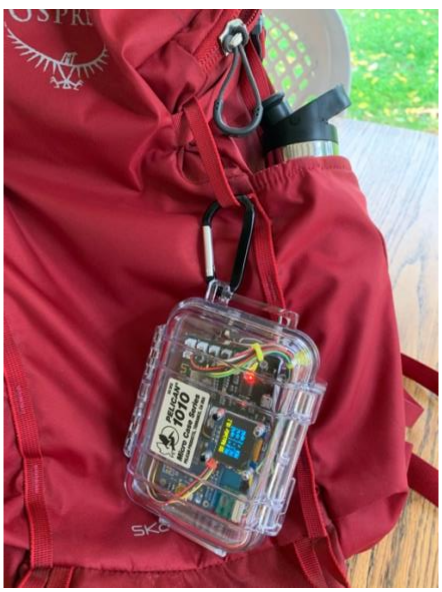
User's Guide

BackpAQ Mobile *Personal* Air Quality Monitor V3



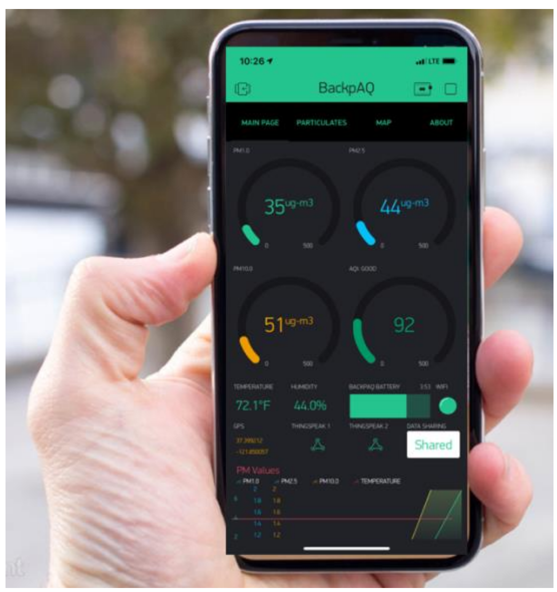


Table of Contents

- Introduction
- Quick Review of What We're Measuring
- Design and Specifications
- Configuring Your BackpAQ
- Using the BackpAQ App
- The AQView Community Air Quality Portal
- A Word About Safety

Appendices

Introduction

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.

What (and how) we'll measure

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 . 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.

The magnitude of the measured pollutants can be viewed and monitored via several powerful methods, including the BackpAQ's own built-in OLED display; gauges, graphs and reports on the companion BackpAQ smartphone app; the Cloud-based ThingSpeak data collection and management tool; and finally the standalone color-coded CO2 display that can be plugged into BackpAQ that provides "traffic light" monitoring of ambient CO2.

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 assert 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.

What we'll learn

To begin with, we'll learn design, build and fabrication techniques - along with some pretty powerful electronics, Internet-of-Things (IOT), and sensor technology skills. Perhaps most importantly, we'll learn how to curate and analyze data we capture from the monitors. Learning how to develop and apply critical judgement to the data and subsequent reporting and sharing of findings and implications are key outcomes of this project.

Outcomes

The intended outcome of this project is twofold: one, obtain a richer, deeper understanding of air pollution, where it comes from, how to measure it, how to harness powerful analytics to responsibly report and share findings, and (hopefully) gain some insight that will enable ordinary concerned people to do something about it. And two, build a monitoring device - BackpAQ - to better understand the science and engineering behind sensors, IOT, the Maker Movement, and have hands-on involvement with one of the more critical challenges facing communities today.

Quick Review of What We're Measuring

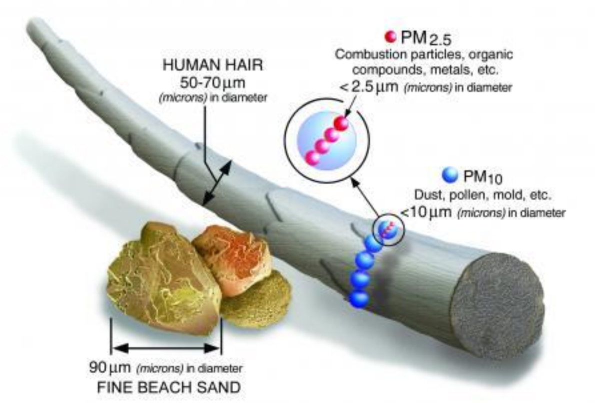
Before we get started building, let's take a look at the science behind air quality, sensors and monitoring.

"I've got one word, just one word….Particulates! (see movie "The Graduate" for why I have paraphrased here.)

So, what are "Particulates" (PM), and how do they get into the air?

Size comparisons for PM particles

PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye.
Others are so small they can only be detected using an electron microscope. Particle pollution includes: PM10: inhalable particles, with diameters that are generally 10 micrometers and smaller; and PM2.5 : fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. How small is 2.5 micrometers? Think about a single hair from your head. The average human hair is about 70 micrometers in diameter – making it 30 times larger than the largest fine particle. See this:



Sources of PM

These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks or fires. Most particles form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted from power plants, industries and automobiles.

What are the Harmful Effects of PM?

Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Some particles less than 10 micrometers in diameter can get deep into your lungs and some may even get into your bloodstream. Of these, particles less than 2.5 micrometers in diameter, also known as fine particles or PM2.5, pose the greatest risk to health. Fine particles are also the main cause of reduced visibility (haze) in parts of the United States, including many of our treasured national parks and wilderness areas. Learn more about health and environmental effects.

The PM Sensor for BackpAQ

The particulate sensor we have chosen for this project is the Plantower PMS7003. It is able to measure the concentration of fine particles of less than 1µm (PM1); less than 2.5µm (PM2.5) and less than 10µm (PM10). The operating principle of the PSM5003 sensor is as follows: a laser illuminates airborne particles. An optical sensor captures the laser light and generates an electrical signal proportional to the rate and size of the particles in the air. This block diagram shows what's going on inside the sensor. Note that there is a microprocessor that does some computation and digitization of the signal so that we can read the data in our own hardware.

What are ATM and CF1?

The CF_ATM and CF_1 values are calculated from the particle count data with a proprietary algorithm developed by the laser counter manufacturer, Plantower. The specifics of the calculation are not available to the public (or us for that matter). However, to convert the particle count data (um/dl) to a mass concentration (ug/m3) they must use an average particle density. They do provide 2 different mass concentration conversion options; CF_1 uses the "average particle density" for indoor particulate matter and CF_ATM uses the "average particle density" for outdoor particulate matter.

Depending on the density of the particles you are measuring the sensor could appear to read "high" or "low". Some groups have developed conversion factors to convert the data from the sensor to match the unique average particle density within their airshed.

Measuring CO2

Carbon dioxide is a gas heavier than air. In small quantities of up to 5000ppm (0.5%) can cause headaches, lethargy, slowing of intellectual ability, irritability, sleep disturbance. In larger quantities can cause dizziness, loss of sight, hearing or knowledge. Typically, fresh air contains between 360ppm and 410 ppm of CO2.

What are the benefits of monitoring CO_2 levels?

When a group of people are indoors, the concentration of CO_2 is expected to increase, as humans naturally exhale CO_2. However, at high concentrations, humans can experience negative effects, including reduced concentration and a compromised well-being (**Figure 4**). CO_2 sensors like the SCD4x serve to measure and control elevated CO_2 concentrations to counteract these negative symptoms. Studies have shown positive effects on productivity and health when CO_2 concentrations in an environment are below 1000 ppm. Comparatively, the normal CO_2 level for outdoor environments is at around 400 ppm. CO_2 sensors can be used to maintain optimal CO_2 levels indoors, as their measurements can be used to monitor levels and act accordingly by bringing in fresh air via mechanical ventilation (Demand Controlled Ventilation (DVC), air handling units, etc.) or natural ventilation (open doors or windows).

