significantly different temperatures, humidities, or gas concentrations. Thus, urban monitoring often requires more densely placed monitors than current standards or budgets allow. Recent advances in low-cost sensors and Internet of Things (IoT) enabled hardware offer possible solutions. We present the Greater Baltimore Open Air project, a network of open-source, IoT-enabled environmental monitors called WeatherCubes and summer field data, including field calibrations, from 2017 and 2018. We discuss the implementation challenges and lessons learned during two years of designing, building, and operating a sensor network. The Greater Baltimore Open Air project was funded in part by the EPA SmartCity Challenge.

Presenting Author:
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Citizen Science and Government Collaborations: Developing Tools to Facilitate Community Air Monitoring

Community and Citizen Science Session #2

Recent availability of new, lower cost (less than $2,500) environmental monitors has increased the popularity of citizen environmental data collection, allowing community members to collect and analyze data and interpret results often as part of collaborative projects with professional scientists. Many of these projects solve complex real-world problems, identify research questions, make new discoveries, and conribute to development of new technologies and applications. However, citizen scientists and professional scientists alike face a high technical hurdle in projects involving air quality monitoring. EPA created the “Air Sensor Toolbox for Citizen Scientists”to help citizens collect, analyze, interpret, and communicate air quality data effectively. The Toolbox is an online resource for information and guidance on new, low-cost, compact technologies used for measuring air quality. The utility of the Toolbox resources was tested collaboratively by EPA’s Office of Research and Development, EPA Region 2, and community action groups in Newark, New Jersey and Ponce, Puerto Rico. In addition, a community sensor evaluation was conducted in collaboration with a community group (Clean Air Carolina in Charlotte, NC) and a tribal nation (Eastern Band of Cherokee Indians in Cherokee, NC.) Lessons learned and tools developed from these projects will be discussed in this presentation.

Presenting Author:
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The Vallejo Citizen Air Monitoring Network: Building Awareness and Strengthening Advocacy for Environmental Justice

Community and Citizen Science Session #3

The Vallejo Community Air Monitoring Network (VCAMN) arose from local air quality incidents and community health concerns. The community driven effort built academic partnerships, established working relationships with state and local officials, and created a crowd-sourced network of twenty monitors for fine particulate matter (PM 2.5) in Vallejo. VCAMN is unique as an entirely community driven project, but one that has also proactively sought input from researchers and regulators. It is also unique in the partnership of both residents and local government officials. This strengthens the opportunities to bring citizen science into management contexts. VCAMN is a source of information helping to build knowledge and empower community collaboration for action. This is a crucial role in South Vallejo, where the population is already more vulnerable to air pollution due to their compounded risk from social inequalities and social stressors. With 3.2 times the state average rate of emergency department visits for asthma, 25% of families living under the federal poverty level, and one of the most diverse cities in the nation, Vallejo has that much more to gain from creative strategies to reduce health and environmental disparities. The structure is in place for VCAMN to grow, and its history and evolution provides an important model to build on in the 2018 roll out of California Assembly Bill 617 to establish a new community-scale air monitoring system in 2019.

Presenting Author:
Trina Mackie
Touro University California
Additional Authors:

On the Ground Urban Citizen Science

Community and Citizen Science Session #3

New research shows that West Oakland, CA, a neighborhood surrounded by freeways and the Port of Oakland, suffers from far more than its fair share of toxic pollution. West Oakland Environmental Indicators Project, (WOEIP) a local environmental justice non-profit, has engaged in Citizen Science since 2003. We learned how data can force action with our truck counting project that helped reroute Port truck traffic away from neighborhood residents. We found shocking results when we used an Aethalometer to measure black carbon in two homes. The residents we studied are breathing diesel particulate matter (DPM) in the air that is roughly five times more concentrated than in other parts of Oakland. West Oakland residents have over five times greater risk of developing cancer from increased exposure to DPM than other Oakland residents. In 2008, Intel heard of our work and offered us assistance in using the TSI Dust Tracker. We trained residents, youth, and EJ groups to use TSI. In 2013, we received the White House Champion of Change Science award for our action-forcing citizen science. In 2016, the Environmental Defense Fund turned to WOEIP for our deep local knowledge to map air pollution block by block with Aclima sensor-equipped Street View Google cars. Resulting maps of West Oakland hots spots of black carbon and Nitrogen Oxides show a vivid picture of air pollution. In 2017, with UC Berkeley, we helped place 100 Air Sensors throughout West Oakland to measure black carbon.

Presenting Author:
Ms. Margaret Gordon
West Oakland Environmental Indicators Project
Additional Authors:

Community Air Monitoring Network and Low Cost Sensor Technology

Luis Olmedo, Comite Civico del Valley

In the rural border agricultural region of Imperial County, CCV brought together community and science to address concerns regarding poor air quality and high rates of asthma. CCV will describe the opportunities and lessons from establishing a community-owned network of forty (40) low-cost particulate matter (PM) sensors.

This presentation will provide an update on the development of a community-engaged project to design an Air Quality Monitoring Network (AQMN) using low-cost PM sensors and to develop strategies to use data from this network for public health action. The study location, Imperial County, CA, is a Latino and Spanish-speaking area, with some of the highest rates of asthma in the state. For decades, Imperial County has exceeded the California standard for particulate matter of 10µm or less (PM10). Awareness of air pollution trends in communities can lead to policies that will reduce exposures and improve population health.

With the assistance of CCV, CEHTP recruited fifteen (15) community advocates and concerned residents to serve on a Community Steering Committee (CSC) to guide project activities. The CSC identified eleven (11) priority vulnerable communities in Imperial County, from which we recruited over thirty (30) residents to participate in the project. We trained CSC members and community residents to identify, map, and collect data on candidate air monitoring sites, community hazards, and community assets using a simple, easy-to-use interface accessible via cell phone web browsers.

Monitor locations were selected through an iterative process of identifying neighborhoods of main concern, mapping of key hazards of concern using existing data, GIS analysis of land use variation in the county, on-the-ground scouting to assess site feasibility, and a site prioritization process carried out by the community participants. Following recruitment of sites to participate as air monitor hosts, we trained local community staff to deploy and operate the monitors. To date, we have deployed approximately forty (40) monitors in Imperial County.

Presenting Author:
Luis Olmedo

Additional Authors:

Using Sensors and Portable Monitors to Guild a Tribal Air Quality Program

Community and Citizen Science Session #3

The presentation will discuss how portable monitors and sensors use influenced the Confederated Tribes of the Colville Reservation air quality program development. In 2013 a combination of events caused high PM2.5 concentrations from multiple sources. A 3M Environmental Monitor proved useful in identifying contributing sources and areas of concern. Then in 2014 the Devil's Elbow wildfire sent smoke into a small community on the Reservation in very high concentrations for a month. An E-Sampler was deployed to better provide health messaging for the community and the data highlighted the potential severity of wildfire smoke. The next year, 2015 the entire population of the Reservation was severely impacted by smoke from multiple large fires. The program used a Met One Aerocet 831 sensor to document smoke concentration inside our government buildings across the Reservation. This resulted in the development of a sampling tool box and operating procedures to standardize measurement of smoke intrusion into buildings. The program recently deployed 10 PurpleAir sensors to document variations of concentrations in an area of concern and as a tool to enhance education and outreach efforts. The data and analysis of these efforts have led to a robust education and outreach effort, development of the Okanogan River Airshed Partnership and the concept of smoke ready communities.

Presenting Author:
Kris Ray
Confederated Tribes of the Colville Reservation
Additional Authors:

Storytelling and air monitoring: A day in the life of an environmental justice youth of color

Community and Citizen Science Session #3

The particulate air pollution in Los Angeles County does not impact all communities equally; communities of color are disproportionately burdened by poor air quality. In order to increase the capacity of local youth and environmental justice organization to use and leverage air quality data and low-cost sensors to protect public health, the USC Environmental Health Centers Use combined air monitoring devices and citizen science to support current advocacy work incorporating personal stories and art. Storytelling using a variety of media and air pollution monitoring using low cost sensors that display air pollution data in real time on a mobile phone app are two tools that are accessible and appealing to youth, many of who are continually seeking to express their individual stories as a collective to better communicate their daily experiences to others while using science to enhance the environmental justice and health aspect of their daily experiences.

25 youth participants from 3 different neighborhoods wore mobile PM2.5 monitors for a day in each of their respective communities documenting and mapping their exposure to PM2.5 during their daily routine including their school, job, and other community activities. Participants documented their days through taking photos and videos of what they see and experience during the course of their day

(pollution sources, parks, stores etc.). Results of the curriculum develop and monitoring projects will be shared.

Presenting Author:
Jill Johnston
University of Southern California
Additional Authors:

From the Ground Up: An Environmental Justice Approach to Community Science and Air Monitoring

Community and Citizen Science Session #3

This session will provide an overview of the community science efforts that the Central California Environmental Justice Network (CCEN) has undertaken in the community of Arvin, located in the Southern part of Kern County.

Central California Environmental Justice Network was formed in 2012 as a network of environmental justice organizations and leaders across California's Central Valley. Using the lens of environmental justice CCEJN has generated field experience with in the organization and with residents in community air monitoring. Over the last 3 years CCEJN has implemented a variety of citizen science projects with the aim of getting a better understanding of the local air quality in this disadvantaged community by collecting data from the various sources of emissions overburdening this community.

CCEJN's community air monitoring efforts in Arvin have grown through various phases and have involved a variety of air monitoring methods ranging from collection of bucket samples, to tours of oil & gas facilities using a FLIR camera, and the establishment of a robust network of monitors that can measure PM, VOCs, and Ozone that communicate information real-time in a public bilingual website.

The session will describe the journey that CCEJN has pioneered to become one of the only grassroots organization in the San Joaquin Valley to design and implement community air monitoring projects. We will share lessons learned and how other similar efforts could be implemented in other communities.

Presenting Author:
Gustavo Aguirre Jr
Central California Environmental Justice Network
Additional Authors:

Leveraging Citizen Science and the Internet of Things to create a statewide community monitoring network

Community and Citizen Science Session #3

Clean Air Carolina (CAC) was one of two organizations to partner with the EPA to assist in the development of Air Sensors Toolbox Colocation Guide and Macro Analysis Tool. EPA scientists conducted hands-on training in March 2017. CAC set up shelters to house the low-cost sensors, collected and recorded sensor data; and used the tools to compare results from the low-cost sensors to data from federal reference air monitors. As a part of its AirKeepers Program, CAC is expanding on this work to build a statewide monitoring network of low-cost sensors in North Carolina designed to serve both the gathering of scientifically-relevant particle pollution (PM2.5) data and connecting communities with information needed to protect their health and advocate for change. While NC has 100 counties, there are just 23 PM2.5 monitors reporting to the EPA's AirNow network. Yet PM2.5 can vary from one neighborhood to another and different levels of exposure over time have been shown to correlate with high degrees of disparity in mortality rates. CAC currently has low-cost sensors installed in 24 NC counties, and aims to have a sensor installed in all 100 counties by the end of 2018. The low-cost sensors present a data quality

challenge for citizen scientists and researchers, but the goals are to collect data to empower communities and individuals to advocate for the clean air they have or want, and to provide important input to scientific questions about air quality and health.

Presenting Author:
Calvin Cupini
Clean Air Carolina
Additional Authors:

Cleaner Air, Cleaner Communities: 6 Steps to Develop Environmentally Just State Implementation Plans

Community and Citizen Science Session #3

This presentation describes and introduces a guidance document, developed by the Environmental Justice Leadership Forum on Climate Change (EJLF) to provide state agencies, local governments and community-based organizations with a step-by-step process, tools and case studies to integrate environmental justice considerations into Clean Air Act State Implementation Plans (SIPs). The Clean Air Act requires that emissions such as nitrogen oxides, sulfur dioxide, carbon monoxide, ozone, lead and particulate matter must be reduced by heach state. The toolkit was informed by interviews with EJLF member organizations, and research on existing SIPs, environmental justice tools and best practices.

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WE ACT for Environmental Justice
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Data Analytics Session

Gaussian process regression models for dynamic low-cost particulate matter sensor calibration in a wireless sensor network in New Delhi

Data Analytics

Low-cost sensors can extend the spatial precision of a sensor network by decreasing the amount of pure interpolation between sensor locations. However, their calibration remains a challenge. The transferability of the pre-determined calibration by collocation with reference sensors before field deployment is questionable as calibration factors typically vary with operating conditions and aerosol properties, and the stability of low-cost sensors can develop drift or degrade over time. Routine recalibration which requires frequent transit of the deployed sensors between field and reference sensor locations is not only too labor intensive for a large-scale network, but also still cannot address the impact of urban heterogeneity of ambient conditions on calibration models. This study aims to improve the calibration strategies for relatively dense wireless sensor networks by exploring the feasibility of combining gaussian process models with multiple linear regression models (including true ambient PM2.5 and meteorological information) to calibrate low-cost PM sensors on-the-fly based on all available reference sensors around city without pre-deployment calibrations. This concurrent kriging and calibration strategy has substantial implications in reducing the amount of manual labor for the calibration of extensive wireless PM sensor networks, improving the spatial comprehensiveness of PM evaluation, and enhancing the accuracy of and extending the effective lifetime of the network.

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Duke University
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Machine learning and data analytics to calibrate sensors and map air quality in real-time with the RAMP network

Data Analytics

Low-cost sensors can increase the spatial and temporal resolution of air quality monitoring by an order of magnitude. The Real-time Affordable Multi-Pollutant (RAMP) monitor, developed by CMU and SenSevere, uses AlphaSense electrochemical sensors to measure CO, SO2, O3, and NO2; an optical nephelometer (Met-One/PurpleAir) to measure PM2.5; and an NDIR sensor for CO2.

A 50-RAMP network has been deployed in and near Pittsburgh, PA. Data collected four times per minute by each RAMP are transmitted over GSM every 7-8 minutes. QA checks are currently conducted manually every day using Python scripts, with plans to automatically conduct these checks in real-time.

Individual calibration models for each RAMP are developed using machine learning (ML) algorithms applied to data from collocations with regulatory-grade monitors. A hybrid of random forests and linear regression shows good results for most species. Neural network algorithms are better for SO2. PM data are corrected using an assumed aerosol composition and a hygroscopic growth model, and by collocation with regulatory monitors if available. Generalized RAMP calibration models can provide robust performance without significant loss of data quality if individual collocation datasets are not available.

Real-time maps currently show individual nodes and use simpler linear calibration models. Efforts are underway to implement the more accurate but complex ML-based calibration models in real-time and with spatial interpolation.

Presenting Author:
Subramanian Ramachandran
Carnegie Mellon University
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Realtime low cost sensor calibration using widely available resources: a proof of concept

Data Analytics

Current air monitoring frameworks are characterized by sparsely distributed equipment often placed in environments not entirely representative of concentrations of concern (e.g. where people spend time, near critical infrastructure, in sensitive ecosystems). In response to the need for denser monitoring networks, an active movement supporting low-cost air pollution sensing has emerged. In many cases, the same technical advances that keep such sensors' costs low also prevent them from producing direct readings with high precision and accuracy. Yet calibration of these sensors is infrequent and often improperly performed. As a result, low cost sensor data can be prone to major error and bias.

We provide a novel machine learning-powered framework to transform low-cost sensor output into reliable, actionable air quality data through the analysis of spatial and temporal patterns taken from widely available data (e.g. meteorology, traffic, industrial activity, regulatory monitoring, etc.) to produce nearly real-time sensor calibration. The framework can be applied to sensors that evaluate a variety of pollutants. Preliminary findings of a beta implementation of the framework in the San Francisco Bay Area using co-located low-cost particulate matter sensing devices and industry-standard reference monitors will be presented.

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Real Time Normalization of Small Sensor Data

Data Analytics

2018 marks a year where public air agencies begin to implement small air sensors, like the Purple Air 2, into their networks, moving them from the experimental phase to field deployment. However, many technical challenges remain for agencies in their implementation:

- Data connectivity: How do we get data from sensors into our regular data management systems?
- Data correction and normalization: how do we correct raw data and make it meaningful
- Data verification: how do we review the data and exclude data that is probably invalid.

Most importantly, how can we perform these functions in real-time, so as to provide timely health information?

This paper/presentation explores tools that are and could become available to collect, normalize, verify, and present data in real-time, growing beyond the current state of performing some or all of these functions manually and after-the-fact. Data from Purple Air 2 monitors in Iowa and California will be used as the examples of use of data normalization tools. The paper will also discuss potential methods for screening small sensor data to block reporting of spurious values, and methods of continuous data collection for other sensors without strong connectivity options.

