

# Phoenix as a Testbed for Air Quality Sensors (P-TAQS) Sensor Pod Design, Operation, and Maintenance



Office of Research and Development  
Center for Environmental Measurement and Modeling/Air Methods and Characterization  
Division

# **Phoenix as a Testbed for Air Quality Sensors (P-TAQS) Sensor Pod Design, Operation, and Maintenance**

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## **Disclaimer**

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# List of Acronyms

°C	degrees Centigrade
°F	degrees Fahrenheit
4G/LTE	Fourth generation long-term evolution
AC	alternating current
ADC	Analog to Digital Converter
AGM	absorbed glass mat
Ah	amp-hour
AMCD	Air Methods and Characterization Division
AT	ATtention (commands which control modems)
BC	Black Carbon
BLE	Bluetooth Low Energy
BP	barometric pressure
CA	California
ccm	Cubic centimeter
CEMM	Center for Environmental Measurements and Modeling
CO <sub>2</sub>	Carbon Dioxide
CPU	central process unit
DC	Direct Current
DHCP	dynamic host configuration protocol
DIO	digital input/output
DQI	data quality indicator
EEPROM	Electronically Erasable Programmable Read-Only Memory
FAT32	file allocation table (32-bit)
FIFO	First In, First Out
g	gram
GB	Gigabyte
GHz	gigahertz
GPIO	general-purpose input/output
HDMI	high-definition multimedia interface
hPA	hectopascal
HTTP	Hyper Text Transfer Protocol
I/O	input/output
IEEE	Institute of Electrical and Electronics Engineers
IP	internet protocol
IPX	internetwork packet exchange
IR	Infrared

JSON	JavaScript Object Notation
KC-TRAQS	Kansas City Transportation and Local-Air Quality Study
km/h	Kilometers per hour
KS	Kansas
kWh/m <sup>2</sup> /day	kilowatts per square meter per day
LAN	local area network
LED	light-emitting diode
LVD	Low Voltage Disconnect
m/s	meters per second
mA	milliamp
MAC	media access control
Mbps	megabits per second
microSD	micro secure digital
mL/min	milliliters per minute
ms	millisecond
mW	milliwatt
NH	New Hampshire
nm	nanometer
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
OEM	Original Equipment Manufacturer
ORD	EPA Office of Research and Development
OS	operating system
PA	Purple Air
PM	Particulate Matter
PM <sub>1.0</sub>	Particulate Matter < 1.0 microns
PM <sub>10</sub>	Particulate Matter ≤ 10 microns
PM <sub>2.5</sub>	Particulate Matter < 2.5 microns
PM <sub>5.0</sub>	Particulate Matter ≤ 5 microns
ppb	Parts per billion
P-TAQS	Phoenix as a Testbed for Air Quality Sensors
PTFE	Polytetrafluoroethylene
QAPP	Quality Assurance Project Plan
RH	relative humidity
RS	Recommended Standard
RTC	Real-Time Clock
SD	secure digital
SDIO	Secure Digital Input Output
SDRAM	synchronous dynamic random access memory
SFSB	Source and Fine Scale Branch

slpm	Standard Liters per Minute
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TCP	Transmission Control Protocol
Temp	temperature
TTL	Transistor-Transistor Logic
UART	universal asynchronous receiver-transmitter
USB	universal serial bus
UV	Ultraviolet
V	Volts
VDC	volt direct current
VIPER	VIPER is a wireless network-based communications system designed to enable real time transmission of data from field sensors to a local computer, remote computer, or enterprise server and provide data management, analysis, and visualization.
WD	Wind Direction
wi-fi	wireless networking
WS	Wind Speed
$\mu\text{g}/\text{m}^3$	micrograms per cubic meter
$\mu\text{m}$	micrometer

# 1. The Phoenix as a Test-Bed for Air Quality Sensors (P-TAQS) Project – Implementation and History

Over the past few years, concerns have been raised by regional environmental stakeholders regarding air quality in Maricopa County, AZ, with particular attention to the presence of particulate matter and black carbon due to the use of wood burning fireplaces and backyard fire pits in the valley. A similar study – Kansas City Transportation and Air Quality Study (KC-TRAQs) (<https://www.epa.gov/air-research/kansas-city-transportation-and-local-scale-air-quality-study>) - was conducted in 2017-2018 with air pollutant measurements conducted around and in the neighborhoods surrounding rail yards in the Argentine area of Kansas City, KS. Both studies have focused on the development and evaluation of how low-cost sensor networks can be useful when monitoring ambient air pollution while understanding potential data quality limitations. The expanding use of sensors has been driven by a number of entities (e.g., private sector, municipalities, academics, federal/state/local government) interested in higher spatial and temporal resolution monitoring for various purposes. This technology is attractive for state and local agencies to better understand complex and spatiotemporally variable source emissions (such as residential wood burning), respond to citizen complaints about pollution events, and enhance their educational outreach programs. The chief problems with this technology include the limited knowledge of the technology performance under different sampling conditions (meteorology, pollution levels and mixtures) and lack of best practices regarding feasible approaches to calibrate sensor networks after installation. Additionally, the effectiveness of higher spatial and temporal scale monitoring via sensors to inform air quality improvement programs by local agencies is also largely unknown. This study is anticipated to advance knowledge on all these fronts and develop information that would be of national significance regarding both sensor performance, informing best practices for sensor networks, and provide a case study of their usefulness to a local agency.

