SSV's Clean Air Equity Pilot Project
Final Report

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Executive Summary

Recent events surrounding the COVD pandemic have underscored the fact that low-income communities are disproportionately exposed to poor air quality. The Environmental Protection Agency and CARB have identified in Disadvantaged (SB535) and Low Income Communities (AB1550), (https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/communityinvestments.htm). The objective of Clean Air Equality Project (CAEP) is to conduct a community air monitoring program using low-cost sensors to gather hyper local data to explore if students from diverse communities across the SF Bay Area live with different air quality. Our objective requires that we select student participants from diverse backgrounds and communities. CAEP will use low-cost air quality sensor technologies since federal reference measurements are sparse. Low-cost sensors have been making great advances and offer the potential to obtain hyper-local information on air quality. While these low-cost sensors do not have the accuracy and precision of federal reference methods, with proper inter-calibration and interpretation, they can shed light on the different air quality being experienced by diverse socio-economic communities.

To accomplish CAEP objectives we envision selecting 100 students from diverse communities, providing each with a BackpAQ device, training them on its use, and conducting monitoring activities. We propose to have bi-weekly meeting with the students to keep them motivated, teach them about air quality issues, analysis techniques and interpretation of the data. Students or small groups will be encouraged to devise and execute their own experiments. This report covers a pilot project we conducted to demonstrate the feasibility of the project and beta test the BackpAQ devices and related software. We are actively seeking collaborators and funding for the full CAEP project.

Objective of the Pilot Program

The objective of this pilot project is to have a small group of youth use the devices and associated software developed by SSV BackpAQ Labs and provide feedback on the ease of use of the device and software. The youth will be asked to make routine measurements and provide feedback on their measurements and experience.

Methods

To accomplish this objective, we have divided the project into several tasks:

1. Outreach and Identification of High School partners with students willing to participate.
2. Build sensors for each student participant.
3. Distribution of mobile sensors to students and training on use.
4. Execute Project, including bi-weekly virtual meetings to introduce concepts of air quality, scientific method, data analysis, interpretation of data, etc. to the students and review data to date.
5. Dissemination of results by brief out to communities and report.

Task 1. Outreach and Identification of High School partners with students willing to participate.

SSV identified two groups of youth who were interested in participating in this pilot program. These were 6 students from Dublin HS led by Mr. Kaehms and 4 youth from Youth United for Community Action (YUCA) led by Ms. Bello. Our objective requires that we select student participants from diverse backgrounds and communities. The BackpAQ technology leverages the user's smart phone to host the BackpAQ app, and provide GPS location and WiFi hotspot.

Task 2. Build sensors for each student participant.

This project is made possible by a mobile low cost-sensor was developed by Sustainable Silicon Valley's BackpAQ Labs. It measures PM, VOC, CO2, temperature, pressure, relative humidity, and GPS coordinates. (See Figure 1) It is small, battery-powered, weighs 9 oz., and is designed to be worn on a backpack or attached to a belt. We provided each youth participant with a functioning BackpAQ sensor. This allowed us to concentrate on the study objectives.

Task 3. Distribution of mobile sensors to students and training on use. Siting of stationary sensors, likely at schools.

The bi-weekly zoom meetings lasted an hour. The topics were:

1. an introduction to the BackpAQ device, AQView, and the Blynk-based BackpAQ smartphone app and how to use it.
2. a summary of what we will be trying to accomplish in this pilot study
3. feedback from participants, and
4. A brief introduction to air pollution (we will be expanding on this in the coming weeks)

Task 4. Execute Project, including bi-weekly virtual meetings to introduce concepts of air quality, scientific method, data analysis, interpretation of data, etc. to the students and review data to date.

Measurements are displayed in real time on a smart phone and anonymously recorded to cloud for later analysis. These mobile measurements will be backed up by comparison with AirNow.org and fixed low-cost measurements. The fixed sensors will be stationary versions of BackpAQ and Vaisala.