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Sensor networks: data processing for better spatial and temporal resolution

Data Analytics

The U.S. EPA - state air quality monitoring network is essential for determining areas that are out of attainment of the National Ambient Air Quality Standards. EPA's AirNow provides air quality data with a latency of a couple of hours and forecasts. There is a growing need for sensing with lower latency and finer temporal and spatial resolution. We calibrated low cost sensors using satellite validation techniques. Before deployment we pre-calibrated sensors using reference instruments and applying machine learning (ML). Once deployed, we calibrated sensors using ML to estimate the error associated with each observation. In addition, we tracked real-time sensor drift and bias by comparing observation probability distribution functions (PDFs) between neighboring sensors. We used the observation PDFs to make real-time estimates of observation representativeness uncertainty. We leveraged an open data repository that includes real-time data from over 50 countries and networks at several scales. EPA plans to analyze the data using a cloud analytics environment that is in development to: a) support analyses with an Internet of Things platform and distributed compute capability; b) apply containerized analytical environments to support ML; c) evaluate methods for analyzing data from several types of sensors; and d) present methods and results. This approach allows for the utilization of observations from reference instruments and lower cost secondary and tertiary sensors.

Presenting Author:
David Lary
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Assessment of the Performance of NO and NO2 low cost sensors over extended time periods in a real world application

Data Analytics

We present a study on the medium term performance of measurement units consisting of electrochemical sensors for NO and NO2. In order to mimic a realistic application, the units were initially co-located at a rural regulatory air quality monitoring site in Switzerland located next to a major highway for a calibration period of four months. Based on these co-located measurements, three different calibration algorithms were applied (Multivariate Linear Regression, Support Vector Regression, and Random Forest). After calibration, the units were relocated and deployed at two distant air quality monitoring sites representing urban traffic and urban background situations. The aims of this study are the evaluation of the performance of different calibration algorithms and the investigation of the quality of sensor data over extended time periods in order to test procedures and strategies for the operation of low-cost sensors.

The sensors calibrated using Random Forest regression showed the best performance with respect to drift, uncertainty, bias and noise. An interesting potential field of application of sensors is the mapping of urban air pollution with high spatiotemporal resolution. We found that the tested sensors were capable to reliably detect concentration differences of about 5 â€“ 10 ppb for NO and 8 â€“ 10 ppb for NO2. The achieved accuracy appears not to be sufficient for resolving concentration differences in cleaner cities but might be adequate for more polluted urban environments.

Presenting Author:
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Development of a backend application to ingest, validate, analyze, and map data from a large PM sensor network

Data Analytics

The technological advances in low-cost aerosol and gas pollutant sensors have provided the opportunity to build networks of sensors to measure air pollutant concentrations with increased spatial and temporal resolution. In one year, a single air quality sensor can generate more than 2 million measurements, requiring time changes, time averaging, time matching, joining, validations, and calibrations. Environmental air quality projects quickly become a data science project requiring a new set of tools and skills to adequately store, process, and analyze the large volume of generated data. Establishing networks of sensors requires an investment in new infrastructures to handle the data load. The South Coast Air Quality Management District (SCAQMD) is poised to deploy over 500 low-cost sensors by end of 2018. To meet the needs of this oncoming data generation, the SCAQMD has started building a reliable and scalable cloud-based platform to ingest, persist, analyze, and visualize substantial quantities of air quality-monitoring data. We will present an approach to go from Internet-of-Things

(IoT) connected air quality sensors to an online data dashboard for public consumption along with some best practices for data ingestion, validation, data analysis, and mapping.

Presenting Author:
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South Coast AQMD
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Data Assimilation

Data Deluge: It's occurring, Now What? How to Make the Most of Air Sensor Data Using New Tools

Data Assimilation

Data from air sensors are on an ever-increasing path to overwhelm traditional data management systems. This data deluge, combined with growing types of sensor systems, other data sets, and uncertainty about data quality, is challenging the entire air quality community. This talk will outline these challenges of using sensor data and combining it with other data sets. The presentation will show interesting examples of how different organizations are benefiting from sensor data. I will also identify future challenges we will face when seeking to use this emerging data resource.

Presenting Author:
Tim Dye
TD Environmental Services
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Probabilistic Machine Learning for Air Quality Sensor Integration

Data Assimilation

Multiple sensor networks are deployed in cities across the world to measure air pollution and help produce hyper-local estimates. These heterogeneous networks are composed of varying fidelity sensors, with both fixed and mobile elements, different SnR and degradation profiles, that are even measuring different air pollutants across space-time. Hence, there is a great need for evidence integration and data assimilation models that can formally integrate the information available across such sensor networks. In this talk I will present and discuss statistical machine learning algorithms that can address these challenges while retaining the formal probabilistic foundations needed for uncertainty quantification.

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The AirCasting Platform: Communicating & Visualizing Air Quality Data

Data Assimilation

AirCasting is an open-source, end-to-end solution for collecting, displaying, and sharing health and environmental data using your smartphone. The platform consists of wearable sensors that detect changes in your environment and physiology, including a palm-sized air quality monitor called the AirBeam, the AirCasting Android app, the AirCasting website, and wearable LED accessories. By documenting and leveraging health and environmental data to inform personal decision-making and public policy, the AirCasting platform empowers citizen scientists and changemakers.

Presenting Author:
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Big Data for Air Quality: Sensors, Satellites, and Spatial Analysis, Oh My!

Data Assimilation

Low-cost air quality sensors (including stationary and mobile) can provide new information at the human scale. New satellites will provide higher resolution air quality measurements from space, than ever before. Data from these sensors and satellites, along with other geospatial information, can be assimilated in the cloud, and spatial analysis of this big data can be performed at scale for the entire globe. In this talk, Karin will describe how scientists are already starting to do this using data from many sources (including Google Street View cars) to produce neighborhood air pollution maps, and she'll show you how you can get started doing the same.

Presenting Author:
Karin Tuxen-Bettman
Google
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Resolving uncertainties in the urban air quality, climate, and vegetation nexus through citizen science, satellite imagery, and atmospheric modeling

Data Assimilation

Large uncertainties remain in identifying the distribution of urban air quality and temperature risks across neighborhood to regional scales. Nevertheless, many cities are actively expanding vegetation with an expectation to moderate both climate and air quality risks. We address these uncertainties through an integrated analysis of satellite data, atmospheric modeling, and in-situ environmental sensor networks maintained by citizen scientists. During the summer of 2017 we deployed neighborhood-scale networks of air temperature and ozone sensors through three campaigns across urbanized southern California. During each five-week campaign we deployed six sensor nodes that included an EPA federal equivalent method ozone sensor and a suite of meteorological sensors. Each node was further embedded in a network of 100 air temperature sensors that combined a randomized design developed by the research team and a design co-created by citizen scientists. Between 20 and 60 citizen scientists were recruited for each campaign, with local partners supporting outreach and training to ensure consistent deployment and data gathering. We observed substantial variation in both temperature and ozone concentrations at scales less than 4km, whole city, and the broader southern California region. At the whole city scale the average spatial variation with our ozone sensor network just for city of Long Beach was 26% of the mean, while corresponding variation in air temperature was only 7% of the mean. These findings contrast with atmospheric model estimates of variation at the regional scale of 11% and 1%. Our results show the magnitude of fine-scale variation underestimated by current models and may also suggest scaling functions that can connect neighborhood and regional variation in both ozone and temperature risks in southern California. By engaging citizen science with high quality sensors, satellite data, and real-time forecasting, our results help identify magnitudes of climate and air quality risk variation across scales and can guide individual decisions and urban policies surrounding vegetation to moderate these risks.

Presenting Author:
Jun Wang
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Data fusion techniques for mapping urban air quality using low-cost sensor networks

Data Assimilation

The technology of low-cost sensors for air pollution is developing rapidly. Many initiatives worldwide are deploying networks of such sensors. The observations provided by such sensors are improving, yet they are still often prone to high uncertainties, making a direct use of their data challenging. However, merging data from such networks with other data sources such as air quality models can add value to the observations and allows for detailed high-resolution mapping of urban air quality. We present a novel approach for combining observations from low-cost air quality sensors with model data, allowing near-real-time, high-resolution maps of urban air quality. The approach is based on geostatistical data fusion and combines observations with model data in a mathematically objective way, thus adding value to both the observations and the model. Using data from sensor networks deployed in the city of Oslo, Norway, we present the algorithm and examples of resulting urban air quality maps. We demonstrate that the method produces spatially realistic hourly concentration fields, and is able to reproduce typical diurnal cycles. We also show validation results indicating that the method is capable of reproducing the city-wide averaged official NO_2 concentration with R^2 values of around 0.9. Overall the technique is a robust way of extracting useful information from uncertain sensor data using a time-invariant model dataset and the knowledge contained within an entire sensor network.

Presenting Author:
Alena Bartoňová
NILU Norwegian Institute for Air Research

Data Communication

Integrating Communication of Data from Air Quality Monitors, Sensors, and Satellites

Data Communication

The public has access to air quality information from many different sources that have different qualities, including differences in spatial and temporal resolution. There is tremendous potential to help people recognize and reduce risk from air pollution, but only if the information is clear and understandable. It's a challenge that requires consideration of the characteristics and best uses of each dataset to create consistent, integrated communication.

Sensors have an important role in this array of information. EPA has developed behavioral sensor scale messages for real-time information that are useful in informing individual decisions. The messages are intended to be used with Air Quality Index (AQI) health advisories from ambient air monitoring network data.

Sometimes it is critical to help the public understand information from multiple data sets, such as during a smoke event. When there is a wildfire, communicating clearly using output from diverse sources such as air quality forecast models, satellites, ambient monitoring networks, sensors, and even visual range estimates can help people reduce their risk from smoke. This presentation will discuss ways to integrate information from these different data sources.

Presenting Author:
Susan Lyon Stone
US Environmental Protection Agency
Additional Authors:

Street-level air pollution data and advocacy in Oakland

Data Communication

Recent air monitoring efforts in Oakland, CA, including mobile mapping with Google Street View cars, have provided unprecedented insight into within-neighborhood air pollution variability. We will present these innovative results and discuss learnings from ongoing collaborative efforts to leverage the Oakland data to influence community, city, and state level efforts to address harmful air pollution. Our work has shown that community leaders with experiential understanding of local air pollution sources are key partners in interpreting hyperlocal pollution data and are also the most credible and effective communicators of data to fellow residents and advocates for local policy change. Findings must be communicated in clear and compelling terms, and “scientific interpreters”can help accurately represent findings in suitable language and formats. Finally, efforts to translate study results to action require long-term commitment and follow-through â€“ preliminary data and findings should be shared with community partners as early as possible and ongoing support and collaboration must continue long after research is completed. These elements: trust-based partnerships with local advocates, effective communication, and long-term engagement, require substantial investment of resources beyond those required to conduct traditional research, but are core to enabling translation of hyperlocal air pollution data to action.

Presenting Author:
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Environmental Defense Fund
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Air Quality Platform Problematics: Illuminating the Gap Between Design & Application

Data Communication

Proliferating, low-cost sensing technologies are transforming the politics of air quality monitoring in the United States by presenting opportunities for the collection of localized exposure data in real-time (Lewis and Edwards, 2016; Snyder et al, 2013). However, the quality of data emerging from these technological platforms precludes direct, comprehensive responses on the part of the U.S. government towards localized claims of poor air quality. This study examines how motivations behind the design and advertised applications for three air quality sensing platforms may be contributing to this issue. This study reveals prominent gaps between platform design and applications, mirrored in code, website content and representations of air quality facilitated by each of the platforms' reductive focus on one or more of the U.S National Ambient Air Quality Standard criteria pollutants. It also contributes to a prominent gap in the literature regarding the experiences and perspectives of platform â€˜architects.'

Presenting Author:
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Effectively communicating air quality to a largely apathetic general population

Data Communication

Among the many challenges with mitigating the impact of poor air quality is the general population's general apathy regarding the topic. IBM, through its Weather Channel and Weather Underground brands, has researched this problem and adjusted its products to bring this valuable information to people around the world. By approaching the problem through education and effective but simple consumer level visualizations we hope to improve overall public awareness.

At first glance visualizing and communicating such information seems reasonably straightforward but once cultural differences, competition for attention, and a general apathy regarding air quality the problem is considered it quickly becomes an interesting challenge. IBM has done consumer level user interaction research and is in the process of revising its approach as it releases new air quality features. Since both The Weather Channel and Weather Underground websites and mobile applications are used daily by tens of millions of people the opportunity to better engage the public is substantial.

In addition, IBM has been actively engaged in expanding its community driven Personal Weather Station (PWS) network to include air quality observations. The network is used extensively by both the public and businesses to gather hyper-local weather information.

IBM will present its latest findings and product visualizations on the topic.

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IBM/The Weather Company
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Sensing the need to communicate sensor data

Data Communication

South Coast Air Quality Management District's (SCAQMD) Air Quality Sensor Evaluation and Performance Center (AQ-SPEC) has been leading many efforts for the testing and deployment of sensors and sensor networks. As sensors become a more widespread source of air quality information, it becomes more important to ensure a common understanding of the data and its interpretation in the context of other air quality information such as air monitoring networks, different sensor networks, special studies, and satellite measurements.

SCAQMD is conducting work that integrates the different types of data and is collaborating to obtain input for how to provide the maximum usefulness and understanding as part of its work on engaging the community with low cost sensors. SCAQMD is moving forward on evaluations of different data platforms and visualization techniques to incorporate these complex and varying types of data assist stakeholder to make sense out of sensor (and other) air quality data.

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Community engagement in development of a community air monitoring network in Imperial County, California

Data Communication

Community members collaborated with researchers at every stage of development of a community air monitoring network to provide local data on air quality that can be used to protect community health. Data was visualized using an environmental health web platform developed by the community. Local schools and businesses facilitated monitor deployment, promoting local capacity for maintenance. Training on air monitoring established a common knowledge base. Selection of monitor sites and hosting of monitors by local residents promoted community ownership of the monitoring network. Community input determined priority data display needs.

Substantial engagement of and leadership by community members at every stage of planning and implementation of an air monitoring network enhanced responsiveness of research to community priorities; fostered community ownership of the project and built local capacity; ensured accessibility, usability and usefulness of data displayed; and promoted potential for network sustainability beyond the research period.

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Community Air Monitoring Data Portal

Data Communications

To fulfill statutory requirements of Assembly Bill (AB) 617 (Garcia, C., Chapter 136, Statutes of 2017), the California Air Resources Board (CARB) is developing a dynamic Community Air Monitoring Data (CAMD) portal to allow public access to data and visualization tools to improve communication and information sharing with communities. The community air monitoring data will demonstrate the nature and scope of air quality within the most impacted communities, provide more insight into the effectiveness of air quality programs, better inform the particular strategies that CARB, air districts, and communities employ to reduce emissions and their impacts within the community, and track progress over time. CARB's goal is to make the community air monitoring data available in a timely and transparent manner through a flexible portal that ingests a variety of data (various pollutants, meteorological data, and metadata), from various platforms (sensors, regulatory grade monitors, mobile monitoring, fenceline monitoring, remote sensing, etc.), with different time resolutions. The CAMD portal will satisfy the needs of a wide range of users (general public, community organizations, air districts, researchers, etc.) by making the real-time and historical data accessible, meaningful, and interpretable, through dynamic features including apps, maps, plots, tables, and data download capabilities.

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California Air Resources Board
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Engaging Community to Design Data Communication for the Ysidro Air Quality Study

Data Communications

Casa Familiar and its collaborators operate a community air monitoring network in the US-Mexico border community of San Ysidro, CA. This network consists of 13 research-grade monitors that were sited with input from a Community Steering Committee (CSC) made up of residents. The monitors collect real-time data on PM2.5, CO, NO, NO2, O3, temperature and relative humidity levels. Community members and researchers interfaced throughout all aspects of this project, including (1) Needs assessment, (2) Education on air quality and health, (3) Monitor siting, (4) Monitor colocation, calibration, and data quality assurance, (5) Data access and visualization, (6) Data interpretation and community action planning, and (7) Evaluation. Data and information from the monitoring network is available via (www.syairstudy.org), which was designed collaboratively, using open source software, in both English and Spanish. The data undergoes an automated QA/QC inspection that flags and filters out suspect data. In developing the website, discussion with CSC included appropriate color scales for the pollutants, understanding concentration measures, selecting the time averaging meaningful to the community and developing bilingual descriptions of pollutants and associated health effects. We present strategies used in the San Ysidro project, the most successful elements and upcoming ideas to increase community environmental health literacy through effective data return strategies.