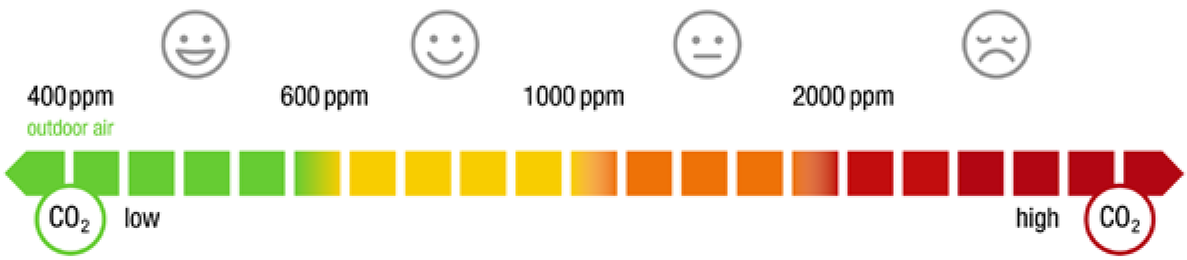


Figure 4: *Indoor levels of CO_2 concentration and its effect on well-being.*

Additionally, studies have shown that high indoor CO_2 concentrations have an impact on cognitive and work performance (**Figure 5**). In a specific test case, individuals that were taking an exam in a room with high CO_2levels of around 2500 ppm generally performed worse and scored lower than when exposed to a CO_2environment at 1000 ppm (Source: NY Times). Moreover, in tighter office spaces like conference rooms, high CO_2levels are often heightened, resulting in a negative impact on human productivity and decision making.

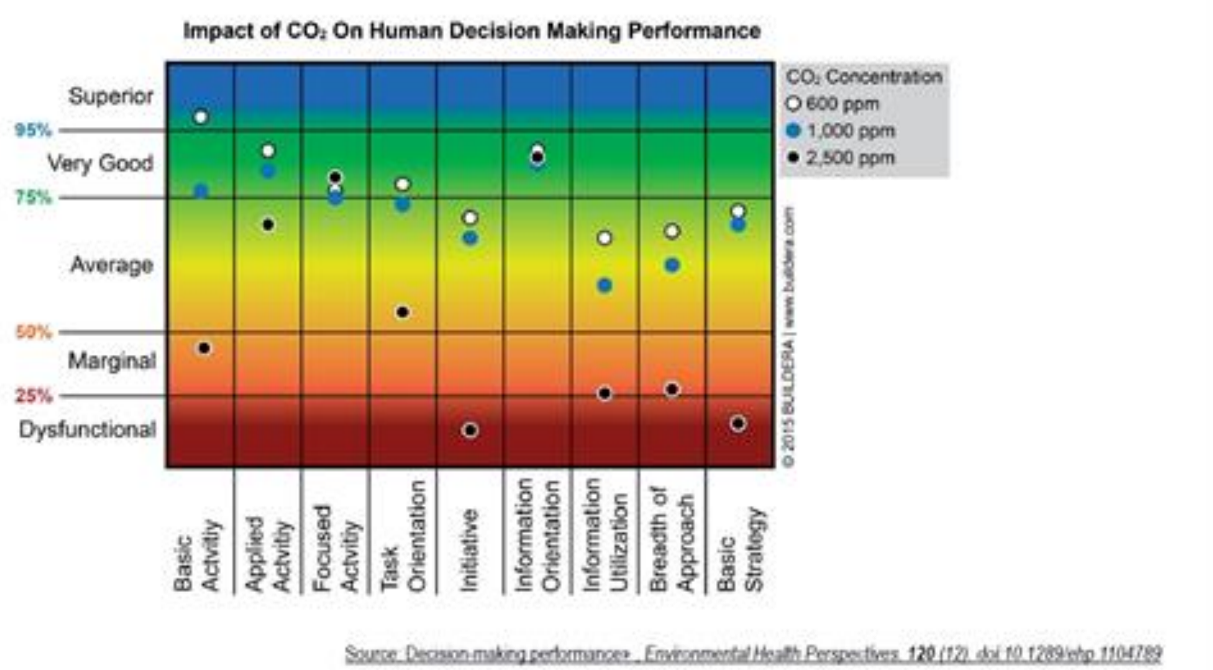


Figure 5: Impact of CO_2 on human decision-making performance.

The onset of COVID-19 in 2020 heightened the concern of being exposed to human-exhaled airborne infectious aerosols. In indoor environments, these harmful agents can easily accumulate due to poor air ventilation or contaminated filters from air handling units. To combat this, proper ventilation and exposure to fresh air has become one of the best methods to reduce the risk of infection indoors.

The question then becomes, how can building administrators measure the amount of potential airborne infections indoors? Since buildings generally do not have significant internal sources of CO_2 without humans occupying them, the presence of CO_2 molecules has become a good indicator of how much exhaled breath is accumulating indoors (which in turn also serves as a good surrogate for human-exhaled infectious aerosols). Sensors like the SCD4x can now play an important role for ventilation systems, as they can accurately determine the levels of airborne viruses indoors and initiate any ventilation needed once CO_2 levels exceed a certain risk threshold. The use of such CO_2 controlled ventilation systems can also improve energy efficiency, as they are able to optimize the supply of fresh air according to the actual need for outside air as determined by the CO_2sensor.

Health impact

Carbon Dioxide is a contributing factor to the **Sick building syndrome** (**SBS**), a medical condition where people in a building suffer from symptoms of illness or feel unwell for no apparent reason. The symptoms tend to increase in severity with the time people spend in the building, and improve over time or even disappear when people are away from the building. The main identifying observation is an increased incidence of complaints of symptoms such as headache, eye, nose, and throat irritation, fatigue, and dizziness and nausea. These symptoms appear to be linked to time spent indoors, though no specific illness or cause can be identified. A 1984 World Health Organization (WHO) report suggested up to 30% of new and remodeled buildings worldwide may be subject of complaints related to poor indoor air quality.

In homes and offices:

A 100 ppm increase in indoor CO2 concentration was significantly associated with headache (..). Office workers exposed to indoor CO2 concentrations higher than 800 ppm reported a significant increase in eye irritation and upper respiratory symptoms. A 100 ppm increase in dCO2 in the range from 467 to 2800 ppm in indoor CO2 was significantly associated with dry throat, tiredness, and dizziness (417 participants from 87 offices) (Lu et al., 2015). A 100 ppm increase in CO2 concentration (range, 549–1318 ppm) was positively correlated with non-specific symptoms including headache and dizziness (107 participants from 11 offices) although the correlation was not significant (Azuma et al., 2018). Twenty-two participants were exposed to CO2 at 600, 1000, and 2500 ppm (three 2.5-h sessions, one day; artificially elevated CO2 concentrations) in an office-like chamber. Statistically significant decrements occurred in cognitive performance (decision making, problem resolution) starting at 1000 ppm (Satish et al., 2012).