We met with the youth every other week via zoom to talk about how things are going and explore the data. We will be looking at the difference between their measurements and federal measurements, such as AirNow.gov, and any low-cost sensor measurements in the area such as Purple Air. We will look at the effect of time-averaging on what the data looks like. We will also look at the different air quality in different parts of the Bay Area, and inside versus outside air quality. To facilitate these discussions, we will ask that the students do a couple of things:

1. We would like the students to have a standard walk that they can do during the day and to do the same walk at least every other day but at different times. This will allow us to compare the air quality as it varies from day to day and at different times. They should use the track naming feature in the app to indicate when they are starting the walk.
2. The students should use the comment feature of the app to indicate when there is a change of venue, such as going outside, moving from room to room in the house, etc. We will be looking at the difference between air quality outside and inside and how if varies from room to room. This will also be important if they go to a different neighborhood or part of the Bay Area.

Students will be able to download the data as a csv or other type of file so they can manipulate the data. We will be going over how to do this in our sessions.
Task 5. Dissemination of results by brief out to communities and preparation of final report.

Anonymity

SSV will not know which student is associated with what sensor. We track the sensors by a unique device name and only the school representative will know which student is assigned to which device.

Prior Work

Sustainable Silicon Valley is a non-profit "think & do tank" focused on water use & reuse, air quality & mobility and leading a prosperous, equitable & sustainable life in a decarbonized Bay Area.

The most relevant project that SSV has completed is SmartTA, which was completed in 2019. The project objective was to see if high traffic congestion through East Palo Alto from the Dumbarton Corridor could be linked to poorer air quality in the region. SSV partnered with Greenaction, YUCA, and the BAAQMD to measure air quality and traffic congestion in the area for 4 months. PM, CO, O3, and NO2 were measured at 3 sites along University Ave. in East Palo Alto. A final report was delivered to BAAQMD and presentation of results were made to the community, East Palo Alto City Council and other city officials. The findings of the study were:

- There is a correlation between traffic congestion and outdoor air quality
- In general, outdoor air quality was good to moderate during our field tests.
- No evidence of point pollution sources.

Results

The BackpAQ project is an essential part of a middle and high school STEM curriculum that promotes learning about and experience with the monitoring of air quality (AQ) particularly in disadvantaged communities, and drives engagement among underrepresented youth in STEM activities.

Key to the program is deployment of a suite of community-based mobile air quality monitors that leverage new low-cost sensors. These handheld units can be readily assembled by advanced middle-school and high school students and other STEM-oriented youth who are motivated by interest in obtaining, understanding and sharing hyper-local air quality data.

As designed, the monitors will measure and display criteria pollutants PM1, PM2.5, and PM10 concentrations in ug/m3, as well as display the US EPA Air Quality Index (AQI). Gases such as TVOC and CO2 are also easily monitored with BackpAQ and can be optionally built in. Monitoring of additional pollutants, such as CO, O3, NO2 and SO2 are possible future enhancements. The latest version pairs with a smartphone app to provide an interactive user experience and allow customization and personalization of monitored data and how it's displayed. BackpAQ automatically uploads data to the ThingSpeak cloud where it can be visualized using powerful analytics, and shared with other students or local community officials.

With the built-in Wifi Connectivity, BackpAQ will measure and report PM, TVOC and CO_2 concentrations automatically. The design is open source, with complete hardware and software details publicly available on Github. It comes pre- programmed, but further modifications on its software are possible using Arduino. By default, all measurements are sent to the cloud IOT database ThingSpeak, and are accessible with the API or can be viewed online. This makes it convenient for the classroom, for workshops or citizen science projects. On a larger scale, a network of BackpAQs constitutes a global array of interconnected monitoring stations, focused on continuous Environmental Surveillance. Its purpose is to generate fully transparent open data, used to assess the quality of our environment. The AQView toolset makes the BackpAQ data accessible and visible in real time via an API interface directly from the ThingSpeak cloud.