## 1.1 Study Objectives

The science questions and drivers for this project and the motivations for the development of the sensor pods are:

- What is the spatial and temporal extent of local air pollution sources in and around the Maricopa County?
- Can the sensor network withstand the impact of the intense heat and climate the southwestern U.S. will deliver?
- What is the spatial and temporal variability of wood burning air pollution impacts, and other sources, under different meteorological conditions and source activities?
- Could air quality be improved by switching to cleaner energy alternatives in the valley?

## 1.2 P-TAQS Pod Package Configuration

The Phoenix as a Test Bed for Air Quality Sensors (P-TAQS) project pod sensor package is designed to measure key parameters of interest, specifically particulate matter (PM), black carbon, and meteorological data. P-TAQS pods are designed to operate autonomously, with quick installation and with minimal maintenance using open source design features. Table 1 below shows the parameter of interest along with the sensors being used to collect data corresponding to each parameter. Several of the sensors and instruments listed have been evaluated by EPA’s Office of Research & Development (ORD) on previous studies. The P-TAQS pod system can be powered by either solar or standard 110 V AC power.

The basic requirements for operating the P-TAQS pod using solar power are as follows:

- 150-watt (or higher) solar panel.
- Built-in voltage regulator.
- 1 x 100+ amp hour (approx.) ballast battery, (deep-cycle battery). Additional batteries may be added depending on region of deployment.

The purpose of the external high capacity battery is to provide back-up power at night and on days when there is little or no sunlight. The recommended battery capacity should provide 7-8 days run time with little or no sunlight. Please see Section 3.2 Solar Considerations.

Detailed specifications for each piece of primary equipment are found in Section 2.

**Table 1. Sensor Pod Instruments**

Parameter	Sample Rate	Sample Interval	Instrument
PM <sub>1.0</sub> , PM <sub>2.5</sub> , PM <sub>5.0</sub> , PM <sub>10</sub>	1 min	Continuous	PurpleAir PA-II-SD (Draper, Utah)
Black carbon			Five-wavelength Aethalometer MA350 (AethLabs, MA series, San Francisco, CA)
Wind Speed			AIRMAR 120WX WeatherStation® Instrument (WS-120WX-RH) (Milford, NH)
Wind Direction			
Relative Humidity			PurpleAir PA-II-SD (Temperature, Humidity and Pressure) AIRMAR 120WX WeatherStation® Instrument (Pressure)
Temperature			
Barometric Pressure			

## 2. Sensor Pod Equipment Specifications

The equipment used in the sensor pods are divided in two categories: primary and secondary. The primary equipment consists of air quality and meteorological instruments that provide data to the user. Secondary equipment includes supporting devices that are required for station operational functions.

### 2.1 Primary Instruments – Air Quality and Meteorological

#### 2.1.1 PurpleAir PA-II-SD

PurpleAir PA-II-SD sensors are used to measure real time PM<sub>2.5</sub> concentrations for residential, commercial, or industrial sources. Internal data storage is saved to the system microSD card. Data is transmitted from the sensor to the central processing unit (CPU) using Wi-Fi. The sensor is pictured in Figure 1 and manufacturer’s specifications are summarized in Table 2.



Figure 1. PurpleAir PA-II-SD

Table 2. PurpleAir PA-II-SD Manufacturer’s Specifications

Measurement	Unit	Specification
Particle range	µm	0.3, 0.5, 1.0, 2.5, 5.0, & 10
Counting efficiency	%	50% at 0.3µm & 98% at ≥0.5µm
Effective range	PM2.5 standard, µg/m <sup>3</sup>	0 to 500 µg/m <sup>3</sup>
Maximum range	PM2.5 standard, µg/m <sup>3</sup>	≥1000 µg/m <sup>3</sup>
Maximum consistency error	PM2.5 standard, µg/m <sup>3</sup>	±10% at 100 to 500µg/m <sup>3</sup> & ±10µg/m <sup>3</sup> at 0 to 100µg/m <sup>3</sup>
Standard Volume	Liter	0.1
Single response time	Seconds	≤ 1
Total response time	Seconds	≤ 10
Temperature range	°F	-40°F to 185°F
Pressure range	hPA	300 to 1100

Humidity	%RH	Accuracy tolerance: ±3%
<b>Power</b>		
Measurement mode	mA (typical)	175
Non-measurement mode	mA (typical) Laser at minimum power; fan off	95
Transient power on start-up	mW for 1 ms	<5000
Voltage range	V DC	5
<b>Network Specifications</b>		
Wireless Networks	N/A	802.11b/g/n @ 2.4GHz
Data storage	micro SD	16 GB
Antenna Type	N/A	External, IPEX Connector, Ceramic Chip
SD Card Format	N/A	FAT32
Weather resistance	N/A	IP68 (rated for outdoor use)
Weight	Grams	352

### 2.1.2 AethLabs Black Carbon MA350

The microAeth<sup>®</sup> MA350 (see Figure 2) is a real-time five-wavelength ultraviolet-infrared (UV-IR) black carbon monitor housed in an outdoor-rated case with an automatic filter tape advance system which allows for three to 12 months of continuous measurements utilizing 85 sampling locations. It uses TTL Serial communication. The manufacturer's specifications are summarized in Table 3.



Figure 2. AethLabs MA350.

**Table 3. Aethlabs MA350 Manufacturer’s Specifications**

<b>Measurement wavelengths</b>	880 nm, 625 nm, 528 nm, 470 nm, 375 nm
<b>Flow Rate Options</b>	50, 100, or 150 mL/min
<b>Filter Material</b>	Polytetrafluoroethylene (PTFE)
<b>Filter Capacity</b>	MA350 Filter Tape Cartridge with PTFE material (85 sampling locations)
<b>Communications</b>	5-V UART

For additional information about this device, please refer to the user manual (web link) in Appendix E.

