EPA Assistance Agreement Annual Report Summary

Period Covered by the Report: May 1, 2020 to April 30, 2021
Date of Report: July 30, 2021
EPA Agreement Number: RD83618401
Title: Engage, Educate, and Empower California Communities on the Use and Applications of "Low-Cost" Air Monitoring Sensors
Investigators: Dr. Andrea Polidori (Contact PI), Dr. Philip M. Fine (PI), Dr. Jason Low (PI), Dr. Yifang Zhu (co-PI), and Hilary Hafner (co-PI)
Institutions: South Coast Air Quality Management District (South Coast AQMD), Diamond Bar, CA 91765; University of California Los Angeles (UCLA), 650 Charles Young Drive. S., Los Angeles, CA 90095; Sonoma Technology Inc. (STI), 1455 N McDowell Blvd, Petaluma, CA 94954
Project Period: May 1, 2016 to April 30, 2019 (3-yr no-cost extension until April 30, 2022 was requested and approved)

Objectives: The overall objective of the proposed research is to provide California communities with the knowledge necessary to appropriately select, use, and maintain "low-cost" sensors and to correctly interpret sensor data. This will be accomplished by pursuing the following four specific aims: (1) develop new methodologies to educate and engage communities on the use and applications of "low-cost" sensors; (2) conduct testing to characterize the performance of commercially available "low-cost" sensors and to identify candidates for field deployment; (3) deploy the selected sensors in California communities, and interpret the collected data; and (4) communicate the lessons learned to the public through a series of outreach activities.

Progress Summary/Accomplishments (Outputs/Outcomes):

Aim 1. South Coast AQMD worked with STI (co-Principal Investigator) to complete the Educational Toolkit. This Toolkit includes the "Community in Action: A Comprehensive Guidebook on Air Quality Sensors", three training videos, data analysis and visualization tools, and copies of resources developed for use during the STAR Grant (e.g., surveys, a release of liability form, examples of data analysis provided to communities, examples of reports created by communities, etc.). The Guidebook and resources are intended to support future air quality sensor projects through all phases: from planning a project to collecting and analyzing the data to taking action. Furthermore, the lessons and resources shared in the Toolkit will better enable communities to collect high quality and usable data. During this period, South Coast AQMD extended the original contract with Mazama Science, and the collaborative work has resulted in enhancements to the AirSensor (version 1.0) and DataViewer package (version 1.0.1). The AirSensor is a publicly available, open-source R-package that facilitates easier access to data from the project sensors, functions to process that data, and tools for analysis and visualization. This package has undergone external review and been released through CRAN (the Comprehensive R Archive Network). The DataViewer is a web-based application that leverages the capabilities of the AirSensor to allow project participants to engage with their sensor data in an intuitive way (i.e., this tool is user friendly, and no programming experience is required). South Coast AQMD staff presented the DataViewer to STAR Grant communities during final workshops, and the tool is now available for public use. The final workshops were completed during this period. All participants were invited to keep their sensors, and they now have the benefit of access to the tools and resources developed through this project.

Aim 2: Activities under Aim 2 were completed during previous reporting periods. Much of this work was undertaken by the South Coast AQMD Air Quality Sensor Performance Evaluation Center (AQ-SPEC, www.aqmd.gov/aq-spec), and we expanded our regular field and chamber testing activities to satisfy the objectives of this STAR project (Aim 2 specifically). AQ-SPEC staff conducted a thorough performance characterization of "low-cost" sensors that were commercially available at the time using both field and laboratory testing. We identified PM and Ozone "low-cost" air monitoring sensor candidates for field deployment. At the time of sensor selection, AQ-SPEC staff had tested around 15 air quality sensors. In addition, partners at UCLA (co-principal investigator) co-located a lower cost particle instrument (Dust Trak by TSI Inc.) with one of the sensors selected for this study. UCLA conducted these co-location tests to further study the accuracy of the sensors and provide supplementary information on performance.

Aim 3. Further analysis of the data from the sensors deployed during the STAR Grant was undertaken in the past reporting period. South Coast AQMD assisted UCLA (co-Principal Investigator) with the preparation of a manuscript sharing an analysis of data from paired indoor and outdoor sensors from a single community. This manuscript has been submitted and is in review. In addition, South Coast AQMD staff leveraged the AirSensor package (version 1.0) to complete an analysis of the performance of all STAR Grant sensors. This analysis covers three years, and data from 257 outdoor sensors are included. In this analysis, SOH metrics and QA/QC algorithms were used to examine sensor performance over time. In addition, one subset of 16 sensors was co-located at an air monitoring station (AMS), and the performance of these sensors was examined with respect to the high-quality reference data from the AMS. This dataset is novel regarding the number of sensors included and the length of the deployment and offered key takeaways in terms of sensor drift, seasonal variability in performance, and the agreement between co-located sensors deployed at different times. This manuscript is currently in preparation.