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Data Sharing & Harmonization

From Air Quality Monitoring Silos to System of Systems - Best Practices based on OGC SensorThings API

Data Sharing & Harmonization

In the near future, millions to billions of small sensors and actuators will be embedded in real-world objects and connected to the Internet forming the Internet of Things (IoT). The basic premise of the IoT is that everyday objects or devices can sense their environment, collect information, and communicate and interact with each other. For example, progressive cities around the world are using IoT to monitoring hyper-local air quality, and changing how we live, work, and play. However one of the biggest challenges in IoT and smart cities is the lacking of interoperability, i.e., each monitoring system is an information silo using different data models, semantics, encodings and API interfaces. These air quality data silos create unnecessary technical, financial, and maintenance challenges. There is a urgent need for a implementation-agnostic and interoperable IoT data model and API standard that is scalable, extensible, efficient and future proof, so that air quality data silos can be aggregated instantly and seamlessly into an inter-connected system of systems.

In this talk, Dr. Liang will present the OGC SensorThings API, an OGC standard designed specifically for IoT data and API interoperability. In particular, Dr. Liang will present the real-world use cases of using the OGC SensorThings API to build air quality monitoring system of systems

Presenting Author:
Steven Liang

AirSensEUR: An open sensor box for air quality monitoring

Data Sharing & Harmonization

AirSensEUR is a low-costs gas sensors box for the fixed and mobile monitoring of air pollution. AirSenSEUR aims at developing tools to meet the Data Quality Objective of indicative measurements set in the European Air Quality Directive, 25 to 50 % of measurements uncertainty for O3, NO2, CO and PM10, in the best cases . It has been developed by the European Commission -Joint Research Centre and LiberaIntentio, an Italian SME specialized in IoT. The dedign of AirSensEUR is made freely available through the use of public licenses. AirSensEUR can act as a node within a network of multi sensors, complying with the INSPIRE Directive (Infrastructure for Spatial Information in the European Community), ensuring interoperability and web access to the observation data.

AirSensEUR includes a few sensor shield connected through a sensor bus to the AirSensEUR cpu host board and web applications. The shields are designed to accommodate electrochemical sensors of many commercial brands, temperature/humidity/pressure sensor, PM sensor and MOx sensor. Details of AirSensEUR electronic and operability are given in part A and Part B of the AirSensEUR tecnical report series [1,2]. The host is based on a low cost Arietta G25 Linux module (acme.it). It collects sensor and GPS data into a local sqlite3 database that is periodically pushed to a PostgreSQL database via GPRS or Wi-Fi according to an influx database or a standard-based transactional Sensor Observation Service (SOS-T). The latter makes it easy to query data through a web-based AirSensEUR Client and to perform sensor data treatment typically under the “R”language [3,4]. Another way of consuming data from the platform is through the SenseEurAir app developed within the MyGEOSS project (http://digitalearthlab.jrc.ec.europa.eu/mygeoss/). The app is available for both Android and iOS and ensures easy access to air quality observations, mash-up with official station data and alerts when limit values from the Air Quality Directive are reached. AirSensEUR is being updated to develop calibration methods.

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Kotsev A., et al., Next Generation Air Quality Platform: Openness and Interoperability for the Internet of Things. Sensors, 2016, http://dx.doi.org/10.3390/s16030403

Kotsev et al., AirSensEUR: an open data/software /hardware multi-sensor platform for air quality monitoring. Part C: INSPIRE and Interoperable Data Management. (2017), ISBN: 978-92-79-77049-4, ISSN: 1831-9424, DOI: 10.2760/93699, EUR 28928 EN.

Building a Principled Interoperable Data System for Air Sensors

Data Sharing & Harmonization

Since the dawn of computerized data systems, developers have struggled to create a scientific infrastructure that would let the system's data gracefully interoperate internally and with data created by other systems or software. Half of the sessions in this Conference directly or indirectly deal with the challenges of working with air sensors data and metadata in interoperable ways.

Fortunately, emerging data systems, data standards and vocabularies, and data analysis tools have increased our ability to build an interoperable data system, even one that integrates many diverse sources, including from commercial deployments, research installations, and individual citizen and community science observing systems. How can these data sources be leveraged to maximize data harmonization and data sharing?

A key facet to address is semantic interoperability. How can we take the many different variables from many different data sources and harmonize them systematically, so that the data they describe can be processed and discovered systematically? We will make several specific suggestions on tools, vocabularies, and strategies to harmonize diverse data sets into a more usable collection.

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Standards-based Tools for Creating and Managing Metadata for EnviroSensing Data

Data Sharing & Harmonization

A recent pilot project called X-DOMES (Cross-Domain Observational Metadata for EnviroSensing) developed and demonstrated tools needed to create and maintain standards-based descriptions of sensing technologies. It was funded by NSF as an EarthCube Integrative Activity to promote syntactic and semantic interoperability in capturing metadata about sensor data.   The model is based upon the community-adopted standards of the Open-Geospatial Consortium Sensor Web Enablement (OGC SWE) framework and the World Wide Web Consortium (W3C Semantic Web).   The goal of the project was to enable stakeholders to sufficiently describe sensors to enable data quality assessment.   The project defines a model that enables a sensor manufacturer to describe a sensor model, with its capabilities and characteristics, and then also create a document that creates a unique ID that further defines the instrument, as built. The as-built document references the model document and thereby inherits all the broad characteristics and capabilities defined for each sensor model. The web-accessible content can be harvested by data managers and associates observations with sensing technologies thereby enabling automated quality control. It can also be used by operations teams to manage sensor resources for large programs. Syntactic and semantic technologies are integrated to enable development of relationships outside of how a program or domain names its resource. Therefore, if a parameter is called seawater temperature or ocean temperature, it can be discovered and treated within a broader ontology. The model leads to discoverable, accessible, interoperable and re-useable data.

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Advancing the Application of Low-cost Sensors with Voluntary Consensus Standards

Data Sharing & Harmonization

Electricity distribution, telecommunications, agriculture, medicine, computing, and the Internet all exist in their current form because there are voluntary consensus standards (VCS) that define procedures, communication, interoperability, data exchange, and quality. The American National Standards Institute (ANSI) coordinates and promotes VCS and serves as the U.S. representative in non-treaty international and regional standards-setting activities. VCS are published by Standard Setting Organizations (SSOs) and SSOs exist for virtually every aspect of commerce. For example ASTM and IEEE are SSOs that are well-known the environmental monitoring community.

Although there is overwhelming interest in the use of low-cost sensors to address the full range of environmental areas, VCS for evaluating, deploying, and reporting low-cost sensor data are limited, typically drawing on elements of VCS for conventional monitoring systems. Like the technologies mentioned earlier, low-cost environmental sensors will achieve their full potential when VCS specific to low-cost sensors are available that address sensor evaluation and validation; deployment and siting, data assimilation, integration, and exchange; and reporting.

This presentation will review VCS that are being used in air sensor programs, examine how VCS are being used in conventional air monitoring programs, and outline the process for developing VCS.

Presenting Author:
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TRC
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Sensor technology in the All of Us Research Program

Data Sharing & Harmonization

The Precision Medicine Initiative's All of Us Research Program is longitudinal observational study of over 1 million Americans lasting at least 10 years. This program aims to better understand the factors that contribute to health, wellbeing, and disease using a combination of biospecimen collection, genomics, electronic health records, survey data, and digital health technologies (DHTs) like smartphones and wearable devices.

Some DHTs use sensors that are already built into computers and smartphones, such as the touch screen, microphone, camera, or motion sensors. Other DHTs employ wearable sensors like wristbands and standalone devices that measure sleep quality, heart rate, or respiration. As these technologies continue to evolve, they will be able to monitor many more factors that influence health and wellbeing.

Environmental factors are among the primary potential contributors to disease that the All of Us Research Program seeks to understand. In particular, air quality sensing is a key opportunity to integrate within this distributed research study architecture. In order to realize this unique opportunity, key questions remain as to the principal data types to be collected, the optimal technology for data capture, and the standards around data harmonization and data sharing.

Through an integrated analysis of the differences in our population of genetics, lifestyle, and environmental factors, the All of Us Research Program aims to accelerate biomedical research and improve health.

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Air Quality Data Commons, an open source, open access platform for air quality data

Data Sharing & Harmonization

Low-cost & medium-cost air quality sensors are growing in popularity and usage. These sensors can be of great value and facilitate high resolution data collection by a variety of users. However, since this is a relatively new space, the trust on the quality of data generated by these sensors and the senor reliability are under scrutiny. In order to enable easier data exchange across various air quality sensors, the Air Sensor Workgroup (ASW) has been developing data standards. Besides, to provide for users to assess data quality and perform data analysis, the ASW has been developing a data platform called Air Quality Data Commons (AQDC). The ASW is a broad-based group representing all domains of organizations and companies interested in air pollution monitoring. The AQDC will be the centralized data repository built using data management best practices. It will democratize air quality data and help advanced users like researchers and also citizen scientists. To begin with, the AQDC will host PM, UFP, CO, CO2, NO, NO2, Ozone, Methane and Black Carbon data along with relevant metadata. As a cloud based platform, it will offer tools and services to optimize data access, analytics and visualization for the users.

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Emerging Technologies

Development and Validation of a Baseline Correction Method for Long-Term Unattended Field Deployment of Electrochemical Sensors

Emerging Technologies

Recent low-cost electrochemical sensors have shown great potentials in grid/community air quality monitoring, smart city development and citizen science applications etc. Although various algorithms have been developed to correct for the impact of meteorological conditions on sensor responses, the sensor drift issues along with long term deployment remains a challenge in the field. Our group has developed an auto-zero system for determining NO2 electrochemical sensor drift in stable environmental conditions, which includes a chemical scrubber in the gas path set to regularly check sensor zero signal output with NO2 free air. To further expand the application of the auto-zero function in variable ambient conditions for long term deployment, we developed and deployed multiple systems in different Chinese cities of Shanghai (2 units), Xi'an (8 units) and Hong Kong SAR (2 units) with a wide coverage of concentration, temperature and humidity combinations. The sensor units in Shanghai were installed co-located with reference research grade monitors on a tethered balloon undergoing complex and rapid temperature/humidity changes during elevation and declination, while other units were deployed in multiple month field campaigns with intermittent side by side reference research grade monitor measurements for sensor data evaluation. A virtual baseline method was developed integrating the continuous zero sensor responses to dynamically correct for the impact of temperature and humidity on the baseline of the sensor response. Data from multiple locations in different campaigns were cross checked and validated on the feasibility of using the virtual baseline to correct for the impact of the temperature and humidity. By adding the correction of virtual baseline to the calibration method, the accuracy of the sensor unit can be improved on board which favors its long-term deployment.

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A new low-cost, electrical-mobility based aerosol sensor for wide size range measurements

Emerging Technologies

The recent availability of low-cost sensors has allowed aerosol scientists to make large-scale field measurements that was not possible before. Most of these low-cost sensors, however, measure particle concentrations based on the same principle of optical scattering. These sensors are, therefore, often insensitive to particles smaller than ~ 300 to 500 nm and their measurements are strongly dependent on the composition and shape of the sampled aerosol particles. Often, a significant fraction of airborne particles present are smaller than 300 nm, and their detection is critical for accurate characterization of ambient aerosol. In this presentation, we will describe a new sensor called the Miniature Electrical Mobility Spectrometer (MEAS) that separates particles based on electrical-mobility and then measures the abundance of particles based on the electric current carried by them. Using a combination of a compact corona charger and a low-cost electrometer, the MEAS can measure particle concentrations over a broad detection size range of 10 nm to 2.5 Âµm. We will describe the design and development of the new sensor and its performance in the lab and the field.

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Atmospheric Monitoring in 2020

Emerging Technologies

Scepter, Inc. is an early stage enterprise founded in late 2015, providing next generation Earth observation capabilities in atmospherics monitoring. The Company's mission is to observe, analyze, and report key atmospherics including greenhouse gases such as CO_2 and methane, as well as a range of 20 other air pollution components of commercial, community and government interest.

Scepter's patented approach to atmospheric monitoring integrates existing, terrestrial sensor networks, aerial sensors, and drone-based sensors with its own space-based sensors to provide a unique 3D view of the atmosphere, a perspective not being provided by any other Earth-observing program today. Scepter's approach is planned in two phases. Initially Scepter will take a consultative approach, focused on terrestrial and aerial monitoring techniques, combining such data with existing atmospherics data sets to generate actionable information. In the second phase, Scepter's proprietary Low Earth Orbit constellation of up to 24 satellites will capture high-resolution air pollution and greenhouse gases data globally and in real-time. These two attributes open new products and services to be sold in commercial and government markets. Scepter is also well positioned to utilize blockchain-based data management infrastructures to ensure that such data is immutable and verifiable. The Company creates additional value by applying proprietary analytics to its large earth-observing data sets in combination with relevant health effects information, weather data, and other data to create information-rich commercial services.

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U.S. EPA Wildland Fire Sensor Challenge: Submission Evaluation Results and Winner(s)

Emerging Technologies

Wildland fires can emit substantial amounts of air pollution that may pose a risk to those in close proximity (e.g., first responders, nearby residents) as well as downwind populations. Quickly deploying air pollution measurement capabilities in response to incidents has been limited to date by the cost, complexity of implementation, and measurement accuracy. Emerging technologies including miniaturized direct-reading sensors, compact microprocessors, and wireless data communications provide new opportunities to detect air pollution in real time. EPA partnered with NOAA; USFS; NASA; CDC; NPS; and Tall Timbers Research Station to sponsor the Wildland Fire Sensor Challenge. EPA and partnering organizations share the desire to advance wildland fire air measurement technology to be easier to deploy, suitable to use for high concentration events, durable to withstand difficult field conditions, with the ability to report high time resolution data continuously and wirelessly. The Wildland Fire Sensor Challenge encouraged innovation worldwide to develop sensor prototypes capable of measuring PM2.5, CO, CO2, and O3 during wildfire episodes, with one or multiple awardees to be determined based upon performance testing. Ten solvers from four countries submitted sensor pods for evaluation as part of the challenge. The sensor evaluation results including sensor accuracy, precision, linearity, and operability will be presented and discussed; and the challenge winner(s) will be announced.

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Using Satellite Data for Health and Air Quality Applications

Emerging Technologies

Satellite data are growing in importance for health and air quality applications in the U.S. and around the world. From their “Gods-eye”view, satellites provide a level of spatial coverage unobtainable by surface monitoring networks. Satellite observations of various pollutants, such as nitrogen dioxide and sulfur dioxide, vividly demonstrate the steady improvement of air quality in the U.S. over the last several decades thanks to environmental regulations, such as the Clean Air Act. However, while better, U.S. air quality is still not at healthy levels and there are occasionally extreme events (e.g., wildfires) that expose Americans to high levels of pollution. Satellite data also show that air quality in many parts of the world is rapidly degrading, and is likely to continue to do so as the global population is expected to increase by 2 billion by 2050. In this presentation, I will discuss the strengths and limitations of current satellite data for health and air quality applications as well as the potential upcoming satellites offer. I will present examples of successful uses of satellite data, discuss potential uses, and highlight ongoing challenges (e.g., data processing and visualization) for satellite data end users.

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Kevin Cromar

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Wireless Distributed Environmental Sensor Networks for Air Pollution Measurement'The Promise and the Current Reality

Emerging Technologies

The evaluation of the effects of air pollution on public health and human-wellbeing requires reliable data. Standard air quality monitoring stations provide accurate measurements of airborne pollutant levels, but, due to their sparse distribution, they cannot capture accurately the spatial variability of air pollutant concentrations within cities. Dedicated in-depth field campaigns have dense spatial coverage of the measurements but are held for relatively short time periods. Hence, their representativeness is limited. Moreover, the oftentimes integrated measurements represent time-averaged records. Recent advances in communication and sensor technologies enable the deployment of dense grids of Wireless Distributed Environmental Sensor Networks for air quality monitoring, yet their capability to capture urban-scale spatiotemporal pollutant patterns has not been thoroughly examined to date. Here, we summarize our studies on the practicalities of using data streams from sensor nodes for air quality measurement and the required methods to tune the results to different stakeholders and applications. We summarize the results from eight cities across Europe, five sensor technologies -, three stationary (with one tested also while moving) and two personal sensor platforms, and eight ambient pollutants. Overall, few sensors showed an exceptional and consistent performance, which can shed light on the fine spatiotemporal urban variability of pollutant concentrations. Stationary sensor nodes were more reliable than personal nodes. In general, the sensor measurements tend to suffer from the interference of various environmental factors and require frequent calibrations. This calls for the development of suitable field calibration procedures, and several such in situ field calibrations are presented.