The BackpAQ App

In order to provide BackpAQ users with a way to interact with the sensor devices and keep the unit cost low, a smartphone-based app was developed, based on the popular IoT app Blynk. As can be seen from the images below, the BackpAQ app allows the user to display and manage all of the realtime data being collected from the particulate and gas sensors, as well as visualize the samples collected along specific “tracks” or, in this instance, walks around the students’ communities. Additionally, the app coordinates communications between BackpAQ and the smartphone-based sensors which provide GPS location, realtime clock, battery monitor, and WiFi networking to the cloud.

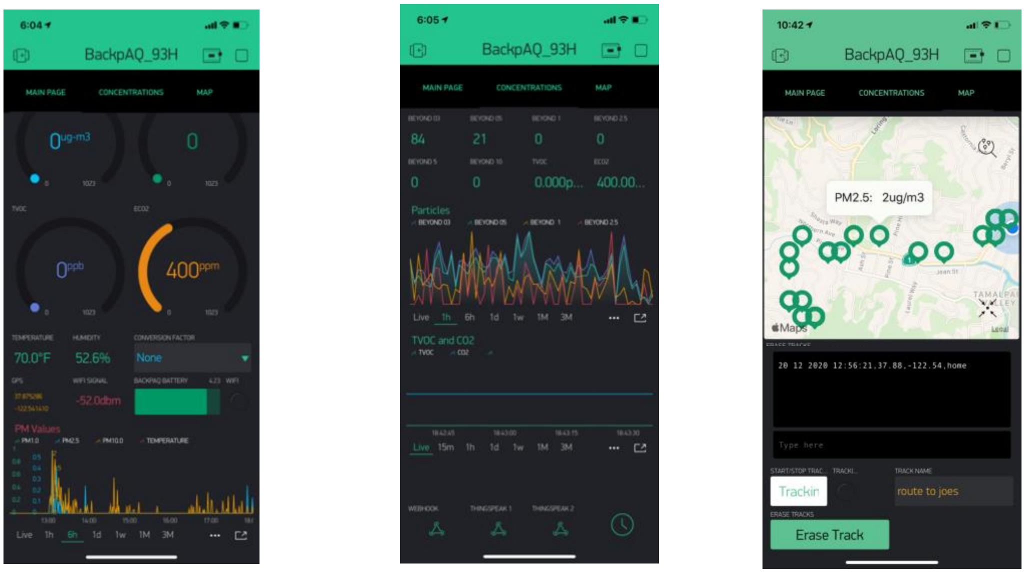


Figure 1 . The BackpAQ App (L to R: Main Screen, Concentations, Map and Track)

ThingSpeak Cloud IoT Database
In order to provide a tool-rich cloud for managing and working with BackpAQ data, we partnered with ThingSpeak to utilize their low-cost and easy-to-use IoT platform. When students are issued their BackpAQ monitors, they are provisioned and ready to start using the ThingSpeak tools like graphs, charts, and custom programs using the powerful Matlab toolset.

AQView
To provide further capabilities to collect, manage and display data from BackpAQ devices, the AQView Community Air Quality Portal was developed. Using this website and tools, users can directly inspect the realtime data coming from registered sensors (via ThingSpeak) alongside data from other's similar devices. For this project, we had a total of 10 registered devices which were displayable on the portal, along with an official reference AQ site (EPA's AirNow). Users can simply click on their device to see the realtime measurements, or open a powerful "superchart" tool to display their detailed data alongside their classmates. Other capabilities include TrackCharts, a tool to visualize users' recorded tracks and associated measurement points.