In schools:

A study in schoolchildren exposed to indoor CO2 concentrations higher than 1000 ppm showed significantly higher risk for dry cough and rhinitis (654 children of 46 classrooms) but outdoor air flow rate per person was inversely correlated with indoor CO2 concentrations (Simoni et al., 2010). A 200 ppm increase in indoor CO2 concentration (range, 1000– 2000 ppm) in 45 day care centers (DCCs) was significantly associated with reported wheezing in the 3186 attending children, and a positive trend was observed between CO2 concentration and the prevalence of asthma.

Source: " Effects of low-level inhalation exposure to carbon dioxide in indoor environments", Web: https://www.sciencedirect.com/science/article/pii/S0160412018312807

An Important Caveat

The data that the Plantower (and other optical counters) produce is an *estimation* of particulate mass concentration that relies on several assumptions for shape, diameter and density. The quality of your data will depend on those assumptions as well as environmental considerations such as humidity, light and temperature.

Because of the fact that optical counters rely on these assumptions, the data produced by them are not FRM or FEM certified.

BackpAQ V3 Specifications

Specifications

- Size: 5" x 2" x 4"
- Weight: 10 OZ
- Case Material: Polycarbonate
- Measured particles: PM1, PM2.5 and PM10 (Plantower PMSA003i)
- Measured gases: Actual CO_2 (Sensirion SDG-41X)
- Environmental: Temperature, Relative Humidity (via SDG41)
- Processor: (1) Heltec ESP32 (240MHz Tensilica LX6 dual core) with WiFi; or (2) AdaFruit Huzzah 32 (240MHZ) with WiFi
- GPS: Via smartphone interface or built-in
- Communication: WiFi, 802.11 b/g/n and cellular via smartphone
- Battery Life: approx.. 10 hours, depending on sampling frequency
- Battery: 3.7V LiPoly- 2500 mAh rechargeable
- Sampling period: adjustable 1 - 60 minutes
- Display: OLED interface for local data display and control
- Smartphone Interface (Android, iOS) via Wifi and Blynk
- Regular OTA software updates (roadmap)

Configuring your BackpAQ (Version 3) Device

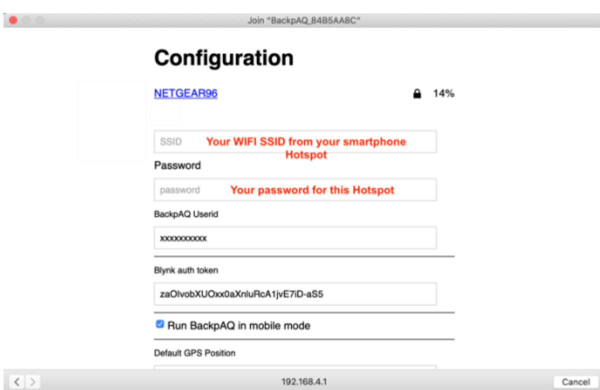
Congratulations on completing the build of your BackpAQ kit, or, if using an already-complete monitor, let's get started configuring your unit for use. You'll need your laptop, tablet or other Internet-connected device for this next step.

When you first power up your BackpAQ unit, after a few seconds you'll see the following display on the top of the case:

This is BackpAQ prompting you to connect your WiFi (on your laptop, tablet or phone) to BackpAQ's own SSID, which is "BackpAQ" + a set of unique hex characters that represent the id of the processor contained within the unit.

Next, your browser should automatically pop up with the BackpAQ Configuration webpage displayed. If this does not happen automatically with about 5 seconds, just launch your browser manually and go to address 192.168.4.1 and the Configuration page will appear.

You will see a page that looks like this:



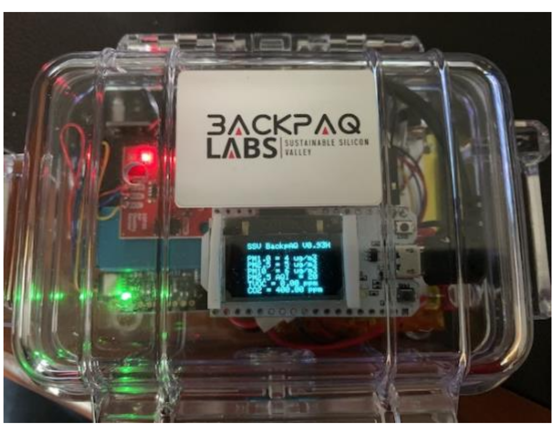
Fill in the required fields, scrolling down to complete all. Most should be pre-filled for you if you are participating in a class or study**. The “SSID” and “Password” fields should be filled in with the WiFi SSID and password from your smartphone’s Hotspot.** If you need help with this step be let your instructor or me know and we’ll help you get connected.

Also, be sure to check “mobile” if you intend to use BackpAQ for mobile monitoring, and ignore the “GPS Location” box.

Once connected and configuration is complete, the device will

continue its setup sequence and should look like the image above. If you don’t see “BLYNK Connected!” then something has mis-fired and you’ll need to click the switch off and restart. Sometimes there are timing or Internet issues…usually it only takes an additional try to get it working.

Finally, once the sensor has stabilized (about 30 seconds), you should see this screen:



You should now see the PM readings displayed. If there is no CO2 reading check to see if you have that sensor installed. On many devices it is optional, so these readings will be zero. You can quickly test to see if the sensor is working…try bringing the left-side opening near a source of particles, say, a candle, a match that's been lit and extinguished (be careful!), or other source. You should see the readings climb quickly and stay up for a time. Don't worry if the readings don't jump immediately – there is some processing delay to properly read and process the input from the sensor so there is usually a delay of several seconds until you see it on the display or on your smartphone.

Using the BackpAQ app

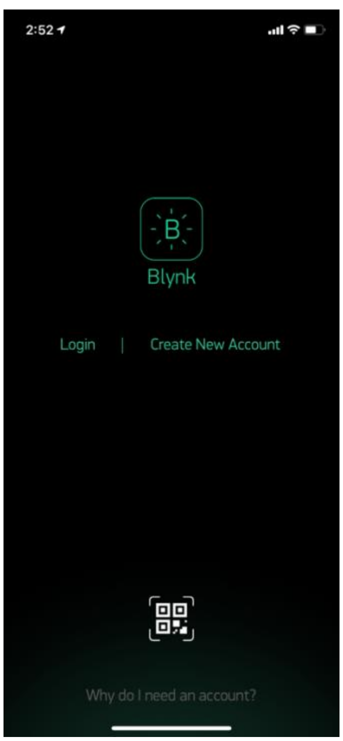
The BackpAQ app has been designed to be useful and engaging to aid you in pursuing your AQ monitoring activities and investigations. However, please recognize that it's a work-in-progress and while highly functional, there are bound to be some bugs, glitches and not-quite-yet functions. Indeed, we hope that you will help refine this design or, better yet, help design something better! Consider this app a starter set of capabilities that you can build on + refine + share.