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<u>Exposure & Health</u>

An mHealth Platform for Predicting Risk of Pediatric Asthma Exacerbation Using Personal Sensor Monitoring Systems: The Los Angeles PRISMS Center

Exposure & Health

Pediatric asthma is a complex and heterogeneous chronic disease that affects millions worldwide and results in significant morbidity and mortality. Studies have shown environmental exposures such as air pollution to be associated with risk of asthma attacks, but little is known about the time lag between exposure and response, the role of multiple exposures in context, and variation in personal risk at short temporal and fine spatial scales.

As part of the Los Angeles PRISMS Center, the LA PRISMS Breathe (Biomedical Real-Time Health Evaluation) Kit is being developed as a non-invasive, secure end-to-end informatics platform that utilizes the latest in mHealth technologies to advance environmental health studies of pediatric asthma. The platform is based on a smartwatch/smartphone that securely and wirelessly communicates with a suite of personal environmental, physiological and health sensors in real time and collects self-report symptoms data and contextual information using Ecological Momentary Assessment methods. External environmental data such as meteorology, traffic and air quality is also collected based on time and location of the participant. Data is integrated and analyzed to build individualized exposure and asthma exacerbation prediction models and the information is fed back to asthmatics, caretakers and physicians to improve asthma management.

This talk will present key components of the Breathe Kit and its deployment in environmental health research studies, including participant engagement, compliance and burden considerations. Data from preliminary pilot testing in a panel study of children with asthma recruited from the UCLA Pediatric Pulmonology clinic will be presented.

The ultimate goal of the LA PRISMS Breathe Kit is to be able to predict a looming asthma attack in an individual so that early intervention methods can mitigate if not prevent the episode entirely.

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Air Quality Monitoring and Emissions Reduction at the Community Level in California: A New Paradigm

Exposure & Health

In response to concerns expressed by groups advocating for environmental justice about toxic emissions from local sources that might occur as a result of allowance trading under California's cape-and-trade program, the state legislature passed Assembly Bill 617 (AB617). This bill mandates the California Air Resources Board (CARB) to develop guidelines for community air quality monitoring and requires local air districts to work with communities identified by CARB as having high cumulative exposure burden to develop plans for community air quality monitoring to determine local "hot spots."The bill also requires the air districts to work with communities to develop emission reductions programs for the identified local hot spots. CARB must review the community emission reduction programs and provide grants to community-based organizations to assist their participation in the programs. Best available retrofit control technology must be used if the district is in non-attainment for one or more pollutants. Stationary sources are required to report their annual emissions of criteria air pollutants and toxic air contaminants to CARB. AB617 represents a paradigm shift from a reliance on regional air quality monitoring and control strategies to an impacted community-focused approach.

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Personal Exposure to Particles and Gaseous Pollutants

Exposure & Health

Historically, personal exposures to airborne pollutants have been estimated using pollutant concentration data derived from ambient air monitors. However, such estimates fail to properly account for the time that people spend in different microenvironments. Consequently, this approach often fails to properly quantify exposures that occur indoors, where some of the highest pollutant concentrations occur and were people spend most of their time. With the availability of accurate and sensitive portable air quality sensors, it has become possible to determine â€“ with high temporal and spatial resolution â€“ an individual’s personal exposure profile. We conducted a pilot study to examine personal exposures to fine (PM 2.5) and ultrafine particulate matter (UFP) for 15 participants in six microenvironments over a 24 hour period. Exposures to the gaseous pollutants, nitrogen dioxide and carbon monoxide, were also examined. Near real-time pollutant concentration data were collected using a sampling backpack outfitted with lightweight, portable air quality sensors. We observed that for all pollutants, the majority of exposures occurred in the indoor environment and ranged from 75 to 84 percent of participants’ total daily exposure. Personal exposures to PM 2.5 and UFP were strongly influenced by proximity to sources. The highest mean particle number counts occurred in proximity to combustion cooking sources and in the transit microenvironment.

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The Influence of Personal Behaviors on Personal Air Pollution Exposures and Acute Health Effects

Exposure & Health

In recent years, the purposes for routine air monitoring have evolved from regulatory and air quality planning to improving community and individual knowledge of exposures. Our group’s involvement in helping establish community-based air quality networks along two US-Mexico border communities has demonstrated benefits for improving exposure assessments in regions that have lacked spatial resolution of regulatory air monitoring. Yet, these networks remain fundamentally flawed in their ability to estimate true personal exposures. Experience with personal exposure monitoring has demonstrated the importance of time-activity patterns and behavioral choices, such as time spent and activities indoors, mobility choices (e.g., active vs non-active modes and routes), as well as regional and seasonal events (e.g., wildfires), which can all dramatically impact exposures, and in some cases, physiologic responses. Personal exposure variations may be particularly important for those susceptible to acute air pollution health effects.

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Development of wearable environmental and physiological sensors

Exposure & Health

To better assess the impact of environmental exposures on human health, it is crucial to develop practical, user-friendly, personal sensors to assess both environmental, health and physiological endpoints. Our multidisciplinary team of engineers and environmental health researchers has developed a series of wearable prototypes to assess ambient temperature, relative humidity, ozone concentration and PM concentration. We have also developed accelerometers that allow for a surrogate measure of minute ventilation (to allow for better estimation of inhaled pollutant dose), a handheld spirometer, and sensors to estimate personal energy expenditure, respiratory rate and respiratory pattern, heart rate blood pressure and body temperature. A major aspect of these program is to develop sensors which are much more energy efficient, allowing ultimately for very low and self-powered sensors to be developed, minimizing service interruption. These devices are all configured to interface with a smart phone, which can directly be used in data analysis as well as transmission to a central monitoring service. Personal data can also be augmented by data from traditional monitoring stations to facilitate personalized prophylactic data assessment of adverse health outcomes due to environmental stressors.

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Temporal and spatial variation in personal air pollution exposures in New York City bicycle commuters: evidence from the Biking and Breathing study

Exposure & Health

Spatially and temporally resolved air pollution data combined with physiological data from personal monitoring offer novel insights into where and when urban residents breath dirty air, and can change both individual behavior and urban planning policy. Drawing on a novel high resolution dataset collected by volunteer bicycle commuters in New York City, we quantify spatial and temporal heterogeneity in air pollution dose, and relate these to cardiovascular risk factors (blood pressure (BP) and heart rate variability (HRV)). Personal black carbon (BC) and PM2.5 monitors were used to assess concentrations over multiple days. Minute ventilation, HRV and BP were assessed using a biometric shirt and an ambulatory BP monitor. We find that cycling in NYC strongly influences daily potential inhaled dose, that BC and to a lesser extent PM2.5 vary considerably over space and time, that truck routes affect exposure, and that cycling-related air pollution exposure increases BP and decreases HRV relative to a pre-ride baseline. Based on these results, we assess the potential health benefits from changes in

individual behavior and from redesigning cycling infrastructure. To provide cyclists with current estimates of route-specific exposures, we have developed a real-time air quality model with high spatial resolution that draws on a seasonal land use regression model based New York City Community Air Survey data and adjusted by hourly temporal variation provided from AirNow PM2.5 levels.

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Field Experience

Sensor based Wireless Air Quality Monitoring Network - A Smart Tool for Urban Air Quality Management: A Case Study of Highly Urbanized Megacity, Delhi, India

Field Experience

High emission of pollutants from numerous heterogeneous sources is major hurdle for robust assessment of air pollution which ultimately results in failure of any air quality management plan (AQMP). The design of any AQM network, basically provides data to community in a timely manner, support compliance with air quality standards and supports research studies. To capture the exposure of air pollution, a high spatial resolution real-time low-cost sensor based air AQM network can be an effective and efficient approach for developing an AQMP.

In view of this, CSIR-NEERI has developed a solar powered continuous AQM network using ten optical and electrochemical sensors to monitor real time particulate and gaseous pollutant concentrations such as PM2.5, PM10, CO, NO, NO2, ambient Noise, Temp., Humidity in a highly urbanized megacity, Delhi, the capital of India. The sensors are spread throughout city covering different land use. The real time data is directly fetched to the server hosted at CSIR-NEERI, Nagpur.

Further, one of the sensor is compared with Aerosol Dust Monitor (ADM) for hourly average PM10 and PM2.5 concentrations and found more or less similar trend with correlation coefficient (r2) value of 0.63 and 0.80, respectively. Hourly average concentrations of PM10 and PM2.5 are 432 and 228 Âµg/m3 by ADM, whereas sensor recorded corresponding values of 328Âµg/m3 and 207 Âµg/m3, respectively. However, sensor monitored slightly lower values compared to aerosol dust monitors for both the pollutants.

The paper presents usefulness of calibrated sensor based network for assessing need as well as evaluating effectiveness of air quality management plans in an urban area

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Application of PM2.5 Low-cost-sensors to Assess Community Sources

Field Experience

Asian residential communities are dotted with various PM2.5 sources, such as restaurants and home factories, resulting in higher intra-urban variability than western communities. It is important to quantify the contribution of community sources which results in direct exposures of residents. The objectives of this study are to evaluate the applicability of low-cost PM2.5 sensors in the field and to quantify PM2.5 contributions from those sources.

AS-LUNG-outdoor (AS-LUNG(O)), a PM2.5 sensor device with a solar panel and water-proof housing, was used for this work. Wireless transmission plus SD-card is available to avoid data loss. Ten AS-LUNG(O) devices were placed at 2.5 meters above ground in Taiwanese communities to assess source contribution and one AS-LUNG(O) at 10 meters above ground to assess ambient levels (high-level site) on July 1-28 and December 1-31, 2017, with 1-min resolution. In addition, sensor devices were evaluated against GRIMM in the laboratory and fields; the measurements were converted accordingly.

The mean PM2.5 levels in near-by EPA stations were 16.3Â±8.9 and 40.7Â±17.5Âµg/m3 for July 1-28 and December 1-31, respectively. Data of AS-LUNG(O) had R2 of 0.81-0.99 with those from EPA stations, showing high consistence of AS-LUNG(O) observations. The monthly mean ratios of community observations over those at the high-level site ranged from 1.05-1.29 and 1.08-1.63 in July and December, respectively. Moreover, the highest 1-min level at a site near vendors and traffic was 100 times of that at the high-level site, with 5-min average 35 times higher than that at the high-level site. Our results showed the applicability of PM2.5 micro-sensors in summer/winter and significant contribution from community PM2.5 sources.

Keywords: AS-LUNG, low cost sensor, PM2.5, exposure assessment

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Navigating the Brave New World of Low-Cost Air Quality Sensing

Field Experience

Remarkable progress in sensor technologies over the last two decades has opened the door to a wide range of new applications based on air quality measurements. This has in turn led to the emergence of a very dynamic and arguably volatile market of integrated air quality monitoring solutions based on low-cost sensors. In the absence of norms and performance standards, the large array of commercially available devices can lead to confusion even in the ranks of expert users, when faced with the choice of an appropriate measurement platform for a particular application, or the evaluation of its actual operational costs.

In this presentation we share Airparif’s perspectives on the topic of air quality sensor use in the Paris region. To this end, we draw from an extensive expertise accumulated in the evaluation of low-cost air quality monitoring devices both in laboratory settings and in real-world conditions, for different target applications.

Furthermore, we discuss our experience in supporting local communities or educational bodies interested in the use of low-cost air quality monitors for educational purposes, or for providing local measurements to their constituencies.

Finally, we present one of our more recent initiatives â€“ AirLab â€“ through which we promote an open innovation model and coordinate an ecosystem for facilitating collaborations between actors from diverse backgrounds holding a stake in the topic of air quality, with the goal of boosting its improvement.

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Validation of our lived experiences through field experience

Field Experience

Often times, marginalized communities are left behind in technical conversations and programs due to the very few number of college graduates, let alone, high school graduates. It usually is, however, marginalized communities that hold a lot of the knowledge and have the solutions to environmental justice issues. We are the experts in our own communities because we are the first impacted. In the Little Village neighborhood on the south west side of Chicago, there are an increasingly large number of residents who have some sort of respiratory illness. Through an EPA funded project, Little Village and three other communities in Chicago were able to conduct air monitoring using low-cost sensors. Low-cost sensors allow our communities to have access to meaningful data collection, empowers community residents to become community scientists, and really have ownership of their lived experiences and translating them into presentable data. Giving marginalized communities the opportunity to monitor their own air quality gives them access to things that are often out of reach. Lack of adequate resources in STEM programs, for example, leaves community youth with little chances of interacting with technological advances that in meaningful and engaging to them. The focus of this presentation will revolve around the kinds of skills ordinary people acquired through field experience and their motivation to mobilize and be involved in environmental justice campaigns.

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Distributed air quality monitoring near a major point source: Measurements of volcanic air pollution on the Island of Hawaii using low-cost sensors

Field Experience

We describe a planned network of air quality sensors on theÂ Island of Hawaiâ€˜i to measure levels of volcanic air pollution from KÄ«lauea, the world's most active volcano and the single largest point source of sulfur dioxide in the United States. Volcanic air pollution ("vogâ€, composed of primarily of sulfur dioxide and particulate matter) is a significant local public health concern, and exposure levels have been linked to negative health effects. However, because emissions are tightly concentrated within a plume, vog levels can be highly variable in both space and time. The planned sensor network, consisting of 50-60 sensor nodes (each with an electrochemical sensor to measure SO2, an optical particle counter to measure particulate matter, and additional sensors to monitor meteorology) will thus serve as a resource for both community members and researchers, enabling a better understanding pollutant concentrations and exposures. Moreover, the Hawaiâ€˜i location serves as an ideal testbed for the use of air-quality sensor networks near pollution point sources, allowing for the exploration of how sensors can provide information on the transport and transformation of pollutants. Here we)i) describe our ongoing evaluation and calibration of low-cost SO2 and particulate matter sensors, (ii) present preliminary results from trial sensor deployments, and (iii) outline plans to expand the network, with a focus on community engagement and education.

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Community Observation Networks for Air - New Zealand's experience with community engagement about air quality

Field Experience

Wood is the dominant fuel for residential heating in New Zealand which translates into high concentrations of pollutants during winter. Up until now, the only source of air quality data in New Zealand were the monitoring stations maintained by the local authorities which is often challenged by local communities as not representative of their specific area which often translates in challenging relationships between the regulators and the communities.

Using NIWA's own low-cost sensors for outdoor (Outdoor Dust Information Node â€“ ODIN) and indoor (Particles, Activity and Context Monitoring Autonomous Node - PACMAN) we developed a programme to involve the local communities by allowing them to take part in the gathering of data and in the development of the communication material based on those data.

We have developed this approach in the town of Rangiora during the southern hemisphere winters of 2015, 2016 and 2017 exploring different study designs, sensor types and communication strategies. In this presentation we will describe the three campaigns and highlight what we learned about sensor performance and community engagement.

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Sensing in three dimensions: Field experience from the Hong Kong D3D Study

Field Experience

High-density high-rise cities have become a more prominent feature globally. Sensor networks provide a possible means of assessing vertical variation in air pollution in such cities.

Seasonal street-level spatial monitoring campaigns were undertaken to create a two-dimensional land-use regression model for Hong Kong. Vertical air pollution monitoring was carried out at 6 locations for 2 weeks in each season using electrochemical gas sensors and light scatting PM and black carbon monitors. Continuous measurements were carried out at 4 heights of residential buildings on both sides of each canyon. Paired indoor monitoring was included for infiltration coefficients calculation.

High sensor precision was necessary to robustly detect vertical variation in concentrations, requiring multiple data scaling techniques. The electrochemical sensors did not exhibit the degree of precision necessary and these results were excluded from the study. Vertical exponential decay rates were higher during the warm season than the cool season, but no robust patterns were identified relating to the canyon physical parameters. We found that values of the median infiltration efficiencies (Finf) were high during the cool season (91%) and somewhat lower during the warm season (81% and 88% for PM2.5 and BC, respectively).

The results from the study provided the first evidence that considering air pollution exposure in a dynamic 3D landscape would benefit epidemiological studies. Only mid to high-cost sensors performanced to the required standard in this setting.