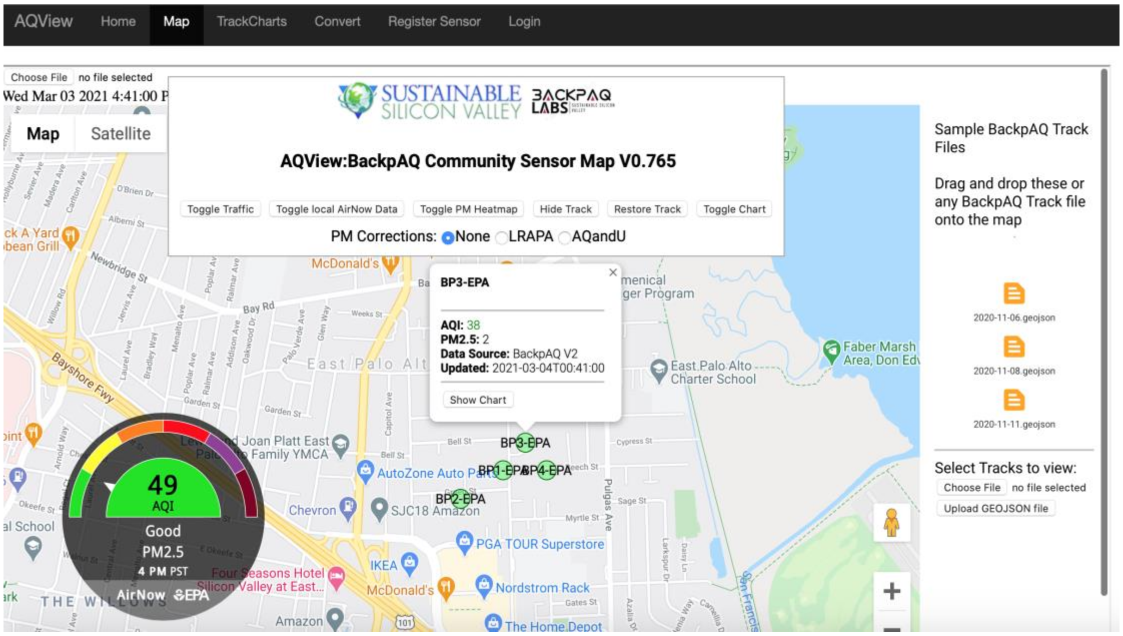


Figure 2. The AQView Community Air Quality Portal and Map

Brief description of getting devices built and to youth.

An important part of collaborating with middle and high school students who are hoping to become citizen scientists is assuring they have the proper understanding of the science behind the research they will be conducting. An identified difficulty in the introduction of low-cost AQ sensors to the public is the citizens' perception of the sensor as a "black box," the workings of which are obscured [5]. Without proper understanding of the research tool the citizen will be using, engagement may suffer, and students may easily reach erroneous conclusions about their data, possibly causing conflict with community partners. For instance, low-cost air quality sensors, like any sensor, may produce biased results, periodically drift, or report unreasonable particulate counts. However, many people who are not accustomed to the difficulties in obtaining and interpreting data tend to accept the numbers from *their* personal sensor with little skepticism, leading to either unnecessary alarm or complacency [6]. When their data conflicts with official government measures of air quality, some citizens have instead questioned the local Division of Air Quality and accused them of underreporting poor air quality, undermining partnerships essential to citizen science efforts.

To both aid students in understanding their AQ monitor and its data and further facilitate connections with educators' learning objectives, we have designed a high-quality instrument that is accessible in an easy-to-assemble kit. The student-built monitors, encased in a lightweight polycarbonate box, weigh less than a pound, and are powered by rechargeable LiPo batteries to give over 8 hours of daily use. They feature carabineers and nylon straps for easy fastening to a backpack or bicycle frame, or can be left plugged-in in a secure location. It's estimated that kits will cost about $85.

Students building and carrying their devices through their daily lives will deepen their engagement with and understanding of air pollution and the importance of hyper-local monitoring. The data SSV and our student partners collect will help inform how to best engage underrepresented students in STEM activities - such as these - and interest them in potential STEM careers. Students will also receive training in and hands-on experience with advanced data science tools. It is hoped that this initial cohort will become ambassadors to their peers across the region, attracting more student, school and city participation. The lessons we'll learn from this project will help others develop similar approaches tailored to their own communities.

Building BackpAQ devices at Dublin High School

In January 2019 SSV launched a BackpAQ pilot program with Dublin High School. Fourteen students signed up for the after-school lab, taught in conjunction with an award-winning engineering academy led by teacher Eugene Chou. Students were provided with BackpAQ kits which included all necessary hardware, software and cloud services. By mid-February 10 of the 14 students had completed assembly of their monitors and are looking forward to the next phase, seeking out pollution sources on their campus and in their community.