**2.1.3 AIRMAR 120WX WeatherStation® Instrument (WS-120WX-RH)**

The AIRMAR 120WX, shown in Figure 3, is used to measure wind speed, wind direction, temperature, barometric pressure, and humidity. The AIRMAR communicates via RS422 serial using the NMEA-0183 standard. This data is converted using the RS422 to universal serial bus (USB) converter for communication with the CPU. The manufacturer’s specifications are summarized in Table 4.



**Figure 3. AIRMAR 120WX WeatherStation® Instrument**

**Table 4. AIRMAR 120WX Manufacturer’s Specifications**

<b>Range:</b>	Wind speed: 0-40 m/s (90 mph) Wind direction: 0-360 degrees
<b>Resolution:</b>	Wind speed: 0.01 m/s Wind direction: 0.1 degree
<b>Accuracy:</b>	Wind speed: 0 to 5 m/s ±10% or 0.1 m/s 5 to 40 m/s ±5% Wind direction: ± 5 degrees (Low 2-5 m/s) ± 2 degrees (High > 5 m/s)
<b>Temperature Range</b>	-40°C to 55°C (-40°F to 131°F)

Barometric Pressure Range	300 hPa to 1100 hPa
Relative Humidity Range	10% to 95% RH
<b>Serial Output</b>	RS-422/RS-232
Formats (continuous)	NMEA-2000 / NMEA-0183
Baud Rates:	4800-38400
<b>General</b>	Output rate: [(total number of char)*10]/baud
Power Supply:	9 to 40 VDC, 20 mA typical, 55 mA max
Protection Class:	CE, IPX6 (Relative Humidity/IPX4), RoHS, IEC60945
Dimensions:	5.16 in high x 2.96 in wide
Weight	300 grams (0.8 lb)
Operating	Temperature: -22 to +55°C

### 2.1.4 Cellular Modem

The cellular modem used is the Sierra Wireless AirLink GX450 as shown in Figure 4. The modem provides 4G/LTE plus WiFi data connection for data transmission and an I/O port for remote restarts of the microprocessor. Any 4G modem with an Ethernet interface, WiFi, and telnet interface that can control an I/O signal can be used for the sensor pod.



**Figure 4. Sierra Wireless AirLink GX450.**

For additional information about this device, please refer to the user manual in Appendix E.

### 2.1.5 Solar Power System

The solar power system (Figure 5) consists of a single solar panel and one 12-VDC battery. One Bioenno Power 150-Watt Solar Module (BSP-150) is used to control the power system.



**Figure 5. Bioenno Power 150-Watt Solar Module (BSP-150)**

### **2.1.6 Bioenno Power, Solar Charge Controller**

The Bioenno Power panel (Figure 6) is connected in parallel to the Bioenno Power Solar Charge Controller SC-122420JUD. The controller maintains the battery charge and has a low voltage disconnect (LVD) feature to prevent the battery voltage from dropping below 11.5 VDC.



**Figure 6. Bioenno Power SC-122420JUD**

### **2.1.7 Battery**

One 12-VDC 100-amp-hour (Ah) absorbed glass mat (AGM) battery is used for power storage and is shown in Figure 7.



Figure 7. Duracell 12-Volt 100-Ah Absorbed Glass Mat (AGM) Battery.

## 3. Siting Considerations

### 3.1 Personnel Requirements

It is recommended that the team installing sensor pods have experience in the following fields:

- **Electrical:** The electrical features of this installation are documented in this design document. It is recommended that the Sensor Pod installation team have the ability to physically assemble and install the pod hardware. Ideally, the team members will be able to interpret and reproduce the system from schematics.
- **Software Development:** The code package documented in this design document provides information on installing and locally logging data to a USB stick. Ideally, team members would be able to understand and troubleshoot any potential software issues during installation.

### 3.2 Solar Considerations

The sensor pod solar panels require unobstructed solar signal to function properly and maintain uptime. With this in mind, the sensor pod should be installed away from trees, building or any other obstructions that could block direct sunlight on to the solar panels. Ideally, the sensor pod should be installed in an orientation such that the solar panel is facing south.

Different areas of the U.S. have varying levels of average solar energy. The map shown in Figure 10 indicates how much energy is available on average in a given day throughout the U.S. While using a 150 W solar panel, as described in this document, at least 5 kWh/m<sup>2</sup>/day is recommended. If sensor pods are installed in areas with less than 4 kWh/m<sup>2</sup>/day, there is an increased potential for downtime and reduced data collection. If sensor pods are deployed in areas of the country with

limited sunlight, additional batteries and/or solar panels should be used to offset the effects of reduced solar signal.

For most areas of the U.S., the optimal angle for solar panel installation is 32 degrees from the horizontal plane. For a southernmost US installation (Texas or Florida) an angle of 27 degrees is recommended. For locations north of Illinois, 36 degrees is recommended.