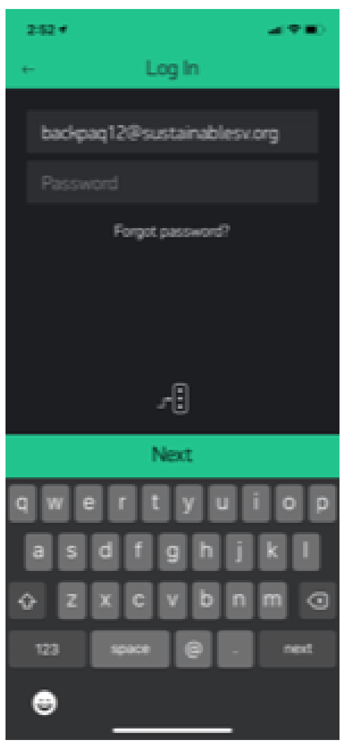
Starting and Using the BackpAQ App

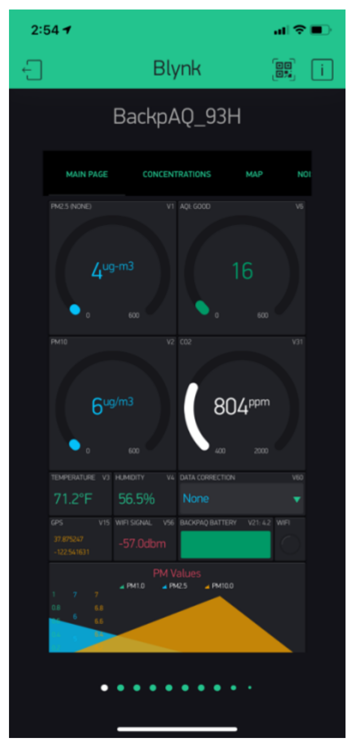
(Note: This section assumes that you have been assigned an email account configured and provisioned with the Blynk software. If not, stop and talk to your instructor where to download the Blynk software and which account to use.)

To install and initialize the Blynk app:

1. Download [Blynk Legacy V0.1]() from the app store.
2. To start the app, scroll your phone to the Blynk icon and click to activate (first image).
3. Next, enter your assigned userid and password (second image).
4. After successful login you should see this screen (third image).



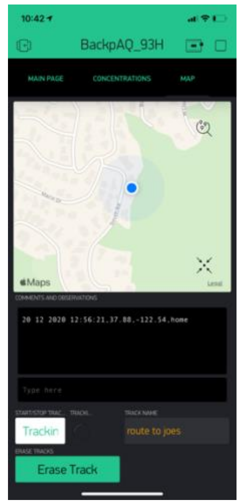




Next, let’s go through each of the BackpAQ app screens in detail.

Main Screen

Detailed Data

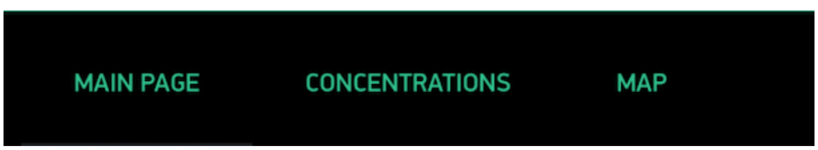


Map &Tracking

Sound Levels

Basic Functions

In the photos above you can see that the current app has three screens: left to right is the main screen, the detailed data screen, and finally the map and tracking screen. To navigate between screens, just click on the tabs at the top (like this):

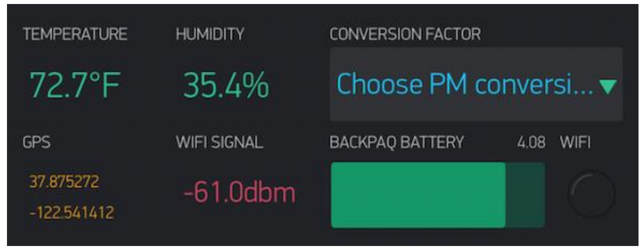


Next, we'll go briefly through each screen, from left to right:

Main Screen

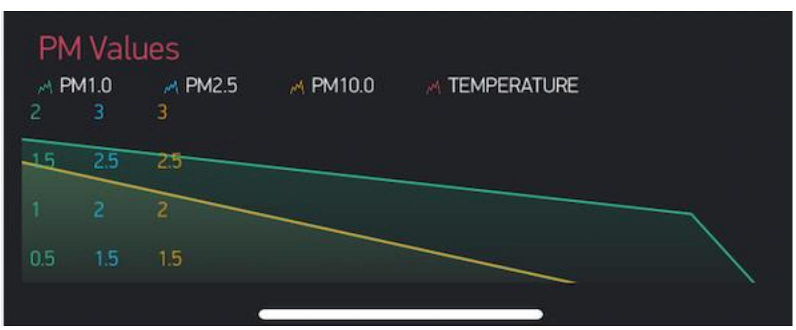
The screen you see when you open BackpAQ . There is a lot of data on this panel but it’s (hopefully) organized well and fairly self-explanatory:

- (Top) Gauges showing PM2.5, AQI based on PM2.5 measurement
- (Second Row) Gauges showing PM10 and CO2 measurements



- Temperature (in degrees F) and Relative Humidity (in %) measurements
- Latitude and Longitude of your current position (see Map below)
- WiFi Signal Strength shows the strength of the WiFi connection between your BackpAQ device and your WiFi router or smartphone Hotspot.
- Estimated battery voltage for the BackpAQ device - when do I need to recharge? You should expect around 9-10 hours of battery life, depending on usage. Plan to recharge overnight as you would for a phone or tablet.
- PM correction selection menu, allowing you to correct the data from the sensor for woodsmoke, according to three well-known factors: US EPA, LRAPA, and AQandU. More detail on these corrections is in the appendix.

- (Bottom) Multi-graph showing these concentrations in Live and various timed intervals

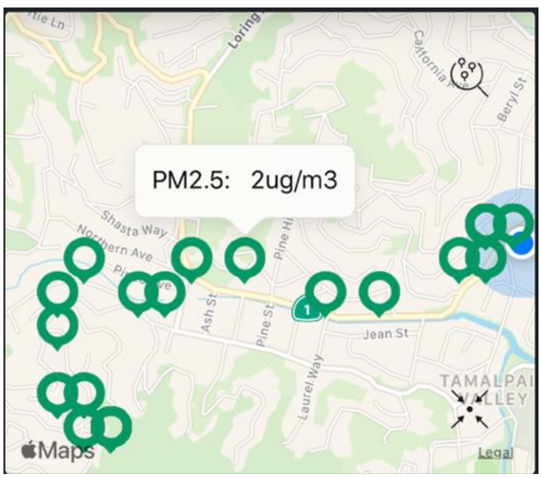


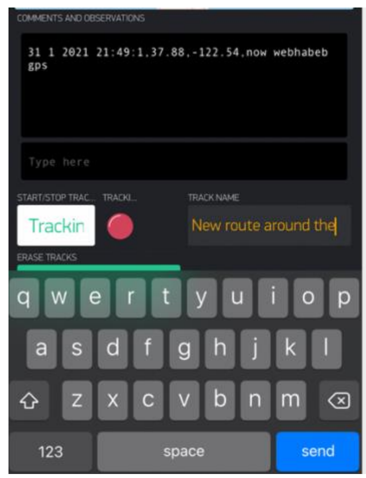
Detailed Data

The Detailed Data screen displays the various particle concentrations from the PM sensor, eg, Number of Particles Beyond 5.0 ug/mL. Also displayed is a graph showing these counts in Live and various timed intervals. You'll also see CO2 readings displayed in a graph.

Map and Track

Using the BackpAQ Map function you can see, in real time, where you have walked and what the PM2.5 and CO2 readings where at each measurement interval.





The Map screen displays your current position and the last 60 positions based on 1 minute intervals (this is adjustable). You can click on any position icon to see the PM reading captured at that position. Note that the color of the track marker reflects the "PM AQI-equivalent" value at the time it was recorded.