CAEP Pilot Program

Kick off

SSV identified two groups of youth who were interested in participating in this pilot program. These were 6 students from Dublin HS led by Mr. Kaehms and 4 youth from Youth United for Community Action (YUCA) led by Ms. Bello. Our objective requires that we select student participants from diverse backgrounds and communities. The BackpAQ technology leverages the user's smart phone to host the BackpAQ app, and provide GPS location and WiFi hotspot.

Summary of youth experience.

In general, the concept and objectives of the project were embraced by both cohorts. Both groups enthusiastically competed the device setup, checkout and initial use. After they were given some basic instruction on usage and measurement technique

Feedback on using the BackpAQ Monitors

Prior to presenting the feedback we collected from our student cohort, we want to remind our readers that the BackpAQ devices and associated BackpAQ App and AQView software, as well as user guides and instruction materials are all at *Beta level*. That is, still under development , and therefore contain limitations and bugs that will hopefully be corrected in future versions.

Overall feedback gathered during the Zoom calls indicated enthusiasm and continued engagement from the students. However, there were several specific "positives" that stuck out for us:

- Several students mentioned that they "felt empowered" and "motivated to explore their communities more often" when carrying the devices. Others felt they could better understand and appreciate the effects that air pollution might be having on their communities.
- Two students mentioned that wearing the BackpAQ "made me want to get more exercise and take longer walks". This was interesting as neither of us had thought of the Pilot or BackpAQ as a personal fitness application.

- Several students made extensive use of the AQView TrackView tools, creating large, detailed surveys of their surrounding community.
- One or two mentioned a science project or other activity that might be a good application for BackpAQ. We encouraged them to follow up with to extend the loan period of the devices.

A couple of opportunities for improvement were also mentioned:

- Some students thought not enough instruction was given at the beginning to help them get started using the devices. Examples included using the GPS location services and WiFi hotspot from their phones, and usage of the BackpAQ app in interpreting the data stream
- In terms of the BackpAQ device itself, several students commented that the WiFi connection at first failed, then appeared to work well once re-connected.
- We heard from several students that the AQView user interface was "not intuitive enough" and needed to be cleaned up a bit.

Visualizations of collected data

Among the more difficult challenges of creating and providing a program such as this one is enabling students to understand and engage with the data they are collecting and managing. This challenge is multiplied when the incoming data is on the move, ie, mobile. Traditional techniques for data visualization work well with stationary sources, but are not really adequate or even useful when considering the kinds of data coming from the BackpAQ devices. New techniques had to be created, such the concept of "tracks" which contain a defined set of time-stamped measurements which are saved to the cloud, and are later searchable and viewable via the AQView tool. And to view these tracks, a set of temporal & spatial visualization tools needed to be designed as well. With TrackView, a user can examine their time-based tracks in sync with PM and Gas measurements taken at specific intervals and GPS-based locations. Details on the design and development of the tools are available from the authors.

By using AQView and the TrackView tools, students can visually reconstruct their community walks and in-home measurements by searching the ThingSpeak database by date and time of the track recording.
Below is a screenshot of one student's tracks recorded on 2/18/21, as they walked around their community collecting AQ samples. Note the relatively "good" air quality indicated by the majority of yellow-colored markers at each measurement point, and the higher PM concentrations at the upper right-hand corner.