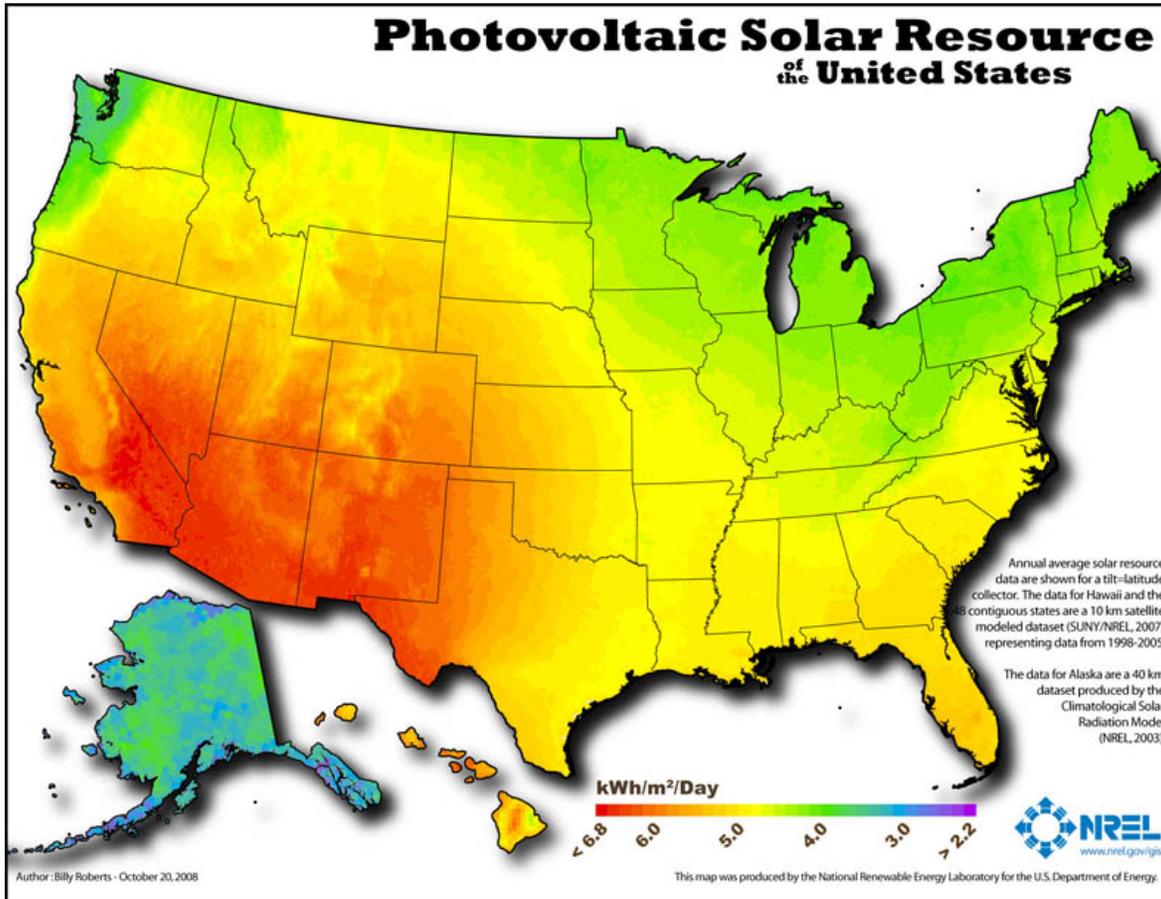


Figure 8. U.S. Solar Energy Map – (from National Renewable Energy Laboratory)

# 4. Instrument Blocks

## 4.1 Overview

This section provides information on the internal components of the P-TAQS pod system that control the sensors and communication.

### 4.1.1 Raspberry Pi 3 Model B+

Raspberry Pi 3 B+ (see Figure 9) is a single-board computer developed by the Raspberry Pi Foundation. There are various models available with the different specifications and capabilities. The advantages of using this product over a microcontroller such as the Teensy (Arduino Clone) is the computer like simplicity of navigating the device. One is not limited to a single programming language such as Arduino. The Raspberry Pi allows the user to program in almost any language. For this project specifically, the Raspberry Pi is using the Raspbian operating system (OS) and utilizing the visual programming tool Node-Red. Node-Red is a flow-based development tool based on JavaScript, runtime built on Node.js, and stored using JSON values. Manufacturer's specifications are summarized in Table 5.



Figure 9. Raspberry Pi 3 Model B+

Table 5. Raspberry Pi 3 Model B+ Manufacturer's Specifications

Specification	Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz
Memory	1GB LPDDR2 SDRAM
Communication	<ul style="list-style-type: none"><li>• 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE</li><li>• Gigabit Ethernet over USB 2.0 (maximum throughput 300 Mbps)</li></ul>
Ports	<ul style="list-style-type: none"><li>• Extended 40-pin GPIO header (all digital, no analog ports)*</li></ul>

	<ul style="list-style-type: none"> <li>• Full-Size HDMI</li> <li>• 4 USB 2.0 ports</li> <li>• CSI camera port for connecting a Raspberry Pi camera</li> <li>• DSI display port for connecting a Raspberry Pi touchscreen display</li> <li>• Micro SD port for loading your operating system and storing data</li> </ul>
Power	V/2.5A DC power input

\*See Raspberry Pi documentation on [www.raspberrypi.org](http://www.raspberrypi.org) for details on specific GPIO tolerances.

#### **4.1.2 RS-422 to USB Converter**

The converter shown in Figure 10 is used to convert the data from the AIRMAR to USB. Any equivalent device could be used to make the RS422 to USB conversion with this system.



**Figure 10. RS-422 to USB Converter**

#### **4.1.3 Solid-State Relay**

The relay (Digi-Key: CC1592-ND) shown in Figure 11 is used to enable a remote restart of the P-TAQS pods. The signal is received from the I/O port from the modem and disconnects the 12 VDC power from the system, thereby causing all devices in the P-TAQS pod to restart.



## 5. Data Streaming

P-TAQS pod data is recorded at a 1-minute time frequency to two locations: (1) an onboard memory card with >2 GB capacity and, (2) wireless transmission to the EPA Office of Land and Emergency Management's (OLEM) VIPER database. VIPER is a well-established data management system that has been used by EPA ORD to receive and store the real-time sensor field data. VIPER documentation is accessible at their project website: <https://www.epaos.org/viper> and the most critical information regarding the data transmission set-up is in Appendix E (web link).