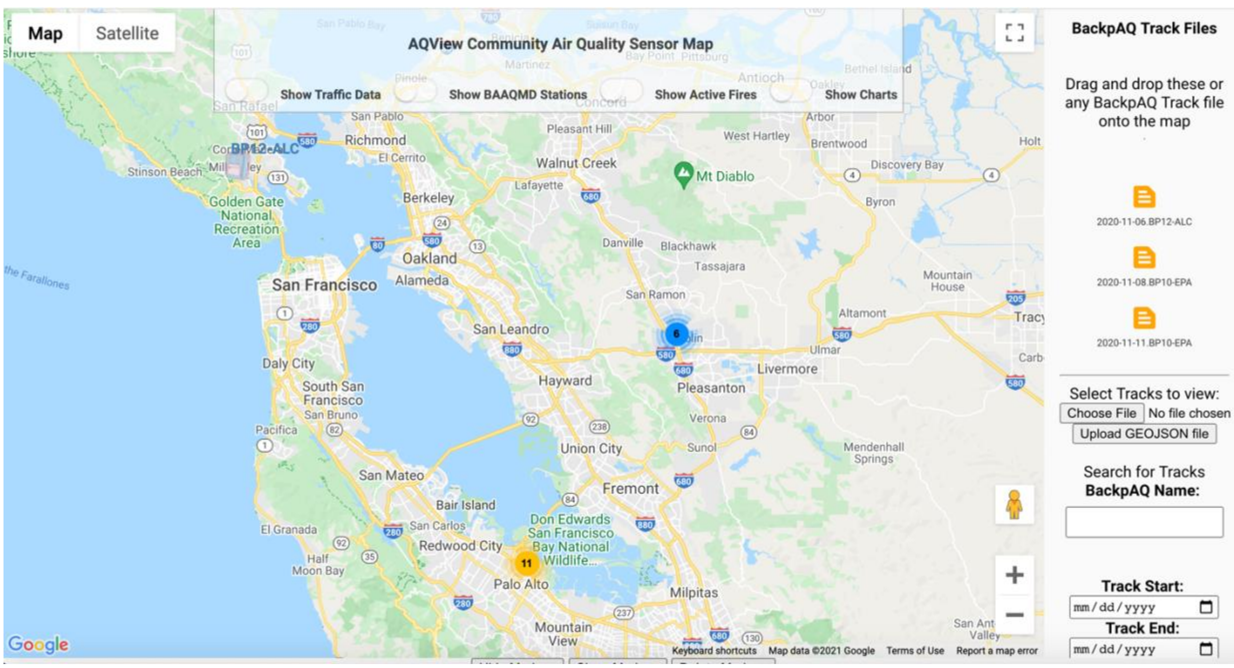
There are buttons to turn tracking on and off, and assign a "track name" to this track. You can also attach comments as you move about. The comments will be tagged along with your current position and will also be recorded in the ThingSpeak data. And you can elect to erase the current track data from the phone screen (the data is still kept in the ThingSpeak database.)

Sound Levels (New!)

New in BackpAQ V3 is the ability to measure and track sound pressure levels (SPL).
To be added

AQView Community Air Quality Map

All BackpAQ users are automatically entitled to use the AQView Community Air Quality portal. Simply point your web browser to http://www.backpaqlabs.com/aqview to get started. This is the main window you'll see:

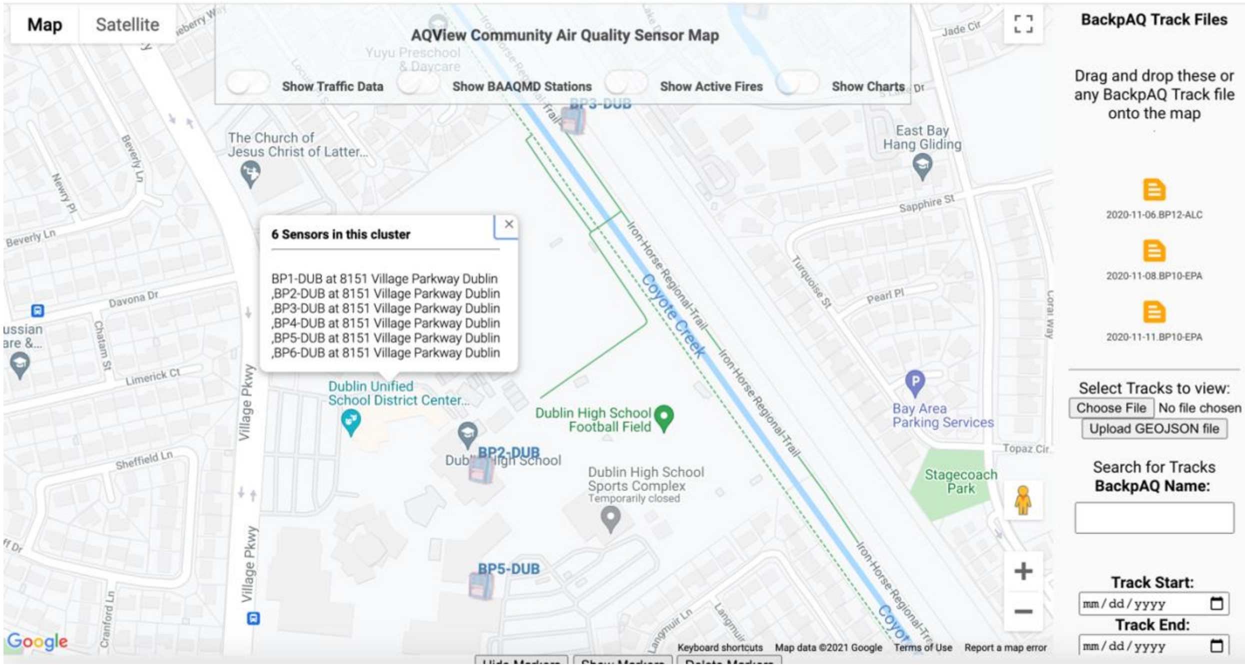


The main page is the Map itself, and where you'll probably spend the most time and receive the biggest value. These maps are highly interactive: click around on the various tabs, options, and markers to see more detailed data.
In the image above you'll notice three colorful icons: in the upper left you'll see the BackpAQ sensor icon  ; in the middle there is a yellow "sensor cluster"  and to the right there's a blue sensor cluster . Other types of sensors are represented by their icons:

- Purple Air  (fixed sensor)

- Met (or metrological sensor)  (fixed sensor)
- Vaisala  (fixed sensor)

These icons represent active sensors located at these positions on the map. A single sensor means there is one sensor at that location; the color clusters represent multiple sensors – click on each and it will expand into multiple sensor locations. Here's an example:

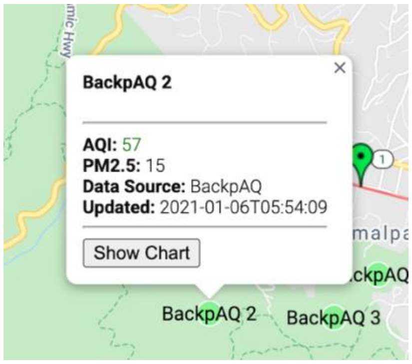


There are several additional functions we can utilize to better understand the data we have collected.