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Proposed Best Practices for Quantifying, Siting, and Using Gas-Phase Sensors in Partnership with Communities

Field Experience

Given the growing interest in low-cost air quality sensors, the further development of best practices will help to ensure the collection of useful data. Furthermore, a variety of guidelines may be needed to speak to the variety of sensor uses likely to emerge. Our own varied work has provided us with lessons on sensor quantification, use, and community partnerships that we hope can contribute to this need for best practices. For example, deployments of sensors in urban/rural areas have pointed to the necessity of location-specific calibration models. Another deployment in which sensor systems were rotated through different sites, all including co-locations with high-quality FRM monitors, allowed us to explore calibration model performance across new locations as well as what factors drive decreases in this performance. Placing multiple sensor systems at a single field site facilitated the comparison of building and neighborhood-scale variability, illustrating how sensors can be sited to meet the objectives of a study. Finally, as much of this work was undertaken with community partners, we have experience with resources (e.g., MOUs) and lessons (e.g., understanding a community's needs and capacity) that can best support these partnerships. We will share an overview of these studies and the recommendations that follow because ensuring the collection of useful data is a necessary step toward sensors reaching their potential to enhance our existing monitoring systems.

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Gas & Vapor Sensing

Field and Laboratory Performance Evaluation of an Ozone Sensor

Gas & Vapor Sensing

The Air Quality Sensor Performance Evaluation Center (AQ-SPEC) at the South Coast Air Quality Management District (SCAQMD) recently completed a laboratory and field evaluation of the U.S. EPA's Citizen Science Air Monitor (CSAM) sensor pod. The CSAM is a multi-pollutant instrument package capable of continuous measurement of ozone, particulate matter, temperature, and relative humidity under ambient monitoring conditions. Ten identical units of the CSAM were involved in the evaluation. Performance testing of the CSAM's electrochemical-based ozone sensor (Aeroqual SM-50) under both field and laboratory conditions was conducted with collocated federal equivalent method (FEM) instruments. Ambient test conditions were associated with the field-based evaluations at the Riverside-Rubidoux regulatory monitoring site in California while a controlled laboratory testing environment (relative humidity, temperature, target and interferent pollutant concentrations) provided data to assess a variety of the ozone sensor's performance characteristics. Field-based results (5-min comparisons) showed excellent correlation with the FEM (R2 > 0.83) with some underreporting of the concentration (10 to 50%) dependent by individual CSAMs. Two CSAM units were selected for extensive laboratory evaluation and yielded excellent correlation with in-line FEM instrumentation (R2 > 0.95) but with significantly reduced response over test conditions of 0 to 310 ppb (accuracy ranging from ~ 18 to 86%). Select conditions of low temperature (5 oC) revealed spurious sensor response while the sensor exhibited minimal response to nitrogen dioxide challenges up to 250 ppb. Features of the CSAM along with test conditions and other features of the evaluations will be presented. The merit of field versus laboratory-based sensor evaluations shall be discussed.

Disclaimer: Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy. Although this work was reviewed by SCAQMD, it may not necessarily reflect official SCAQMD policy.

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How can we use sensors to learn about air quality near energy/transportation infrastructure?

Gas & Vapor Sensing

Energy and transportation infrastructure often involve the movement of high energy molecules from one place to another or the conversion of internal energy in those molecules to much desired thermal energy which is accompanied by the annoying airborne release of lower energy molecules to the air. As scientists and engineers, we have been able to explore those annoying releases at the individual tailpipe or stack or broadly across spatial scales of 10s of kms, but we have not really had the tools to explore how those annoying releases impact people in the real world on spatial scales where they live. Sensors offer the potential to change that situation. In this talk, I will focus on the current ability of a small sensor array, including MOx, electrochemical, PID and NDIR types, to explore 1 km spatial patterns of methane and VOCs in regions that are impacted by oil and gas development as well as major roadways. Specifically, I will present an assessment of the capability of the sensor array to monitor for methane, BTEX and total VOCs in two communities that have differing components of energy and transportation infrastructure. The assessment will focus on the comparison of measurement uncertainty, including bias, and inherent spatial and temporal variability of the atmospheric species of interest. Additionally, challenges associated with confounding gases will be discussed.

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Development of a low-cost, low-power, photoacoustic based nitrogen dioxide (NO2) sensor network for air pollution measurements

Gas & Vapor Sensing

At present, air pollution monitoring is carried out at low spatial resolution due to high costs coming along with high accurate measurement equipment. To overcome this issue a much denser sensor network is required, which is directly able to monitor air pollution values.

A low power photoacoustic based nitrogen dioxide (NO2) sensor with wireless sensor network (WSN) capability, is presented in this work. Due to low power consumption and development costs it is qualified for utilization in high numbers. A differential photoacoustic cell has been simulated and constructed with a Q factor of 25. According to the photoacoustic principle, a modulated light beam of a low power light emitting diode (LED) excites the gas inside the cell, which produces a sound pressure wave. The acoustic wave is measured by a microphone with a second microphone being used for background noise cancelation. With this technique, NO2 concentrations in the low ppm region can be detected, whereby the detection limit is still under investigation. This could easily be improved by using a high power LED.

The sensor is managed by a microcontroller which is directly connected to a low power wide area network (LPWAN) long range (LoRa) transceiver. Using LoRa we are able to reach communication distances exceeding 1.700 m, having a packet delivery ratio of more than 40 percent. This enables large scale sensor networks which do not require existing infrastructure for communication or power management.

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Selective Chemoresistive Hybrid Metal Oxide/Carbon Nanotube-based VOC and Methane Sensors

Gas & Vapor Sensing

We present a new class of chemoresistive gas sensors that can sense methane and VOC gasses, in particular benzene, toluene, and formaldehyde, at single ppm levels using a hybrid metal-oxide nanocrystal/multi-walled carbon nanotube (MOX/MWCNT) technology. The sensors are fabricate using micro- and nanofabrication techniques, and are inherently low-cost and low-power. Alternating the fabrication conditions of the sensors changes their surface morphology at the atomic level, allowing for high degree of selectivity to the target gas. We show extensive experimental evaluation of the sensors to long-term environmental factors such as humidity and temperature fluctuations. The work was conducted as part of the larger effort to develop air-microfluidic lab-on-a-chip type sensors for air quality and gas sensing applications. The research is part of the broader research effort conducted by the Air-Micorfluidic Group (AMFG), a research consortium lead by University of Illinois at Chicago (http://www1.ece.uic.edu/~paprotny/AMFG_index.html)

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A simple and effective technique for remotely calibrating low-cost gas air quality sensors when deployed in the field.

Gas & Vapor Sensing

Previous drift detection work is extended to provide a simple, remote, continuous correction technique for low-cost air quality sensor networks. The network consists of a few well-maintained, high-quality measurement instruments (likely regulatory analyzers) that provide ground-truth information (called ‘proxies’) and a larger number of low-cost sensor devices. The ideas are grounded in a clear definition of the purpose of a low-cost network, here to provide timely and reliable information on local spatiotemporal air quality. The technique uses simple matching algorithms to cause the sensor to follow the general recent distribution of the proxy data, yet retaining local-scale variability in the corrected sensor data. Here, the selected proxy data is from a nearby regulatory analyzer station; a sensor network derived proxy is also discussed. Reported data are from two different urban networks for hourly-averaged ground-level ozone data using semiconductor sensors. Despite its almost naïve simplicity, the correction technique works well as both a drift detection and calibration technique for reporting indicative concentrations (within 30% of co-located regulatory ozone values). Land use regression provides the means to further enhance the proxy estimates about a site.

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Creating air quality intelligence from low cost gas sensors

Gas & Vapor Sensing

There is a growing interest in using low-cost gas sensors to generate local-scale air quality information and many studies have demonstrated their potential through good agreement with regulatory monitors in co-location tests.

However questions remain around what new environmental insights can a network of low-cost air quality sensors provide and what data quality level do they need to reach to do this ?

We have been exploring these questions with sensor-based instruments for over 10 years. In this paper we review the major challenges in deploying low-cost sensors and describe the methodologies that can be applied to overcome issues such as sensor drift, cross-interferences, the transferability of factory calibration to the field and data validation. We explore through examples from gas sensor networks operating in New Zealand, California, Vancouver and China what new insights can be gained from spatially dense air quality measurement once data reliability is understood. We also demonstrate how gas sensor metadata collected simultaeously can support data validation and provide new environmental information.

Presenting Author:
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Additional Authors:

High Accuracy multi-gas monitoring using automated self-calibration

Gas & Vapor Sensing

Monitoring pollutants such as SO2, H2S, and NOx require high accuracy and reliability that were traditionally only achievable through expensive USEPA reference analyzers. In this paper we present a new methodology that uses a combination of NDIR and Electrochemical sensors with a novel self-calibration technology to achieve ppb level detection limits. This new methodology relies on a frequent automated calibration achieved using a series of permeation tubes to generate accurate calibration gases within the system. The self-contained apparatus can create complex mixtures of multiple pollutants with high concentration accuracy. The system can even generate various concentrations on demand allowing the sensors to be calibrated at multiple points along their sensing range. Scentroid's Scentinal Air and Odour Monitoring Stations utilize this new technology to conduct self-calibration every 12 hours measuring with high level of confidence the drift and sensitivity of the sensor at 4 points along the sensing range. This frequent self-calibration not only increases accuracy but also reliability of the system as all sensing malfunctions will be detected. The new system employs a series of other technologies to increase the life of the permeation tubes to nearly 2 years ensuring the system will be able to operate with minimal operator interventions.

Presenting Author:
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Experience of global small sensor co-location comparison studies with AQMesh

Gas & Vapor Sensing

AQMesh is a low power air quality monitoring system which can be located flexibly to increase the number and targeting of air quality monitoring points. It uses electrochemical sensors to measure atmospheric gases at low ppb, with proprietary data processing, including cross-gas correction and environmental compensation. A â€˜limit of confidence' of 5ppb is given for NO, 10ppb for NO2 and O3, to allow for low target gas levels with high environmental noise, although readings closely track FEM below this level. We summarise the results of co-location studies which compare AQMesh data with FEM data, describing challenges overcome, such as O3 / NO2 co-responsiveness and temperature sensitivity. Through a series of sensor and processing developments, typical R2 of AQMesh NO2 readings compared to co-located FEMs has been increased from <0.3 to >0.8. Pre-scaled accuracy for O3 and NO2 is now typically Â±10ppb and can be improved through scaling against FEMs, according to recommended QA/QC.

Case studies show the opportunities and limitations of using small sensor systems in a range of applications, as well as remaining challenges, such as environmental destabilisation by users, which limits use beyond the hands of professionals. We discuss some ways in which the data validity of small sensor systems output can be managed, local node data from small systems integrated effectively with air quality models, and the distinction between citizen science tools and small sensor nodes for validated networks.

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AQMesh

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Indoor Air Quality

Monitoring Indoor Air Quality Using Low Cost Sensors at a Community Scale

Indoor Air Quality

This is an invited talk.

Indoor air pollution has been identified as one of the major environmental risk factors for human health. Previous studies have found that combustion sources such as cooking and candle burning generate significant amount of particulate matter (PM) in indoor environments. These studies, however, were usually conducted in a limited number of controlled environments with expensive and cumbersome laboratory equipment. With the advance of sensor technology, the objective of this study is to test the feasibility of using low-cost air sensors to engage community members to study indoor air quality. The study was conducted at the UCLA university village which is located closely to the I-405 freeway. Thirty PurpleAir || sensors were installed at the study site, with 12 outdoors and 18 indoors. An hourly-based 24-hr log containing activities that could impact indoor air quality was also filled out by the study participants. We found (1) there was a large variability over different apartments due to different indoor activities; (2) compared to cooking, burning candles produced higher concentration of particles; (3) using air purifiers could significantly lower the indoor PM concentrations; and (4) using low-cost air sensors was effective to engage communities to increase their awareness of indoor air quality. These results agree well with previous studies indicating low-cost sensors can be used in large scale air quality studies in the future.

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University of California Los Angeles
Additional Authors:
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Vaporsens, Inc. Salt Lake City, UT

HAPEx: a low cost PM2.5 sensor to monitor household expsoure to solid fuel emissions

Indoor Air Quality

Measuring exposure to Household Air Pollution in developing countries comes with a set of unique difficulties for which available sensors were not well suited. We set to design a low cost PM2.5 data logger based on the GP2Y1014. After 4 years of development the HAPEx was born. This data logger weight less than 50g, boasts a 5-year autonomy, has an accelerometer to assess user compliance and has a detection range between 10 ug/m3 and 50 mg/m3.

The HAPEx have been deployed in 13 countries so far and have performed measurements in more than 750 households. In households relying mostly on one kind of fuel, correlation with collocated gravimetric sampler has been found to be better than 75%.

Of course, the HAPEx has also its limits: it does not have a size selective inlet and it is passive which allow dust to collect on the optics and make the zero drift with time. Mass light scattering works well with an aerosol of constant characteristics, but when households use multiple fuels with wildly different aerosol characteristics, correlation with gravimetric samplers is low.

To address these limitations, we are exploring the following avenues:

- Post processing the data with a drift correction algorithm allows to greatly reduce the impact of zero drift.
- We have developed Stove Usage Monitors. By monitoring which source is active we can apply source-specific calibration coefficient to the personal exposure data.
- We are developing a active version of the HAPEx with a PM2.5 cyclone.

Presenting Author:
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Climate Solutions Consulting
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Using Data to Implement Cleaner Air Solutions

Indoor Air Quality

Several global health initiatives that distribute clean cookstoves to rural households lack the transparent and objective field data needed to measure the effectiveness of their interventions.

This presentation will review how sensor data supports an iterative approach to develop successful clean cooking interventions.

Using sensor technologies, we monitored and collected data on improved cookstove usage from rural households to understand the barriers to sustained adoption of clean cookstoves. The sensor data revealed that many households encounter challenges with supply chains, affordability, cleanliness, or usability of the stoves that lead to the eventual decline of clean cookstove usage. We shifted our methodology to create a sustainable ecosystem supported by data collection to address these barriers and have since witnessed sustained adoption at 90.1% on the data dashboard.

This is an invited presentation to the Indoor Air Quality session.

Presenting Author:
Martin Lukac
Nexleaf Analytics
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Which Sensors? When? How Much? Next Steps

Indoor Air Quality

This panel presentation is intended to encourage accelerated forward movement on development of low cost air sensors by highlighting the value that low cost air sensors could bring to people and economies, and outlines approaches that could help get there more quickly. Low cost air sensors are essential for resolving the conflict between increased outdoor air supply for human health and productivity, and reduced outdoor air supply for lower energy costs. How do we currently address the problem of indoor air pollutants? Brute force! We push what we hope is a sufficient quantity of outdoor air through our buildings in an attempt to flush out indoor air pollutants. This technique of using air movement, as well as the amount of air deemed necessary to continually move through our buildings, has remained roughly unchanged over the past 150 years. Because we do not have a low-cost and reliable way to sense what is in the air we're breathing, one of the largest costs of operating a building is the energy it takes to heat, cool, and control the moisture in all this air that is brought into buildings before being exhausted back outdoors. This is also a primitive approach to protecting and enhancing human health and well-being.

Presenting Author:
Bob Thompson
US EPA
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The PM2.5 Levels in the Metro Cars and Commuters' Awareness: A Questionnaire-based Investigation and AirBeam-based Monitoring in 10 Metro Lines of Beijing

Indoor Air Quality

The study surveys the daily riding features of Beijing metro commuters and their awareness of air pollution and individual protection actions. AirBeam are used to monitor the PM2.5 levels in 10 metro lines from October 2016 to April 2017. The study shows that Beijing metro commuters' awareness and intended behavioral characteristics on PM2.5 exposure in the metro system have to do with age, sex, income and educational levels, and family features as well. In addition, PM2.5 levels in the metro system are significantly higher than the according outdoor ones. Based on the Exposure-Response Functions and Pope's empirical research data on health risk of air pollution, the long-term health risk of PM2.5 exposure in Beijing metro system should be concerned and relevant indoor air quality policy and air quality management measures in metro system need to be taken.Â

Presenting Author:
Ang Zhao
Rock Environment and Energy Institute
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Using lower cost sensors to understand household energy use and its implications on pollution exposure and health

Indoor Air Quality

Exposure to household air pollution (HAP) from the combustion of solid fuels results in between 3 and 4 million deaths per year, predominantly in the developing world. HAP exposures are influenced by the types of fuels used, ventilation characteristics of homes, and behavioral patterns of householders. Our research group has pioneered the use of various low cost sensing systems to better describe household environments and behaviors that impact exposure and ultimately health. These include sensors to (1) measure particulate matter (UCB-PATS and PATS+); (2) to estimate time of use of cooking, lighting, and heating appliances (stove use monitors); (3) to evaluate household ventilation rates using carbon dioxide as a tracer (ARMS); (4) to enable a conditional cash transfer based on clean fuel usage using a novel, inexpensive meal-counting dataloggers; and (5) to objectively track movement through indoor environments using an ultrasound-based locator (TAMS). These sensors provide valuable, repeatable, and objective measurements of parameters that influence exposure and may help explain why expected exposure reductions are not met by certain so-called clean technologies. They additionally provide output that may enable more tailored and targeted policy interventions to reduce the burden of disease associated with household air pollution. This talk will briefly describe the evolution of these systems and new avenues being pursued to help reduce uncertainty in other estimates related to household energy use.