The database server design presented in Figure 13 is used. This design may need to be modified based on the hardware and software available at the host location.

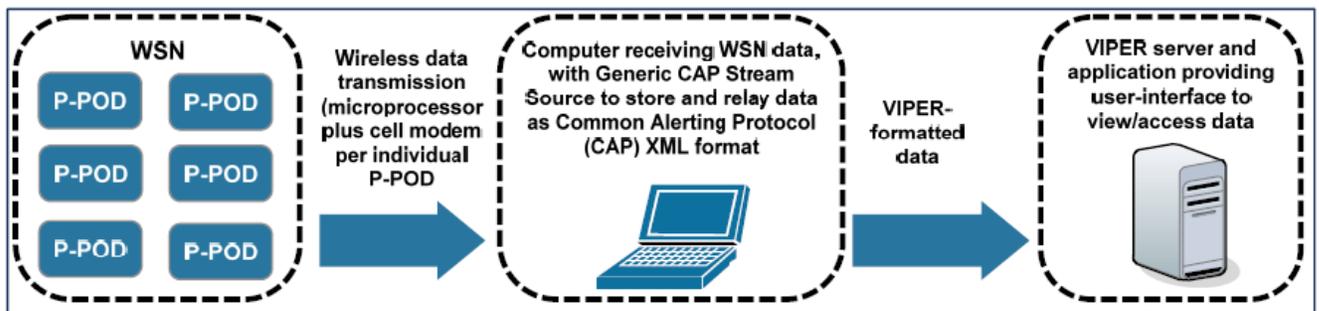


Figure 13. Dataflow to VIPER.

## 6. Data Quality Indicator Goals

Table 6 lists the data quality indicators (DQIs) for measurements collected from the P-TAQS pod instruments. These checks are performed at the database level and are not performed by the Raspberry Pi prior to transmission to VIPER. This allows the raw data to be archived in the database. Only the values that clear these DQIs are displayed and plotted on the webpage. Additional or modified DQIs may be needed depending on the instrument selection or site conditions. These DQIs were determined based upon instrument documentation and additional communication with the manufacturer.

**Table 6. Data Quality Indicators**

Parameter	Analysis Method	Measurement	Criteria
PM <sub>1.0</sub> , PM <sub>2.5</sub> , PM <sub>5.0</sub> , PM <sub>10</sub> , Temp, RH, BP	PurpleAir PA-II-SD	<ol style="list-style-type: none"> <li>1. PM concentration</li> <li>2. Temp</li> <li>3. RH</li> <li>4. BP</li> </ol>	<ol style="list-style-type: none"> <li>1. 0 to 500 µg/m<sup>3</sup></li> <li>2. Temp &gt; -20 °C</li> <li>3. RH ≥ 0%, RH ≤ 100%</li> <li>4. BP ≥ 600, BP ≤ 1200</li> </ol>
BC	AethLabs MA350	<ol style="list-style-type: none"> <li>1. Flow Rate</li> <li>2. BC concentration</li> </ol>	<ol style="list-style-type: none"> <li>1. Within 10% variance from set flow rate (150 ml/min)</li> <li>2. 0-100 ug/m<sup>3</sup></li> </ol>
Wind speed, wind direction and BP	AIRMAR 120WX	<ol style="list-style-type: none"> <li>1. Wind speed</li> <li>2. Wind direction</li> </ol>	<ol style="list-style-type: none"> <li>1. Wind speed &lt; 20 m/s</li> <li>2. Wind direction between 0 and 360 degrees</li> <li>3. BP ≥ 600, BP ≤ 1200</li> </ol>

# 7. Troubleshooting

The P-TAQS sensor pod is a complex system involving many parts and custom code to decipher and deliver information from a variety of instruments. The following topics cover some of the commonly observed system issues and the recommended corrective action.

## 7.1 Required tools

Before attempting to diagnose and fix any issue with a sensor pod, you must have the following tools available:

- Means of grounding – To prevent damage to the system, the operator’s body must always be grounded when accessing system components. (see Section 8.2.1)
- General tools – A set of small-medium screwdrivers (phillips and flathead), pliers, cutters (light gauge).
- Multi-meter – A general purpose multi-meter. The meter should be capable of reading DC voltages up to 20V and resistances up to 10K. An audible tone for connectivity is recommended.
- Field Laptop – This is used to access the Raspberry Pi either through a puTTY connection or a visual VNC connection to troubleshoot the Node-Red program. This can also be used to access the modem for common troubleshooting issues. The console of the Raspberry Pi is accessed by connecting to Port 22 on the remote IP of the Raspberry Pi while on the same network. The administration password is required to connect to the system.

## 7.2 Failure Scenarios

Table 7 below lists the most common failure scenarios and directs the user to specific sections to learn more about possible causes and their resolutions. Please note these sections do not list all possible causes. The purpose of this information is to assist a qualified technician in diagnosing potential failure points.

Additionally, several software code related issues are outside of the scope of this troubleshooting section.

For all troubleshooting issues, the first step is to perform a hard reboot on the entire system. Turn off the circuit breaker, wait 30 seconds, and turn the system back on.

**Table 7. Common Issues**

<b>Instrument</b>	<b>Issue</b>	<b>Section</b>
Entire System	Instruments not on. Powered down.	7.2.1
	Instruments running, but data is not posting.	7.2.2
PurpleAir PA-II-SD	Instrument not on. Powered down.	7.2.3
	Instrument running, but data is not posting.	
	Readings are inaccurate.	
AIRMAR 120WX	No data from sensor.	7.2.4
	Readings are inaccurate.	7.2.4
AethLabs MA350	No data from sensor.	7.2.5

**7.2.1 Sensor Pod System Not Operating. Powered Down**

Observation: The entire system appears offline; no instruments are audible.