Aim 4. During this reporting period, final workshops were completed, at which South Coast AQMD staff shared a summary of project results and provided a demonstration of the DataViewer tool. A manuscript providing an overview of and introduction to the AirSensor package (version 0.5) and DataViewer tool (version 0.9.7) was published. Another manuscript was drafted sharing lessons learned, discussing how these lessons informed the development of the Educational Toolkit, and introducing the Guidebook. Two additional manuscripts are in preparation, sharing results from analyses of the sensor data.
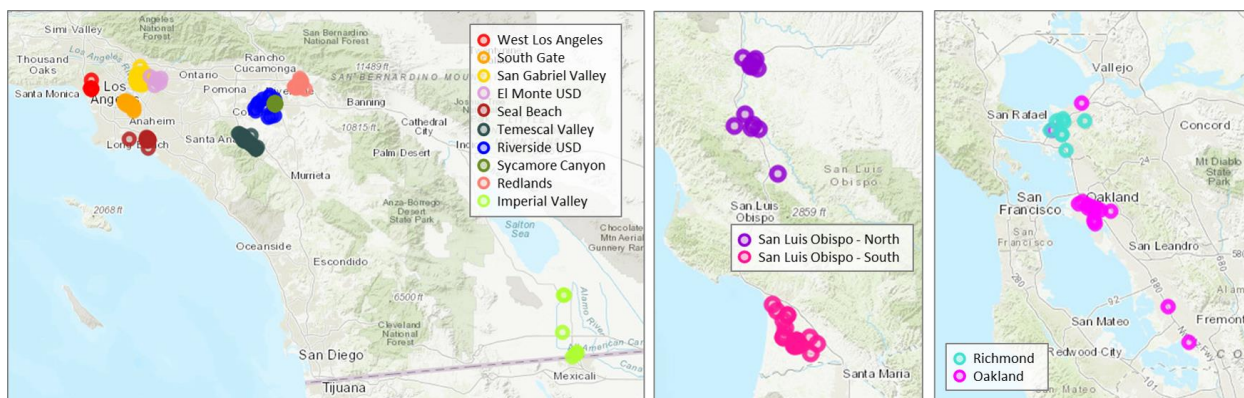

Figure. Sensors deployed in 14 California communities between October 2017 and April 2020.

Publications/Presentations:

During this reporting period, there has been 1 manuscript published, 3 manuscripts in preparation for submission to scientific journals, and 1 podium presentation at a conference:

Collier-Oxandale, A., Papapostolou, V., Feenstra B., & Polidori, A. AirSensor v1.0: Enhancements to the open-source R package to enable deep understanding of the long-term performance and reliability of PurpleAir sensors. *in preparation.* **2021**

Connolly, R., Yu, Q., Wang, Z., Chen, Y., Liu, J., Collier-Oxandale, A., Papapostolou, V., Polidori, A. Long-term evaluation of a low-cost air sensor network for monitoring indoor and outdoor air quality at the community scale. *in preparation.* **2021**

Collier-Oxandale, A., Papapostolou, V., Feenstra B., Boghossian, B., & Polidori, A. On the Use of Air Quality Sensor Networks with Multiple California Communities and the Development of an Educational Toolkit to Support Future Projects. *in preparation.* **2021**

Feenstra, B., Papapostolou, V., Collier-Oxandale, A., Cocker, D., & Polidori, A. The AirSensor Open-source R-package and DataViewer Web Application for Interpreting Community Data Collected by Low-cost Sensor Networks. *Environmental Modelling & Software*, 134, 104832. **2020**

Collier-Oxandale, A., Papapostolou, V., Feenstra, B., Der Boghossian, B., Mui W., and Polidori, A. Leveraging an open-access low-cost sensor network and an open-source R-package to observe changes in air quality both locally and globally before, during, and after the implementation of COVID-19 related measures. presented at 2020 Fall Meeting, AGU, Online. 1-17 Dec. (Podium presentation). **2020**