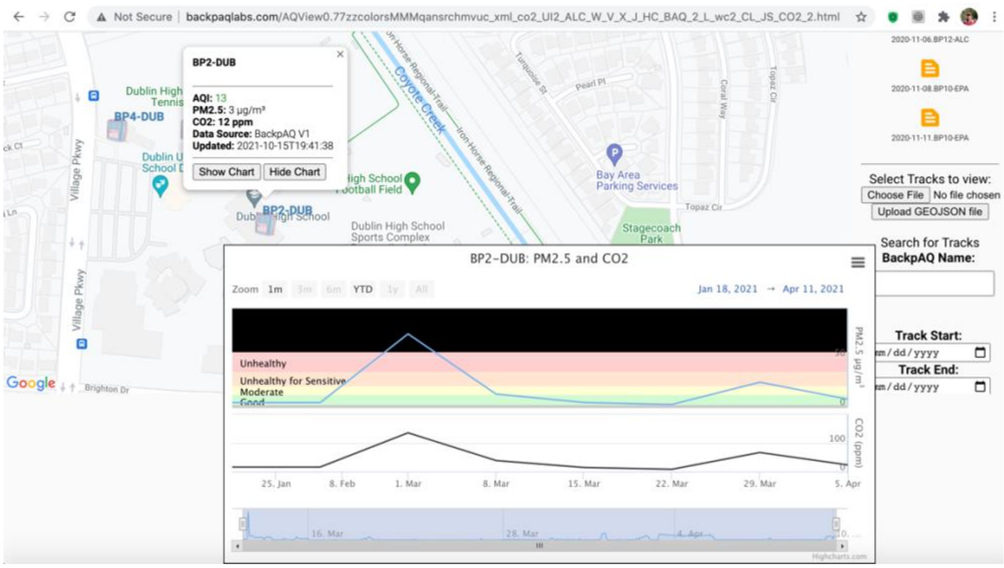
BackpAQ Sensor Data

In general, AQview organizes data in *layers,* with each layer individually selectable.

To see ***your*** sensor data live on the map, click on the name of your BackpAQ (or other) sensor (example: BP1-DUB) and you'll see a popup window appear with the current sensor readings. Note that it may not be positioned where you are actually located because it may not have been updated with your current GPS location. You can re-click this periodically to see the current reading refresh.


BackpAQ 2
AQI: 57
PM2.5: 15
Data Source: BackpAQ
Updated: 2021-01-06T05:54:09
Show Chart
BackpAQ 2
BackpAQ 3

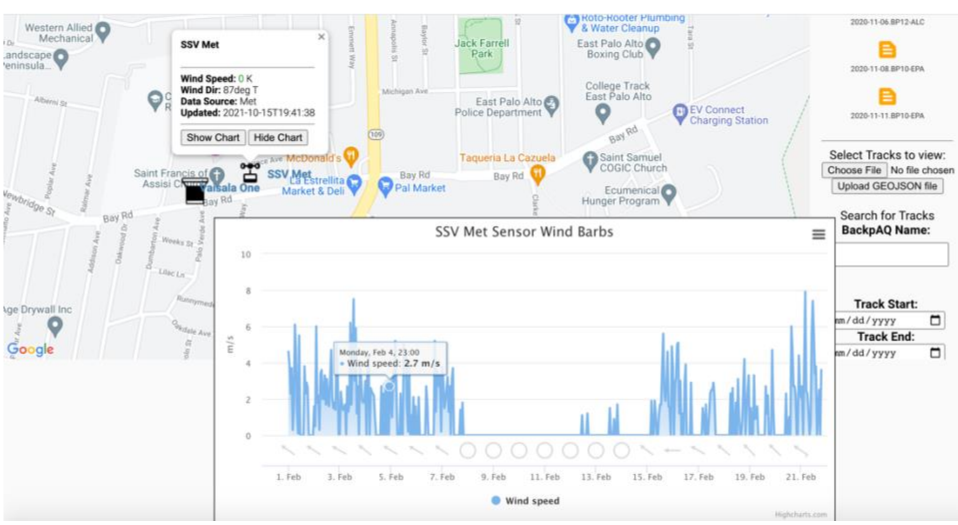
If you click on the **Show Chart** button an interactive chart will appear below the window, like this one:



A couple of things to point out here…the chart is *actually two charts* which are “synced”, meaning that as you scroll one the other scrolls along in sync. The top chart shows PM2.5 in ug/m3, with the US EPA color scale in the background. The bottom chart shows CO2 in ppm, which was from an onboard CO2 sensor in the BackpAQ. (Note: Not all sensors will have CO2 measurement capability, for example Purple Air which is PM-only.)

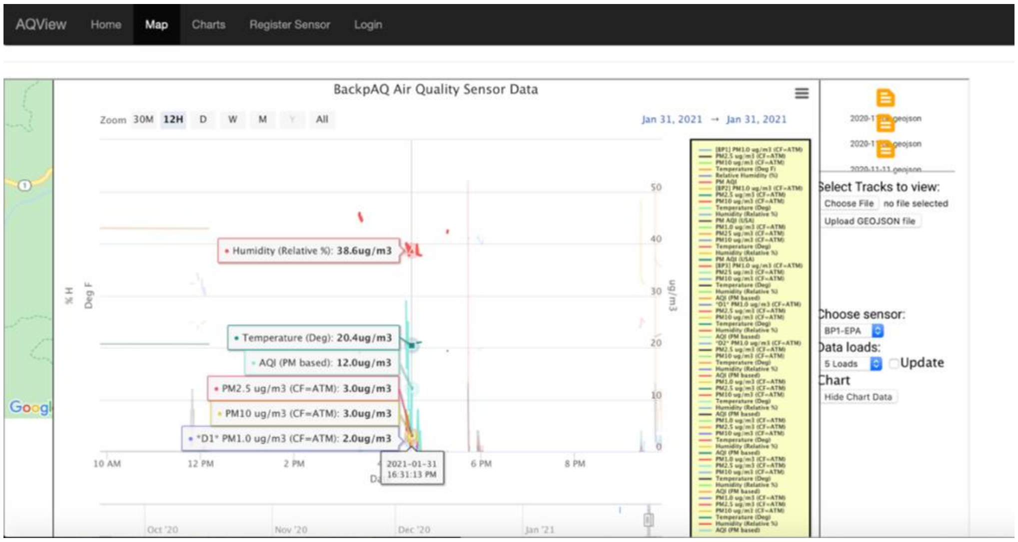
The other thing to note is the Zoom capability which allows you to vary the time period for the data on the chart, eg, realtime, 30 mins, 1 hour, 1 month, etc.

Another example of sensor graphing is the Met graph which will show “Wind Barbs” representing wind speeds (in m/s) at specific times and dates on the Y-axis, with wind direction shown on the same time scale in the barbs below the graph.



Mega-Chart

You can click over to "**Chart**" on the front panel menu and you'll see this mega-chart appear:



This powerful chart will display all of the BackpAQ (or other) devices participating in your study or class. To better focus on *your* BackpAQ data, click "Hide Chart Data" and then re-select only the data pertaining to your device, for example, "BP1-DUB", in the yellow box. Or, load all of the data and see how yours compares to your classmates. Note that you can select or de-select data simply by clicking on the fields in the yellow box. Have fun! Oh, and one more feature…you can download the data for sharing or further analysis by clicking the "hamburger" icon in the upper right corner of the chart. There are options for downloading PDFs, JPEGs, CSV and other formats. And once you've downloaded the data into a CSV you can open in Excel and create your own charts and graphs!

Using Track Data

A Brief Intro

Since BackpAQ is aimed at *mobile* air quality monitoring, the most useful data is probably the data that is collected and stored in time-sequence form, as you walk around. This is one of the reasons we chose ThingSpeak to store and manage the data, as it's primarily a time-sequence data store. But we've also come up with some data visualizations that should help you interpret your data using the same *temporal* cues and visual representations that were there when you first collected the data. You've already no doubt seen and used the "Map" function on the BackpAQ app. Here are a few additional ways to get the most out of your AQ monitoring wanderings.