Check system voltage. There should be 12-14 V at the battery and up to the circuit breaker.

**Table 8. Sensor Pod Troubleshooting**

<b>~12 V Voltage at Battery?</b>	<b>~12 V Voltage at Instrument Rail?</b>	<b>Instruments On?</b>	<b>Possible Cause</b>	<b>Next Steps/Solution</b>
No	No	No	Dead battery. Poor solar uptime or misconfigured/mis-wired power system. Solar controller error.	Check configuration. Replace battery. Replace solar controller.
Yes	No	No	No power to instrument rail.	Check disconnect switch, circuit breakers, loose wires.
Yes	Yes	No	5 VDC rail is disconnected.	Check connection to 5 VDC regulator, and connection in the terminal block.

## 7.2.2 Sensor Pod System Operating. No data on website.

Observation: User hears instruments running but nothing is posting.

**Table 9. Sensor Pod Operating, No Data on Website Troubleshooting**

Is Pod Posting all PA Data?	Is Pod Posting BC?	Instruments Logging to USB?	Possible Cause	Next Steps/Solution
No	No	No	Any or all component failure	Reset the system. On reboot, verify blinking green light on Raspberry Pi (reading OS). If only solid red light present then SD card is corrupted. Consult an expert on the system to image a new SD card to be inserted into the system. Replace the Raspberry Pi
No	No	Yes	Webserver, signal or WiFi communication issues.	Check cell signal quality and data plan. If modem does not obtain solid signal then it may need to be replaced. Replace antenna.
No	Yes	Yes	PurpleAir lost WiFi connection, or its IP address has changed.	Log into the modem and verify the MAC address for the PurpleAir is present. More details in section 7.2.2.1-7.2.2.3.
Yes	Yes	No	USB missing or not properly configured.	Confirm the USB is plugged into the system. In order for a USB stick to correctly mount to the data folder and be subsequently written to by the code, the hardware identifier for the USB stick must be configured on the Raspberry Pi system. If you have changed the USB stick (due to loss or corruption) an expert on the system will need to adapt it.

### **7.2.3 PurpleAir PA-II-SD. Data is not posting.**

The first step to any problem involving the PurpleAir is to cycle power. This can be done remotely using the modem interface (see Section 8.3.5), or you can just unplug power and plug it back in.

- Observation: Particulate Matter and/or environmental data is not posting to USB or the web.

Check voltage at PurpleAir connection on outside of the box. Ensure it is ~5 V. If there is voltage, unplug the sensor, hold it upside down and plug it back in. The LED indicator will show the status of the system and logging. The frequency of the blue LED indicates the status of the SD card. If it is flashing slowly, everything is working properly. If it is blinking quickly, there is a problem. If the SD card is present and replacing it does not resolve the issue, follow Steps 1-6 to replace the PurpleAir. If the indicator LED is indicating everything is OK, skip to Step 7.

1. Plug in the new PurpleAir.
2. Scan the QR code on the sensor and follow the steps to connect it to the system WiFi.
3. Connect a laptop or phone to the system WiFi and access the modems user interface. (ACEmanager).
4. Go to the current LAN IP/MAC table and look for the corresponding MAC address (Device ID) to the PurpleAir sensor.
5. Copy that MAC Address. Go to LAN -> DHCP Reservation list and paste the new MAC address to be assigned to 192.168.17.125
6. Reboot the system including the modem.
7. Check the SD card in the PurpleAir to verify that it is logging data locally.
8. If it is - follow Steps 3-6 above to ensure it is set up properly.  
If not - follow Steps 1-6 to replace the sensor.
9. If all else fails, replace the sensor. (Steps 1-6)

- Observation: Readings are inaccurate.

Replace PurpleAir sensor.

### **7.2.4 AIRMAR 120WX (Wind Sensor). Data is not posting.**

- Observation: The wind sensor is not posting to VIPER.

Check voltage at wind sensor plug on outside of the box ~12-14 V.

Make sure baud rate on instrument and program are set according to specifications in Section 8.3.1.

Double check wires and cables for flaws and disconnections.

Check RS-422 to USB Converter to ensure it is connected to the Raspberry Pi, illuminated, and blinking.

Test 1: Connect wind sensor to PC through RS-422 converter. Setup communication according to manual (web link) in Appendix E. Does instrument send reading to PC every 1 second?

If Test 1 passes:

There could be a programming issue within the sensor pod. This is not easily fixed, and an expert should be consulted.

If Test 1 fails:

It is possible the instrument has failed. Consider trying a new or alternate AIRMAR 120WX and see if the problem is fixed.

- Observation: Readings are inaccurate.

See maintenance activities to properly align wind sensor. Make sure sensor is located in an open area free from obstructions.

### **7.2.5 AethLabs MA350. No data from sensor.**

Connect the sensor to PC and run AethLabs MicroAeth Manager Software. For the sensor pod, make sure the verbose output option is selected; timebase is set to 10 seconds; flow rate is set to 150 mL/min. See the application instructions in Appendix E (web link).

Check to ensure the unit is powered on and running a measurement. The pump should be audible.

Direct connect the MA350 to PC with manufacturer supplied cable. Setup communication according to the user manual and application instructions. Does instrument reply with reading every 10 seconds?

If direct communication with the PC fails, there is a problem with the instrument. Contact the manufacturer.