Presenting Author:
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Low & Middle Income Countries

Application of affordable monitoring for low and middle income countries

LOW AND MIDDLE INCOME COUNTRIES

In many low and middle-income countries, air quality monitoring networks are challenging to sustain and scale mainly due to the prohibitive cost of reference grade instruments and limited financial resources to build capacity to manage, analyze and report on pollution levels. This presentation describes a case study using low cost sensors as a proxy to influence policy action and raise public awareness. The presentation aims to convey the broader utility and value that low cost sensor technology can provide for the public sector.

Presenting Author:
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LOW AND MIDDLE INCOME COUNTRIES

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LOW AND MIDDLE INCOME COUNTRIES

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Mobile Technologies

City Scanner: High-Resolution Mobile Air Quality Monitoring

Mobile Technologies

Urban air pollutants vary dramatically over short distances (<< 1 km). Mobile air quality monitoring has become an effective technique to detect these variations in cities. The temporal variations in air pollutants make aggregating over mobile measurements, to find a representative level of pollution for a given location difficult. This is exacerbated by the fact that most mobile air quality monitoring studies are done by dedicated mobile air quality monitoring laboratories that are limited by resource constraints. This paper examines the utility of routine mobile air quality monitoring using low-cost air quality monitors, via a fleet of vehicles, in this case - trashtrucks, to extract information about the spatial variation of particulate matter pollution in the city of Cambridge.

Specifically, this paper analyses data collected by two low-cost optical particle counters mounted on two different trash trucks, that report the mass concentration of particulate matter: PM2.5, as well as the number concentration of particles in sixteen size bins ranging from 0.38 Âµm to 17.5 Âµm, for 29 distinct sampling runs. This paper uses a time-series smoothing technique to derive the background concentration for the mass and number concentrations to correct for regional diurnal variations in pollution for each of the 29 sampling runs. It then employs the median as a metric of central-tendency which is resistant to local emissions, to derive the corrected value of pollution for road segments in the area scanned. It reports the relative distribution of PM2.5 over the city of Cambridge, as well as provides a qualitative description of the relative magnitude of local/regional sources using the number concentrations from the OPCs.

Presenting Author:
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Interpreting On-Road Mobile Air Pollution Measurements in Multiple Communities

Mobile Technologies

Concentrations of air pollutants emitted by mobile and stationary sources vary over distances of 10s of meters from the source. Some communities are disproportionately impacted by high exposure to these pollutants, which are not characterized by observations at sparsely distributed regulatory monitors. In this work we interpret concentrations of fine particle mass (PM2.5), black carbon, ultrafine particle number, nitrogen oxides, total volatile organic compounds, and carbon dioxide, measured by a mobile vehicle that makes repeated passes through multiple communities over several months in Richmond, CA. We aim to answer the questions: 1) are some regions of the neighborhood associated with higher concentrations? And 2) can sources contributing to higher concentrations be identified? We develop an approach that estimates the background concentrations in the communities and we evaluate the estimated PM2.5 background using stationary concentration measurements at a regulatory monitoring site. We develop a method to identify hotspots, spatial regions associated with elevated concentrations, and show how the method can be used to present spatial concentration variation in a robust way. We discuss next steps that relate observations with specific sources and source groups by 1) estimating traffic emission factors and 2) developing empirical models to interpret concentrations using traffic activity and other proxies of source activity.

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CAPTURING THE EFFECT OF DATA COLLECTION PROTOCOL ON LAND-USE REGRESSION MODELS AND EXPOSURE SURFACES FOR ULTRAFINE PARTICLES, BLACK CARBON, and NOISE

Mobile Technologies

The development of exposure surfaces using data collected during short-term sampling campaigns have gained momentum in recent years, primarily in light of advances in air pollution monitoring technology. Small portable instruments have enabled the development of data collection protocols that involve mobile sampling by foot, by bike, or by cars fitted with various sensing devices. The development of inexpensive air pollution sensors will further enable these protocols and might even lead to ad-hoc data collection means through participatory air pollution sensing. The question of robustness of land-use regression models (LUR) will become of utmost importance.

We measured Ultrafine Particles (UFP), Black Carbon (BC), and noise in Toronto during the summer of 2016, using two short-term data collection protocols: mobile, involving 3,023 road segments sampled on bicycles, and stationary, involving 92 fixed locations. In addition, a panel study was conducted whereby GPS data and exposure information were collected for approximately 55 individuals. Different LUR models and associated exposure surfaces were developed based on the two measurement protocols. The exposure surfaces were then used with GPS data collected by the panel of participants in order to compare personal exposures and surface predictions, revealing a large sensitivity of the LUR model to the data collection protocol.

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Low-cost Air Pollution Monitors for Deployment in an Urban Setting

Mobile Technologies

The main objective of The SEARCH (Solutions for Energy, AiR, Climate, and Health) Center is to investigate emerging energy transitions in the U.S. and resulting air pollution and health outcomes through state-of-the-science modeling and measurements to characterize factors contributing to emissions, air quality and health. Our project focuses on characterizing the within-city variability of air pollutants and greenhouse gases. To accomplish this, we have developed novel online multipollutant monitors (both stationary and portable models), leveraging emerging low-cost technologies, to measure air pollutants and greenhouse gases at high spatiotemporal resolution. We deployed these units in downtown Baltimore, Maryland. Currently, the monitors can measure particulate matter ($PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), methane (CH_4), nitric oxide (NO), carbon dioxide (CO_2), temperature and relative humidity. The monitors can transmit data through the cellphone 3G network, so we are able to view the data in real time. Preliminary field and laboratory results suggest that these monitors can reliably measure ambient air pollutants with high accuracy and precision when temperature and humidity calibrations are appropriately applied. The correlation coefficient of the PM sensors to the reference instrument at a regulatory monitoring site was 0.95 during the initial deployment, with somewhat lower precision for NO_2 (0.89), and O_3 (0.82).

Presenting Author:
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Sensor performance characteristics from an extended mobile monitoring deployment

Mobile Technologies

Aclima has developed a next-generation sensing platform that enable routine, wide-scale mobile measurement. Mobile monitoring as a sampling strategy has demonstrated potential to measure pollutants at a hyper-local spatial scales, revealing unexpected features that are the least straightforward to predict. These unexpected features may account for errors in emissions inventories and also represent opportunities for mitigation efforts. Actions based on mobile monitoring requires data of sufficient quality to have confidence in the accuracy of the results. Characterization of sensor performance has been a key component of our research and design process. Assessing sensor performance in mobile applications has unique challenges in that pollutant concentrations and atmospheric conditions are dynamic and rapidly changing compared to what might be experienced during a traditional stationary validation exercise. Aclima has been using their fleet of mobile laboratories, Google StreetView cars equipped with reference-grade equipment, to evaluate the performance of our sensor-based devices. In this presentation, we will discuss (1) case studies of sensor performance based on this mobile collocation exercise, (2) the calibration strategy used (in situ mobile vs stationary), and (3) select science questions that can be addressed using the sensor data.

Presenting Author:
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Mobile BTEX and VOC Monitoring with the AROMA Vapor Analyzer: Results and Lessons from Field Studies and Emergency Response Deployments

Mobile Technologies

Precision mobile sensing of hazardous air pollutants (HAPs) can provide critical information regarding chronic and acute exposures to toxic volatile organic compounds (VOCs) and allow for localization and source identification. We will present results of long-term fixed location and mobile VOC surveys performed using the AROMA-VOC trace vapor analyzer. Special focus will be given to emergency response measurements performed in the city of Houston in the week following Hurricane Harvey, where multiple chemical plumes were identified. The AROMA technology provides laboratory grade speciated VOC analysis with method detection limits (MDLs) as low as 1.6 pptv for benzene, with an end-to-end measurement time of <15 minutes. Additional data will be presented for surveys of urban areas, rural areas, and chemical production facilities. Real-time data has been employed to isolate background sources (including mobile and transient sources) from facility emissions. Results using benzene, toluene, ethylbenzene, and xylene (BTEX) fingerprint ratios to identify and differentiate sources will also be presented.

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Intra-city variability of PM exposure driven by carbonaceous sources

Mobile Technologies

Localized primary emissions of carbonaceous aerosol from sources such as traffic and cooking are the major driver of intra-city variability of submicron particulate matter (PM1) concentrations. We performed mobile sampling in a variety of neighborhoods in Pittsburgh, PA and Oakland, CA with an aerosol mass spectrometer (AMS) to investigate spatial variations in PM1 composition and sources. We used source apportionment with positive matrix factorization (PMF) to attribute primary organic aerosol (OA) to traffic (HOA) and cooking OA (COA). These two sources dominate the local OA and PM1 hotspots in the sampling domain. In locations with high local source impact, the average concentration of PM1 can be 2 ug m-3 higher than low-source, urban background locations. Traffic emissions are the largest source contributing to population-weighted exposures to primary PM, while cooking is comparable and can be especially important in some residential areas with large numbers of restaurants. The concentration of both the traffic- and cooking-related primary PM components are positively correlated to their respective geographical covariates: vehicle-miles travelled (VMT) and restaurant count. VMT is found to be a reliable predictor for HOA and black carbon (BC) concentrations for use in air pollutant spatial models. Restaurant count is an imperfect predictor for COA concentration, likely due to the highly variable emissions of individual restaurants. COA concentration is also positively correlated to VMT, which suggests that near-road cooking emission can be mistakenly attributed to traffic sources in the absence of PM source apportionment.

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Monitor Siting

The fast deployment method of widespread low-cost and portable sensors for national ambient air monitoring

Monitor Siting

The conventional siting method aims at choosing appropriate locations for several air monitoring stations for limited resource and is often a time-consuming process. Since the low-cost and portable sensor technology emerged, we have more resource than before and then the problem is transformed as how to appropriately deploy hundreds or even thousands sensors. Moreover, the public sector is forced to respond rapidly when the environmental issue attracts the public attention and is getting seriously, such as the PM2.5 issue. Our government thus planned a national monitoring plan, environmental IoT, to use 10,200 sensors to monitor and track the pollution closely for policy making. It is an unprecedented challenge. Herein we devised a two-tier fast development method that meets this situation and applied it to the national deployment plan in Taiwan. The method can be a good start for the sensor deployment of environmental IoT, and policy makers may integrate conventional siting methods with it afterwards or alter the deployment results based on the local monitoring requirements.

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Study design considerations for successful air sensor projects

Monitor Siting

Opportunities for actionable insights from sensor-based air monitoring campaigns depend on many study design parameters beyond the number of sensors deployed. The need to consider study design in sensor-based campaigns is amplified by growing expectations that governmental agencies will translate data from sensor networks into actionable findings. Establishing and maintaining good alignment between the monitoring approach and stakeholder goals and expectations, including those of community members, is one of the primary elements needed to improve the odds of success. We will discuss guidelines for siting decisions and quality control/quality assurance methods, which can also increase the likelihood of successful data collection. Important considerations also include available resources, characteristics of the issue being studied, assessments of the measurement methods, and the context of the desired decision or action. Finally, we stress the importance of detecting, controlling, and accounting for unwanted differences, either in the sensors or in background conditions, that limit the ability of stakeholders to draw reasonable and actionable conclusions from the data.

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Wintertime Air Toxics from Wood Smoke in Sacramento

Monitor Siting

Residential wood smoke is a main source of wintertime air pollution in Sacramento; it is strongly suspected to be a source of some toxic air pollutants. However, the variation and contribution of air toxics from wood smoke at a community scale are unknown. To understand how air toxic and particulate matter (PM) concentrations varied across Sacramento, and between environmental justice (EJ) and non-EJ communities, measurements were conducted during December 2016 and January 2017. EJ and non-EJ communities were identified using the EJScreen environmental justice screening tool (https://www.epa.gov/ejscreen), community stakeholder input, and scientific considerations such as terrain, meteorology, and traffic information. Volunteers were solicited in Sacramento to host temporary air quality monitoring sites for the study.

Monitoring included measurements of air toxics, PM, and wood smoke indicators such as levoglucosan, using a combination of regulatory-grade instruments and low-cost sensors. A phone survey was conducted during the study period in communities where the monitoring occurred to characterize wood burning behaviors with associated monitor measurements. Data was analyzed and results were

obtained by applying various statistical methods to the measurements, sensor-to-sensor analysis, and comparison of measurements to the phone survey results.

The study provided important results for Sacramento County, such as the contribution to air toxic and PM concentrations from wood burning, concentrations of fossil-fuel related pollutants, correlations with wood burning behavior as measured by the phone survey, and recommendations to future outreach programs to reduce wood smoke pollution in Sacramento.

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The role of Citizen Science Projects in the context of information made available by the New York City Community Air Survey

Monitor Siting

Traditional approaches to air quality monitoring generally involve regulatory agencies that utilize expensive and complex stationary equipment maintained by trained staff to provide the type of highly accurate data needed for demonstrating attainment with federal air quality standards. While this type of monitoring is a vital component to air quality management, in urban areas these monitors are often deployed at a limited number of rooftop locations. They are intended to track urban scale trends in pollution levels and are not spatially dense enough to characterize intra-urban spatial variation in air quality due to local emissions sources such as traffic. To address this limitation, in 2007 the NYCDOHMH in partnership with Queens College launched the New York City Community Air Survey, a high density monitoring network designed to assess spatial variation in longer term exposures (seasonal and annual average) at the neighborhood-level. NYCCAS uses less expensive monitoring technology than those that meet federal requirements for NAAQS-attainment determination (Federal Reference Methods), trading high temporal resolution achieved by more expensive monitoring methods with increased spatial coverage that can be achieved by deploying larger numbers or lower cost and easier to deploy instrumentation.

NYCCAS has become vital to the City's understanding of the variation in pollution exposures within New York City; however, its operation relies on trained technical, analytic, and field staff to collect and analyze air quality data. In recent years, technological advancements in air quality monitoring have brought to market many lower-cost, easy-to-use, portable air quality sensors that provide high time resolution data in real time which provides exciting opportunities for additional data collection. Simultaneously, there is a growing field of â€˜citizen scientists', non-scientists who are engaged in specific issues that collect or analyze data to contribute to scientific research or advocate for environmental or public health improvements. The NYCCAS team is currently expanding into the area of community engagement and community-based participatory research by developing air quality "citizen-science"toolkits that will include how-to guides for accessing available data on emission sources, designing neighborhood air pollution surveys using new, low-cost technologies, and sharing data online.

We will discuss the role of citizen science projects in metropolitan areas where a considerable understanding of local air pollution exposure already exists.

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Building Best Practices for an Air Quality Distributed Sensor Network

Monitor Siting

Portland community members, researchers, government and health practitioners want improved information about localized air quality. Lower cost air quality sensors are one pathway to increased measurements across the heterogeneous urban landscape. Current sensor technology is limited due to sensitivity and interference issues. Deploying many sensors to create a distributed network also has challenges for a city such as procurement, installation and management of unique asset types. City of Portland Bureau of Planning and Sustainability is using a variety of co-located deployments to understand the uses of lower cost sensors and develop guidelines for larger deployments. The co-located deployments involve testing sensor devices against known concentrations of gases and particles in the Sustainable Atmospheres Research lab at Portland State University, co-locating devices of the same type at the Oregon Department of Environmental Quality ambient monitoring station, and co-locating different devices at three intersections on an urban arterial road. Results of the co-location studies will be shared and lessons learned from coordinating across city agencies to purchase, install, and maintain the roadside sensor installation. To best utilize air quality sensors, we need to further develop communication methods for short-term measurements compared to air quality and health standards and create a dialogue about sensor limitations while still fostering community participation.

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Sensor networks for public and regulatory information

Monitor Siting

Technological change in air quality monitoring is taking place globally. In addition to regulatory monitoring, low-cost sensor systems and air quality models provide information. This changing environment may allow us to improve regulatory information and give data more relevant to individual users who often require local real time information.