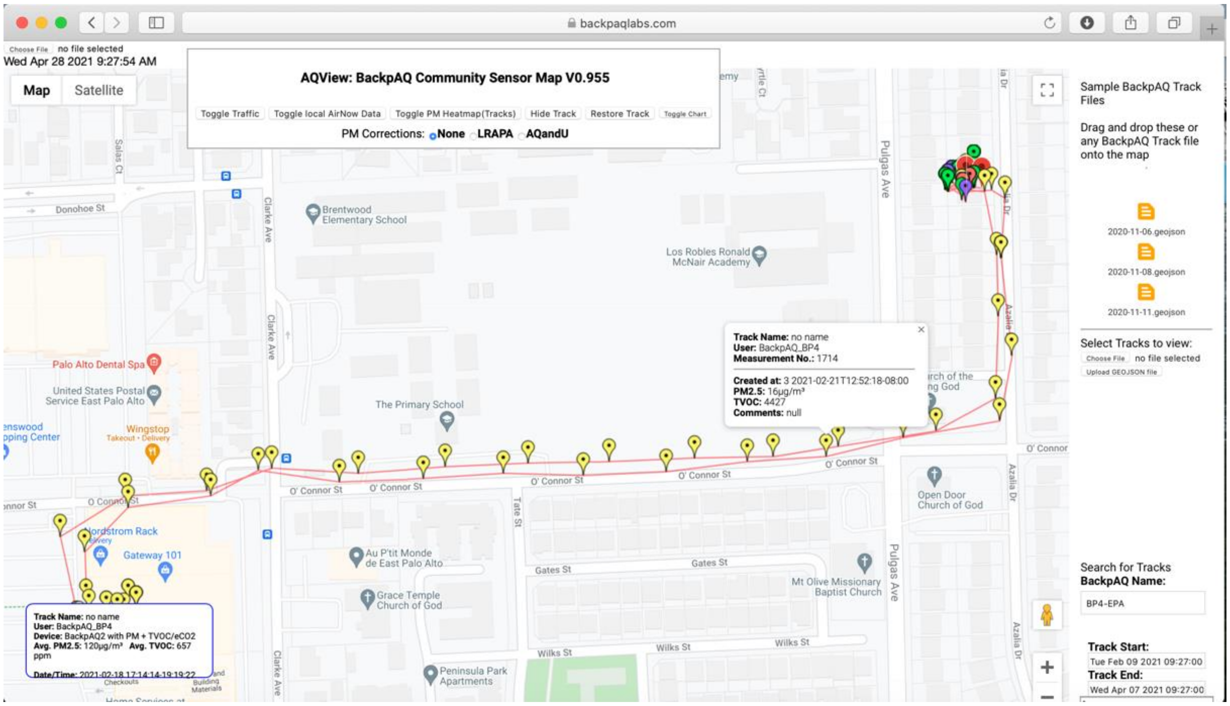
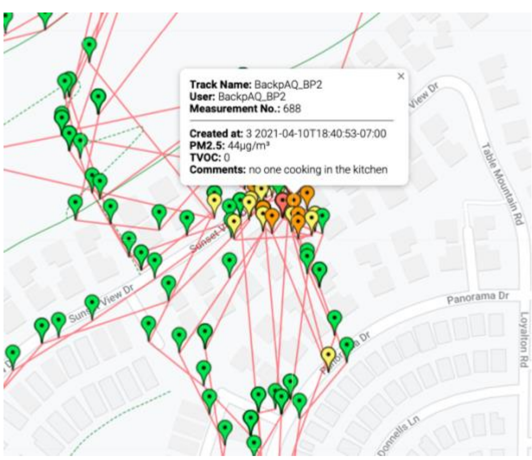
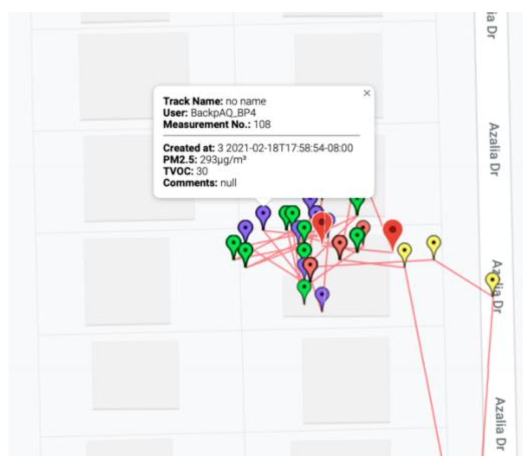


Figure 4. TrackView, allowing visualization of students' tracks and associated PM, TVOC measurements

Here are two other TrackViews (zoomed-in) that show indoor AQ measurements. Evident are relatively higher PM samples indicated by the corresponding yellow, orange and red colors that follow the EPA AQI color/breakpoint scheme. Note also the TVOC value of 30 in Fig. 6. Note also the comments displayed which were entered via the BackpAQ app as the user walked around with the device.