If direct communication with the PC is successful, check all physical connections to the CPU and try again. Make sure the correct serial port is called out in code. If the problem persists, check the communication channel for connections and potentially try replacing the Raspberry Pi.

# 8. Operations and Maintenance

## 8.1 System Overview

A schematic of the overall system setup showing key system components is shown in Appendix A.

## 8.2 Accessing the System

### 8.2.1 Grounding (Recommended)

Before accessing system components, the operator must ground their body to the system ground to prevent damage to the system.



**Figure 14. Wrist Strap Grounding System.**

A wrist strap like the one shown in Figure 14 allows the operator to physically connect their wrist to the grounding rod of the bench. Simply place the wrist strap (conductive side down to your skin) on your wrist and tighten appropriately. Next, connect the supplied cable from the wrist strap to clamp. Finally, clamp the wrist strap to a secure ground. Inside the sensor pod, all earth grounds are connected with green wiring or bare copper. Find one ground near your working area (within reach) and connect the clamp.

## **8.3 System Operations**

### **8.3.1 AIRMAR 120WX**

The AIRMAR 120WX is powered by 9-40V and communicates with the Raspberry PI over RS422 to USB communication. This communication conversion is handled by an FTDI FT232 Chip.

The AIRMAR must be configured accordingly to work with the sensor pod's electronics:

- Output: Continuous, RS422
- Units: m/s
- Baud rate: 4800 Baud

### **8.3.2 AethLabs MA350 BC Sensor.**

The AethLabs MA350 BC Sensor is powered by 5 V and connected directly to the USB of the Raspberry PI. The MA350 operates at 1,000,000 baud.

### **8.3.3 PurpleAir PA-II-SD**

The PurpleAir PA-II-SD is powered by 5 V and connected to the Raspberry Pi via HTTP communication over WiFi.

### **8.3.4 Solid State Relays**

The sensor pod system relays to control instrument power and microcontroller/modem power as described in Section 4.1.3. See schematics for information on where to connect this sensor (Appendix A).

### **8.3.5 Sierra Wireless AirLink GX450**

The Sierra Wireless GX450 cellular router allows remote resetting of the system. When the Sierra Wireless GX450 digital output is brought high, the normally closed contact of the board mounted relay opens, removing power from the main power rail. The user then must turn the output to ground to allow power back to the system. The digital output on the Sierra Wireless GX450 can be used to reset the system remotely by using the following two procedures:

Procedure 1:

- From the “cmd” prompt: telnet [XXX.XXX.XXX.XXX] 2332
- To turn off: at\*relayout[Y]=0
- To turn on: at\*relayout[Y]=1
- [XXX.XXX.XXX.XXX] is the assigned static IP address of the station's modem.

- [Y] is the output number, may vary by station. This information is given to station operators.

Brackets are not part of the syntax, there are used in the examples above just to signify the use of a variable.

**Actual Syntax Example:**

- From the “cmd” prompt: telnet 167.153.2.98 2332
- To turn off: at\*relayout1=0
- To turn on: at\*relayout1=1

Mobile applications are also available to perform this function from a smartphone. Mocha Telnet Lite is available on the Google Play Store for Android.

The GX450 must be configured with a Static IP address for remote restarts and the DIO settings must allow for AT commands to set the state of the DIO pin. These settings are found in the product manual (web link) found in Appendix E.

**Procedure 2:**

If the static IP is known to the user the system can be reset using the modems UI.

- In any Web Brower connected to the internet type in the IP address followed by port 9191
  - XX.XX.XX.XXX:9191
- Log into the modem (user will need password). Navigate to the I/O Tab.
- Under Relay Output select “Drive Active low(1)” and click apply. This will reset the system power, but not the modem.
- Then select Off and hit apply. This will restore power back to the system.
- Reboot complete.

**8.4 Maintenance**

Maintenance activities are summarized in Table 10.

**Table 10. Maintenance Activities**

<b>Instrument</b>	<b>Maintenance Requirements</b>	<b>Manual Calibration and Flow Checks</b>
PurpleAir PA-II-SD	No specific maintenance requirements.	None‡
AIRMAR 120WX	No specific maintenance requirements.	Quarterly verification of meteorological data with data obtained from a nearby weather station
AethLabs MA350	Change filter tape ~every 6 months	Quarterly Zero and Flow Check

‡Prior to deployment, the devices may be placed in a clean chamber or room to perform a “zero check”. The devices would be powered on and collecting data over the span of a few hours or a day. The idea is that a clean room will have very low particulate levels and one can examine the data from this activity to determine if the device “in a clean environment” reports zero levels of particulate or very low levels of particulate.

#### **8.4.1 Temperature and Humidity Check**



**Figure 15. Handheld Temperature/RH Meter.**

Ambient temperature, relative humidity (RH), and barometric pressure (BP) are measured via the PurpleAir (BME280 sensor) and AIRMAR. The results of these measurements are logged to the microSD card and system USB. Checks on the performance of this sensor are made by comparing these measurements with a temperature and humidity reference device. An Omega HH310 meter is shown in Figure 15. The user is free to use any transfer standard or reference device that is available and that complies with existing QA requirements. Acceptable values for temperature are within  $\pm 2$  °C of reading and  $\pm 10\%$  of reading for RH. To compare to the reference device, simply place the reference probe near the AIRMAR 120WX and give adequate time for the readings to stabilize. Record data from both devices using the previously referenced options and ensure the readings are within the acceptance criteria.

The temperature, RH, and BP sensor produce voltages proportional to their values. These are measured by the PurpleAir sensor, and a linear correction is applied to convert them to engineering units. If the values measured fall outside of the acceptable range, the values obtained can be used to create a calibration curve and the factors can be changed or you can replace the AIRMAR 120WX.