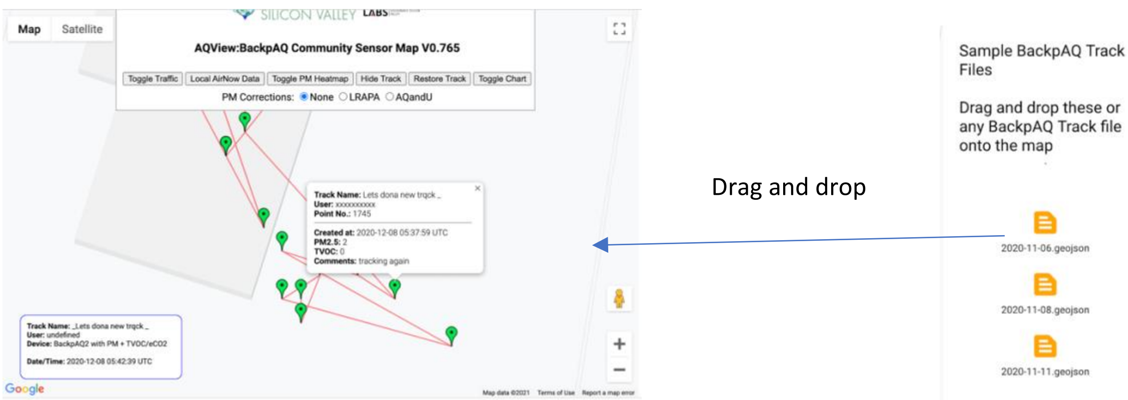
How to do it

There are three ways to retrieve your stored track data from the ThingSpeak data store:

- Downloading Track Files
- Search for tracks using date and time ← EASIEST!
- TrackChart ← MOST FUN!

How to see your Tracks on the map

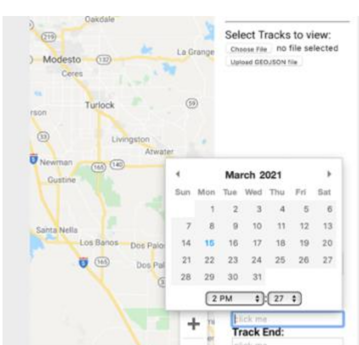
To see how this works, you can try the sample *Tracks* located in the "dock" on the right-hand side of the window.



Grab by clicking and hold the button done while dragging over the main map. Then drop onto the map by letting go of the (mouse or scroll) button. You should then see a series of color markers which represent a time-sequenced based visual of the track data you've collected and submitted. Notice that they also might appear in different colors, mapping to the US AQI color scheme we've grown familiar with. You can then click on any marker to see the sensor data that was captured at that location, along with the *Track Name* you gave it, and any *comments* you entered at that moment.

Search for Track data using date and time

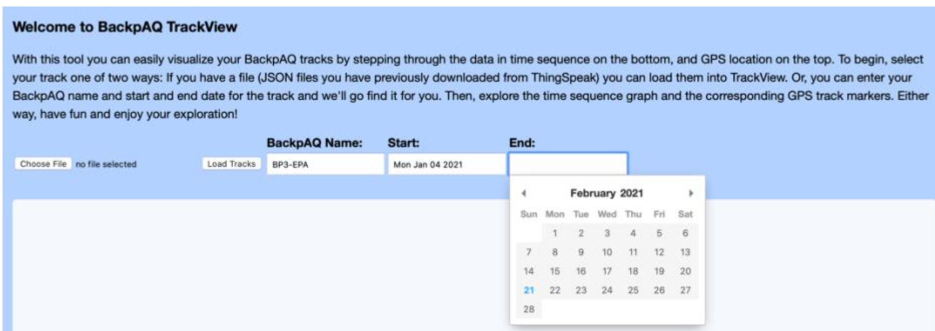
This is easy and quick: just enter your BackpAQ device name (eg, "BP8-EPA") in the box to the right of the map and start and end dates (and times if you need to) in the panel on the right-hand side of the AQView map.



Using TrackCharts

There is one more function you might want to try. It's the newest so least tested, but offers some capabilities not present in the one's we've just discussed.

If you click on "Charts" on the main menu bar you can enter your tracks file name. You should then see something like this. Just enter your BackpAQ device name (eg, "BP3-EPA") and click in the start & end dates to pop up the calendar to set for the track(s) you want to view. Hint: fto view Tracks very recently recorded, you might have to enter the "next" day in order to include these tracks. So, if you do this…



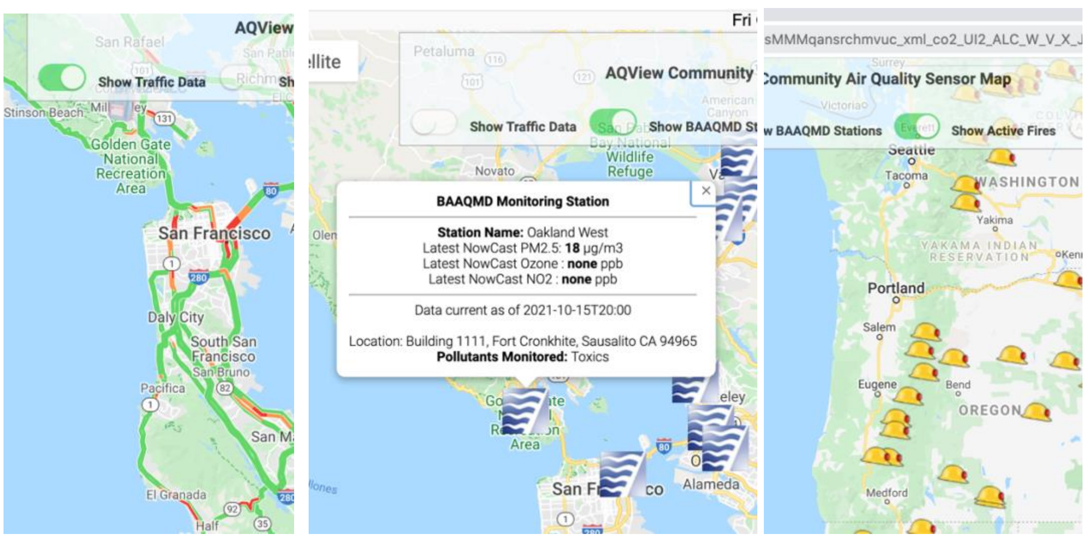
…then you'll see this display:

Here, in the upper window, you'll see the familiar map with your track data displayed. But a new chart now sits below this, with a time-sequenced representation of your journey that's liked to the map above. The x-axis shows the time of day, and the y-axis represents the PM2.5 value (in ug/m3) at that time. The background colors represent the EPA AQI color index scale. You can ***click on the marker*** in either window and see the corresponding location or time sequence. This should help greatly in providing important *context* to your data analysis.

Other Data Layers

There are additional data layers you can access through AQView, including

- Traffic Data   Data from Google showing realtime traffic on local roads
- US EPA / BAAQMD   Data from US EPA AirNow API showing current measurements from local official air quality monitors
- Active Fires Data from InciWeb API showing all active fires



This data is useful when comparing your personal sensor to official regulatory monitors, when analyzing your data and looking to see what mobile or stationary sources might be influencing what you are seeing.

Conclusion

If you have questions or comments about the BackpAQ devices or program, contact your instructor/study facilitator or email us at SSV: dclark@sustainablesv.org.

Good luck and good data!