Usually, the purpose of monitoring activity determines suitable technologies. Products giving information based on different sources of information about air quality are not particularly common: we do not think in terms of e.g., data quality objectives for such products, and thus their legislative use is limited, but their information value may be large.

The CITI-SENSE project included sensor monitoring in 8 European cities, each of them required to perform regulatory monitoring. In these cities, number of reference stations varied between 1 and over 10, which rarely allowed to give locally specific information to the inhabitants. Low-cost sensor systems, even placed using opportunities such as public buildings locations (e.g., kindergartens), were shown to fill in some information gaps. However, practical sensor network deployment requires (1) reasonably functioning sensor systems (preferably low cost), (2) ability to harvest data from several technologies, (3) ability to process and store data, and (4) ability to provide end-user products. We will discuss barriers and opportunities of all of these elements.

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Particle Measurements in Sri Lanka using Low-Cost Air Sensors

Monitor Siting

Sri Lanka is a developing country where ambient air monitoring is restricted to a very small number of pollutants and sites mainly due to the financial and human resource limitations. Automated ambient air monitoring with low-cost air sensors is well suited for such resource-limited developing countries. We will describe the design, construction, installation, and field testing of low-cost particle sensors, co-located with regulatory-grade particle sensors, in the capitol city of Colombo in Sri Lanka. These sensor packages, compact and easily relocatable, can be deployed country-wide with limited resources and can also be used to identify hot-spots in the country. Due to their relative simplicity and transparency in construction, they are ideal tools for engaging youth (at both High School and College level) in community-based environmental protection: Such involvement is severely lacking in developing countries.

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<u>Particle Sensing</u>

South Coast Air Quality Management District – Air Quality Sensor Performance Evaluation Center

Particle Sensing

In recent years, progress has been made in the development of low-cost air quality sensing technologies. These low-cost sensors offer increased spatial and temporal air pollutant measurements and are quickly becoming mainstream components in many air monitoring applications. Understanding the performance and the data quality produced by these sensors is necessary for designing air monitoring projects and selecting the correct sensor technology for an air monitoring application. In an effort to inform the public about the actual performance of commercially available low-cost air quality sensors, the South Coast Air Quality Management District (SCAQMD) established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) in June 2014. The Center performs a thorough characterization of low-cost sensors under ambient (in the field) and controlled (in the laboratory) environmental conditions. During the field testing, air quality sensors are operated in triplicate side-by-side with Federal Reference Method (FRM) and Federal Equivalent Method (FEM) instruments which are routinely used to measure ambient concentrations of particle pollutants for regulatory purposes. Sensors that demonstrate an acceptable performance in the field are subsequently tested under controlled environmental conditions in a laboratory characterization chamber that is used to challenge these devices with known and varying concentrations of particle pollutants under different temperature and relative humidity levels. Testing results for each sensor are then summarized in a technical report and posted on a dedicated website (www.aqmd.gov/aq-spec) to educate the public about the capabilities and potential applications of commercially available sensors. To date, AQ-SPEC has evaluated over 25 PM sensors in the field and 10 PM sensors in the laboratory. This presentation will discuss the field and laboratory testing methods and will provide a summary of results from field and laboratory evaluations performed on twelve PM sensors.

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An Overview of TSI's capabilities in product development from conception to commercialization

Particle Sensing

Low-cost sensors are becoming more and more common in the environmental monitoring space. There are some key differentiators along the spectrum of environmental monitoring devices including drift, accuracy, calibration capabilities and reliability, to name a few. Given the number of devices that are entering this market, end-users need to ensure they know what they are getting from a low cost device. This presentation will briefly showcase TSI’s platform product strategies from low-cost modules to our high-end options. We will also address the corresponding processes and systems in place to ensure agility in developing cost effective products that we will market on a highly configurable platform with options for customer customization.

This presentation will also highlight TSI’s calibration capabilities, the ISO certification process in place and how a cross-functional team works to get from concept to a finished product.

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Innovative Designs for Low Cost PM Sensors: Calibration, Characterization, and Application

Particle Sensing

The advent of new optical device technology is causing a revolution in particulate matter sensing. However, there are many issues with some of the components resulting in issues such as drift, necessity for dynamic calibration, and lack of robust inversion techniques that have resulted in inaccurate reporting of PM concentrations. This presentation will provide an overview of new designs for a low cost PM sensor, coupled with robust inversion algorithms.

The first part of the talk will discuss laboratory calibration methodologies for optical sensors based on recommendations from the USEPA. The calibration data will be used to develop an inversion technique (1) that enhances the accuracy of existing PM sensors such as those based on Shinyei PPD42NS, Samyoung DSM501A, and Sharp GP2Y1010AU0F devices. A new design based on more robust optical scattering and absorption will be presented for accurate measurement of particulate matter in a variety of applications. The final part of the presentation will discuss case studies of various applications: a) in a networked format to map out PM concentrations in occupational settings by use of an ordinary Kriging method and an Artificial Neural Network model (2); b) mounting on a robot to map out concentrations and movement guided by PM sensing and mapping out the temporal distribution at a construction site; c) a field study in Raipur, India where a network of sensors have been utilized to study the ventilation efficiency in households during cooking using biomass stoves (3).

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2. Li, J. et al. (2018). Spatiotemporal distribution of indoor particulate matter concentration with a low-cost sensor network. Building and Environment, 127, 138-147.

3. Patel, S. et al. (2017). Spatio-temporal measurement of indoor particulate matter concentrations using a wireless network of low-cost sensors in households using solid fuels. Environmental research, 152, 59-65.

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Low-cost optical sensors: Laboratory and field performance evaluation

Particle Sensing

The availability and use of low-cost optical sensors for particulate matter (PM) measurements has exploded in the recent years. Researchers and community members have been using these sensors for a variety of applications including: determination of micro-sources, calculation of aerosol exposure for urban populations, characterization of indoor air, etc. These sensors are based on the same principle of light scattering, but their differing geometries, light sources, and detectors, make their performance characteristics different. Here we evaluate four popular low-cost sensor units: Shinyei, Samyoung, Plantower, and Honeywell. We establish the performance of these sensors as a function of particle size, composition, and concentration under laboratory conditions and then determine the field performance by co-locating the sensors with conventional aerosol instruments. In this presentation, we will describe the procedure followed for the lab experiments, identify the size-dependent detection limits of the different units, and then describe our semi-theoretical to predict the performance of the units under different field conditions. We will also briefly compare the performance of our predictions with field measurements.

Presenting Author:
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Minimizing the influence of environmental conditions on the performance of low-cost PM sensors

Particle Sensing

The availability of low-cost PM sensors significantly broadens opportunities for improved air monitoring, personal exposure assessment, health studies, as well as better data resolution in mapping PM levels over space and time to support citizen science and emergency situations. The sensor community has already identified significant limitations that must be addressed for low-cost PM sensors. For example, are they sufficiently sensitive and unbiased to replace or at least augment stationary monitorsin environments with changing humidity and temperature, such as over diurnal cycles and during weather events? The aims of this presentation are to describe how variation in humidity and temperature influence sensitivity and bias in low-cost PM sensors, identify ways to account for temperature and humidity dependence, and estimate how much these improvements could improve sensor performance.

Presenting Author:
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Low-cost air quality sensor network deployment and data analysis

Particle Sensing

The deployment of high-density networks of low-cost sensor-based instruments can provide useful spatiotemporal data that may not be captured in traditional monitoring networks. Here we present data from the deployment of 100 instruments each measuring PM2.5, temperature, and relative humidity, around the greater Los Angeles region. The instruments contain a low-cost (<$30USD) fan-driven sensor that samples via a metal inlet in order to avoid electrostatic losses. Readings are corrected in real-time, based on the relative humidity in order to provide a more accurate measurement. The deployment, spanning across several counties and numerous neighborhoods, provides varying scales of granularity for analysis. These instruments push data to a cloud server, allowing real-time interpretation and visualization of air quality trends. Using these instruments and tools, patterns can be observed across regions that may otherwise be difficult to detect and observe. A number of instruments were co-located at reference stations to examine measurement quality and network validation. Performance of the instruments, data analysis and methods of visualizing data from this network will be covered.

Presenting Author:
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Aeroqual
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Calibration, QC, and Visualization of Data from the Purple Air Monitor

Particle Sensing

The number of low-cost air sensors has grown dramatically in recent years. There has been a concerted effort to understand the performance and application of these new technologies. Work by the South Coast Air Quality Management District's (SCAQMD) AQ-SPEC program has helped to shed light on the variability in performance across the low-cost sensor market. According to their research, one of the highest performing and cheapest particulate matter sensors is the Purple Air. Purple Air monitors are gaining increasing traction in the low-cost sensor marketplace, with over 1500 units online as of April 2018. However, there is significant concern among regulatory agencies and academics about the accuracy of the Purple Air monitors. While the Purple Air monitors read very similar to each other (precision) they often read much higher than collocated regulatory monitors (accuracy). This is particularly concerning since the raw, inaccurate, values are being publically displayed on the Purple Air website.

At the Puget Sound Clean Air Agency in Seattle, WA, I have worked to understand the performance of the Purple Air monitors, including the effect of relative humidity, and have developed local calibration equations. Comparing these calibration constants to those reported by SCAQMD and Iowa's Department of Natural Resources, it was found that the constants differ significantly across the US.

The density of the Purple Air monitoring network provides an opportunity to look at network metrics for detecting malfunctioning sensors. To this end, I developed an intra- and inter-monitor confidence score that represents confidence in the measurements of the Purple Air monitor. Finally, I took what I learned from the previous analyses and created a new web visualization of the calibrated Purple Air data. Monitors with low confidence scores are made more transparent on the air quality map. It is my hope that sharing this research can help other agencies, community groups, and academics understand how to better interpret data from their Purple Air and other low-cost sensors.

Presenting Author:
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Puget Sound Clean Air Agency
Additional Authors:

Understanding the fundamental limits of low-cost optical particle counters in the "real world"

Particle Sensing

In an ideal world, particulate matter (PM) would be characterized on a spatial and temporal scale sufficient to resolve the real-world concentration gradients that persist. Data obtained through this idealized sensor network could be used to quantify the strength and use-patterns of pollutant sources, inform PM exposure levels, and promote pollution mitigation strategies to improve local air quality (AQ). Low-cost optical particle counters (at price points ~ 50-1000x lower than reference) have emerged as one potential tool through which distributed sensor networks could be built. But despite the obvious advantage of affordability, key questions remain regarding the trustworthiness of PM sensor data. In this talk I will outline the fundamental limits of low-cost OPC systems and discuss how these limits impact measurements of ambient PM across a variety of field applications. The talk will draw upon empirical datasets from urban, peri-urban, near-field, and rural sites spanning 6-24 mo. deployment timelines.

Presenting Author:
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Regulation & Performance Standards

Application of Innotvative Sensor Technology in China

Regulation and Performance Standards

Faced with severe air pollution, China had committed unprecedented efforts and achieved significant progress over the past five years. The PM10 concentrations of all 338 middle size cities improved by 23% and the average concentration of PM2.5 in Beijing-Tianjin-Hebei Region had improved by almost 40%. Strengthen monitoring is a key approach China adopted and in fact, China is already the world’s pioneer in applying new monitoring technologies (including sensor technologies) to support policy making and implementation. We would like to share the experience of a two China cities. Jinan city is now planning to expand its mobile monitoring taxi fleet to 500 vehicles to support more accurate and scientific air quality management work.

Facing further air quality improvement demands, China needs more comprehensive air quality monitoring database to help authorities to spot different local pollution problems and to support them making targeted air pollution prevention and control measures. It is estimated that an over 100 billion RMB market will be created in air monitoring in China, and over 10 billion will belongs to sensors based technologies.

Presenting Author:
Tonny Xie
Bluetech Clean Air Alliance

Opportunities to Utilize Low-Cost Sensors to Address Regulatory Air Monitoring Network Resource Constraints

Regulation and Performance Standards

The cost of operating a regulatory air monitoring network is continually on the rise, including equipment purchase, operation and maintenance, and data quality management practices. In certain cases, monitoring networks exceed the federal minimum monitoring requirements, or are designed to meet other programmatic needs, such as burn management and community awareness. With limited monitoring resources, CARB is interested in actively exploring the use of alternative technologies and practices to meet our program goals.

In this presentation, we will highlight the costs associated with developing and maintaining a regulatory air monitoring site and examine several case studies of monitoring networks that exceed the minimum monitoring requirements. We will explore how low-cost sensors could be used instead of traditional regulatory monitors in some situations. We will also highlight several examples where low-cost sensors have been deployed to augment regulatory monitors to address specific needs.

Presenting Author:
Kyle Vagadori
California Air Resources Board
Additional Authors:

PERFORMANCE EVALUATION OF SENSORS FOR GASEOUS POLLUTANTS AND PARTICULATE MATTER MONITORING IN AMBIENT AIR

Regulation and Performance Standards

The Working Group 42 of Technical Committee 264 on Air Quality of the European Committee for Standardization has been drafting a protocol for the evaluation of low-cost sensors and sensor systems for air pollution monitoring since the end of 2015 .

The list of pollutants that are considered in the protocol includes PM10, PM2.5, O3, NO2, NO, CO, benzene, SO2, and CO2. The protocol concentrates on outdoor measurements at fixed sites.

It defines 3 classes of sensors depending on whether sensor measurements can meet the Data Quality Objectives (DQO) of “indicative methods”for class 1 or “objective estimations”for class 2 that are defined in the European Air Quality Directive [2]. The 3rd sensor category is not bound with any data quality target. In the Directive, “indicative methods”and “objective estimations”are associated with less stringent DQOs than “reference methodsâ€.

The protocol is intended to estimate the uncertainty of sensor measurements at prescribed concentration levels that can be directly compared with the DQOs defined in the Directive. In fact, the DQOs are expressed in relative expanded measurement uncertainties in percentage.

There is still on-going discussion within WG 42 in order to balance the cost and number of laboratory and field tests and the objective to correctly evaluate and classify sensors. Additionally, the pre-tests of

PM sensors are difficult to apply to the very low-priced PM sensors without forced flow systems, they are more suited to lost cost PM sensors with pumps that are generally more expensive. Another point of discussion is on the possibility to apply a slope and intercept correction on sensor measurements based on the result of the field tests of this protocol. This correction would allow improving the agreement between sensor and reference measurement while it raises doubt on its appropriateness at future locations.

Presenting Author:
Michel Gerboles
EC-JRC
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The Emergence of Sensors - An EPA Perspective

Regulation and Performance Standards

This presentation will provide a perspective on the emergence of air sensors and the role of EPA. Topics covered will include the development of performance targets for low cost devices, applications for sensor data, and research gaps. Data quality, data interpretation, and data management issues will also be discussed.

Presenting Author:
Kristen Benedict
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Air Sensors and U.S. Diplomacy

Regulation and Performance Standards

Caroline D'Angelo will discuss DOSAir, the U.S. Department of State's ambient air quality monitoring program, including the technological components and how low cost sensors could fit into the network. One immediate tension is that DOSAir is built on EPA regulations, guidelines, and health messaging - this foundation is a critical component for the program's success. As the program as grown, by necessity DOSAir's global footprint is leading to updates in technologies, including moving to the cloud. She will also highlight current technological barriers to widely adopting low cost sensors into the program, as well as the various related management policy and communication challenges for DOS.

Presenting Author:
Caroline D’Angelo
U.S. Department of State’s Global Air Quality Monitoring Program
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Assembly Bill 617 and Low Cost Sensors - How Can This Technology Provide Actionable Results

Regulation and Performance Standards

The use of lower cost sensors can be a tool that can be brought to bear for use to collect air monitoring data required by Assembly Bill 617 (AB 617), either through coordinated use by communities or by air districts. Actionable data requires that goals and plans be clearly articulated, contain quality control/quality assurance procedures and appropriate siting of equipment. Sensor's low cost and relative ease of use can be used to provide wide spatial coverage and can be employed to collect air monitoring data for AB 617 if a monitoring objective is clearly identified and an effective monitoring plan developed and followed. The Bay Area Air Quality Management District intends to provide technical assistance to communities who may wish to deploy sensors and may utilize data from sensors already in place to aid in the evaluation of air quality on a highly localized scale. A discussion of plans and methodologies, as well as experience and lessons learned from the use of lower cost sensors in the Bay Area will be presented and discussed.

Presenting Author:
Eric Stevenson
Bay Area Air Quality Management District
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How sensors are and can be used in Indian Country

Regulation and Performance Standards

Use of small air quality sensors in Indian Country have gained interest in recent years, but their usefulness and merit are still in question as consideration of these low-cost sensors are looked at to replace expensive regulatory monitors. This presentation will look at various pilot projects, case studies and mere curiosity of various small air quality sensors in Indian Country and perspectives on its merit and potential for future use and decision making.