#### **8.4.2 Wind Speed and Direction Check**

Wind speed and direction are measured with a serial output wind sensor (AIRMAR 120WX), the output is logged to the web and USB drive. These data can also be viewed on the serial monitor (See the communication section of the user manual for more information—Appendix E). Currently, these data are compared with wind speed and direction data from a local airport, NOAA, or other website with logged weather data for the particular time at which field

observations were made. Wind direction should match within  $\pm 20$  degrees; and wind speed should match within  $\pm 3$  m/s.

Buildings and trees in the vicinity of the sensor will significantly influence the readings and correlation may be poor when compared to a remote reference station. In the event that site specific factors affect the ability to compare with a local weather station; alternative evaluation can be conducted on-site by comparing the real-time wind direction against a surveyor's compass reading and wind speed against a portable wind sensor.

If readings do not agree with the reference, check to ensure the sensor is correctly oriented. There is an alignment notch on the device and this orientation should be towards true north. See the manual (web link) in the Appendix E for instructions on how the wind sensor should be oriented.

### **8.4.3 MA350 Flow Check**

The AethLabs MA350 Black Carbon sensor installed on select stations should have its flow checked with a reference device. The MA350 uses special fittings for its inlet connections that can be obtained from the manufacturer. Take a minimum of 5 flow readings and record them along with their average. The target flow rate for this device is 150mL/min. If the flow measurement fails,  $\pm 10\%$  of the flow set point, ensure the flow is set properly. The flow setpoint can be set using the AethLabs software. See Appendix E (web link) for more information.

### **8.4.4 MA350 Zero Check**

To check the MA350 zero, simply connect a particulate filter onto the device inlet and ensure the readings go to zero. As this sensor is still experimental, if any issues arise with questionable readings it is suggested to contact the manufacturer directly.

### **8.4.5 MA350 Cartridge Replacement**

The MA350 measures concentrations optically by reading attenuation on specific spots on an automatically advancing filter tape cartridge. The positions on this cartridge are limited and it must be replaced occasionally as it runs out of spots. Runtime for each cartridge will depend on ambient loading conditions and is estimated to be about six months. Replacement cartridges can be purchased directly from the manufacturer.

To replace the cartridge, loosen the flathead screw on the top of the instrument front panel. The cartridge will be locked in place. Scroll to "Release Tape" on the menu, by navigating using the left or right panel buttons beneath the screen. Press the center button to select the option, and you will hear the cartridge release. Remove the old tape and replace it with a new unit. Before beginning a new measurement, scroll to "Clamp Tape" on the menu by navigating using the left or right panel buttons beneath the screen. Press the center button to select the option and you should hear the cartridge lock into place. You can now begin a new measurement.

# Appendix A. P-TAQS Schematic

Appendix A is provided in separate files.

# Appendix B. P-TAQS Code

Appendix B is provided in separate files.

# Appendix C. P-TAQS Parts List

Appendix C is provided in separate files.

- Parts List

# Appendix D. P-TAQS Photos

Appendix D is provided in a separate file.

- [Appendix D - Photos.pdf](#)

# Appendix E. P-TAQS Instrumentation User Manuals

Appendix E is provided as web links.

File Name	Manual
<a href="https://www2.purpleair.com/products/purpleair-pa-ii-sd">https://www2.purpleair.com/products/purpleair-pa-ii-sd</a>  Please contact the manufacturer for the manual.	PurpleAir PA-II-SD Operating Manual PurpleAir LLC
<a href="https://aethlabs.com/sites/all/content/microaeth/maX/MA200%20MA300%20MA350%20Operating%20Manual%20Rev%2003%20Dec%202018.pdf">https://aethlabs.com/sites/all/content/microaeth/maX/MA200%20MA300%20MA350%20Operating%20Manual%20Rev%2003%20Dec%202018.pdf</a>	microAeth® MA Series MA200, MA300, MA350 Operating Manual AethLabs
<a href="https://www.sensata.com/sites/default/files/a/sensata-dc60%20series-panel%20mount%20relay-datasheet.pdf">https://www.sensata.com/sites/default/files/a/sensata-dc60%20series-panel%20mount%20relay-datasheet.pdf</a>	Solid-State Relay Installation and Operation Manual Sensata-Crydom
<a href="http://www.airmar.com/uploads/InstallGuide/17-461-01.pdf">http://www.airmar.com/uploads/InstallGuide/17-461-01.pdf</a>	Meteorological Instruments Instructions WS-120WX-RH AIRMAR
<a href="https://source.sierrawireless.com/resources/airlink/hardware_reference_docs/airlink_gx450_userguide/#sthash.UF99uJQk.dpbs">https://source.sierrawireless.com/resources/airlink/hardware_reference_docs/airlink_gx450_userguide/#sthash.UF99uJQk.dpbs</a>	AirLink GX450 Hardware User Guide Rev 11 Sierra Wireless
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<a href="https://www.bioenno.com/products/150-watt-foldable-solar-panel-for-charging-power-packs-bsp-150?_pos=1&amp;_sid=41f3db477&amp;_ss=r">https://www.bioenno.com/products/150-watt-foldable-solar-panel-for-charging-power-packs-bsp-150?_pos=1&amp;_sid=41f3db477&amp;_ss=r</a>	Solar Panel 150 Watts / 12 Volts Bioenno Power
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<a href="https://response.epa.gov/sites/5033/files/VIPER%20User%20Guide-December%202017.pdf">https://response.epa.gov/sites/5033/files/VIPER%20User%20Guide-December%202017.pdf</a>	VIPER User Guide

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