Safely Using Your BackpAQ

Your BackpAQ has been designed and tested to work safely with the internal LiPO battery, charging circuit, and supplied charger. But, to keep things on the safe side, it is important to follow these rules:

- Use only the supplied charger! It is unsafe to plug anything else into the charging connector
- Charge your BackpAQ at night in a safe place, preferably outside, a garage, or in a metal enclosure
- Do not overcharge! It is ok to charge until the green light comes on, indicating full charge. Then disconnect the charger. Usually about 5-6 hours will do it
- If you see or smell something unusual coming from the BackpAQ device or it seems to be warm, immediately disconnect the charger and take it outside

Outdoor use and exposure to elements

The unit comes in a rugged polycarbonate plastic enclosure that protects the sensitive electronics from the elements. It can be directly installed outdoors. Make sure the PM sensor vent holes face down, so no rain can get inside. Needless to say, do not cover the air circulation holes.

Precautions

Do not expose the BackpAQ to a large amount of dust such as in the woodworking centers. Do not expose BackpAQ to solvents or to a large amount of concentrated vapors of chemicals (acetone, paints, alcohol, butane, propane, etc.), because the sensors can wear out, or the measurements may become inconclusive. Do not expose the apparatus to mechanical shocks.

Your BackpAQ has been designed and tested to work safely with the internal LiPO battery, charging circuit, and supplied charger. But, to keep things on the safe side, it is important to follow these rules:

- Use only the supplied charger! It is unsafe to plug anything else into the charging connector

- Charge your BackpAQ at night in a safe place, preferably outside, a garage, or in a metal enclosure

- Do not overcharge! It is ok to charge until the green light comes on, indicating full charge. Then disconnect the charger. Usually about 5-6 hours will do it

- If you see or smell something unusual coming from the BackpAQ device or it seems to be warm, immediately disconnect the charger and take it outside

Appendicies

AQI, Air Quality Index

The AQI is an index for reporting daily air quality. It tells you how clean or polluted your air is, and what associated health effects might be a concern for you. The AQI focuses on health effects that you may experience within a few hours or days after breathing polluted air. EPA calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect public health. Ground-level ozone and airborne particles are the two pollutants that pose the greatest threat to human health in this country.

How Does the AQI Work?

Think of the AQI as a yardstick that runs from 0 to 500. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 represents good air quality with little potential to affect public health, while an AQI value over 300 represents hazardous air quality. An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level EPA has set to protect public health. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy-at first for certain sensitive groups of people, then for everyone as AQI values get higher. Here is what it looks like:

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*..air quality conditions are:*	*...as symbolized by this color:*
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

How is AQI Calculated?

Consult the above figure (1) for the actual AQI calculation.
See AQI Calculation for more detail on how the AQI is calculated.
NOTE: By definition, the AQI is calculated using data from a 24-hour period. That's because the science we have about air pollution exposure and health is based on 24 hours and therefore EPA's air quality standards are based on 24 hours average of sampled AQ. **It is not valid to use shorter-term (e.g. hourly) data to calculate an AQI value.**

Making AQI More Useful Now: Nowcasting

The AQI is used to deliver a daily air quality report which means at the end of the day, we attain an effective reading for the air quality, but this also means that we defeat the purpose of the AQI in the first place. The AQI is intended to help users take immediate actions if air is of harmful quality. This is where the Nowcasting algorithm comes into place. A mixture of the words “now” and “forecasting”, Nowcasting in air quality is a method to give readings for concentrations of harmful substances in the air in a form that immediately usable.

Obviously, simply giving a reading for a harmful concentration in an environment of frequently changing air would be misleading as the immediate reading would in most cases present just an anomaly to an overall cleaner air than what is depicted. This means that even on days when the AQI forecast at the end of the day predicts unhealthy conditions, it is possible that pollution levels might be lower during some parts of the day and vice versa.

Thus the NowCast allows current condition maps to *align more closely with what people are actually seeing or experiencing*. The technique of Nowcasting is to take a weighted average instead of taking the average of the last relevant span of time. The equation (2) above is used to Nowcast a concentration at any given time.

So to separate the two, for momentary AQI readings, Nowcasting is used; for a daily report the general formula is practiced. Here is an excellent overview of where AQI and Nowcasting are headed.

Particulate Matter Sensor Specifications

Sensor: Plantower PMS-A003i

TECHNICAL DETAILS

Sensor module specifications:

- Particle Range of measurement: 0.3~1.0,1.0~2.5, 2.5~10 Micrometer
- Particle Counting Efficiency: 50% @ 0.3μm 98% @ >=0.5 μ m
- Particle Effective Range (PM2.5 standard): 0~500 μ g/m ^{3}
- Particle Maximum Range (PM2.5 standard): ≥ 1000 μ g/m ^{3}
- Particle Resolution: 1 μ g/m ^{3}
- Particle Maximum Consistency Error (PM2.5 standard): ± 10% @ 100~500 μ g/m ^{3}
±10 μ g/m ^{3} @0~100 μ g/m ^{3}
- Particle Standard Volume 0.1 Liter
- Single Response Time ＜1 second
- Total Response Time ≤ 10 seconds
- DC Power Supply Typ: 5.0V Min: 4.5V Max: 5.5V
- Active Current ≤ 100 mA
- Standby Current ≤ 200 μ A
- Interface Level: 3.3V logic, L <0.8V, H >2.7V
- Working Temperature Range -10 ~ 60 ℃
- Working Humidity Range 0~99%
- Storage Temperature Range -40 ~ 80 ℃
- MTTF ≥ 3 Year
- I2C address 0x12 (cannot be changed)

Product Dimensions: 51.0mm x 35.5mm x 13.6mm / 2.0" x 1.4" x 0.5"

Product Weight: 28.0g / 1.0oz

Quirks, Bugs, and Not-quite-working, ...

As mentioned above this app is at a Beta stage of maturity and naturally has some quirks and bugs, as well as some functions that are still being developed. Here's a list of what's known (help us find the rest!)

- The sensor *readings* will not be accurate until the sensor has warmed up and various connections are complete. Wait for at least 30 seconds until things settle down. This is particularly true with the TVOC/CO2 sensor (if installed) as proper use requires a brief "burn-in" period prior to using.
- The *Map* occasionally misbehaves and places position markers in strange countries. Not sure what's going on but it does seem to know where you currently are and have been.
- The *Battery Level* indicator is approximate...best practice is to just recharge nightly as you would your smartphone. You should get about 8-9 hours of battery life.
- The *PM sensor* is obviously directional in this application as it depends on pulling in air through the intake hole in the BackpAQ case. So, best to orient the device so that the intake has a "view" of where you wish to monitor and is not impeded or blocked.
- The *PM sensor* is either the larger PMS5003 or the more *svel*t PMS7003, depending on which unit we shipped with your kit. Future versions will utilize only the 7003.
- The TVOC/eCO2 sensor is likewise sensitive to airflow and must not be impeded by blocking the airflow hole.
- The BackpAQ V2 monitors utilize a new chip (Heltec ESP32) and new code base to go with it. There may be some hiccups with the new software so appreciate your patience as we get a feel for how this chip will perform.
- The *BackpAQ software* running on the device is still young and fragile. This means it may crash occasionally or need to be restarted when it "bogs down". The prototype units have been run successfully for 12-15 hours at a time without problems but things do happen in software, especially when handing several temperamental sensors with a low-cost processor, on a small battery.
- The *AQI gauge* and values are slightly controversial in the way they are calculated here and in most other portable devices. The NowCast function (code included but not invoked) is designed to handle this. We will discuss this in class and hopefully come up with a better way to calculate and use it in this context.
- The AQView tool is brand new and will need several more iterations before the functions and interfaces settle down. We hope you find it useful and appreciate your feedback and comments!