Feenstra, B., Papapostolou, V., Hasheminassab, S., Zhang, H., & Boghossian, B., Cocker, D., Polidori, A., Performance evaluation of twelve low-cost PM2.5 sensors at an ambient air monitoring site. *Atmospheric Environment*. 216, 116946. DOI: 10.1016/j.atmosenv.2019.116946. **2019**

Collier-Oxandale, A., Feenstra, B., Papapostolou, V., Zhang, H., Kuang, M., Der Boghossian, B., Polidori, A. Field and Laboratory Performance Evaluations of 28 Gas-Phase Air Quality Sensors by the AQ-SPEC Program. Atmospheric Environment. 220, 117092 DOI: 10.1016/j.atmosenv.2019.117092. **2019**

Williams R, Duvall R, Kilaru V, Hagler G, Hassinger L, Benedict K, Rice J, Kaufman A, Judge VR, Pierce G, Allen G, Bergin M, Cohen RC, Fransioli P, Gerboles M, Habre R, Hannigan M, Jack D, Louie P, Martin N, Penza M, Polidori A, Subramanian R, Ray K, Schauer J, Seto E, Thurston G, Turner J, Wexler AS, Ning Z. Deliberating performance targets workshop: potential paths for emerging PM2.5 and O3 air sensor progress. *Atmospheric Environment: X*. 2, **2019**

Marino, E., Collier-Oxandale, A., Zhang, F., Wang, Z., & Yifang, Z. The Air You Breathe: Lessons from the Community Air Monitoring Project at UCLA's University Village Apartments. Los Angeles. 2019. (Report)

Watanabe, K., Choy, E., Boerboom, S., Cohen, E., Ranheim, E., Mendell, C., & Mora Solis, B. PM 2.5 Air Quality Trends at Mark Keppel High School for Asian Pacific Islander Movement. Roberts Environmental Center at Claremont McKenna College. **2019**. (Report)

Papapostolou, V., Collier-Oxandale, A., Feenstra, B., Ranheim, E., Martin, H., Callahan J., Polidori, A., Exploring Different Ways of Communicating Results and Visualizing Data from Low-cost Sensor Networks. American Geophysical Union, Fall Meeting 2019, December **2019**, San Francisco (Poster presentation)

Collier-Oxandale, A., Papapostolou, V., Feenstra B., Boghossian, B., & Polidori, A. Lessons Learned from the Deployment of Low-Cost Air Quality Sensors in 14 California Communities. American Geophysical Union, Fall Meeting 2019, December **2019**, San Francisco (Poster presentation)

Martin, H., Callahan J., Collier-Oxandale, A., Feenstra, B., Papapostolou, V., Ranheim, E., R Package for Air Sensors. American Geophysical Union, Fall Meeting 2019, December **2019**, San Francisco (Poster presentation)

Collier-Oxandale, A., Papapostolou, V., Feenstra B., Boghossian, B., & Polidori, A. Preliminary Assessments of Sensor Performance and Data Analysis for California Communities under a US EPA STAR Grant Project. 37th AAAR Annual Conference. October **2019**, Portland (Poster presentation)

Jia, S. An Analysis of Effects of Woolsey Wildfire on UCLA University Village Air Quality using low-cost sensors. UCLA. ProQuest ID: Jia_ucla_0031N_17934. Merritt ID: ark:/13030/m50s4ngz. Retrieved from https://escholarship.org/uc/item/8s65z1fw, **2019**. (Master's Thesis)

DeWinter, J., Hafner, H. R., Papapostolou, V., Polidori, A. Community-Based Air Quality Monitoring with Low-Cost Sensors: Developing a Toolkit, Best Practices, and Lessons Learned. American Geophysical Union, Fall Meeting 2018, December **2018**, Washington D.C. (Poster presentation)

Feenstra, B., Papapostolou, V., Pikelnaya, O., Polidori, A., Doraiswamy, P., Gupta, P. Lessons learned and analysis from a year-long deployment of a network of low-cost particulate matters sensors. American Geophysical Union, Fall Meeting 2018, December **2018**, Washington D.C. (Poster presentation)

Papapostolou, V. Air Quality Sensing & Monitoring in Citizen Science. Brown Bag Lunch Meeting Presentation at the South Coast Air Quality Management District. October **2018**. (Podium Presentation)

Papapostolou, V., and Hafner, H. Community Sensor Training: Best practices and lessons learned for Engaging Communities in Air Quality Monitoring. Air Sensors International Conference. September **2018**, Oakland, California. (Pre-Conference Training Session and Panel Discussion)

Feenstra, B. Development of a cloud-based application to ingest, validate, analyze, and map data from a large PM sensor network. Air Sensors International Conference. September **2018**, Oakland, California. (Podium Presentation)

Papapostolou, V. South Coast Air Quality Management District – Air Quality Sensor Performance Evaluation Center. Air Sensors International Conference. September 2018, Oakland, California. (Podium Presentation).