Presenting Author:
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Air Quality Sensor Performance Evaluation Center (AQ-SPEC): Lessons Learnt and New Challenges

Regulation and Performance Standards

Low-cost sensor networks enable real-time air quality monitoring with unprecedented temporal- and spatial resolution. Since 2014, the South Coast Air Quality Management District (SCAQMD) has been conducting testing and technology demonstration projects to evaluate the quality and effectiveness of this and other emerging measurement technologies. In this presentation activities of the Air Quality

Sensor Performance Evaluation Center (AQ-SPEC) will be discussed, along with a perspective on how data collected using low-cost sensor technology can inform effective policy decisions and assist with fulfilling the requirements of the most recent SCAQMD rules and California legislation.

Presenting Author:
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SCAQMD
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Source Characterization

Characterizing point, line, and area sources with RAMP monitors: Case studies from Pittsburgh, PA and San Juan, PR

Source Characterization

Low-cost sensors have enabled a dramatic shift in the spatial and temporal resolution at which air quality data can be gathered, coupled with minimal infrastructure needs and power consumption. These capabilities can be used to characterize line, area, and point source emissions. The Real-time Affordable Multi-Pollutant (RAMP) monitor uses AlphaSense electrochemical sensors to measure CO, SO2, O3, and NO2; an optical nephelometer to measure PM2.5; and an NDIR sensor for CO2.

As part of a 50-node network, RAMP monitors have been deployed near major point sources of PM2.5 and SO2 in Allegheny County, Pennsylvania. The low-cost distributed network effectively captures plume movement within the Monongahela Valley and into Pittsburgh. RAMP data suggests that the two major point sources, both associated with the steel industry, have different source profiles. The RAMPs deployed in and near Pittsburgh enable the determination of real-world in-use emission factors from vehicular sources. Preliminary analysis shows that results for CO emission factors are comparable to emission factors from more conventional tunnel studies.

RAMPs deployed in San Juan in the aftermath of Hurricane Maria detected high SO2 levels that likely exceed EPA standards on a regular basis. The diurnal patterns of SO2 and strong correlations with CO and BC (measured with an external monitor) suggest that widespread backup generator usage is now a major source of pollution in this generally clean environment.

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Kansas City Transportation Local-Scale Air Quality Study (KC-TRAQS): Examining Local Air Quality with a Network of Low-cost Sensors.

Source Characterization

Low-cost air sensing technologies enable the deployment of networks of measurement sites that would be too expensive with traditional monitoring technologies. These sensor technologies also capture air pollution data at high-time resolution, enabling advanced data analysis techniques. In Fall 2017, the U.S. Environmental Protection Agency (EPA) launched the Kansas City Transportation Local-Scale Air Quality Study (KC-TRAQS) to learn more about local community air quality in three neighborhoods in Kansas City, KS, with a yearlong deployment of a network of low-cost sensors with measurements as frequent as every minute (up to approximately 525,000 measurements annually per sensor). Six sensor pods, including Alphasense OPC-N2 particulate matter (PM), Aethlabs mobile black carbon (BC) monitors (MA350), and meteorological sensors were deployed in the Argentine, Armourdale, and Turner neighborhoods of Kansas City. Additionally, four Met One E-BAM PM sensors were also deployed in January 2018. A preliminary analysis of the data from these sensors examined the spatiotemporal variation of particulate pollution in these community areas and explored potential contributors to local PM. Techniques used in this analysis include separating measurements into slow- and fast-varying components to examine potential local and background PM levels and the use of Nonparametric Trajectory Analysis (NTA) to identify local areas associated with high measured concentrations.

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ORAU/US EPA
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Development and Establishment of a Monitoring Network using Portable Emissions AcQuisition System to Quantify Heavy-Duty In-Use Vehicles Emissions in California

Source Characterization

There are over 1 million on-road heavy-duty vehicles (HDVs) in California, and the California Air Resources Board (CARB) has implemented several programs to regulate HDV emissions. There exists a need for fast, large scale, reliable methods to ensure existing regulations are being implemented effectively in real-world operations.. CARB has developed an autonomous real-time roadside plume emissions measurement system, named the Portable Emissions AcQuisition System (PEAQS), to provide a cost-effective measurement of individual and fleet-wide emissions with high spatial and temporal resolution. This system has been designed to quantify fuel-specific emission factors of black carbon (BC) and oxides of nitrogen (NOX). The PEAQS variants include lab-grade, mid-grade and low-cost systems to meet different program needs and continuously incorporate technological innovations.

CARB deployed PEAQS at 4 locations across California in 2016-2017, with > 7,000 vehicles measured. The results suggested that a small fraction of the in-use fleet is responsible for disproportionate amounts of NOX and PM. This presentation will highlight the several methods to assess the accuracy of fuel-based emission factors and the selection criteria for determining whether the calculated emissions factor is representative based on the duty cycle of the passing vehicle. Finally, we will discuss the design of a lower-cost PEAQS using sensors, and how this innovation can support establishing a PEAQS community monitoring network in CA, with a focus on HDV emissions.

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California Air Resources Board
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Integrating Spatiotemporal Variability and Modifiable Factors into Air Pollution Estimates

Source Characterization

City-wide air pollution measurements have typically relied on a small number of widely separated regulatory monitoring sites or land use regression (LUR) maps built using time-integrated samples to assess exposure. However, air pollutant concentrations may exhibit significant spatiotemporal variability depending on local sources and features of the built environment, which may not be captured by the existing monitoring regime. To better understand urban spatiotemporal pollution gradients on the <1 km scale, 15 fixed air quality monitoring stations were deployed in Pittsburgh from August 2016-May 2017. The fixed stations were deployed at locations with a range of traffic, restaurant and population densities and included measurements of ultrafine particle number (UFP), PM2.5, and a low-cost air quality monitor, the Real-time Affordable Multi-Pollutant (RAMP) sensor package for measuring CO, NO_2, O_3, and CO_2. Wavelet decomposition was used to separate short-lived (<2h) pollution events from partial-day events (2-8h) and persistent enhancements above the regional background. The average local (<2h) and persistent enhancement pollutant signals were better correlated with modifiable factors typically used as covariates in LUR building. The findings support building more accurate and time-resolved LURs, which may be more transferable to other domains by isolating the truly â€˜local’ pollutant signal. These improved LURs will enable better air pollutant exposure estimates.

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Characterizing urban emissions using low-cost, high-density sensor network

Source Characterization

In urban environments, air quality has complex spatial and temporal heterogeneity. Conventional approaches to understanding emissions, chemistry and exposure rely on continuous measurements with limited spatial resolution or passive sampling with high-spatial density and low temporal resolution. To better characterize the spatial and temporal patterns of urban emissions, we have deployed a low-cost, high-density sensor network in San Francisco Bay Area. The BErkeley Atmospheric CO2 Observation Network (BEACO2N) consists of approximately 65 sensor nodes, each measuring CO2, CO, NO, NO2, OÂ¬3, and aerosol using low cost technology. The sensors are packaged in a weather proof container and each node transmits data to an open access central repository routinely. Here we describe approach to characterizing emission sources at the spatial resolution of the network and emphasizing the correlation between atmospheric trace gases co-emitted from distinct source types.

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Data analysis of the particulate matter sensor network in two Chinese cities

Source Characterization

Particulate matter (PM) sensor networks have been increasingly set up around the world, however, data quality of such a network is a concern. Sensors near conventional air quality monitoring stations can be evaluated against data from these stations. For sensors located far from conventional stations, there is a lack of “reference data” for data quality analysis. In this study, we explored machine learning methods to evaluate the data quality of these sensors. PM sensor networks in two Chinese cities were evaluated and will be discussed in this talk.

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Plume Capture Method to Characterize On-Road Emissions by Heavy-Duty Diesel Trucks

Source Characterization

Heavy-duty diesel trucks are a major source of black carbon (BC) and nitrogen oxides (NOx) in urban areas, contributing to persistent air quality problems. Recently, diesel particle filter (DPF) and selective catalytic reduction (SCR) emission control systems have become standard equipment on new trucks.

To evaluate the in-use performance of DPF and SCR systems, a plume capture method was employed at the Port of Oakland and Caldecott Tunnel in the San Francisco Bay Area. With this method, pollutants in the exhaust of individual trucks are measured at high time resolution (â‰¥1 Hz) from a mobile lab stationed above passing traffic. Peaks in the concentration time series are integrated, and the ratio of each pollutant to carbon is multiplied by the carbon fraction of diesel to yield fuel-based emission factors (g kg-1). These emission profiles are linked to engine model year and installed emission control systems via recorded license plates.

Emissions from several thousand trucks were evaluated with the plume capture method. DPFs reduced the BC emission rate by up to 95% at both locations. SCR systems were more effective at reducing NOx emissions under the uphill, highway driving conditions at the Tunnel. The emission rates of co-emitted species (NO2, ultrafine particles, and N2O) depended on driving mode. Some trucks with 2007â€"2009 model year engines showed degradation in DPF performance over time, leading to higher BC emission rates compared to trucks without filters.

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Ambient and Fenceline Observations from Low-cost Gas and Particle Sensor Packages Deployed in Rural Malawi

Source Characterization

The nearly complete lack of continuous surface observations in much of Africa limits understanding of air quality trends and climatology and evaluation of atmospheric models or remote sensing products. For example, Malawi, a poor (7% of population has grid access), rural country in Southern Africa, has no air monitoring and is subject to a seasonally varying mix of sources (e.g., diverse biofuel combustion, open burning, regional transport). In response, we are deploying a network of low-cost/power sensor packages in rural Malawi to collect data on gases (CO2, CO, NO/NO2, O3), particles (size/count) and meteorological parameters. Sensor packages include the Aerodyne Research â€˜ARISense’ and the â€˜RAMP’ developed at Carnegie Mellon University. Particles are measured via optical particle counters and gases via electrochemical and non-dispersive infrared sensors. Before deployment in Malawi in June, 2017 and 2018, sensor packages were collocated with regulatory monitors in Pittsburgh, PA (RAMPs) and Durham, NC (ARIsense); algorithms and data products are evaluated against reference monitor data and each other. Initial pooled deployment in Malawi at a peri-urban university campus have been followed by long-term (1 year) deployment at the campus and two rural sites. Village-scale and fence-line sampling in communities dominated by biofuel combustion activities (e.g. domestic biomass burning, brick burning) also measured with emission sampling equipment has enabled evaluation of sensor packages under high-concentration conditions. This presentation will critically evaluate the measurement systems, provide an overview of air pollutant spatio-temporal variability and give insight into the utility of low-cost, low-power measurement systems in resource-poor environments, where they have great potential to fill large data gaps.

Presenting Author:
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North Carolina State University
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Building and Coding Low Cost Air Monitors in an Urban School Campus

Youth Education

Seventh grade students don't often think of the importance of air quality. How can this topic be made more engaging for these students and their families? As part of a classroom exploration, students built and programmed portable weather stations using a Raspberry Pi. Sensors were placed around the urban campus as well as in various student households. Over the course of eight weeks, students collected data from these sensors as well as particle monitors deployed by Duke University. Students gained invaluable knowledge of circuitry, programming and environmental science that otherwise would have been taught through a worksheet. The students responded enthusiastically to the project and wanted to learn more about a topic that is vital to their everyday life. Having built the sensors themselves, the data collection and analysis was more meaningful to the students. Understanding the engineering and science behind air quality will create a community more invested in environmental issues.

Presenting Author:
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Durham School of the Arts
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<u>Youth Education</u>

Student and Teacher-led Data Collection using Air Sensors during the DISCOVER-AQ Study

Youth Education

Citizen scientists can contribute valuable information to research studies through activities such as data collection and data analysis. The emergence of low-cost air sensors has stimulated more citizen science involvement in collecting air measurements, complementing citizen's desire to be more engaged and aware of air quality within their local community. In September 2013, a low-cost air sensor project involving citizen scientists was conducted in the Houston, Texas area under the umbrella of the NASA-led DISCOVER-AQ Earth Venture Mission. Teachers and students at seven local schools collected ozone (O3) and nitrogen dioxide (NO2) measurements using the CairClip sensor (O3/NO2 version and the NO2 version) for approximately one month. The participating schools were within 18 miles of a monitoring site containing regulatory-grade air quality measurements for comparison. Results indicated that the data collected by citizen scientists had similar trends compared to the nearby regulatory-grade monitoring site measurements. The schools provided supplementary measurement sites to understand the spatial variability of O3 and NO2 in the Houston area. Additional results of this study will be discussed along with lessons learned and recommendations for collaborating with students and teachers on low-cost sensor projects.

Disclaimer: Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.

Presenting Author:
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Team Science: A Cross-Disciplinary Training Approach to Citizen Science

Youth Education

Citizen Science has become a popular training tool for academic institutions, community groups, and government agencies trying to collect and analyze scientific data. A cross-disciplinary team is needed to train the public in addressing our complex sustainability challenges. This approach, known as “Team Scienceâ€�, seeks to address environmental challenges by bringing together leaders in the fields of education, public health, medicine, law, social justice, and environmental epidemiology, to work together to train individuals in Citizen Science. Using Team Science alongside Citizen Science promotes community based research that leads to the translation of scientific findings into effective policies, programs and practices. Our collaborative case-study, “Citizen Science in NYC School Communities,”will share how Team Science can be utilized as a replicable training model to empower urban educators and their students. Participants will learn how NYC teachers and students collected and analyzed air quality around their school community using AirBeam monitoring devices and as a result gained an understanding of the interdependence of economic, environmental, public health and social justice factors around air quality. In addition, this session will demonstrate how the teachers and students were able to use their research findings to develop targeted interventions that benefit the larger school community.

Presenting Author:
Luz Guel
The Mount Sinai Transdisciplinary Center on Early Environmental Exposures
Additional Authors:

Air Quality Sensors and Environmental Education at EPA

Youth Education

Come learn how EPA is using air quality sensors to promote STEAM education and cultivate the next generation of environmental leaders! Air sensors provide a unique opportunity to engage students in fun, hands-on, experiential learning that combines technical knowledge with civic participation. Students learn how air quality impacts their community and what they can do to improve it. We will be discussing case studies in which EPA has conducted environmental education activities using both high and low-cost air quality sensors as well as the different types of air quality curriculum available from EPA.

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Using a community air monitoring network to develop environmental health literacy and leadership with youth in Imperial Valley, CA

Youth Education

The proliferation of low-cost air sensors provides opportunities to bring awareness about air contaminants to new audiences. In California's Imperial Valley, an area known for high rates of asthma hospitalizations and poor air quality, advocates and researchers developed a network of 40 real-time air monitors to generate more information about air contaminants locally. The information from the network is publically available on the website IVAN Air (www.ivanair.org) and is especially useful to community members with respiratory sensitivities, to let them know when to stay indoors. Despite announcements about the network, not all residents of Imperial Valley are aware of the network. To increase awareness and to encourage participation of local youth with the network we developed a ten week internship for high school students. In the internship, youth reflect on their own experiences related to air contaminants and learn new information about sources of air contaminants. The youth also learn about how air contaminants are measured and how they can use the IVAN Air website to protect their health. After reviewing this information, youth interns present this information to the peers in their own words. The internship culminates with a visit to the state capitol where they share their experiences and concerns with elected representatives. Through the internship, the youth develop a deeper understanding about the connection between air contaminants and health and what they can do to improve air quality.

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Public Health Institute
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Development of Low-Cost Air Sensor Packages for Youth Education, Citizen/Community Science, and Developing Countries

Youth Education

The Air Quality Club of the Albany High School in California is actively developing low-cost air sensor packages for youth education, Citizen/Community Science, as well as for field deployment in resource-limited developing countries, with the first such field test taking place in Sri Lanka. We combine off-the-shelf components such as meteorology sensors, particle sensors, and microprocessors into sensor packages using enclosures designed by Club members for different indoor/outdoor environments. The "big data"gathered using these sensor packages will also be used in science and mathematics/statistics Advanced Placement classes at the Albany High School. These non-proprietary packages and associated software form a basic template for Citizen & Community Science groups to build upon. We will also discuss our plan to form a Citizen & Community Science group in Albany, California in the near future. This will allow us to deploy our sensor packages beyond the High School into the community. We also hope that this community group will serve as a blueprint for developing Citizen/Community Science programs elsewhere with High School resources (especially science and mathematics teachers) as the core.

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