Figures 5. And 6. TrackView is displaying some indoor tracks with higher PM concentrations

Finally, TrackView has an "advanced mode" which allows users to examine each BackpAQ measurement point in detail (lower graph), and at the same time see where in their journey that measurement took place (upper map). Note that tracks can be selected by searching by date and time.

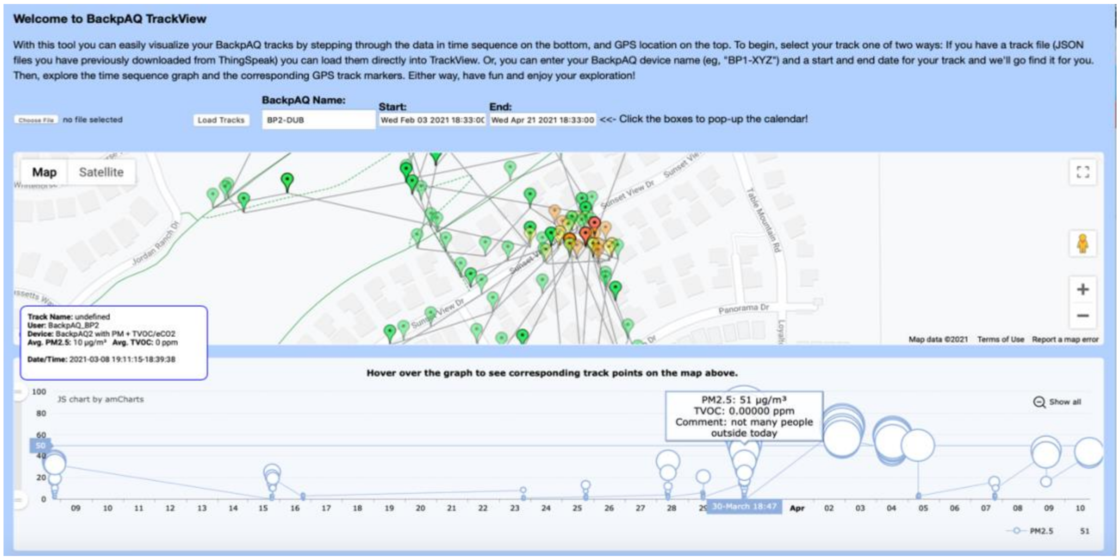


Figure 7. TrackView advanced mode showing detailed measurement graph view

Suggestions for future development.

- Pilot program overall
  - Make it more fun. Improve engagement by "gamifying" certain activities and adding some competitive elements to data collection and analysis functions
  - Allow participants to design their own experiments, coming up with a hypothesis and designing analytics to show results of their investigation

- BackpAQ Monitors
  - Better user documentation and "getting started" tutorials
  - Clean up the AQView user interface to make it more intuitive and easier to get started
  - Improve the smartphone interface and make setup faster and more reliable
  - Enhance the charting and graphing capabilities
  - Add averaging and other statistical capabilities to AQView
  - Improve battery life through better power management
  - Upgrade all devices to include TVOC and CO2 measurement capability
  - Explore addition of new sensors such as ambient noise and other gases
  - Explore use of machine learning to train a model for predicting areas of pollution based on collected data

Summary & conclusions

The CAEP Pilot program accomplished all of its objectives and was highly successful. The BackpAQ devices and associated software worked well and reliably. Ten youth at Dublin HS and YUCA were highly engaged in the program and working with the devices. Two Dublin students are keeping their sensors over the summer to conduct additional tests. The youth provided valuable insights into the workings of the BackpAQ device and had useful suggestions on the user interface of the Blynk app and AQView. They also had relevant suggestions on how to make the program more attractive and usable to students in the future.

We are actively seeking collaborators to implement the full CAEP project. We are in particular looking to engage Bay Area high schools and high school districts to explore ways to include using the BackpAQ devices as part of their curriculum, as a extracurricular activity or as part of student science projects.