Papapostolou, V. Air Quality Sensing & Monitoring in Citizen Science. Brown Bag Lunch Meeting Presentation at the South Coast Air Quality Management District. October **2018**. (Podium Presentation)

Feenstra, B., Papapostolou, V., Cheung, R., Polidori, A. One Year Spatial and Temporal Variability of PM in a Southern California Community using an Air Quality Sensors Network. 10th International Aerosol Conference, September **2018**, St Louis, Missouri. (Podium presentation)

Feenstra, B., Papapostolou, V., Cheung, R., Polidori, A. Cloud-based Application to Manage Data from Distributed Air Quality Sensors Networks. 10th International Aerosol Conference, September **2018**, St Louis, Missouri. (Podium presentation)

Papapostolou, V., and Feenstra, B. Low Cost Sensors: The "How" of Performance Evaluation, Network Design and Data Handling. 10th International Aerosol Conference, September **2018**, St Louis, Missouri. (Presentation and Tutorial Session)

Hagler GSW, Williams R, Papapostolou V and Polidori A. Air quality sensors and data adjustment algorithms: When is it no longer a measurement? *Environmental Science and Technology*, DOI: 10.1021/acs.est.8b01826, **2018**

Papapostolou V, Zhang H, Feenstra BJ and Polidori A. Development of an environmental chamber for evaluating the performance of low-cost air quality sensors under controlled conditions. *Atmospheric Environment*, 171: 82-90, **2017**

Papapostolou V, Feenstra B, Zhang H, Polidori A. "Low-cost" Sensors for Measuring Gaseous and Particle Air Pollutants: Performance Results from Three Years of AQ-SPEC Field and Laboratory Testing and Network Applications at the Fenceline and Community Level. Air and West Management Association – 2017 Air Quality Measurement Methods and Technology, November **2017**, Long Beach, California. (Podium presentation).

Papapostolou V, Zhang H, Feenstra B, Polidori A. Development of an Environmental Chamber for the Laboratory Evaluation of "Low-Cost" Air Quality Sensors. 36th American Association for Aerosol Research, October **2017**, Raleigh, North Carolina. (Podium presentation)

Polidori A, Feenstra B, Papapostolou V, Zhang H. Performance Evaluation of "Low-Cost" Sensors for Measuring Gaseous and Particle Air Pollutants: Results from Three Years of Field and Laboratory Testing. 36th American Association for Aerosol Research, October **2017**, Raleigh, North Carolina. (Podium presentation)

Feenstra B, Papapostolou V, Pikelnaya O, Zhang H, Polidori A. Spatial and Temporal Variability of Particulate Matter Using a Network of Air Quality Sensors in a Southern California Community. 36th American Association for Aerosol Research, October **2017**, Raleigh, North Carolina. (Poster presentation)

Upcoming Activities:

Aim 3. We anticipate the completion of two publications that provide in-depth sensor data analysis during the subsequent reporting period. As described, one publication will focus on air quality sensor data from a single community. In contrast, the second publication provides an overview of the long-term performance of all sensors deployed under the STAR Grant.

Aim 4. Work during the subsequent reporting period will focus primarily on the dissemination of lessons learned and final products. For example, South Coast AQMD staff will present the Educational Toolkit both internally and externally. Internal presentations will increase awareness of these resources among other groups at South Coast AQMD, including groups involved with public engagement and outreach. External presentations or webinars (e.g., at scientific conferences) will increase awareness of these resources among communities and researchers working with low-cost air quality sensors. In addition to presentations, we will explore other methods of dissemination, for example, attending local outreach events or making video tutorials to introduce the AirSensor package. Furthermore, the completion of the three publications in preparation will also support disseminating lessons learned and final products.

Supplemental Keywords: community recruitment, community engagement, community education, community empowerment, sensor testing, sensor selection, sensor deployment, particulate matter, PM2.5, PM10, ozone, data interpretation, public outreach, community outreach, educational outreach, STEM

Relevant website: www.aqmd.gov/aq-spec